Yandicoogina Iron Ore Project – Revised Proposal

Public Environmental Review

November 2015

State Assessment Number: Assessment No. 2017

Prepared for Rio Tinto by Eco Logical Australia

Invitation to make a submission

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal. The environmental impact assessment process is designed to be transparent and accountable, and includes specific points for public involvement, including opportunities for public review of environmental review documents. In releasing this document for public comment, the EPA advises that no decisions have been made to allow this proposal to be implemented.

Hamersley Iron – Yandi Pty Limited proposes to construct and operate a new mine pit, waste dumps and associated infrastructure at Pocket and Billiard South, located in the central Pilbara region of Western Australia. In accordance with the Environmental Protection Act 1986, a Public Environmental Review (PER) document has been prepared which describes this proposal and its likely effects on the environment. The PER document is available for a public review period of six weeks from **2nd November 2015** closing on **14th December 2015**.

Comments from government agencies and the public will assist the EPA to prepare an assessment report in which it will make recommendations to government.

Printed and CD copies of this document may be obtained from Ms Melinda Brand at Rio Tinto Iron Ore, 152-158 St Georges Terrace, Perth or +61 8 6211 6991. Hard copies of the document cost of $10 (including postage); CDs will be provided free of charge.

The PER may also be accessed through the proponent's website at: http://www.riotinto.com/ironore/documents-9622.aspx.

Why write a submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action – including any alternative approaches. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions received by the EPA will be acknowledged with electronic submissions being acknowledged electronically. The proponent will be required to provide adequate responses to points raised in submissions. In preparing its assessment report for the Minister for Environment, the EPA will consider the information in submissions, the proponent's responses and other relevant information. Submissions will be treated as public documents unless provided and received in confidence, subject to the requirements of the Freedom of Information Act 1992, and may be quoted in full or in part in the report.

Why not join a group?

If you prefer not to write your own comments, it may be worthwhile joining a group or other groups interested in making a submission on similar issues. Joint submissions may help to reduce the workload for an individual or group, as well as increase the pool of ideas and information. If you form a small

group (up to 10 people) please indicate all the names of the participants. If your group is larger, please indicate how many people your submission represents.

Developing a submission

You may agree or disagree with, or comment on, the general issues discussed in the PER document or on specific elements. It helps if you give reasons for your conclusions, supported by relevant data. You may make an important contribution by suggesting ways to make the proposal more environmentally acceptable.

When making comments on specific elements of the PER:

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable; and
- suggest recommendations, safeguards or alternatives.

Points to keep in mind

By keeping the following points in mind, you will make it easier for your submission to be analysed:

- attempt to list points so that issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section, chapter or recommendation in the PER document;
- if you discuss different sections of the PER document, keep them distinct and separate, so there is no confusion as to which section you are considering; and
- attach any factual information you may wish to provide and give details of the source. Make sure your information is accurate.

Remember to include:

- your name;
- address;
- date; and
- whether you want your submission to be confidential.

The closing date for submissions is: **14th December 2015**

The EPA prefers submissions to be made at:
https://consultation.epa.wa.gov.au.

Alternatively, submissions can be

- posted to: Chairman, Environmental Protection Authority, Locked Bag 10, EAST PERTH WA 6892; or
- delivered to the Environmental Protection Authority, Level 8, The Atrium, 168 St Georges Terrace, Perth.

If you have any questions on how to make a submission, please ring the Office of the Environmental Protection Authority on 6145 0800.

Executive summary

INTRODUCTION

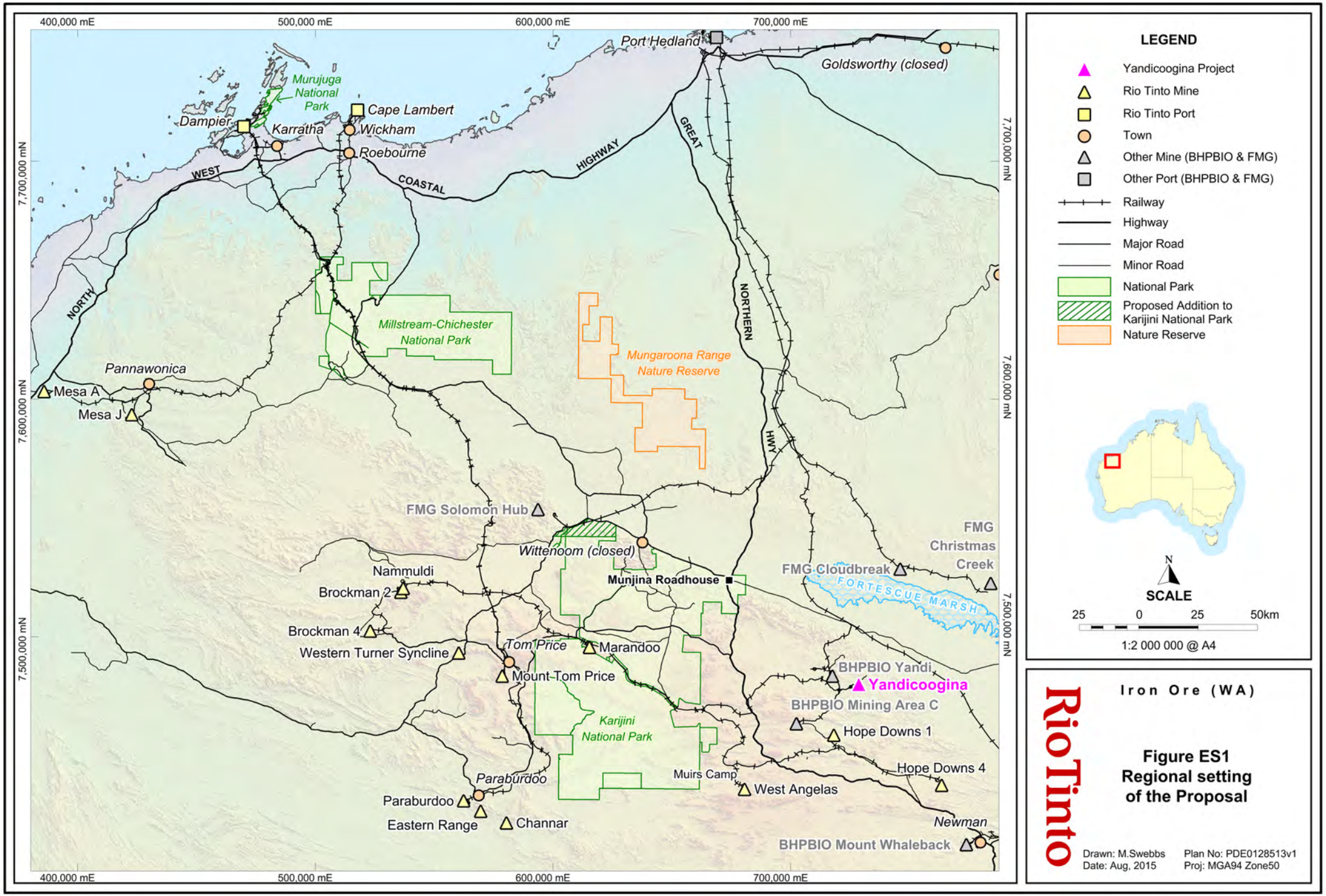
This Public Environmental Review (PER) has been prepared to assess the potential environmental impacts of the proposed 'Yandicoogina Pocket and Billiard South Iron Ore Development' (the Proposal).

The Proposal is located in the central Pilbara region of WA approximately 90 km north west of Newman and 300 km south east of Dampier (**Figure ES1**). The Proposal deposits are centred on a substantial channel iron deposit (CID), located immediately east of the existing Yandicoogina Operations (Yandi Operations: Junction Central (JC) and Junction South East (JSE) deposits; and the more recently approved Junction South West (JSW-A & C) and Oxbow deposits; **Figure ES2**). The Proposal is a revision to the existing Yandi Operations as approved under Ministerial Statement No. 914 (MS 914) in 2012 and involves construction and operation of a new mine pit, waste dumps and associated infrastructure. The purpose of the proposal is to enable sustained production from the existing Yandi Operations by providing replacement tonnages as the existing approved resources are depleted. The Proposal contemplates saleable ore production up to 31 Million tonnes per annum (Mtpa) with an expected operational mine life of approximately 16 years. The Proponent for the Proposal is Hamersley Iron – Yandi Pty Limited (herein 'the Proponent'), a wholly owned member of the Rio Tinto Group.

EXISTING YANDI OPERATIONS

The existing Yandi Operations is subject to the *Iron Ore (Yandicoogina) Agreement Act 1996*, and comprise a number of individual pits located within a continuous CID formation, which also forms a major aquifer in the area. The existing Yandi Operations, as approved, currently consists of:

- five open cut pits within the CID: JC, JSE and JSW-C (currently operating); and JSW-A and Oxbow (approved but not yet operating);
- a 90 km rail line to Juna Downs;
- mine infrastructure (e.g. product stockpiles, waste dumps, topsoil, low grade stockpiles, waste fines storage facilities and haul roads);
- associated infrastructure (e.g. overland conveyors, mine access roads, offices, warehouses, accommodation, bore fields, fuel storage facilities and utilities);
- abstraction of 53 gigalitres per year (GL/y);
- a water management system including on-site reuse of water abstracted from pit dewatering, and discharge of surplus volumes into creek systems;
- dry and wet processing plants;
- flood protection structures; and
- power and communications infrastructure.


400,000 mE
500,000 mE
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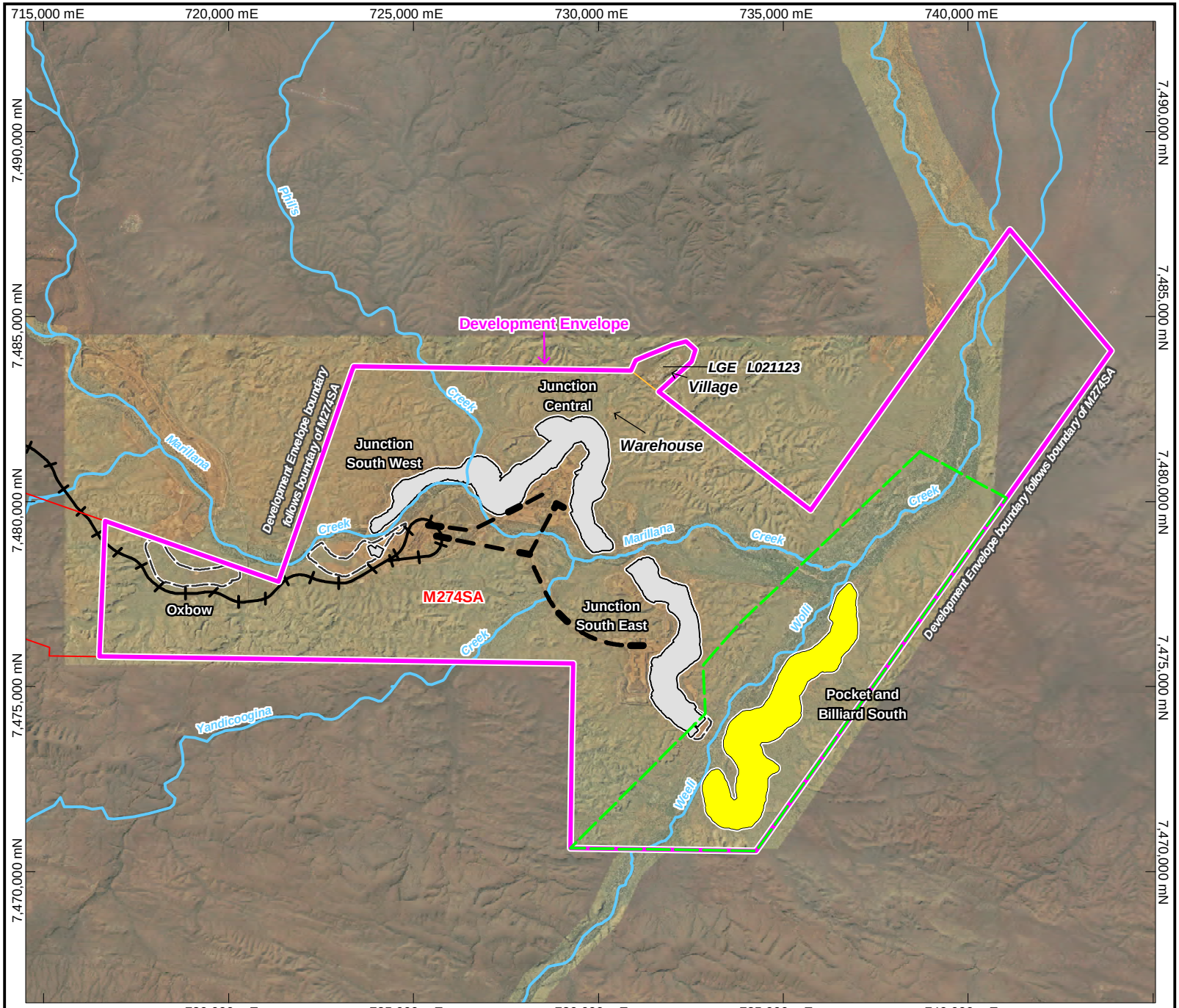
Port Hedland
Goldsworthy (closed)
Murujuga National Park
Dampier
Karratha
Cape Lambert
Wickham
Roebourne
WEST COASTAL HIGHWAY
GREAT NORTHERN HWY
NORTH
Millstream-Chichester National Park
Mungaroona Range Nature Reserve
Pannawonica
Mesa A
Mesa J
FMG Solomon Hub
Wittenoom (closed)
Munjina Roadhouse
FMG Christmas Creek
FMG Cloudbreak
FORTESCUE MARSH
Nammuldi
Brockman 2
Brockman 4
Western Turner Syncline
Tom Price
Marandoo
Mount Tom Price
BHPBIO Yandi
Yandicoogina
BHPBIO Mining Area C
Hope Downs 1
Hope Downs 4
Karijini National Park
Muirs Camp
West Angelas
Paraburdoo
Eastern Range
Channar
Newman
BHPBIO Mount Whaleback
LEGEND
Yandicoogina Project
Rio Tinto Mine
Rio Tinto Port
Town
Other Mine (BHPBIO & FMG)
Other Port (BHPBIO & FMG)
Railway
Highway
Major Road
Minor Road
National Park
Proposed Addition to Karijini National Park
Nature Reserve
N
SCALE
25 0 25 50km
1:2 000 000 @ A4
Iron Ore (WA)
Figure ES1
Regional setting of the Proposal
Drawn: M.Swebbs
Date: Aug, 2015
Plan No: PDE0128513v1
Proj: MGA94 Zone50



LEGEND

- Development Envelope
- Proposal Area
- M274SA
- Yandi Accommodation Village General Lease L021123
- Proposed Mine Pit
- Existing Mine Pit
- Approved Mine Pit
- Existing Conveyor
- Existing Railway
- Major Watercourse

N

SCALE

0 2 4 6km

1:150 000 @ A4

Iron Ore (WA)

Figure ES2
General location of the Proposal

Drawn: M.Swebbs Plan No: PDE0133270v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

DESCRIPTION OF THE PROPOSAL

The Proposal will minimise the disturbance footprint by optimising the use of existing infrastructure already installed at the existing Yandi Operations. Key additional components of the Proposal are:

- **A new below water table open cut iron ore pit** to the east of the existing Yandi Operations within the CID.
- **Temporary surface waste dumps**, including mineral waste dumps, sub-grade dumps, low grade ore dumps and topsoil and subsoil stockpiles.
- **Major infrastructure, including:**
  - **A flood protection levee** along the western margin of the pit.
  - **A diversion drain** along the eastern margin of the new pit.
  - **A culvert-floodway** creekline crossing structure.
- **Supporting mine infrastructure** – haul roads and ramps, mine access and internal road network, dewatering pumps and associated pipelines, discharge outlet(s), power and communications.

In addition, a number of the Yandi Operation's existing facilities and processes will be upgraded or integrated as part of the Proposal including:

- **Trucking ore** back to the existing Yandi Plant.
- **Yandi plant** including JC and JSE processing plants (including a wet plant), and associated conveyors, stackers, reclaimers, train load-out and other materials handling infrastructure.
- **A water management system** including on-site reuse of water abstracted from pit dewatering, and discharge of surplus volumes into creek systems. Discharge infrastructure servicing the existing Yandi Operations will be used where possible.
- **Mine support facilities** (e.g. power supply infrastructure, communications infrastructure, offices, explosives storage, waste water treatment plants etc.).

The Proposal is scheduled to be commissioned with first ore production from the first half of 2019, however project schedules may change, depending on business priorities.

Rio Tinto's existing rail network will be used to transport mined and processed ore from the Proposal to existing port operations at Cape Lambert.

A summary of the existing Yandi Operations and the Proposal key characteristics, which together would comprise the Yandicoogina Iron Ore Project – Revised Proposal (hereafter Revised Proposal), are outlined in **Table ES1**.

Table ES1: Summary of the existing Yandi Operations, the Proposal and the Revised Proposal Key Characteristics

Characteristic	Yandi Operations (existing)	The Proposal (additional proposed)	Yandi Operations (Revised Proposal)
Short description	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West and Oxbow, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) – car dumpers, conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops; • Rail corridor allowing for rail lines and associated infrastructure; • Construction and operations support infrastructure; • 220kV power network, including switchyard and powerlines; • A diesel-fired power station and transmission lines; • Dry and wet processing plants (including in pit waste fines storage facilities); • Flood protection structures; • Accommodation camps; • Access roads; and • An airstrip.	The proposal is to develop a below water table open cut Iron Ore mine at Pocket and Billiard South, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Temporary surface waste dumps; • Major infrastructure including a flood protection levee, a diversion drain and Weeli Wolli Creek crossing; and • Supporting mine infrastructure including power spur, haul roads and ramps, mine access and internal road network, and dewatering infrastructure (dewatering pipeline, bores and outlets).	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West, Oxbow and Yandi PBS, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) – overland conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops. • Rail corridor allowing for rail lines and associated infrastructure. • Construction and operations support infrastructure. • 220kv power network including switchyard, back-up diesel power and transmission lines. • Dry and wet processing plants (including in pit waste fines storage facilities). • Flood protection structures and creek crossings. • Accommodation camps. • Access roads.
Physical elements			
Mine and associated infrastructure	Vegetation clearing up to 5,600 ha within Restricted Clearing Area 1; and Vegetation clearing up to 60 ha within Restricted Clearing Area 2	Vegetation clearing up to 1,300 ha for mining and waste dumps Vegetation clearing up to 500 ha for infrastructure	Vegetation clearing up to 7,400 ha within Revised Proposal Development Envelope. Vegetation clearing up to 129 ha within proposed Restricted Clearing Area.

Characteristic	Yandi Operations (existing)	The Proposal (additional proposed)	Yandi Operations (Revised Proposal)
Railway and associated infrastructure	90 km rail line	No additional rail required	No additional rail required.
Operational elements			
Dewatering	No more than 35 GL/year from Junction South East and Junction Central operations. No more than 18 GL/year from Junction South West A, Junction South West C and Oxbow operations.	Approximately 50 GL/year for the Proposal	No more than 83 GL/year for the entire Revised Proposal.
Surface water discharge	Up to 16 GL/year from Junction South West A, Junction South West C and Oxbow operations.	Approximately 50 GL/year for the Proposal	Up to 78 GL/year for the entire Revised Proposal. No water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence.

The key characteristics of the Revised Proposal, as per EAG 1 *Defining the Key Characteristics of a Proposal* (EPA 2012a), are also listed in **Table ES2**.

Table ES2: Key Proposal Characteristics

Summary of the Proposal		
Proposal title	Yandicoogina Iron Ore Project – Revised Proposal	
Proponent name	Hamersley Iron – Yandi Pty Limited	
Short description	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West, Oxbow and Pocket and Billiard South, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) –overland conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops. • Rail corridor allowing for rail lines and associated infrastructure. • Construction and operations support infrastructure. • 220kv power network including switchyard, back-up diesel power and transmission lines. • Dry and wet processing plants (including in pit waste fines storage facilities). • Flood protection structures and creek crossings. • Accommodation camps. • Access roads.	
Physical elements	**Location**	**Proposed Extent**
1. Mine and associated infrastructure	Figure 4 and Figure 79	Vegetation clearing up to 7,400 ha within Revised Proposal Development Envelope. Vegetation clearing up to 129 ha within proposed Restricted Clearing Area.
Operational elements	**Location**	**Proposed Extent**
1. Dewatering	Figure 34	No more than 83 GL/year for entire Revised Proposal.
2. Surface water discharge	Figure 34	Up to 78 GL/year for entire Revised Proposal. No water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence.

ASSESSMENT PROCESS

The Proposal was referred to the Western Australian (WA) Environmental Protection Authority (EPA) under Section 38 of the *Environmental Protection Act 1986* (EP Act) on 4 July 2014. The EPA determined that the Proposal required environmental assessment at the level of PER (with a six week public review period), whereby the Proponent must fulfil the requirements of Section 10.2 of the *Environmental Impact Assessment (Part IV Division 1) Administrative Procedures 2012* for environmental assessment prescribed under the EP Act.

The EPA issued an Environmental Scoping Document (ESD) for the Proposal on 31 December 2014. The ESD provides an outline of the key environmental factors, a description of the scope of the assessment of the Proposal and an indicative timeline for the assessment process.

Subsequent to a six week public review period of the PER document, the Proponent will respond to any public submissions received and then the EPA will assess the Proposal and submit its assessment report to the Minister for the Environment. The Minister will publish the EPA report and subsequent to the determination of appeals (if any) received on the findings or recommendations of the EPA's assessment report, the Minister will then decide whether or not the Proposal should be implemented and if so, under what conditions.

The Proposal was also referred to the Commonwealth Department of the Environment (DoE) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) on 26 September 2014. DoE determined that the Proposal was 'not a controlled action' on 25 October 2014 (Decision notice 2014-7343), and therefore does not require assessment and approval under the EPBC Act.

The ESD was prepared with input from other WA decision making authorities and the Proponent. The EPA identified seven preliminary key environmental factors relevant to the Proposal that require detailed consideration by the Proponent. These preliminary key environmental factors were:

- Flora and Vegetation;
- Terrestrial Fauna;
- Subterranean Fauna;
- Hydrological Processes;
- Inland Waters Environmental Quality;
- Rehabilitation and Closure (integrating factor); and
- Offsets (integrating factor).

The EPA identified air quality, amenity and (indigenous) heritage as 'other environmental factors' that it considers relevant to the Proposal. Other environmental factors are also addressed in this PER to demonstrate how the Proposal will meet the relevant EPA objectives and principles.

ENVIRONMENTAL IMPACTS AND MANAGEMENT

Assessment of the key environmental factors and other environmental factors is provided below.

HYDROLOGICAL PROCESSES AND INLAND WATERS ENVIRONMENTAL QUALITY

The Proposal Area is located within the Weeli Wolli Creek surface water catchment, with Weeli Wolli Creek flowing through and adjacent to the Proposal Area from south of the Proposal ore deposits. Weeli Wolli Creek is part of an ephemeral system characterised by a generally singular, meandering low-flow channel set within a broader floodplain. The high flow channel comprises a gravel-bed stream, with large gravel bars present within the channel and more active anabranches. These numerous anabranches of the Weeli Wolli Creek that cross the Proposal Area convey flows towards the creek as a result of episodic high rainfall events.

Weeli Wolli Creek drains parallel to the Proposal ore deposits in a predominantly north easterly direction, receiving flows from Marillana Creek (its major tributary), and terminates as an alluvial fan at the Fortescue Marsh, outside of the Revised Proposal Development Envelope.

The Proposal will operate within a modified and managed hydrological system. The existing approved mining operations within the Weeli Wolli Creek catchment undertake dewatering and discharge activities as part of their mining operations and have modified the natural hydrological conditions of Marillana and Weeli Wolli Creeks since the mid 1990's and mid 2000's, respectively. The BHP and Rio Tinto mining operations that occur within the CID (Rio Tinto's existing Yandi Operations, BHP's Marillana Creek [Yandi]), are within the same hydrological and hydrogeological setting as the Proposal, with the dewatering and discharge activities undertaken to manage the productive aquifers of the CID. Hamersley HMS's Hope Downs 1 upstream operation occurs in a different local hydrogeological setting; however discharges into the same catchment (into Weeli Wolli Creek), which ultimately recharges the aquifers in the vicinity of the Revised Proposal (adjacent to Junction South East and the Proposal Area).

The groundwater levels in the aquifers underlying Weeli Wolli Creek have increased in recent history, as a consequence of surplus water discharge from upstream mining operations. In some locations along Weeli Wolli Creek, the groundwater table has risen such that it is now only a few metres from the surface. Dewatering associated with the Proposal will lower the artificially elevated groundwater table. After mining, however, the aquifers beneath Weeli Wolli Creek are projected to return to within approximately 10% of their natural (pre-mining) levels, which will enable Weeli Wolli Creek to return to the ephemeral system that existed prior to continuous surplus water discharge from mining activities in the area.

Development of the Proposal will modify local topography and intercept a portion of surface water flows. The Proposal mine pit will marginally encroach into the Weeli Wolli Creek floodplain, requiring a flood protection levee to be installed to prevent floodwaters from Weeli Wolli Creek flowing into the mine pit. Additionally, as the Proposal ore deposit is entirely located on the east side of Weeli Wolli Creek, a creek crossing via a culvert-floodway structure and an upgrade to the existing road crossing to an engineered floodway will be required to access facilities at the existing Yandi Operations. The

changes associated with surface hydrology are confined to specific sections of Weeli Wolli Creek and are considered unlikely to affect the wider catchment flows.

Due to the nature of the orebody being located below the water table, dewatering will be required to allow for mining. Peak cumulative abstraction volumes from the existing Yandi Operations and the Proposal of up to 83 gigalitres per year (GL/y) are modelled to occur within the first 6 years of mining. Local maximum drawdown during this period would be most pronounced along the CID aquifer and is predicted to be in the order of 75 to 85 m below ground level (bgl).

The Proposal will contribute at its peak up to 50 GL/y of the total 83 GL/y abstraction from the Revised Proposal. Of the 50 GL/y, up to approximately 70% is estimated to be associated with surplus water discharge from the upstream Hope Downs 1 project that has infiltrated into the downstream Weeli Wolli Creek floodplain and CID aquifers. Groundwater abstracted through the dewatering network will be integrated with the existing and proposed site water demand, with surface water of up to 78 GL/y discharged to Marillana and Weeli Wolli Creeks. The remaining 5 GL/y (to a maximum of 11 GL/y for the Revised Proposal) is expected to be used for on-site operations purposes across the Revised Proposal.

Surplus water will be discharged and constrained to a well defined low-flow channel, with the modelled wetting extent within the existing MS 914 approved footprint of 17 km beyond the Marillana – Weeli Wolli Creek confluence. Given the wetting front is expected to remain within existing approved limits, it is considered that there will be minimal additional effects on the downstream hydrological system of Weeli Wolli Creek and negligible impacts are expected on Fortescue Marsh.

FLORA AND VEGETATION

The Proposal Area lies within the within the Hamersley and Fortescue subregions of the Pilbara bioregion. The majority of the landscape within the Proposal Area is considered to be typical of the Hamersley subregion, while the creek systems have affinities with the Fortescue subregion. Twenty-three vegetation units have been mapped and described in the Proposal Area, grouped according to the following major landforms with which they are associated:

- Vegetation of Major Creeklines and Tributaries.
- Vegetation of Minor Creeklines, Floodplains and Valleys.
- Vegetation of Hills, Ridges and Breakaways.
- Vegetation of Plains.

Further refined mapping within the riparian zones in Marillana and Weeli Wolli Creeks was also undertaken, differentiating 13 riparian sub-associations throughout the greater Yandicoogina area.

None of the vegetation types recorded in the Proposal Area represent Threatened Ecological Communities or Priority Ecological Communities. Some of the vegetation units recorded are considered to have elevated local conservation significance, specifically those that support riparian vegetation species *Melaleuca argentea*, *Eucalyptus camaldulensis and Eucalyptus victrix.*

Vegetation clearing will be required to enable development of the mine pit and associated infrastructure. The Proposal Area covers approximately 4,486 ha of which a maximum of 1,800 ha (including 69 ha of riparian zone vegetation) is proposed to be cleared for the Proposal. The majority of vegetation proposed to be cleared was assessed to be in Good condition (46% of all mapped vegetation) and has been historically impacted by grazing and trampling by domestic and feral animals, weed invasion, frequent fire, and mining and exploration activities.

Riparian vegetation in the vicinity of the Proposal Area has been subject to the effects of groundwater drawdown and discharge of surplus groundwater by existing approved mining activities within the catchments of Marillana Creek since the mid 1990s and Weeli Wolli Creek since the mid 2000s. Dewatering associated with the Proposal will lower the water table by approximately 75 to 85 m bgl over two to three years, with the water table in the vicinity of the mine pit remaining at that depth for the duration of mining. Approximately 50 GL/y of surplus water is proposed to be discharged from a new discharge outlet, adjacent to the existing discharge outlet (DO9) as a result of developing the Proposal, with the total peak discharge from the Revised Proposal being approximately 78 GL/y. Surface water modelling indicates Weeli Wolli Creek could accommodate the maximum discharge rate without exceeding MS 914 condition 6-3, which limits the perennial surface water wetting front to 17 km downstream of the Marillana and Weeli Wolli Creek confluence. Local impacts around the discharge outlet and immediate vicinity are likely to be associated with waterlogging, which may result in declining health of some species.

One flora species, *Lepidium catapycnon* (Hamersley Lepidium), listed under the *Wildlife Conservation Act 1950* as Threatened (Declared Rare) Flora and under the EPBC Act as Vulnerable, has been recorded in the Proposal Area. *L. catapycnon* was recorded in areas that were originally designated for waste dumps in earlier versions of the conceptual design; however, the Proponent re-configured the waste dumps to avoid known and recorded populations of *L. catapycnon*. Further, all recorded populations of *L. catapycnon* have currently been designated as 'areas of special protection from ground disturbance' and therefore will not be cleared.

Four records (37 individuals) of *Goodenia nuda* (Priority 4) will be impacted by the Proposal. Rio Tinto records show that *Goodenia nuda* has been recorded at least 551 locations across the Pilbara surveys, including 5,862 individual plants. The loss of the individuals recorded from the Proposal Area is therefore considered negligible and would not affect the species' conservation status.

Vegetation clearing will be minimised as much as practicable and restricted to the extent approved by clearly delineating areas and adhering to internal ground disturbance procedures for areas to be cleared. Disturbed areas will be rehabilitated following completion of mining, in accordance with the Yandicoogina Closure Plan.

TERRESTRIAL FAUNA

Terrestrial Vertebrate Fauna

Five fauna habitat types have been mapped in the Proposal Area: Alluvial Plain (Flood Plain), Mulga woodland, Hilltops and Slopes, Pediment Slope and Major Drainage Line. These habitats are considered to be common and widespread in the Hamersley and

Fortescue subregions of the Pilbara bioregion, and are therefore not restricted to the Proposal Area.

Five conservation listed terrestrial vertebrate species have been recorded in the Proposal Area, including four species listed under the EPBC Act and/or the *Wildlife Conservation Act 1950* (WC Act), and one species listed in the Parks and Wildlife Priority Fauna List, as follows:

- Pilbara Olive Python, *Liasis olivaceus barroni* (Vulnerable, Schedule 1);
- Fork-tailed Swift, *Apus pacificus* (Migratory, Schedule 3);
- Eastern Great Egret, *Ardea modesta* (Migratory, Schedule 3);
- Rainbow Bee-eater, *Merops ornatus* (Migratory, Schedule 3); and
- Western Pebble-mound Mouse, *Pseudomys chapmani* (Priority 4).

An additional species, the Chocolate Wattled Bat (*Chalinolobus morio*), while currently not listed under Commonwealth or State legislation, is also considered to be of regional significance as the population appears to be geographically restricted, with records existing only at Weeli Wolli Spring and extending along Weeli Wolli Creek and Marillana Creek.

Clearing of terrestrial fauna habitat is required to facilitate construction of the mine and associated infrastructure. Clearing will include up to 69 ha of riparian zone vegetation. Approximately 87 ha of core habitat, which includes riparian zone vegetation, will be lost within the Proposal Area for the conservation listed Pilbara Olive Python. Aside from one record of a Rainbow Bee-eater, the records of the Western Pebble-mound Mouse are the only conservation listed species recorded within the proposed mine pit and waste dump locations.

Vegetation clearing is not anticipated to cause any significant fragmentation of habitat or disruptions to ecological linkages. The Proposal Area contains fauna habitats that are consistent with the surrounding landscape. Based on the distribution of land systems, fauna habitats occurring in the Proposal Area are well represented in the surrounding area, and connectivity will remain with the intact habitats outside the Proposal Area.

Short Range Endemic Fauna

Twenty potential short range endemic (SRE) invertebrate specimens were recorded from within the Proposal Area, with genetic analysis determining six putative species. Of these species, four mygalomorph spider species are considered to represent potential SREs: Idiopidae sp. I1, Idiopidae sp. I9, Nemesiidae sp. N42 and Nemesiidae sp. N44. All species have been previously observed outside the Proposal Area. These species have been recorded in multiple land systems and substrate types, suggesting they are not restrained to a specific landscape-scale habitat unit. Therefore the probability that these mygalomorph spiders possess a narrow spatial distribution is lower, and thus it is less likely that the removal of potential SRE habitat within the Proposal Area will adversely affect these species.

Aquatic Fauna

The most recent aquatic fauna surveys completed in 2013 and 2014 recorded 283 invertebrate fauna taxa in the Proposal Area. Several undescribed hyporheic taxa were considered to be new species, including species *Cephalodella* n. sp. and *Lecane* 'bulloid' n. sp. Five stygobitic amphipod/isopod species were considered to be potential SREs, of these, two (*Maarrka weeliwolli* and *Pygolabis weeliwolli*) appear to be restricted to Marillana Creek and Weeli Wolli Creek. Three fish species were observed, none of which are conservation listed. Limited aquatic fauna habitat will be lost or fragmented as a result of the Proposal, as the low-flow channel will remain in situ and larger rainfall events will continue to provide natural flood flows in Weeli Wolli Creek, which sustains connection upstream to Weeli Wolli Spring and downstream to Fortescue Marsh. In addition, surplus water discharge has increased the range extent due to increased water availability.

SUBTERRANEAN FAUNA

Stygofauna

A total of 13 phases of stygofauna sampling have been conducted in and around the Revised Proposal Development Envelope since 2003. A total of 2,761 specimens from 62 taxa have been found in the Proposal Area to date, 39 of which occur within the proposed mine pit boundary. Of the 39 taxa recorded within the proposed pit boundary, three species are not known from any other records outside this area: *Notobathynella* sp., *Billibathynella* sp. B02 and *Brevisomabathynella* cf. *pilbaraensis*. These species are not currently conservation listed.

Excavation of the mine pit would result in direct loss of individuals and habitat, and alteration of habitat would also occur as a result of groundwater abstraction and discharge.

The taxa that are present in the proposed pit footprint and the drawdown cone of depression are most at risk from the Proposal. However, the habitat in which the stygofauna occur extends beyond the predicted area of impact from pit excavation and groundwater drawdown. Almost half of the stygofauna assemblage recorded from the Revised Proposal Development Envelope is known from the wider region and the frequency of wider ranging taxa indicates there is unlikely to be geographically restricted taxa. It is considered likely that the three taxa recorded only from the proposed pit would occur throughout the broader alluvials, colluvium calcrete and CID units and therefore would not be significantly impacted by the Proposal. The paucity of records of these taxa may be an artefact of sampling, rather than an indication of an extremely restricted distribution. Due to the large abundance of stygofauna throughout the Proposal Area and the broader Weeli Wolli Creek and Marillana Creek catchments, it is considered unlikely that there will be a substantial regional impact on stygofauna.

Troglofauna

Two phases of troglobitic fauna surveys were undertaken across the Proposal Area and additional troglofauna were opportunistically collected during stygofauna sampling. Six potential troglobitic fauna specimens have been recorded in the Revised Proposal Development Envelope, three of which have been recorded within the Proposal Area: *Myrmopopaea* sp. nov (confirmed troglobite), *Draculoides* sp. indet (confirmed troglobite) and Pauropoda sp. indet (unconfirmed troglobite). *Myrmopopaea* sp. nov. is the only

taxon recorded from within the proposed pit boundary and it is not currently known from any other locations.

The excavation of the mine pit will result in the direct removal of the habitat for troglobitic fauna. However, the low number of specimens recorded within the Proposal Area indicates it is unlikely that troglobitic fauna inhabit the ore deposit in high densities.

The confirmed troglobite *Myrmopopaea* sp. nov. was recorded from interconnected calcrete and alluvium formations within the proposed pit area. These largely interconnected geological formations are located adjacent to, and extend parallel to Weeli Wolli Creek and contain sufficient interstitial spaces and cavities to allow movement of troglobitic fauna. This habitat continuity outside the Proposal Area suggests that all three troglofauna taxa are likely to occur outside the proposed pit.

REHABILITATION AND CLOSURE

The proposed closure strategy, described within the Yandicoogina Closure Plan, has been developed to create a safe, stable, non-polluting landform that supports a native ecosystem. The available overburden and waste materials will be utilised to stabilise the pit walls adjacent to the floodplain and to create a spillway that will facilitate flood water ingress into the final mine void during the peak of large flood events.

The volume of overburden and waste material generated by implementing the Proposal is relatively low compared to the volume of ore extracted. As a consequence, there is insufficient overburden and waste material available to backfill into the pit to cover the groundwater table on closure. Proximity to Weeli Wolli Creek is also an important consideration in development of the closure strategy. Removal of the flood protection levee of closure will reduce the stressors on the riparian floodplain vegetation, but will also enable flood water to interact with the final mine void.

Pit lakes are expected to develop either side of the flood ingress area. The groundwater aquifers, dewatered by implementing the Proposal, will recover to natural (pre-disturbance) levels and provide the base flow for the pit lakes. Flood water entering the mine void will result in rapid increases in the pit lake water levels, creating a dynamic wetland environment on the fringe of the Weeli Wolli Creek floodplain.

Research and trials are required to develop an appropriate revegetation strategy for the wetland areas that will be developed inside the final mine void. Outside of the final void area, rehabilitation will be completed using standard practice techniques, as successfully implemented across Rio Tinto's Pilbara mining operations.

The following closure objectives have been established for the Yandi Operation and will be applied to the Revised Proposal:

- Rehabilitated landforms are stable and designed to manage floodwater appropriately.
- The environmental and cultural heritage values associated with creek flows and function are maintained post-closure.
- Environmental values of Fortescue Marsh are not compromised.

- Water quality within pit lakes support natural ecosystems and are compatible with post-mining land use.
- Alluvial groundwater systems support remnant phreatophytic vegetation.
- Final landforms are rehabilitated to be compatible with post-mining land use.
- Public safety hazards have been addressed.

Completion criteria to measure closure implementation success against these closure objectives have been recommended within the Yandicoogina Closure Plan. The completion criteria will be refined based on information developed during implementation of the Proposal, from baseline studies and rehabilitation trials, then finalised with stakeholders as the Proposal approaches closure.

During the life of the Proposal, investigations will be undertaken and an adaptive management approach will be used to ensure that risks to closure are identified and addressed so as to meet the EPA's objective for rehabilitation and closure.

The key anticipated long term outcomes are as follows:

- Pit walls of the final mine void that are adjacent to Weeli Wolli Creek are stabilised in a way that prevents the creek from collapsing into the mine voids post-closure ensuring continued function of Weeli Wolli Creek.
- All areas disturbed for mining (with the exception of pit walls) and infrastructure that are not required by the State (under conditions of applicable State Agreements) are rehabilitated to a condition compatible with the post-mining land use following decommissioning.
- Creation of two pit lakes and associated dynamic wetland environment within the mine void with water levels that will rise and fall in accordance with flooding of the creek systems.
- Regional hydrogeological impacts are minimised and adequately managed.
- Outside of the mining disturbance areas and more than 2 km from the Proposal mine voids, water levels are largely predicted to return to pre-disturbance levels.
- No impacts to the hydrological regime of the Fortescue Marsh as a result of closure of the site.

OTHER FACTORS

Aboriginal Heritage

Aboriginal archaeological and ethnographic surveys have been completed across the proposed footprint and for the majority of the Proposal Area, with numerous Aboriginal archaeological sites recorded, ranging from low to high in archaeological and cultural significance. The major risks to Aboriginal heritage are related to the disturbance of archaeological or ethnographic sites and impacts on the heritage values of sites and places. Aboriginal heritage sites could potentially be disturbed by proposed activities such as clearing, dewatering, excavation and surface water discharge, although it is Rio Tinto's policy to avoid heritage sites, wherever practicable.

A heritage zone is currently delineated around Weeli Wolli Creek, due to the association of this site with camping activities, ceremonial activities and other cultural activities.

However, it is noted that part of the proposed mining activities occur within this zone. Any long term alteration to the regional water regime will be undertaken in consultation with local traditional owner groups.

The Proposal is expected to have some effect on the ethnographic cultural values of Weeli Wolli Creek, however any disturbance within the Weeli Wolli Creek heritage zone or of other archaeological/ethnographic sites will be in accordance with the provisions of the *Aboriginal Heritage Act 1972* (WA) and will have the consent of the relevant Traditional Owners. Rio Tinto will maintain ongoing consultation with Aboriginal stakeholders over the life of the Proposal, in accordance with processes established for the existing Yandi Operations.

Air Quality

Dust will be generated by construction and mining activities such as vegetation clearing, earthworks and mining (including blasting), vehicle movements and dry ore processing, stockpiling, reclaiming and transport.

As the majority of the Iron Ore at the Proposal is below watertable ore, the moisture content of the ore will reduce the likelihood of dust-related impacts from materials handling. Additionally, the Proposal is remote from sensitive air quality receptors, with other mining operations being the nearest premise.

Amenity

Temporary visual effects in the immediate region around the mine pit will occur from the development of the waste dumps and infrastructure/facilities. The extent and condition of riparian vegetation is also expected to be reduced in the long term as the creeks are ultimately returned to the pre-mining ephemeral system.

During mine closure, the maintenance of aesthetic values for cultural and amenity purposes are an important consideration. Rehabilitation is expected to return the visual amenity as much as possible to the original pre-disturbance landscape. Two pit lakes will be created within the Proposal Area and while changing components of the pre-mining amenity, they are expected to create new ecosystems.

OFFSETS

The Proponent has considered measures to avoid, minimise and rehabilitate impacts to environmental values throughout the design of the Proposal. Taking into account these measures, the following significant residual impact arising from the Proposal has been identified:

- Clearing of up to 1,731 ha of native vegetation in Good to Excellent condition within the Proposal Area, including fauna habitat (excluding riparian zone vegetation[1]).
- Clearing of up to 69 ha of native riparian zone vegetation[1] within the Proposal Area, including fauna habitat.

The EPA has established a strategic conservation initiative to coordinate offsets in the Pilbara. Consistent with the WA Environmental Offsets Guidelines, it is considered that

[1] For the purposes of the offset calculation, riparian zone vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

the residual impact of disturbance of vegetation in Good to Excellent condition or riparian zone vegetation is significant and will therefore require compensation via an offset. A standard offset approach has been developed by the EPA in regard to this residual impact and it has been applied consistently to projects in the Pilbara. As such, the Proponent is proposing to contribute funding of $1,500 (excluding GST) per hectare of native vegetation, and funding of $3,000 (excluding GST) per hectare of riparian zone vegetation cleared to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.

ENVIRONMENTAL MANAGEMENT

The Proponent is a member of the Rio Tinto Group, which has extensive experience in managing the development, operation and environmental compliance of Iron Ore mining projects similar to the Proposal. This experience, along with stakeholder consultation, has been used to define the potential environmental impacts from the Proposal, and the proposed mitigation and management measures. The Proponent aims to conduct its business in an efficient and environmentally responsible manner that is compatible with the expectations of stakeholders. A systematic process of environmental management has been adopted, which improves the likelihood that significant environmental impacts have been identified, investigated and mitigated, as far as practicable. As a result, there is greater certainty in achieving desirable environmental outcomes.

Environmental Management System

Rio Tinto requires its operations to implement and maintain an EMS that provides a model for continuous improvement, the key elements of which include assessing environmental risk and legal requirements, developing objectives and targets for improvement, training, operational control, communication, emergency response, corrective actions, audits and reviews.

Environmental Management Plans

The following key Yandi Operations site specific management documents will be implemented to manage potential impacts associated with the Proposal:

- Yandicoogina Monitoring and Management Plan, which includes:
    - Yandicoogina Vegetation and Groundwater Dependant Ecosystems Monitoring and Management Plan; and
    - Yandicoogina Surface Water Discharge Monitoring and Management Plan;
- Yandicoogina Weed Action Plan:
- Proponent's Pilbara-wide Significant Species Management Plan, including Yandi Operations site specific addendum; and
- Yandicoogina Closure Plan.

Environmental Values Statement

As part of the approval for the existing Yandi Operations, an Environmental Values Statement (EVS) was developed for Weeli Wolli Creek. The current EVS for the Weeli Wolli Creek catchment, included in the revision to the Yandicoogina Monitoring and Management Plan, identifies three high level values; Fortescue Marsh, Flora and

Vegetation and Stygofauna. Other recognised values include fauna, heritage and social aspects.

Environmental Control Instruments and Proposed Environmental Conditions

There are a number of existing regulatory controls that will ensure that environmental values are protected during implementation of the Proposal including requirements under the EP Act regarding discharges and emissions and the Rights in Water and Irrigation Act regarding dewatering. Another of these controls includes environmental conditions in a Ministerial Statement that may be issued by the Minister for Environment allowing the Proposal to be implemented as approved.

The Proponent has proposed environmental conditions for consideration by the Minister for Environment. These conditions are based on those outlined in MS 914 for the existing Yandi Operations, which would be superseded by a new Ministerial Statement, subject to approval of the Revised Proposal.

OUTCOMES

In summary, the key outcomes of the assessment for the Proposal, relating specifically back to the ESD include:

Hydrological processes and Inland waters environmental quality

- Natural surface water systems and flows – potential impacts likely to be minor due to the main creekline surface water flowpaths being maintained and can be managed through typical stormwater management measures such as levees around the pit, diversion drains around waste dumps, and culverts under roads.
- Surface water resources – discharge wetting front will be within existing approved limits, and therefore there will be negligible additional impacts on the downstream hydrological system of Weeli Wolli Creek.
- Altered flow regime to the Fortescue Marsh – surface water wetting front associated with the additional discharge from the Proposal is predicted to remain within existing approved limits of MS 914.
- Potential contamination of surface water and groundwater – acid rock drainage risk at the Revised Proposal Development Envelope has been assessed as low. Site drainage will be designed to minimise or eliminate surface runoff into areas where activities with a potential risk of hydrocarbon contamination occur. Management of waste dumps will ensure that risks of contamination of surface and groundwater are minimised. Groundwater discharged at the surface is fresh and is currently monitored and managed following ANZACC guidelines for freshwater ecosystems.

Flora and vegetation

- Clearing of up to 1,800 ha of vegetation (including 69 ha riparian vegetation).
- Stress and loss of some riparian vegetation associated with dewatering activities (drawdown), particularly more groundwater dependant vegetation and younger recruitment/augmented areas of riparian vegetation sustained by pre-existing

discharge, with the vegetation expected to return to a more 'natural' state (i.e. pre-mining).

- Loss of some riparian vegetation associated with surplus water discharge, particularly waterlogging affects and the establishment of waterlogging tolerant species including sedges and rushes, though overall impacts will be limited to the currently approved footprint limit within MS 914 (17 km downstream from confluence of Marillana and Weeli Wolli Creeks).
- No loss of known and recorded individuals of *Lepidium catapycnon* (Hamersley Lepidium); redesign of the waste dumps has avoided recorded individuals.
- Other vegetation communities within the Proposal Area are largely typical of that occurring in similar habitats elsewhere in the region, or are considered relatively widespread in the Pilbara beyond the Proposal Area.
- Removal of some individuals of Priority 4 flora species (*Goodenia nuda*), which will not affect the species' conservation status.
- Rehabilitation using native vegetation of areas disturbed by the Proposal, consistent with the Yandicoogina Closure Plan.

Terrestrial fauna

Terrestrial vertebrate fauna

- Clearing of up to 1,800 ha of terrestrial fauna habitat over the life of the project and habitat degradation due to the altered groundwater regime (some tree deaths within the riparian zone), which may lead to local reductions in current fauna populations in the Proposal Area.
- The habitat types present in the Proposal Area are considered to be well represented in the local and regional area. It is considered likely that terrestrial fauna will continue to persist in the remaining habitats within and adjacent to the Proposal Area during operations.
- Clearing will result in the direct removal of up to 1,800 ha of potential SRE habitat within Proposal Area; this habitat is considered widespread locally and regionally.
- Limited aquatic habitat will be lost or fragmented as a result of the Proposal.
- Vegetation clearing within the Proposal Area is not anticipated to cause any significant fragmentation of habitat or disruptions to ecological linkages.
- Progressive rehabilitation, with consideration given to restoring pre-mining fauna habitat values where practicable.

Short range endemic fauna

- Four mygalomorph spider species are considered to represent potential SREs: Idiopidae sp. I1, Idiopidae sp. I9, Nemesiidae sp. N42 and Nemesiidae sp. N44.
- All species have been previously recorded outside the Proposal Area.
- Potential SRE habitat within the Proposal area is considered widespread locally and regionally.

Aquatic fauna

- The most recent aquatic fauna surveys in 2013 and 2014 recorded 283 invertebrate fauna taxa in the Proposal Area.
- Some undescribed hyporheic taxa are potential new species.
- Five stygobitic amphipod/isopod species were considered to be potential SREs.
- Three fish species were observed, none of which are conservation listed.
- Limited aquatic fauna habitat will be lost or fragmented as a result of the Proposal, as the low-flow channel will remain in situ and larger rainfall events will continue to provide natural flood flows in Weeli Wolli Creek, which sustains connection upstream to Weeli Wolli Spring and downstream to Fortescue Marsh.

Subterranean fauna

- Thirteen phases of stygofauna sampling have been conducted in and around the Revised Proposal Development Envelope since 2003.
- A total of 2,761 specimens from 62 taxa have been recorded in the Proposal Area to date, 39 of which occur within the proposed mine pit boundary.
- Of the 39 taxa recorded within the proposed pit boundary, three species are not known from any other records outside this area: *Notobathynella* sp., *Billibathynella* sp. B02 and *Brevisomabathynella* cf. *pilbaraensis*. These species are not currently conservation listed and current distribution is considered likely to be an artefact of sampling.
- Direct mortality and reduction in available subterranean habitat will occur as a result of pit excavation and groundwater drawdown.
- Potential impacts will be localised to the proposed pit area and the groundwater drawdown zone during mining operations. However, it is not expected to significantly impact subterranean assemblages and species persistence.
- The continuous nature of the alluvium, colluvium and calcrete units in which the subterranean fauna were predominately recorded indicates that geology is not a limiting factor in the distribution of the taxa currently known from the proposed pit area and the groundwater drawdown zone within the Proposal Area.
- The risk of pollutants being transported into the subterranean habitats is likely to be low and restricted to localised areas.

Rehabilitation and closure

- Pit walls of the final mine void that are adjacent to Weeli Wolli Creek are stabilised in a way that prevents the creek from collapsing into the mine voids post-closure, ensuring continued function of Weeli Wolli Creek.
- All areas disturbed for mining (with the exception of pit walls) and infrastructure that are not required by the State (under conditions of applicable State Agreements) are rehabilitated to a condition compatible with the post-mining land use following decommissioning.

- Creation of a dynamic wetland environment within the mine void, including two pit lakes and associated lake fringe, with water levels that will rise and fall in accordance with flooding of the creek systems.

- Regional hydrogeological impacts are minimised and adequately managed.

- Outside of the mining disturbance areas and more than 2 km from the Proposal mine voids, water levels are largely predicted to return to pre-disturbance levels.

- No impacts to the hydrological regime of the Fortescue Marsh as a result of closure of the site.

Other Factors

Aboriginal heritage

- Aboriginal heritage sites could potentially be disturbed by proposed activities such as clearing, dewatering, excavation and surface water discharge; however it is Rio Tinto's policy to avoid heritage sites, wherever practicable.

- Any disturbance to archaeological/ethnographic sites will be in accordance with the provisions of the *Aboriginal Heritage Act 1972* (WA) and will have the consent of the relevant Traditional Owners.

Air quality

- The proposal will generate dust during construction and mining activities such as vegetation clearing, earthworks and mining (including blasting), vehicle movements and dry ore processing, stockpiling, reclaiming and transport.

- Existing Rio Tinto procedures and practices used at the existing Yandi Operations to effectively prevent significant dust emissions will be applied to the Proposal.

Amenity

- Temporary visual effects in the immediate region around the mine pit with the use of waste dumps and infrastructure/facilities.

- Extent and condition of riparian vegetation is expected to be reduced in the long term as the creeks (that are currently receiving discharge water from mining operations) are ultimately returned to an ephemeral system.

- Rehabilitation is expected to return the visual amenity as much as possible to the original pre-disturbance landscape. Two pit lakes will be created within the Proposal Area; while changing components of the pre-mining amenity, they are expected to create new ecosystems.

- The management measures outlined in the Yandicoogina Closure Plan are expected to maintain the key amenity values after mine closure.

Offsets

Taking into account measures to avoid, minimise and rehabilitate impacts, the following significant residual impact arising from the Proposal has been identified:

- Clearing of up to 1,731 ha of native vegetation in Good to Excellent condition within the Proposal Area, including fauna habitat (excluding riparian zone vegetation[2]).

- Clearing of up to 69 ha of native riparian zone vegetation[2] within the Proposal Area, including fauna habitat.

[2] For the purposes of the offset calculation, riparian vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

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Part 1 – Introduction

This part introduces and broadly outlines the Proposal and the purpose and scope of this document. This part also outlines development alternatives considered and describes the stakeholder engagement process undertaken for the Proposal.

1. Introduction

1.1 Overview

Hamersley Iron – Yandi Pty Limited is seeking to develop a new brownfields iron ore mine pit to sustain its existing Yandicoogina Operations (Yandi Operations). This Proposal is referred to as the 'Yandicoogina Pocket and Billiard South Iron Ore Development' (the Proposal) and will involve construction and operation of a new mine pit, waste dumps and associated infrastructure to enable sustained production from the existing Yandi Operations. Collectively, the Proposal and the existing Yandi Operations are referred to as the 'Revised Proposal'.

The Proposal is expected to have a total throughput of up to 31 million tonnes per annum (Mtpa), as the existing Yandi Operations are depleted, and is expected to have an operational mine life of approximately 16 years.

1.2 Proponent

The Proponent for the Proposal is Hamersley Iron – Yandi Pty Limited ('the Proponent'). The Proponent is a wholly owned member of the Rio Tinto Group and forms part of Rio Tinto's global Iron Ore business. This includes several wholly owned subsidiaries and joint venture initiatives in the Pilbara region of north west Western Australia (WA).

The Proponent contact person in relation to the environmental approvals process for the Proposal is:

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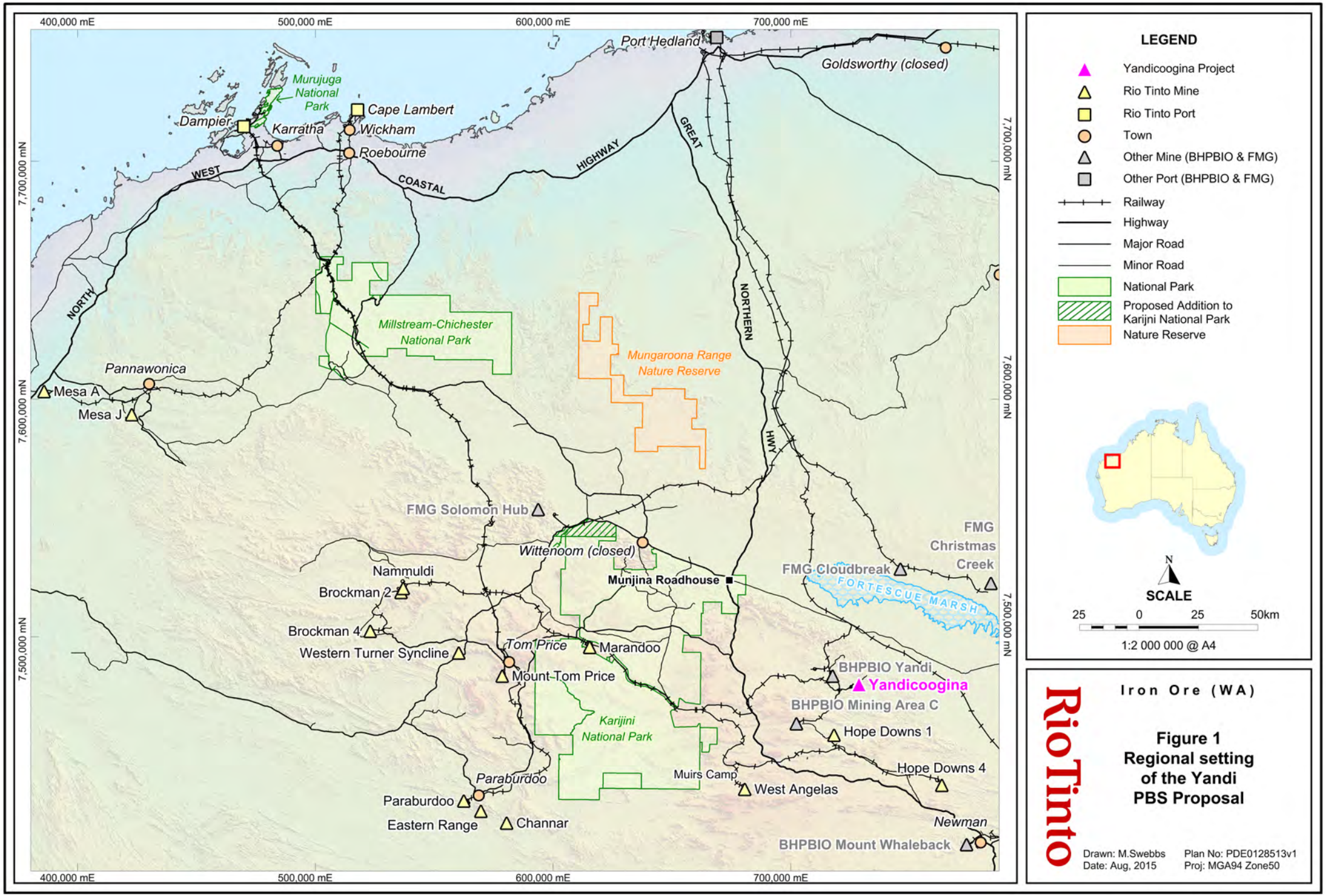
Facsimile: +61 8 9327 2696
Email: melinda.brand@riotinto.com

1.3 Location of the Proposal and Proposal elements

The Proposal (the Proposal) is located in the central Pilbara region of WA approximately 90 kilometres (km) north west of Newman and 300 km south east of Dampier (

Figure 1). The Proposal deposits are located immediately east of the existing Yandi Operations Junction Central (JC) and Junction South East (JSE) deposits and the more recently approved Junction South West (JSW) and Oxbow deposits (**Figure 2**).

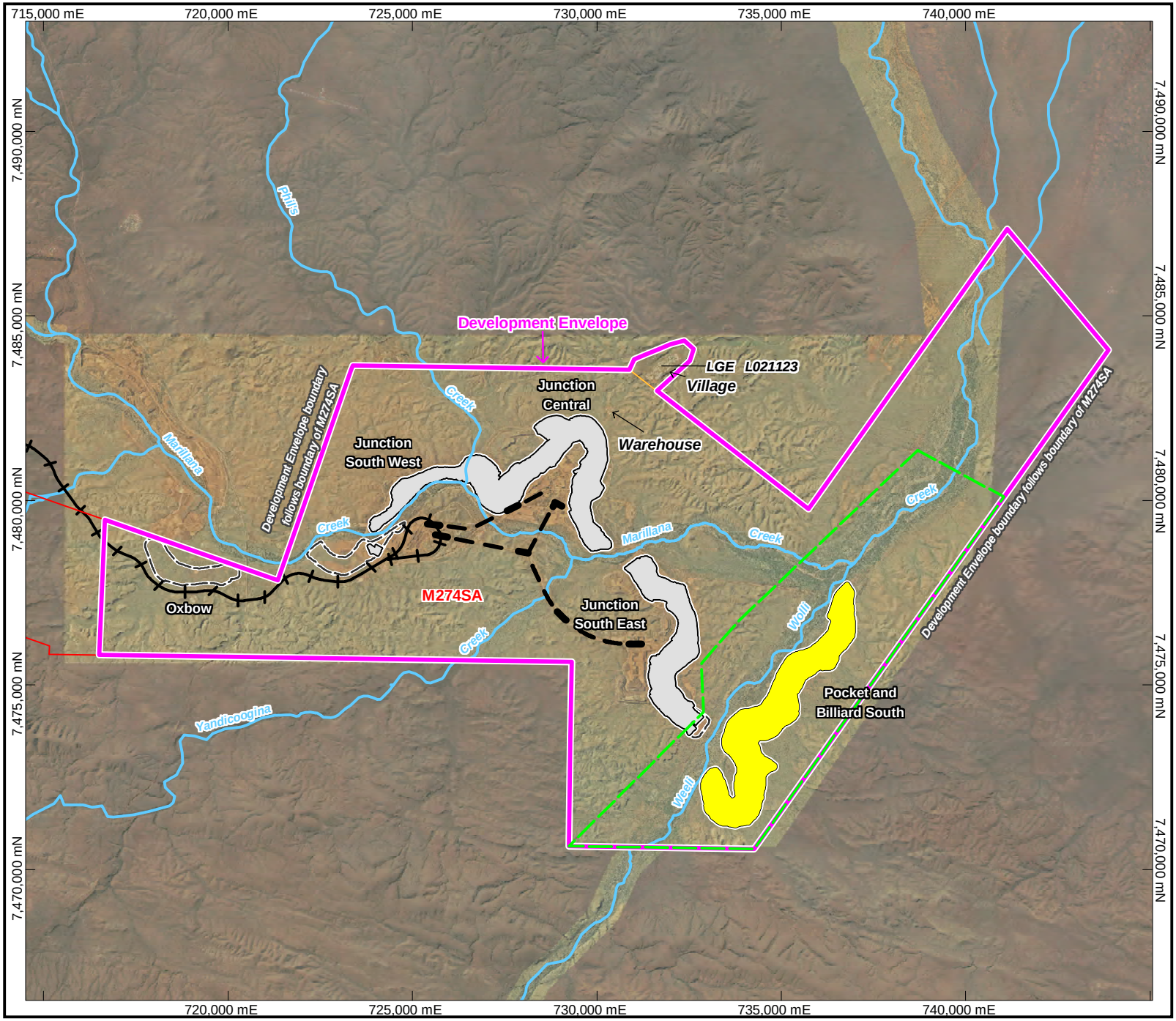


Iron Ore (WA)

Figure 1 Regional setting of the Yandi PBS Proposal

Drawn: M.Swebbs
Date: Aug, 2015

Plan No: PDE0128513v1
Proj: MGA94 Zone50



LEGEND

- Development Envelope
- Proposal Area
- M274SA
- Yandi Accommodation Village General Lease L021123
- Proposed Mine Pit
- Existing Mine Pit
- Approved Mine Pit
- Existing Conveyor
- Existing Railway
- Major Watercourse

N

SCALE

0 2 4 6km

1:150 000 @ A4

Iron Ore (WA)

Figure 2
General location of the Proposal

Drawn: M.Swebbs
Date: October, 2015
Plan No: PDE0133270v2
Proj: MGA94 Zone50

Geospatial Information and Mapping

The Proposal is centred on a substantial CID immediately to the east of the existing Yandi Operations. The Proposal is a revision to the existing Yandi Operations as approved under Ministerial Statement No. 914 (MS 914) in 2012, and includes the following key additions:

- A new below water table open cut pit and associated infrastructure (ore and waste dumps and haul roads).
- Supporting infrastructure (light vehicle roads, creek crossing, flood protection levees, diversion drains, dewatering infrastructure, power and telecommunications).
- Additional dewatering of the CID aquifer, including discharge to local creeks.

The Proposal will utilise processing and materials handling infrastructure already installed at the existing Yandi Operations.

1.4 Proposal context

1.4.1 Existing Yandi Operations

The existing Yandi Operations are currently centred over three mining areas: JC, JSE and JSW (A & C); with a replacement orebody Oxbow due to come online in 2017.

The mine pits are all contained within a continuous CID orebody, which also forms a major aquifer in the area. Approximately 80% of the orebody is situated below the pre-mining water table and as a consequence, dewatering is a key requirement of mining activities for the existing Yandi Operations.

The existing Yandi Operations, as approved, currently consists of:

- Five open cut pits within the CID: JC, JSE and JSW-C (currently operating); and JSW-A and Oxbow (approved but not yet operating).
- A 90 km rail line to Juna Downs.
- Mine infrastructure (e.g. product stockpiles, waste dumps, topsoil, low grade stockpiles, waste fines storage facilities and haul roads).
- Associated infrastructure (e.g. overland conveyors, mine access roads, offices, warehouses, accommodation, bore fields, fuel storage facilities and utilities).
- Abstraction of up to 53 gigalitres per year (GL/y).
- A water management system including on-site reuse of water abstracted from pit dewatering, and discharge of surplus volumes into creek systems.
- Dry and wet processing plants.
- Flood protection structures.
- Power and communications infrastructure.

The key characteristics of the existing Yandi Operations, as described in Schedule 1 of MS 914, and the Proposal key characteristics, which together comprise the Yandicoogina Iron Ore Project – Revised Proposal, are outlined in **Table 1**.

Table 1: Summary of Revised Proposal key characteristics

Characteristic	Revised Proposal		
	Yandi Operations (existing)	**The Proposal (additional proposed)**	**Yandi Operations (Revised Proposal)**
Short description	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West and Oxbow, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) – car dumpers, conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops. • Rail corridor allowing for rail lines and associated infrastructure. • Construction and operations support infrastructure. • A diesel-fired power station and transmission lines. • Dry and wet processing plants (including in pit waste fines storage facilities). • Flood protection structures. • Accommodation camps. • Access roads. • An airstrip.	The proposal is to develop a below water table open cut Iron Ore mine at Pocket and Billiard South, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Temporary surface waste dumps; • Major infrastructure including a flood protection levee, a diversion drain and Weeli Wolli Creek crossing; and • Supporting mine infrastructure including power spur, haul roads and ramps, mine access and internal road network, and dewatering infrastructure (dewatering pipeline, bores and outlets).	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West, Oxbow and Yandi PBS, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) – overland conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops. • Rail corridor allowing for rail lines and associated infrastructure. • Construction and operations support infrastructure. • 220kv power network including switchyard, back-up diesel power and transmission lines. • Dry and wet processing plants (including in pit waste fines storage facilities). • Flood protection structures and creek crossings. • Accommodation camps. • Access roads.
Physical elements			
Mine and associated infrastructure	Vegetation clearing up to 5,600 ha within Restricted Clearing Area 1; and Vegetation clearing up to 60 ha within Restricted Clearing Area 2	Vegetation clearing up to 1,300 ha for mining and waste dumps Vegetation clearing up to 500 ha for infrastructure	Vegetation clearing up to 7400 ha within Revised Proposal Development Envelope. Vegetation clearing up to 129 ha within the proposed Restricted Clearing Area.
Railway and associated infrastructure	90 km rail line	No additional rail required	No additional rail required.

Characteristic	Revised Proposal		
	Yandi Operations (existing)	**The Proposal (additional proposed)**	**Yandi Operations (Revised Proposal)**
Operational elements			
Dewatering	No more than 35 GL/year from Junction South East and Junction Central operations. No more than 18 GL/year from Junction South West A, Junction South West C and Oxbow operations.	Approximately 50 GL/year for the Proposal	No more than 83 GL/year for the entire Revised Proposal.
Surface water discharge	Up to 16 GL/year from Junction South West A, Junction South West C and Oxbow operations.	Approximately 50 GL/year for the Proposal	Up to 78 GL/year for the entire Revised Proposal. No water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence.

1.4.2 Approvals history of the existing Yandi Operations

Iron Ore mining at the existing Yandi Operations is subject to the *Iron Ore (Yandicoogina) Agreement Act 1996*, which came into effect on 22 October 1996. Mining at JC received approval from the Minister for the Environment on 24 May 1996 (MS 417) and was subsequently amended on 1 October 1999 (MS 523). Mining at JSE received approval from the Minister for the Environment on 22 October 2005 (MS 695), with mining activities commencing at JC and JSE in 1998 and 2006 respectively.

The most recent approval (MS 914, issued on 18 October 2012) amalgamated the existing JC and JSE Ministerial Statements to a single set of contemporary conditions via s46B of the WA *Environmental Protection Act 1986* (EP Act), and included the incorporation of three new mine pits at JSW-A & C and Oxbow. The JSW and Oxbow approval was also subject to Commonwealth approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) via Decision notice 2011/5815.

1.5 Purpose and scope of this document

This Public Environmental Review (PER) document is required for the formal assessment of the Proposal under Part IV of the EP Act, administered by the WA Environmental Protection Authority (EPA). The Proposal was referred to the WA EPA on 4 July 2014 and the EPA determined that the Proposal required assessment at the level of PER.

The purpose of the PER is to present an environmental review of the principal components of the Proposal, including a detailed impact assessment and description of proposed environmental management measures for key environmental factors in accordance with the Environmental Scoping Document (ESD) prepared by the EPA (**Appendix 1**).

The preliminary key environmental factors relevant to the Proposal are (as outlined in the ESD):

- Flora and vegetation.
- Terrestrial fauna.
- Subterranean fauna.
- Hydrological processes and inland waters environmental quality.
- Rehabilitation and closure (integrating factor).
- Offsets (integrating factor).

During the assessment of proposals, other factors or matters may be identified as relevant to the proposal, but are not of significance to warrant further assessment by the EPA, or are impacts that can be regulated by other statutory processes to meet the EPA's objectives. However in some circumstances, other factors, while not being considered as preliminary key environmental factors or integrating factors, may require greater emphasis in the PER document. The preliminary other environmental factors relevant to the Proposal are (as outlined in the ESD):

- Aboriginal heritage.
- Air quality.
- Amenity.

The State environmental assessment process and the identification of key environmental factors for the Proposal are further described in Section 8 and Section 9 respectively.

The PER addresses all phases of the Proposal (construction, commissioning, operations and closure) and is structured as follows:

- **Part 1 Introduction**: A discussion of the purpose and scope of this document, the background to and development of the Proposal, the development alternatives considered, and details of the stakeholder engagement process undertaken.
- **Part 2 Description of Proposal**: A detailed description of the Proposal.
- **Part 3 Overview of Existing Environment**: An overview of the relevant features of the existing environment of the Revised Proposal Development Envelope and surrounding area.
- **Part 4 Approach to environmental factors**: A description of the State and Commonwealth environmental assessment processes, the applicable legislative and policy context and the approach taken for considering the potential environmental impacts of the Proposal.
- **Part 5 Assessment of environmental factors**: An assessment of key potential environmental impacts of the Proposal on the identified key environmental factors and the environmental management measures and predicted outcomes.
- **Part 6 Summary of cumulative impacts**: A summary of the cumulative impacts associated with the Proposal and nearby projects.
- **Part 7 Proposed environmental management program and environmental commitments**: A description of the environmental management framework and measures to offset any significant residual impacts that may arise from implementation of the Proposal, and proposed conditions of approval.

2. Development justification and alternatives considered

2.1 Proposal rationale and benefits

The Proposal is in close proximity to the existing Yandi Operations including ore processing plants and rail load-out facilities at JC, and will sustain mining as the existing deposits become depleted.

The Proposal will optimise Rio Tinto's existing infrastructure where possible, including railway, power, communications and road networks. This will reduce the extent of new infrastructure typically required for greenfield developments and result in a smaller disturbance footprint than would otherwise be required for a project of this scale.

These aspects make the Proposal a highly desirable option to contribute to the continued success of the WA Iron Ore industry, with consequent benefits for the wider economy.

New employment will be created during the mine construction phase of the Proposal. Further, the operating life of existing mine and rail transportation infrastructure will be extended resulting in the operational workforce being maintained beyond the lifespan of the existing Yandi Operations.

The Proposal will result in the continuation of economic benefits for WA and Australia through:

- contribution to the value of mineral exports;
- royalties and taxation payments;
- capital investment;
- increasing direct and indirect employment opportunities in the region;
- increasing demand for goods and services supporting the regional economy; and
- assisting to sustain the Pilbara Iron Ore industry.

The Banjima, Nyiyaparli and Yinhawangka people (the Traditional Owners) will also benefit under the terms of the Yandicoogina Land Use Agreement (YLUA). The YLUA was the first major land use agreement to be signed in Australia, and provides the basis for delivering social and economic benefits to Aboriginal stakeholders.

The ongoing activities of the Proponent, and more broadly Rio Tinto, in the Pilbara region will continue to support social and economic development projects, including:

- increasing the potential education, training, employment and business options for local Aboriginal people; and
- funding a range of organisations in the region, including sporting and cultural groups.

In connection with its existing and planned mining activities in the Pilbara, Rio Tinto also contributes to a range of research activities addressing regionally relevant environmental impacts. Examples of these projects include research into:

- Plant-water relationships in Pilbara vegetation, including:
  - the occurrence and nature of groundwater dependence in different tree species;
  - developing methods for measuring the effects of groundwater drawdown on vegetation; and
  - water use physiology of Mulga vegetation and strategies for maintaining surface flow regimes for Mulga conservation.
- The distribution and taxonomy of subterranean and short range endemic fauna, in collaboration with the Western Australian Museum (WAM) and in association with the Department of Parks and Wildlife (Parks and Wildlife).
- Predicting and managing water quality in pit voids.
- The palaeoclimatic history, geology and hydrology of the Fortescue Marsh.
- Recharge and hydrological process of Weeli Wolli Creek.
- Adaptive responses of fish to altered flow regimes and Pilbara regional study of bioaccumulation of metals in fish.

Key research collaborators in these projects include the University of Western Australia, Parks and Wildlife and WAM.

2.1.1 Demand for Iron Ore

Mining is an important component of the WA and national economies. The value of Western Australia's mineral and petroleum industry in 2014 reached just over $114 billion (DMP 2015). Iron Ore remained the State's highest value commodity, accounting for a $65 billion (75%) of total mineral sales in 2014. This represents a decrease of 6% from 2013, which can be attributed to the sharp drop in Iron Ore prices in the second half of the year. In total 697 million tonnes of Iron Ore were exported which was an increase of 25% on the previous calendar year (DMP 2015).

Mining and petroleum contributed approximately 91% of WA's merchandise exports in 2014. China remained the state's largest market, accounting for 51% of the state's total merchandise exports. As at March 2015, Western Australia had an estimated $179 billion worth of resource projects under construction or in the committed stage of development. A further $118 billion has been identified as being allocated to planned or possible projects in coming years (DMP 2015).

2.2 Evaluation of development alternatives

2.2.1 Evaluation of crusher and ore transport alternatives

A number of crusher and conveyor configurations were investigated based on varying saleable ore product tonnages to test crushing and conveying as an alternative to trucking to the plant. Some of the various conveyor routes and crusher locations examined are shown in **Figure 3**.

Two crusher locations were assessed; one to the east of the orebody, and one to the west, using a combination of trucking to the crushers and then conveying to the existing processing plant(s). From the analysis carried out, the crusher facilities at the existing

Yandi Operations will be utilised and trucking is the preferred ore transport option for the Proposal.

2.2.2 Evaluation of options for crossing Weeli Wolli Creek

A crossing at Weeli Wolli Creek is required to enable ore movement from the Proposal deposits to the various JSE and JC processing plants. As the Proposal deposit is entirely located east of Weeli Wolli Creek, a creek crossing via a culvert-floodway structure will be required to access facilities at the existing Yandi Operations, located entirely west of Weeli Wolli Creek. A number of locations for a creek crossing were identified, with the aim of minimising disturbance and water velocities and thus the potential impact to Weeli Wolli Creek and any heritage or environmentally sensitive areas.

The following three options for design of the crossing on Weeli Wolli Creek were considered:

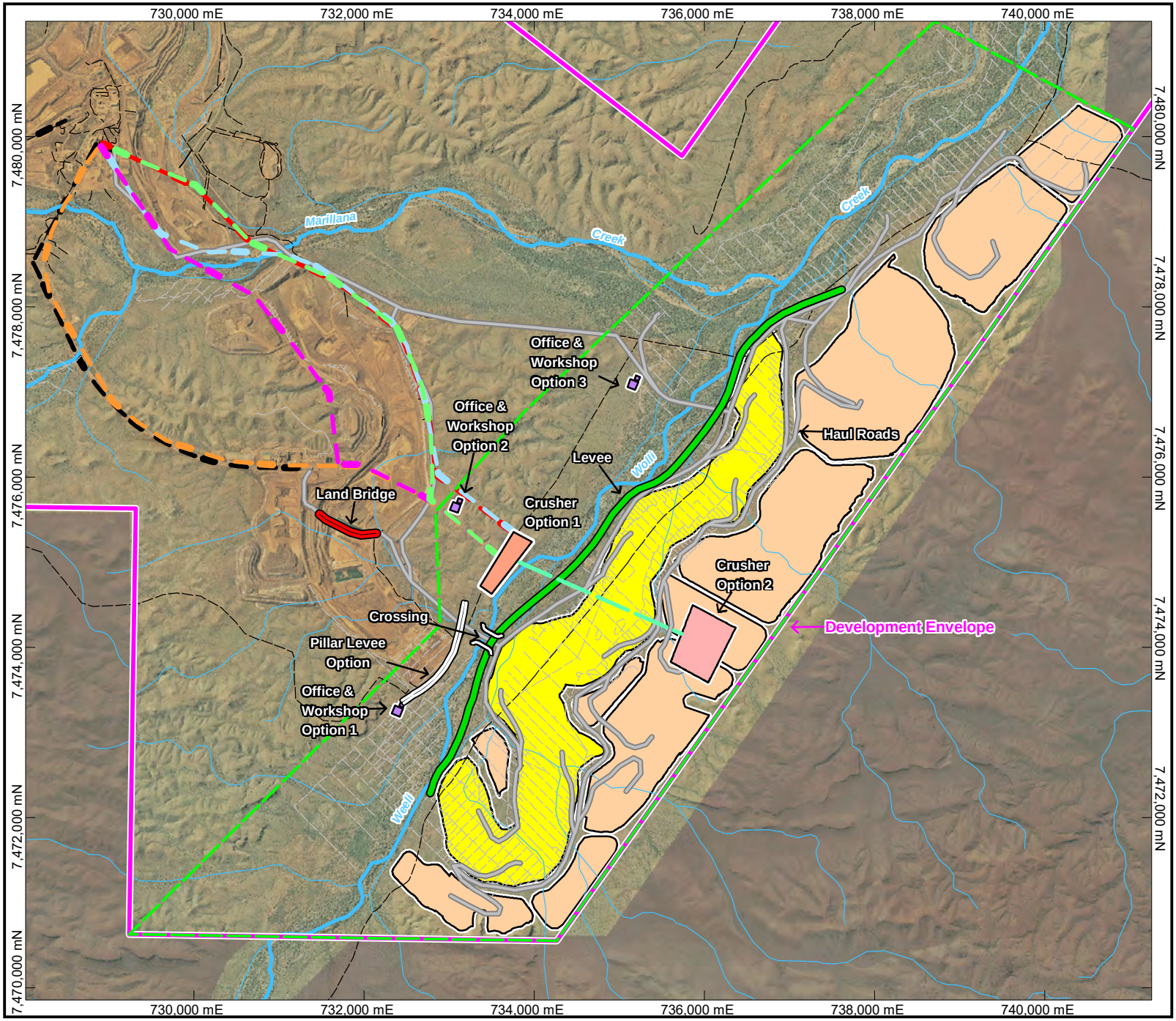
- an engineered bridge;
- the existing Marillana-type floodway option; and
- a culvert-floodway consisting of cement stabilised base-course overlaid with a crushed rock wearing course, overlying eight 3.6 m corrugated steel pipes over the low-flow channel.

Following consultation with technical representatives on the study team for water, environment and heritage, the culvert-floodway concept was chosen as the option preferred. The culvert-floodway appears to be a more stable design than the existing Marillana-type floodway in a flooding situation, and is anticipated to cause less disruption to the flow of Weeli Wolli Creek during construction and operation.

2.2.3 Evaluation of water management options

Dewatering for the Proposal will be fully integrated with the existing Yandi Operations whole-of-site water demand; however, a substantial volume of surplus water is likely to be generated over the life of the Proposal, ranging from the existing approved approximately 16 GL/y[3] up to 78 GL/y. Some of the groundwater abstracted is expected to be used for on-site purposes such as dust control, camp usage and ore processing. The remainder will be discharged into the Marillana and Weeli Wolli Creek systems at controlled, release discharge points. Water discharge for the Proposal will tie in with the existing Yandi Operations water disposal infrastructure in the lower reaches of Marillana Creek towards the Weeli Wolli Creek confluence.

[3] Note that this limit relates to JSW and Oxbow, and does not include JC and JSE surplus water discharge. Total surplus water discharge is approximately 48 GL/y for existing Yandi Operations.



LEGEND

- Development Envelope
- Proposal Area
- Existing Conveyor
- Existing Road
- Existing Track
- Existing Exploration Track
- Major; Minor Watercourse

Conceptual Mine Layout

- Mine Pit
- Waste Dump / Stockpile
- Crusher Option 1
- Crusher Option 2
- Office & Workshop Options

Conveyor Options

- 1
- 2
- 3
- 4
- 5

- Levee Option
- Pillar Levee Option
- Haul Road
- Land Bridge

N

SCALE

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Iron Ore (WA)

Figure 3
Proposal development alternatives

Drawn: M.Swebbs Plan No: PDE0128630v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Alternative options for the use of surplus water over and above the existing approved discharge limits for the Yandi Operation have been investigated during the pre-feasibility study, in line with the *Pilbara Water in Mining Guidelines* [Department of Water (DoW) 2009)] and *Strategic Policy 2.09: Use of mine dewatering surplus* (DoW 2013) including consideration of:

- reuse on-site;
- transfer to other current and future mining projects;
- aquifer recharge info aquifers;
- re-injection into aquifers;
- storage and evaporation;
- seasonal storage and release of water; and
- continuous surface release of water.

Additional options that have been investigated include the transfer of water to other sites such as Koodaideri and/or Hope Downs 1 and storage of water in the JC pit lake. These options and the rationale behind the selected option are described in detail in Section 13.3.4.

2.2.4 Evaluation of alternative office and workshop locations

A workshop for daily and weekly maintenance and potentially heavy vehicle refuelling facilities are proposed to be constructed, along with new office facilities consisting of an administration building for daily crew shift change meetings and a crib room with toilets. Three options were identified for the location of the workshop, refuelling and office facilities, taking into account considerations for minimal potential impact to heritage and environmental sites (**Figure 3**). An alternative location to the three options originally identified was selected due to optimisation of the location based on existing facilities.

2.2.5 No development option

The 'do nothing' alternative would result in the loss of opportunity to add value to Australia's raw materials exports, the loss of economic, social and employment opportunities and the loss of potential for future developments in downstream processing of raw materials. If the Proposal does not proceed, the State of WA would forego substantial economic benefits, including:

- viable Iron Ore deposits at the Yandi Operations remaining undeveloped; and
- the decline and eventual end of production from the existing mines at Yandi Operations.

Not proceeding will prematurely reduce the existing workforce at the Yandi Operations and opportunities for supporting local communities and infrastructure would also be foregone. The ore quality within the Proposal deposits will maintain product quality specifications from the existing Yandi Operations and the Proposal will also prolong the use of the existing ore processing and transport infrastructure at Yandi.

If the Proposal did not proceed, the world's demand for Iron Ore would then be met through the development of alternative ore deposits and processing facilities (which may have greater potential environmental impacts than the Proposal) or the development of equivalent projects located overseas with the resultant loss of benefits to the Pilbara, WA and Australia.

3. Stakeholder engagement

3.1 Key stakeholders

The following key stakeholders have been identified for the Proposal:

- Government agencies:
  - Office of the Environmental Protection Authority (OEPA).
  - Department of the Environment (DoE; Commonwealth).
  - Department of Aboriginal Affairs (DAA).
  - Department of Parks and Wildlife (Parks and Wildlife) – Pilbara regional office and Perth office Environmental Management Branch.
  - Department of Environment Regulation (DER).
  - Department of Mines and Petroleum (DMP).
  - Department of State Development (DSD).
  - Department of Water (DoW) – Pilbara regional office and Perth office.
  - Shire of East Pilbara.
- Non-government organisations:
  - Conservation Council of WA.
- Community:
  - Traditional Owners (Gumala Aboriginal Corporation).
  - Marillana Pastoral Station operators.
- Industry:
  - BHP Billiton Iron Ore (BHP).

3.2 Stakeholder engagement process

Discussions regarding the Proposal have been held with a number of stakeholders (**Table 2**).

The timing of the consultation program has enabled topics raised to be considered in the early design phase of the Proposal, during determination of management measures and as part of the preparation of the PER.

3.3 Stakeholder comments and Proponent responses

The main common topics/issues raised by stakeholders as part of the stakeholder engagement process were:

- impacts to vegetation and flora (particularly riparian vegetation and relationship to MS 914 clearing limits);
- surface and groundwater impacts, and water management;
- potential impacts to the Marillana and Weeli Wolli Creek systems;
- cumulative impacts (particularly to the creek systems);
- rehabilitation and closure (including the development of pit lakes); and
- employment opportunities for Traditional Owners.

These are outlined in more detail in **Table 3**, with the Proponent responses.

3.4 Ongoing consultation

The Proponent will continue consultation with relevant stakeholders during the environmental assessment process and through the implementation of the Proposal. In addition to the Traditional Owner groups represented by the Gumala Aboriginal Corporation and the pastoral station operators, the Proponent will consult with regulators including, but not limited to:

- DoW on the management of water resources and other matters related to the WA *Rights in Water and Irrigation Act 1914* (the RIWI Act) licensing requirements for the operations.
- DAA on the management of Aboriginal heritage sites and other matters related to the WA *Aboriginal Heritage Act 1972* requirements.
- Parks and Wildlife regarding Threatened and Priority flora and fauna species, and the Fortescue Marsh.
- DER regarding licensing matters (Part V of the EP Act).
- DSD regarding approval of the Proposal pursuant to the provisions of the *Iron Ore (Yandicoogina) Agreement Act 1996* (WA).
- OEPA regarding details of the Proposal and environmental offsets.
- DMP and other relevant stakeholders regarding closure objectives and indicative completion criteria for the Proposal.

Table 2: Stakeholder consultation relevant to the Proposal

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
OEPA		
21 March 2014	Proposal Pre-referral Presentation to OEPA. The Proponent discussed the Proposal being a Revised Proposal and provided a summary of the results of the biological surveys, potential impacts and preliminary key environmental factors for assessment. The OEPA queried why Billiard North was not included. Also queried why Billiard North was included in the Closure Plan update if not being included in the referral. Cumulative impacts – OEPA indicated that FMG's Nydinghu project and BHP's Jinidi project would need to be considered with the Proposal impacts. Queried if FMG had consulted with the Proponent on their Project. OEPA suggested that because this was a Revised Proposal that Rio would need to identify the key changes for this project in relation to the existing Yandi Operations as approved under MS 914. OEPA indicated that management of surplus water was a key focus, and recommended early consultation with the Department of Water. OEPA also queried disturbance in avoidance areas as delineated in MS 914 i.e. where/how the MS 914 avoidance area was delineated and what we were proposing in terms of disturbance. The Proponent also discussed the expected schedule for formal referral to the OEPA and a proposed Commonwealth referral.	The Billiard North project is not currently at a stage of evaluation where enough information is available to support an Environmental Impact Assessment. It was included in the Closure Plan to support a change in approach to the existing Closure Plan for JC and JSE, and to illustrate the broader life of mine closure objectives as required by DMP. A description of the Proposal and a comparison to the existing Yandi Operations is outlined in Sections 1 and 4 of this PER. The assessment process and referral timing is outlined in Section 8. Potential impacts to hydrological processes, and vegetation and flora are outlined in Sections 13 and 14 respectively. Cumulative impacts are discussed within the environmental factor sections.
21 March 2014	Presentation of the New Yandicoogina Life of Mine Closure Plan Including: • Yandicoogina project overview. • Closure objectives and criteria. • Preferred closure strategy. • Landform design.	Rehabilitation and closure associated with the Proposal is outlined in Section 17.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	• Water management. • Habitat considerations for rehabilitation (and proposed wetland rehabilitation trial). • Unexpected closure. • Further study focus areas. • Compliance review. Key queries included salinity range of pit lakes, modelling undertaken, potential for metals to be released with increased salinity, interaction of saline pits and fresh water pits, and interactions with the creeklines, frequency of flushing of the pit lakes. Also access to pit lakes and safety issues. Discussion on development of completion criteria. Interest in wetland rehab trial and interest in rehabilitation success.	
21 April 2014	The Proponent provided detailed overview of Proposal, current/planned environmental studies, potential environmental impacts and proposed management. The preferred approvals pathway was discussed – existing management in place via MS914 – Level of Assessment will depend on significance of proposal. OEPA queried: • Closure - why Billiard North was not included in the referral if it is included in the Yandi life of mine Closure Plan. • Cumulative impacts – FMG Nyidinghu would need to be included in the cumulative impact assessment as well as Jinidi. • Avoidance areas in MS 914 – queried where they were derived from and what Hamersley Iron was proposing in terms of disturbance. • Referral – to focus on key changes for this Proposal in relation to the existing Yandi Operations.	The Proponent believes that existing conditions and management required under MS 914 for Yandi Operations would adequately address key potential impacts for the Proposal. An increase in disturbance, additional water management, and consideration of cumulative impacts are the key additional features for the Proposal. The Billiard North project is not currently at a stage of evaluation where enough information is available to support an Environmental Impact Assessment. It was included in the Closure Plan to support a change in approach to the existing Closure Plan for JC and JSE and to illustrate the broader life of mine closure objectives as required by the DMP.
21 April 2014	The Proponent provided detailed overview of the life of mine Closure Plan for the Revised Proposal. OEPA were interested in approach to wetland rehabilitation and also rehabilitation success /	The Proponent provided a copy of the presentation to the OEPA and submitted the Yandi life of mine Closure Plan to the OEPA on 31 March 2014.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	monitoring. Discussion on pit lakes and potential for Oxbow to be saline.	Rehabilitation and closure associated with the Proposal is specifically outlined in Section 17.
12 June 2014	Updated hydrological information discussed with OEPA. Discussion on Proposal pit encroachment into Weeli Wolli Clearing Avoidance Area depicted on MS 914. Referral – to focus on key changes for this proposal in relation to the existing project (Flora and Vegetation, Fauna, hydrological processes, Closure and Rehabilitation). Context and justify impacts to environmental values identified in MS 914.	The referral document was updated to include further details on Proposal pit encroachment on the clearing avoidance zone depicted in MS 914, and focus on key changes from the existing Yandi Operations.
5 November 2014	Updated presentation on hydrogeological aspects of PBS Timing. Latest data. Surface water update – flood modelling and discharge extent modelling. Groundwater update – modelling and pump test data. Surplus water management – run through of all of the options investigated and discussion of discharge option into Marillana – Weeli Wolli creek as the only feasible option. Closure update. Other items discussed included details of the proposed levee including design, height, flood Annual Recurrence Interval (ARI) design, materials, changes to the low-flow line, and impacts on riparian vegetation from construction of the levee. Closure – stability of the pit lakes and how they will be designed and water quality.	Modelling results and predicted impacts to hydrological processes is outlined in Section 13. The Yandi life of mine Closure Plan has been updated to include the Proposal, with rehabilitation and closure of the Proposal specifically outlined in Section 17.
9 February 2015 4 March 2015	Brief update and discussion of aspects of the Proposal. Discussion of timeframes for PER and ESD. Details of the ESD discussed. Minor or Preliminary works discussion for element of the Proposal. Monitoring bores at the Tree Health monitoring sites discussed including number of sites, type of rig, clearing required and timelines.	Application for Minor or Preliminary works to be submitted. Notice for proposed monitoring works in Weeli Wolli submitted to compliance branch in June 2015.
21 April 2015	Update on Proposal Environmental Impact Assessment, including presentation of DVD's to	Information regarding hydrological processes is outlined in

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	convey: • Updated impact predictions from discharge. • Updated impact predictions from drawdown. • Timeframes. Discussion undertaken covering current altered environment and change from current to change from baseline. Discussion of any mitigation the Proponent was proposing to manage uncertainty on predictions, using an adaptive management approach, such as uncertainty of rate of change of water availability.	Section 13.
EPA		
9 June 2014	Discussed Proposal including Minor or Preliminary Works application and upcoming draft PER. Key queries raised by EPA included: *Closure.* • Details of pit lakes, including size, depth, water quality (metals and salinity), interactions with the creeklines, potential for plumes and impacts on Fortescue Marsh, long term implications. • Rehabilitation. • The Proponent's current understanding, science, results, gaps, timeframes.	Information regarding rehabilitation and closure is outlined in Section 17.
9-10 September (Site Visit: EPA / OEPA)	Site visit to Yandi Operations to specifically view and discuss the Proposal Presentation and DVD presentation of the project, predicted environmental impacts and current scientific knowledge Fly over of existing Yandicoogina Operations including review of Marillana and Weeli Wolli Creeks from Weeli Wolli Spring to the alluvial outwash fan near Fortescue Marsh Discussion of the environmental values of the Fortescue and Weeli Wolli Creek catchment and principles around operating in the Weeli Wolli Creek catchment Review of existing Yandicoogina Operations and the proposed PBS pit	Updates to the revised draft PER document including, but not limited to: articulate the Environmental Values Statement; and to clearly show the configuration of Weeli Wolli Creek and vegetation associations to more clearly present the impacts of the flood protection levee.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Review of wetland rehabilitation trial Discussion of closure aspects including pit depths, interactions of the pit lakes with groundwater and surface water. Discussion and look at the Weeli Wolli Creek Riparian zone and existing Clearing Avoidance Area – highlighted differences between the vegetation of the Major Creeks (the open riparian woodland around the low-flow line) and the broader floodplain (including the high flow lines). Discussion of the changes to the vegetation (augmentation) from upstream discharge An example of the existing Yandi Operations pit walls adjacent to Marillana Creek was viewed – showing the disconnect between the alluvial aquifer supporting the creek and the lower CID aquifer which had been drawn down to 60m bgl. The vegetation of Marillana Creek was sustained even with adjacent drawdown for over a decade. Discussion of existing environmental management on-site and how Yandi Operations was tracking against original impact predictions.	
Parks and Wildlife		
5 April 2014	The Proponent provided detailed overview of Proposal, current/planned environmental studies, potential environmental impacts and proposed management, with focus on biological issues. Updated details on Fortescue Marsh hydrogeology presented. The Yandi life of mine Closure Plan was presented. Key queries from Parks and Wildlife included how the 'avoidance areas' in MS 914 were developed, how water would be managed, interactions of surface water and groundwater in terms of riparian vegetation; results of biological surveys and significant flora, fauna; if the Proposal was a new assessment or would be amalgamated (as a Revised Proposal) with MS 914. Discussion of other projects in the vicinity.	The Proposal is considered a Revised Proposal of the existing Yandi Operations. The Proponent believes that existing conditions and management required under MS 914 for the existing Yandi Operations would adequately address key potential impacts for the Proposal. Results of investigations and discussion of potential impacts for key factors raised by Parks and Wildlife are outlined in Section 13 (Hydrological processes and inland waters environmental quality), Section 14 (Flora and vegetation) and Section 15 (Terrestrial fauna).
8 September 2014	Proposal update presentation including latest flora and vegetation, terrestrial fauna and hydrological investigations. Subterranean fauna also discussed.	Results of surveys/investigation, impact assessment and mitigation for key environmental factors is outlined in Section 13

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Surplus water management options presented, including challenges of some options. Parks and Wildlife indicated that it did not require a further update on the Proposal unless any substantial changes or impacts predicted.	(Hydrological processes and inland waters environmental quality), Section 14 (Flora and vegetation), Section 15 (Terrestrial fauna) and Section 15 (Subterranean fauna).
16 April 2015	Update Presentation provided to Parks and Wildlife based on updated hydrological modelling and impact predictions. Proposal in final stages of completion to integrate the surface water and groundwater modelling and to assist with predictions of environmental impacts based on water availability in the alluvials. Discussed riparian vegetation in the Proposal Area is mostly sustained by surface water inputs, and very little dependency on groundwater. Predicted water availability changes in the alluvial aquifer as a result of drawdown from developing the Proposal deposit presented. Discussed that the key functioning elements of the system will be maintained to support longer term system function: alluvial substrate retained, which contains riparian seed bank and habitat for aquatic fauna (and subterranean fauna); flow paths (low-flow line) undisturbed; and water quality maintained. Flooding regime would still continue. System is expected over time to recover and return to pre-mining ecosystem – with some changes to the ecosystem communities upon closure. URS study has quantified this from a water availability perspective. Discussed extent of current wetting footprint in Weeli Wolli Creek remains within a 5-9 km extent from the Marillana – Weeli Wolli Creeks confluence since 2009. Modelling for the Proposal indicates that the range is still predicted to be within the existing approved 17 km limit. Options to address the environmental impacts as a result of the predicted change of water availability (and rate of change) are currently being investigated. However, the system is expected to return to that similar to pre-mining conditions (and water availability), hence the overall change in water availability to the end of mine life and closure is not proposed to be mitigated. Management plan updates: Updates to the existing Yandi Management Plans and Environmental Values Statement – values will be amended to specific environmental values, rather than broader factors e.g. hydrological processes.	Impacts to hydrological processes and, flora and vegetation is outlined in Sections 13 and 14 respectively.
14 September 2015	Brief Proposal update as part of a broader Rio Tinto Projects update.	Provide a copy of the updated EVS and MMP to Parks and Wildlife

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Brief discussion of proposed changes (and rationale of the changes) to: • the Yandicoogina Weeli Wolli Catchment High level Environmental Values Statement (EVS; updated from 2012 version); and • the updated Yandicoogina Monitoring and Management Plan	Copy of the updated MMP and EVS sent 12/10/15 The MMP and EVS is attached in **Appendix 3**
DoE		
29-30 April 2014 (Site visit)	The Revised Proposal presented including a fly over of existing Yandi Operations and of the Proposal. DoE were interested in Matters of National Environmental Significance species found in the Revised Proposal Development Envelope. Northern Quoll not captured, however sightings at the warehouse near the camp have occurred on one occasion. Pilbara Olive Python found at the camp and sampled in Weeli Wolli Creek within the Proposal Area. No populations encountered. Significant species management procedures discussed. Outline of the Proposal presented and discussion of surveys completed and results. Discussion of proximity to Fortescue Marsh and water management. Discussion of proposal timing. Threatened Species Offset Plan for Revised Proposal discussed, including status.	A referral under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) was proposed for the Proposal in Q3 2014, subsequent to the State referral. The Proposal was determined to be not a controlled action.
DER		
10 June 2014	Non-standard operation approval – Test pumping for Proposal. Test pumping requested for two bores, 3.8 GL over six months.	Approved by DER on 19 June 2014. Proponent notified DER on commencement (18 September 2014) and completion (24 November 2014) of test pumping regime
15 June 2015	Telephone discussion of Proposal including components relevant to DER: • additional discharge point (DO9A); • potential WWTP facilities; • potential mobile crushing and screening plants involved with construction works; and • potential workshop / washbay facilities with associated oily water treatment systems.	Presentation will be provided to DER. Awaiting confirmation of a suitable date.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Request to present broader Proposal.	
DoW		
21 March 2014	Presentation of the new Yandi life of mine Closure Plan.	No significant issues raised or outcomes.
10 April 2014	Pre-referral meeting to present the Proposal details and provide a high level summary of the groundwater and its abstraction and the proposed water management options including the hierarchy of use and the proposal to discharge into Marillana/Weeli Wolli Creeks. DoW queried what was in place for tree health monitoring and frequency of monitoring. Existing Yandi Operations management plan details discussed and provided. Discussed hydrological monitoring including the potential use of alluvial bores and nested bores to understand the interactions with tree health. EC and in situ loggers are currently used in the existing monitoring bores and at the discharge outlets. Flood protection levees discussed and surface water modelling associated with the location of the levees and other infrastructure. Levees would be backfilled into the Proposal pit upon closure. Discussion of what the Proponent had found in the way of stygofauna and troglofauna at the Proposal Area, and how habitat will be maintained in different areas as drawdown impacts across the entire operations variable at different times. Existing flood regime maintained to provide habitat connection.	Impacts to hydrological processes and inland waters environmental quality are outlined in Section 13; impacts to flora and vegetation are outlined in Section 14. Results of surveys and impacts to subterranean fauna are outlined in Section 15.
21 April 2014	Rio Tinto provided detailed overview of Yandi life of mine Closure Plan, including the Proposal. DoW queried the pit lakes and options if future deposits were not approved; likely salinity ranges; interactions for saline and fresh water pits; metals released in hypersaline conditions.	Rio Tinto has looked at 'early closure' contingencies and has addressed the possible options of future deposits not being approved. Further details regarding pit lakes are outlined in Section 17 (Rehabilitation and closure).
23 September 2014	An update was presented on the Proposal Environmental Impact Assessment including: • Timing. • Latest data. • Environmental Scoping requirements, including requirement for DoW endorsement of	Results of investigations and impacts to hydrological processes are outlined in Section 13.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	consultants used for peer reviewers – selection discussed. DoW will discuss with OEPA. • Surface water update – flood modelling and discharge extent modelling. • Groundwater update – modelling and pump test data. • Surplus water management – run through of all of the options investigated and discussion of discharge option into Marillana – Weeli Wolli Creek system as the only feasible option. • Other items discussed included details of the proposed levee including design, height, flood ARI design, materials, base foundation conditions and control of subsurface water.	
26 November 2014 (site trip)	Site trip to Revised Proposal Development Envelope with DoW to present the existing Yandi Operations and specifically the Proposal. Discussed proposed plan for water management for the Proposal and discharge into Marillana/Weeli Wolli Creeks. Reviewed and discussed tree health monitoring data and limitations. Discussed existing hydrological monitoring - DoW indicated their interest in having monitoring bores located with tree health monitoring sites and if feasible to undertake with a Sonic rig. Infiltration testwork presented, discussing extremely high infiltration rates to the north of the Marillana - Weeli Wolli Creeks confluence and discussion on how this work supported Shawan Dogramaci's paper on the discharge from the existing Yandi Operations, as well as current observations of the wetting front from discharge (still in the range of 5-9 km past the confluence – similar since 2010). Discussed hydrological modelling, taking into account cumulative impacts. Discussed details of the recent hydrogeological pump test program, and future programs.	Results of investigations and impacts to hydrological processes are outlined in Section 13.
22 April 2015	The Proponent presented a series of DVD's to provide an environmental impact update and outline the baseline ecological regime, with a focus on riparian (phreatophytic) vegetation and water availability. • Discussed riparian vegetation in the Proposal Area is mostly sustained by surface water inputs, and very little dependency on groundwater. This is reflected in both current and historical riparian communities / species. No mature C1 vegetation (containing Melaleuca argentea,	Impacts to Flora and vegetation are outlined in Section 14.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	which is the environmental value defined in the Environmental Value Statement) occurs in the Proposal Area. Vegetation community composition changes have occurred in Weeli Wolli Creek as a result of increased water availability including recruitment of Melaleuca argentea. • Discussed that the key functioning elements of the system will be maintained to support longer term system function: alluvial substrate retained, which contains riparian seed bank and habitat for aquatic fauna (and subterranean fauna); flow paths (low-flow line) undisturbed; and water quality maintained. Flooding regime would still continue. Ecosystem is robust and adaptive to changed conditions. • Significant ecosystem monitoring and management currently occurring (trees, water quality, aquatic fauna), and will continue to occur throughout the life of mine and through to closure. • Predicted water availability changes in the alluvial aquifer as a result of drawdown from developing the Proposal deposit presented. The likely result is increased drought stress (and some tree deaths) through this reach as a result of the Proposal. • System is expected over time to recover and return to pre-mining ecosystem – with some changes to the ecosystem communities upon closure. URS study has quantified this from a water availability perspective: A net reduction of about 10% in total water availability is expected upon closure. • Updates to the existing Yandi Operations management plans and Environmental Values Statement – values will be amended to specific environmental values, rather than broader factors e.g. hydrological processes. • DoW queried the Melaleuca recruitment and if this was a result of elevated water table from Hope Downs 1. • DoW queried the root morphology changes and about the rate of change of the phreatophytic root system in response to water availability. Also how this contexts with historical riparian communities in the catchment. Queried what would be the rate of change of water availability in the alluvials i.e. How long normal residence time was compared to changed (mining drawdown)	

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	conditions. Options to address the environmental impacts as a result of the predicted change of water availability (and rate of change) are currently being investigated. However, the system is expected to return to that similar to pre-mining conditions (and water availability), hence the overall change in water availability to the end of mine life and closure is not proposed to be mitigated.	
29 September	The Proponent discussed DoW comments on the draft PER document. • Design criteria for surface water infrastructure • Stygofauna habitat and cumulative impacts • Dewatering volumes and consistency between reports • Historical / baseline groundwater levels Boundary conditions used in modelling including in relation to Fortescue Marsh	Updates made to the Revised draft PER document.
DMP		
21 March 2014	Presentation of the new Yandi life of mine Closure Plan, including: • Yandicoogina project overview. • Closure objectives and criteria. • Preferred closure strategy. • Landform design. • Water management. • Habitat considerations for rehabilitation (and proposed wetland rehabilitation trial). • Unexpected closure. • Further study focus areas. • Compliance review. Key queries included salinity range of pit lakes, modelling undertaken, potential for metals to be released with increased salinity, interaction of saline pits and fresh water pits, and interactions with the creeklines, frequency of flushing of the pit lakes. Also access to pit lakes and safety issues.	Rehabilitation and closure is outlined in Section 17.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Discussion on development of completion criteria. Interest in wetland rehab trial and interest in rehabilitation success.	
21 April 2014	The Proponent provided a detailed overview of the Yandi life of mine Closure Plan for the Revised Proposal. DMP discussed that their guidelines are being changed so that Section 4 flows better. DMP commented about future unapproved projects in the Closure Plan. Discussed focus on rehabilitation in the Pilbara; access to pits and safety issues post-closure; completion criteria – want to target frames as "not to exceed" – need a way in which to measure/assess completion criteria.	Rehabilitation and closure is outlined in Section 17.
20 November 2014	Joint Yandi Operations site trip with DSD and DMP to Yandi to discuss rehabilitation and closure planning. Discussed the Closure Plan at a high level. DMP noted that the plan contained a lot of very technical information. Wetland rehabilitation trial area visited and discussed. DMP interested to see the outcomes. Progressive rehabilitation discussed including planning process and seed collection. Topsoil management, Tailing storage facility, Landfill, Turkey's nest management discussed.	No significant issues raised or outcomes.
27 May 2015	Brief update presentation and DVD's of updated Yandi life of mine Closure Plan to support the Proposal PER, including closure objectives and conceptual completion criteria. Aspects of closure discussed included the establishment of a wetland rehabilitation trial so as to better determine what plants will do best and how far away from the water table they need to be located in order to be sustained.	Rehabilitation and closure is outlined in Section 17.
3 August 2015	Presentation and DVD's of updated Yandicoogina life of mine Closure Plan to support the Proposal PER, including closure objectives and conceptual completion criteria. Items discussed included: Plan for backfill areas including sloped walls Impact of flood events and remedial work required	The Proponent acknowledged the importance of ongoing stakeholder consultation to developing the final land use and detailed completion criteria. The updated Closure Plan contains a risk assessment to identify gaps and support a process to address. The PER document will be updated to include further information

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	Wetland rehabilitation trial details Abandonment bunds Final land use & completion criteria – plan for developing details Water quality including salinity and other potential leachates Timing for closure DMP were interested if closure and waste management would be integrated with BHP's Yandicoogina Operations	from the updated Closure Plan.
DSD		
20 August 2014	Overview of 2015-2017 Pilbara mine plan including Proposal.	No significant issues raised or outcomes.
20 November 2014	Joint Yandi Operations site trip with DSD and DMP to discuss rehabilitation and closure planning. Discussed the Closure Plan at a high level. DMP noted that the plan contained a lot of very technical information. Wetland rehabilitation trial area visited and discussed. DMP interested to see the outcomes. Progressive rehabilitation discussed including planning process and seed collection. Topsoil management, Tailing storage facility, Landfill, Turkey's nest management discussed.	No significant issues raised or outcomes.
18 June 2015	High level overview of the Proposal provided.	DSD requested to be provided with further information in writing, which was provided on 25 June 2015.
31 August 2015 (Site visit)	Site visit to Yandicoogina Operations to present the Pocket and Billiard South Proposal The overall scope of the Proposal was presented Details of the Environmental Impact Assessment including predicted impacts and timing for the PER document discussed. Predicted impacts to Weeli Wolli Creek were discussed.	DSD requested to be provided with ongoing updates of the Proposal, including the PER timing.
DAA		
7 July 2014	The Proponent met with DAA and provided a high level overview of the Proposal.	The Proponent confirmed with DAA that a large portion of the Proposal Area has already been surveyed and that surveys will

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	DAA requested information on disturbance of sites when available.	be conducted prior to the commencement of any ground disturbance as per Rio Tinto's protocols. The Proponent is also reviewing designs to avoid areas of concern (including heritage sites) to avoid/minimise impact. The Proponent will continue to liaise with DAA and the Traditional Owners through its existing meeting forums to provide updates on the Proposal, the existing operations and where approvals may be required to disturb sites.
Gumula – Traditional Owners		
June 2013	Yandicoogina Land Use Agreement Monitoring and Liaison Committee meeting. An overview of the mine closure process was presented to the Gumala Aboriginal Corporation board members. It was agreed at the meeting to form a sub-committee/working group to address issues relating to closure and land management. The terms of reference for the sub-committee/working group are yet to be resolved.	The Proponent subsequently (October 2013) met with the Gumala Aboriginal Corporation Lore and Culture Committee to discuss participation of Elders in the closure working group. A decision on Elder's participation and representation is still pending.
4 February 2014 5 May 2014 12 August 2014 15 December 2014 15 April 2015 13 May 2015 16 July 2015	Monitoring and Liaison Committee Meeting update presentations of Yandicoogina Closure Plan. Topics discussed included: • Preservation of remaining ecosystems and protection for creek banks. • Lake water quality. • Ongoing importance of ethnographic and archaeological surveys. • Role of Gumala Aboriginal Corporation in closure planning. • Importance of including Elders and young people in consultation. • Management of artefacts at closure. • Potential community use of site infrastructure after closure. • Access through and around the mine and into the lake areas. Presentations and DVD presentations on the Proposal. Topics discussed included: • Overview of the Proposal including tie in with existing Yandi Operations.	A copy of the Draft PER will be provided to Gumala Aboriginal Corporation. Presentation of the Proposal was provided at the Hope Downs 1 Weeli Wolli Co-Management Board Forum.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	• Timing of the Proposal. • Infrastructure requirements. • Outline of baseline biological surveys and findings. • Water related impacts presented and discussed, including drawdown and discharge into Marillana and Weeli Wolli Creeks and predicted environmental impacts on the system. Existing creeklines artificially altered from many years of discharge – especially Weeli Wolli and so currently look different to their original ephemeral state. Water availability after mining will revert back to pre-mining levels and therefore will not be able to sustain current water availability for trees and fish – some tree stress and death expected and less waterholes for fish/fishing. • Access to Weeli Wolli Creek will be permanently limited in the vicinity of the Proposal. • Discussion on cumulative impacts from the Proposal and other mines in the area and how this may change the water in the creeklines – query on Hope Downs 1 and if they will continue to discharge. • Presentations and discussion of tree health and water quality monitoring. Discussion of potential involvement of Traditional Owners in future monitoring. • Traditional Owners also expressed interest in the expected life of mine, water quality, water quality of pit lakes, ecosystems recovery, particularly along the creeklines, rehabilitation and involvement with rehabilitation.	
13 May 2015	An ethnographic survey was conducted with Gumula during which the focus was on: • Surface water management and discharge in relation to Weeli Wolli Creek. • Proposal dewatering requirements. • Ongoing management of Weeli Wolli Creek. • Hydrogeological drilling program.	The Proponent to consult Gumala Aboriginal Corporation about the potential for business and employment opportunities for the new Yandi developments. A number of archaeological sites identified to be avoided across the existing Yandi Operations.
Ongoing	Any issues relevant to the Gumula People are raised at quarterly Monitoring and Liaison meetings. It is a condition of the Agreements that notification of any activities is provided to Gumula prior to works	The Proponent will continue with regular consultation with Gumula through the Monitoring and Liaison meetings and through the pre-feasibility and feasibility studies.

Date	Topics/Issues Raised	Outcome and Proponent response where relevant
	taking place and effort is made to address any areas of concern raised by the group. Key concerns raised relate to potential impacts (including clearing, drawdown and discharge) within the Marillana and Weeli Wolli Creek systems, final life of mine closure landform, and future access.	Regular technical updates are provided including the approval process; Environmental Impact Assessment predictions and findings; and closure workshops.
Pastoral Station – Marillana Station		
20 April 2015	Informal discussion on upcoming Proposal and Closure Plan. Details of the Proposal requested to be provided, including key dates.	Updated presentation package including key dates provided to Marillana Station on 22 June 2015.
Shire of East Pilbara		
23 April 2015	Provided update of current Rio Tinto operations in the Pilbara with proposed projects for the Shire of East Pilbara. This included the Proposal and the proposed PER seeking feedback around September 2015.	Proposed to provide an update on the PER at next meeting (August 2015), and 'big picture' overview of clearing requests.
28 August 2015	Presentation of the Proposal details and estimated timing for Public Environmental Review.	No significant issues raised or outcomes.
BHP		
22 April 2015	Consultation on closure planning for BHP and the Proponent's Yandi Operations. Discussion to understand: • The Proponent's underlying strategy for closure; • the key driving assumptions; and • outcomes that are important for consideration in the upcoming revision of the BHP Closure Plan which may also have implications for the Proponent's Yandi Operations. Given the water focus for water and closure planning in the Fortescue Marsh area (particularly when considering the relationship between the closure strategies for the sites) and due to adjacent pits at Oxbow, a presentation and discussion on closure strategies and assumptions was undertaken. It was agreed that any presented materials would be publically available, but elaborated on through discussion.	Further discussion may be required at various stages of Closure planning to ensure closure model assumptions are understood and to avoid misalignment of adjacent (boundary) model predictions. Publically available material to be agreed on a case by case basis.

Part 2 – Description of the Proposal

This part describes the Proposal to be implemented, including information on the key characteristics, design, exclusions and scheduling of the Proposal.

4. Development overview

4.1 Key characteristics

The Proposal will involve construction and operation of a new mine pit, waste dumps and associated infrastructure. The Proposal deposits occur across the eastern extents of an 80 km long CID characterised by relatively continuous iron mineralisation along a palaeo-channel. Mining will consist of a single, below water table open cut pit along the CID palaeo-channel.

Key aspects of the Proposal include:

- **A new below water table open cut iron ore pit** to the east of the existing Yandi Operations within the CID.
- **Temporary surface waste dumps**, including mineral waste dumps, sub-grade dumps, low grade ore dumps and topsoil and subsoil stockpiles.
- **Major infrastructure, including:**
  - **A flood protection levee** along the western margin of the pit.
  - **A diversion drain** along the eastern margin of the new mine pit.
  - **A culvert-floodway** creekline crossing structure.
  - **Supporting mine infrastructure** – haul roads and ramps, mine access and internal road network, dewatering pumps and associated pipelines, discharge outlet(s), power and communications.

In addition, a number of the Yandi Operation's existing facilities and processes will be upgraded or integrated as part of the Proposal including:

- **Trucking ore** back to the existing Yandi Plant.
- **Yandi plant** including JC and JSE processing plants (including a wet plant), and associated conveyors, stackers, reclaimers, train load-out and other materials handling infrastructure.
- **A water management system** including on-site reuse of water abstracted from pit dewatering, and discharge of surplus volumes into creek systems. Discharge infrastructure servicing the existing Yandi Operations will be used where possible.
- **Mine support facilities** (e.g. power supply infrastructure, communications infrastructure, offices, explosives storage, waste water treatment plants etc.).

The Proposal is scheduled to be commissioned with first ore production from the first half of 2019, however these project schedules may change, depending on business priorities.

Rio Tinto's existing rail network will be used to transport mined and processed ore from the Revised Proposal to existing port operations at Dampier and Cape Lambert.

A preliminary summary of key features for the Proposal are described in **Table 3**.

Table 3: Summary of the Proposal

Component	Project Characteristic	Detail
General	Project life	~ 16 years
	Resources	The current resource consists of 452 million tonnes of CID ore
	Production rate	Up to 31 Mtpa
Development footprint	Approximate disturbance area – mining/waste stockpiles and infrastructure	Up to 1,800 ha (69 ha of riparian zone vegetation)
Mining	Ore type	Pisolite (Channel Iron Deposit)
	Mining in relation to the watertable	99% BWT mining
	Mineral waste disposal	Surface waste dumps, with progressive backfilling once individual pit stages are completed
Processing	Processing type	Both wet and dry processing using existing Yandi Operations facilities
	Residue disposal	Current Yandi Operations in pit and new WFSFs will be used for residue from wet processing
	Water demand	Peak demand (with wet processing) approximately up to 11 GL/y
	Roads	Existing and new access roads to approach/depart the Proposal and internal road system
	Ore transport	Haul road to transport ore from the Proposal to the existing Yandi Operations processing plants and use of existing rail
	Power spur	Connection into the existing Yandi Operations 220 kV power line

4.2 Development of the mining operation

4.2.1 Site plan

The existing Yandi Operations is outlined in **Figure 2**. A conceptual site plan for the Proposal is shown in **Figure 4**, which also shows the Proposal in relation to the Revised Proposal Development Envelope and existing roads.

4.2.2 Ground disturbance

The Proposal will result in up to 1,800 ha of new ground disturbance, within the Revised Proposal Development Envelope of 19,351 ha. The majority of the proposed 1,800 ha of disturbance will occur within the Proposal Area, with a small portion of this disturbance required for infrastructure tie-ins with the existing Yandi Operations.

As planning for the Proposal is ongoing, the exact locations of some ancillary infrastructure and tie-ins with the existing mines is dependent on final engineering design. The specifics of the infrastructure require flexibility in terms of siting once detailed designs are finalised. A conceptual site plan is indicated in **Figure 4**.

4.2.3 Vegetation clearing and topsoil

Topsoil is an important resource for rehabilitation as it contains a natural seed bank and, typically, contains organic material and nutrients. Topsoil layers in the Pilbara region are

highly variable in thickness, ranging from very little soil development on rocky slopes to approximately 300 mm in valley areas.

The open pit, waste dumps, low grade dumps, haul roads and lay down areas will be cleared of all vegetation. Topsoil (approximately 200 mm) and subsoil (approximately 600 mm) will be collected prior to mining and stored in stockpiles for use in post-mining rehabilitation. Topsoil and subsoil will be collected from both the pit and dump areas, while only topsoil will be collected from the other areas (lay down areas and other infrastructure). The topsoil and subsoil will be cleared in a phased manner as and when the new pit and dumping areas come into operation.

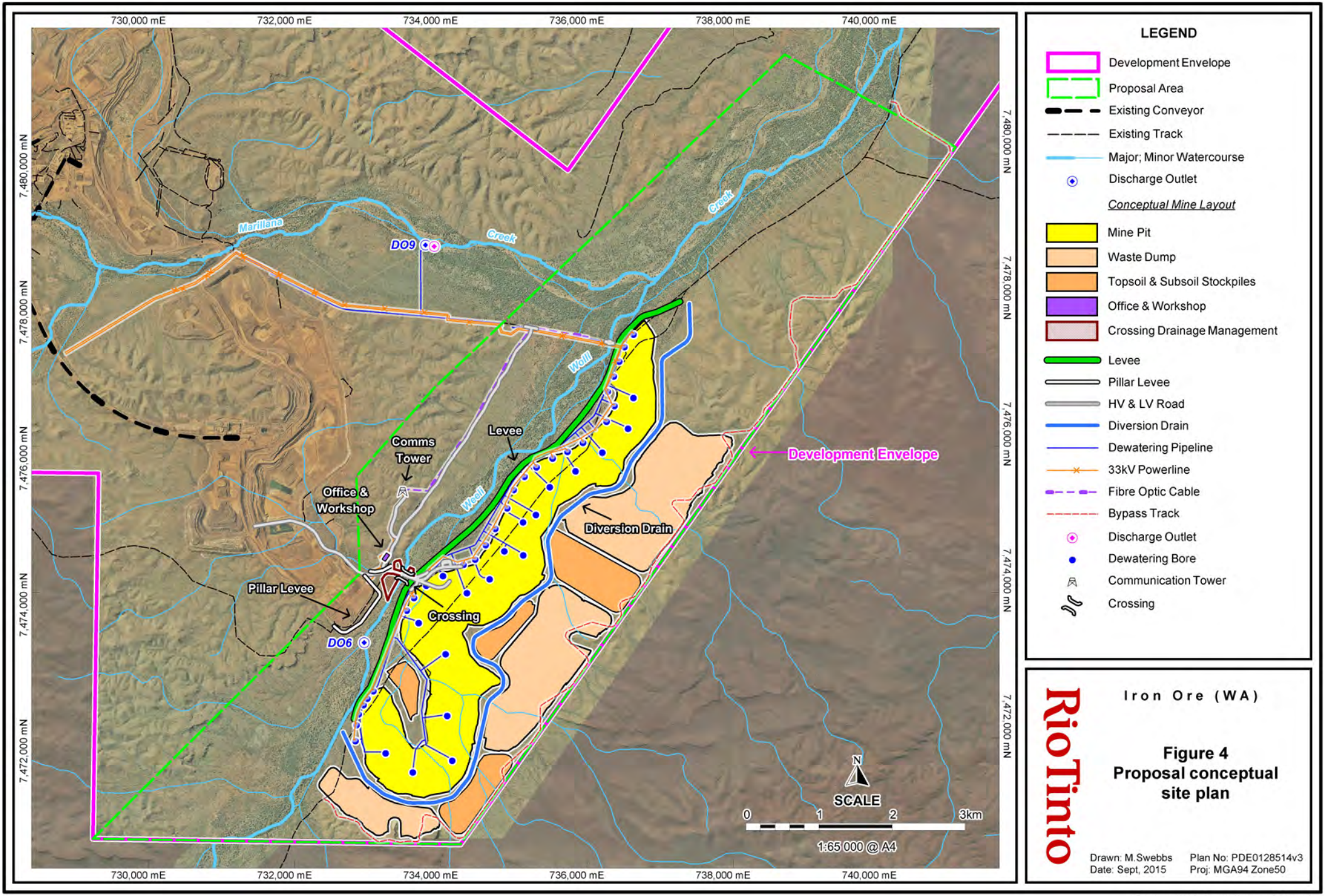
Throughout the life of the Proposal, an estimated 2.1 million m^3 of topsoil and 6.72 million m^3 of subsoil will be collected. All the topsoil and subsoil collected from pit and other areas will be stockpiled in line with the Proponent's standards. Cleared vegetation will also be stockpiled. This material will be used during rehabilitation (Section 17).

4.2.4 Mining

The scope of mining for the Proposal includes CID ore resources located within existing tenure ML274SA. The Proposal will involve developing a single pit, of which approximately 99% of the ore is below the water table. The pit will be approximately 10 km from end to end (~7 km strike length) and mining will involve conventional drill, blast, load and haul methods, as currently used at the existing Yandi Operations. For ore blending purposes, several faces within the mine pit will be worked simultaneously.

Based on current knowledge, the total quantity of extractable ore from the proposed pit is estimated to be ~452 Mt over the life of the Proposal. The maximum depth of mining is expected to be approximately 85 m below the surface.

Mining (pre-stripping) is proposed to start from 2018 and progress northwards and southwards consecutively from an initial mining area. The initial mining area location, rate and sequence of mining will ultimately be dictated by ore blending requirements to meet product specification from the Revised Proposal. A small portion of the proposed mine pit (approximately 17 ha) will encroach into the riparian woodland community of Weeli Wolli Creek to access the CID ore, which extends below the floodplain alluvials (see **Figure 55** in Section 14).



LEGEND

- Development Envelope
- Proposal Area
- Existing Conveyor
- Existing Track
- Major; Minor Watercourse
- Discharge Outlet

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil & Subsoil Stockpiles
- Office & Workshop
- Crossing Drainage Management
- Levee
- Pillar Levee
- HV & LV Road
- Diversion Drain
- Dewatering Pipeline
- 33kV Powerline
- Fibre Optic Cable
- Bypass Track
- Discharge Outlet
- Dewatering Bore
- Communication Tower
- Crossing

Rio Tinto

Iron Ore (WA)

Figure 4
Proposal conceptual site plan

Drawn: M.Swebbs
Date: Sept, 2015

Plan No: PDE0128514v3
Proj: MGA94 Zone50

Geospatial Information and Mapping

Overburden and waste will be used to progressively backfill the depleted pit, where possible. If the development sequence changes, temporary surface storage options will be required.

Mining is estimated to produce approximately 272 Mt of waste rock. Above ground stockpiles and mineral waste dumps have been provided for in the mine design. It is planned that all of the waste material will be used progressively to backfill the mine pit. However during development of the pit, temporary ex-pit waste dumps will be required and will be located in close proximity to the mine pit. The quantity of material to be placed in temporary storage areas will depend on the mine design, mining and dewatering sequence, and managed in line with the closure strategy.

A portion of the overburden from the initial mining area will be used as 'borrow material' for construction activities. As a result, the total area that would otherwise be disturbed during construction will be reduced.

Initial start-up mining crusher feed rates will be in the order of 28 Mtpa, which may increase up to 36 Mtpa, bringing the Revised Proposal crusher feed rates up to a total of 70 Mtpa.

4.2.5 Ore handling, processing and transport

The existing Yandi Operations are well established with central administration and workshop facilities at JC. Some new infrastructure will be required to accommodate the Proposal including:

- Civil infrastructure such as light and heavy vehicle road networks to connect the Proposal deposits to existing plant and facilities.
- The main workshop and storage areas will remain at JC. Heavy vehicle refuelling facilities and a workshop for daily and weekly maintenance may be constructed closer to the Proposal deposits.
- Small office facilities will be developed central to the Proposal Area. These facilities will consist of an administration building for daily crew shift change meetings and a crib room with toilets.
- A crossing at Weeli Wolli Creek is required to enable ore movement from the deposits to the various processing plants via heavy haulage trucks. As these deposits are entirely located on the east side of Weeli Wolli Creek, a creek crossing (via a culvert-floodway structure) will be required to access the facilities at the existing Yandi Operations, located entirely on the western side of Weeli Wolli creek.
- Local drainage and flood management protecting against stormwater runoff as well as water ingress into the pit adjacent to Weeli Wolli Creek.
- Electrical distribution via additional 33 MW installations will be required to support the Proposal.

Dewatering to enable mining of the Proposal wherein the orebody is essentially 99% below the water table. Based on initial hydrogeological modelling, dewatering of the pit will be required to occur at least a year prior to productive mining.

The existing capacity of the processing plants at JC (secondary and tertiary crushing and screening) with minor upgrades will accommodate all of the production from the Proposal. Any plant expansion requirements at JC will be subject to the provisions of the EP Act.

The existing waste fines cells at JSE in addition to new waste fines storage facilities (WFSF) in JSE will be used for the disposal of waste generated by wet processing. In accordance with existing operational practices, any water reclaimed through a decant process will be recycled back into the wet processing cycle.

Processed ore will be trucked from the Proposal to one of the existing operations wet or dry processing plants, where it will then be conveyed to the Loop Stockyard for rail loading and export. The existing capacity of the Loop Stockyard is expected to accommodate all of the production from Proposal. Upgrades or extensions to the existing Yandi Operations plants are a consideration, and would be managed under Part V of the EP Act.

4.2.6 Mineral waste

Overburden and waste rock will be used to backfill the depleted pit where mine pit sequencing and schedules allow. However, temporary surface storage options for waste and low grade ore stockpiles will be required over the life of the Proposal. The quantity of material to be placed in temporary storage areas will depend on the final mining and processing sequence selected.

Locations for waste dumps are presented in **Figure 4**, which provides for a conservative case should mine sequencing or dewatering sequencing change over the life of the operation. However, in line with the closure strategy, there will be sequential in pit disposal of waste, and stockpiling of low grade ore.

The existing Yandi JSE pit, which is adjacent to the Proposal Area, will serve as an in pit fines tailings storage facility (WFSF) for any material from the Proposal which is wet processed during the life of operations. The JC and JSE pits are currently used as a waste fines storage facility for the existing Yandi Operations.

Asbestiform minerals are not known from the CID orebody. However, there is a risk of encountering asbestiform material in the surrounding banded iron formation (BIF) and alluvium. Asbestiform fibres have been identified in the alluvium within the current mine operations at Yandi JC. Any fibrous waste encountered during construction or mining of the Proposal pit will be disposed of at the existing on-site facilities (store, encapsulate and record in the same waste dump), in accordance with the current Yandi Operations fibrous mineral protocols and procedures.

4.2.7 Dewatering and water management

The Proposal deposit is situated almost entirely (approximately 99%) below the water table and will require dewatering to commence approximately 12 months before mining activities start. Groundwater modelling has indicated that the dewatering required for the Proposal ranges from approximately 30 – 50 GL/y (cumulative peak of 83 GL/y when combined with existing Yandi Operations), of which up to 70% is not new dewatering; rather, it is the result of re-abstraction and discharge of upstream operations' surplus discharge water that has passively re-entered into the orebody (recirculation of water).

Dewatering will be undertaken using vertical bore holes completed in curtain or cluster arrangements within or adjacent to the mine pit; permanent bores will be placed along the western perimeter of the Proposal pit and permanent and sacrificial bores will be placed within and around the Proposal pit. The sacrificial bores will be decommissioned and replaced as the pit advances over time. Pumping of residual groundwater from in pit sumps will also be used when the mine pit reach final bench elevation.

Dewatering supply from the Proposal will be integrated with the existing Yandi Operations site water demand. It is estimated that approximately 5 GL/y will be used for on-site purposes (dust control, camp usage and ore processing) and approximately 48 GL/y to 78 GL/y will be discharged to Marillana and Weeli Wolli Creek systems over the life of the Revised Proposal, with a forecast average of 61 GL/y. Discharge will occur at controlled, release discharge points (refer to Section 13 for further details regarding surplus water management).

4.2.8 Surface water management

Two key surface water management structures will be required to protect the mine pit from accumulating water during large surface water flow events. This will result in localised disruptions to hydrological flow regimes. These structures include:

- An 8 km long flood protection levee along the western margin of the Proposal pit, adjacent to Weeli Wolli Creek. This will encroach into the Weeli Wolli Creek floodplain in some areas to facilitate the proposed pit extent.
- A diversion drain along the eastern edge of the pit, collecting rainfall runoff from hills to the east.

The preliminary design of the levee has been undertaken by a team of engineers who are familiar with the local conditions and have had experience with design and construction of levees at the existing Yandi Operations. The detailed design of the flood protection levee will be undertaken by experienced civil design engineers based on findings from geotechnical, geomorphological and hydraulic technical studies. The investigations and analysis undertaken to date are at a higher level than would normally be undertaken at the current stage of the Proposal in recognition of the importance of the levee and have been reviewed by the Proponent's engineers, consultant design engineers and independent third party geotechnical and hydrology experts.

The purpose of the levee is to prevent flooding of the open mine pit mine during high flow periods within Weeli Wolli Creek which is located adjacent to the proposed pit. The proposed levee is approximately 8 km in length; a crest width of 5 m, with a height ranging in the order of 2.5 to around 7 m (subject to final engineering designs) including a freeboard allowance of 0.5 m, and with upstream and downstream slopes of 1:3 (V:H; refer to **Figure 5**). The levee has been designed as a homogenous structure constructed from clayey gravels sourced from in situ materials along the alignment. Additional borrow material for the construction of levee and haul road embankments may be sourced from the proposed footprint of the Proposal pit (i.e. pre-strip waste). Laboratory analysis of samples collected during testing pitting activities for this study suggests that two thirds of the surficial soils in the pit footprint would be suitable for use. A potential source of dolerite rock for use in scour protection has also been identified.

A keyway is considered necessary to limit the risk of piping failure under the crossing structure and to key it in to the existing alluvial soils of the Weeli Wolli Creek. A minimal depth of 5 m depth and a minimum width of 2 m can be expected at this stage of design.

Risk assessments will be undertaken prior to construction, to ensure public safety is maintained and environmental risks are identified and managed. During operations, the levee will be subject to regular post-wet season inspections. The objective of the inspections is to ensure the long term stability of the levee and identify any deterioration in the condition of the levee before it becomes a risk to its integrity. If deterioration in the

levee condition is identified, geotechnical engineers will assess the potential impact and identify any required remedial works.

Numerical slope stability analyses, using the limit equilibrium slope stability software package SLIDE Version 6.0, against the design acceptance criteria of a Factor of Safety (FOS) of greater than 1.5, was carried out at three critical sections. Relatively conservative effective stress (drained) shear strength parameters were attributed to each of the geological units based on correlations with field investigation, laboratory testing results and experience.

Three cases of levee stability analysis were assessed under static conditions based on a standoff distance of 30 m, 65 m and 100 m from the pit crest to the downstream toe of the levee. The analysis carried out under seismic loading only for dry conditions and for Peak Ground Accelerations (PGA) of 0.063 and 0.1g. The FOS for failure of the levee during either flood events or earthquakes exceed the required acceptance criteria (e. g. FOS=1.5 and FOS=1.1, respectively). The groundwater phreatic surface and location of the levee with respect to the pit crest has negligible effect on the stability of the levee.

A numerical analysis was also carried out using the finite element software package Plaxis, to assess the minimum offset required between the levee and the alluvial pit slope. The analysis indicates that the surcharge load from the levee structure has only marginal influence on the pit slope.

Limited potential for piping failure of fine dispersive materials in the levee and its foundation structure was determined in the engineering geotechnical study. As the levee will be constructed of compacted non-dispersive clayey gravel/gravelly clay materials and due to short duration of the flood events, the wetting front is not expected to penetrate more than 1-2 m into the levee materials. Therefore piping within the levee embankment is not expected and not considered a significant risk.

4.2.9 Water supply

Process water will be sourced from groundwater abstracted through the mine dewatering process. Potable water will be sourced from the borefields servicing the existing Yandi Operations.

4.2.10 Power supply

Power supply will be derived from the existing distribution system at the Yandi Operations, sourced from the Rio Tinto power grid network. Power connections to the Proposal will be largely aligned with other infrastructure corridors (e.g. roads).

Back-up power supply will be provided by the existing on-site 10 MW diesel-fired generator, currently servicing the existing Yandi Operations.

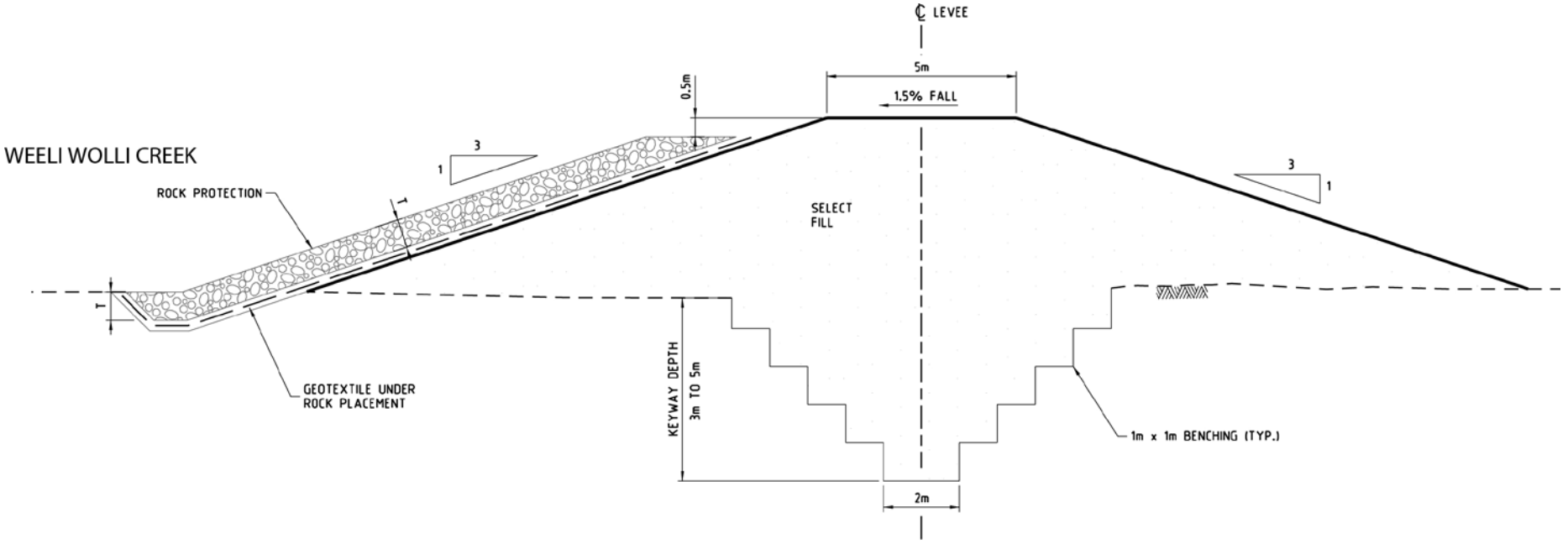


Figure 5: Typical levee cross section.

4.3 Mine support facilities and other infrastructure

4.3.1 Workforce and accommodation

The existing Yandi Operations currently employs around 1,400 people (including construction workforce and contractors) who are accommodated in a well established permanent village and a temporary construction camp. The workforce currently operates on a Fly In-Fly Out (FIFO) basis from Perth or other WA regional centres using the Barimunya airport.

The existing operational workforce is not expected to increase to support the Proposal and as such the existing accommodation village is expected to meet anticipated FIFO workforce requirements.

The recently re-commissioned construction camp for JSW and Oxbow operations comprises single and double storey rooms which will be maintained to accommodate the additional construction capacity (approximately 450 personnel) required for the Proposal.

The permanent village and construction camp are both part of the existing mining operation and approved under MS 914.

4.3.2 Wastewater treatment

Wastewater generated by the existing Yandi Operation is treated using the licensed wastewater treatment plants at the JC mine site and the recently expanded facility servicing the accommodation village. These will continue to be used over the life of the Proposal.

The Proposal mining areas are not anticipated to need new wastewater treatment facilities. However, existing facilities may need to be expanded for construction and future operations, and septic facilities will be required for offices and administration buildings. If any new facilities are required (to treat more than 20 m^3/day), appropriate licences will be obtained under Part V of the EP Act.

4.3.3 Non-mineral waste

Current systems servicing the existing Yandi Operations will be used to collect and recycle a number of waste streams including: hydrocarbon wastes (oil, drums, rags, filters etc.), tyres, batteries, scrap metal, printer cartridges, paper and cardboard, conveyor belting and computing equipment.

The licensed landfill facilities servicing the existing Yandi Operations will be used to dispose of putrescibles and inert materials, such as household waste, cardboard, furniture, fill and demolition material. Appropriate licences under the EP Act will be obtained if any new landfill facilities are required.

Hazardous wastes will be collected and sent off-site for treatment by licensed contractors. An existing land farm bioremediation facility used to treat hydrocarbon contaminated soils, will continue to be operated over the Proposal life. Contaminated soil is spread in a thin layer (approximately 300 mm) on an impermeable base. The soil is watered and tilled to stimulate aerobic microbial activity resulting in the degradation of hydrocarbon products into non-hazardous materials suitable for conventional disposal.

4.3.4 Fuel

The fuel storage and handling facilities at the existing Yandi Operations may be upgraded to service the Proposal mining operations. These are likely to be supplemented by local heavy vehicle refuelling facilities near the Proposal pit.

4.3.5 Road Access

Mine roads will be developed in and alongside the Proposal pit. The roads will provide access to mining areas, soil and waste stockpiles and supporting infrastructure. The mine road network is expected to change to some extent during the life of the Proposal, in accordance with the mine plan.

A bypass track around the Proposal will be constructed to allow for public access and to manage public safety as the current access track extending from Hope Downs 1 to Fortescue Marsh runs directly through the proposed borefield and mining area. This track will also ensure separation of the public from the construction work related to the Proposal.

Based on the current mine plan, the primary heavy vehicle access road for the Proposal will be aligned along the perimeters of the mine pit. A culvert-floodway crossing will be constructed across Weeli Wolli Creek, together with an upgrade to the existing Weeli Wolli Creek crossing (Greys' crossing) to create an engineered floodway with culverts to support heavy vehicle traffic and reduce ponding and upstream impoundment of flow. Larger rain events will continue to overtop the floodway as designed.

Road access from the Great Northern Highway is provided through the existing sealed Yandi Operations access road shared with BHP.

4.3.6 Other facilities/infrastructure

Other facilities that will be required for the Proposal include heavy/light vehicle maintenance workshops, offices and laydown areas. Locations of these facilities are depicted in **Figure 4**. Additional facilities may also include an ammonium nitrate storage facility and fabrication workshops.

4.4 Work excluded from the proposal

The scope of the Proposal subject to this Environmental Impact Assessment specifically excludes:

- Associated site offices, access roads, temporary concrete batch plant, borrow pit/quarry for suitable material, temporary services (communications, water supply, on-site power generation), upgrades to existing access roads/tracks and lay down areas and drilling/geotechnical/water investigation activities (to be subject to relevant provisions of Part V of the EP Act and DoW RIWI Act water licensing requirements).
- Low impact activities, including drilling activities associated with geology (including resource drilling), geotechnical and water investigations (including bore installation and test pumping) and power generation investigations (to be subject to relevant provisions of Part V of the EP Act and DoW RIWI Act water licensing requirements).

Iron Ore resources held by Rio Tinto (or its related companies) are present outside and proximate to the Proposal. These may be subject to future development proposals, but are

outside the scope of the Proposal. Any proposals to develop these resources will be subject to separate environmental approval processes.

Part 3 – Overview of existing environment

This part provides an overview of relevant features of the existing environment. More detailed descriptions of the relevant existing environmental features of each of the preliminary key environmental factors are provided in Part 5.

5. Physical environment

5.1 Biogeographic region

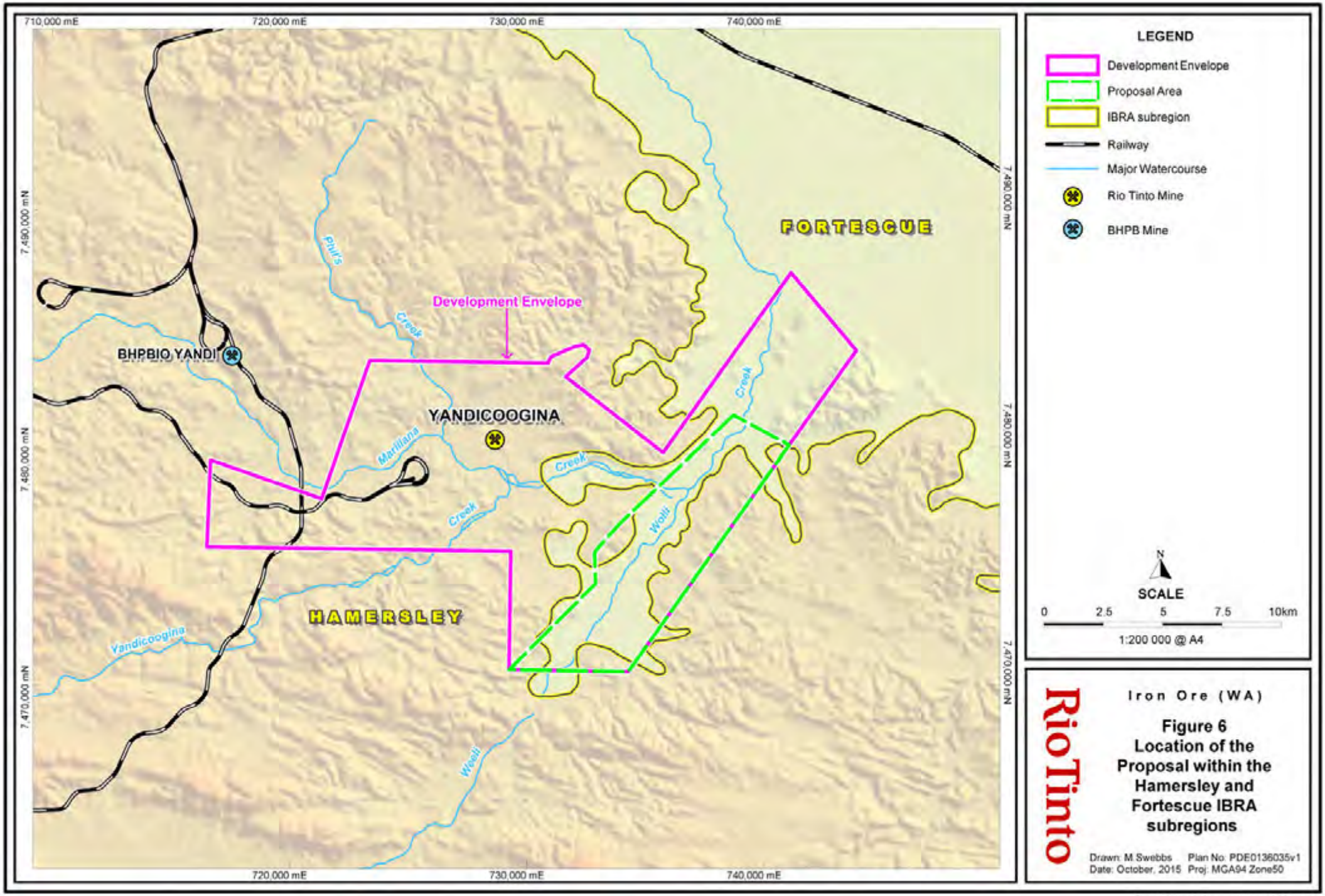
A biogeographic regionalisation of Australia has been developed collaboratively, in which bioregions (broad-scale regionalisations) are formally recognised and mapped in the Interim Biogeographic Regionalisation for Australia (IBRA), currently version 7. IBRA provides a landscape-based approach to the classification of the land surface of Australia, with bioregions being classified according to common climate, geology, landform, native vegetation and species information. Bioregions each reflect a unifying set of major environmental influences which shape the occurrence of flora and fauna and their interaction with the physical environment across Australia (DoE 2015a).

The Proposal Area lies within the Pilbara bioregion, which comprises four subregions: Hamersley, Fortescue, Chichester and Roebourne. Subregions are more localised and homogeneous geomorphological units within each bioregion. The Proposal Area is located within the Hamersley and Fortescue subregions (**Figure 6**). The majority of the landscape within the Proposal Area is considered to be typical of the Hamersley subregion, while the creek systems have affinities with the Fortescue subregion. A description of the major characteristics of the two subregions is provided in **Table 4**.

The Hamersley subregion is approximately 6.2 million hectares in area, with the dominant land uses being grazing of native pastures, unallocated Crown land and Crown reserves, urban settlements, conservation and mining (Kendrick 2003a). The main land uses of the smaller (approximately 2 million hectares) Fortescue subregion include grazing, unallocated Crown land and Crown reserves, conservation and Aboriginal land (Kendrick 2003b).

Table 4: Hamersley and Fortescue Subregions of the Pilbara bioregion

Pilbara Subregion	Description
Hamersley	Recognised as the southern section of the Pilbara Craton. The Hamersley subregion consists of mountainous areas of Proterozoic sedimentary ranges and plateaux, dissected with gorges (basalt, shale and dolerite; Kendrick 2003b).
Fortescue	Consists of alluvial plains and river frontages (Kendrick 2003a). There are calcrete aquifers and localised springs in sections of the Fortescue system. It is the northern limit of the *Acacia aneura* complex (mulga).


710,000 mE
720,000 mE
730,000 mE
740,000 mE
7,490,000 mN
7,480,000 mN
7,470,000 mN
FORTESCUE
Development Envelope
BHPBIO YANDI
YANDICOOGINA
HAMERSLEY
Phil's Creek
Marillana Creek
Creek
Wolli Creek
Yandicoogina
Wolli
LEGEND
Development Envelope
Proposal Area
IBRA subregion
Railway
Major Watercourse
Rio Tinto Mine
BHPB Mine
N
SCALE
0 2.5 5 7.5 10km
1:200 000 @ A4
RioTinto
Iron Ore (WA)
Figure 6
Location of the Proposal within the Hamersley and Fortescue IBRA subregions
Drawn: M.Swebbs Plan No: PDE0136035v1
Date: October, 2015 Proj: MGA94 Zone50
Geospatial Information and Mapping

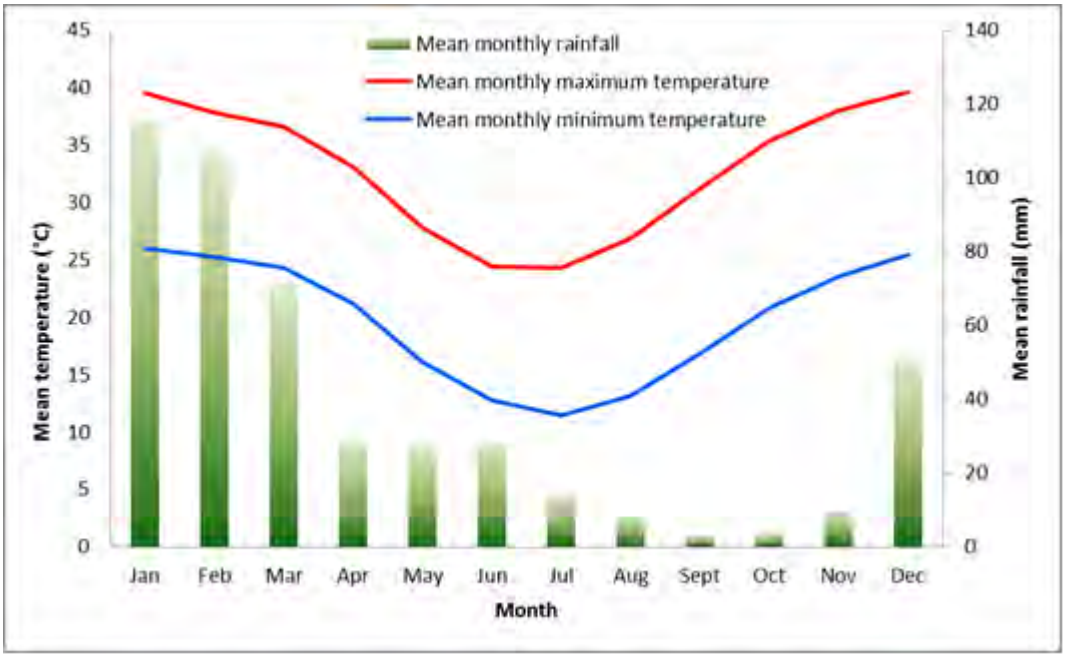
5.2 Climate

The Proposal Area is situated in the Pilbara bioregion of WA, which experiences a semi-arid to arid tropical climate that is characterised by hot humid summers (October to April) and relatively cool, dry winters (May to September). The mean monthly maximum temperature is approximately 40°C during the summer months (December/January), and drops to approximately 24°C in winter (June/July; BoM 2015). See **Figure 7** for further details.

The majority of the Pilbara has a bimodal rainfall distribution; from January to March rains result from tropical storms producing sporadic thunderstorms. Tropical cyclones moving south also bring heavy rains. From May to June, extensive cold fronts move eastwards across the state and sometimes reach the Pilbara. These fronts usually produce only light rains.

Long term, mean annual rainfall at the Yandicoogina locality is estimated to be approximately 400 mm, but is highly variable among years and over longer timescales. Annual evaporation is estimated to be between 3,200 mm to 3,600 mm and evaporation typically exceeds rainfall on a monthly basis throughout the year (MWH and Equinox Environmental 2011).

The closest operating meteorological station to the Proposal Area recording both temperature and rainfall data is the Wittenoom Weather Station (Station Number 005026), located approximately 95 km away. A summary of climate data recorded at the Bureau of Meteorology Wittenoom Weather Station is provided in **Figure 7**.



Source: BoM (2015)

Figure 7: Mean monthly rainfall, maximum and minimum temperatures recorded at the Wittenoom Weather Station between October 1951 to April 2015

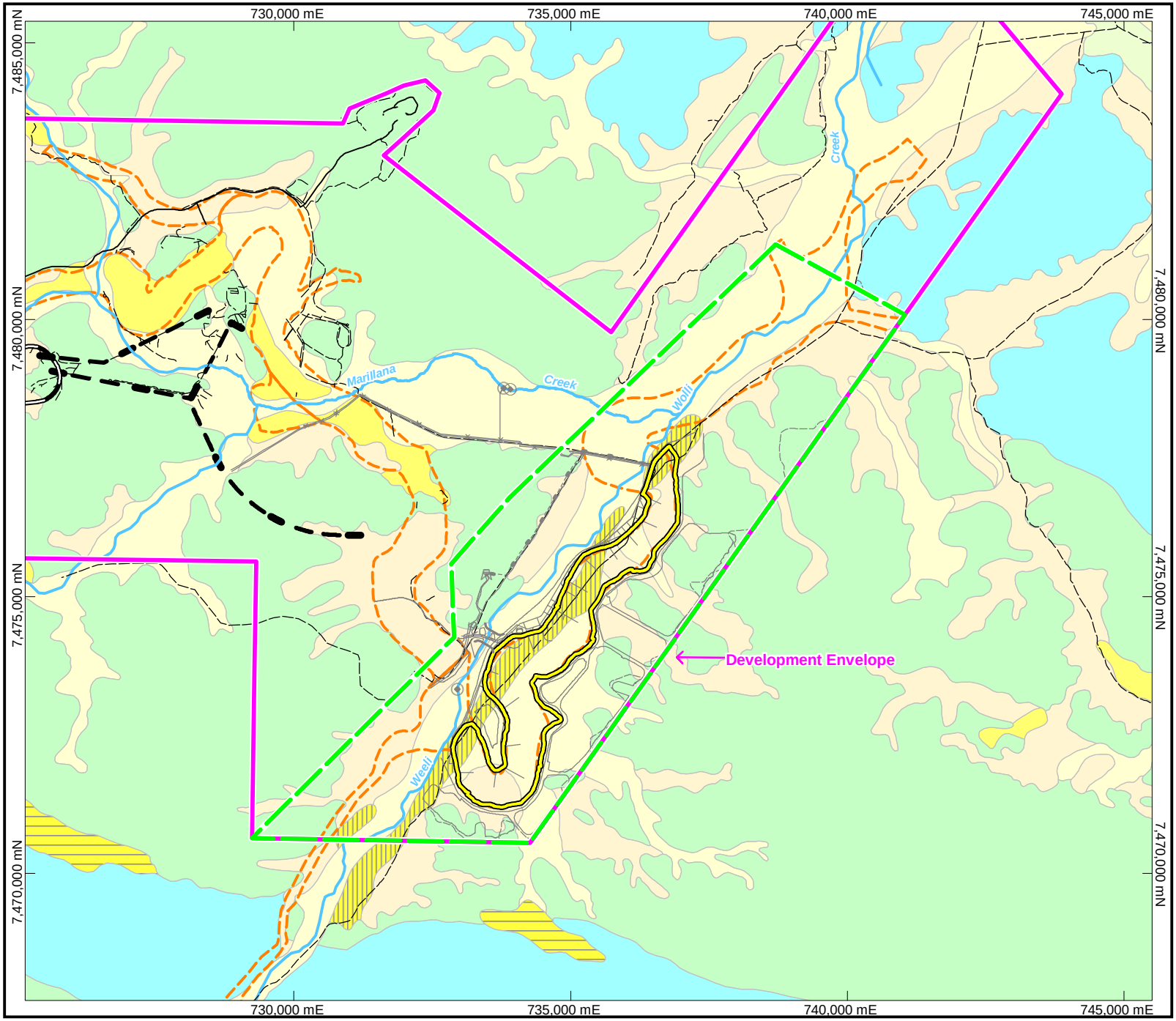
5.3 Geology

The Yandicoogina CIDs represent an accumulation of pisolitic iron that formed during the Tertiary Period. The CIDs are located in the Yandicoogina, Marillana and Weeli Wolli Creek regional catchments and comprise a palaeo-channel system that extends for a strike distance of approximately 80 km (Rio Tinto 2014a).

Most of the Yandicoogina area CID outcrops occur in association with Marillana Creek and its floodplain, or are covered by colluvium and alluvium up to 60 m thick. The palaeo-channel is between 450 and 750 m wide, with the main ore zone being 40-60 m thick in the centre of the channel and thinning out towards the channel margins, giving it a saucer-shape in cross-section. The top of the ore zone is generally weathered, silicified or clay rich due to infiltration of clays along joints, fractures, faults and tree roots (Rio Tinto 2014a). The stratigraphy of the CID includes six main material types:

- Eastern Clay Conglomerate/Laterite.
- Weathered Channel.
- Goethite Vitreous Upper.
- Goethite Vitreous Lower.
- Limonite Goethite Channel.
- Basal Conglomerate.

The proposal area marks the eastern extent of the CID palaeo-channel prior to entering and fanning out onto the Fortescue Plains. The palaeo-channel follows a north easterly course, located to the east of the JSE deposit, and continues along the borders of the Weeli Wolli valley before infiltrating the Fortescue Plains in the north. The Proposal deposit lies to the east and runs parallel to the floodplain of the current Weeli Wolli Creek for a total length of approximately 7 km (when measured in a straight line; Rio Tinto 2014a). The surface geology of the Proposal Area is presented in **Figure 8**.



LEGEND

- Development Envelope
- Proposal Area
- Existing Conveyor
- Existing Road
- Existing Track
- Major Watercourse

Conceptual Mine Layout

- Mine Pit
- Mine Layout/Infrastructure

Geology

- Alluvuim
- Eolian sand forming dunes and sheets
- Colluvium
- Pisolite and Limonite
- Calcrete
- Hematite and geothite

HAMERSLEY GROUP

- Weeli Wolli
- Brockman Iron
- Extent of CID

N

SCALE

0 1 2 3 4 5km

1:100 000 @ A4

Rio Tinto

Iron Ore (WA)

Figure 8
Surface geology of the Proposal Area

Drawn: M.Swebbs
Date: Sept, 2015

Plan No: PDE0129377v2
Proj: MGA94 Zone50

Geospatial Information and Mapping

5.4 Landform and land systems

The Proposal Area is dominated by Weeli Wolli Creek and its associated floodplains and hill slopes (Biota 2014a). The Creek flows in a northeast direction and ends in an alluvial fan at the Fortescue Marsh, outside of the Revised Proposal Development Envelope. The confluence of Weeli Wolli Creek and Marillana Creek is located in the north west of the Proposal Area. Four major landforms occur within the Proposal Area:

- **Major creeklines and tributaries**: predominately *Eucalyptus victrix* open woodland over *Acacia* low woodland over tussock grassland, with some sections of *Eucalyptus camaldulensis* and *E. victrix* woodland over *Melaleuca* and *Acacia* open woodland.
- **Minor creeklines, floodplains and valleys**: Predominantly *Eucalyptus leucophloia*/*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia* shrubland, over *Triodia* hummock grassland.
- **Hills ridges and breakaways**: Predominantly *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla*, *Acacia inaequilatera*, *Grevillea wickhamii* tall open shrubland over *Triodia* sp. *Shovelanna Hill* (S.van Leeuwen 3835) hummock grassland.
- **Plains**: *Eucalyptus leucophloia* subsp. *Leucophloia* and *Corymbia hamersleyana* scattered low trees over *Acacia* low open woodland over open *Acacia*, *Eremophila* shrubland over *Triodia* open hummock grassland.

The physical resources of the Pilbara region have been characterised and mapped into a number of land system units based on landforms, soils, vegetation and drainage patterns (Van Vreeswyk et al. 2004). Four land systems as mapped by Van Vreeswyk et al. (2004) were identified as occurring within the Proposal Area (Biota 2014a). These land systems and their associated descriptions are presented in **Table 5** and spatially depicted in **Figure 9**. The River land system includes the major drainage lines of the area (Marillana, Yandicoogina and Weeli Wolli Creeks). All of the land systems are widely represented across the central Pilbara region.

Table 5: Major land systems within the Proposal Area

Land system	Description	Extent in Proposal Area (ha)	Proportion of Proposal Area (%)
Newman	Rugged ironstone ridges, plateaux and mountains; hard spinifex pastures in Good to Excellent condition; no erosion	1,161	26
Boolgeeda	Stony lower slopes and plains below hill systems; not degraded or eroded	1,491	33
River	Active flood plains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands	1,336	30
McKay	Hills, ridges, plateaux remnants and breakaways of metasedimentary and sedimentary rocks supporting hard spinifex grasslands	499	11

5.5 Hydrogeology

Conceptually, three main hydro-stratigraphic units are recognised in the Yandicoogina region. They are comprised of the:

- relatively impermeable basement of the Weeli Wolli Formation;
- overlying highly permeable fractured CID; and
- semi-permeable floodplain alluvium of the creeks.

The aquifers are recharged primarily by direct infiltration of rainfall and via creek bed alluvials as a result of surface water flows during and/or following heavy rainfall (Rio Tinto 2010).

The Yandicoogina Iron Ore deposits infill the dissected palaeo-river valley of the Marillana - Yandicoogina - Weeli Wolli Creek system to form the CID (Rio Tinto 2014a). The CID aquifer is characterised by a relatively high water yield associated with secondary porosity. The CID is overlain and flanked by both alluvium and unconsolidated materials, which are also relatively transmissive and variably connected with the CID aquifer (Rio Tinto 2014a). Together, the CID and alluvium aquifers range in width from 1,000 to 2,000 m. The overall groundwater system is bounded by low transmissivity parent rocks, and the depth of the CID channel diminishes towards the flanks of the flood plain (Rio Tinto 2014a).

The natural depth to groundwater at the existing Yandi Operations pre-mining varied from 3 - 20 m below ground level (Rio Tinto 2010). However, due to leakage into the CID aquifer from surplus water discharge associated with upstream operations, the depth to groundwater has decreased with the general flow direction to the east within the Marillana Creek catchment and to the northeast at the Proposal locations, along Weeli Wolli Creek (Kirkpatrick and Dogramaci 2010a, 2010b).

Groundwater values of the Proposal Area are described in further detail in Section 13.

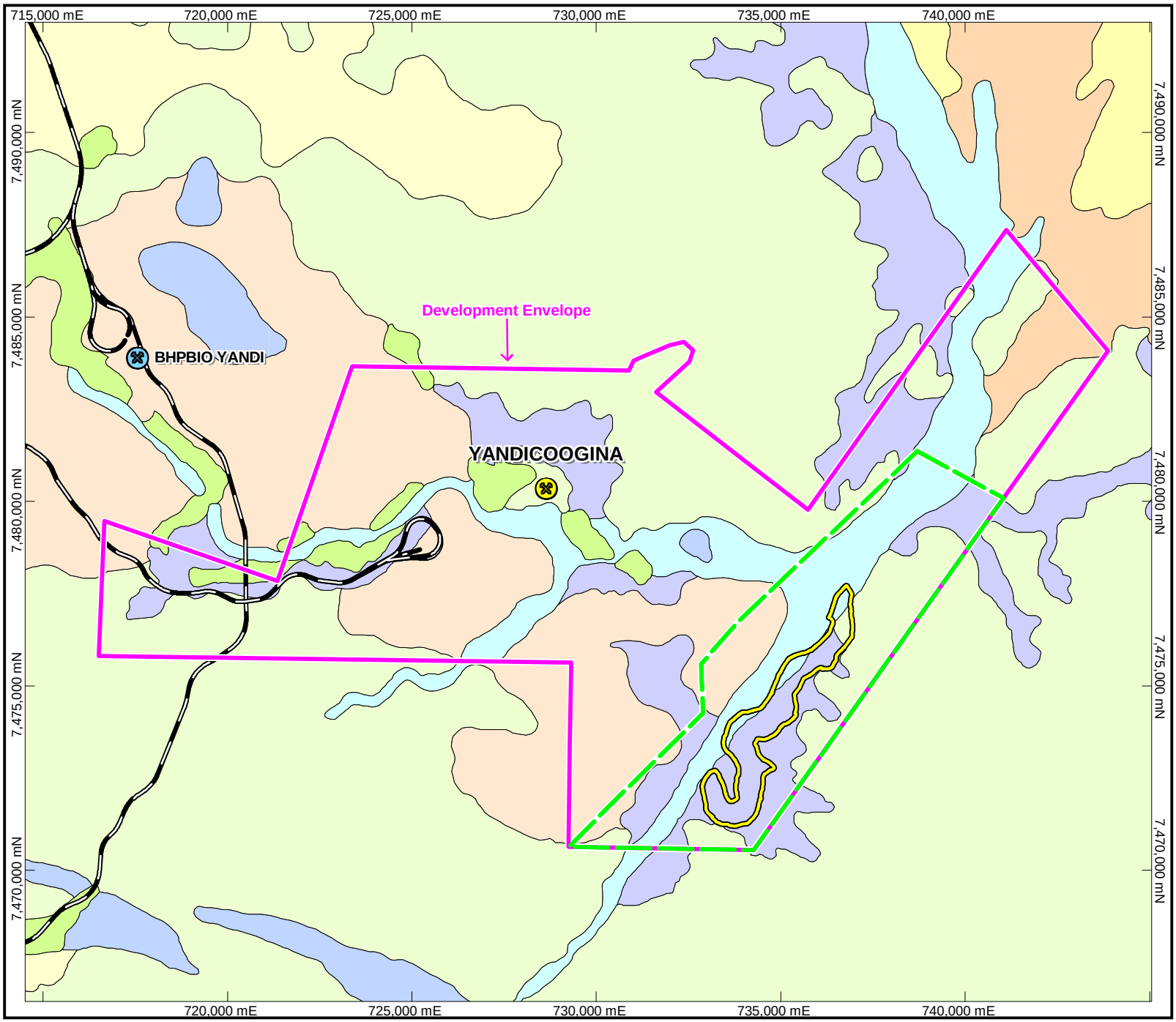
5.6 Surface hydrology

The topography of the central Pilbara region generally supports well defined surface catchments. Most rivers in the Pilbara are ephemeral and flow only occasionally, usually after heavy rainfall events. Larger flows are correlated with storms or high intensity cyclonic events, which bring heavy rain over a large area of the catchment. The Revised Proposal is located in the Weeli Wolli Regional Catchment within the Upper Fortescue River Catchment, near the intersection of Marillana/Yandicoogina Creek, Phil's Creek and Weeli Wolli Creek (**Figure 10**).

Weeli Wolli Creek is the dominant drainage feature which enters the Proposal Area from south of the Proposal deposit. Weeli Wolli Creek is a major Pilbara drainage system, with a catchment area of 4,769 km^2, and length of approximately 71 km. Weeli Wolli Creek drains parallel to the Proposal deposit in a predominantly north easterly direction, which runs downstream of the deposit and the Marillana Creek confluence. It then drains into the fluvial outwash fan south of Fortescue Marsh, with Fortescue Marsh located approximately 40 km to the north of the Revised Proposal. As Weeli Wolli Creek approaches Fortescue Marsh, the creekline becomes increasingly braided and ill-defined within the fluvial outwash fan (Rio Tinto 2014b).

Weeli Wolli Creek and its tributaries are altered systems, receiving surplus water from existing mining projects specifically Yandi Operations, BHP's Marillana Creek (Yandi) operations and Hamersley HMS's Hope Downs 1 operation. The Hope Downs 1 surplus water release into Weeli Wolli Creek, which commenced in 2007, together with surplus water discharge from JSE into Weeli Wolli Creek (near the southern end of the Proposal

deposit) during late 2006, has temporarily shifted the section of Weeli Wolli Creek adjacent to the Proposal from an ephemeral to a perennial system (Rio Tinto 2014a).



LEGEND

- Development Envelope
- Proposal Area
- Existing Railway
- Rio Tinto Mine
- BHP Mine
- Conceptual Mine Pit

Land System

- Boolgeeda Land System
- Calcrete Land System
- Fan Land System
- McKay Land System
- Newman Land System
- Platform Land System
- River Land System
- Robe Land System
- Rocklea Land System
- Urandy Land System

N

SCALE

0 2 4 6km

1:150 000 @ A4

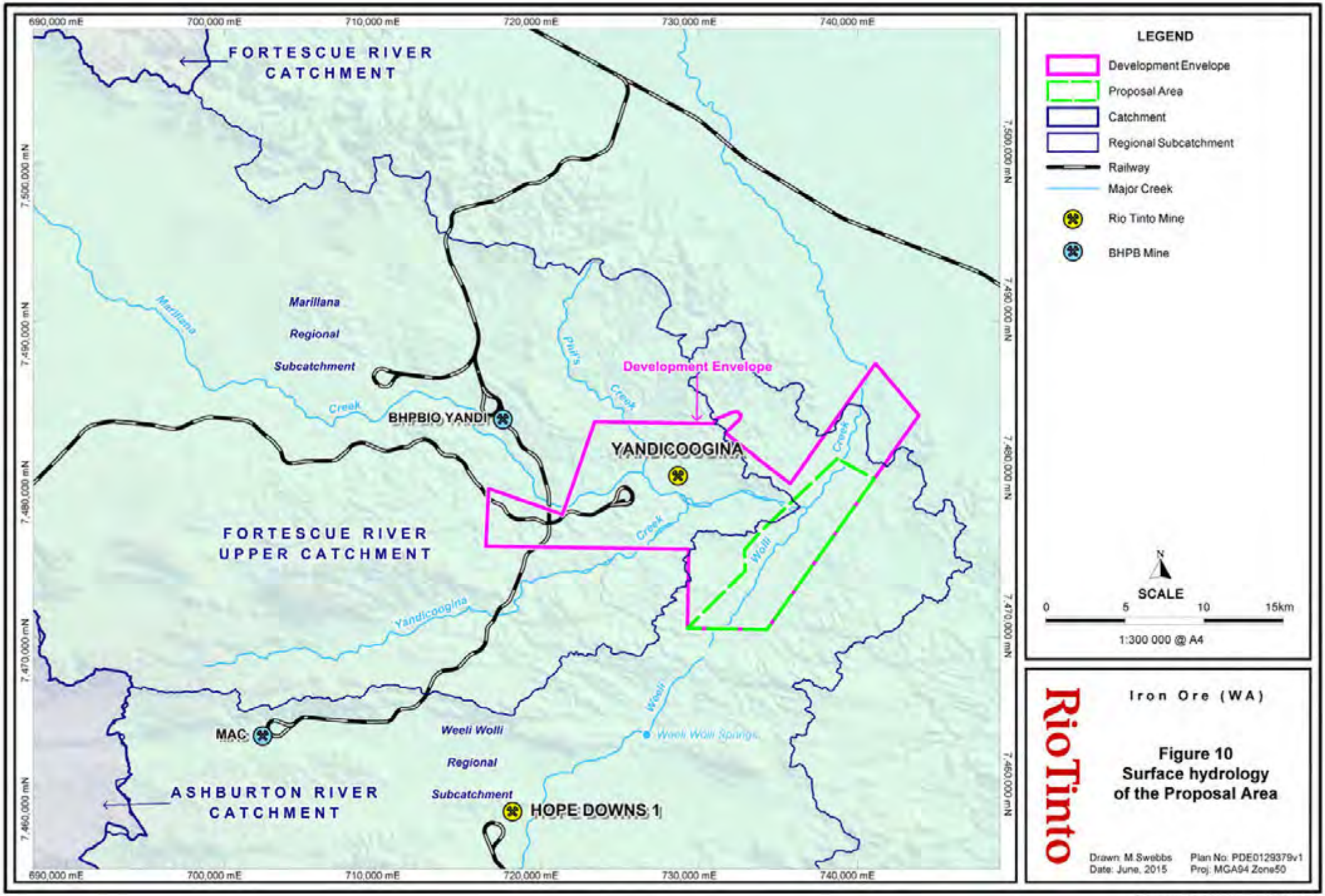
Iron Ore (WA)

Figure 9
Land systems of the Proposal Area

Drawn: M.Swebbs
Date: Aug, 2015

Plan No: PDE0129378v1
Proj: MGA94 Zone50

Geospatial Information and Mapping


690,000 mE
700,000 mE
710,000 mE
720,000 mE
730,000 mE
740,000 mE
7,500,000 mN
7,490,000 mN
7,480,000 mN
7,470,000 mN
7,460,000 mN
FORTESCUE RIVER CATCHMENT
Marillana
Regional
Subcatchment
Marillana Creek
BHPBIO YANDI
Phil's Creek
Development Envelope
YANDICOOGINA
Wolli Creek
Creek
FORTESCUE RIVER UPPER CATCHMENT
Yandicoogina
Wolli
Weeli Wolli Springs
MAC
Weeli Wolli
Regional
Subcatchment
ASHBURTON RIVER CATCHMENT
HOPE DOWNS 1
LEGEND
Development Envelope
Proposal Area
Catchment
Regional Subcatchment
Railway
Major Creek
Rio Tinto Mine
BHPB Mine
N
SCALE
0
5
10
15km
1:300 000 @ A4
Iron Ore (WA)
Figure 10
Surface hydrology
of the Proposal Area
Drawn: M.Swebbs
Date: June, 2015
Plan No: PDE0129379v1
Proj: MGA94 Zone50
Geospatial Information and Mapping

6. Biological environment

6.1 Environmental Values Statement

As part of the approval for the existing Yandi Operations, under MS 914, an Environmental Values Statement (EVS) was required to be developed for Weeli Wolli Creek, as per condition 6-1 and 6-2:

- *Condition 6-1: The proponent shall ensure that the discharge of excess water from the Yandicoogina Iron Ore Project - Expansion to include Junction South West and Oxbow Deposits as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek System.*

- *Condition 6-2: To verify that condition 6-1 is being met, the proponent shall develop an Environmental Values Statement for the Weeli Wolli Creek System that defines the environmental values of the Weeli Wolli Creek System to the satisfaction of the CEO in consultation with the DEC.*

The high level values identified related to hydrology/hydrogeology, flora and vegetation, fauna, heritage and social aspects. This EVS was developed in consultation with the former Department of Environment and Conservation (DEC) and approved by the CEO of the OEPA on 14th October 2012 (**Table 6**).

Table 6: High level values statement for Weeli Wolli Creek catchment, October 2012

Value	Description
Hydrology/ hydrogeology	Marillana and Weeli Wolli Creeks are ephemeral watercourses supported by a combination of groundwater flows and surface run off. This system ultimately drains into Fortescue Marsh, approximately 40 km downstream of Yandicoogina.
Flora and vegetation	A number of populations of the DRF (Declared Rare Flora) *Lepidium catapycnon* occur within the Project Area. The species is listed as a DRF under the *Wildlife Conservation Act 1950* and as Vulnerable under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). Four main Riparian woodland vegetation communities exist along the Weeli Wolli and Marillana creekline areas within the Yandicoogina Project footprint. One community (open riparian woodland of *Eucalyptus victrix, Eucalyptus camaldulensis, Melaleuca argentea, M. glomerata*) is considered to have local significance due to its association with a major creekline in the area.
Fauna	The riparian woodland and ephemeral nature of the Weeli Wolli and Marillana Creeks, together with the underlying CID aquifer provide habitat for a range of fauna, including terrestrial, avian, aquatic and subterranean. Assemblages include aquatic fauna (micro and macroinvertebrates and fish), stygofauna, and animals of the hyporheic zone. The Project Area does not contain any permanent pools as refuge for aquatic fauna, and as a result there is no elevated conservation significance for aquatic fauna in the Project footprint. A number of stygofauna fauna species are known only from the Marillana-Weeli Wolli Catchment. In the wider catchment the Weeli Wolli Spring (upstream from the Project Area) is known to support a significant microbat species assemblage, which includes the most northerly population of the Chocolate Wattle Bat (*Chalinobolus morio*). No threatened fauna are known from the Weeli Wolli and Marillana creeklines in the Yandicoogina Project Area; however it may contain habitat for the Northern Quoll and the Pilbara Olive Python.
Heritage and social	Aboriginal culture is spiritually and physically connected to the landscape through *Jukurppa* (Dreaming) stories, ceremony, and physical places such as ethnographic and archaeological heritage sites. Weeli Wolli Creek is an important ephemeral water source, food source, camping and meeting place and has been visited by the Traditional Owners of the area for many thousands of years. Significant ethnographic and archaeological heritage sites are also associated with the Marillana and Weeli Wolli water courses. Weeli Wolli Creek is significant for tourism in the region.

These original values are proposed to be amended to reflect specific identified environmental values (rather than processes). This alteration is being undertaken in consultation with Parks and Wildlife. The updated EVS for the Weeli Wolli Creek catchment, included in the revision to the Yandicoogina Monitoring and Management Plan (**Appendix 4**), is described in **Table 7**.

Table 7: High level values statement for Weeli Wolli Creek catchment, October 2015

High Level Values	Description
Fortescue Marsh	The Fortescue Marsh is the largest ephemeral wetland in the Pilbara region and is listed on the Directory of Important Wetlands of Australia as a wetland of national significance. The diverse ecosystem includes endemic flora, fauna and supports a rich diversity of restricted aquatic and terrestrial invertebrates. The Fortescue Marsh is classified as a Priority Ecological Community (PEC). Marillana and Weeli Wolli Creeks are ephemeral watercourses supported by a combination of groundwater flows and surface run off. This system ultimately drains into Fortescue Marsh, approximately 40 km downstream of Yandicoogina.
Flora and vegetation	A number of populations of the DRF (Declared Rare Flora) *Lepidium catapycnon* occur within the Yandicoogina Development Envelope. The species is listed as a DRF under the Wildlife Conservation Act and as Vulnerable under the EPBC Act. Five broad riparian woodland vegetation communities exist along the Weeli Wolli and Marillana creekline areas within the Yandicoogina Development Envelope. One community (C1A - open riparian *eucalypt* woodland containing a mature and co-dominant *Melaleuca argentea* component) is considered to have local conservation significance due to its groundwater dependency, associated values, somewhat restricted distribution, and association with a major creekline in the area. This community is similar but of different structure and reduced significance to the vegetation community of Weeli Wolli Spring (significant *Melaleuca argentea* woodlands).
Stygofauna	A number of subterranean fauna species are known only from the Marillana-Weeli Wolli Catchment. The riparian woodland and ephemeral nature of the Weeli Wolli and Marillana Creeks, together with the underlying CID aquifer provide habitat for a range of fauna, including terrestrial, avian, aquatic and subterranean. Assemblages include aquatic fauna (micro and macroinvertebrates and fish), stygofauna, and animals of the hyporheic zone. The Development Envelope does not contain any permanent pools as refuge for aquatic fauna, and as a result there is no elevated conservation significance for aquatic fauna in the Development Envelope.
Other Recognised Values	**Description**
Fauna	In the wider catchment, the Weeli Wolli Spring (upstream from the Development Envelope) is known to support a significant microbat species assemblage, which includes the most northerly population of the Chocolate Wattle Bat (*Chalinobolus morio*). This bat species has been recorded in the south west corner of the Development Envelope. The Pilbara Olive Python (*Liasis olivaceus barroni*) has been recorded within Weeli Wolli Creek within the southern area of the Development Envelope, and the Development Envelope may contain habitat for the Northern Quoll (*Dasyurus hallucatus*). The Weeli Wolli Creek catchment also contains records of listed migratory birds and Priority species.
Heritage and Social	Aboriginal culture is spiritually and physically connected to the landscape through Jukurppa (Dreaming) stories, ceremony, and physical places such as ethnographic and archaeological heritage sites. Weeli Wolli Creek is an important ephemeral water source, food source, camping and meeting place and has been visited by the Traditional Owners of the area for many thousands of years. Significant ethnographic and archaeological heritage sites are also associated with the Marillana and Weeli Wolli water courses. Heritage and social values are recognised and are addressed by the Heritage of Western Australia Act 1990. Weeli Wolli Creek is also a significant tourism destination in the region.

6.2 Vegetation and flora

6.2.1 Context

6.2.1.1 Surveys in the region

Numerous flora and vegetation surveys have been conducted in the wider Yandicoogina locality, with surveys commencing in 1994 (refer to Section 14.2 for further details), to varying levels of detail. Within the Revised Proposal Development Envelope, 30 vegetation units (**Figure 11** to **Figure 19**) have been identified within the following broad landscape categories (Biota 2015a):

- Major creeklines and tributaries - A total of five vegetation types were associated with creeklines that supported true riparian vegetation, as characterised by the presence of the tree species *Eucalyptus camaldulensis* (River Red Gum), *E. victrix* (Coolibah) and/or scattered stands of *Melaleuca argentea* (Cadjeput).
- Minor creeklines, floodplains and valleys - A total of five vegetation types were associated with minor creeklines, floodplains and valleys.
- Hills, ridges, gorges and breakaways - A total of 11 vegetation types were associated with hills, ridges, gorges or breakaways.
- Plains - A total of nine vegetation types were associated with stony plains.

A total of 548 native vascular flora taxa from 173 genera and 53 families have been recorded within the Revised Proposal Development Envelope, based on all survey in the area to date. This includes one Threatened species (*Lepidium catapycnon*) and five Priority flora species. A total of 36 introduced flora species were also recorded (Biota 2015a).

6.2.1.2 Establishment of Clearing Avoidance Area

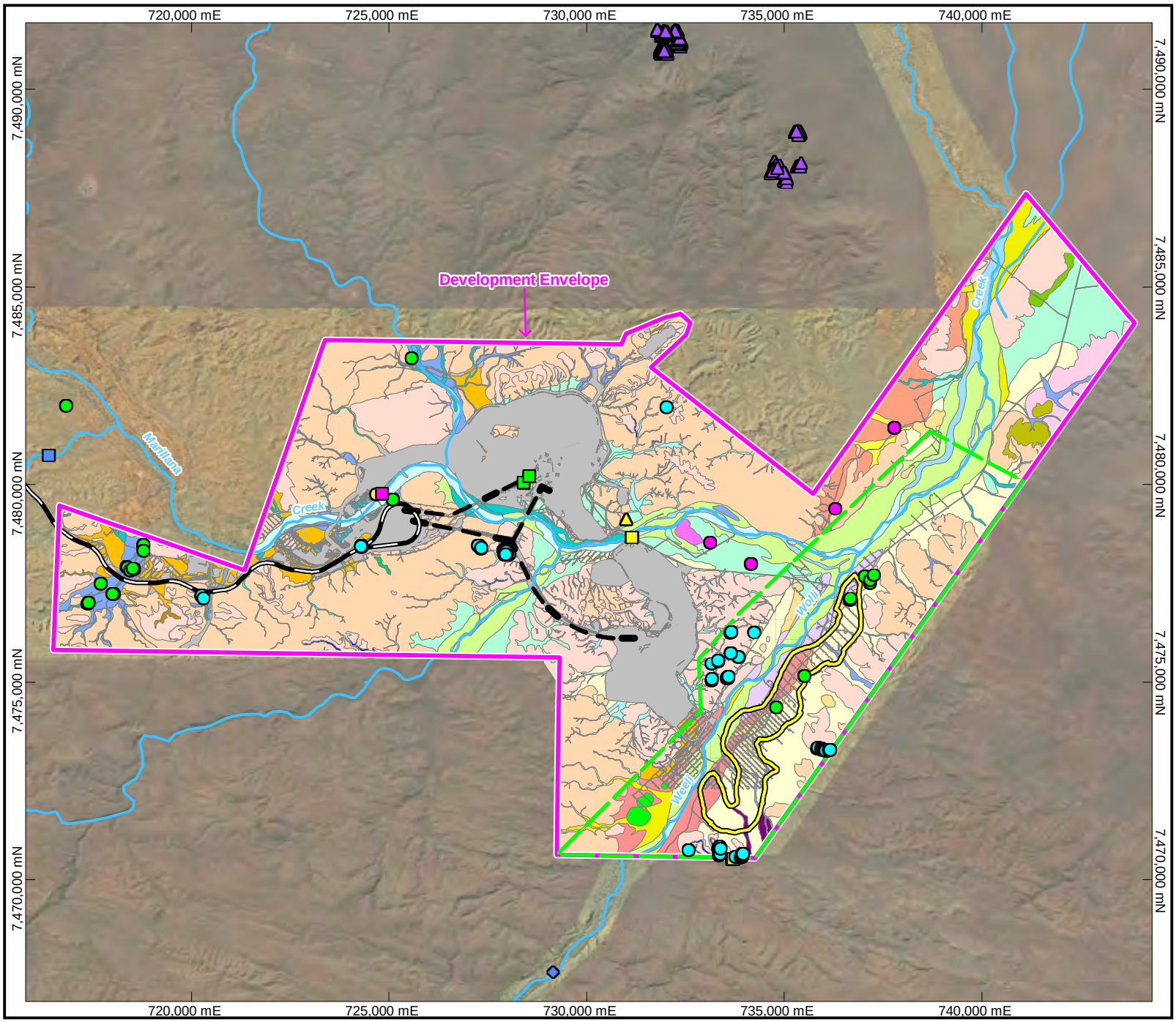
During assessment and approval of the existing Yandi Operations, a Clearing Avoidance Area (CAA) was defined as part of MS 914. The CAA was developed in recognition of the local conservation significance of the creeklines (as described in detail in the original EVS) and their ecological function. The boundary of the CAA was based on vegetation mapping specifically delineating riparian vegetation and encompassing creekline vegetation communities representing the broader floodplain.

The CAA was originally developed for the JSW and Oxbow environmental assessment whereby a Development Envelope was defined and key areas for reduced or limited clearing were delineated along Marillana Creek. This included delineating areas of the creekline not proposed to have any clearing undertaken during implementation of the proposal. However, during a subsequent s46B amendment under the EP Act to include the existing operations (JC and JSE), the boundary of the CAA was extended from Marillana Creek to also include Weeli Wolli Creek to match the expanded Development Envelope, and delineated areas which were not intended to have any clearing associated with implementation of the operations which were included and approved in MS 914.

The applicability of the CAA delineated in MS914 was therefore related to implementation of the JSW, Oxbow, JC and JSE deposits only, and not intended to apply to potential future developments (such as this Proposal). To avoid confusion, the CAA and Restricted Clearing Area polygons have been revised to an overall Restricted Clearing Area as depicted in **Figure 79**, Section 24.

6.2.1.3 Riparian vegetation trends

Riparian vegetation along Pilbara watercourses are often dominated by dense, tall, large trees of *Melaleuca argentea, Eucalyptus camaldulensis* and *E. victrix*. These species occur in an environment subject to ecological shifts that can be quite large and dynamic, with episodic occurrences of drought, defoliating wildfire, severe flood and stand replacement by regeneration, even when in a “natural and protected” condition. Shifts in species composition and in tree health are inevitable over time.



LEGEND

- Development Envelope
- Proposal Area
- Existing Railway
- Existing Conveyor
- Major Watercourse
- Conceptual Mine Pit

Priority 1 Flora
- Synostemon hamersleyensis

Priority 2 Flora
- Rhodanthe frenchii
- Stylidium weeliwolli

Priority 3 Flora
- Rostellularia adscendens var. latifolia
- Sida sp. Barlee Range (S. van Leeuwen 1642)
- Themeda sp. Hamersley Station (M.E. Trudgen 11431)

Priority 4 Flora
- Goodenia nuda
- Rhynchosia bungarensis

Species of Interest
- Eulalia sp. (Three Rivers Station, B.Forsyth AQ6789133)
- Glycine sp. aff. arenaria

Rare Species
- Lepidium catapycnon

N

SCALE

0 2 4 6km

1:140 000 @ A4

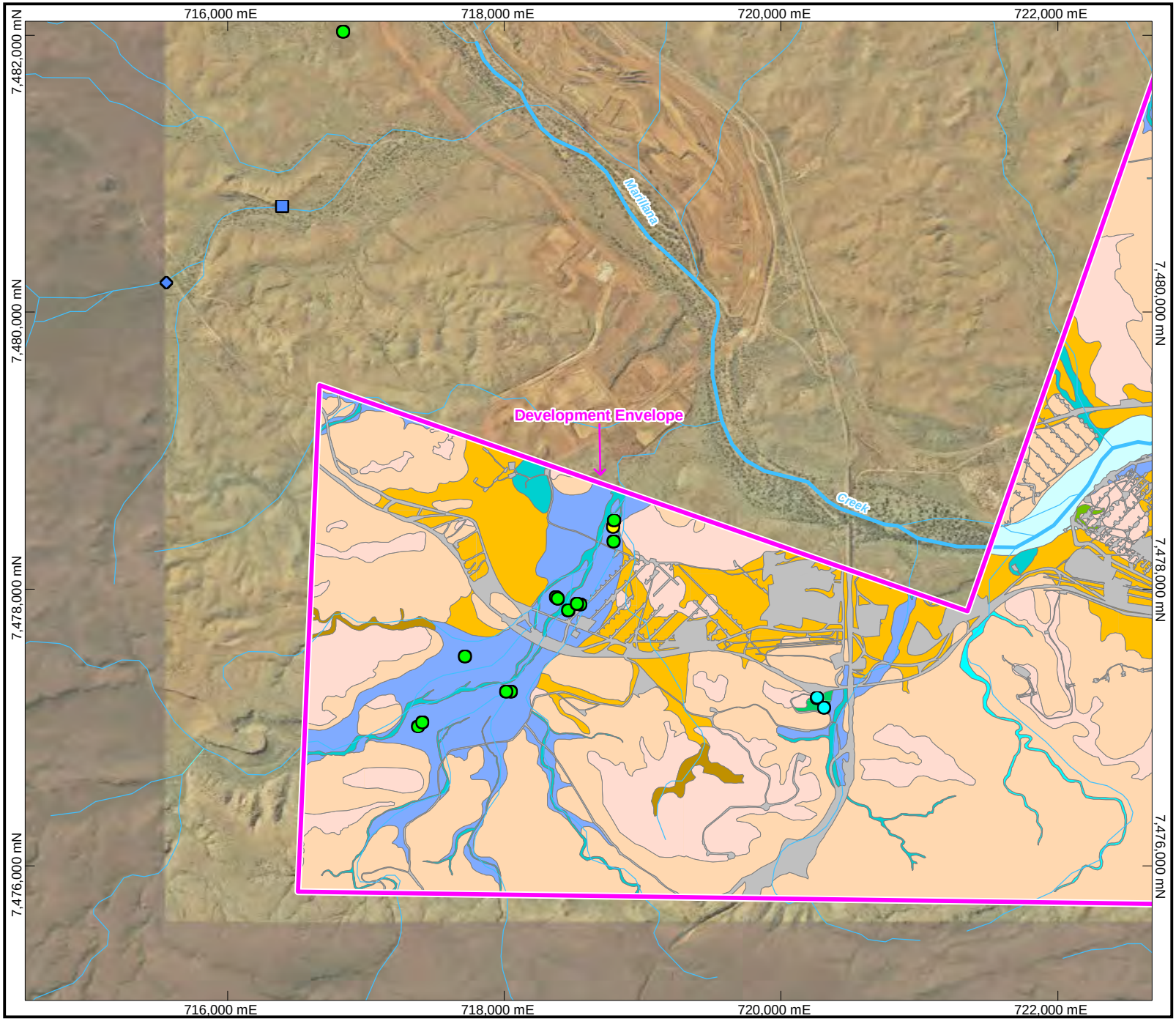
RioTinto

Iron Ore (WA)

Figure 11
Vegetation units in the Revised Proposal Development Envelope (Overall Map)

Drawn: M.Swebbs Plan No: PDE0131734v3
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

Development Envelope

Rare Species

Lepidium catapycnon

Priority 2 Flora

Rhodanthe frenchii

Stylidium weeliwolli

Priority 3 Flora

Rostellularia adscendens var. ***latifolia***

Priority 4 Flora

Goodenia nuda

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

Rio Tinto

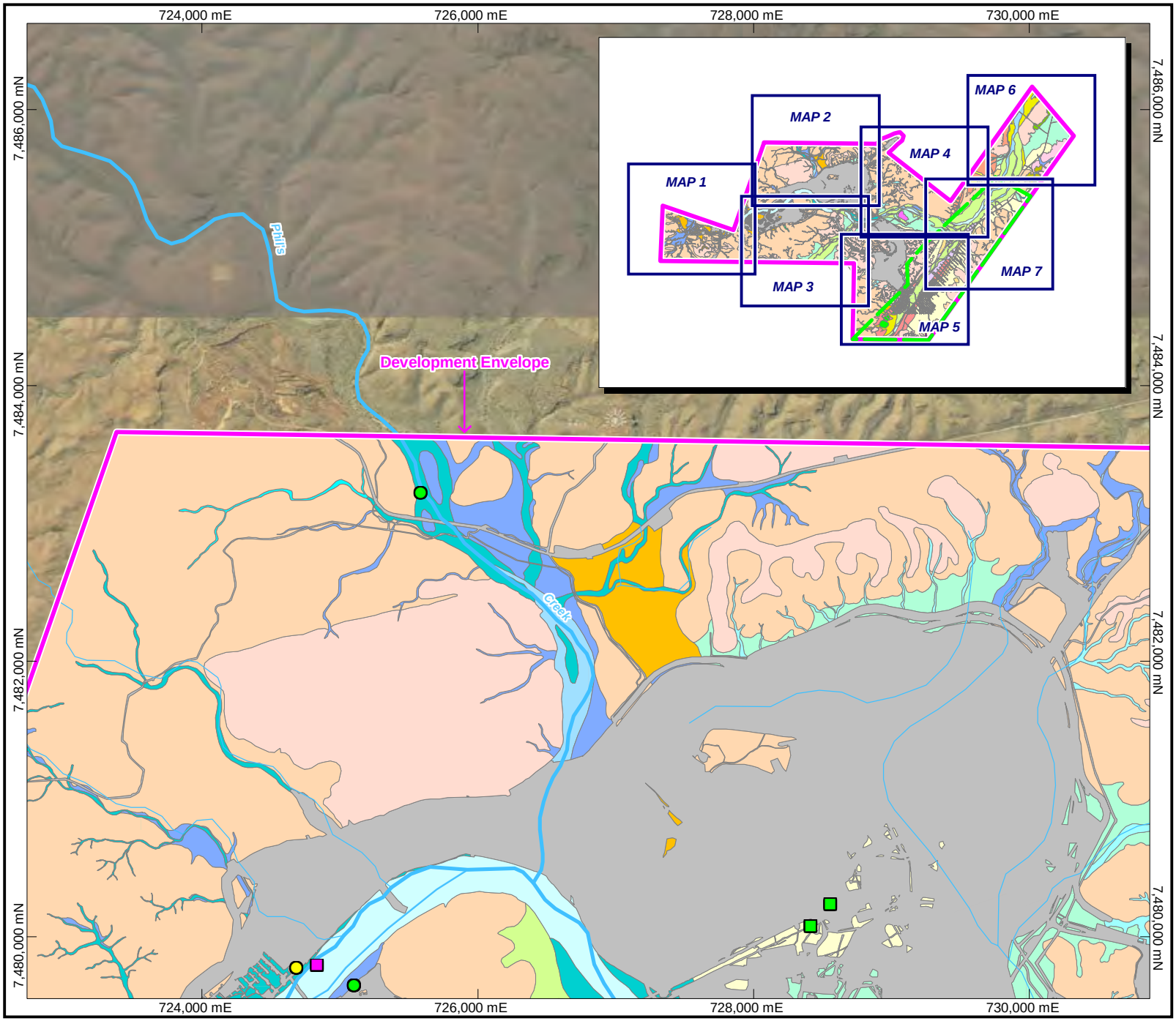
Iron Ore (WA)

Figure 12 Vegetation units in the Revised Proposal Development Envelope (Map 1)

Drawn: M.Swebbs Plan No: PDE0131734v2

Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

Development Envelope

Priority 3 Flora

Rostellularia adscendens var. ***latifolia***

Priority 4 Flora

Goodenia nuda

Rhynchosia bungarensis

Species of Interest

Glycine sp. aff. ***arenaria***

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

Rio Tinto

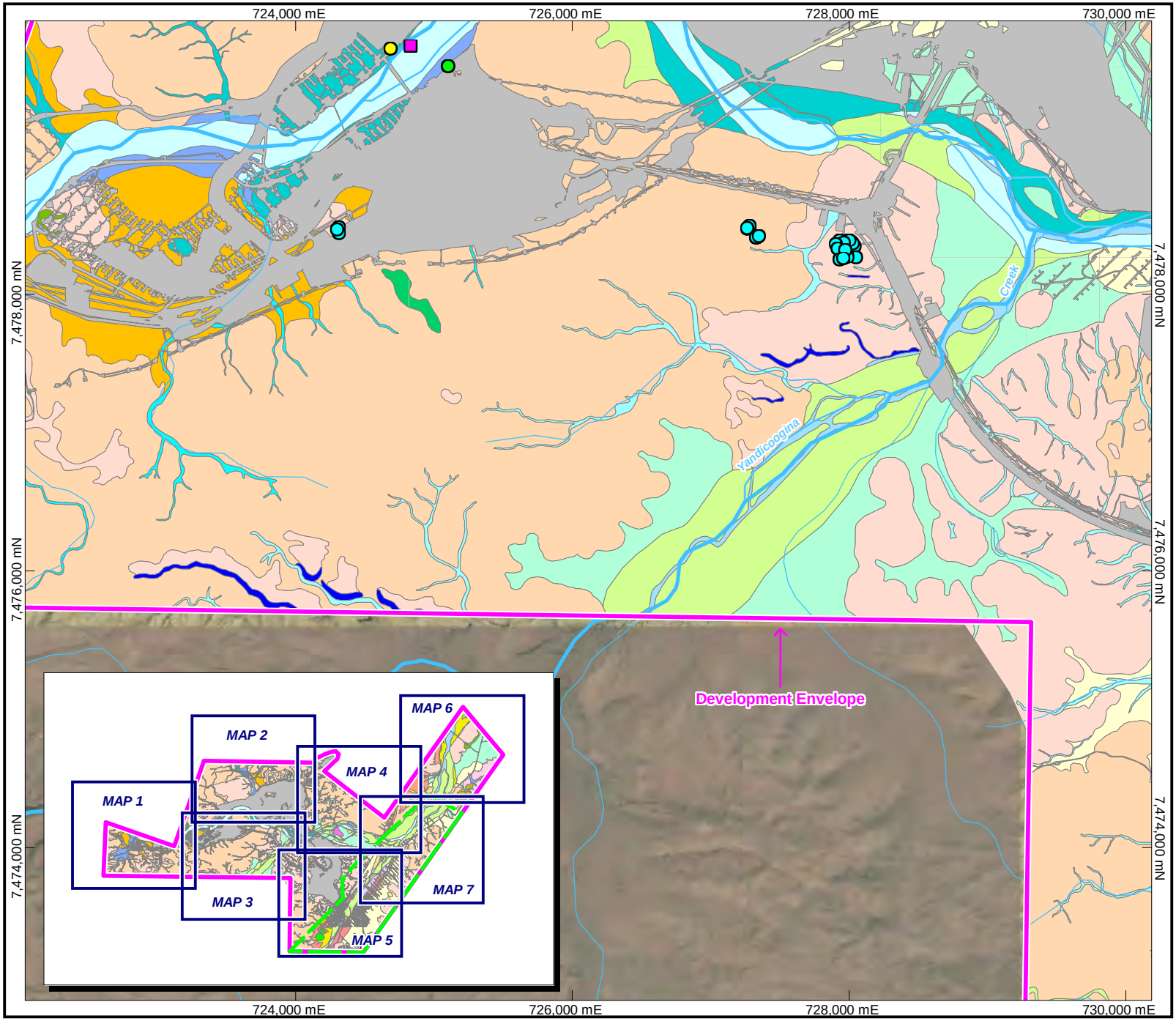
Iron Ore (WA)

Figure 13 Vegetation units in the Revised Proposal Development Envelope (Map 2)

Drawn: M.Swebbs Plan No: PDE0131734v2

Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

Development Envelope

Rare Species

Lepidium catapycnon

Priority 3 Flora

Rostellularia adscendens var. ***latifolia***

Priority 4 Flora

Goodenia nuda

Species of Interest

Glycine sp. aff. ***arenaria***

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

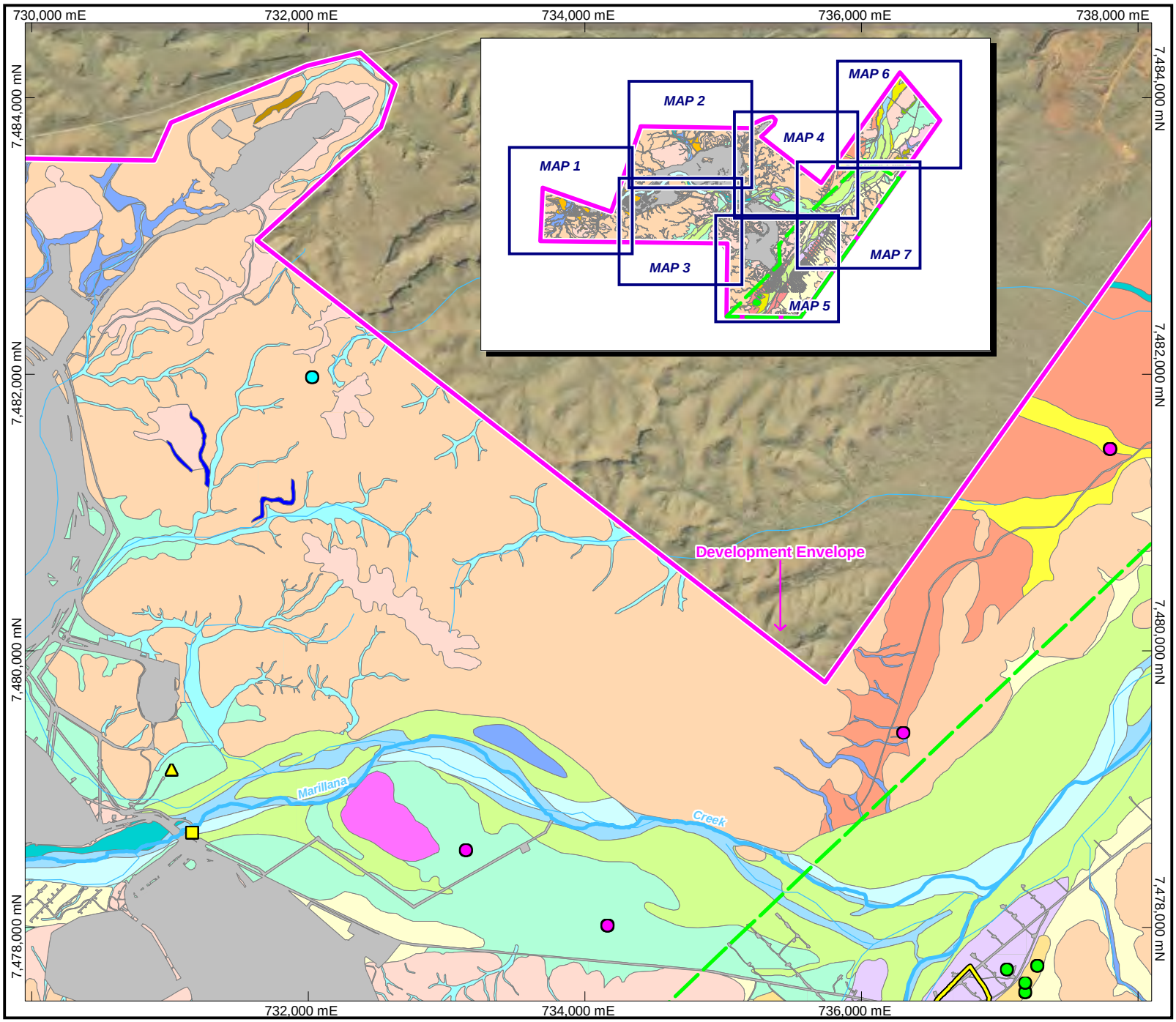
Rio Tinto

Iron Ore (WA)

Figure 14
Vegetation units in the Revised Proposal Development Envelope (Map 3)

Drawn: M.Swebbs Plan No: PDE0131734v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump

Rare Species

- ***Lepidium catapycnon***

Priority 3 Flora

- ***Sida*** sp. Barlee Range (S. van Leeuwen 1642)
- ***Themeda*** sp. Hamersley Station (M.E. Trudgen 11431)

Priority 4 Flora

- ***Goodenia nuda***

Species of Interest

- ***Eulalia*** sp. (Three Rivers Station, B.Forsyth AQ6789133)

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

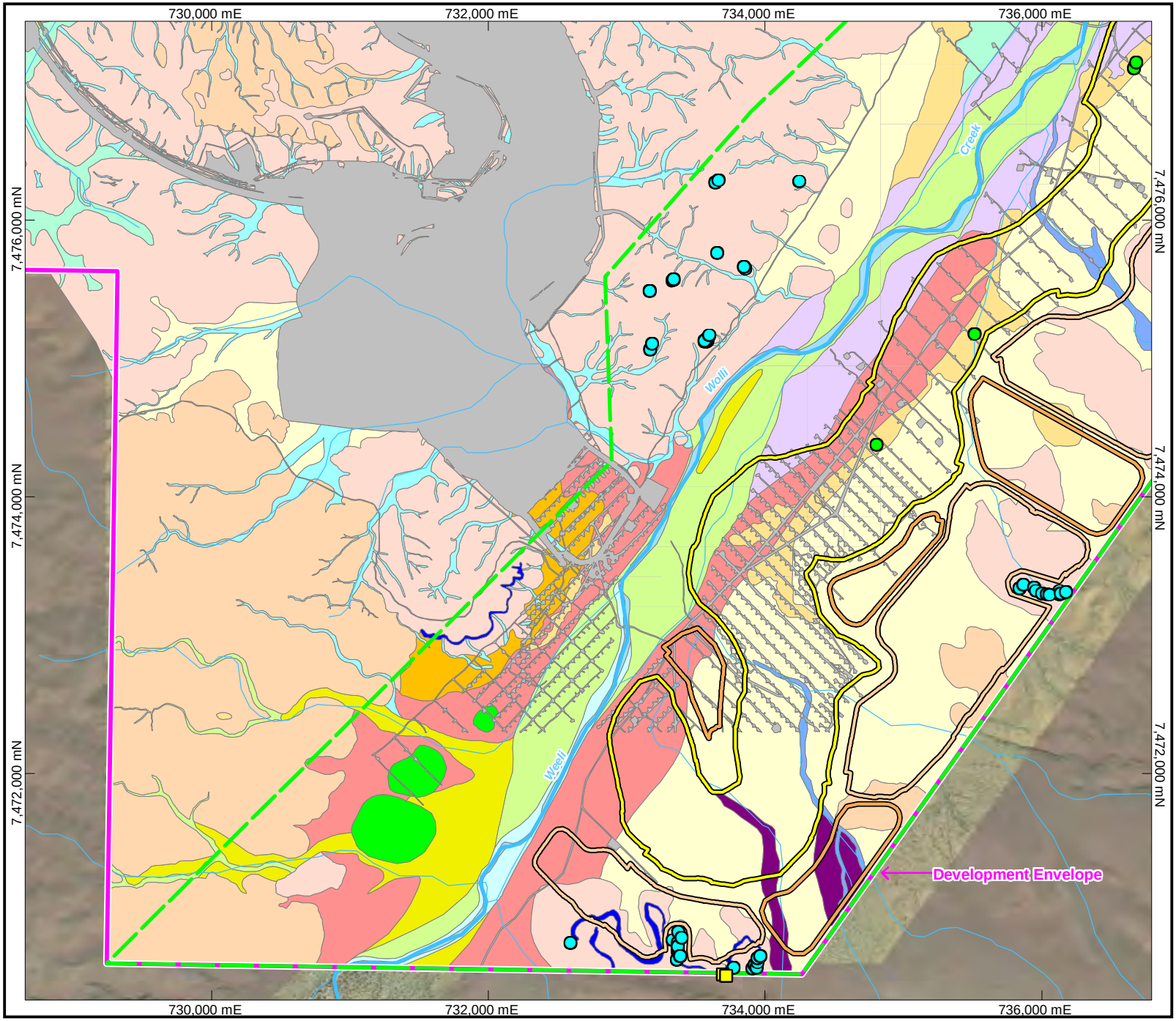
Rio Tinto

Iron Ore (WA)

Figure 15 Vegetation units in the Revised Proposal Development Envelope (Map 4)

Drawn: M.Swebbs Plan No: PDE0131734v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Rare Species

- ***Lepidium catapycnon***

Priority 3 Flora

- ***Sida*** sp. Barlee Range (S. van Leeuwen 1642)

Priority 4 Flora

- ***Goodenia nuda***

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

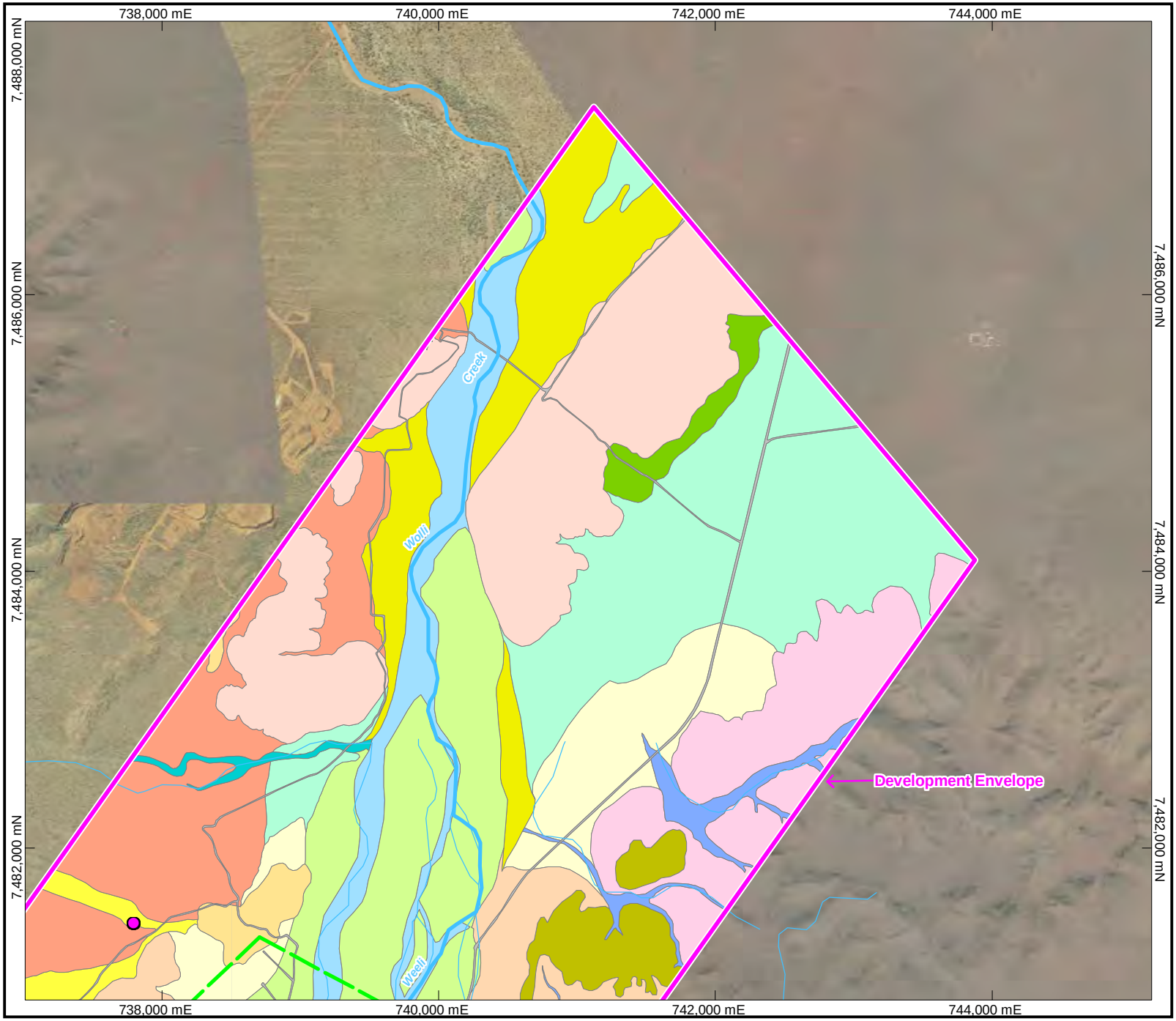
Rio Tinto

Iron Ore (WA)

Figure 16 Vegetation units in the Revised Proposal Development Envelope (Map 5)

Drawn: M.Swebbs Plan No: PDE0131734v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

Development Envelope

Proposal Area

Species of Interest

Eulalia sp. (Three Rivers Station, B.Forsyth AQ6789133)

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

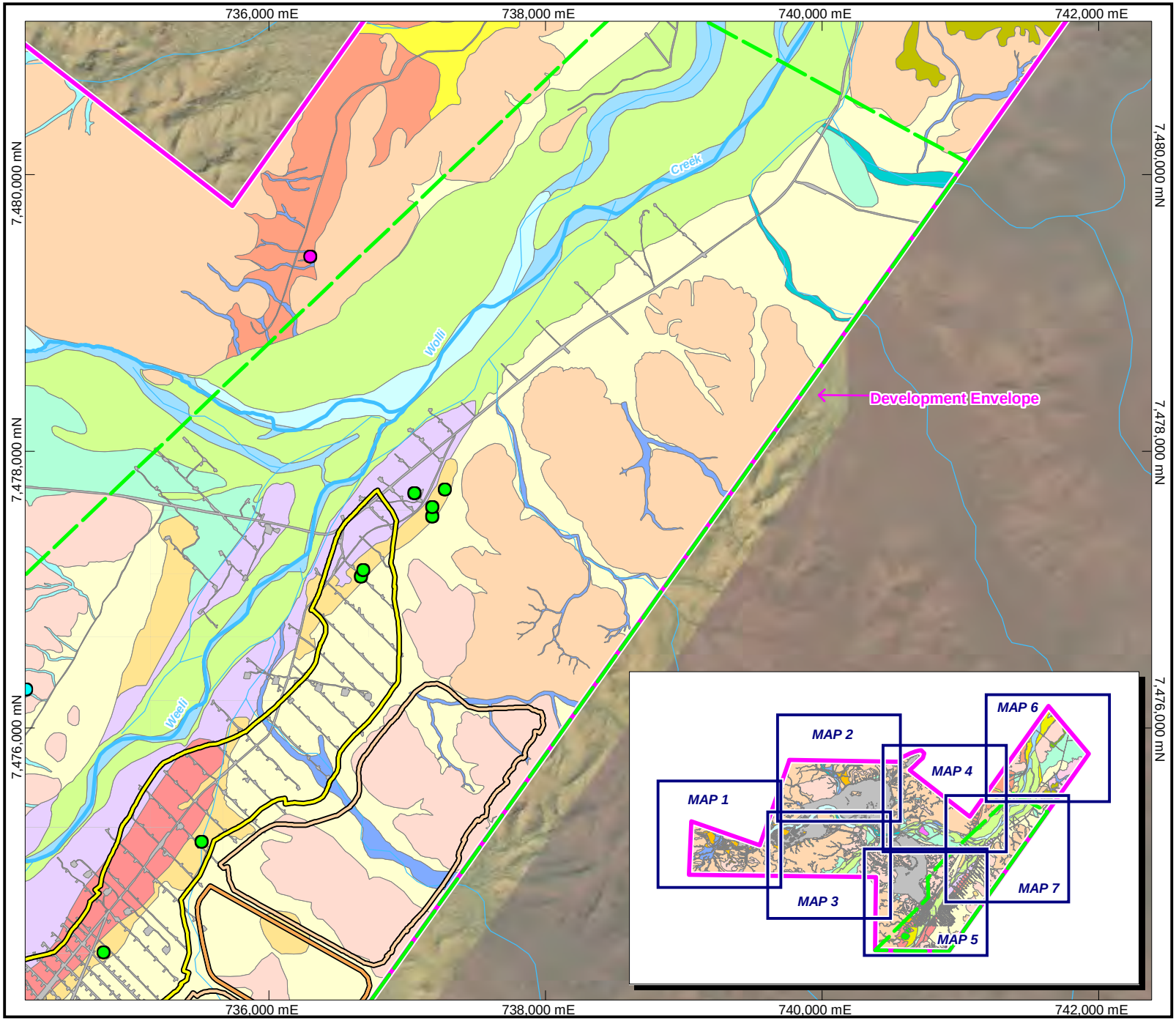
Iron Ore (WA)

Figure 17 Vegetation units in the Revised Proposal Development Envelope (Map 6)

Drawn: M.Swebbs Plan No: PDE0131734v2

Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Rare Species

- ***Lepidium catapycnon***

Priority 4 Flora

- ***Goodenia nuda***

Species of Interest

- ***Eulalia*** sp. (Three Rivers Station, B.Forsyth AQ6789133)

N

SCALE

0 0.5 1 1.5 2km

1:40 000 @ A4

Iron Ore (WA)

Figure 18
Vegetation units in the Revised Proposal Development Envelope (Map 7)

Drawn: M.Swebbs Plan No: PDE0131734v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Figure 19 - Vegetation units in the Revised Proposal Development Envelope

Vegetation of Major Creeklines and Tributaries

C1: EcEvMaMgAc
Eucalyptus camaldulensis subsp. refulgens, E. victrix woodland over Melaleuca argentea, M. glomerata, Acacia coriacea subsp. pendens low open woodland

C2: EvChAtuGwTErCYpERItTHt
Eucalyptus victrix, (Corymbia hamersleyana) scattered low trees over Acacia tumida var. pilbarensis, Grevillea wickhamii tall shrubland over Tephrosia rosea var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over Cymbopogon ambiguus, C. procerus Eriachne tenuiculmis, Themeda triandra very open tussock grassland

C3: EvAciAcMgCEc
Eucalyptus victrix scattered trees over Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata tall open shrubland over *Cenchrus ciliaris scattered tussock grasses

C4: EvAciAprAThCEc
Eucalyptus victrix open woodland over Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca low woodland over *Cenchrus ciliaris tussock grassland

C5: EvAbAaAmERItTHt
Eucalyptus victrix scattered low trees over Acacia bivenosa, A. ancistrocarpa, A. maitlandii tall open shrubland over Eriachne tenuiculmis, Themeda triandra very open tussock grassland

Vegetation of Minor Creeklines, Floodplains and Valleys

F1: ChAtuGwTp
Corymbia hamersleyana scattered low trees to low open woodland over Acacia tumida var. pilbarensis, Grevillea wickhamii tall open shrubland over Triodia pungens hummock grassland

F2: AprAciCEc
Acacia pruinocarpa, A. citrinoviridis tall open shrubland over *Cenchrus ciliaris tussock grassland

F3: ElChAtuAaAbGwTspp
Eucalyptus leucophloia, Corymbia hamersleyana low open woodland over Acacia tumida var. pilbarensis, A. ancistrocarpa, A. bivenosa, Grevillea wickhamii tall open scrub over mixed Triodia hummock grassland

F4: ChAtuAaPcAtenBONeARhPAmTp
Corymbia hamersleyana scattered low trees over Acacia tumida var. pilbarensis tall open shrubland over A. ancistrocarpa, Petalostylis cassioides, A. tenuissima open shrubland over Bonamia erecta very open herbland over Aristida holathera var. holathera var. holathera, Paraneurachne muelleri very open tussock grassland and Triodia pungens very open hummock grassland

Vegetation of Hills, Ridges and Breakaways

F5: ChAciAaAiSENsppTp
Corymbia hamersleyana scattered low trees over Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera tall open shrubland over Senna spp. open shrubland over Triodia pungens open hummock grassland.

H1: ElHcAiGwTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii tall open shrubland over Triodia sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

H2: ElAiTwTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over Acacia inaequilatera scattered tall shrubs over Triodia wiseana, (T. sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland

H3: ElGwAarTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over Grevillea wickhamii tall open shrubland over Acacia arida shrubland over Triodia sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland

H4: ChAarTspsTw
Corymbia hamersleyana scattered low trees over Acacia arida open shrubland over Triodia sp. Shovelanna Hill (S. van Leeuwen 3835), T. wiseana hummock grassland

H5: ElCfERlmTHspp
Eucalyptus leucophloia subsp. leucophloia, Corymbia ferriticola scattered low trees over Eremophila latrobei subsp. filiformis, Senna spp. scattered shrubs over Cymbopogon ambiguus, Eriachne mucronata, Themeda sp. Mt Barricade (M.E. Trudgen 2471), T. triandra open tussock grassland

H6: ElAbTw
Eucalyptus leucophloia scattered low trees over Acacia bivenosa open shrubland over Triodia wiseana hummock grassland

H7: ElAprTwTp
Eucalyptus leucophloia scattered low trees over Acacia pruinocarpa tall open shrubland over Triodia wiseana, T. pungens open hummock grassland

H8: AmoTspsTw
Acacia monticola tall shrubland over Triodia sp. Shovelanna Hill (S. van Leeuwen 3835), T. wiseana closed hummock grassland

H9: ChGOrANlAtuGwTHtCYa
Corymbia hamersleyana scattered low trees over Gossypium robinsonii, Androcalva luteiflora, Acacia tumida var. pilbarensis, Grevillea wickhamii shrubland over Themeda triandra, Cymbopogon ambiguus open tussock grassland

H10: AiERfTp
Acacia inaequilatera scattered tall shrubs over Eremophila fraseri subsp. fraseri scattered shrubs over Triodia pungens very open hummock grassland

H11: GpERfTp
Grevillea pyramidalis subsp. leucodendron, Eremophila fraseri tall open shrubland over Triodia pungens hummock grassland

Vegetation of Plains

P1: ElEgAprAbAaAdTwTpTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over E. gamophylla scattered low mallees over Acacia pruinocarpa scattered tall shrubs over A. bivenosa, A. ancistrocarpa, A. dictyophleba shrubland over Triodia wiseana, T. pungens, T. sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

P2: ChAprAiAsclApaTp
Corymbia hamersleyana, Acacia pruinocarpa scattered low trees over A. inaequilatera, A. sclerosperma subsp. sclerosperma, A. pachyacra tall open shrubland over Triodia pungens hummock grassland

P3: AprAciAiAsclTlo
Acacia pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera, A. sclerosperma subsp. sclerosperma open shrubland over Triodia longiceps hummock grassland

P4: AprAsyAiTw
Acacia pruinocarpa low open woodland over A. synchronicia, A. inaequilatera scattered tall shrubs over Triodia wiseana open hummock grassland

P5: ElEgAbAaTb
Eucalyptus leucophloia subsp. leucophloia scattered low trees over E. gamophylla scattered low mallees over Acacia bivenosa, A. ancistrocarpa open shrubland over Triodia basedowii open hummock grassland

P6: AapERfoERl/g
Acacia aptaneura low open forest over Eremophila forrestii subsp. forrestii open shrubland over E. lanceolata low open shrubland over mixed very open grassland

P7: ERf/G
Eremophila fraseri subsp. fraseri open shrubland over mixed very open grassland

P8: EgAiTs
Eucalyptus gamophylla scattered low mallees over Acacia inaequilatera scattered tall shrubs over Triodia schinzii hummock grassland

P9: ChEgAiAaAprPcTb
Corymbia hamersleyana scattered low trees over Eucalyptus gamophylla scattered low mallees over Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa tall open shrubland over Petalostylis cassioides open shrubland over Triodia basedowii open hummock

Disturbed
Disturbed

The Proponent monitors riparian tree health utilising a variety of methods, specifically ground transects (record flora present, structure and visual rating of crown health condition), Digital Cover Photography, and aerial photography. Monitoring results show varying changes to riparian vegetation (when comparing reference and impact sites). Some areas show increased health, others decreased (including dead trees) and others that have changed little (Eastham 2015). These results indicate that the vegetation even at reference sites in the Pilbara is not static, but is highly dynamic in its responses to altered environmental conditions.

The hydrology of the Weeli Wolli Creek system is complex. In addition to a high level of natural variation in rainfall and surface water flow, the creek is also influenced by dewatering, spur irrigation, discharge and re-injection associated with mines operating in the catchment. Ecological changes are inevitable where an ephemeral creek system is altered to a perennial system for a number of years. **Plate 1** shows the extent and density of vegetation associated with the Weeli Wolli Creek system prior to hydrological alterations by mining operations, when the system was ephemeral. The vegetation is much sparser in comparison to **Plate 2**, which shows the extent and density of vegetation subsequent to hydrological alterations where the system is now perennial and natural regeneration from local seed sources is occurring.

Plate 1: Vegetation associated with portion of Weeli Wolli Creek system in 2006

Plate 2: Vegetation associated with portion of Weeli Wolli Creek system in 2014

Tree responses to drought and waterlogging (associated with dewatering and surplus water discharge) will differ between the three dominant riparian species (*M. argentea, E. camaldulensis* and *E. victrix*), as well as being influenced by the proximity of the trees to the disturbance (dewatering or discharge), the ecological niche occupied by individual trees (especially elevation above water table), valley shape and soil type.

6.2.2 Vegetation

The Proposal Area lies within the Fortescue Botanical District of the Eremaean Botanical Province as defined by Beard (1975a). Vegetation of this province is typically open and frequently dominated by spinifex, wattles and scattered eucalypts. The Proposal Area intersects two of the vegetation units defined by Beard (1975b), all of which have the majority of their pre-European extent remaining. These vegetation units are described in

Table 8: Broad vegetation of the Proposal Area

Beard Vegetation Association	Description
Fortescue Valley_29	Sparse low woodland; mulga, discontinuous in scattered groups
Fortescue Valley_82	Hummock grasslands, low tree steppe; Snappy Gum over *Triodia wiseana* (equivalent to Hamersley_82)

Source: Beard (1975b)

Biota Environmental Sciences (Biota) has mapped and described vegetation sub-associations (referred to herein as vegetation units) within the Proposal Area (Biota 2014a); and additional refined riparian vegetation mapping has been undertaken along Marillana and Weeli Wolli Creek (Rio Tinto 2015a). The vegetation units have been grouped according to major landform, with the following relevant to the Proposal Area:

- Vegetation of Major Creeklines and Tributaries.
- Vegetation of Minor Creeklines, Floodplains and Valleys.
- Vegetation of Hills, Ridges and Breakaways.
- Vegetation of Plains.

Most of the vegetation was in Excellent or Good condition (utilising the scale by Trudgen 1988), however the creekline and floodplain vegetation ranged from Good to Very Poor condition. This was due to dense weed invasion (particularly by *Cenchrus ciliaris*) and disturbance from cattle in the form of tracks, grazing, trampled vegetation and scats (Biota 2014a).

Details of the vegetation recorded within the Proposal Area, including the conservation significance of vegetation communities and vegetation condition, are described further in Section 14.

6.2.3 Flora

A total of 455 native vascular flora taxa from 147 genera and 47 families have been recorded from the Proposal Area, based on all survey effort to date (Biota 2014a). This includes one Threatened species and two Priority flora species, with an additional three Priority species potentially occurring in the Study area. When compared to other studies within the region, the total number of native flora taxa recorded from the Proposal Area is in the range that would be expected and does not contain a particularly high level of vegetation or plant species diversity for the Pilbara bioregion (Biota 2014b). Eighteen introduced flora species have also been recorded.

The flora recorded in the Proposal Area, including conservation significant flora, are described further in Section 14.

6.3 Terrestrial fauna

6.3.1 Terrestrial fauna habitats

Five fauna habitat types have been categorised in the Proposal Area, classified on the basis of landform, substrate and vegetation (Biota 2014c). In addition, disturbed areas were identified. The fauna habitats included:

- Alluvial Plain (Flood Plain).
- Mulga woodland.
- Hilltops and Slopes.
- Pediment Slope.
- Major Drainage Line.

The major drainage channels of the Marillana and Weeli Wolli Creeks provide suitable habitat for conservation significant fauna species such as the Pilbara Olive Python (*Liasis olivaceus barroni*). Habitat for the conservation significant Northern Quoll (*Dasyurus hallucatus*) is limited, but some small areas of rocky breakaway habitat do exist throughout the Proposal Area (Biota 2014d).

Terrestrial fauna habitats are described further in Section 15.

6.3.2 Terrestrial vertebrate fauna

A total of 147 vertebrate fauna species have been recorded in the Proposal Area, including five conservation listed species under the EPBC Act, the *Wildlife Conservation Act 1950* (WC Act) and/or the Parks and Wildlife Priority List. An additional species, the Chocolate Wattled Bat (*Chalinolobus morio*), while currently not listed under Commonwealth or State legislation, was also identified to be of significance. A further 11 conservation listed species have been identified as likely or potentially occurring within the Proposal Area (Biota 2015b; 2014c).

The terrestrial vertebrate fauna of the Proposal Area, including conservation listed species, are described further in Section 15.

6.3.3 Short range endemic terrestrial invertebrate fauna

Species are identified as potential short range endemics (SREs) if they have a known distribution less than 10,000 km^2 (Harvey 2002). SRE invertebrate fauna were targeted during recent fauna surveys of the Proposal Area. Genetic analysis from collected specimens determined four potential SRE putative species from two families of mygalomorph spiders (Biota 2014c, 2015b). The SREs of the Proposal Area are described further in Section 15.

6.3.4 Aquatic fauna

Aquatic fauna surveys have been conducted biannually (wet and dry seasons) since September 2007 by Wetland Research and Management (WRM 2015a, b) in Marillana Creek and Weeli Wolli Creek. The most recent survey in September/October 2013 (late dry) and April/May 2014 (late wet) found the following number of taxa in the Proposal Area:

- 108 microinvertebrate taxa.
- 141 macroinvertebrate taxa.

- 34 hyporheic fauna taxa: 15 taxa classified as occasional hyporheos stygophiles, 7 taxa as stygobites, and 12 were possible hyporheic taxa.
- 3 fish species.

Several undescribed hyporheic taxa were considered to be new species, and five stygobitic amphipod/isopod species were considered to be potential SREs, with *Maarrka weeliwolli* and *Pygolabis weeliwolli* appearing to be restricted to Marillana Creek and Weeli Wolli Creek. The aquatic fauna sampled within the Proposal Area are described further in Section 15.

6.4 Subterranean fauna

Subterranean fauna can be classified into two main groups:

- Stygofauna which are obligate groundwater-dwelling aquatic fauna that spend their entire life cycle below ground, occasionally occurring very close to surface waters as well as deep aquifers; and
- Troglofauna which are obligate subterranean terrestrial fauna that inhabit caves and the many small voids and tunnels that occur within some unconsolidated and rocky substrates above the water table.

Subterranean fauna in WA are generally invertebrates and often exhibit high levels of endemism. The absence of light in subterranean ecosystems results in limited energy resources originating from surface environments. As a consequence, subterranean fauna have evolved to survive in unique environments, often being highly specialised with morphological, physiological and biological adaptations that reflect severe environmental constraints (Gibert & Deharveng 2002 as cited in EPA 2013b). WA's subterranean fauna is recognised as being globally significant because of its extraordinarily high species richness and high levels of endemism (EPA 2013b).

In total there were 2,761 stygofauna specimens from 62 taxa found in the Proposal Area to date. There is limited troglofauna habitat within the Proposal Area, and the CID formation proposed for excavation (known to provide habitat for troglofauna in other areas of the Pilbara) is located 99% below the water table. Three troglofauna specimens (three taxa) have been recorded within the Proposal Area.

Subterranean fauna of the Proposal Area are described in further detail in Section 15.

7. Social environment

7.1 Socio-economic setting

The Pilbara is one of the largest regions in WA, encompassing 507,896 km^2 (Pilbara Development Commission 2015). In June 2014, the estimated resident population of the Pilbara region was 67,503 people, with almost 60% of the population aged between 20 and 49 years. The mining and construction industries account for 60% of all jobs in the region. In 2014, the gross regional product for the Pilbara was almost $35 billion (REMPLAN 2015).

The Proposal Area lies within the Shire of East Pilbara, which has an estimated population of 25,000 people, including FIFO workers. The East Pilbara economy is primarily based on mining and associated supporting industries, tourism and pastoral activities. The main regional centres of the East Pilbara are Newman, Marble Bar and Nullagine. There are a number of Aboriginal Communities within the Shire, including Jigalong, Punmu, Parngurr, Irrungadgi and Parnpajinya (Shire of East Pilbara 2014).

Newman, with a population of 9,000 people, is the nearest significant population centre to the Proposal Area, located approximately 90 km to the south east. Newman is an important regional centre due to its proximity to mining and mineral exploration sites, and airport that supports the FIFO mine workforces. The 54 km bitumen access road into Yandicoogina, shared by the Proponent and BHP, is located 135 km north west of Newman on the Great Northern Highway.

7.1.1 Land use

The principal land use in the region is pastoral cattle production. The Proposal Area co-exists with Pastoral Lease N50368 which is currently held by a BHP subsidiary and operated as Marillana Station (**Figure 20**). A number of the Proponent's existing Yandi Operations deposits (JC, JSE, and part of JSW) also co-exist with this pastoral lease. Marillana Station has a long history of cattle grazing and is still used for this purpose.

There are a number of other mining projects that occur in the vicinity of the Proposal and existing Yandi Operations. These are operated by Rio Tinto (or its subsidiaries) or a number of other third party operators (**Figure 21**).

Other regional land uses include tourism and conservation. The Proposal Area is located approximately 70 km from the nearest boundary of the Karijini National Park, approximately 200 km from the Millstream Chichester National Park and approximately 115 km from the Mungaroona Range Nature Reserve (**Figure 22**).

Additionally, the Proposal Area is located in the catchment of the Fortescue Marsh, which has regionally and nationally important conservation values and is listed in the Directory of Important Wetlands of Australia (Environment Australia 2001; EPA 2013a). Fortescue Marsh is almost 1,050 km^2 in size, the largest ephemeral wetland in the Pilbara, within a larger management area of over 5,800 km^2 (EPA 2013a). The northern section of the Revised Proposal Development Envelope is located in this broader management area, Zone 2b Poonda Plain, which has a medium environmental significance (EPA 2013a). However, the Proposal Area is primarily located outside this zone and the only potential impact from the Proposal is related to the surplus discharge wetting front (see Section 13). The highly diverse ecosystem of the Fortescue Marsh is an important regional conservation asset and supports populations of restricted aquatic and terrestrial invertebrates, threatened vertebrate fauna and Priority flora (DPaW 2014).

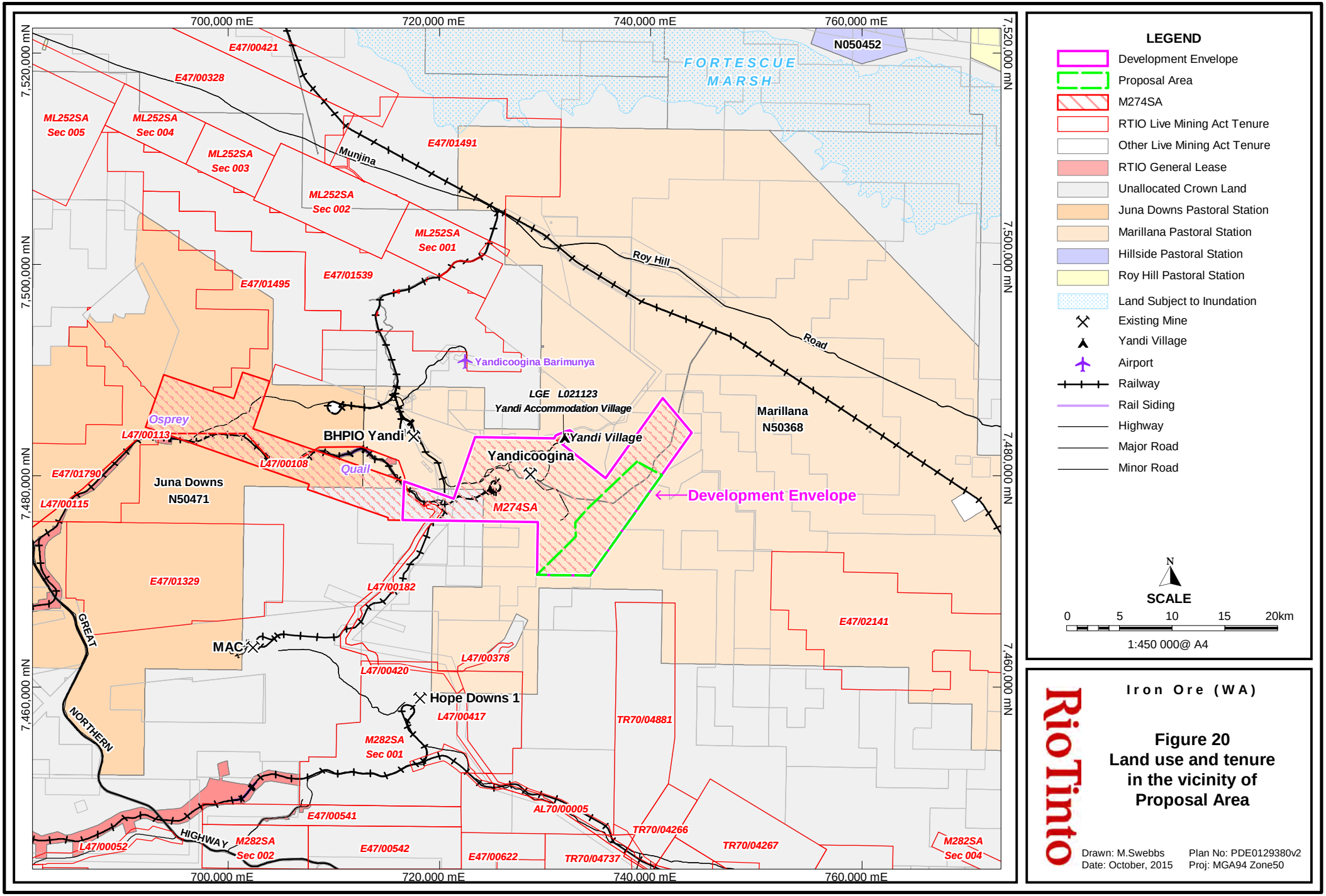
7.1.2 Tenure

The Revised Proposal is located on mining lease 274SA (ML274SA) held by Hamersley Iron – Yandi Pty Ltd established under the *Iron Ore (Yandicoogina) Agreement Act 1996* (**Figure 20**).

The Proponent operates a railway corridor that runs in a west, and then north westerly direction, extending from the rail load-out facility located near JC. Part of this railway runs through BHP's Yandicoogina Operation to the west of the existing Yandi Operations on Mining Lease 270SA. The Proponent has been granted Lease L21124 under the *Land Administration Act 1997* for this section of the railway. The railway corridor connects with existing Rio Tinto port facilities at Dampier and Cape Lambert.

The Proponent's workforce for the existing Yandi Operations is accommodated in the village/camp facilities located on Lease L21123 under the *Land Administration Act 1997,* which abuts the northern boundary of ML274SA.

BHP operates a railway line and power transmission corridor which crosses ML274SA in a north south direction immediately east of the Oxbow deposit.



LEGEND

- Development Envelope
- Proposal Area
- M274SA
- RTIO Live Mining Act Tenure
- Other Live Mining Act Tenure
- RTIO General Lease
- Unallocated Crown Land
- Juna Downs Pastoral Station
- Marillana Pastoral Station
- Hillside Pastoral Station
- Roy Hill Pastoral Station
- Land Subject to Inundation
- Existing Mine
- Yandi Village
- Airport
- Railway
- Rail Siding
- Highway
- Major Road
- Minor Road

N

SCALE

0 5 10 15 20km

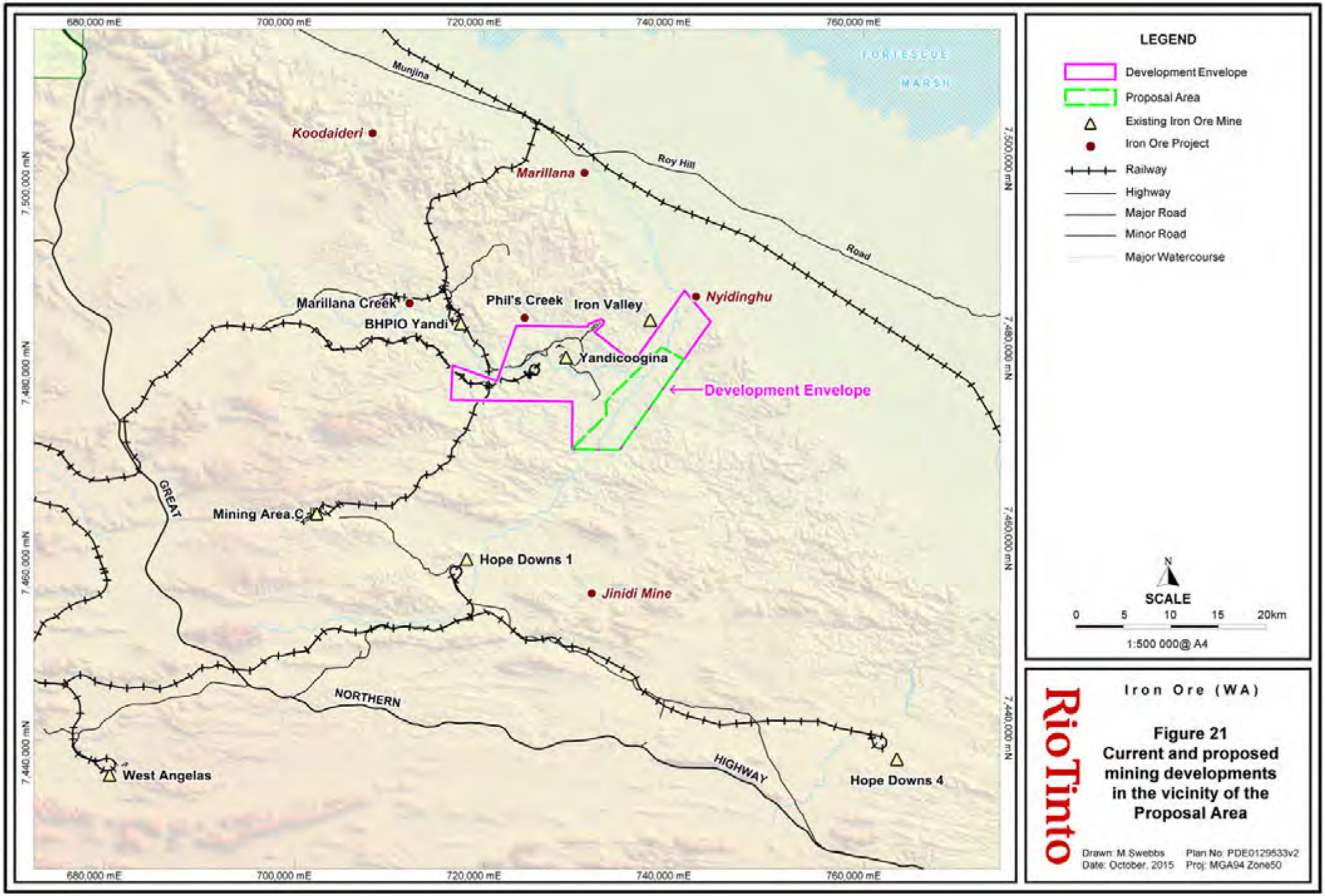
1:450 000@ A4

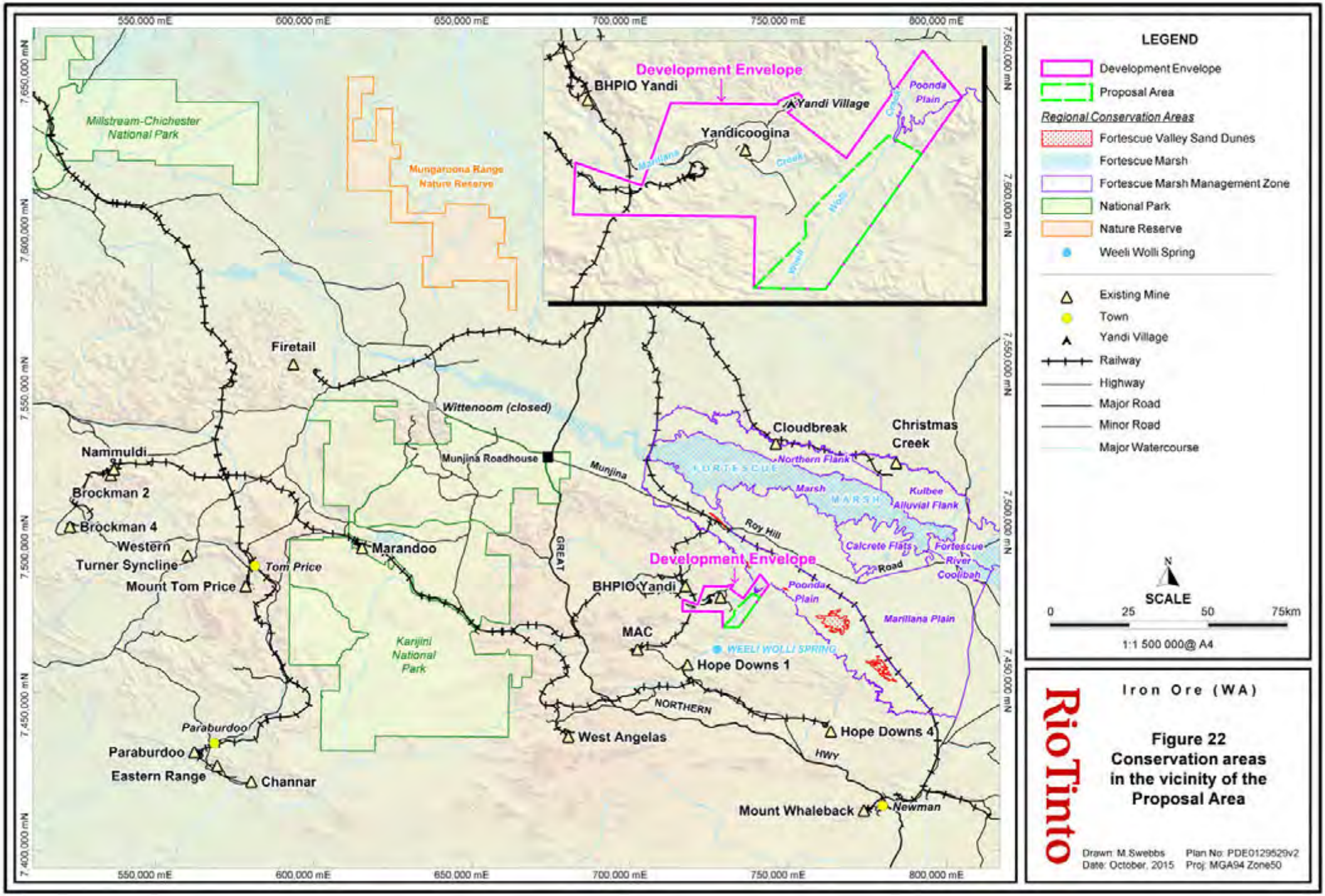
Iron Ore (WA)

Figure 20
Land use and tenure in the vicinity of Proposal Area

Drawn: M.Swebbs
Date: October, 2015

Plan No: PDE0129380v2
Proj: MGA94 Zone50


680,000 mE
700,000 mE
720,000 mE
740,000 mE
760,000 mE
7,500,000 mN
7,480,000 mN
7,460,000 mN
7,440,000 mN
FORTESCUE
MARSH
Munjina
Roy Hill
Road
Koodaideri
Marillana
Marillana Creek
Phil's Creek
Iron Valley
Nyidinghu
BHPIO Yandi
Yandicoogina
Development Envelope
GREAT
NORTHERN
HIGHWAY
Mining Area.C
Hope Downs 1
Jinidi Mine
West Angelas
Hope Downs 4
LEGEND
Development Envelope
Proposal Area
Existing Iron Ore Mine
Iron Ore Project
Railway
Highway
Major Road
Minor Road
Major Watercourse
N
SCALE
0 5 10 15 20km
1:500 000@ A4
RioTinto
Iron Ore (WA)
Figure 21
Current and proposed mining developments in the vicinity of the Proposal Area
Drawn: M.Swebbs
Date: October, 2015
Plan No: PDE0129533v2
Proj: MGA94 Zone50


550,000 mE
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800,000 mE
7,650,000 mN
7,600,000 mN
7,550,000 mN
7,500,000 mN
7,450,000 mN
7,400,000 mN
Development Envelope
BHPIO Yandi
Yandi Village
Yandicoogina
Poonda Plain
Marillana Creek
Weeli Wolli Creek
Millstream-Chichester National Park
Mungaroona Range Nature Reserve
Firetail
Wittenoom (closed)
Munjina Roadhouse
Munjina
Nammuldi
Brockman 2
Brockman 4
Western Turner Syncline
Mount Tom Price
Tom Price
Marandoo
GREAT
Karijini National Park
Paraburdoo
Paraburdoo
Eastern Range
Channar
West Angelas
Cloudbreak
Christmas Creek
Northern Flank
FORTESCUE MARSH
Marsh
Kulbee Alluvial Flank
Roy Hill
Calcrete Flats
Fortescue River
Coolibah
Road
Development Envelope
BHPIO Yandi
Poonda Plain
Marillana Plain
MAC
WEELI WOLLI SPRING
Hope Downs 1
NORTHERN
HWy
Hope Downs 4
Mount Whaleback
Newman
LEGEND
Development Envelope
Proposal Area
Regional Conservation Areas
Fortescue Valley Sand Dunes
Fortescue Marsh
Fortescue Marsh Management Zone
National Park
Nature Reserve
Weeli Wolli Spring
Existing Mine
Town
Yandi Village
Railway
Highway
Major Road
Minor Road
Major Watercourse
N
SCALE
0
25
50
75km
1:1 500 000@ A4
Iron Ore (WA)
Figure 22
Conservation areas in the vicinity of the Proposal Area
Drawn: M.Swebbs
Date: October, 2015
Plan No: PDE0129529v2
Proj: MGA94 Zone50

7.2 Aboriginal heritage, culture and Native Title

7.2.1 Native Title

There are more than 31 Aboriginal cultural groups (socio-linguistic groups) recognised in the Pilbara region (Pilbara Development Commission 2015). In the Shire of East Pilbara, over 16% of the population identify as Aboriginal (REMPLAN 2015).

Rio Tinto's Yandi Operations are covered by the YLUA, which has been in place since 1997 and was negotiated with Gumala Aboriginal Corporation, a representative body for the Traditional Owners of the Yandicoogina area.

At the time the YLUA was entered into, the Innawonga (now 'Yinhawangka'), Bunjima (now 'Banjima') and Niapaili (now 'Nyiyaparli') claimant application (NNTT number: WC 96/61, Federal Court number: WAD 6096/98; "IBN Claim") was registered over the Revised Proposal Development Envelope in its entirety.

Since 1998, native title claims for the area have undergone some significant changes, namely Yinhawangka and Banjima have separated out their claims and Martu Idja Banyjima and Bunjima are now native title holders as part of a single 'Banjima' language group. Both Nyiyaparli and Yinhawangka have separate Claim Wide Participation Agreements with Rio Tinto in their own right, however, the YLUA is not superseded by the existence of these newer commercial agreements.

Rio Tinto works with Gumala Aboriginal Corporation as the representative body for these claimant groups in relation to Hamersley Iron's Yandicoogina mining lease area (ML274SA). The Agreement provides financial and other benefits to the Aboriginal parties over the life of the mining operations for education, training, employment, business and community development.

7.2.2 Heritage sites

Archaeological and ethnographic heritage surveys have been completed across the Proposal footprint and for the majority of the Proposal Area. These surveys have documented artefact scatters, rock shelters and engravings (Rio Tinto 2014a). Extensive surveys have also been undertaken within the Revised Proposal Development Envelope; these surveys have identified numerous Aboriginal archaeological sites in addition to those listed above, including quarries, stone structures and scarred trees. These sites range from low to high archaeological and cultural significance. Possible burial sites (high significance) have also been identified within the area.

Weeli Wolli Creek and Marillana Creek have been identified as ethnographic sites. These creeks have important associations with camping, ceremonies and cultural activities.

Aboriginal heritage values in the Proposal Area are described further in Section 19.1.

Part 4 – Approach to Environmental Impact Assessment

Part 4 of the PER outlines the State and Commonwealth environmental assessment processes and the applicable legislative context. This part also describes the approach taken in considering the potential environmental impact of the Proposal and the environmental studies conducted to support the assessment of impacts.

8. Environmental assessment process

8.1 State environmental assessment process

The Proposal was referred to the WA EPA under Section 38 of the EP Act on 4 July 2014. The EPA determined that the Proposal required environmental assessment at the level of PER (with a six week public review period), whereby the Proponent must fulfil the requirements of the *Environmental Impact Assessment (Part IV Division 1) Administrative Procedures 2012* (EPA 2012b) for environmental assessment prescribed under the EP Act.

The EPA issued an Environmental Scoping Document (ESD; **Appendix 1**) for the Proposal on 31 December 2014. The ESD provides an outline of the key environmental factors, a description of the scope of the assessment of the Proposal and an indicative timeline for the assessment process.

The key aim of the PER is to present an assessment of impacts to environmental factors relevant to the Proposal in accordance with the ESD. The Environmental Impact Assessment uses various EPA guidance documents to determine the significance of the environmental effects of the Proposal (Section 8.2).

The EPA will need to confirm the PER document as suitable for a public review period on the basis that it adequately addresses the expectations of the EPA set out in the ESD. Following the public review period, the EPA will provide to the Proponent copies (and a summary) of all submissions received. The Proponent will respond to matters raised in the submissions to the satisfaction of the EPA.

The EPA will then assess the PER document, submissions received, the Proponent's response to submissions, and obtain advice from any other persons it considers appropriate before submitting its assessment report on the Proposal to the Minister for Environment.

The Minister will then publish the EPA report. Any person may lodge an appeal to the Minister for Environment against the content of, or recommendations in the EPA assessment report within 14 days of its publication. Subsequent to the determination of appeals (if any), the Minister then decides whether or not the Proposal should be implemented and if so, under what conditions.

The environmental assessment process for a PER is depicted diagrammatically in **Figure 23**.

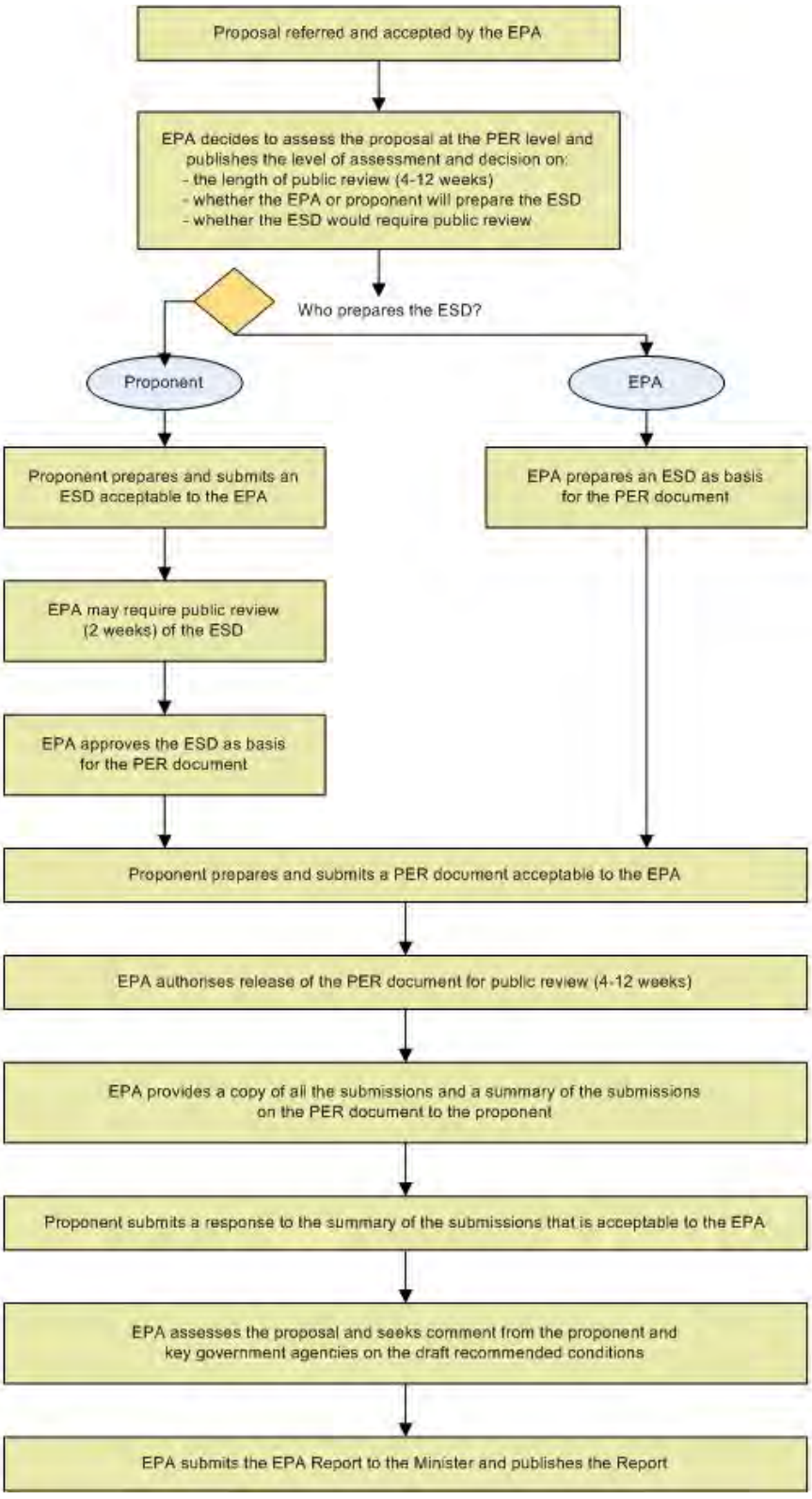


Figure 23: Public Environmental Review assessment process

8.2 State legislation, policy and guidance

The Proposal is subject to compliance with relevant state legislation and regulations and is guided by relevant key over-arching state policies and strategies. In addition, there are EPA Position Statements and Guidance Statements that have been used to determine the significance of the environmental effects of the Proposal. The relevant state legislation/regulations, policies, strategies, EPA Position Statements and Guidance Statements, and other guidance documents, are listed in Section 8.2.1 to Section 8.2.5.

8.2.1 State legislation and any subsidiary regulations

- *Aboriginal Heritage Act 1972*.
- *Biosecurity and Agricultural Management Act 2007.*
- *Bush Fires Act 1954.*
- *Contaminated Sites Act 2003.*
- *Country Areas Water Supply Act 1947.*
- *Dangerous Goods Safety Act 2004.*
- *Electricity Act 1945.*
- *Environmental Protection Act 1986.*
- *Health Act 1911.*
- *Heritage of Western Australia Act 1990.*
- *Iron Ore (Yandicoogina) Agreement Act 1996.*
- *Land Administration Act 1997.*
- *Local Government Act 1995.*
- *Main Roads Act 1930.*
- *Mines Safety and Inspection Act 1994.*
- *Mining Act 1978.*
- *Native Title (State Provisions) Act 1999.*
- *Occupational Health and Safety Act 1984.*
- *Poisons Act 1964.*
- *Public Works Act 1902.*
- *Rights in Water and Irrigation Act 1914.*
- *Soil and Land Conservation Act 1945.*
- *Waste Avoidance and Resource Recovery Act 2007.*
- *Waterways Conservation Act 1976.*
- *Wildlife Conservation Act 1950.*

8.2.2 State policies and strategies

- State Water Quality Management Strategy Document No. 6 – Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting (Government of Western Australia 2001).
- Hope for the Future: The Western Australian State Sustainability Strategy (Government of Western Australia 2003).
- Western Australian Greenhouse Strategy (Government of Western Australia 2004).
- Pilbara water in mining guideline (Government of Western Australia 2009).
- WA Environmental Offsets Policy (Government of Western Australia 2011).
- WA Environmental Offsets Guidelines (Government of Western Australia 2014).
- Western Australian Water in Mining Guideline (Government of Western Australia 2013a).

8.2.3 EPA Position Statements

- Environmental Protection Bulletin No. 1 – Environmental Offsets (EPA 2014a).
- Position Statement No. 2 – Environmental Protection of Native Vegetation in WA (EPA 2000).
- Position Statement No. 3 – Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002).
- Position Statement No. 7 – Principles of Environmental Protection (EPA 2004a).

8.2.4 EPA Guidance Statements

- No. 6 – Rehabilitation of Terrestrial Ecosystems (EPA 2006).
- No. 20 – Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in WA (EPA 2009a).
- No. 33 – Environmental Guidance for Planning and Development (EPA 2008).
- No. 41 – Assessment of Aboriginal Heritage (EPA 2004b).
- No. 51 – Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in WA (EPA 2004c).
- No. 54a – (Draft) Sampling Methods and Survey Considerations for Subterranean Fauna in WA (EPA 2007).
- No. 56 – Terrestrial Fauna Surveys for Environmental Impact Assessment in WA (EPA 2004d).

8.2.5 Other guidance documents

- Environmental Assessment Guideline (EAG) 8 – Environmental Factors and Objectives (EPA 2013a).
- Environmental Assessment Guideline (EAG) 12 – Consideration of subterranean fauna in Environmental Impact Assessment in Western Australia (EPA 2013b).
- Cumulative environmental impacts of development in the Pilbara region (EPA 2014b).

- Guidelines for Preparing Mine Closure Plans (DMP and EPA 2015).
- EPA and DEC Technical Guide - Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment (EPA and DEC 2010).
- DoW – Water Quality Protection Notes.

8.3 Commonwealth environmental assessment process

The Proposal was referred to the DoE under the requirements of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) on 26 September 2014. DoE determined that the Proposal is 'not a controlled action' on 25 October 2014, which means the Proposal does not require assessment and approval under the EPBC Act.

8.4 Principles of environmental protection

The Proponent acknowledges the environmental protection principles listed in Section 4a of the EP Act and presented in EPA Position Statement No. 7 (EPA 2004a). These environmental principles are:

- The precautionary principle.
- The principle of intergenerational equity.
- The principle of the conservation of biological diversity and ecological integrity.
- Principles relating to improved valuation, pricing and incentive mechanisms.
- The principle of waste minimisation.

Consideration has been given to these principles in the assessment of the potential environmental impacts associated with the Proposal. These principles are addressed in Part 7.

8.5 Principles of EIA

The *Environmental Impact Assessment (Part IV Division 1) Administrative Procedures 2012* (EPA 2012b) outlines the principles of Environmental Impact Assessment (EIA) for the Proponent, as follows:

1. Consult with all stakeholders, including the EPA, decision making authorities (DMAs), other relevant government agencies and the local community as early as possible in the planning of their proposal, during the environmental review and assessment of their proposal, and where necessary during the life of the project.

2. Ensure the public is provided with sufficient information relevant to the EIA of a proposal to be able to make informed comment, prior to the EPA completing the assessment report.

3. Use best practicable measures and genuine evaluation of options or alternatives in locating, planning and designing their proposal to mitigate detrimental environmental impacts and to facilitate positive environmental outcomes and a continuous improvement approach to environmental management.

4. Identify the environmental factors likely to be impacted and the aspects likely to cause impacts in the early stages of planning for their proposal. The onus is on the Proponent through the EIA process to demonstrate that the unavoidable impacts will meet the EPA objectives for environmental factors and therefore their proposal is environmentally acceptable.

5. Consider the following, during project planning and discussions with the EPA, regarding the form, content and timing of their environmental review:

(a) The activities, investigations (and consequent authorisations) required to undertake the environmental review.

(b) The efficacy of the investigations to produce sound scientific baseline data about the receiving environment.

(c) The documentation and reporting of investigations.

(d) The likely timeframes in which to complete the environmental review; and use best endeavours to meet assessment timelines.

6. Identify in their environmental review, subject to the EPA's guidance:

(a) Best practicable measures to avoid, where possible, and otherwise minimise, rectify, reduce, monitor and manage impacts on the environment.

(b) Responsible corporate environmental policies, strategies and management practices, which demonstrate how the proposal can be implemented to meet the EPA's environmental objectives for environmental factors.

The Proponent has considered these principles of EIA throughout the PER process for the Proposal.

9. Identification of key environmental factors

Scoping of relevant environmental factors was completed as part of the EPA process in preparing and finalising the ESD for the Proposal. The ESD was prepared with input from other WA DMAs and the Proponent (**Appendix 1**).

The EPA identified seven preliminary key environmental factors relevant to the Proposal that require detailed consideration by the Proponent. These preliminary key environmental factors are:

- flora and vegetation;
- terrestrial fauna;
- subterranean fauna;
- hydrological processes;
- inland waters environmental quality;
- rehabilitation and closure (integrating factor); and
- offsets (integrating factor).

Table 2 of the ESD sets out for each preliminary environmental factor:

- the EPA objective;
- the relevant aspects;
- the identified potential impacts;
- the work required to be undertaken; and
- the relevant policy/guidance documents.

The EPA identified other environmental factors that it considers relevant to the Proposal; air quality, amenity and (indigenous) heritage. These other environmental factors also warrant attention as part of the environmental review of the Proposal to the extent that the PER must demonstrate how these factors will be mitigated and the extent to which other statutory decision making processes can regulate the potential effects to meet EPA objectives and principles of Environmental Impact Assessment.

A compliance table has been developed (**Appendix 2**) showing where the ESD listed work requirements for each of the preliminary key environmental factor (and the other environmental factors) have been addressed or presented in the PER.

10. Cumulative impact assessment approach

10.1 Cumulative impact assessment overview

Cumulative impact assessment (CIA) is the process of assessing the impacts from all relevant historical, current and reasonably foreseeable future activities that may affect one or more specific components of the environment. This is in contrast to conventional 'project specific' EIA, which typically focuses on the impacts caused by a single development within a limited temporal or spatial boundary. CIA provides a spatial and temporal extension to conventional EIA and considers both direct and indirect impacts that may combine over time and/or space. Assessment of cumulative impacts can provide a means to identify potentially significant effects that may not be evident in conventional EIA, such as the potential for multiple mining projects to incrementally affect environmental values.

In its advice to the Minister for Environment under Section 16(e) of the EP Act (EPA 2014b), the EPA expressed concerns about cumulative environmental impacts to key environmental values in the Pilbara region, due to current and future mining developments in the region, combined with threatening processes of other land uses such as pastoralism and tourism. Consequently, CIA is an important consideration for Pilbara mining developments. The EPA identified cumulative impacts as a key issue for the Proposal in the ESD and specified the following required work:

- Flora and vegetation: "Provide a detailed description of the cumulative impacts associated with the proposal, including direct impacts from clearing, and indirect impacts such as groundwater drawdown, surface discharge of excess groundwater, altered drainage, changes in water quality, dust emissions and fragmentation of vegetation".
- Flora and vegetation: "Discuss potential direct and indirect (including downstream) and cumulative impacts to flora and vegetation as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance".
- Terrestrial fauna: "Discuss potential direct/indirect (including downstream) and cumulative impacts to fauna as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance".
- Hydrological processes: "Investigate groundwater drawdown due to groundwater abstraction associated with the proposal. Analyse and discuss any impacts to groundwater levels and flows taking into consideration the cumulative impacts with other proposals. Analyse, discuss and assess surface water and groundwater impacts, including changes in groundwater levels and changes to surface water flows associated with the proposal together with cumulative impacts with other projects and referred proposals (including the BHP strategic proposal) for which relevant information is publicly available".
- Inland waters environmental quality: "Model cumulative impacts with other mines in the catchment (currently operating and referred proposed mines, including the BHP strategic proposal, where information is publicly available). Develop strategies and controls to minimise the impacts".

The scope of the CIA conducted for the Proposal was defined with regard to the spatial boundary (Section 10.2), the key environmental receptors considered for each preliminary key environmental factor (Section 10.3) and the mining projects and referred proposals considered (Section 10.4). The outcomes of the CIA are provided in *Part 5 – Assessment of Environmental Values* of this document for each of the individual factors and is also summarised in *Part 6 – Summary of cumulative impacts*.

10.2 Spatial boundary

When approaching a CIA, decisions are required to be made regarding the spatial boundary; it is seldom practical or appropriate to include everything in the assessment. A balance needs to be found between the practical constraints (e.g. publically available data) and the rigour of the analysis. Including too little will lead to insufficient insight in the analysis, while including too much has the potential to overwhelm and obscure insight into meaningful trends.

The spatial boundary defined for the Proposal CIA was the Upper Fortescue River Catchment, which is approximately 30,000 km^2 (EPA 2013c), surrounds the Fortescue Marsh area and extends to the south of the Great Northern Highway (**Figure 24**). The proposed disturbance footprint of the Proposal is wholly contained within this catchment.

The Upper Fortescue River Catchment was regarded as the largest extent of potential cumulative impacts from the Proposal. For some receptors (Section 10.3), a smaller boundary within the Upper Fortescue River Catchment was defined where appropriate; for example, where the receptor was spatially restricted and/or not expected to be significantly affected by projects or referred proposals outside this boundary, for which or where available information (e.g. mapping) was restricted.

The distribution of some of the key environmental receptors considered extends beyond the spatial boundary used for the Proposal CIA. This assessment may therefore overstate the potential impacts to these receptors. The results of the assessment should be considered in the context of the spatial boundary used and are not necessarily applicable to the full extent or distribution of the receptor, where it extends beyond the catchment in question.

10.3 Key environmental receptors

Unlike conventional EIA, in which a single project is typically the focus of the assessment, CIA requires the identification of environmental receptors that provide the investigative focal point for the assessment (Hegmann et al. 1999). Environmental receptors tend to be at the end of ecological pathways and are therefore the ultimate recipients of impacts; they integrate the cumulative effects of different pressures and activities (IFC 2013).

Key environmental receptors relevant to the Proposal CIA were identified from the requirements of the ESD and findings of ecological surveys undertaken in the Proposal Area. They are outlined in Sections 10.3.1 for flora and vegetation receptors, Section 10.3.2 for terrestrial fauna receptors, and Section 10.3.3 for receptors related to hydrological processes and inland waters environmental quality.

10.3.1 Flora and vegetation

Flora and vegetation receptors considered for assessment in the Proposal CIA were those that have been recorded, or are considered likely to occur, in the proposed disturbance footprint of the Proposal and that meet one of the following criteria:

- Threatened flora species – species listed as Specially Protected under the WC Act and published under Schedule 1 of the Wildlife Conservation (Rare Flora) Notice and/or listed as Critically Endangered, Endangered or Vulnerable under the EPBC Act.
- Threatened Ecological Communities (TECs) – communities endorsed by the Western Australian Minister for Environment as Presumed Destroyed, Critically Endangered, Endangered or Vulnerable and/or listed as Critically Endangered, Endangered or Vulnerable under the EPBC Act.
- Any other flora species or vegetation community identified in the Proposal ESD and/or from findings of ecological surveys undertaken in the Revised Proposal Development Envelope as being of confirmed or potential elevated significance at the local level.

Flora and vegetation receptors that met one of the aforementioned criteria and were therefore included in the Proposal CIA were:

- Riparian vegetation along Weeli Wolli and Marillana Creeks, characterised by the presence of the tree species *Eucalyptus camaldulensis* (River Red Gum) and/or *E. victrix* (Coolibah) and/or *Melaleuca argentea* (Cadjeput). In the Revised Proposal Development Envelope, Biota (2014a, 2015a) mapped riparian vegetation as vegetation types C1, C2, C3, C4 and C5. These communities have been further refined by the Proponent (Rio Tinto 2015a) into 13 riparian sub-associations.

Lepidium catapycnon (Vulnerable, WC Act and EPBC Act) has been recorded in the Revised Proposal Development Envelope (Biota 2014a), including in the Proposal Area; however, this species has been avoided and does not occur within the proposed disturbance footprint of the Proposal. All known and recorded populations are avoided and therefore this species was not included in the CIA.

10.3.2 Terrestrial fauna

Terrestrial fauna receptors considered for assessment in the Proposal CIA were those that have been recorded, or are considered likely to occur, in the proposed disturbance footprint of the Proposal and that meet one of the following criteria:

- Threatened fauna species – species listed as Specially Protected under the WC Act and published under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice and/or listed as Critically Endangered, Endangered or Vulnerable under the EPBC Act.
- Migratory birds – species listed as Specially Protected under the WC Act and published under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice, and/or listed as Migratory under the EPBC Act.
- Other Specially Protected fauna species – species declared to be in need of special protection other than for the reasons for Schedules 1 (Threatened), 2 (Presumed Extinct), or 3 (Migratory) and listed as Specially Protected under the WC Act and published under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

- Any other fauna species identified in the Proposal ESD and/or from findings of ecological surveys undertaken in the Revised Proposal Development Envelope as being of confirmed or potential elevated significance at the local level.

Terrestrial fauna receptors that met one of the aforementioned criteria and were therefore included in the Proposal CIA were:

- Pilbara Olive Python – listed as Vulnerable under the WC Act and EPBC Act. This species has been recorded in the Proposal Area (Biota 2015b) and may utilise habitats in the proposed disturbance footprint of the Proposal.
- Chocolate Wattled Bat – not listed under the WC Act or EPBC Act, but locally restricted within the Pilbara region, being recorded only in Marillana and Weeli Wolli Creeks. This species has been recorded in the Proposal Area (Biota 2015b) and may utilise habitats in the proposed disturbance footprint of the Proposal.
- Potential SRE invertebrate fauna recorded from the Proposal Area, comprising four mygalomorph spiders: Idiopidae sp. I1, Idiopidae sp. I9, Nemesiidae sp. N42 and Nemesiidae sp. N44.

The following terrestrial fauna receptors met one of the criteria for consideration in the Proposal CIA, but were excluded from the CIA:

- Pilbara Leaf-nosed Bat – listed as Vulnerable under the WC Act and EPBC Act. Weeli Wolli Creek is considered to be potential foraging habitat for the Pilbara Leaf-nosed Bat and the species is considered likely to occur in the Proposal Area; however, the species has not been recorded in the Revised Proposal Development Envelope (Biota 2014c). There was no evidence of roost caves suitable for the species despite extensive searches along the ridgelines of the Proposal Area. Consequently, while the Proposal Area as a whole could be considered dispersal habitat for the species, it was not considered core habitat as there was no evidence that a roost occurs within 15 km (the maximum foraging distance of individuals; Biota 2013).
- Peregrine Falcon – listed under Schedule 4 of the WC Act. One individual of this species has been recorded from the Robe land system in the Yandicoogina Junction Central Project area; however, it was considered likely to be a transitory or foraging individual (Biota 2015b). The species has not been recorded in the Proposal Area (Biota 2015b).
- Rainbow Bee-eater – listed under Schedule 3 of the WC Act and as Migratory under the EPBC Act. This species has been recorded in the Revised Proposal Development Envelope. The Rainbow Bee-eater is widespread throughout much of Australia and typically occurs in open country in most vegetation and landform types; however, the habitats in the Revised Proposal Development Envelope are not considered core habitat for this species (Biota 2015b).
- Fork-tailed Swift – listed under Schedule 3 of the WC Act and as Migratory under the EPBC Act. This species has been recorded in the Revised Proposal Development Envelope. The Fork-tailed Swift would not rely on any terrestrial habitats in the Revised Proposal Development Envelope since it is an aerial species and the habitats in this area are not considered core habitat for this species (Biota 2015b).
- Eastern Great Egret – listed under Schedule 3 of the WC Act and as Migratory under the EPBC Act. One individual Eastern Great Egret was observed flying

over Weeli Wolli Creek; however, this species is considered either uncommon or not a regular visitor in the Revised Proposal Development Envelope (Biota 2015b).

- Common Greenshank – listed under Schedule 3 of the WC Act and as Migratory under the EPBC Act. This species has been recorded previously within 10 km of the Revised Proposal Development Envelope and may be present on occasion in drainage line habitats with water in this area (Biota 2015b). This species is not considered to be a regular visitor.

10.3.3 Hydrological processes and inland waters environmental quality

The key hydrological receptors near the Proposal are Marillana Creek, Weeli Wolli Creek and Fortescue Marsh. Of these, an assessment of potential cumulative impacts has been conducted for Marillana and Weeli Wolli Creeks (Section 13.4). Fortescue Marsh will not be affected by the Proposal and therefore has been excluded from the CIA. The wetting front of surplus water discharge from the Proposal is expected to be contained within the current MS 914 limit of 17 km downstream of the confluence of Marillana and Weeli Wolli Creeks. Therefore, there is no additional impact proposed as a result of the Proposal.

10.4 Mining projects considered

At the scoping stage of a CIA, current and future actions with potential cumulative impacts need to be identified. Firm boundaries need to be drawn around the extent of future actions to be included. Best practice is to include actions determined to be certain and those actions that are reasonably foreseeable (and can be reasonably considered to contribute to significant cumulative impacts). Deciding how long into the past and the future (temporal boundaries) to examine and assess impacts is also a critical part of the scoping phase. It is rarely practical for the temporal boundaries to extend back in time to a pre-impact condition or to a time into the future when, for example, a sensitive receptor has recovered. In practice, CIA's typically commence with current conditions and extend to a point in time when there is meaningful certainty in the key inputs such as future activities.

Publically available information was reviewed to determine existing and reasonably foreseeable future mining projects located within each spatial boundary defined for this CIA. From this review:

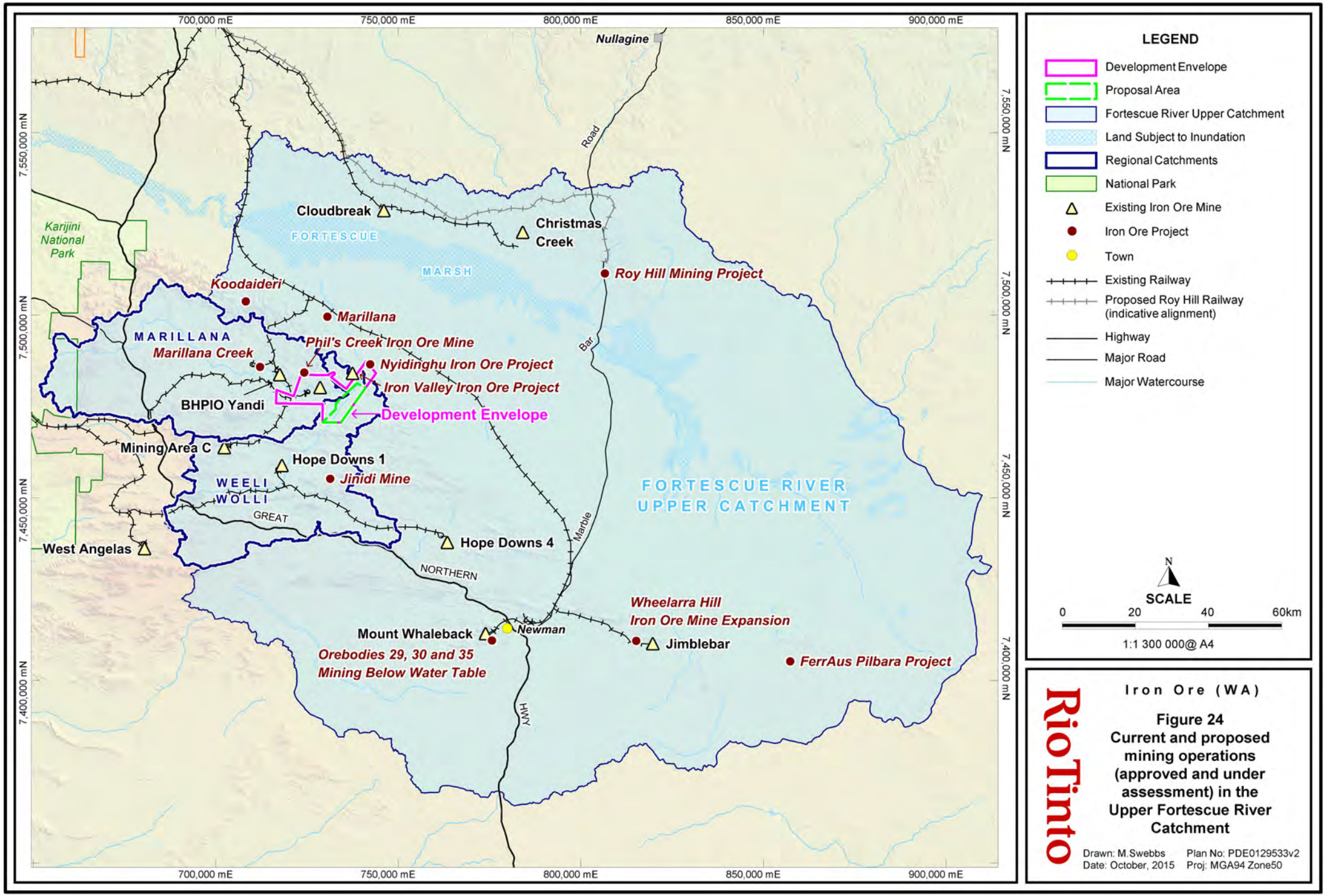
- 23 existing mining projects were identified within the Upper Fortescue River Catchment. These mining projects were operational and/or approved under the EP Act at the time of writing. Of the 23 identified projects, five were excluded as they are a significant distance from the Proposal Area and/or from key environmental receptors within the catchment, such as Fortescue Marsh. These were Atlas Iron's FerrAus Pilbara Project and BHP's Jimblebar, Mt Whaleback, Orebodies 29, 30 and 35, and Wheelarra Hill Expansion projects. Five of the remaining 18 projects were also located within the Weeli Wolli Creek regional catchment (**Table 9**; **Figure 24**).
- Two reasonably foreseeable future projects were identified within the Upper Fortescue River Catchment (excluding Proposal). Of these, none were located within the Weeli Wolli Creek regional catchment (**Table 9**; **Figure 24**). These mining projects had been referred under the EP Act at the time of writing. The BHP Strategic Assessment was also identified and is specifically referred to in the

ESD for the Proposal; however, at the time of writing, only the scoping document was publically available and information on potential impacts of the BHP Strategic Assessment was not included (or publically available). The BHP Strategic Assessment was therefore excluded from the Proposal CIA. The Proposal (this assessment) is also included as a reasonably foreseeable future project in **Table 9** and shown in **Figure 24**.

Table 9: Existing and reasonably foreseeable future mining projects considered for inclusion in the Proposal cumulative impact assessment

Project	EP Act Assessment No.	EPBC Act Ref.	Proponent/ Operator
Existing projects – included in CIA			
Christmas Creek Mine - Water Management Scheme	1873	2010/5706	FMG
Cloudbreak Iron Ore Mine	1577	2005/2205	FMG
Cloudbreak Life of Mine	1848	2010/5696	FMG
Hope Downs 1 Iron Ore Mine Expansion	1308	-	Hamersley HMS (Rio Tinto managed)
Hope Downs 4 Iron Ore Mine	1738	2008/4636	Hamersley HMS (Rio Tinto managed)
IO Direct Shipping Iron Ore Project	Not Assessed - Public Advice Given	N/A	FMG
Iron Valley Iron Ore Project	1905	2012/6458	Iron Ore Holdings
Jinidi Iron Ore Mine	1904	2012/6299	BHP
Koodaideri Iron Ore Mine	1933	2012/6422	Mount Bruce Mining (Rio Tinto managed)
Marillana Creek (Yandi)	1555	-	BHP
Marillana Iron Ore Project	1781	2011/5892	Brockman
Mining Area C	1108	-	BHP
Phil's Creek Iron Ore Mine	Not Assessed – Managed Under Part V of EP Act	2009/5107	Mineral Resources
Pilbara Iron Ore and Infrastructure Project - Railway Stage A	1505	-	FMG
Pilbara Iron Ore and Infrastructure Project - Railway Stage B	1520	2004/1897	FMG
Roy Hill 1 Iron Ore Mining Project Stage 1	1589	2008/4624	Roy Hill
Roy Hill 1 Iron Ore Mining Project Stage 2	1822	2008/4624	Roy Hill

Project	EP Act Assessment No.	EPBC Act Ref.	Proponent/ Operator
Rio Tinto Yandi Operations	809, 946, 1590 & 1726	2011/5815	Hamersley Iron – Yandi (Rio Tinto managed)
Existing projects – excluded from CIA due to distance			
FerrAus Pilbara Project	1908	2011/6036	Atlas Iron
Jimblebar Iron Ore Project	1847	-	BHP
Mt Whaleback	N/A	N/A	BHP
Orebodies 29, 30 and 35 Mining Below Water Table	1982	-	BHP
Wheelarra Hill Iron Ore Mine Expansion	1558	-	BHP
Future projects			
Proposal (this assessment)	2017	2014-7343	Hamersley Iron – Yandi (Rio Tinto managed)
Christmas Creek Expansion Project (under assessment)	1989	2013/7055	FMG
Nyidinghu Iron Ore Project (under assessment)	1068	2013/6945	FMG



RioTinto

Iron Ore (WA)

Figure 24
Current and proposed mining operations (approved and under assessment) in the Upper Fortescue River Catchment

Drawn: M.Swebbs
Date: October, 2015
Plan No: PDE0129533v2
Proj: MGA94 Zone50

11. Environmental studies

The Proponent conducted a number of environmental studies as part of the Environmental Impact Assessment (EIA) process for the Proposal. Previous studies have also been undertaken as part of the approvals process for the original Yandicoogina mine (JC) and the previous Yandicoogina mine developments (Yandi JC Expansion, JSE, JSW and Oxbow Deposits), some of which overlap the Proposal Area. The requirement and scope of the environmental studies was defined through the preliminary risk assessment, sustainable development assessment, stakeholder consultation and scoping of the Proposal as part of the ESD. The studies provided the basis for assessing the significance of the potential environmental impacts for each key environmental factor identified in the ESD. Where applicable, the studies were undertaken using commonly accepted methodologies and in accordance with relevant EPA Guidance Statements.

Key reports generated by these studies are listed in **Table 10** (many are also attached in **Appendix 3**). All environmental studies applicable to the Proposal, as well as other supporting studies and documentation, are referenced as appropriate throughout the PER. A number of the studies form part of an ongoing monitoring and survey effort to establish a baseline for ongoing environmental management.

Table 10: Studies and investigations supporting the PER

Environmental factor	Studies, investigations and/or reports
Hydrological Processes and Inland Waters Environmental Quality	• Environmental risk assessment for riparian zones on Weeli Wolli Creek (URS 2015; **Appendix 3**). • Revised discharge extent modelling in Weeli Wolli Creek based on measured channel loss rates (Rio Tinto 2014c; **Appendix 3**). • Peer review of surface water modelling (WorleyParsons 2015; **Appendix 3**). • Groundwater model setup, calibration and estimation of dewatering requirements (Rio Tinto 2014d; **Appendix 3**). • Peer review of groundwater modelling (Hydrogeologic 2015; **Appendix 3**). • Geomorphological assessment of Weeli Wolli Creek (MWH 2015; **Appendix 3**). • Weeli Wolli Creek Ecohydrology (Rio Tinto 2015b; **Appendix 3**). • Hydrogeology and groundwater dynamics of Weeli Wolli and Marillana Creeks and Fortescue Marsh (Fellman et al. 2011; Dogramaci et al. 2012; Dogramaci and Skrzypek 2015; Dogramaci et al. 2015; Burke et al. 2014a; Burke et al. 2014b; Burke et al. 2015; Skrzypek et al. 2013; Skrzypek et al. 2015 Roullard et al. 2015).
Flora and Vegetation	• March 2014 and July 2014 flora and vegetation survey of Yandi Pocket and Billiards South Deposits Phase 1 and 2 (Biota 2014a; **Appendix 3**). • Riparian vegetation of Marillana and Weeli Wolli Creeks: Mapping refinement and assessment of values and significance (Rio Tinto 2015a; **Appendix 3**). • Yandi Vegetation and Flora Integration Report (Biota 2015a; **Appendix 3**). • Environmental risk assessment for riparian zones on Weeli Wolli Creek (URS 2015; **Appendix 3**). • Understanding riparian vegetation responses to groundwater drawdown and discharge from below water table mining in the Pilbara (Eastham

Environmental factor	Studies, investigations and/or reports
	2015; **Appendix 3**).
Terrestrial Fauna	• October 2009 Targeted Northern Quoll survey at Yandi (Biota 2009). • July 2008 and March 2010 fauna surveys of the Yandi Expansion Billiard Deposit (Biota 2011; **Appendix 3**). • March 2014 and September 2014 fauna surveys of Pocket and Billiards South Deposits – Phase 1 and 2 (Biota 2014c, 2014e; **Appendix 3**). • August 2014 Targeted Northern Quoll survey at Yandi Billiards Deposit (Biota 2014d; **Appendix 3**). • October 2013 and April 2014 aquatic fauna surveys at Marillana & lower Weeli Wolli Creeks (WRM 2015a, 2015b; **Appendix 3**). • Yandi Terrestrial Fauna Integration Report (Biota 2015b; **Appendix 3**).
Subterranean Fauna	• Stygofauna sampling was conducted in 2003, 2005 and between 2008 and 2014 (Biota 2015c; **Appendix 3**). • Troglofauna phase 1 sampling was conducted in 2009. Phase 2 sampling was completed between 17th May and 10th July 2014 (Biota 2015d; **Appendix 3**).
Rehabilitation and Mine Closure	• Yandicoogina Closure Plan (Rio Tinto 2015c; **Appendix 4**). • Yandicoogina Billiard acid and metalliferous drainage risk (Rio Tinto 2014e; **Appendix 3**). • Water balance modelling for pit lakes (RPS 2015; **Appendix 3**).
Offsets	• Refer to Section 18.
Aboriginal Heritage	• Refer to Section 19.1.
Air Quality	• Refer to Section 19.2.
Amenity	• Refer to Section 19.3.

12. Environmental management system

Environmental management controls to be implemented as part of the Proposal, consistent with the information presented in this PER, are described in the Proponent's Environmental Management System (EMS), together with the Yandi Operations site specific management plans.

All Rio Tinto businesses, their managed sites and functional locations (including its Pilbara iron ore operations) must implement, or demonstrate conformance to an EMS, which is an integrated health, safety, environment and quality management system and outlines environmental standards that must be adhered to.

The Rio Tinto environment standards have been in place for over ten years, and have supported its operational environmental performance over this period. The current standards have been developed to provide consistency across all of Rio Tinto managed operations and to support the Group's approach to avoid and minimise impacts to the environment. The EMS covers key environmental risk areas and provides detail for their application to operational sites. The process includes internal site and Rio Tinto Corporate audits to ensure conformance with the five environment standards and one management system standard as outlined below.

12.1 Health, Safety, Environment and Quality (HSEQ) Management System Standard

The HSEQ Management System Standard details the requirements for Rio Tinto Group businesses to implement an integrated system for the management of health, safety, environment, communities and social performance and quality. Statutory and permitting requirements take precedence over Rio Tinto standards, except where the Rio Tinto standards are more stringent.

The standard comprises 17 key elements including:

- HSECQ policy;
- legal requirements;
- hazard identification and risk management;
- management improvement planning;
- organisational resources, accountabilities and responsibilities;
- training, competency and awareness;
- supplier and contractor management;
- documentation and document control;
- communication and consultation;
- operational control;
- management of change;
- business resilience and recovery;
- monitoring and measuring;
- incident and action management;

- data and records management;
- performance assessment and auditing; and
- management review.

12.2 Environmental standards

Rio Tinto has five environment standards:

- E11 Water Quality Protection and Water Management.
- E12 Air Quality Protection.
- E13 Chemically Reactive Mineral Waste Control.
- E14 Land Disturbance Control and Rehabilitation.
- E15 Hazardous Materials and Non-Mineral Water Control and Minimisation.

12.2.1 E11 Water Quality Protection and Water Management

The E11 Water Quality Protection and Water Management Standard addresses all activities associated with water withdrawal, use, storage, treatment, and discharge. It is applicable to any impacts or risks associated with water abstraction and discharge, including changes in water level, flow and quality. The E11 Standard outlines performance requirements to mitigate water related impacts, control water quality, optimise water use efficiency and adequately design and operate water related infrastructure to manage predicted variability and control risks.

12.2.2 E12 Air Quality Protection

The E12 Air Quality Protection Standard addresses air emissions from all sources including point sources and diffuse sources. The E12 Standard outlines performance requirements to monitor and manage emissions to prevent harm from air impacts, quantify the constraints that cumulative air impacts may pose, and prevent breaches of applicable criteria.

12.2.3 E13 Chemically Reactive Mineral Waste Control

The E13 Chemically Reactive Mineral Waste Control Standard addresses all mineral wastes including waste rock and overburden, tailings, rejects and other mineral processing residues. It covers all potential and actual releases from reactive mineral waste including primary waste material (erosion, fugitive dust) and reaction by-products (eg. acid mine drainage). The E13 Standard outlines performance requirements to monitor and manage chemically reactive mineral waste so contaminant release does not cause harm, and avoids riverine impacts.

12.2.4 E14 Land Disturbance Control and Rehabilitation

The E14 Land Disturbance Control and Rehabilitation Standard addresses all land owned, leased or managed by the business or for which the business may have liability. It includes both land directly disturbed by activities, as well as undisturbed land held as a buffer or for other reasons. The E14 Standard outlines performance requirements to confine disturbance within legally designated areas, locate and design facilities to limit new disturbance footprints, design and construct mineral waste facilities in a manner that facilitates successful rehabilitation, rehabilitate consistent with planned final land use, undertake rehabilitation as soon as practicable on land that is no longer needed, and define impact acceptance criteria for land, biodiversity and ecosystem services.

12.2.5 E15 Hazardous Materials and Non-Mineral Waste Control and Minimisation

The E15 Hazardous Materials and Non-Mineral Waste Control and Minimisation Standard addresses the import, storage, use and ultimate disposal of hydrocarbons, reagents, process fluids, non-mineral wastes and other materials which could pose environmental risks because of their physical and chemical properties. The E15 Standard outlines performance requirements to prevent contamination of surface water, groundwater and soil from hazardous materials and non-mineral wastes, minimise impacts of non-mineral waste disposal, and remediate or manage for the long term contaminated sites where investigation has demonstrated an unacceptable impact or risk.

12.3 Yandicoogina Environmental Management

The existing Yandi Operations environmental management utilises the Rio Tinto EMS, together with site specific management plans and procedures for environmental aspects that are potentially impacted by the Yandi Operations.

The existing Yandi Operations environmental management is currently managed via:

- Management plans and commitments required by MS 914 or EPBC Decision 2011/5815 requiring endorsement from either a State or Commonwealth government department:
  - Yandicoogina Monitoring and Management Plan (MMP; **Appendix 4**) which includes:
    - Yandicoogina Vegetation and Groundwater Dependant Ecosystems Monitoring and Management Plan
    - Yandicoogina Surface Water Discharge Monitoring and Management Plan
  - Yandicoogina Closure Plan (**Appendix 4)**; and
  - EPBC Threatened Species Offset Plan.
- Management plans and commitments that support implementation of MS 914 or EPBC Decision 2011/5815 that do not require endorsement from either a State or Commonwealth government department:
  - Yandicoogina Weed Action Plan;
  - Yandicoogina Weed Monitoring Plan; and
  - Yandicoogina addendum to the Proponent's Pilbara-wide Significant Species Management Plan (SSMP; **Appendix 4**).
- Site related management and monitoring actions required to comply with Rio Tinto HSECQ Performance Standards (outlined above).

The existing MMP has been reviewed and updated to apply to the Proposal.

12.3.1 Yandicoogina MMP

The Yandicoogina MMP specifically addresses the requirements of Conditions 6 and 7 of MS 914, including the development of an Environmental Values Statement (EVS) and a comprehensive monitoring program for surface water and groundwater dependent ecosystems with associated management strategies.

The key environmental objectives of the plan are to ensure that ensure that dewatering activities required to implement the Yandi Project, and any contingency measures implemented, will not result in long term impacts to the environmental values identified.

The EVS of the Weeli Wolli Creek system was updated in the revision of the MMP and is outlined in Section 6.1.

The MMP includes monitoring the health parameters of riparian vegetation including Digital Canopy Photography (DCP), vegetation condition transects, and spectral imagery. Water quality parameters include monitoring the discharge wetting footprint, ground water levels, surface water quality, and erosion and sediment assessments.

12.3.2 Significant Species Management Plan

The Rio Tinto SSMP applies across all Pilbara based projects. The SSMP addresses Matters of National Environmental Significance (MNES) relevant to the Pilbara, outlining management measures to be applied across all Pilbara based operations and projects to avoid or reduce impacts to these MNES. The SSMP provides the framework for Rio Tinto to minimise impacts to Pilbara populations of significant species from activities associated with its operations. The scope of the SSMP includes extensions to existing operations and new mining and infrastructure projects. The SSMP outlines over-arching management measures to be implemented to avoid and minimise impacts to MNES across all projects.

Additionally, for each Pilbara based project or operation, a site specific addendum to the SSMP has been prepared, detailing management measures for MNES relevant to the project. The Yandicoogina SSMP addendum is included with the Pilbara-wide SSMP (**Appendix 2**). The Yandicoogina SSMP addendum addresses management measures relevant to EPBC Act listed threatened species occurring, or potentially occurring, within the Revised Proposal Development Envelope including the Northern Quoll, Pilbara Olive Python, Pilbara Leaf-nosed Bat and *Lepidium catapycnon*. The Yandicoogina SSMP addendum outlines key management actions and accountabilities for clearing and direct disturbance, indirect disturbance and other operational issues and outlines surveys/monitoring requirements.

12.3.3 Yandicoogina Closure Plan

The Yandicoogina Closure Plan (**Appendix 4**) has been prepared to meet MS 914 Condition 9-4 ('…review and revise the Yandicoogina Decommissioning and Rehabilitation Plan…'). It addresses the closure of several mining areas associated with the Revised Proposal, including future development areas such as the Proposal. This Plan documents the current closure knowledge base for Yandicoogina. It outlines the objectives that need to be met at closure, the strategies and plans to be employed to achieve them, and provides an indication of the criteria that will be used to assess closure success. It has been developed in consultation with key stakeholders and will be regularly reviewed and revised throughout the life of the Revised Proposal to incorporate new information. The Yandicoogina Closure Plan has been prepared in accordance with the DMP and EPA (2015) Guidelines for Preparing Mine Closure Plans, as well as Rio Tinto's Closure Standard.

Part 5 – Assessment of environmental factors

This part assesses the potential environmental impacts of the Proposal on each identified preliminary key environmental factor (and other environmental factors). Proposed management measures and predicted outcomes are also presented.

13. Hydrological processes and inland waters environmental quality

13.1 Key statutory requirements, environmental policy and guidance

13.1.1 EPA objective

The EPA has applied the following objectives for the Proposal to its assessment of hydrological processes and inland waters environmental quality:

"To maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance, are protected.

To maintain the quality of groundwater and surface water, sediment and/or biota so that the environmental values, both ecological and social, are protected."

13.1.2 Regulatory framework

The following legislation is relevant to the Proposal Area with respect to the protection of surface water and groundwater and the above EPA objective:

- *Rights in Water and Irrigation Act 1914* (WA).
- *Environmental Protection Act 1986* (WA).

13.1.3 Relevant guidelines and policy

A number of State and Commonwealth policies are relevant to the protection of surface water and groundwater:

- Australian Water Quality Guidelines for Fresh and Marine Waters. (Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ) 2000).
- State Water Quality Management Strategy Document No.6. Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting (Government of Western Australia 2001).
- Pilbara Water in Mining Guideline. Report No 34 (Government of Western Australia 2009).
- Western Australian Water in Mining Guideline. Report No 12 (Government of Western Australia 2013a).
- Statewide Policy No 5 - Environmental water provisions policy for Western Australia (WRC 2000).

- DoW Water Quality Protection Guidelines No. 1 to 11 and Water Quality Protection Note 22 (DoW 2008).
- Strategic policy 2.09: Use of mine dewatering surplus (DoW 2013).
- Environmental and water assessments relating to mining and mining related activities in the Fortescue Marsh management area (EPA 2013c).

13.2 Description of factor

Existing approved mining operations within the Weeli Wolli Creek catchment, including BHP's Marillana Creek (Yandi) and Mining Area C mine, Rio Tinto's Yandi Operations and Hamersley HMS's Hope Downs 1 Joint Venture undertake dewatering as well as discharge activities as part of their mining operations and have contributed to changes to the natural hydrological conditions of Marillana and Weeli Wolli Creeks since the mid 1990's and mid 2000's respectively. The BHP and Rio Tinto mining operations that occur within the CID (Rio Tinto's Yandi Operations, BHP's Marillana Creek [Yandi]), are within the same hydrological and hydrogeological setting as the Proposal, with the dewatering and discharge activities undertaken to manage the productive aquifers of the CID, in which the target mineralisation occurs. The aquifers associated with BHP's Mining Area C and Hamersley HMS's Hope Downs 1 operations occur in bedded ore deposits and dolomites with more alkaline groundwater conditions and are subject to different hydrological surface water-groundwater interactions.

The following sections provide a description of the pre-mining and modified hydrological and hydrogeological setting (Sections 13.2.1 to 13.2.3), identify the likely potential impacts of the Proposal, and propose mitigation measures to minimise potential impacts on the hydrological and hydrogeological regime.

The following studies provide an understanding of the hydrological setting of the Proposal:

- Hydrologic and hydraulic assessments undertaken as part of the Proposal Order of Magnitude study, to define the surface water hydrology and flow conditions of Weeli Wolli Creek (Rio Tinto 2013).
- A hydrogeological assessment of the CID to determine hydraulic properties as well as connectivity with the adjacent Weeli Wolli Creek floodplain alluvial aquifer, including bore installation and test pumping.
- A detailed geomorphological assessment of Weeli Wolli Creek (MWH 2015).
- Measurements of discharge and infiltration along Weeli Wolli Creek undertaken as part of the pre-feasibility Study, to better quantify the channel loss rates in reaches of the creek system and inform modelling of discharge scenarios (Rio Tinto 2014c).
- Investigations on the impact of current and proposed mine operations on the water quality and the potential for cumulative impacts on the Fortescue Marsh, including development of a surface water and groundwater model for the Proposal Area.
- Ecohydrological assessment to identify the likely changes to surface water flow regime as a result of implementing the Proposal and potential effects on riparian vegetation along Weeli Wolli Creek (Rio Tinto 2015b).

In addition to these studies, a number of additional research projects have been undertaken within both the Weeli Wolli Creek catchment and broader Fortescue Marsh catchment to understand the hydrogeological and hydrological processes of these catchments. This work underpins the hydrogeological studies undertaken for the Proposal.

13.2.1 Local hydrological setting of the Proposal

The Proposal Area is located within the Weeli Wolli Creek surface water catchment. Marillana Creek, a major tributary of Weeli Wolli Creek, discharges to Weeli Wolli Creek downstream of the Proposal (**Figure 25**). Approximately 10 km north of the confluence of Weeli Wolli and Marillana Creeks, Weeli Wolli Creek drains to a wide alluvial floodplain in the Fortescue Valley with flows terminating at the Fortescue Marsh (approximately 40 km north of the Weeli Wolli and Marillana Creek confluence). The Weeli Wolli Creek catchment, including Marillana Creek, represents approximately 10% of surface water flow into the Fortescue Marsh (Aquaterra 2001 as cited in Johnson and Wright 2003). The characteristics of the Weeli Wolli catchment are described in Section 5.6.

13.2.2 Pre-mining surface water hydrology

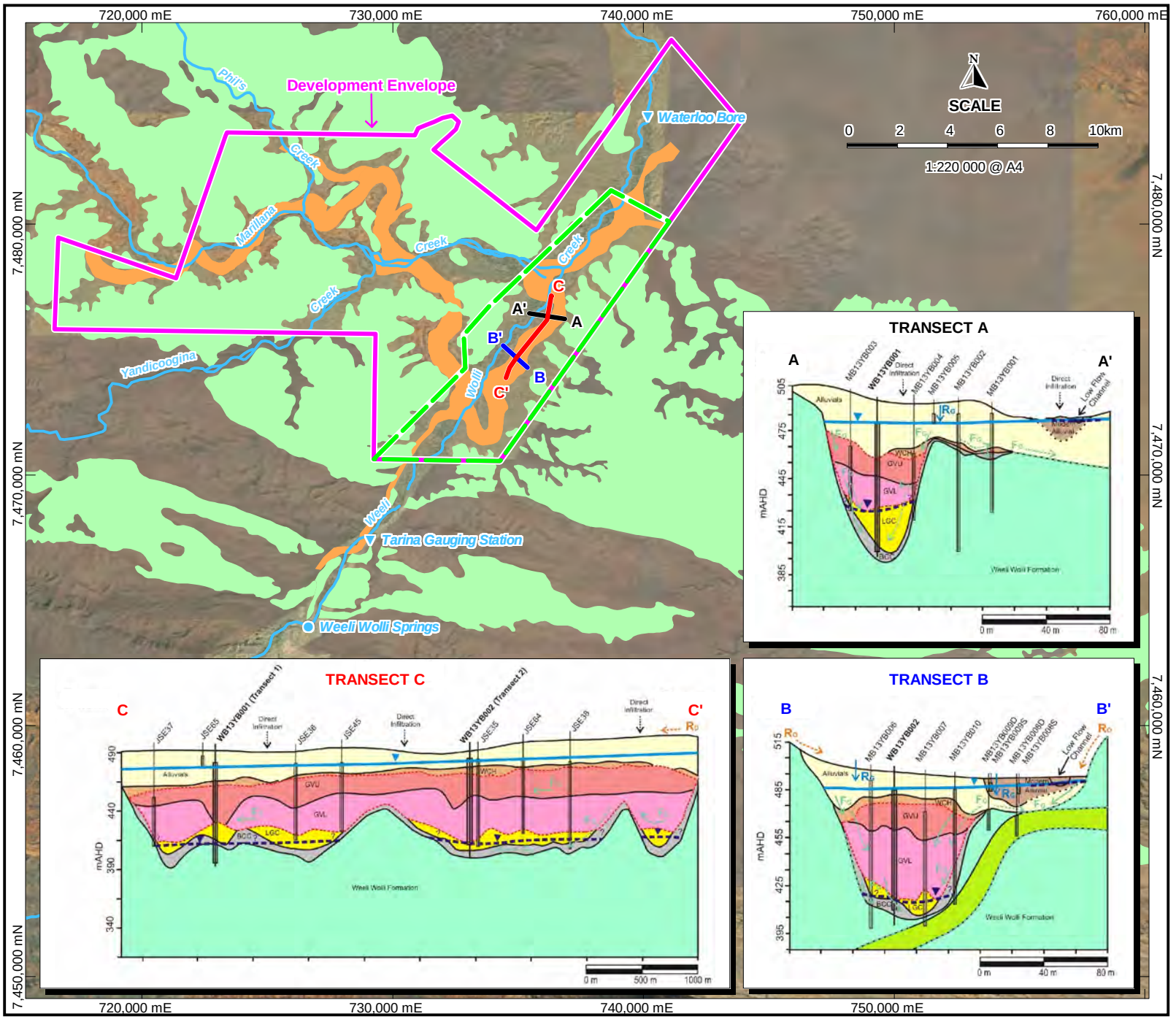
Weeli Wolli Creek is the dominant drainage feature which enters the Proposal Area from south of the Proposal deposit. This creek drains parallel to the Proposal deposit in a predominantly north easterly direction and drains into an alluvial fan on the southern flanks of Fortescue Marsh, outside of the Revised Proposal Development Envelope.

Marillana Creek is a major tributary of the Weeli Wolli Creek system. The lower Marillana Creek drains in an easterly direction through the existing BHP Yandicoogina (Marillana Creek) operations and the Revised Proposal Development Envelope. It continues its path downstream onto wide flat plains (400 – 600 m) located downstream of the existing Yandi Operations, before discharging into Weeli Wolli Creek (Rio Tinto 2014f). The confluence of Weeli Wolli Creek and Marillana Creek is located in the north west of the Proposal Area.

Weeli Wolli Creek is characterised by a generally singular, meandering low-flow channel set within a broader floodplain. The high flow channel comprises a gravel-bed stream, with large gravel bars present within the channel and more active anabranches (MWH 2015). These numerous anabranches of the Weeli Wolli Creek that cross the Proposal Area convey flows towards the creek as a result of episodic high rainfall events (**Figure 26**).

Long term stream flow records for Weeli Wolli Creek since 1985 to the present are available for sites located both upstream and downstream of the Proposal Area, at Tarina and Waterloo Bore respectively (**Figure 25**). The period until 1997 is representative of stream flow conditions prior to the commencement of discharge of surplus dewatering volumes as a result of mining operations within the catchment. Observations indicate that historically Weeli Wolli Creek was ephemeral, flowing only once or twice per year during episodic rainfall events. Baseline flow was widely variable with the initiation of runoff strongly dependent on antecedent conditions and the intensity and spatial distribution of rainfall. Generally only large rainfall events were sufficient to generate stream flow. During dry years, in which less than 300 mm of rainfall was experienced, surface water runoff was generally not sufficient to generate flow at either streamflow gauging station (URS 2015).

Natural perennial flows on the Weeli Wolli Creek did occur at Weeli Wolli Spring, located approximately 4.5 km upstream from Tarina (**Figure 25**). Pre-mining aerial photographs show that Weeli Wolli Creek was characterised by wetlands, pools and a shallow water table on reaches extending approximately 12 km downstream from Weeli Wolli Spring. As flow was not perennial at Tarina, this suggests a large proportion of the overflow from Weeli Wolli Spring was infiltrated to the underlying aquifer and transmitted as groundwater through-flow (URS 2015).



LEGEND

- Development Envelope
- Proposal Area
- Spring
- Gauging Station
- Major Creek
- Extent of CID
- Weeli Wolli Formation

Floodplain Alluvial Aquifer

- Modern Alluvials
- Alluvials

CID Aquifer

- WCH - Weathered Channel
- GVU - Goethitic Vitreous Upper
- GVL - Goethitic Vitreous Lower
- LGC - Lower Goethitic Clay
- BCC - Basal Conglomerate Clay

Basement Aquifer

- Weeli Wolli Formation
- Dolerite

- Contact
- Inferred Contact
- Ore Boundary
  Defined at 'JORC Measured' Status
- FG Groundwater Flow
- RO Runoff
- RG Recharge
- Groundwater Level Current
- 2030 Predicted Groundwater Lever
- Bore Screen Interval

Iron Ore (WA)

Figure 25
Major hydrological features

Drawn: M.Swebbs Plan No: PDE0133901v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

13.2.2.1 Surface water quality

Water quality data indicates that surface water in the vicinity of the Proposal is (Rio Tinto 2013):

- Neutral to slightly alkaline with median total dissolved solids (TDS) content of approximately 550 mg/L.
- Comprised of trace elements such as aluminium, iron, manganese and zinc at low levels.
- Subject to nitrogen increases, which are considered to originate from natural elevations within groundwater.

13.2.3 Hydrogeology

Hydrogeological investigations have been undertaken within and surrounding the Proposal Area since the late 1970's. The regional hydraulic gradient and discharge of groundwater at the Proposal is in a north-northeast direction towards the Fortescue Marsh. Groundwater is also lost from the area through the process of evapotranspiration within the riparian floodplain zone.

There are three main hydro-stratigraphic units recognised within the Yandicoogina region (Rio Tinto 2014d; **Figure 29**). They comprise:

- the fractured and weathered basement of the Weeli Wolli Formation;
- the overlying fractured CID; and
- the surficial unconfined floodplain aquifer.

These hydro-stratigraphic units are described below.

13.2.3.1 Weeli Wolli Formation

The Weeli Wolli Formation is a fractured rock aquifer consisting of inter-bedded banded iron formation, banded chert, shale and dolerite. It underlies and surrounds the alluvial/in situ weathered aquifer. Aquifer permeability is largely dependent on the development of structural features. Groundwater in the basement rocks only occurs in secondary porosity associated with the weathered zone and within fractures in the bedrock, with lower hydraulic conductivities than both the CID and the floodplain aquifers. There may be transmissive structures in the basement aligned beneath Weeli Wolli Creek (Fowers et.al.; cited in URS 2015).

13.2.3.2 Channel Iron Ore deposit

The Tertiary CID constitutes a relatively narrow meandering palaeo-channel between 600 m to 1,000 m wide and 100 m deep, imbedded into the low transmissivity Weeli Wolli Formation. The highly-transmissive CID forms a channel aquifer system, some of which underlies the modern day Weeli Wolli Creek system. Recent drilling has indicated that the CID is bound by an alluvium and weathered bedrock aquifer between the CID aquifer and the Weeli Wolli aquifer. The CID is variably connected with the floodplain aquifer.

13.2.3.3 Alluvial floodplain aquifer

Overlying the CID aquifer, and more broadly the Weeli Wolli Formation, is the alluvial floodplain aquifer. The floodplain aquifer consists of three geological units that exhibit strong hydraulic connection. Coarse creek bed colluviums and alluvium underlie Weeli Wolli Creek. This is the major source of recharge to the alluvial aquifer. The creek bed unit is incised within and discharges to floodplain sediments, comprising mixtures of poorly sorted gravels, sand, silt and clay. These sediments lie adjacent to the CID. The

floodplain sediments unconformably overlie in situ weathered basement, heavily fractured and weathered in situ Weeli Wolli Formation.

Transmissivity is variable within the floodplain aquifer. Groundwater moves freely within the coarser less clayey sediments, but flow may slow within the underlying clayey sections of the weathered basement material. The coarse river gravels of the upper alluvium of the creek bed are highly permeable and, in locations of reasonable thickness, have the ability to transmit and store large volumes of groundwater. The thickness of the floodplain alluvials is estimated from 6 m to 24 m, with the greatest thickness adjacent to Weeli Wolli Creek and limited cover at locations away from the Creek.

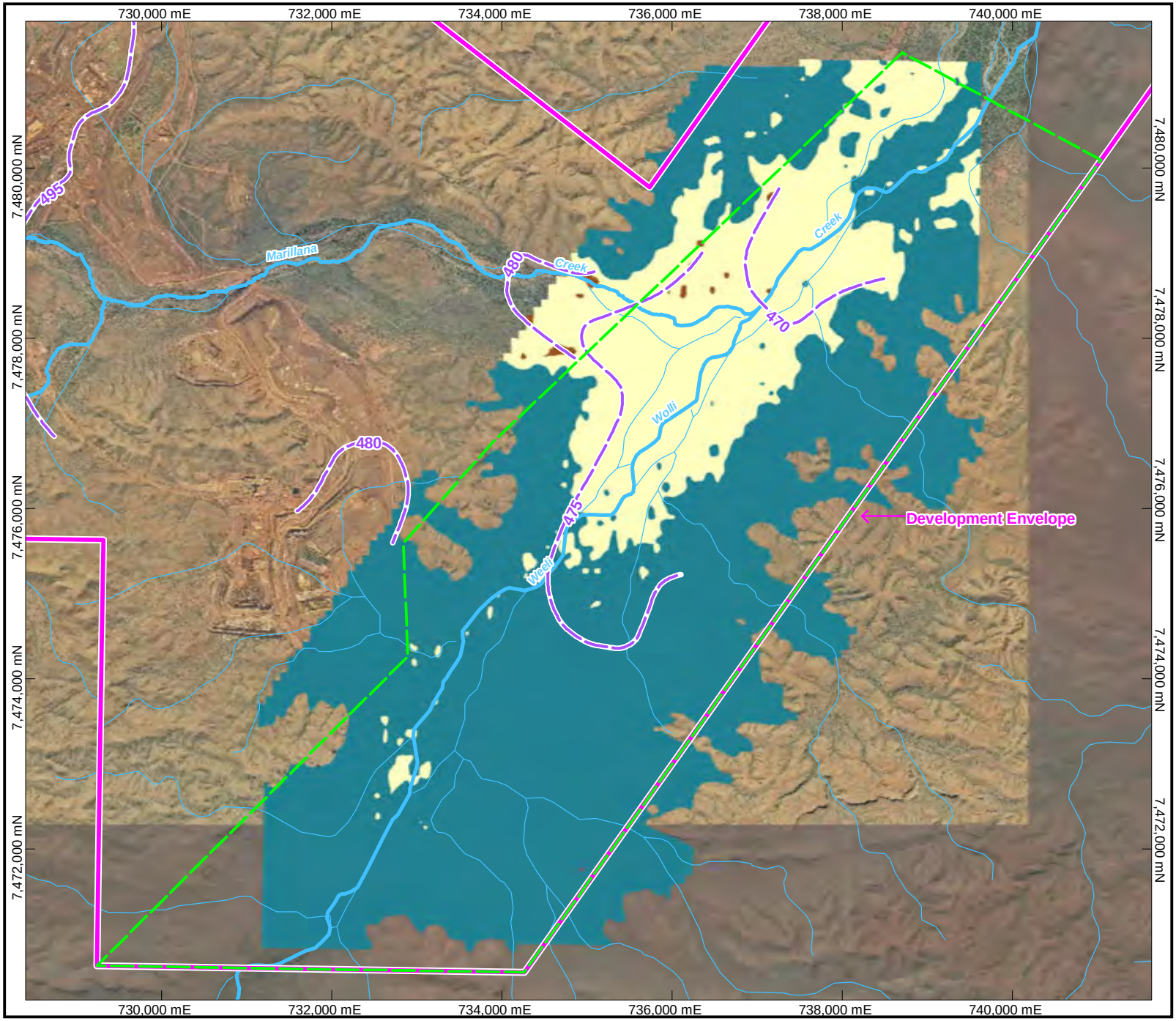
13.2.3.4 Groundwater quality

Baseline groundwater quality is typically characterised as fresh, with TDS concentrations of approximately 500 mg/L. Groundwater hosted by the floodplain aquifer tends to be comparatively higher in salinity (although still considered fresh), with measured TDS concentrations up to 1,290 mg/L. At greater depth, within the CID aquifer, known groundwater qualities occur in the range 370 to 780 mg/L TDS and pH from 6.8 to 9.6 (URS 2015).

The groundwater samples obtained from the monitoring bores close to Weeli Wolli Creek displayed increasing chloride concentrations in comparison to the groundwater samples within the monitoring and production bores away from the Creek. This is likely due to infiltration of surface water from Weeli Wolli Creek into the surficial aquifer and subsequently into the CID aquifer (Rio Tinto 2014d).

13.2.3.5 Groundwater levels

In areas where Weeli Wolli Creek intersects the CID, the coarse colluviums and alluvium are considered to be the conduit for recharge to the CID aquifer primarily from surface flow. Historically, groundwater levels were recorded to rise by up to 10 m within the CID aquifer as a result of through-flow from the floodplain aquifer following intense or prolonged rainfall events. Pre-mining water table elevations in the Proposal Area are shown below in **Figure 26**. Groundwater levels show significant spatial and temporal variation due to rainfall, stream flow and evaporation. The depth to water table cyclic-low and episodic high snapshots are presented in **Figure 27** and **Figure 28**.



LEGEND

- Development Envelope
- Proposal Area
- Snapshot of Baseline Water Table Elevations (early -1995)
- Major; Minor Watercourse

Baseline Groundwater Environment (m)

- 6 - 12
- 12 - 20
- 20 - 50

N

SCALE

0 1 2 3km

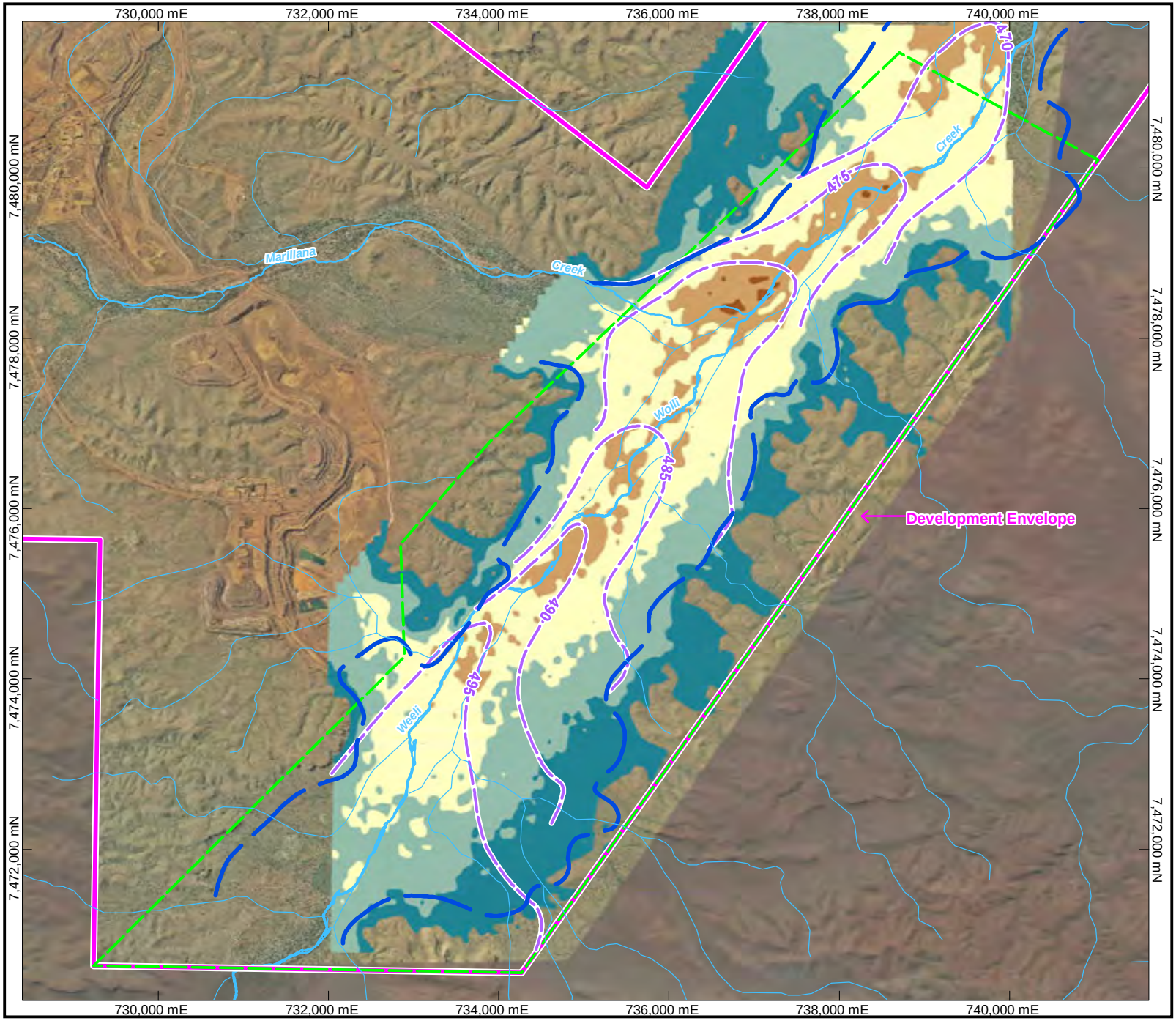
1:65 000 @ A4

Iron Ore (WA)

Figure 26
Pre-mining groundwater levels

Drawn: M.Swebbs Plan No: PDE0133928v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Nominal Extent of Floodplain Aquifer
- Cyclic Low Water Table Elevations (Early-2006)
- Major Watercourse
- Minor Watercourse

Depth to Water (m)

- 0 - 2
- 2 - 6
- 6 - 12
- 12 - 20
- > 20

Source: URS Australia Pty Ltd

N

SCALE

0 1 2 3km

1:65 000 @ A4

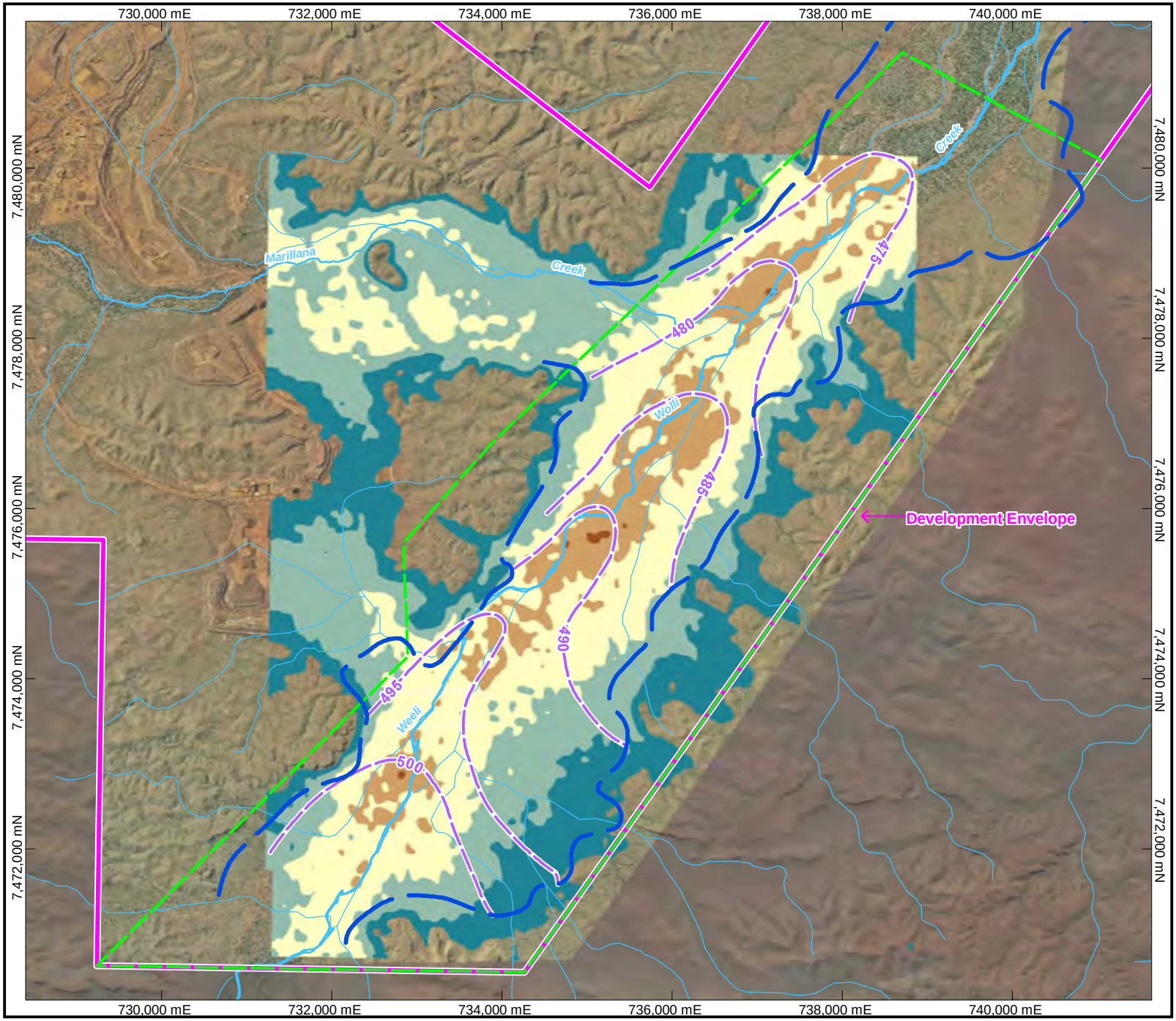
RioTinto

Iron Ore (WA)

Figure 27
Depth to Water Table Cyclic-Low Snapshot

Drawn: M.Swebbs Plan No: PDE0136075v1
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Nominal Extent of Floodplain Aquifer
- Episodic High Water Table Elevations (mid-2006)
- Major Watercourse
- Minor Watercourse

Depth to Water (m)

- 0 - 2
- 2 - 6
- 6 - 12
- 12 - 20
- > 20

Source: URS Australia Pty Ltd

N

SCALE

0 1 2 3km

1:65 000 @ A4

Iron Ore (WA)

Figure 28
Depth to Water Table Episodic-High Snapshot

Drawn: M.Swebbs Plan No: PDE0136079v1
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

13.2.4 Current altered hydrological regime

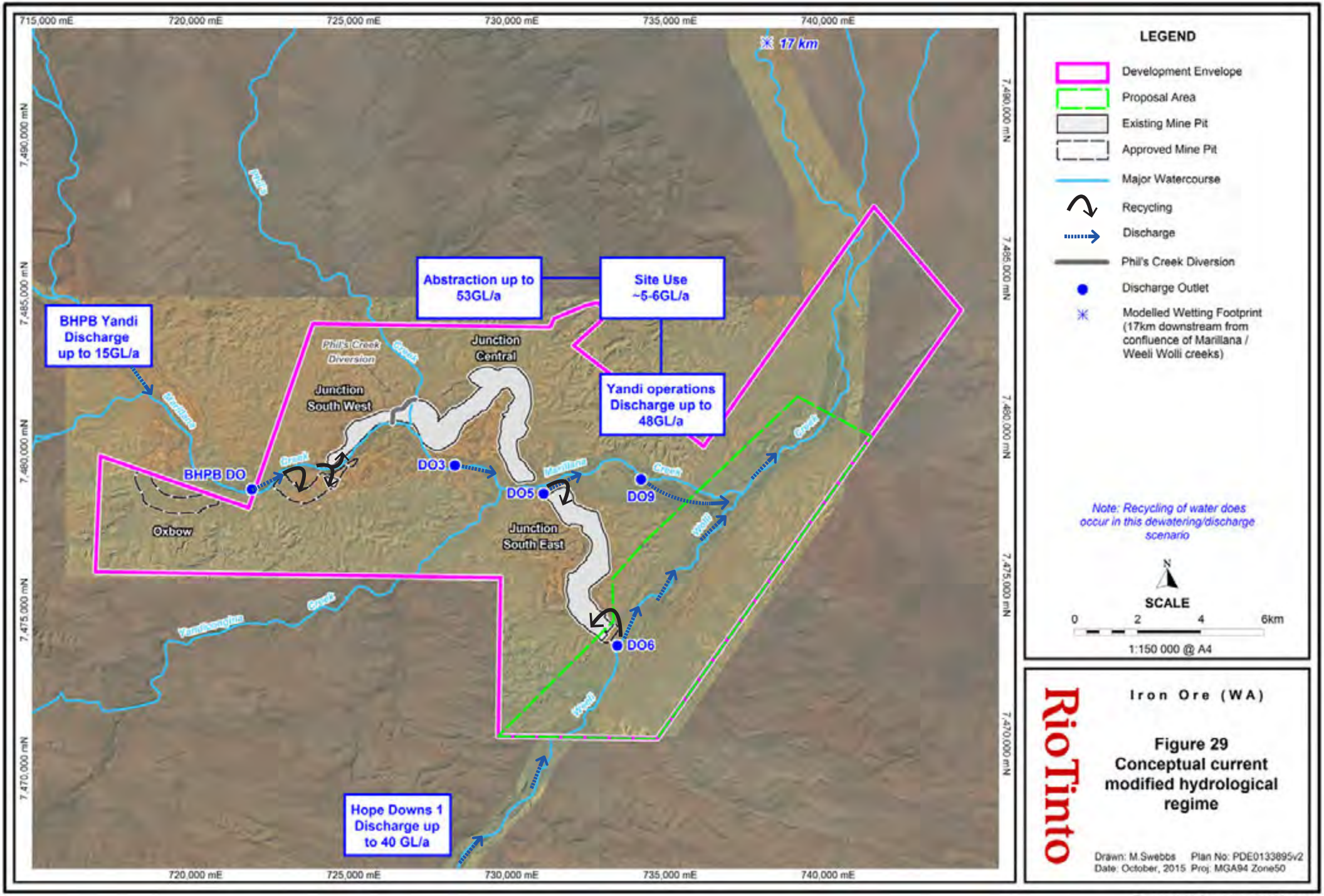
13.2.4.1 Water flow

Surface water and groundwater in the Proposal locality has been modified and managed for a number of years (since the mid 1990s) as a result of mining activities in the area. This includes dewatering of groundwater and discharge of surplus water to Marillana and Weeli Wolli Creeks. **Figure 29** provides a conceptual water balance for mines operating within the Proposal Area including discharge locations, and **Figure 30** provides a waterfall graph to demonstrate the cumulative water abstraction and discharge volumes across these operations.

The following sections provide a summary of the abstraction, discharge, recirculation and water use regime in the Proposal Area. The summary provides a sequence of mining upstream along the CID and Marillana Creek through to the Proposal Area. **Table 11** summarises the water balance described below.

Dewatering and discharge:

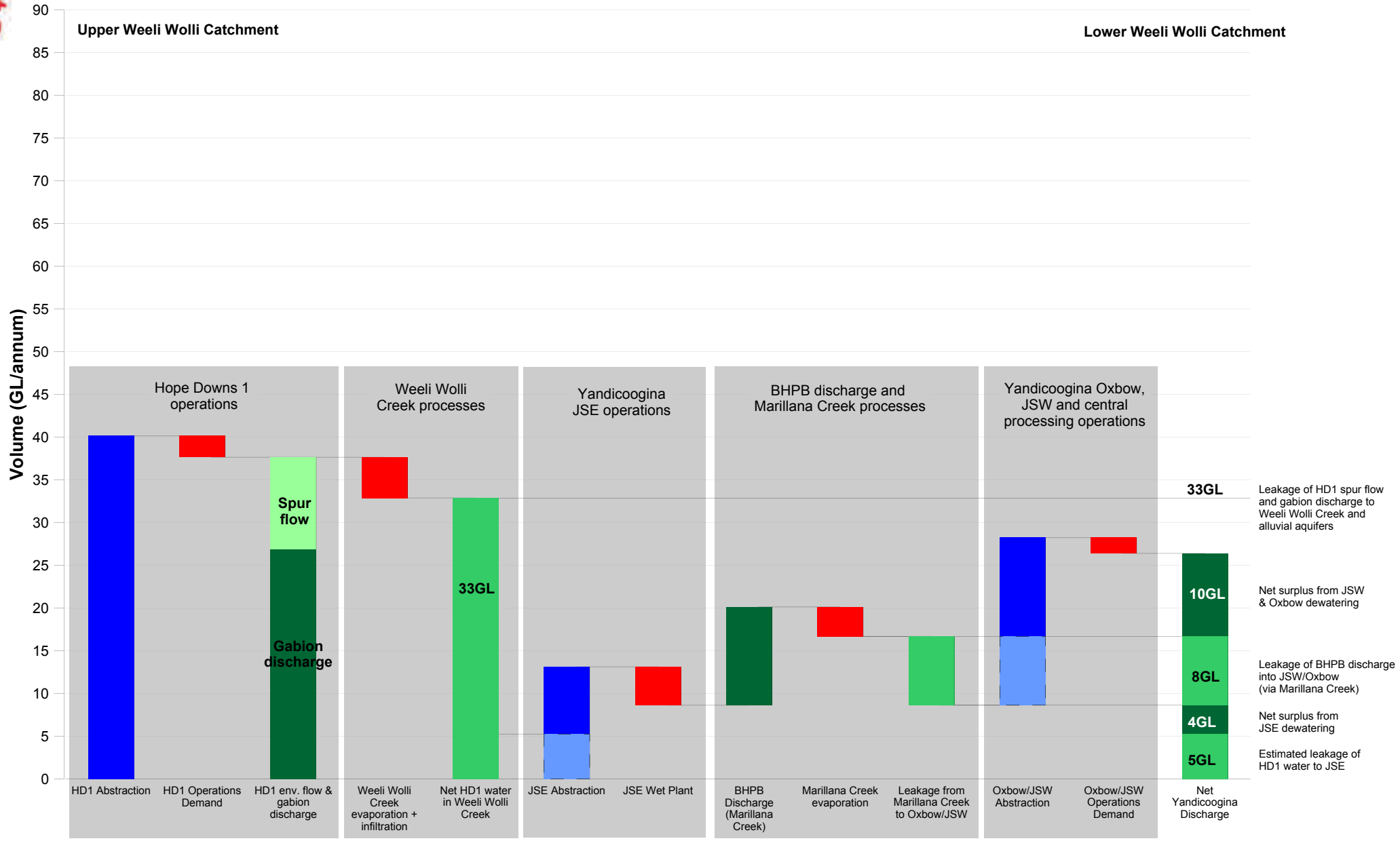
- BHP discharge from its Marillana Creek (Yandi) Mine upstream of the Proposal at an upstream point in Marillana Creek on to the Proponent's tenure boundary. Historical averages have been in the order of 9 GL/y with a licence limit of 15 GL/y.
- Oxbow is scheduled to discharge surplus water from Discharge Outlet(s) (DO) along Marillana Creek with a modelled peak of approximately 8 GL/y. A commitment was made in the JSW and Oxbow approvals to maintain some upstream discharge (including D03) to manage water levels as a result of drawdown from the existing Yandi Operations to maintain areas of stygofauna habitat and allow for riparian readjustment.
- JC is currently near the end of its mine life and so is not actively being dewatered for mining purposes; however, the groundwater table is kept locally depressed by sump pumping to keep water levels manageable after wet seasons. JC historically discharged from several discharge locations along Marillana Creek (DO2*, DO3, DO5, DO8*) with limited discharges currently from DO3.
- JSW currently discharges from DO9 into Marillana Creek with an estimated operational peak of 23 GL/y.
- JSE has historically discharged from DO5, DO6 & DO9, however discharge into the future will be maintained from DO5 and DO9, with DO6 being decommissioned and the water being diverted for use in the JSE wet plant.
- Hope Downs 1 is approved to discharge up to 40.15 GL/y into the upper reaches of Weeli Wolli creek from two locations: into the Weeli Wolli Spring through a spur system to negate the impacts of drawdown; and also from a gabion structure downstream of the Spring.


715,000 mE
720,000 mE
725,000 mE
730,000 mE
735,000 mE
740,000 mE
7,490,000 mN
7,485,000 mN
7,480,000 mN
7,475,000 mN
7,470,000 mN
17 km
Abstraction up to 53GL/a
Site Use ~5-6GL/a
BHPB Yandi Discharge up to 15GL/a
Yandi operations Discharge up to 48GL/a
Phil's Creek Diversion
Junction Central
Junction South West
Junction South East
BHPB DO
DO3
DO5
DO6
DO9
Oxbow
Marillana Creek
Weeli Wolli Creek
Yandicoogina Creek
Hope Downs 1 Discharge up to 40 GL/a
LEGEND
Development Envelope
Proposal Area
Existing Mine Pit
Approved Mine Pit
Major Watercourse
Recycling
Discharge
Phil's Creek Diversion
Discharge Outlet
Modelled Wetting Footprint (17km downstream from confluence of Marillana / Weeli Wolli creeks)
Note: Recycling of water does occur in this dewatering/discharge scenario
N
SCALE
0
2
4
6km
1:150 000 @ A4
RioTinto
Iron Ore (WA)
Figure 29
Conceptual current modified hydrological regime
Drawn: M.Swebbs
Plan No: PDE0133895v2
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping

Weeli Wolli Catchment Water Balance

Pocket-Billiards South PER

Figure 30



Recirculation (re-dewatering of surplus water discharge):

Hydrogeological investigations into the catchment have shown that substantial amounts of the "dewatering" conducted by downstream operations is recirculation of surplus water discharged by upstream operations. This "recirculation" has been estimated between operations in the Proposal Area as follows:

- Up to 70% of BHP Marillana Creek (Yandi) Mine discharge is re-abstracted and discharged by the Proponent's Yandi Operations dewatering.
- A portion of the discharge from Hope Downs 1 has been recharging into JSE.

Water use:

- Approximately 5-6 GL/y of water is re-used on-site across the existing Yandi Operations for potable water supply, dust suppression and in the existing plants. A further 5 GL/y (total of 11 GL/y) is estimated to be used in the JSE wet plant which is currently being commissioned.

Table 11: Modified hydrological regime of the Proposal Area

Mine	Year commenced abstraction / discharge	Location of discharge	Creek	Abstraction Actual or proposed Individual pit contribution –(peak) (GL/y)	Abstraction Ministerial / licence limit (GL/y)	Site Use	Discharge Actual or Proposed (GL/y)	Discharge Ministerial limit (GL/y)	Recycling volume (or %)
BHP Yandi	1996	Upstream of JSW	Marillana	15	15	N/A	Up to 15	15	70%
Oxbow	Proposed 2017	– D03	Marillana	8	18	6	8	16	
JSW	2013	– D09	Marillana	23			20^		
JC	1997	– D02*, D03, D05, D08*	Marillana	NA	35		NA	NA	
JSE	2007	– D06 – D05 & D09	Weeli Wolli Marillana	19			16^		Unquantified
Proposal	Proposed 2017	– D09	Marillana	50	Additional 30	5**	45 - 50		70%
HD1	2007	Upstream of Proposal	Weeli Wolli	40.15	40.15	3	37.15	40.15	33GL to Proposal

*Now decommissioned
** from JSE wet plant: so total reuse on-site will be existing 6 GL/y + 5 GL/y from wet plant = 11 GL/y
^ Assumes of the 6 GL/y used on-site, 3 GL/y attributed to JSW and 3 GL/y attributed to JSE

Due to the continuous discharge of surplus dewater from multiple operations in the Proposal Area, permanent surface water within the low-flow channel occurs along Weeli Wolli Creek. MS 914 condition 6-3, currently limits the wetting front from surplus water discharge to 17 km downstream of the Marillana and Weeli Wolli Creek confluence. This limit also accommodates the surface water released from Hope Downs 1. The current wetting front reaches between 5 and 9 km downstream of the Weeli Wolli Creek and Marillana Creek confluence.

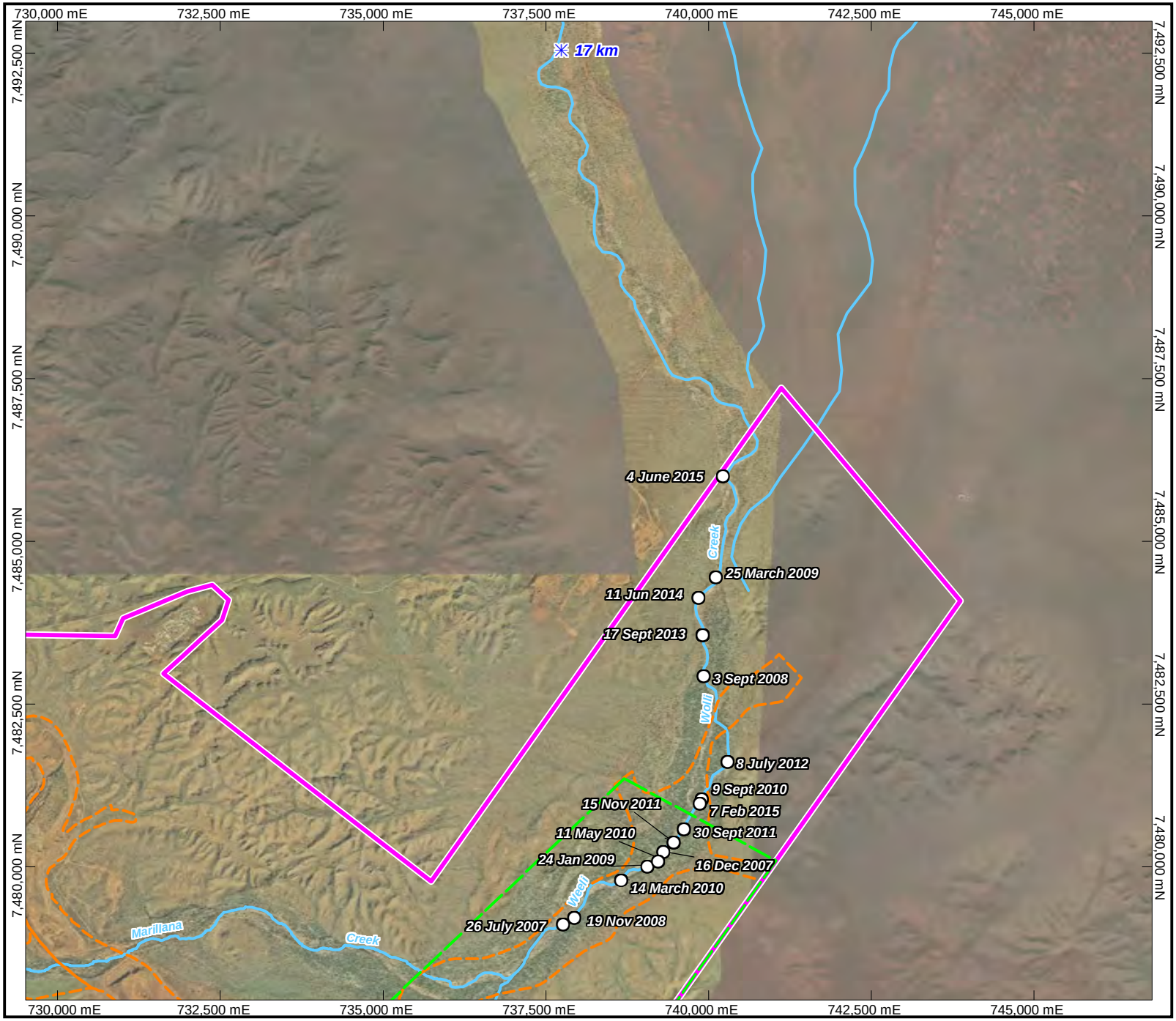
The current modified groundwater table is connected to the low-flow channel for the majority of the length of the surface water wetting front. The location of the surface water wetting front changes due to the capacity for infiltration of surface water flows to the floodplain and CID aquifer. Where groundwater levels are high and the profile is fully saturated, there is no additional capacity for infiltration to the aquifer, therefore surface water flows will propagate further downstream but still within accordance of MS 914. Where the aquifer is not fully saturated (i.e. the groundwater table is not at or near the surface) there is capacity for surface flows to infiltrate to the floodplain aquifer, which will result in a retreat of the surface water wetting front. The wetting front appears relatively stable, with observations since continuous discharge began indicating no further propagation of the wetting front further downstream (**Figure 31**).

Discharge of surplus water from mine dewatering operations to Weeli Wolli Creek has resulted in greater recharge within the creek bed alluvium to the floodplain aquifer (**Figure 32**), and has increased mounding below the alluvial aquifer when compared to pre-mining conditions (URS 2015; **Figure 32**). Drilling undertaken within the Proposal Area in 2013 recorded groundwater levels between 2 - 10 m below ground level (Rio Tinto 2014d).

An investigation has been undertaken to understand the impact that continuous discharge has had on the overall water balance of Weeli Wolli Creek and underlying aquifers (Dogramaci et al. 2015). For the purpose of the investigation, results of surface water and groundwater sampling were combined with field observations of surface saturation along Weeli Wolli Creek and recorded discharge rates at the Hope Downs 1 discharge location.

The major finding of the study suggests that the impact of recharge from continuous flow on the hydrological regime of the creek has not extended beyond 27 km from the discharge point, which is no further than 8 km from the Weeli Wolli Creek and Marillana Creek confluence. It was concluded that although more than 220 gigalitres (GL) of mine water discharge since 2007 has changed the nature of the connectedness of Weeli Wolli Creek to the underlying aquifer in the upper section, associated with the impermeable Weeli Wolli Formation, there has been negligible impact on the overall hydrological regime of the broader catchment. Most of the recharge to the groundwater aquifer along Weeli Wolli Creek occurs where the creek flows adjacent to or across the CID aquifer.

The calculated rates of recharge as a result of continuous discharge from Hope Downs 1 were found to be commensurate with those from large flooding events that occur in the region every few years (Dogramaci et al. 2015). It was noted, that changes in surface water connectivity and sustained periods of saturation may have localised impacts on the ecology of streams. Section 14.3.3 provides an assessment of the potential impacts on riparian vegetation from the modified hydrological regime.



LEGEND

- Development Envelope
- Proposal Area
- Extent of CID
- Major Watercourse
- Observed Surface Water Wetting Front and Date of Measurement
- Approved Wetting Front Extent (MS914)

N

SCALE

0 1 2 3 4km

1:85 000 @ A4

Iron Ore (WA)

Figure 31
Surface water wetting fronts

Drawn: M.Swebbs Plan No: PDE0133898v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

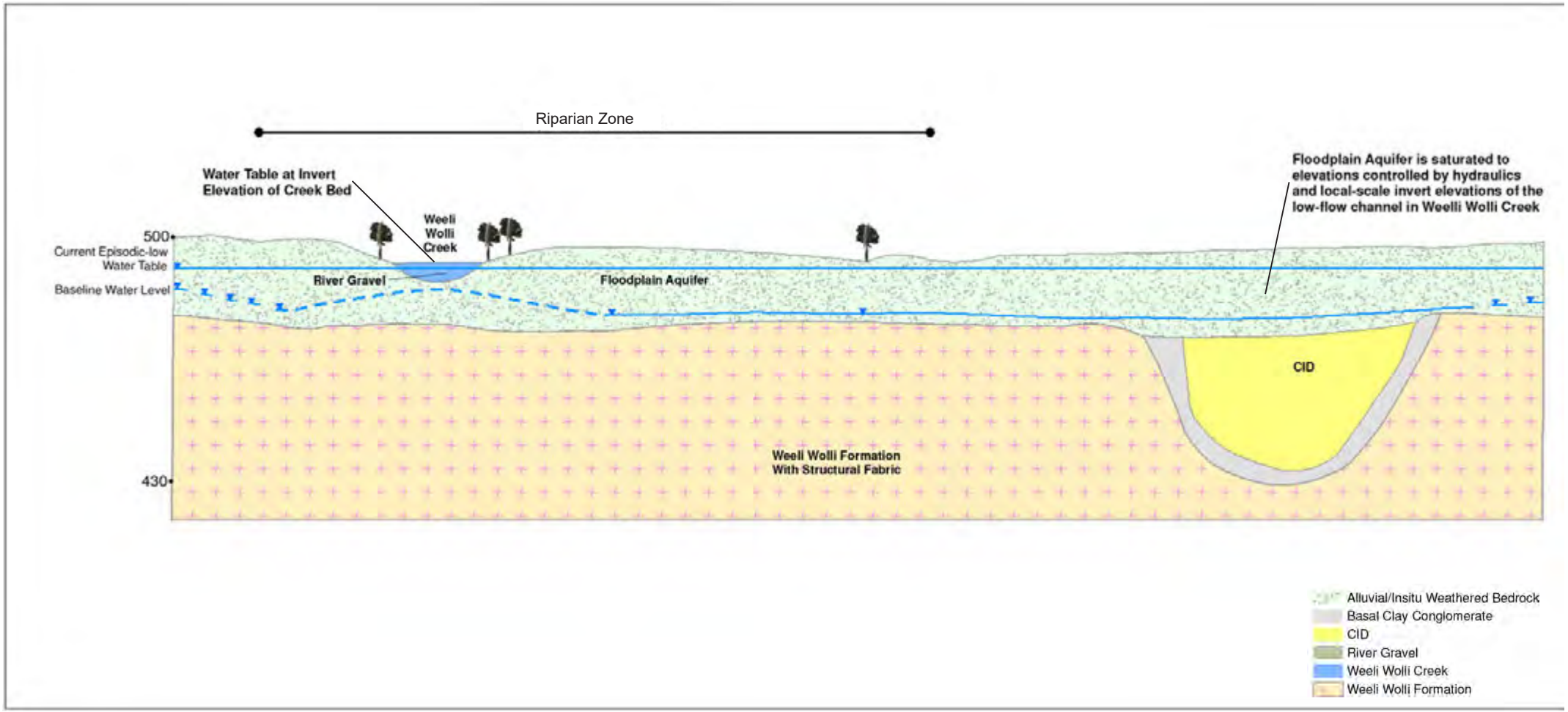


Figure 32 - Post mining groundwater levels

Source: Figure courtesy of URS Australia Pty Ltd

13.2.4.2 Water quality

Water quality monitoring has been undertaken along Weeli Wolli Creek and Marillana Creek prior to and following abstraction and discharge activities. The analysis of water quality is based on a standard suite of water quality parameters including electrical conductivity, total suspended solids, TDS, alkalinity, pH, hardness and a range of nutrients and other elements such as barium, boron, calcium, chloride, magnesium, nitrate, total nitrogen, total phosphorus, potassium, sodium, sulphate, sulphur, and uranium.

Monitoring results to date indicate some minor variation in water quality parameters, however this is considered to be natural fluctuations and no significant effects on baseline water quality has occurred as a result of abstraction and discharge activities.

Water availability and discharge by transpiration and evaporation has resulted in salt accumulation within the groundwater environment. Chloride ion levels have increased slightly (by approximately 50 mg/L) along the surface water wetting front extending from Hope Downs 1 operations along Weeli Wolli Creek, which is considered to be a result of salt accumulation due to evaporation and transpiration losses along the flow path (Dogramaci et al. 2015).

13.3 Assessment of potential impact, mitigation and residual impact

The EPA has listed the following potential impacts for the Proposal in relation to hydrological processes and inland waters environmental quality:

- Impacts to natural surface water systems and flows as a result of placement, design and operation of a new mine pit and associated infrastructure (including surface waste dumps and stockpiles, and drainage structures).
- Impacts to surface water resources including Weeli Wolli Creek due to surface discharge of surplus mine dewater.
- Altered flow regime to the Fortescue Marsh due to groundwater drawdown and discharge of surplus water into Weeli Wolli and Marillana Creeks.
- Potential changes to the groundwater quality over time from pit lakes left by the proposal.
- Potential contamination of surface water and groundwater, if management of waste dumps containing at risk material (material with potential for acid or metalliferous drainage) is not appropriate.

The potential impacts as a result of the development of the Proposal are described in the following sections.

Impacts to groundwater dependent ecosystems and subterranean fauna as a result of groundwater drawdown are discussed in Section 14 and 15 respectively.

Cumulative impacts of groundwater drawdown and discharge of surplus water into Weeli Wolli and Marillana Creeks, and any potential impacts to Fortescue Marsh, are discussed in Section 13.4.

13.3.1 Natural surface water systems and flows

The construction and physical presence of the pit, overburden storage areas, roads and other associated mine infrastructure will modify local topography and intercept surface water flows. Modifications to surface drainage patterns have the potential to cause changes to flood depths and velocities in downstream environments.

There is the potential for high velocity water movement off areas with steep gradients to contribute to the erosion of cleared landforms and unconsolidated materials in the Proposal Area. This has the potential to result in increased sediment load into the downstream environment.

A local surface water management strategy for the Proposal has been prepared to address surface water risks associated with local runoff from catchments east of Weeli Wolli Creek (Rio Tinto 2014f). The strategy includes measures to minimise the impact of surface water movement by the construction of a comprehensive framework of stormwater management structures. This is likely to include (but not be limited to) levees around the pit, diversion drains around waste dumps, and culverts under roads. These management measures will aim to maintain surface water drainage regimes by diverting surface water flows around infrastructure and into downstream drainage lines, thereby limiting opportunities for sediment transport from disturbed surfaces. Any incident surface water intercepted within operational areas will be diverted to sediment traps or retained in in pit sumps, to minimise sediment load prior to discharge to the natural drainage system.

Stormwater management design in Australia is guided by Australia Rainfall and Runoff (Pilgrim 2001) and the AUSTROADS Waterway Design Guide (Flavell 1994). Using these guidelines, a minimum of a 1% Annual Exceedance Probability (AEP; or a 100 year Annual Recurrence Interval; ARI) flood protection criteria will be adopted for the design of the flood protection levee. A 2% AEP (50 year ARI) flood protection will be adopted for the design of local diversion drains.

13.3.2 Weeli Wolli Creek

Development of the Proposal will encroach into the Weeli Wolli Creek floodplain. Results of hydrologic modelling of catchment runoff and hydrodynamic modelling of flood conditions have been used to assist in the design of a flood protection levee for the Proposal. The results that have been derived from the modelling are considered to provide a reliable representation of flow conditions during the major flooding of Weeli Wolli Creek, and are therefore suitable for use in the development of concept designs for the proposed flood protection levee (WorleyParsons 2015), with further detailed engineering work to be undertaken as the Proposal progresses.

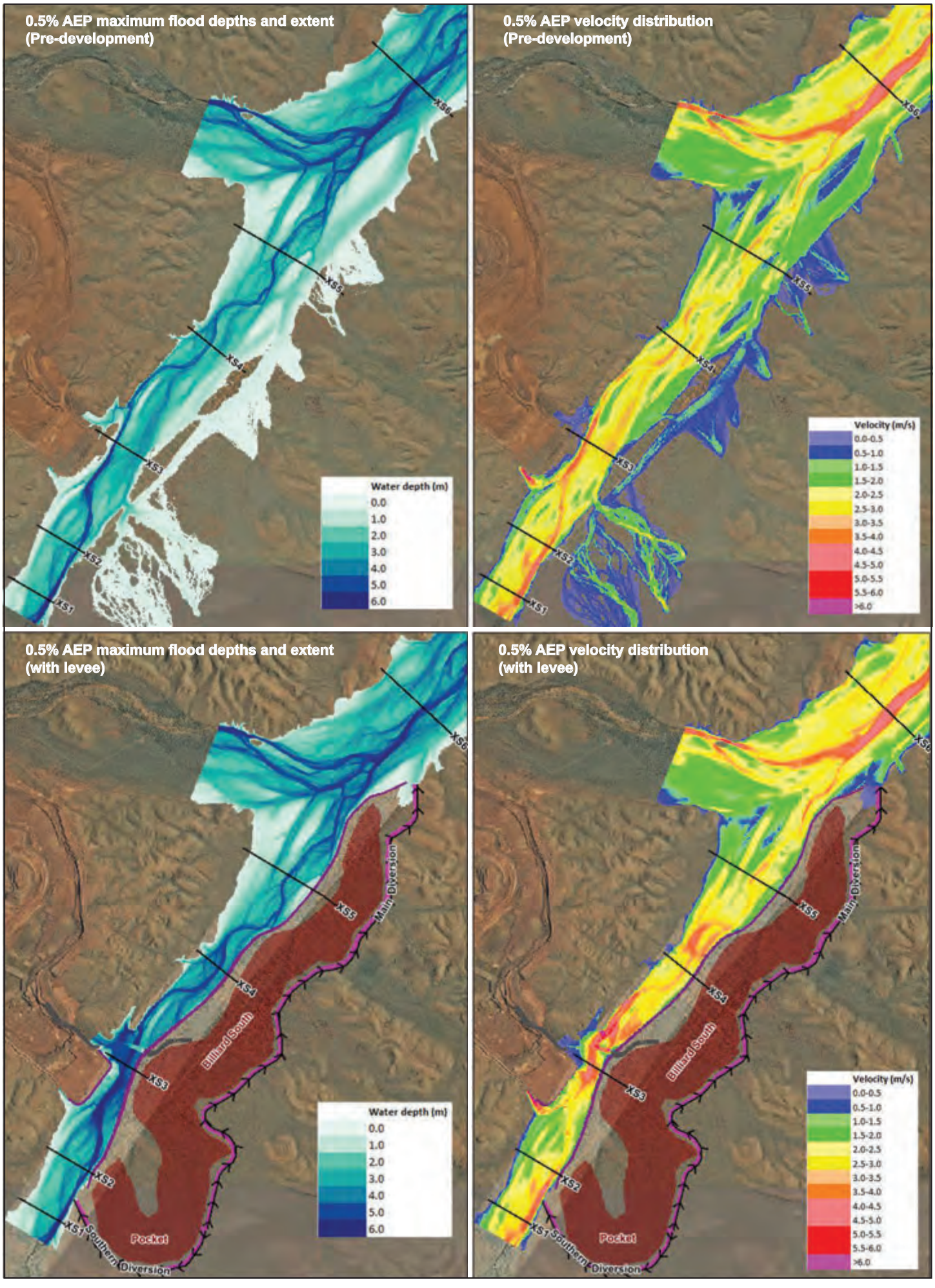
Disruption to the existing surface water flows along Weeli Wolli Creek is currently negligible during low-flow events. As the magnitude of the flood increases, changes to the flow regime also increase due to greater constriction and obstruction of flows imposed by the infrastructure along the creek. Overall change is confined to a section of creek adjacent to the proposed mine and unlikely to impact the wider creek area (URS 2015; **Figure 33**).

13.3.3 Dewatering and groundwater drawdown

Due to the nature of the orebody being located below the water table, dewatering will be required to allow for mining. A numerical groundwater model has been developed to simulate dewatering scenarios and assess resulting impacts to groundwater. This model

is a regional model covering the whole of the Revised Proposal Development Envelope, including the Oxbow, JSW and JSE pits together with the Proposal pit. It is based on a groundwater model first developed for the existing Yandi Operations in 2008.

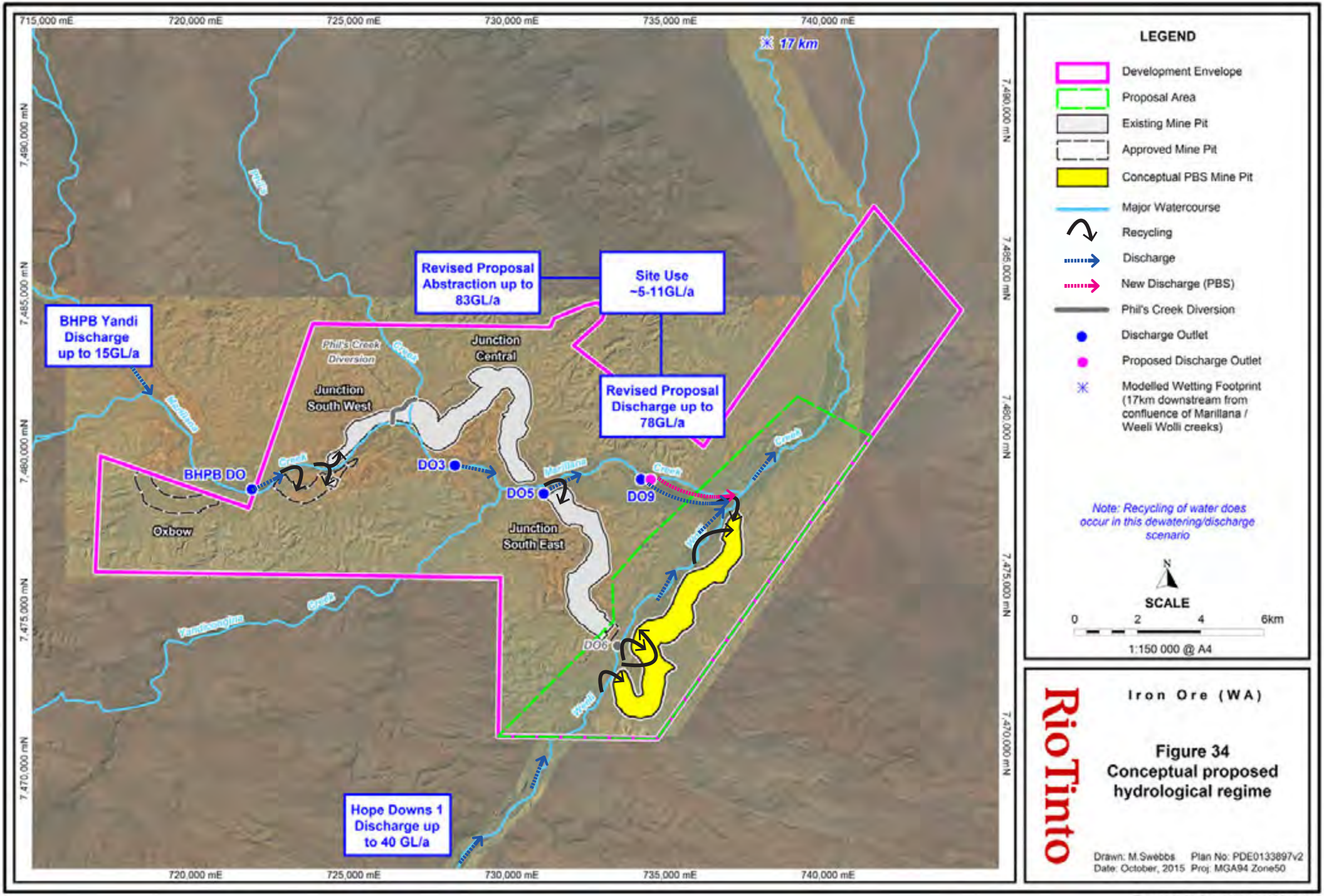
The model predicts peak cumulative abstraction volumes from current and proposed operations from the Yandi Operations, including the Proposal of up to 83 GL/y may occur (**Figure 34** and **Figure 35**) within the first 6 years of dewatering. Local maximum drawdown during this period within the floodplain and CID aquifer system would be in the order of 45 to 50 m to enable dry mining conditions. Drawdown would be most pronounced along the CID aquifer, and would separate the groundwater and surface water flows that currently occur along the low-flow channel of Weeli Wolli Creek from continuous discharge of surplus dewatering from upstream mining operations. Predicted drawdown over the expected life of the mine is shown in **Figure 36** and **Figure 37** for Pocket and Billiard South respectively.



RioTinto

Figure 33 - Flood footprints pre- and post-mining

Source: Figure courtesy of URS Australia Pty Ltd



LEGEND

- Development Envelope
- Proposal Area
- Existing Mine Pit
- Approved Mine Pit
- Conceptual PBS Mine Pit
- Major Watercourse
- Recycling
- Discharge
- New Discharge (PBS)
- Phil's Creek Diversion
- Discharge Outlet
- Proposed Discharge Outlet
- Modelled Wetting Footprint (17km downstream from confluence of Marillana / Weeli Wolli creeks)

Note: Recycling of water does occur in this dewatering/discharge scenario

N

SCALE

0 2 4 6km

1:150 000 @ A4

RioTinto

Iron Ore (WA)

Figure 34
Conceptual proposed hydrological regime

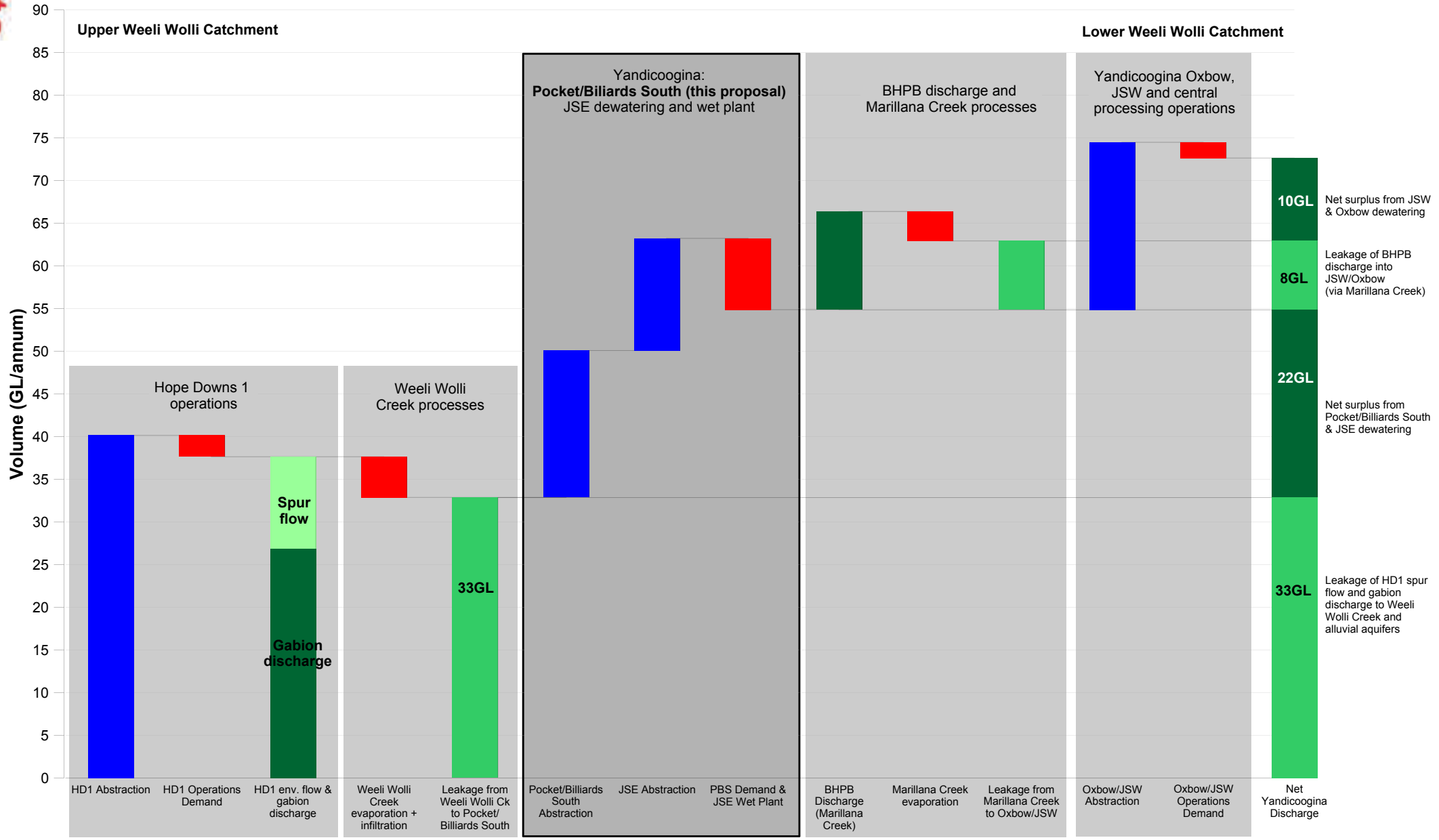
Drawn: M.Swebbs Plan No: PDE0133897v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

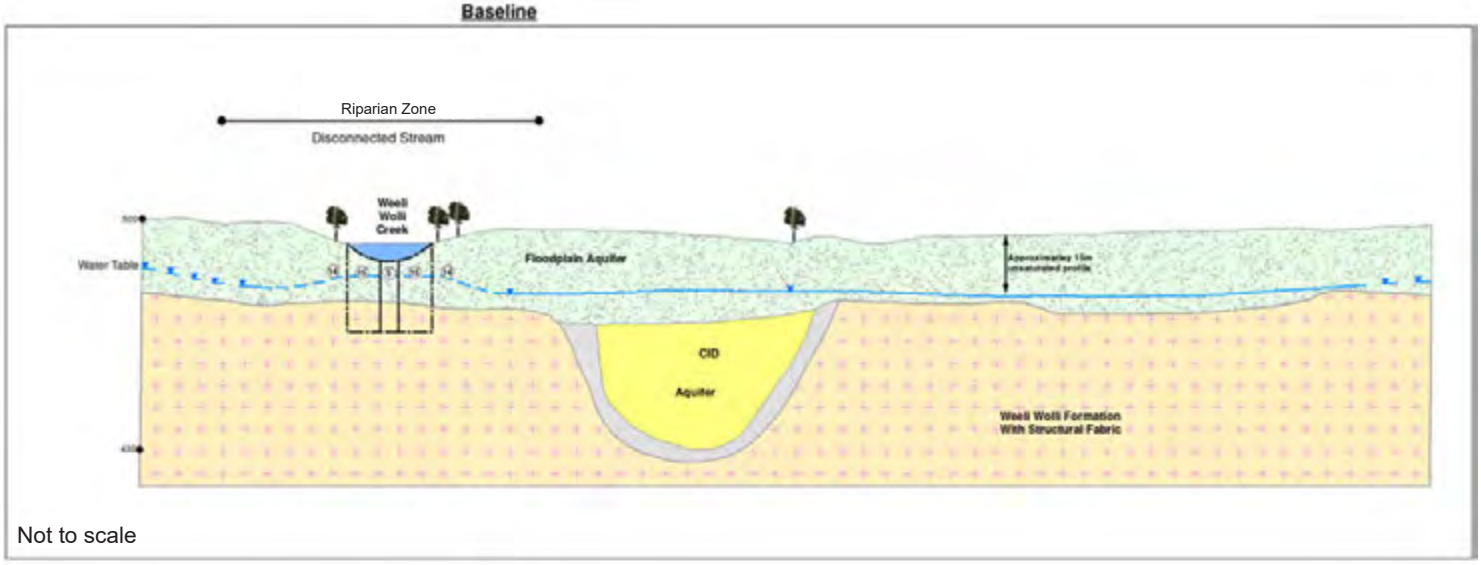
Weeli Wolli Catchment Water Balance

Pocket-Billiards South PER

Figure 35

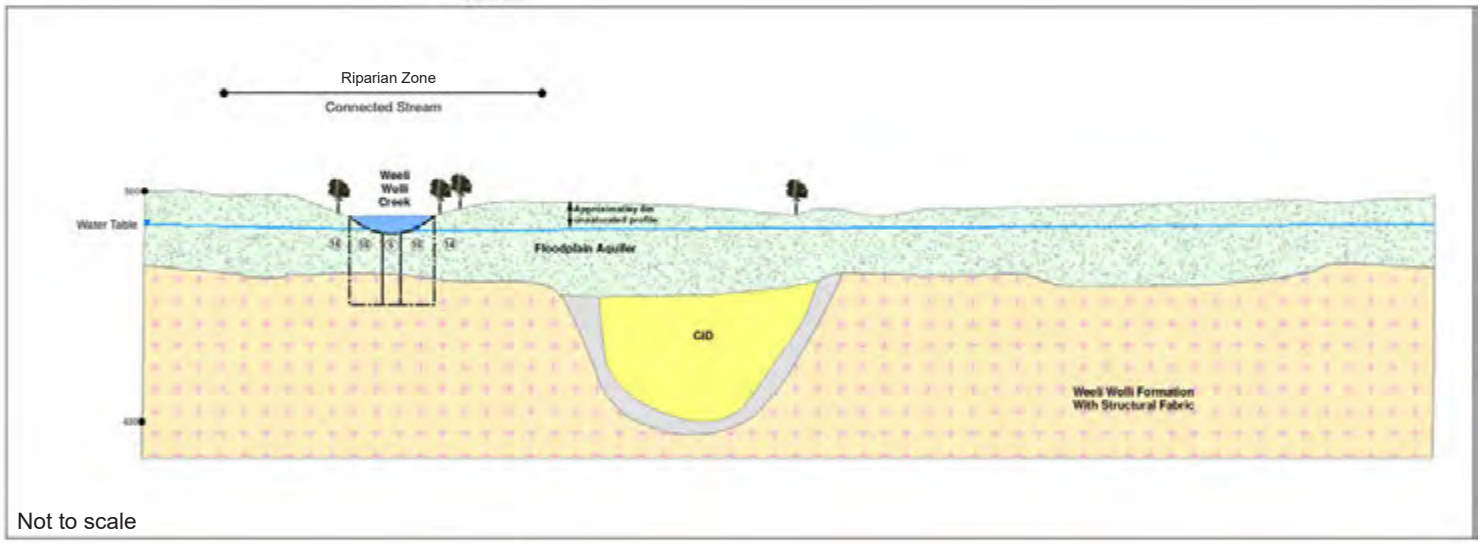


Baseline



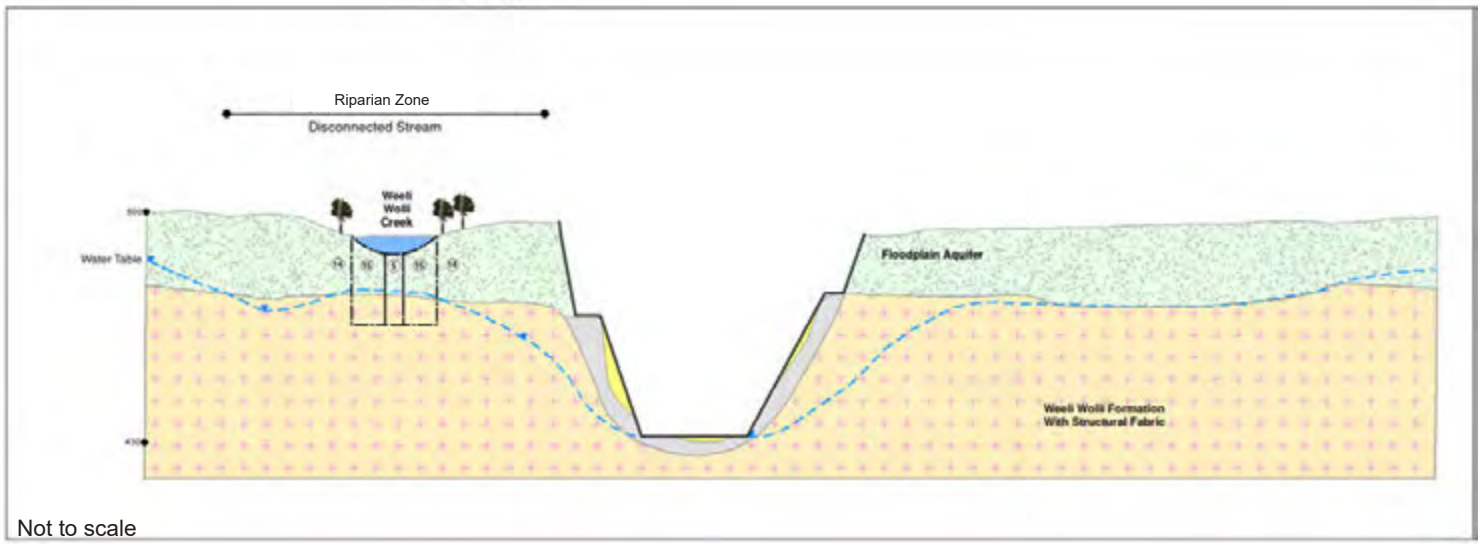
Not to scale

Current



Not to scale

Mining



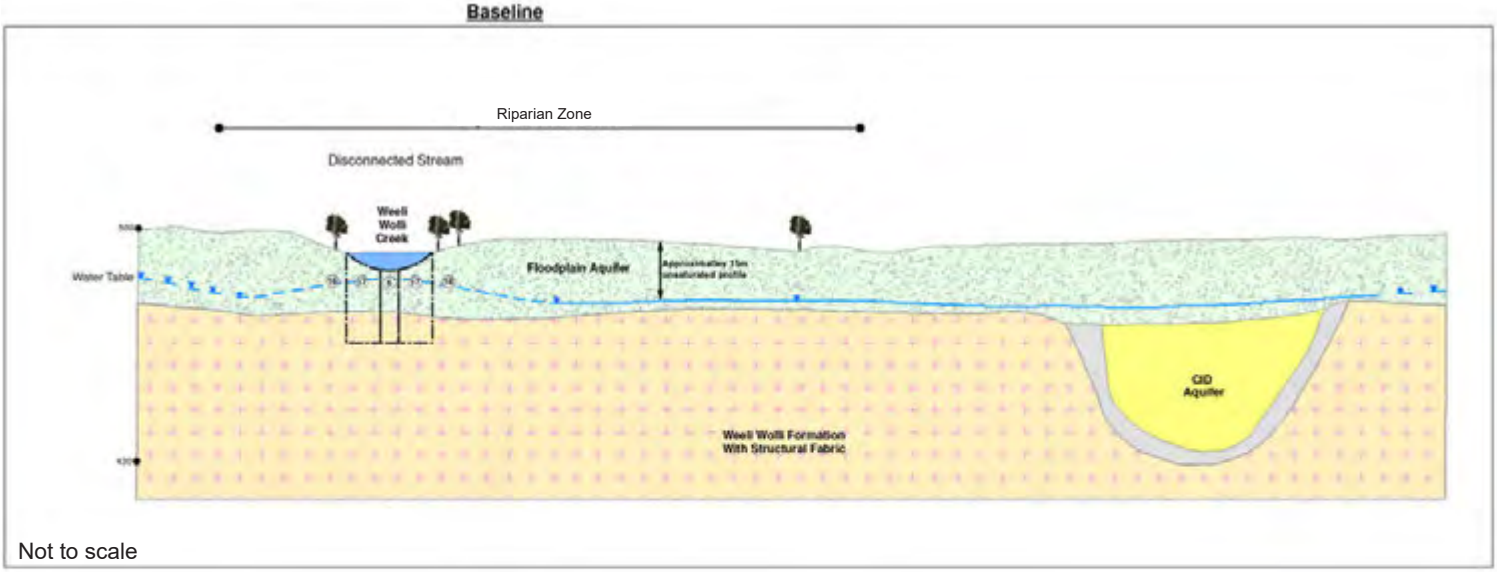
Not to scale

⑥ Zone Budgets
Alluvial/Insitu Weathered Bedrock
Basal Clay Conglomerate
CID
Weeli Wolli Creek
Weeli Wolli Formation

Figure 36 - Groundwater drawdown schematic - Pocket

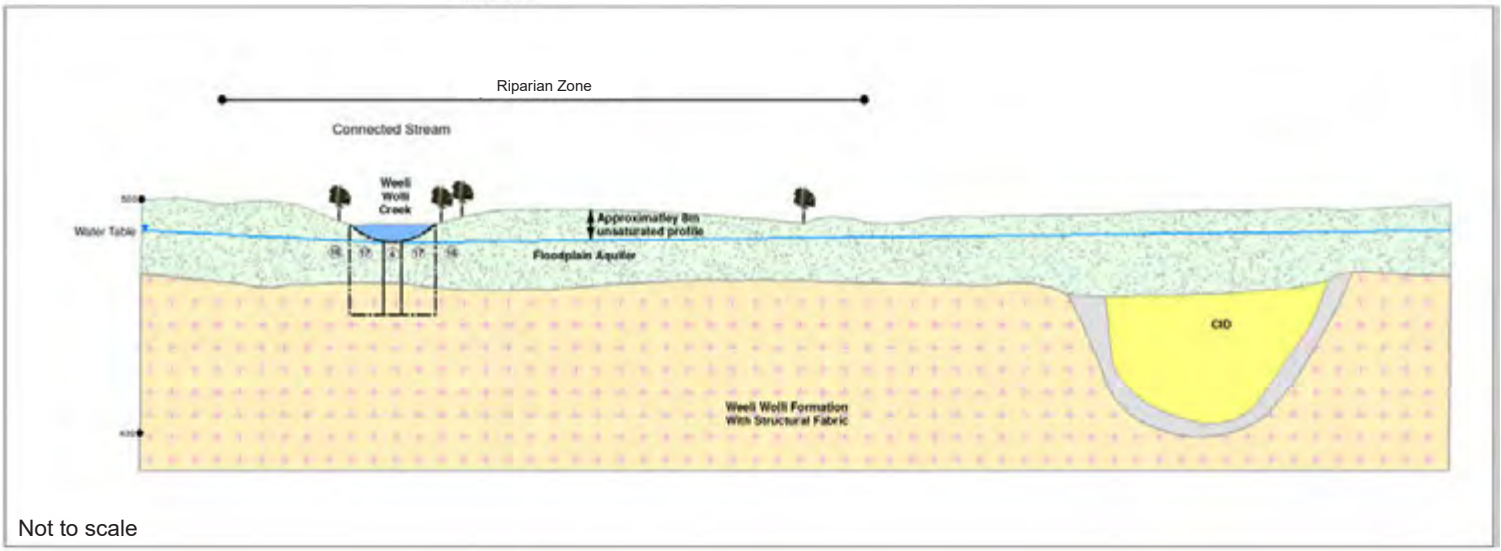
Source: Figure courtesy of URS Australia Pty Ltd

Baseline



Not to scale

Current



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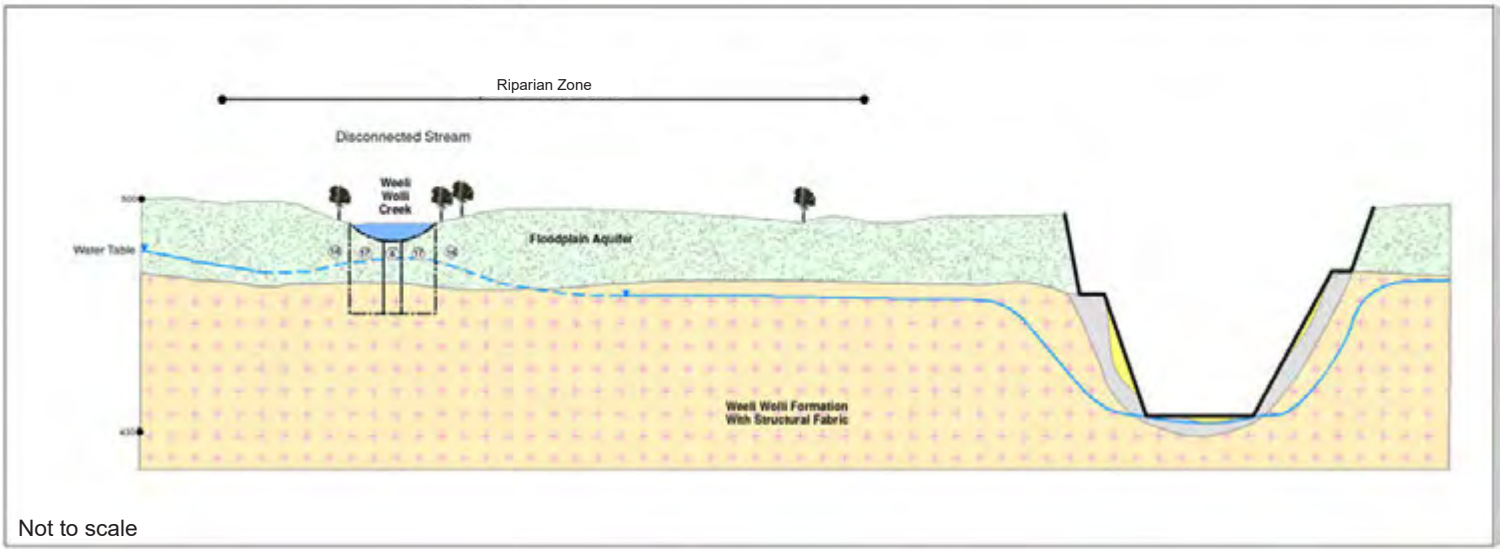
Mining



Not to scale

⑥ Zone Budgets
Alluvial/Insitu Weathered Bedrock
Basal Clay Conglomerate
CID
Weeli Wolli Creek
Weeli Wolli Formation

Figure 37 - Groundwater drawdown schematic - Billiard South

Source: Figure courtesy of URS Australia Pty Ltd

PDE0133863v2

13.3.4 Discharge of surplus water

The Proposal is estimated to require, at its peak, approximately 50 GL/y of dewatering from the total dewatering volume of 83 GL/y produced by the Revised Proposal. Of the 50 GL/y, approximately 33 GL/y is modelled to be from re-dewatering of the discharge volumes from upstream discharge, equivalent to approximately 70% of the Proposal dewatering volume (**Figure 34** and **Figure 35**).

Dewatering volumes will be integrated with the existing and proposed site water demand, with approximately 5 GL/y (up to 11GL/y) to be used for on-site purposes at the Yandi Operations, such as dust control, camp usage and ore processing. Surplus water discharge will include the existing Yandi Operations approved 47 GL/y, which will increase up to 78 GL/y (average of 61 GL/y). The Proposal is predicted to contribute an additional 45-50 GL/y (**Figure 34** and **Figure 35**) of this discharge at its peak.

An extensive range of options (numbering over 20) were considered, with five possible options investigated in further detail for the management of surplus water from the Proposal. Detailed options assessments were carried out for the following:

- Storage of water in JC pit lake.
- Reduction of Hope Downs 1 discharge by reinjecting Hope Downs 1 dewatering volumes.
- Transfer to other current and future mining projects (including Koodaideri).
- Re-injection of Proposal water close to Yandi lease.
- Creek discharge to Marillana Creek.

The findings of these investigations are summarised in **Table 12** with the only technically feasible option being identified as potential to discharge to Marillana Creek.

Table 12: Options assessment for alternative surplus water management strategies

Option	Outcome
Store water in JC pit lake	This option was not feasible because it was found that 90% of the volume would recirculate to nearby dewatering wells.
Re-injection of Hope Downs 1 water	This option was not feasible due to the lack of third party tenure approval/access (to undertake preliminary drilling testwork to prove up suitable locations, and potentially for ongoing use), availability of unsaturated thickness of suitable host aquifers, and limited technical feasibility.
Early transfer to other options	This option cannot manage volumes from the Proposal during peak dewatering periods. Transfer to other projects will continue to be investigated as opportunities arise (including a potential option for the Koodaideri Project).
Re-injection of Proposal water close to Yandi lease	This option was eliminated because the target aquifers were found to be small and would fill quickly. In addition, the proximity of target aquifers to Fortescue Marsh was highlighted as a constraint.
Creek discharge to Marillana Creek	Discharge was determined to be a technically feasible option.

Given the limitations of the water management options, surplus water produced by the Proposal is proposed to discharge in Marillana Creek from a new discharge outlet

adjacent to D09. Discharge has been occurring from D09 since the second half of 2013. The water is constrained to a well defined low-flow line, and is not predicted to extend beyond the existing MS 914 approved extent of 17 km beyond the Marillana – Weeli Wolli Creek confluence. By discharging from D09, the impact footprint along Weeli Wolli Creek is constrained to within currently approved limits.

Given the wetting front is modelled to be within existing approved limits, it is considered that there will be minimal additional effects on the downstream hydrological system of Weeli Wolli Creek. **Figure 38** to **Figure 42** shows a time series of the groundwater drawdown and mounding sequence throughout the Proposal mine life.

13.3.5 Fortescue Marsh

The results of modelling the potential wetting front as a result of discharge from Proposal is not expected to extend beyond the current approved wetting footprint limit in MS 914 of 17 km beyond the Marillana – Weeli Wolli confluence. Given that the current wetting footprint limit is set 28 km from the boundary of the Fortescue Marsh and that wetting front is predicted to be within existing approved limits, it is considered there will be negligible impacts on Fortescue Marsh.

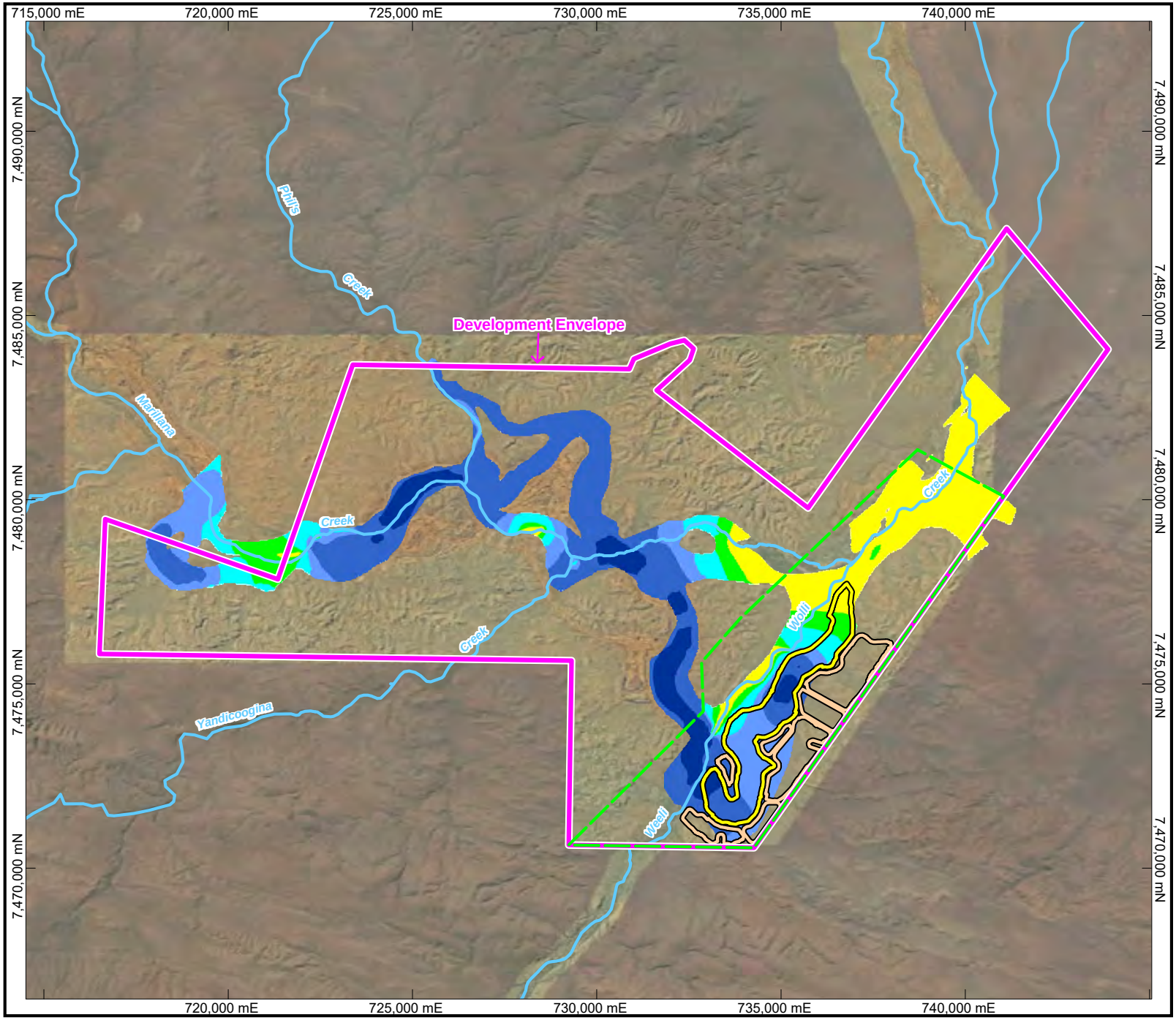
The controlled nature of CIA (impact of the Revised Proposal, Hope Downs 1 and BHP Yandi on Fortescue Marsh water balance) in terms of volume of discharge, and the extent of surface water expression and extensive transient sampling of the surface water and groundwater for chlorine concentration and environmental isotope composition, allowed partitioning of components of water balance that otherwise would not have been possible by water mass balance method alone. The study concluded that although mine water discharge has changed the nature of the connectedness of Weeli Wolli Creek to the underlying aquifer in the upper section associated with the impermeable Weeli Wolli Formation, there has been negligible impact on the overall water balance of the broader catchment.

Most of the recharge to the groundwater aquifer along Weeli Wolli Creek occurs where the creek flows adjacent or across the CID aquifer. The calculated rates of recharge are also commensurate with large flooding events that occur in the region every few years. Changes in surface water connectivity and sustained periods of saturation may nevertheless have localised and probably relatively short term impacts (until the next flood) on the ecology of streams.

Groundwater modelling results suggest that the maximum extent of the drawdown in the CID is 2 km downstream from the Proposal (Rio Tinto 2014d; updated addendum 2015). The location of zero drawdown is approximately 7 km upstream from the Weeli Wolli fluvial plan and 35 km from the Fortescue Marsh.

The cumulative impact of creek discharge and dewatering clearly shows no measurable chlorine concentration change in CID groundwater 4 km up gradient from Weeli Wolli fluvial plane and 32 km from the Fortescue Marsh.

For further details, please see Dogramaci et al. (2015), Dogramaci and Skrzypek (2015), Skrzypek et al. (2013) and Rouillard et al. (2015).



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Drawdown in December 2017

metres

50
30
20
10
5
0

N

SCALE

0 2 4 6km

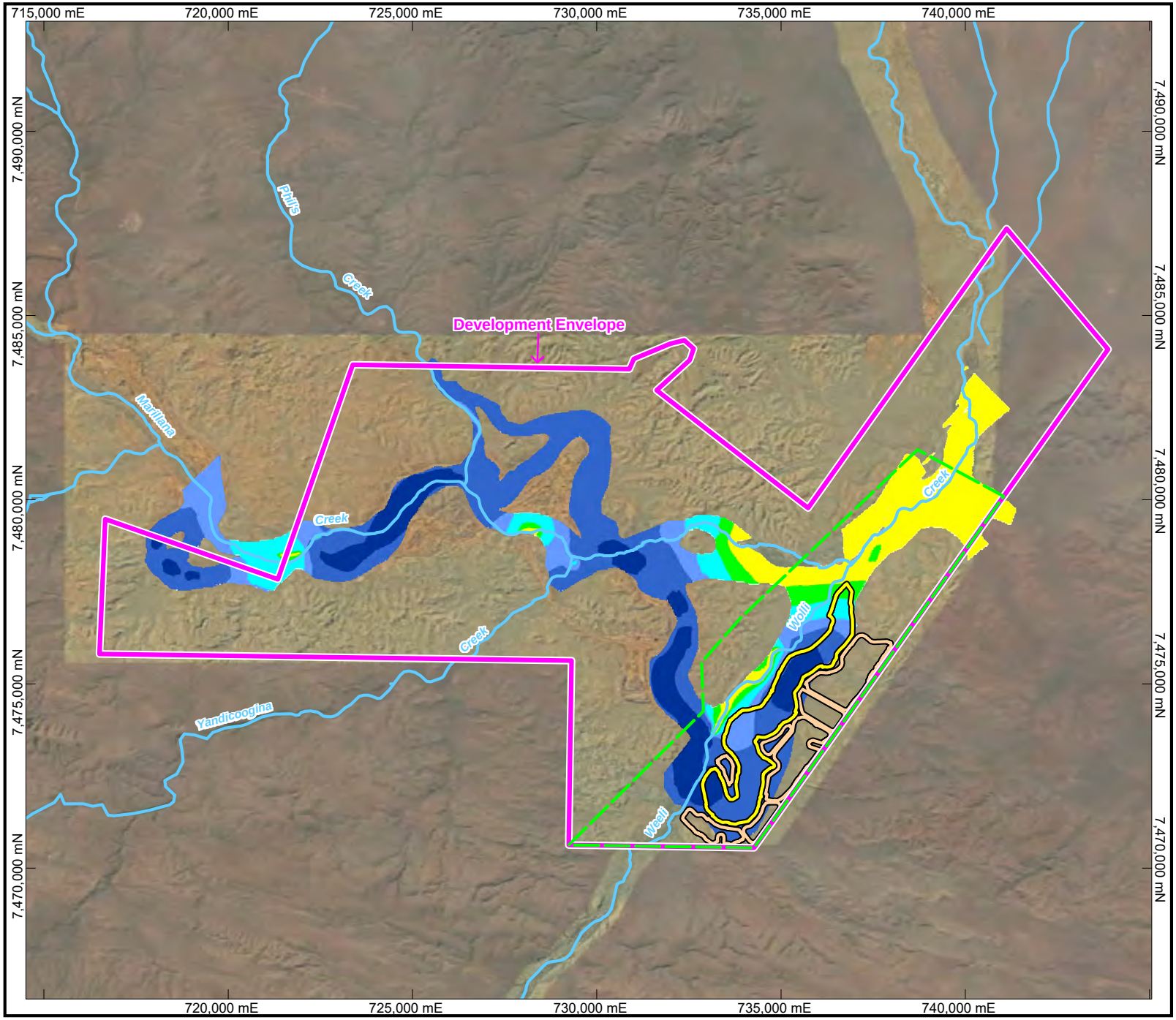
1:150 000 @ A4

Iron Ore (WA)

Figure 38
Predicted water table drawdown in 2017

Drawn: B Jackson Plan No: PDE0133868v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Drawdown in December 2019

metres

50
30
20
10
5
0

N

SCALE

0 2 4 6km

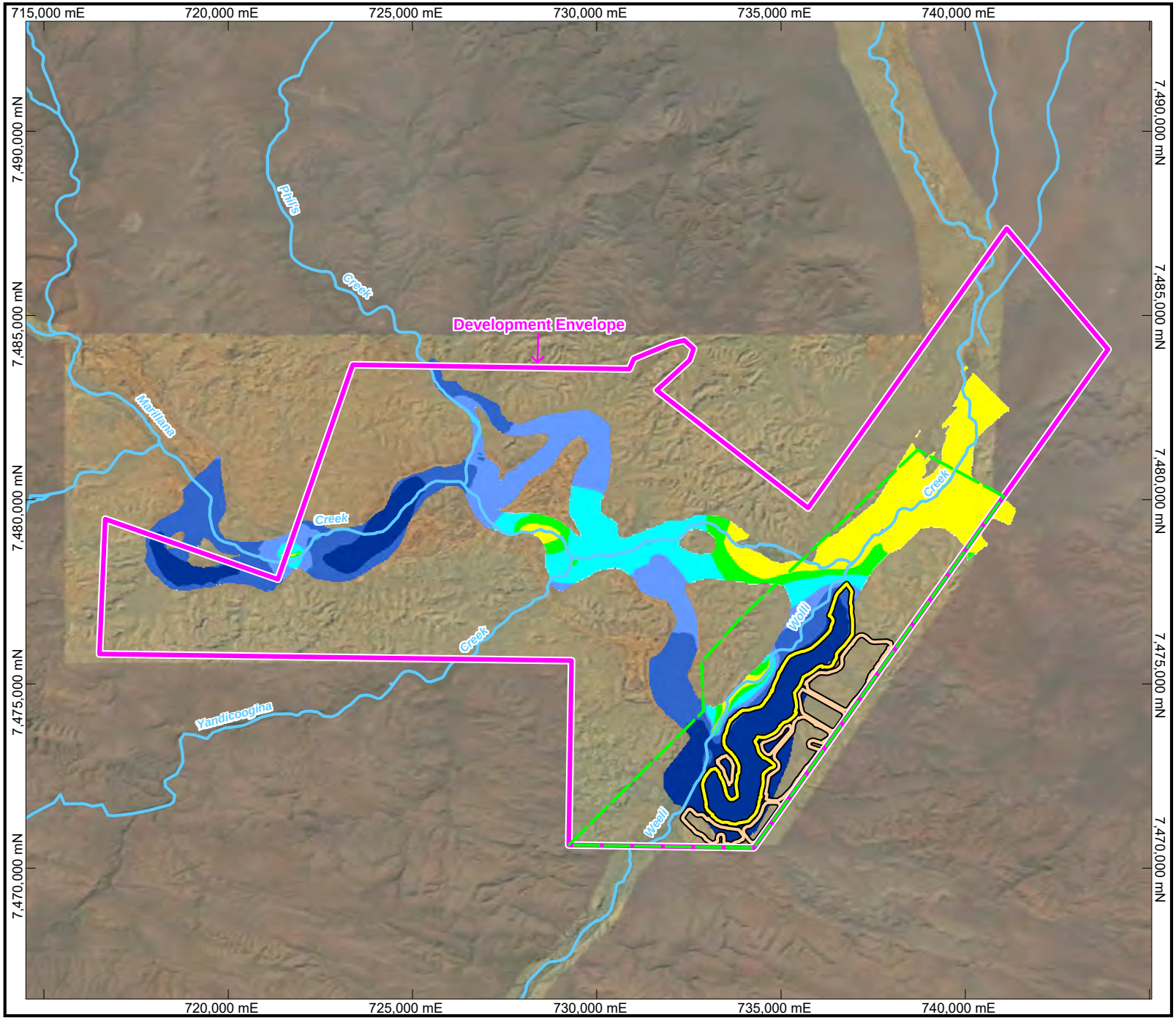
1:150 000 @ A4

Iron Ore (WA)

Figure 39
Predicted water table drawdown in 2019

Drawn: B Jackson Plan No: PDE0133869v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Drawdown in December 2023

metres

50
30
20
10
5
0

N

SCALE

0 2 4 6km

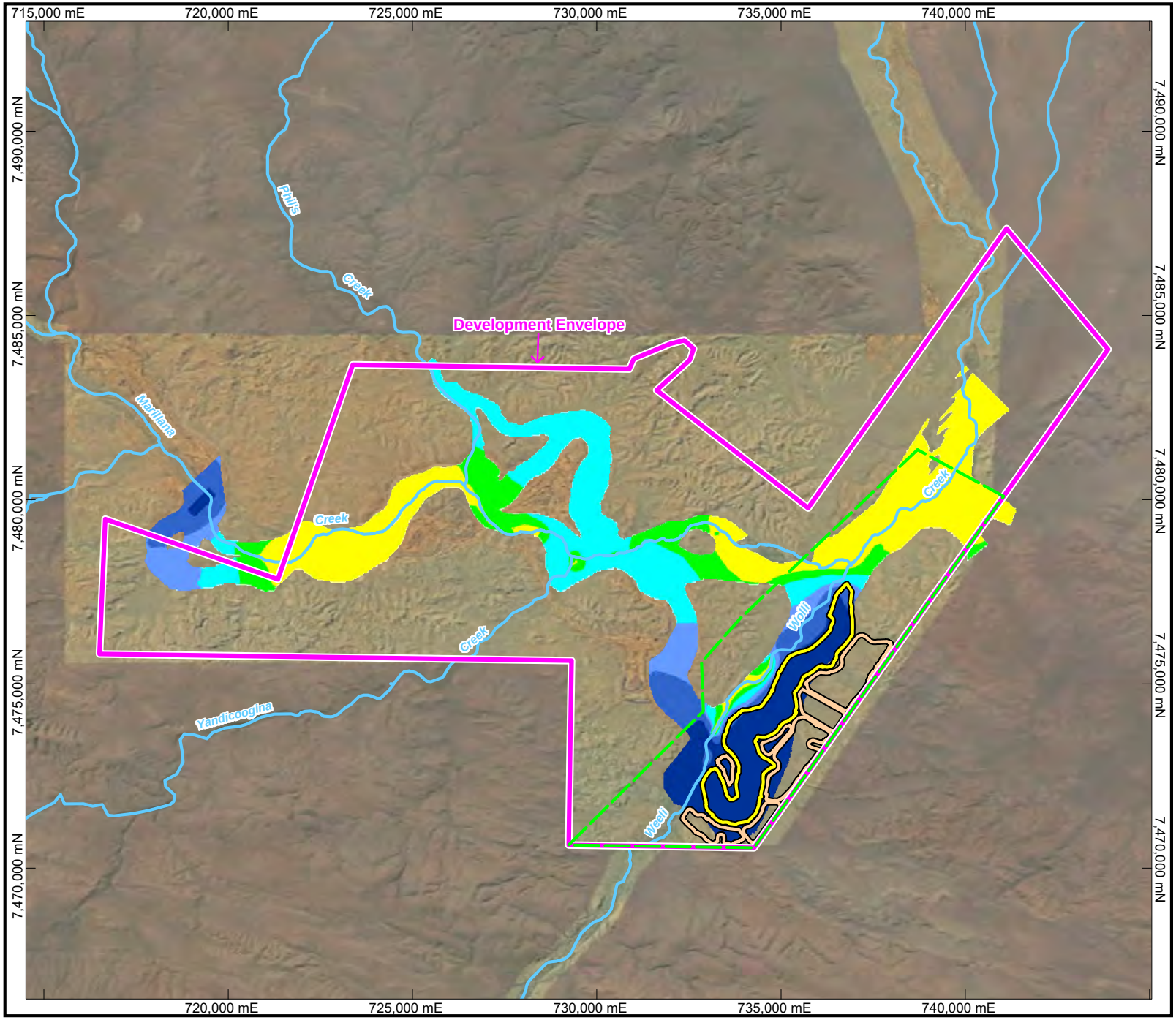
1:150 000 @ A4

Iron Ore (WA)

Figure 40
Predicted water table drawdown and mounding in 2023

Drawn: B Jackson Plan No: PDE0133870v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Drawdown in December 2027

metres

50
30
20
10
5
0

N

SCALE

0 2 4 6km

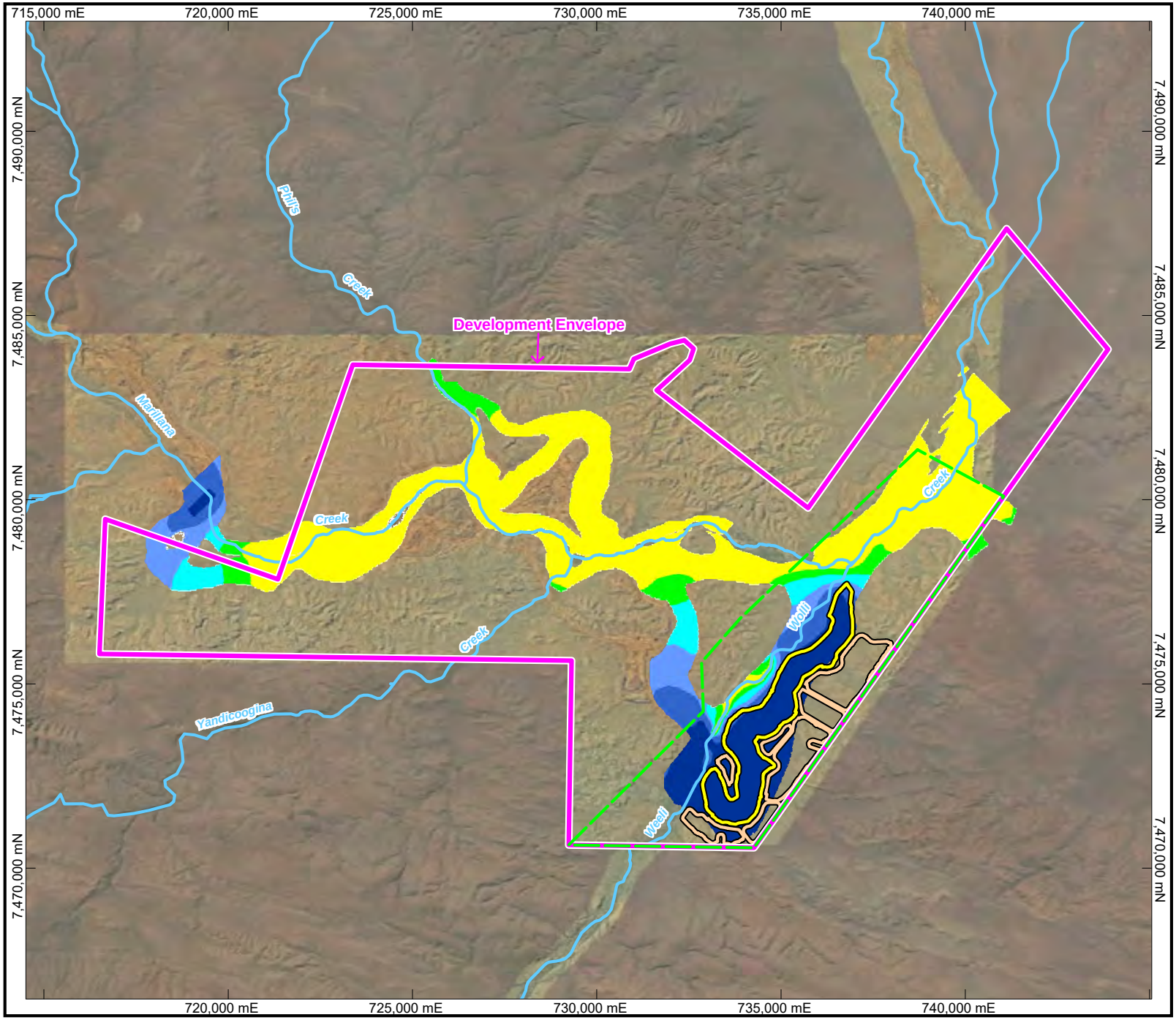
1:150 000 @ A4

Iron Ore (WA)

Figure 41
Predicted water table drawdown and mounding in 2027

Drawn: B Jackson Plan No: PDE0133871v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Drawdown in December 2031

metres

50
30
20
10
5
0

N

SCALE

0 2 4 6km

1:150 000 @ A4

RioTinto

Iron Ore (WA)

Figure 42
Predicted water table drawdown and mounding in 2031

Drawn: B Jackson Plan No: PDE0133872v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

13.3.6 Water quality

As described in Section 13.2.4.2, water quality monitoring to date indicates some minor variation in water quality parameters. However, this is considered to be within natural fluctuations and no significant effects on baseline water quality has occurred as a result of abstraction and discharge activities.

Given the abstraction and discharge of water from the Proposal is from the same water source as the current approved operations, and the wetting front would remain within the limits of MS 914, it is expected that there will not be any significant effects on water quality as a result of the Proposal activities.

Water monitoring will continue in accordance with the Surface Water Discharge and Groundwater Dependent Ecosystem Monitoring and Management Plan.

13.3.7 Contamination of surface and groundwater from waste dumps

Appropriate management of waste dumps will ensure that risks of contamination of surface and groundwater are minimised. Rio Tinto has developed practice standards for handling and managing mineral wastes, as described in the following internal standards:

- Iron Ore (WA) Mineral Waste Management Plan.
- Iron Ore (WA) Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan.
- Iron Ore (WA) Rehabilitation Management Plan.
- Iron Ore (WA) Landform Design Guidelines.

Operational waste dumps will incorporate water management features to reduce the potential for sediment-laden surface water runoff, such as continuous windrows around the base of the dumps and on-site drainage structures being stabilised to minimise erosion. Stormwater will be directed to sedimentation traps to reduce sediment loads in surface water discharged off-site.

The risk of acid rock drainage at the Revised Proposal has been assessed as low based on geochemical interpretation and analytical testing of drill hole samples. As a result, waste rock stockpiles are not considered to present a risk to water quality in the surrounding environment.

Ongoing geochemical sampling and analysis will be undertaken during the life of the Proposal and if the risk from acid rock drainage increases, an Acid Rock Drainage Management Plan for Yandicoogina will be prepared and implemented with endorsement of the relevant decision making authority.

13.3.8 Contamination of surface water from hydrocarbons

Site drainage will be designed to minimise or eliminate surface runoff into areas where activities with a potential risk of hydrocarbon contamination occur.

All areas where there is risk of hydrocarbon contamination will be contained and stormwater collected in these areas will be treated to remove hydrocarbons. These locations may include:

- Bulk fuel storage and handling.
- Heavy vehicle refuelling.

- Light vehicle refuelling.
- Bulk lubricant storage and handling.
- Heavy vehicle workshop.
- Light vehicle workshop.
- Fixed plant maintenance workshop.
- Heavy vehicle wash down.
- Light vehicle wash down.

Treated oily water will be discharged to local evaporation ponds. Treated water from the evaporation ponds may be used for dust suppression on roads within the Revised Proposal Development Envelope. Provision will be made in operating plans for periodic removal of sludge residue from the oily water separators to a licensed disposal facility.

The Proposal will comply with all relevant Australian Standards (e.g. Australian Standard 1940-2004) and statutory requirements (e.g. Operating Licence conditions) for the transport, handling and storage of hydrocarbons, ammonium nitrate and other chemicals required on-site for operations and maintenance purposes.

13.3.9 Post-mining hydrology and pit lakes

Discussion of the post-mining hydrology, including information regarding the two pit lakes that will be formed is addressed in Section 17.

13.4 Cumulative impacts

13.4.1 Cumulative impacts to Marillana and Weeli Wolli Creeks

A preliminary assessment of cumulative impacts to surface water hydrology in the Marillana-Weeli Wolli Creek system was conducted based on a review of the potential impacts of the Proposal, the existing Yandi Operations and six other projects identified as being potentially relevant based on their location in the Weeli Wolli Creek or Marillana Creek sub-catchments of the Upper Fortescue River Catchment (**Table 13**).

The average of existing discharge to the Marillana - Weeli Wolli Creek system is approximately 46 GL/y, with a peak of approximately 70 GL/y. Average discharge is expected to increase to approximately 97 GL/y and may reach a peak of approximately 140 GL/y. The Proposal (this assessment), is predicted to account for approximately 50 GL/y of discharge (approximately 35% of the total peak discharge), with the Revised Proposal modelled to reach a peak discharge of approximately 78 GL/y (approximately 54% of the total catchment peak discharge; **Table 13**).

Table 13: Assessment of potential cumulative impacts to surface water hydrology in the Marillana-Weeli Wolli Creek system

Project	Surface water discharge to the Marillana-Weeli Wolli Creek system	Reference
Past and present actions		
Hamersley HMS's Hope Downs 1 Iron Ore Mine Expansion (EP Act Assessment No. 1308)	Approximately 28 GL/y (up to 36 GL/y) existing discharge. Up to 40 GL/y future discharge. Groundwater abstraction and associated surface discharge of excess water commenced in 2007. Average discharge from 2007 to 2013 was approximately 28 GL/y, with a peak of approximately 36 GL/y. Future discharge is expected to increase to approximately 40 GL/y.	URS (2015)
Iron Ore Holdings Iron Valley Iron Ore Project (EP Act Assessment No. 1905; EPBC Act Ref. 2012/6458)	0 GL. The Iron Valley Iron Ore Project, as referred in 2012, did not include mining below the water table, nor dewatering for pit excavation and ore extraction (and therefore did not include surface discharge of excess dewater).	URS (2012)
BHP Jinidi Iron Ore Mine (EP Act Assessment No. 1904; EPBC Act Ref. 2012/6299)	0 GL existing discharge. 1 GL/y, potentially up to 7 GL/y future discharge. As referred in 2011, construction of the Jinidi Iron Ore Mine was proposed to commence in 2012; however, the proposal is yet to commence. The 2011 referral documentation stated that the proposal could potentially discharge the maximum mine dewatering volume of approximately 7 GL/y to one or more nominated creek locations during discrete periods; however, approximately 6 GL/y was expected to be used during operations for ore conditioning and dust management.	BHP (2011)
BHP Marillana Creek (Yandi) (EP Act Assessment No. 1555)	Approximately 7 GL/y (up to 13 GL/y) existing discharge. Up to 15 GL/y future discharge. Average discharge from 1997 to 2013 was approximately 7 GL/y, with a peak of approximately 13 GL/y. The licensed limit is for a discharge of 15 GL/y.	URS (2015)
BHP Mining Area C (EP Act Assessment No. 1108)	0 GL. The Mining Area C Project, as documented in 1997, did not include mining below the water table, nor dewatering for pit excavation and ore extraction (and therefore did not include surface discharge of excess dewater).	Woodward-Clyde (1997)
Mineral Resources Phil's Creek Iron Ore Mine (EPBC Act Ref. 2009/5107)	0 GL. The Phil's Creek Iron Ore Mine, as referred in 2009, did not include mining below the water table, nor dewatering for pit excavation and ore extraction (and therefore did not include surface discharge of excess dewater).	URS (2009)

Project	Surface water discharge to the Marillana-Weeli Wolli Creek system	Reference
Rio Tinto Yandicoogina Iron Ore Project, comprising: • Junction Central (EP Act Assessment No. 809 & 946) • Junction South East (EP Act Assessment No. 1590) • Junction South West and Oxbow (EP Act Assessment No. 1726; EPBC Act Ref. 2011/5815)	Approximately 11 GL/y (up to 25 GL/y) existing discharge. Average discharge from 1998 to 2013 was approximately 11 GL/y, with a peak of approximately 25 GL/y. The expected future discharge from the Yandicoogina Iron Ore Project (as approved under MS914), is up to 47 GL/y.	URS (2015)
Anticipated project actions		
Rio Tinto Yandi PBS Proposal (this assessment)	The forecast discharge is approximately 50 GL/y from the Proposal. The Revised Proposal will include a combined cumulative peak discharge of up to 78 GL/y and average of approximately 61 GL/y (which includes recycling of discharge from upstream operations).	URS (2015)
Reasonably foreseeable future actions		
NA – none located in the Weeli Wolli Creek or Marillana Creek sub-catchments		
Cumulative impact		
All projects	Existing discharge 46 GL/y (average) up to 70 GL/y (peak). Future discharge 97 GL/y (average/standard) up to 140 GL/y (peak).	As above

13.5 Key management actions

Surface and groundwater values in the Revised Proposal Development Envelope will be protected through implementation of measures set out in the Yandi MMP (**Appendix 4**); the Yandicoogina Groundwater Operating Strategy (GWOS); the E11 Standard: Water Quality Protection and Water Management; the E13 Standard: Chemically Reactive Mineral Waste Control; the E15 Standard: Hazardous Materials and Non-Mineral Waste Control and Minimisation; the Yandicoogina Closure Plan; and existing DoW and DER licence conditions. Key measures include:

- Establishing baseline surface water quality for the local catchment, including the development of site specific trigger values (**SSTV**s) in accordance with ANZECC guidelines. This has also included a hazard analysis to focus on key analytes of concern for the local ecosystem.
- Monitoring of surface water quality at discharge outlets, at upstream inputs of surface water discharge and downstream pools 'mixing zones' to enable a comprehensive understanding of any changes to water chemistry as a result of upstream operations discharges, Revised Proposal discharge, and cumulative downstream water chemistry.
- Monitoring the surface water discharge wetting extent on a monthly basis to ensure that the discharge footprint remains within a 17 km limit from the Marillana – Weeli Wolli confluence.

- Monitoring of aquifer groundwater levels and groundwater quality on a monthly basis via a network of monitoring bores to ensure pH, TDS and hydrocarbons are within acceptable limits.
- The borefield design is optimised and informed by numerical groundwater modelling, field test pumping programs, and the existing monitoring bore network.
- Contaminants such as hydrocarbons are managed via appropriate storage and containment facilities (eg. secondary containment such as bunding); and leak detection systems installed for any below ground storage. Hydrocarbon treatment facilities are used at wash down and workshop areas to minimise potential release into the environment.
- Non-mineral waste is disposed of in engineered, controlled and approved facilities.

13.5.1 Status of existing Yandi Operations management

The ESD prepared by the EPA required provision of information on:

- The current status and outcomes of surface water discharge management actions required by MS 914 Condition 6 – Surface water discharge (Weeli Wolli Creek).
- The effectiveness of the current water management scheme and provide a comparison of its actual operation versus what was predicted including discussion of accuracy. Also detail any problems with how the system has operated and what management measures have been taken when it is not operating as expected.
- Surface water and groundwater quality collected from the existing mining operation at the site. Identifying any adverse changes caused by the mining operation and outlining avoidance, minimisation and management methods to be used to prevent further impacts.

This information is provided in the following sections.

13.5.1.1 Current status and outcomes of MS 914 Condition 6

Condition 6 requires that the Proponent ensures discharge of excess water from the existing Yandi Operations does not cause long term impacts to environmental values of the Weeli Wolli Creek system, and that it does not cause water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence.

Surface expression of discharge is managed through implementation of the Yandi MMP. Surface water discharge modelling predicted that the discharge wetting footprint for the Revised Proposal would have a maximum perennial surface expression up to 17 km downstream from the confluence of Marillana and Weeli Wolli Creeks, assuming that Hope Downs 1 and BHP Yandi Operations are discharging at their full licensed capacity.

Ongoing monitoring indicates that since implementing JSW in 2013, the wetting footprint has ranged between 4 and 10 km downstream from the confluence. Historical measurements of the wetting footprint since 2010 has ranged between 5 and 9 km from the confluence, so the current risk of extending beyond the predicted wetting footprint is deemed low. This is also supported by more recent hydrogeological studies.

The dewatering infrastructure network includes six active discharge outlets, and accommodates an adaptive approach to discharge management. Riparian vegetation condition is monitored concurrently with discharge, taking into account the relationship between vegetation health and water availability. Monitoring results inform the discharge management regime, and discharge volume is adjusted at individual outlets where it is deemed appropriate to support the riparian communities. This adaptive functionality is also taken into consideration in the planning and design phase of new dewatering infrastructure, to maintain capacity to respond to monitoring results throughout the life of mine, as outlined in the management actions of the Yandi MMP.

13.5.1.2 Effectiveness of current water management scheme

Hydrogeological conceptualisation for the Revised Proposal has been refined through numerous investigations, with aquifer geometry, hydraulic properties, response to dewatering stress and groundwater / surface water interactions and is well understood. This detailed level of hydrogeological understanding has allowed for development of appropriate dewatering strategies over time to allow mining of the below water table component of the CID deposit.

The dewatering requirements are reviewed annually to determine if the planned mining progression can be achieved with current dewatering infrastructure. A numerical groundwater model is used to predict temporal and spatial variations in groundwater levels for the period of the mine plan and dewatering targets for each bore and borefield are developed and updated regularly and are set against current mine (medium term plan and Life of Mine) and abstraction licence volumes.

For input into the groundwater model and for reporting purposes, monthly water level data gathered from observation bores across the site is analysed against historical data, taking into account seasonal trends. Water levels generally rise and fall due to seasonal activity and water levels in some monitoring bores can vary significantly due to adjacent operational pump activity, which itself varies over time.

Review of historical abstraction performance shows that actual abstraction was between 90-100% of modelled volumes from 2010 to 2012, decreasing to approximately 70-75% of model target volumes in during 2013 and 2014. These dewatering volumes are lower again from the Groundwater Licence volume allocation which allow for a conservative buffer between the modelled volumes and the licence limit. Therefore the actual volume of dewatering at Yandi Operation has been up to 30% less than the licensed limit. This divergence of actual from modelled volumes has been attributed to: periodical mining disruptions; delay in fit-out of bores during 2013; achievable rates from installed bores being less than model-assumed rates; and engineering design matters resulting in non-continuous bore pumping (i.e. oversized pumps and electrical faults).

To date, the mine plan has not been affected by the lower than expected (modelled) abstraction rates.

The effectiveness of the existing re-injection scheme in the vicinity of Billiard South has been limited with the system never reaching full capacity as designed. The maximum re-injection reached was 6.0 GL/y, with an average re-injection rate of around 3.4 GL/y. The limiting factors being attributable to clogging of the bores from iron-reducing bacteria; suitability of localised geology at individual bores to receive large volumes of water; and location of the re-injection scheme within an aquifer receiving discharge from upstream operations, which has been effectively “filling up” the aquifer, limiting available storage to

receive re-injection water. The re-injection scheme was subsequently decommissioned in mid 2014.

13.5.1.3 Review of surface and groundwater quality

Surface water quality is managed in alignment with ANZECC/ARMCANZ (2000) guidelines, to protect the environmental values of Weeli Wolli Creek listed in the Environmental Values Statement. Water quality is monitored at each active discharge outlet, and in the surface waters of Marillana and Weeli Wolli Creeks, upstream and downstream from operational discharge. A conservative approach has been adopted by establishing baseline water quality conditions in Marillana and Weeli Wolli Creeks individually, and selecting the 80th percentile of the baseline range as outlined in the ANZECC/ARMCANZ guidelines, as a trigger to investigate water quality trends downstream from discharge outlets. Investigation includes water quality trends within the catchment up to the furthest extent of the wetting footprint, and reviewing the potential impacts of water quality on aquatic fauna.

A specialist consultancy (Wetland Research and Management) has been engaged to complete extensive studies on aquatic fauna, and provide annual wet and dry season monitoring and reports to validate the impacts of discharge water quality to the surrounding catchment.

Complementary to the aquatic fauna program, a hazard analysis was completed for operational discharge into Marillana and Weeli Wolli Creeks. The hazard analysis took into consideration baseline information on aquatic fauna monitoring along with the Environmental Values Statement, and provided a risk ranking for individual analytes naturally occurring in the groundwater being discharged. Stress from nitrates and carbonate were identified as the most notable risks, as they can support processes which lead to eutrophication and creek bed 'armouring' as a result of deposition of precipitate, which has the potential to remove suitable habitat for aquatic fauna. Toxicity from a range of analytes was acknowledged as posing a lower risk to the catchment.

Ongoing monitoring and analysis of both water quality and aquatic fauna has improved the understanding of aquatic ecology within the lower Weeli Wolli Creek catchment. The 2014 Annual Compliance Assessment Report (required by condition 4-6 of MS 914) details the results of water quality monitoring, including each individual water quality result which exceeded the 80th percentile trigger value. The 80^{th} percentile trigger value was exceeded at least once during the reporting period for hardness, alkalinity, bicarbonate alkalinity, electrical conductivity, total suspended solids, total dissolved solids, barium, boron, calcium, chloride, magnesium, nitrate, total nitrogen, total phosphorus, potassium, sodium, sulphate, sulphur, and uranium. These exceedances have triggered the "focus" and "investigate" actions (including resampling to check for potential sampling issues such as cross contamination during the sampling process). The occurrence of exceedances is not unexpected given the triggers have been established using a conservative 80^{th} percentile value to ensure that any management response (if necessary) can be implemented sufficiently soon to ensure environmental impacts are minimised. To date, no management or control actions in response to water quality exceedances have been necessary.

Field observations, which included localised variation in aquatic fauna assemblages and habitat both upstream and downstream of operational discharge, indicate that the existing Yandi Operations discharge is not causing long term impacts to the values of Weeli Wolli Creek. Taxa richness of microinvertebrates, macroinvertebrates, hyporheic invertebrates

and fish does not appear to be adversely impacted by water quality, indicating that eutrophication and creek bed 'armouring' risks are currently low. Algal growth, nitrate concentrations and nutrient cycling remain key components of ongoing monitoring, and a continually developing understanding of the relationships between these components at a local scale will ensure that the correct approach is taken to evaluate ecosystem health.

13.6 Predicted outcome

A range of measures have been or will be implemented to reduce potential impacts to the environmental values of hydrological processes and inland waters environmental quality (**Table 14**).

Table 14: Mitigation hierarchy for hydrological processes and inland waters environmental quality values

Mitigation measure	Description
Avoidance	Direct disturbance to Weeli Wolli Creek will largely be avoided and low-flow lines will be maintained. Impacts to the Fortescue Marsh are predicted to be avoided. No impacts from acid mine drainage are expected due to the low risk presented by the geochemistry of the waste rock and pit wall material.
Minimisation	Infrastructure in Weeli Wolli Creek designed to avoid disruption of low-flow line and flood flows. Discharge would occur from existing approved locations. The surface water wetting front is predicted to remain within existing approved limits.
Rehabilitation	Disturbed areas will be rehabilitated consistent with the Yandicoogina Closure Plan. Key functional creek elements retained (e.g. flood pathways, vegetation seed bank) to support natural rehabilitation upon closure.

After the mitigation hierarchy has been applied, it is expected that the Proposal will result in the following residual outcomes in relation to hydrological processes and inland waters environmental quality:

- **Natural surface water systems and flows** – potential impacts likely to be minor and can be managed through typical stormwater management measures such as levees around the pit, diversion drains around waste dumps, and culverts under roads.
- **Surface water resources including Weeli Wolli Creek due to surface discharge of surplus mine dewater** – wetting front will be within existing approved limits, and therefore there will be negligible additional impacts on the downstream hydrological system of Weeli Wolli Creek.
- **Altered flow regime to the Fortescue Marsh** – surface water wetting front associated with the additional discharge from the Proposal is predicted to remain within existing approved limits of MS 914.
- **Potential contamination of surface water and groundwater** – acid rock drainage at the Revised Proposal has been assessed as low due to the geology. Site drainage will be designed to minimise or eliminate surface runoff into areas where activities with a potential risk of hydrocarbon contamination occur. Management of waste dumps will ensure that risks of contamination of surface and groundwater are minimised.

With the exception of the development of pit lakes upon closure (which are addressed further in Section 17), the above residual outcomes are potential environmental impacts that may occur during the mine life and are not predicted to result in long term or significant changes for hydrological processes and inland water quality.

14. Flora and vegetation

14.1 Key statutory requirements, environmental policy and guidance

14.1.1 EPA objective

The EPA has applied the following objective for the Proposal to its assessment of flora and vegetation:

"To maintain representation, diversity, viability and ecological function at the species, population and community level."

14.1.2 Regulatory framework

The following legislation is relevant to the Proposal with respect to the protection of flora and vegetation values and the above EPA objective:

- *Wildlife Conservation Act 1950* (WA) and associated Wildlife Conservation (Rare Flora) Notice 2014.
- *Conservation and Land Management Act 1984* (WA).
- *Environmental Protection Act 1986* (WA) and associated Native Vegetation Regulations 2004.
- *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth).

14.1.3 Relevant guidelines and policy

The following guidelines are relevant to the Proposal with respect to the protection of flora and vegetation values and the above EPA objective:

- EPA Position Statement No. 2: Environmental Protection of Native Vegetation in Western Australia (EPA 2000).
- EPA Position Statement No. 3: Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002).
- EPA Position Statement No. 7: Principles of Environmental Protection (EPA 2004a).
- EPA Guidance Statement No. 51: Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia (EPA 2004c).

14.2 Description of factor

14.2.1 Flora and vegetation surveys

Biota conducted a number of flora and vegetation surveys within the Proposal Area and in the wider Yandicoogina locality (Biota 2014a, Biota 2015a). A consolidated list of all flora and vegetation surveys completed to date is provided in **Table 15**. In March and July of 2014 Biota conducted seasonal surveys of the Proposal Area (Biota 2014a).

A total of 121 quadrats and 28 relevés have been sampled in the study area to date, with 46 quadrats and eight relevés established during Phase 1 of the most recent survey, and three additional quadrats established during Phase 2. In total, 68 quadrats have been sampled twice within the Proposal Area, including quadrats sampled prior to this survey (**Table 16**; **Figure 43**).

In addition to the Biota vegetation mapping, a Rio Tinto botanist further refined the mapping within major creeklines and tributaries and identified 12 additional riparian associations (**Table 16**; Rio Tinto 2015a).

Limitations of the flora and vegetation surveys primarily constituted the following factors:

- While targeted searches for conservation significant flora were undertaken and opportunistic taxa were recorded during representative traverses through all habitats in the study area, the entire study area was not systematically searched. The list of vascular flora documented from the study area is therefore not exhaustive.
- The Phase 1 survey was undertaken in March 2014 and was optimally timed for the collection of annual flora. The Phase 2 survey was undertaken in July, which is typically a dry time of year in the Pilbara, however, above average rainfall was received prior to this survey. Given the favourable rainfall conditions, most species should have been present during the field surveys, however, it is possible that some annual fire ephemeral or cryptic perennial species would have been absent during the Phase 2 survey due to the seasonal timing.
- Consistent with the accepted level of effort for a survey of this type and scale, fungi and nonvascular flora (algae, mosses and liverworts) were not sampled.
- One Hills, Ridges and Breakaways vegetation type (H5) was described from relevés rather than quadrats. Quadrats could not be established in this vegetation type due to the narrow dimensions of the habitat and the steep, rocky terrain.
- Areas already cleared for drilling and associated activities were not surveyed.

Table 15: Flora and vegetation survey effort within the wider Yandicoogina locality

Study (Reference)	Area Surveyed Within Study Area (Total Area of Survey)	Survey Description Survey Timing (Conditions for Plant Growth)
Yandi Billiards – Phase 1 and Phase 2 (Yandi PBS; Biota 2014a)	8,640 ha (8,640 ha)	Two phase (seasonal) vegetation and flora survey of the PBS survey area to expand the existing data for the area to a Level 2 standard. 8 – 20 March 2014 (favourable); 7 – 11 July 2014 and 14 July 2014 (favourable)
Yandi Junction South West (JSW)/Oxbow (YOX) Vegetation and Flora Integration Report (Biota 2014b cited in Biota 2015a)	2,133 ha (2,192 ha)	Integration of existing data with a further botanical survey to provide additional information on the values associated with the JSW and YOX survey areas. 27 February – 4 March 2012 (favourable)
Yandi Additional Areas (Biota 2014c cited in Biota 2015a)	2,807 ha (2,828 ha)	Establish additional quadrats to validate vegetation mapping of additional areas around the JSW and YOX deposits to match the project footprint. 12 – 18 June 2012 (favourable)
Yandicoogina Additional Vegetation Mapping (Biota 2011a cited in Biota 2015a)	2,806 ha (3,030 ha)	Mapping of additional areas around the JSW and YOX deposits to match the project footprint. 29 November – 3 December 2010

Study (Reference)	Area Surveyed Within Study Area (Total Area of Survey)	Survey Description Survey Timing (Conditions for Plant Growth)
		(unfavourable)
Vegetation and Flora Surveys of the Oxbow and Junction South West Deposits, near Yandicoogina (Biota 2010a cited in Biota 2015a)	YOX: 665 ha (725 ha) JSW: 1,460 ha (1,460 ha)	Two phase (seasonal) vegetation and flora survey of the JSW and YOX survey areas. YOX: 27 July-6 August 2008 (unfavourable); 3-9 June 2009 (favourable). JSW: 4 – 16 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable)
A Flora and Vegetation Survey of the Billiards Deposit, near Yandi (Biota 2009a cited in Biota 2015a)	1,512 ha (1,512 ha)	Two phase (seasonal) vegetation and flora survey of the Billiards survey area. 11 – 20 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable)
Yandicoogina Waste Dumps, Topsoil Stockpiles and Haulroads Native Vegetation Clearing Permit Report (Biota 2009b cited in Biota 2015a)	406 ha (406 ha)	Single phase vegetation and flora survey of four development areas to support a Native Vegetation Clearing Permit. 4 – 7 September 2008 (unfavourable)
Vegetation Mapping and Rare Flora Searches of Yandi Backfill Hill (Biota 2005 cited in Biota 2015a)	189 ha (189 ha)	Vegetation mapping and systematic Rare Flora searches of the Yandi Backfill Hill survey area. 31 May – 2 June 2005 (unfavourable)
Yandi Expansion Vegetation and Flora Survey (Biota 2004a cited in Biota 2015a)	2,245 ha (2,245 ha)	Single phase vegetation and flora survey of the Yandi Expansion area, near the YJC deposit. 30 August – 5 September 2004 (unfavourable)
Flora and Vegetation Survey of the Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b cited in Biota 2015a)	1,492 ha (3,977 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor Extension through the Hamersley Range. April 2003 (favourable)
Vegetation and Flora of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002 cited in Biota 2015a)	805 ha (2,774 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli. 25 April – 14 May 2001 (favourable) 29 May – 10 June 2001 (favourable)
Hope Downs Rail Corridors Biological Surveys (Halpern Glick Maunsell 2000a cited in Biota 2015a)	2,594 ha (16,420 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridors. 25 November – 3 December 1999 (unfavourable)
Flora and Vegetation: Yandicoogina Junction Area (Mattiske 1995a cited in Biota 2015a)	3,591 ha (3,745 ha)	Single phase vegetation and flora survey of the YJC survey area. January and March 1994 (unknown) February 1995 (unknown)
Flora and Vegetation: Northern Transport Corridor, Yandicoogina Junction Project Area (Mattiske 1995b cited in Biota 2015a)	3,035 ha (24,703 ha)	Single phase vegetation and flora survey of the Yandi Northern Transport Corridor. February 1995 (unknown)
Flora and Vegetation: Southern Transport Corridor, Yandicoogina	2,450 ha (30,103 ha)	Single phase vegetation and flora survey of the Southern Transport

Study (Reference)	Area Surveyed Within Study Area (Total Area of Survey)	Survey Description Survey Timing (Conditions for Plant Growth)
Junction Project Area (Mattiske 1995c cited in Biota 2015a)		Corridor. January and March 1994 (unknown) February 1995 (unknown)
Ecological appraisal of the Yandicoogina Project Area (Integrated Environmental Services 1981)	25,000 ha	Single phase Flora, fauna and vegetation survey of the area in favourable conditions

Table 16: Flora and vegetation survey effort within the Proposal Area

Survey	Timing	Methodology
Riparian vegetation of Marillana and Weeli Wolli Creeks: Mapping refinement and assessment of values and significance (Rio Tinto 2015a)	April 2015	Desktop and mapping traverses
Yandi PBS flora and vegetation survey (Phase 2; Biota 2014a)	July 2014	Three new quadrats established and 30 quadrats resampled
Yandi PBS flora and vegetation survey (Phase 1; Biota 2014b)	March 2014	46 quadrats established, 32 quadrats resampled and eight relevés recorded
Yandi additional areas Level 2 flora and vegetation survey (Biota 2014c cited in Biota 2015a)	June 2012	11 quadrats and five relevés established
Vegetation and flora survey of the Billiards deposit, near Yandi (Biota, 2009a cited in Biota 2015a)	June 2007	29 quadrats and 14 relevés established
	July/August 2008	Seven new quadrats established and 11 quadrats resampled
	June 2009	Six quadrats resampled
Flora and Vegetation Survey of the Yandi Expansion Area (Biota 2004a cited in Biota 2015a)	Aug/Sept 2004	13 quadrats and one relevés established
Flora and Vegetation Survey of the Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b cited in Biota 2015a)	April 2003	Nine quadrats established
Vegetation and Flora of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002 cited in Biota 2015a)	April/May 2001	Two quadrats established
Hope Downs rail Corridor Biological Surveys (Halpern Glick Maunsell 2000a cited in Biota 2015a)	Nov/December 1999	One quadrat established

14.2.2 Vegetation

14.2.2.1 Vegetation communities present in the Proposal Area

The Proposal lies within the Fortescue Botanical District of the Eremaean Botanical Province as defined by Beard (1975a, 1975b). The Proposal intersects two of the vegetation units defined by Beard (1975a, 1975b), both of which have the majority of their pre-European extent remaining (Table 17).

Table 17: Beard's (1975b) mapping units that occur in the study area and their extent in the Pilbara bioregion

Beard's vegetation mapping unit	Current extent in the Hamersley/Fortescue subregion (ha) (% remaining)	Extent within the study area (% of the current mapped extent)
Fortescue Valley 29	893,222 (>99.9%)	2,586 (0.3%)
Hamersley 82	2,165,235 (99.4%)	1,909 (0.1%)

Source: Government of Western Australia (2013b)

Biota (2014a) mapped and described 23 vegetation sub-associations ('vegetation units') within the Proposal Area (**Figure 44** to **Figure 47**). A full list of the Biota (2014a) mapping units are provided in **Appendix 3**. The Biota (2014a) vegetation units have been grouped according to the major landform with which they are associated. In addition to the Biota vegetation mapping, a Rio Tinto botanist further refined the mapping within the riparian zones in Marillana and Weeli Wolli Creeks. Biota's original C1-C5 units were further differentiated and a total of 13 riparian sub-associations throughout the greater Yandicoogina area (**Appendix 3**). The vegetation units shown in **Figure 44** to **Figure 47** are the Biota mapping units, the refined riparian vegetation mapping is shown in **Figure 48** to **Figure 52**. Refer to Appendix 3 for full descriptions of all refined riparian vegetation units (Rio Tinto 2015a).

Vegetation of Major Creeklines and Tributaries

Of Biota's five original riparian units, four (C1-C4) were mapped within the Proposal Area. Further refinement of these units by Rio Tinto (2015a) identified 13 sub-associations of which 10 occurred in the Proposal Area. These units were characterised by the presence of *Eucalyptus camaldulensis* and *E. victrix* and to a lesser extent *Melaleuca argentea*. All of these units are associated with the "all major ephemeral water courses" ecosystem at risk listed by Kendrick (2003a, 2003b).

The major creekline vegetation units comprised 18% of the Proposal Area.

Vegetation of Minor Creeklines, Floodplains and Valleys

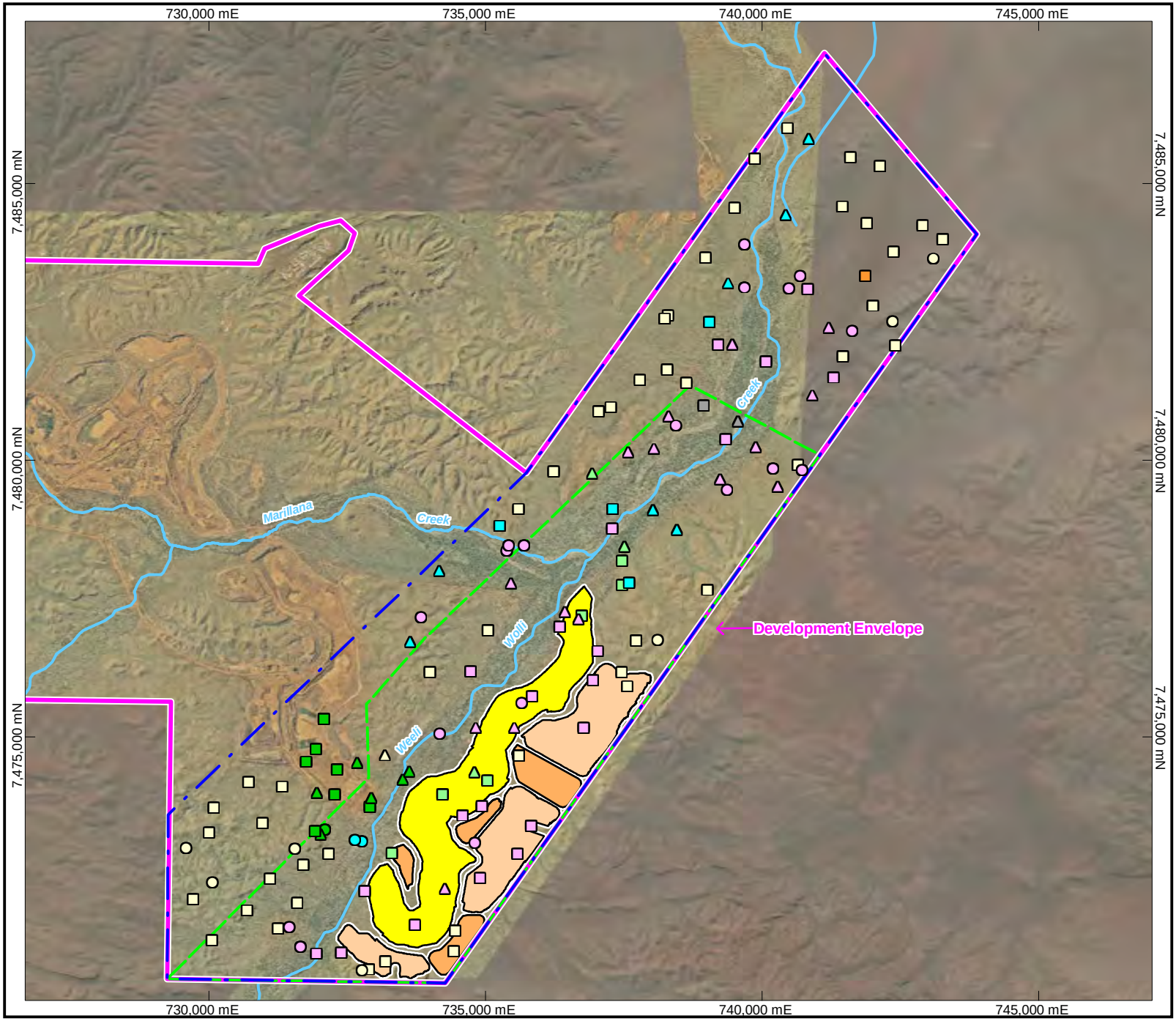
Five vegetation units (F1-F5) have been mapped in minor drainage lines, floodplains and valleys. The minor creekline, floodplain and tributaries vegetation units comprised 8% of the Proposal Area.

Vegetation of Hills, Ridges and Breakaways

Five vegetation units (H1-H5) have been mapped associated with hills, ridges and breakaways. These units comprised 28% of the Proposal Area and supported the recorded populations of the Threatened *Lepidium catapycnon*.

Vegetation of Plains

Eight vegetation units (P1-P8) have been mapped associated with plains. The Priority 4 *Goodenia nuda* is associated with claypans of the Plains units. Plains vegetation units comprised 46% of the Proposal Area.



LEGEND

- Development Envelope
- Proposal Area
- Biota 2014a Study Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Flora Sampling Sites

Site Type

- Quadrat
- Quadrat (Resampled)
- Releve

Study

- Biota (Current Study)
- Biota (2014b)
- Biota (2009b)
- Biota (2004a)
- Biota (2004b)
- Biota 2002
- Halpern Glick Maunsell (2000)

N

SCALE

0 1 2 3 4 5km

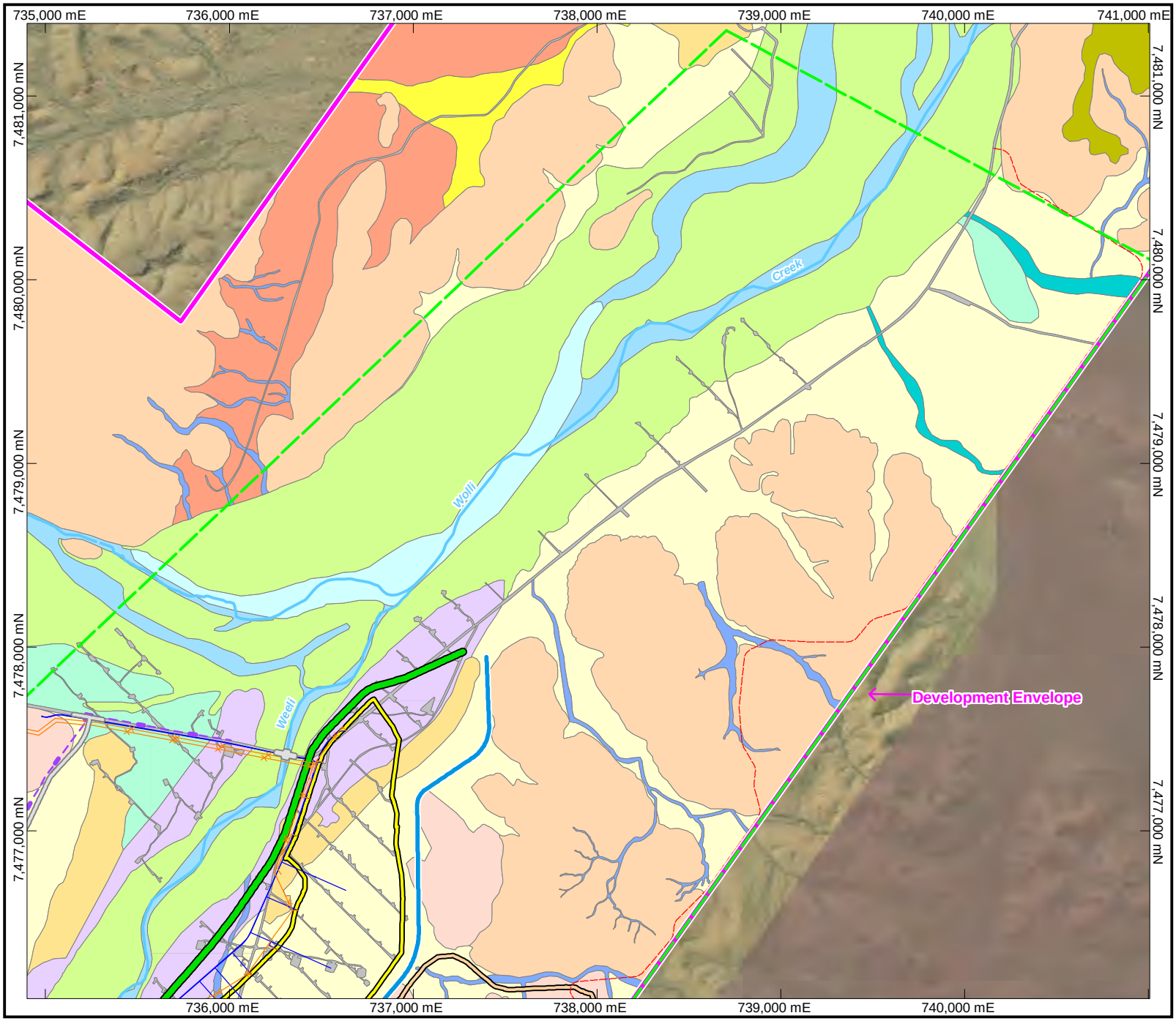
1:100 000 @ A4

Iron Ore (WA)

Figure 43
Flora and vegetation sampling locations in the Proposal Area

Drawn: M.Swebbs Plan No: PDE0131880v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Major Watercourse

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Levee
- HV & LV Road
- Diversion Drain
- Dewatering Pipeline
- 33kV Powerline
- Fibre Optic Cable
- Bypass Track

N

SCALE

0 0.5 1 1.5km

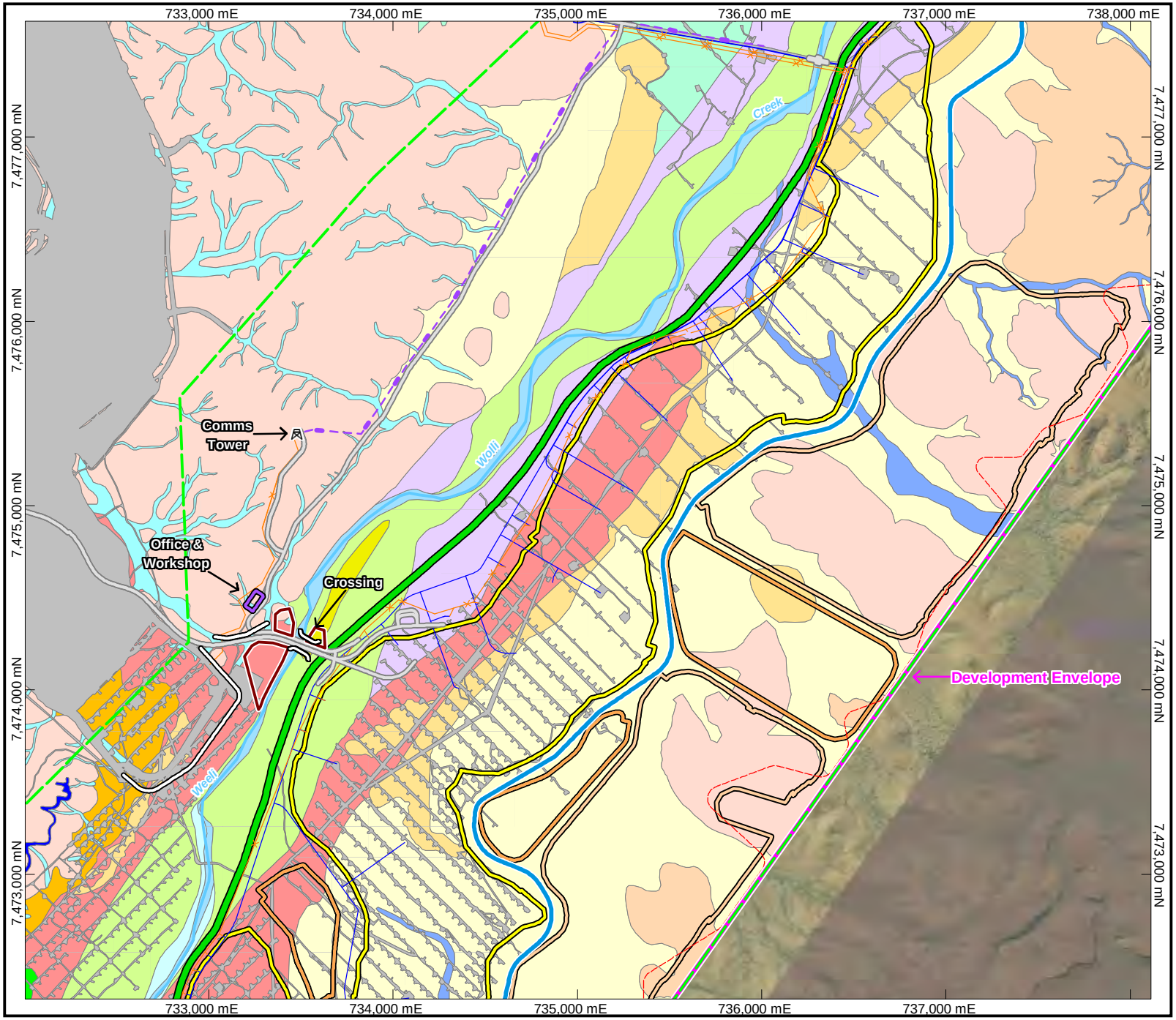
1:30 000 @ A4

Iron Ore (WA)

Figure 44
Vegetation units in the Proposal Area (Map 1)

Drawn: M.Swebbs Plan No: PDE0131793v3
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Major Watercourse

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil / Subsoil Stockpile
- Office & Workshop
- Crossing Drainage Management
- Levee
- Pillar Levee
- HV & LV Road
- Diversion Drain
- Dewatering Pipeline
- 33kV Powerline
- Fibre Optic Cable
- Bypass Track

N

SCALE

0 0.5 1 1.5km

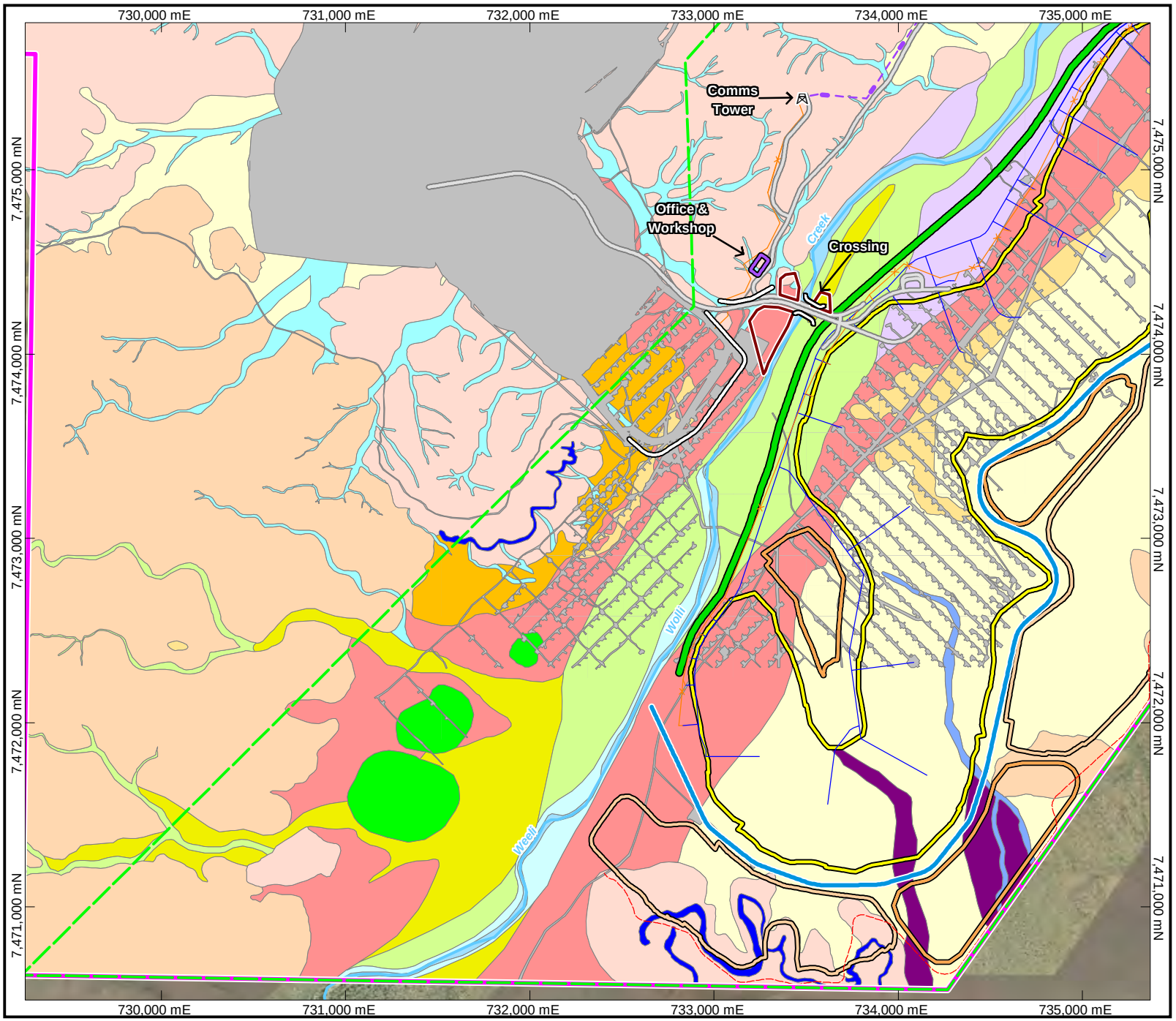
1:30 000 @ A4

Iron Ore (WA)

Figure 45
Vegetation units in the Proposal Area (Map 2)

Drawn: M.Swebbs Plan No: PDE0131793v3
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Major Watercourse

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil / Subsoil Stockpile
- Office & Workshop
- Crossing Drainage Management
- Levee
- Pillar Levee
- HV & LV Road
- Diversion Drain
- Dewatering Pipeline
- 33kV Powerline
- Fibre Optic Cable
- Bypass Track

N

SCALE

0 0.5 1 1.5km

1:30 000 @ A4

Iron Ore (WA)

Figure 46
Vegetation units in the Proposal Area (Map 3)

Drawn: M.Swebbs Plan No: PDE0131793v3
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Figure 47 - Vegetation units in the Proposal Area

Vegetation of Major Creeklines and Tributaries

C1: EcEvMaMgAc
Eucalyptus camaldulensis subsp. refulgens, E. victrix woodland over Melaleuca argentea, M. glomerata, Acacia coriacea subsp. pendens low open woodland

C2: EvChAtuGwTErCYpERltTHt
Eucalyptus victrix, (Corymbia hamersleyana) scattered low trees over Acacia tumida var. pilbarensis, Grevillea wickhamii tall shrubland over Tephrosia rosea var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over Cymbopogon ambiguus, C. procerus Eriachne tenuiculmis, Themeda triandra very open tussock grassland

C3: EvAciAcMgCEc
Eucalyptus victrix scattered trees over Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata tall open shrubland over *Cenchrus ciliaris scattered tussock grasses

C4: EvAciAprAThCEc
Eucalyptus victrix open woodland over Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca low woodland over *Cenchrus ciliaris tussock grassland

Vegetation of Minor Creeklines, Floodplains and Valleys

F1: ChAtuGwTp
Corymbia hamersleyana scattered low trees to low open woodland over Acacia tumida var. pilbarensis, Grevillea wickhamii tall open shrubland over Triodia pungens hummock grassland

F2: AprAciCEc
Acacia pruinocarpa, A. citrinoviridis tall open shrubland over *Cenchrus ciliaris tussock grassland

F3: ElChAtuAaAbGwTspp
Eucalyptus leucophloia, Corymbia hamersleyana low open woodland over Acacia tumida var. pilbarensis, A. ancistrocarpa, A. bivenosa, Grevillea wickhamii tall open scrub over mixed Triodia hummock grassland

F5: ChAciAaAiSENsppTp
Corymbia hamersleyana scattered low trees over Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera tall open shrubland over Senna spp. open shrubland over Triodia pungens open hummock grassland.

Vegetation of Hills, Ridges and Breakaways

H1: ElHcAiGwTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii tall open shrubland over Triodia sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

H2: ElAiTwTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over Acacia inaequilatera scattered tall shrubs over Triodia wiseana, (T. sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland

H5: ElCfERlmTHspp
Eucalyptus leucophloia subsp. leucophloia, Corymbia ferriticola scattered low trees over Eremophila latrobei subsp. filiformis, Senna spp. scattered shrubs over Cymbopogon ambiguus, Eriachne mucronata, Themeda sp. Mt Barricade (M.E. Trudgen 2471), T. triandra open tussock grassland

Vegetation of Plains

P1: ElEgAprAbAaAdTwTpTsps
Eucalyptus leucophloia subsp. leucophloia scattered low trees over E. gamophylla scattered low mallees over Acacia pruinocarpa scattered tall shrubs over A. bivenosa, A. ancistrocarpa, A. dictyophleba shrubland over Triodia wiseana, T. pungens, T. sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

P2: ChAprAiAsclApaTp
Corymbia hamersleyana, Acacia pruinocarpa scattered low trees over A. inaequilatera, A. sclerosperma subsp. sclerosperma, A. pachyacra tall open shrubland over Triodia pungens hummock grassland

P3: AprAciAiAsclTlo
Acacia pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera, A. sclerosperma subsp. sclerosperma open shrubland over Triodia longiceps hummock grassland

P4: AprAsyAiTw
Acacia pruinocarpa low open woodland over A. synchronicia, A. inaequilatera scattered tall shrubs over Triodia wiseana open hummock grassland

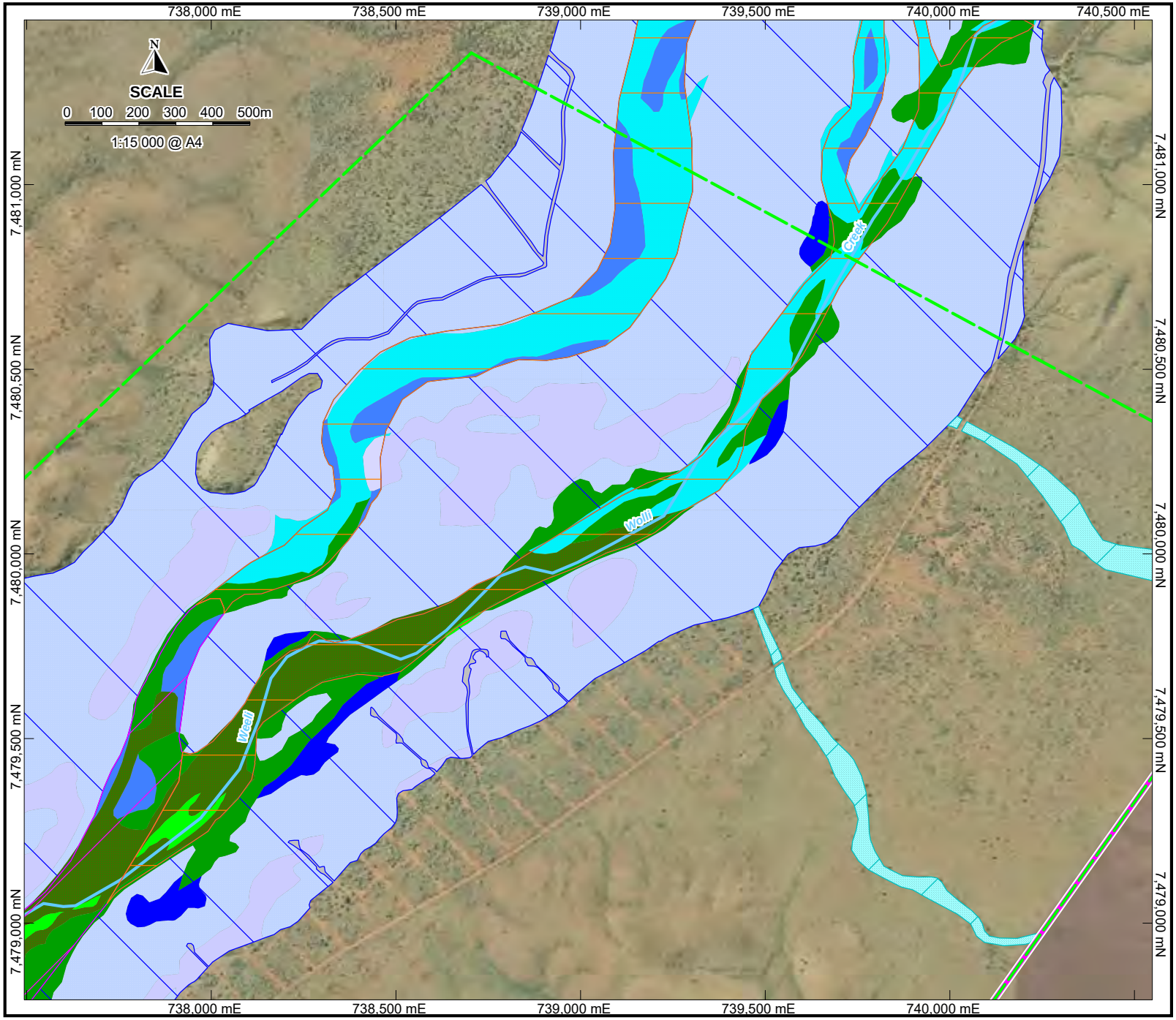
P5: ElEgAbAaTb
Eucalyptus leucophloia subsp. leucophloia scattered low trees over E. gamophylla scattered low mallees over Acacia bivenosa, A. ancistrocarpa open shrubland over Triodia basedowii open hummock grassland

P6: AapERfoERl/g
Acacia aptaneura low open forest over Eremophila forrestii subsp. forrestii open shrubland over E. lanceolata low open shrubland over mixed very open grassland

P7: ERf/G
Eremophila fraseri subsp. fraseri open shrubland over mixed very open grassland

P9: ChEgAiAaAprPcTb
Corymbia hamersleyana scattered low trees over Eucalyptus gamophylla scattered low mallees over Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa tall open shrubland over Petalostylis cassioides open shrubland over Triodia basedowii open hummock

Disturbed
Disturbed



LEGEND

- Development Envelope
- Proposal Area

Refined Riparian Zone Vegetation Units

- C1/C2-A
- C1B
- C2/C1
- C2A
- C2Asb
- C2B
- C3A
- C3Asb
- C4
- F2
- Disturbed

Biota 2014 Major Creekline Vegetation Units

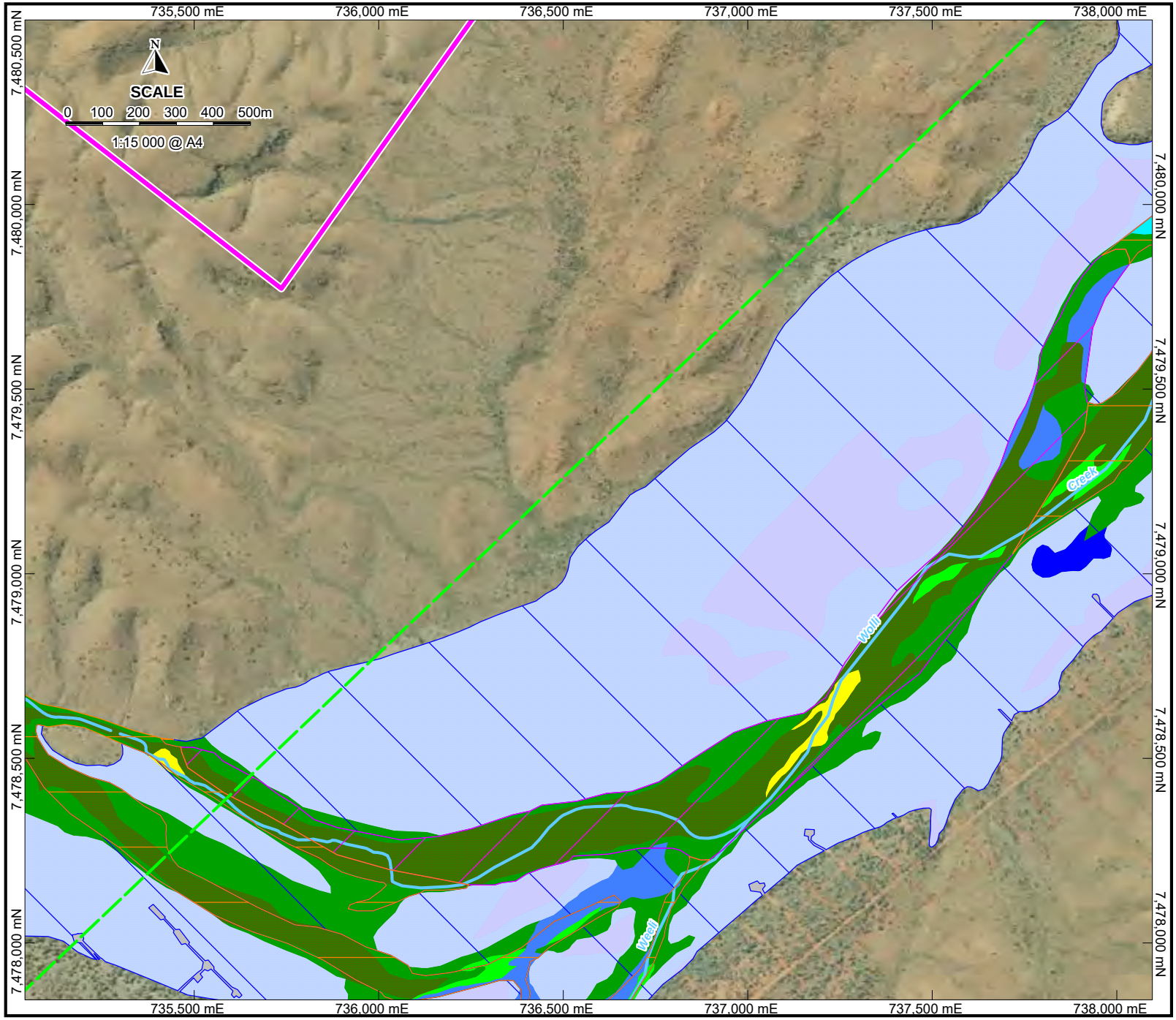
- C1: EcEvMaMgAc
- C3: EvAciAcMgCEc
- C4: EvAciAprAThCEc

Iron Ore (WA)

Figure 48
Refined riparian zone vegetation units in the Proposal Area (Map 1)

Drawn: M.Swebbs Plan No: PDE0134176v2
Date: October 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area

Refined Riparian Zone Vegetation Units

- C1/C2-A
- C1B
- C2/C1
- C2A
- C2Asb
- C2B
- C3A
- C3Asb
- C4
- F2
- Disturbed

Biota 2014 Major Creekline Vegetation Units

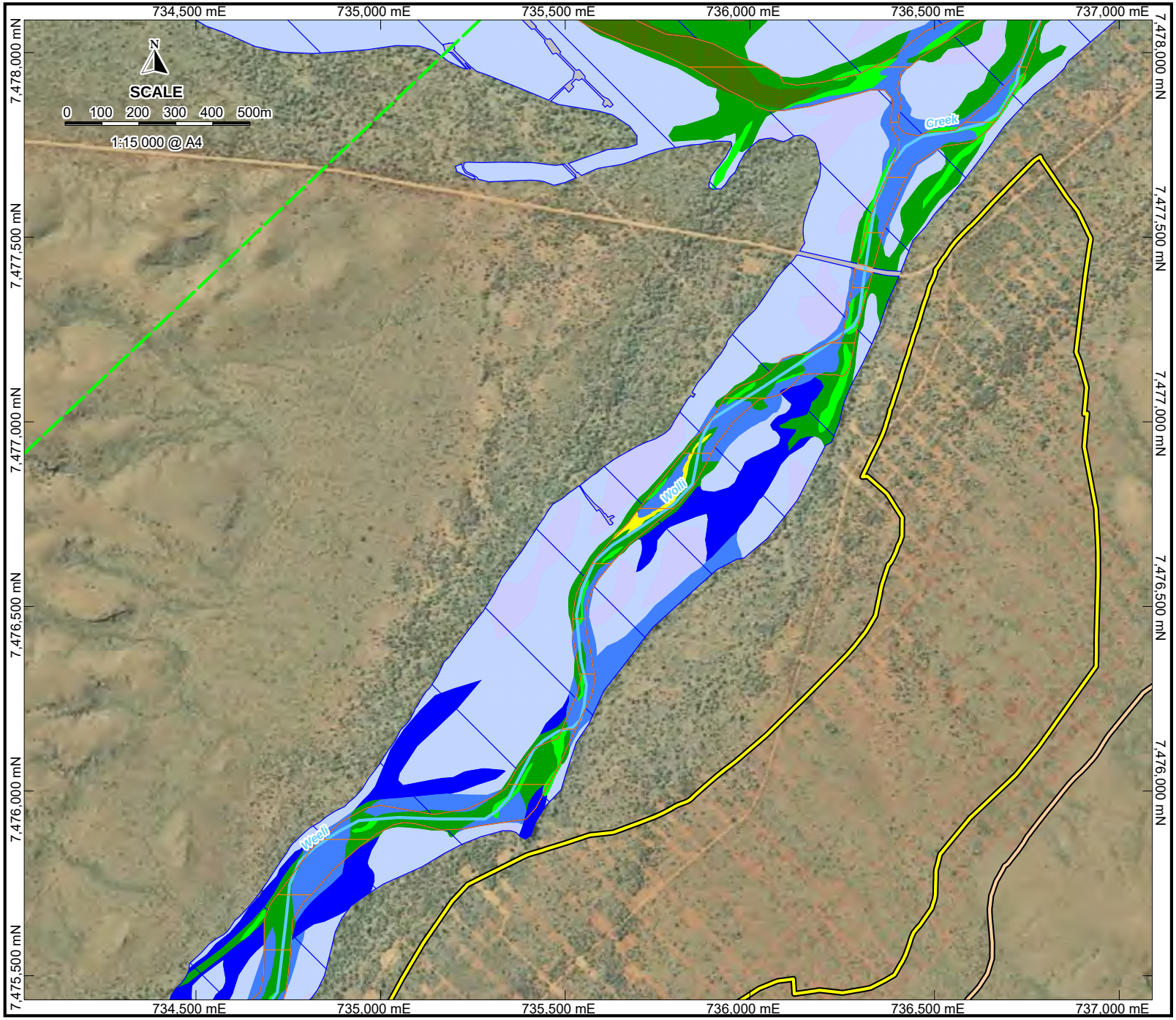
- C1: EcEvMaMgAc
- C3: EvAciAcMgCEc
- C4: EvAciAprAThCEc

Iron Ore (WA)

Figure 49
Refined riparian zone vegetation units in the Proposal Area (Map 2)

Drawn: M.Swebbs
Date: October 2015
Plan No: PDE0134176v2
Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump

Refined Riparian Zone Vegetation Units

- C1/C2-A
- C1B
- C2/C1
- C2A
- C2Asb
- C2B
- C3A
- C3Asb
- C4
- F2
- Disturbed

Biota 2014 Major Creekline Vegetation Units

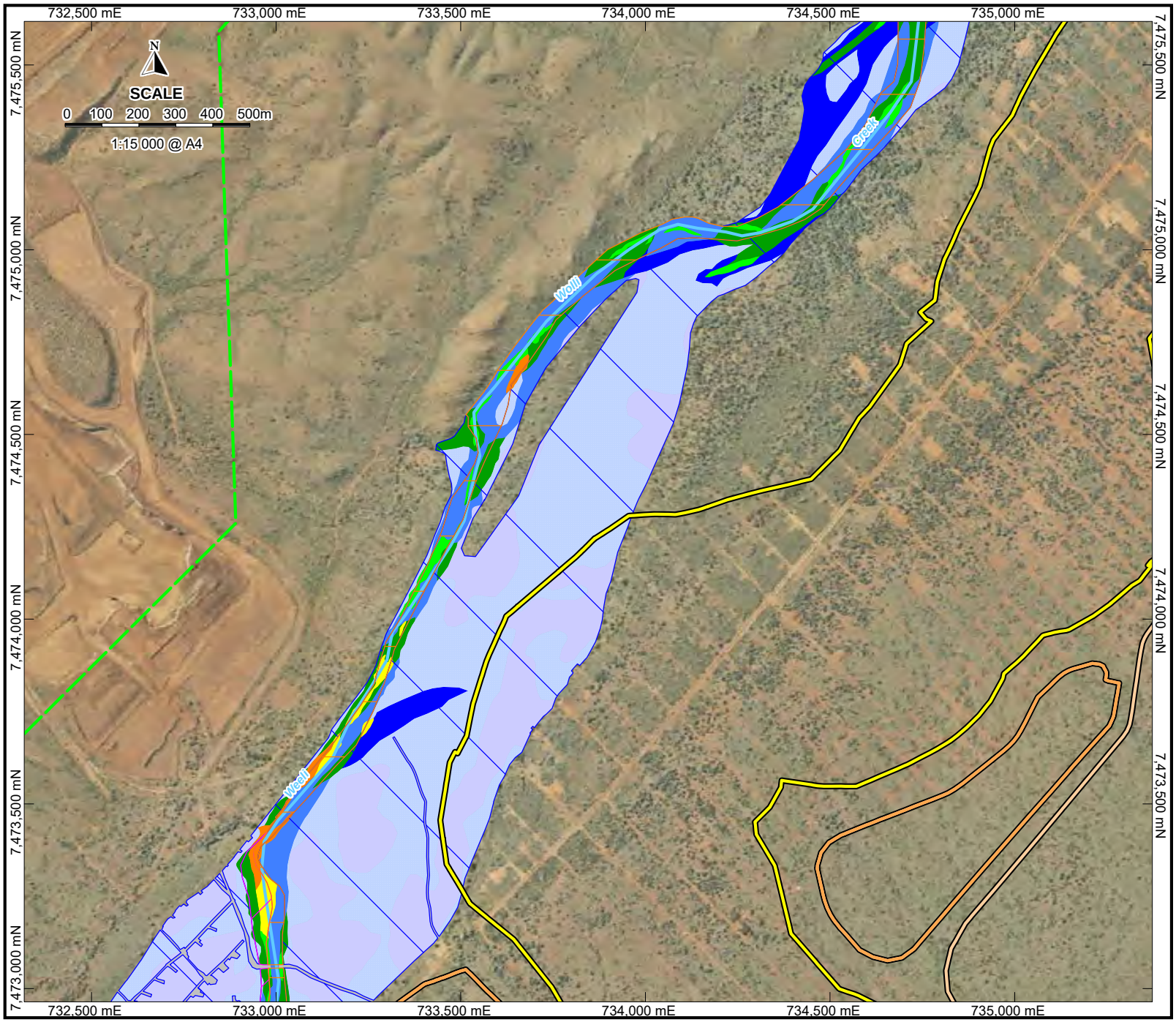
- C1: EcEvMaMgAc
- C3: EvAciAcMgCEc
- C4: EvAciAprAThCEc

Iron Ore (WA)

Figure 50
Refined riparian zone vegetation units in the Proposal Area (Map 3)

Drawn: M.Swebbs Plan No: PDE0134176v2
Date: October 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Refined Riparian Zone Vegetation Units

- C1/C2-A
- C1B
- C2/C1
- C2A
- C2Asb
- C2B
- C3A
- C3Asb
- C4
- F2
- Disturbed

Biota 2014 Major Creekline Vegetation Units

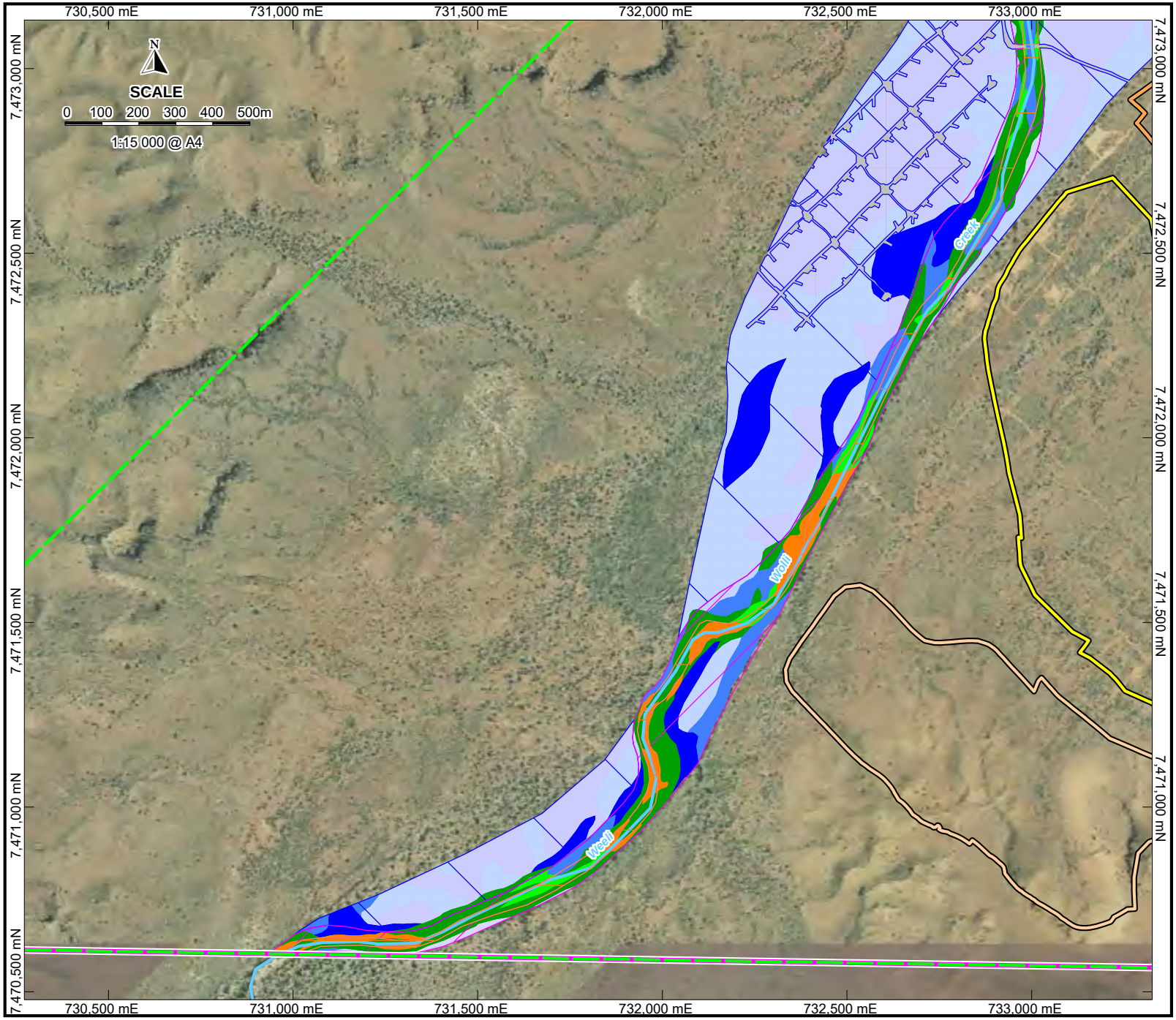
- C1: EcEvMaMgAc
- C3: EvAciAcMgCEc
- C4: EvAciAprAThCEc

Iron Ore (WA)

Figure 51
Refined riparian zone vegetation units in the Proposal Area (Map 4)

Drawn: M.Swebbs
Date: October 2015
Plan No: PDE0134176v2
Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Refined Riparian Zone Vegetation Units

- C1/C2-A
- C1B
- C2/C1
- C2A
- C2Asb
- C2B
- C3A
- C3Asb
- C4
- F2
- Disturbed

Biota 2014 Major Creekline Vegetation Units

- C1: EcEvMaMgAc
- C3: EvAciAcMgCEc
- C4: EvAciAprAThCEc

Iron Ore (WA)

Figure 52
Refined riparian zone vegetation units in the Proposal Area (Map 5)

Drawn: M.Swebbs
Date: October 2015
Plan No: PDE0134176v2
Proj: MGA94 Zone50

Geospatial Information and Mapping

Vegetation condition

Surveys within the Proposal Area recorded vegetation condition (after Trudgen 1988) to be Excellent to Very Poor (Biota 2014a; see **Table 18** and **Figure 53**). The main disturbance factors in the area are weed invasion and disturbance from livestock (cattle) including grazing, tracks, and trampled vegetation. Approximately 3% of the study area is mapped as Disturbed or Completely Degraded. These areas comprised current and historic vehicle roads and tracks, drill lines and drill pads. The majority of the Proposal Area is comprised of vegetation in either Good or Excellent condition (73%).

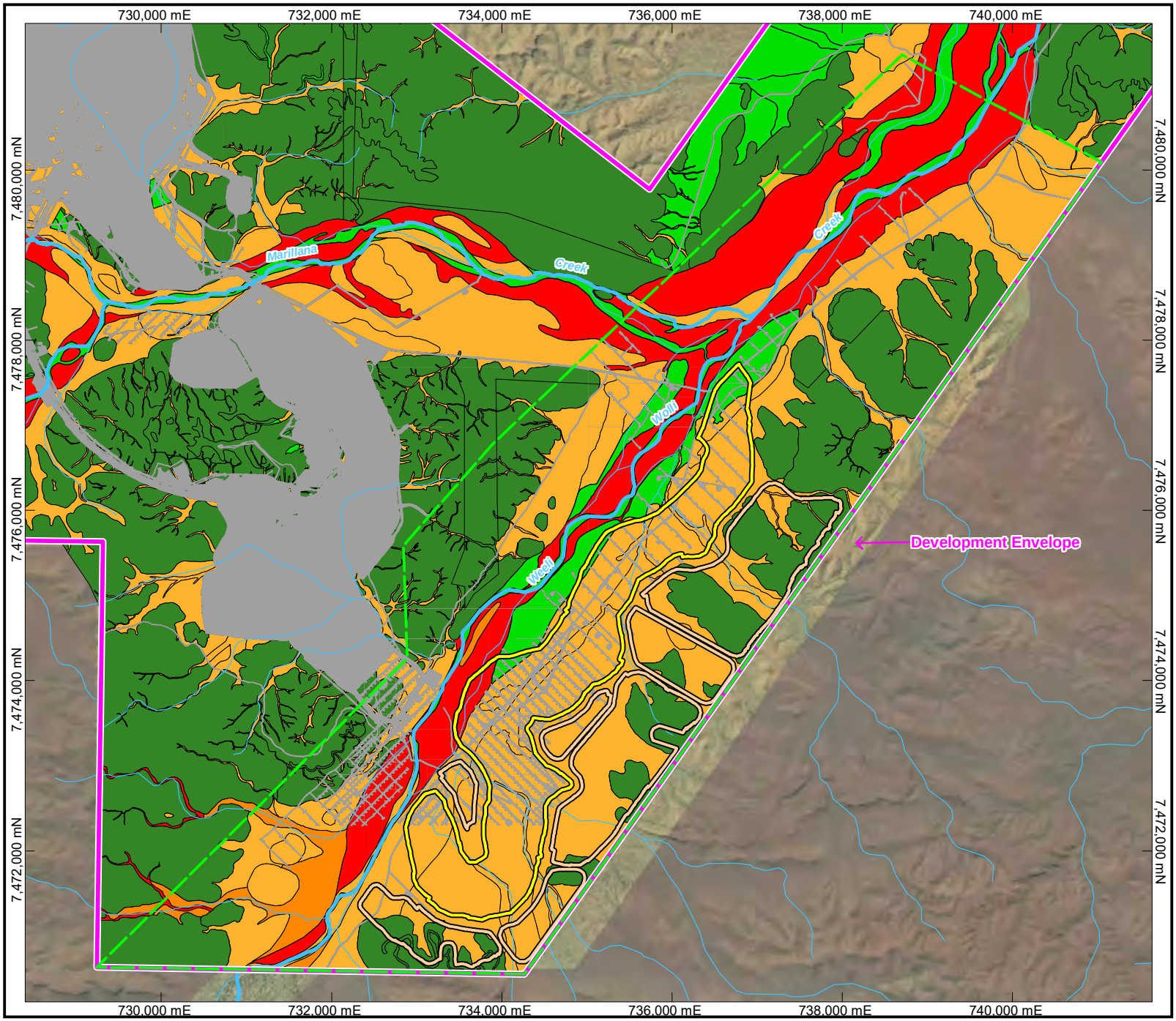
Table 18: Vegetation Condition (%) in the Proposal Area

Vegetation condition	% of Project Area
Excellent	26.6
Very Good	7.0
Good	46.0
Poor	0.8
Very Poor	16.5
Completely Degraded	3.1

Most creekline and floodplain vegetation types were rated as being in Good condition, although some areas were rated as Very Poor due to the high weed cover and evidence of extensive grazing and trampling by cattle. Buffel grass (**Cenchrus ciliaris*) was the most prolific weed in these habitats, sometimes occurring together with **Cenchrus setiger*. **Cenchrus* species were present as a continuous population along the edges of Weeli Wolli and Marillana Creeks and on adjacent floodplains (Biota 2014a).

The vegetation condition of the plains ranged from Good to Excellent. Some weed species were recorded, although they were usually only present as scattered individuals. Occasionally a very open tussock grassland of **Cenchrus ciliaris* was present, usually on plains adjacent to creeklines or floodplains. Evidence of cattle was also occasionally noted on the plains (Biota 2014a).

The hills, ridges and breakaways of the study area were in Excellent condition and were mostly free from any form of disturbance. Some of the hills and slopes of the study area had been recently burnt. Fire is a natural process in the Pilbara region, and natural fire regimes need not affect the overall condition of vegetation (Biota 2014a).



LEGEND

- Development Envelope
- Proposal Area
- Major; Minor Watercourse

Conceptual Mine Layout

- Mine Pit
- Waste Dump / Stockpile

Vegetation Condition

- Excellent
- Very Good
- Good
- Poor
- Very Poor
- Completely Degraded

N

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Rio Tinto

Iron Ore (WA)

Figure 53
Vegetation condition in the Proposal Area

Drawn: M.Swebbs Plan No: PDE0131812v3
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

14.2.2.2 Conservation significance of vegetation communities

Threatened and Priority Ecological Communities

None of the vegetation types recorded in the Proposal Area represent Threatened Ecological Communities or Priority Ecological Communities.

Vegetation units of elevated conservation significance

A number of "other ecosystems at risk" are identified for the Hamersley and Fortescue subregions of the Pilbara bioregion (Kendrick 2003a, 2003b). These are ecosystems with some level of significance that are at risk of degradation from a variety of factors including development, groundwater drawdown, frequent fires, grazing and weed invasion. One of these is relevant to the Proposal Area:

- 'All major ephemeral water courses' in the Hamersley subregion (Kendrick 2003a). These water courses are described as supporting "Eucalyptus forests with a shrubby understorey", which are under threat of degradation from weed invasion and grazing and trampling by feral herbivores (Kendrick 2003a). Groundwater drawdown could also potentially impact such vegetation if it included phreatophytic (groundwater dependent) species such as *Melaleuca argentea* (Cadjeput) or *Eucalyptus camaldulensis* (River Red Gum).

While Kendrick (2003a) referred to this ecosystem at risk being represented by the National Vegetation Information System (NVIS) major vegetation sub-group 4 (Eucalyptus open forests with a shrubby understory), no communities in the Proposal Area are classified as having Eucalyptus species consistently of this density (30-70%). Despite this, many of the C coded vegetation units occurring in the main incised channel of the Proposal Area are generally considered representative of this ecosystem at risk.

The Biota C1 vegetation unit was initially considered to be of elevated conservation significance however this unit was further differentiated into the C1B community and three closely associated sub-associations (C1/C2A, C2/C1 and C2A units). These four units are now considered to represent the key riparian communities of elevated significance. Of these units, the C1B unit is considered more significant; C1/C2A and C2/C1 are those units which have been interpreted by Rio Tinto (2015a) as being discharge augmented versions of the C2A community; and the C2A unit represents the regionally well represented *Eucalyptus camaldulensis* and *Eucalyptus victrix* open woodland community of large creek systems in the Pilbara. These communities are associated with Marillana and Weeli Wolli Creeks and are considered to be of elevated significance due to their inherent ecological values, restricted distribution in the Hamersley subregion, and their similarity to the Kendrick (2003a) ecosystem at risk (**Table 19**). The remaining C coded vegetation types comprise riparian vegetation but do not generally feature eucalypt forests and are widespread in moderate-sized creek systems throughout the Pilbara (Biota 2014a).

Table 19: Vegetation units of elevated significance in the Proposal Area

Vegetation unit	Condition	Total extent (ha)
C1B	Good	6
C1/C2-A	Good	3
C2/C1	Poor	11
C2A	Good - Poor	115
C2Asb	Very Good	52

14.2.3 Flora

A total of 455 native vascular flora taxa from 154 genera and 47 families have been recorded from the Biota (2014a) study area. This level of species richness is high for the broader locality but within the range that would be expected for a survey area of this size (Biota 2014a).

14.2.3.1 Conservation listed flora

Threatened (Declared Rare) Flora

One species, *Lepidium catapycnon* (Hamersley Lepidium), listed under the WC Act as Threatened (Declared Rare) Flora has been recorded in the Proposal Area. *L. catapycnon* is also listed as Vulnerable under the EPBC Act. *L. catapycnon* was recorded from two locations in the Proposal Area during previous surveys (Biota 2015a).

Searches undertaken during the Phase 1 survey at the locations of existing records, as well as targeting areas deemed potentially suitable habitat, found no individuals of *L. catapycnon*. Further targeted searches undertaken during the Phase 2 survey recorded *L. catapycnon* from 26 locations comprising three separate populations, two of these represented new populations for the area (Biota 2014a; **Figure 54**). A total of 777 individuals were recorded in the wider Yandicoogina locality during the Phase 2 surveys, with 948 recorded in this area to date. At present the Rio Tinto Rare and Priority flora database contains 1317 records of *L. catapycnon* totalling approximately 27,400 individuals.

It is noted that the conservation status of *L. catapycnon* is currently under review due to the extent of new records in the Pilbara.

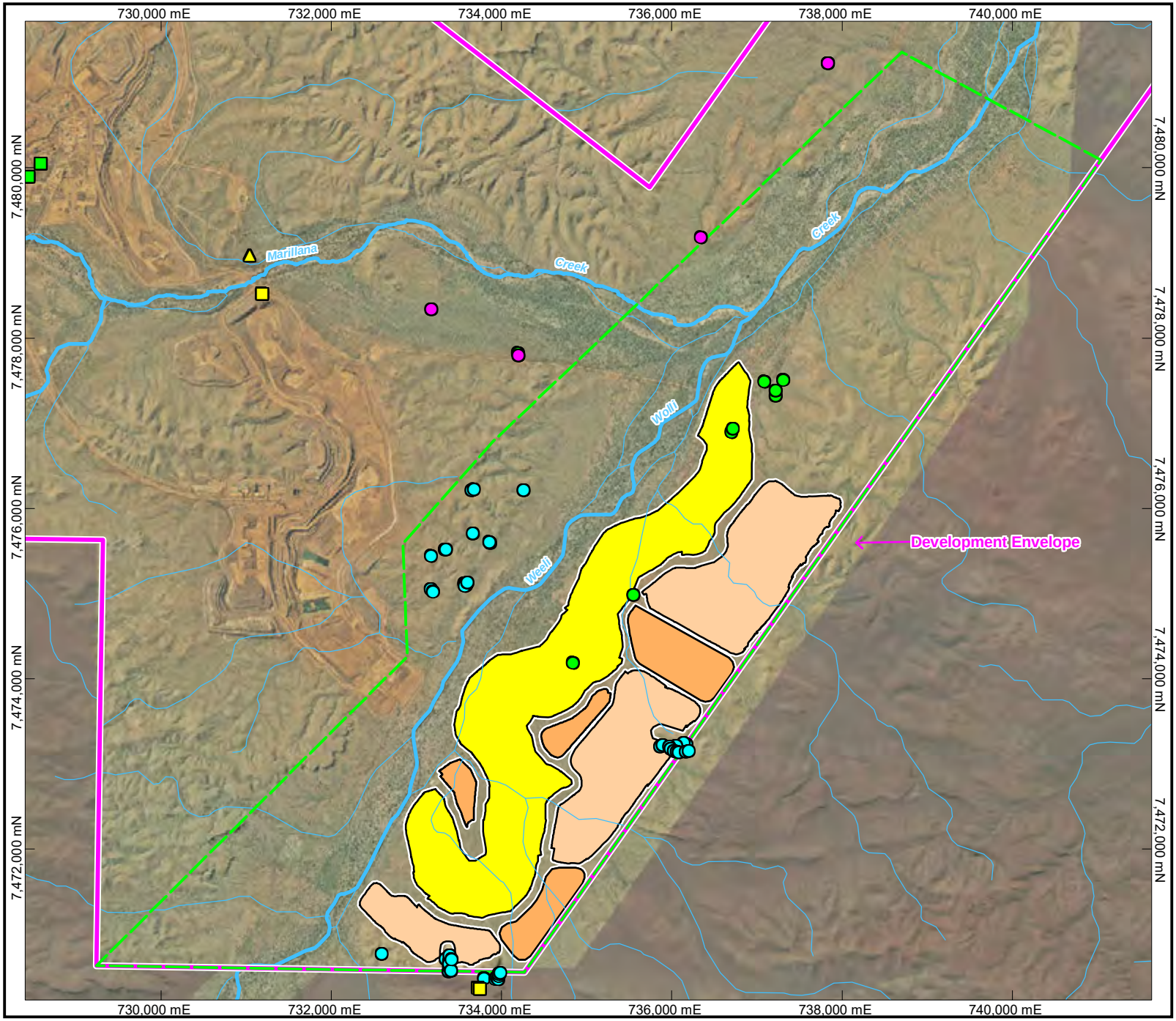
Priority flora

One Priority flora species, *Goodenia nuda* (Priority 4), was recorded in the Proposal Area (Biota 2014a; **Figure 54**). Seventy-two *Goodenia nuda* individuals were recorded in the Proposal Area.

A Priority 3 species, *Sida* sp. Barlee Range (S. van Leeuwen 1642), was located 1.5 m (three individuals) and 11 m (two individuals) outside the southern boundary of the Proposal Area. Additional historical records of *Sida* sp. Barlee Range (S. van Leeuwen 1642), Themeda sp. Hamersley Station (M.E. Truden 11431; Priority 3), *Rhynchosia bungarensis* (Priority 4), *Eulalia* sp. (Three Rivers Station B. Forsyth AQ6789133; species of interest) and *Glycine* sp. aff. *arenaria* (species of interest) are located between 0.25 – 3.7 km from the Proposal Area (Biota 2015a; see **Figure 54**). As these populations are outside the Proposal Area, they will not be disturbed as part of the Proposal.

14.2.3.2 Introduced flora species

Eighteen introduced flora species were recorded within or in the vicinity of the Proposal Area (Biota 2014a). One species, **Argemone ochroleuca* (Mexican Poppy) is listed as a Declared Plant for the whole of WA under the *Biosecurity and Agricultural Management Act 2007*. None of the species recorded were ranked as Very High or High Management priorities for the Pilbara under the Parks and Wildlife Weed Prioritisation Process (DPaW 2013). **Acetosa vesicaria* (Ruby Dock) is ranked by Parks and Wildlife as a Medium management priority and all other species were ranked as Low, Negligible or were not listed. It is important to note that some species are ranked as lower priorities more because of the difficulty of control rather than their perceived invasiveness (e.g. Buffel grass, **Cenchrus ciliaris*; Biota 2014a).



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse

Rare Species

- *Lepidium catapycnon*

Priority 3 Flora

- *Sida* sp. Barlee Range (S. van Leeuwen 1642)
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431)

Priority 4 Flora

- *Goodenia nuda*
- *Rhynchosia bungarensis*

Species of Interest

- *Eulalia* sp. (Three Rivers Station, B.Forsyth AQ6789133)
- *Glycine* sp. aff. *arenaria*

N

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Iron Ore (WA)

Figure 54 Records of conservation significant flora within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133743v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

14.3 Assessment of potential impact, mitigation and residual impact

Potential impacts associated with the Proposal in relation to flora and vegetation were identified by the EPA in the ESD as follows:

- The proposal involves additional clearing that will increase the disturbance footprint in the Revised Proposal Development Envelope from 5,600 ha to 7,400 ha for the mine and supporting infrastructure.
- The clearing includes up to 69 ha of riparian zone vegetation within Weeli Wolli Creek, consisting of approximately 16 ha for the mine pit and 9 ha for flood protection levees. There are potential for impacts on Priority flora species and *Lepidium catapycnon*, which is a Threatened Flora species.
- Groundwater drawdown from the mine has the potential to impact on the health of riparian vegetation along an 8 - 10 km stretch of Weeli Wolli Creek.
- Discharge of surplus water from mine pit dewatering has the potential to impact on riparian vegetation along Marillana and Weeli Wolli Creeks.
- There is the potential for the introduction of weeds through vehicle movements and earthworks.
- There is also the potential to impact on vegetation through the generation of dust from mining operations.

14.3.1 Clearing of native vegetation and potential loss of important vegetation communities

Vegetation clearing is an unavoidable component of mine development and infrastructure construction. Clearing will be required to enable development of the mine pit and associated infrastructure that were outlined in Section 4. The conceptual layout of each element of the Proposal is shown in **Figure 4**. Where practicable, the final mine site layout and infrastructure alignment will be designed to minimise clearing within the Clearing Restriction Area and areas containing vegetation and flora of elevated significance subject to mine planning and engineering constraints.

The Proposal Area covers 4,363 ha of which 1,327 ha of vegetation is currently proposed to be cleared (**Table 20**; note that vegetation mapped as Completely Degraded condition has been excluded from this clearing total as it has already been cleared). The majority of the clearing is of vegetation of Plains and Hills, Ridges and Breakaways (clearing of vegetation units P4, P5, and H1 makes up 1,061 ha or 80% of all proposed clearing). Vegetation within the proposed clearing footprint is largely typical of that occurring in similar habitats elsewhere in the same section of the Hamersley and Fortescue subregions, or is considered relatively widespread in the Pilbara beyond the Proposal Area. The majority of vegetation proposed to be cleared was assessed to be in Good condition (71% of all mapped vegetation, ranging from Very Poor to Excellent condition) and has been historically impacted by grazing and trampling by domestic and feral animals, weed invasion, frequent fire and mining and exploration activities (Biota 2014a).

While 1,327 ha of vegetation is currently proposed to be cleared within the Proposal Area as part of the current mine layout, consisting of the pit, waste dumps, levee and support infrastructure, approval for clearing of up for 1,800 ha of the Proposal Area is being requested as part of the Proposal, to allow for flexibility with mine planning and development.

A total of 69 ha of vegetation is proposed to be cleared to support the development of the Proposal from within what is currently depicted as the Clearing Avoidance Area (CAA) within MS 914; however the current clearing requirement (prior to finalisation of detailed engineering designs) is approximately 51 ha within this area (proposed Restricted Clearing Area; RCA). The 69 ha is being requested as part of the Proposal to allow for flexibility to accommodate changes to engineering deigns. The majority of vegetation proposed for clearing within the RCA (96% or 49 ha of the total 51 ha) is of units C4 and F2 and not the higher local conservation value vegetation discussed in Section 14.2.2.3. Both of these units proposed to be cleared are associated with the floodplain of Weeli Wolli Creek and not the denser open forests of the creek itself.

Vegetation unit C4 is composed of *Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland and F2 represents floodplain vegetation comprised of *Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland. Neither of these units contains the Eucalyptus open forests characteristic of the riparian ecosystem at risk described by Kendrick (2003a; 2003b) and additionally they are mapped as being in Poor condition, comprising a tussock grass layer dominated by Buffel grass. A further 851 ha of C4 and 145 ha of F2 vegetation is represented within the RCA outside of the Proposal Area. Clearing of these units is unlikely to affect the integrity of the higher local conservation value vegetation that the RCA aims to protect.

Three vegetation units identified by Rio Tinto (2015a) to be of elevated significance are proposed to be directly affected by the Proposal:

C2/C1 - **Thin strips of vegetation lining the low flow channel of:** *Eucalyptus camaldulensis* subsp. *refulgens* scattered (to open woodland), over low open woodland (to low open forest generally dominated by saplings to young trees) of *Eucalyptus camaldulensis* subsp. *refulgens* and *Melaleuca argentea* (and to a lesser extent *E. victrix*), over scattered tall-shrubs/shrubs of *Melaleuca glomerata*, *Acacia coriacea* subsp. *pendens*, *Atalaya hemiglauca*, and *Melaleuca glomerata* over very open sedgeland of *Cyperus vaginatus* and other mixed sedges often accompanied by fringing strips of *Typha domingensis*. Clearing proposed 0.04 ha, mapped condition Good to Poor.

C2A - *Eucalyptus camaldulensis subsp. refulgens, E. victrix woodland, over Acacia coriacea subsp. Pendens and Atalaya hemiglauca scattered low trees, over Melaleuca glomerata and Acacia citrinoviridis tall open shrubland, over mixed shrubland/low shrubland typically dominated by Corchorus crozophorifolius and Tephrosia sp. Fortescue creeks and outcrops of Cenchrus ciliaris open tussock grassland.* Clearing proposed 0.55 ha, mapped condition Good to Poor.

C2B - *Eucalyptus victrix and E. camaldulensis subsp. refulgens open woodland, over E. victrix scattered low trees, over Acacia citrinoviridis, A. pruinocarpa, and Atalaya hemiglauca tall open shrubland, over Atalaya hemiglauca, Gossypium sturtianum and Corchorus crozophorifolius scattered shrubs over *Cenchrus ciliaris tussock grassland.* Clearing proposed 0.83 ha, mapped condition Poor.

These communities commonly occur along larger creek systems throughout the Hamersley subregion (the C2/C1 community to a lesser extent) and as only 1.43 ha is proposed to be cleared as part of the Proposal the impact is not considered significant at a local or regional scale. Additionally a further 579 ha of the higher significance C1

(including C1/C2-A, C1A, and C1B) and C2 (including C2/C1, C2A, C2Asb, C2B, and C2C) vegetation units within the RCA are not proposed to be cleared. It is also important to note that riparian communities in the vicinity of the Proposal Area have been affected by surplus water discharge into Weeli Wolli Creek from upstream discharge since 2007. The most significant change has been the appearance of *Melaleuca argentea* saplings/young trees which have been sustained by the presence of an unnatural, perennial stream flow (Rio Tinto 2015a). Within the Proposal Area, the C2/C1 community is representative of the key structural and compositional changes which have occurred due to the provision of perennial water flow in the low-flow channel.

Internal ground disturbance procedures will be followed prior to commencing clearing of vegetation (subject to relevant regulatory approvals). The boundaries of vegetation to be cleared will be clearly defined as spatial coordinates in a Global Positioning System, including within earthworks machinery, or in some instances (particularly areas of higher significance) with ground markings (e.g. flagging), thus ensuring that personnel are aware of clearing limits prior to commencement of ground-disturbing activities.

Table 20: Area of vegetation proposed to be cleared

	Total extent (ha) in Proposal Area	Extent (ha) proposed to be cleared	% of total extent in Proposal Area	Total extent (ha) in Revised Proposal Development Envelope	% of total extent in Revised Proposal Development Envelope
Vegetation of Major Creeklines and Tributaries					
C2/C1	11	<1	<1	32	<1
C2A	91	1	1	309	<1
C2B	37	<1	2	41	2
C2C	12	<1	3	175	<1
C3A	53	1	1	161	<1
C4	503	30	6	1,106	3
Vegetation of Minor creeklines, Floodplains and Valleys					
F1	49	26	54	414	6
F2	244	20	8	462	4
F3	29	3	11	260	1
F5	31	23	74	31	74
Vegetation of Hills, Ridges and Breakaways					
H1	628	238	38	2,823	8
H2	566	38	7	5,842	1
H5	11	4	35	28	14
Vegetation of Plains					
P1	38	<1	<1	396	<1
P2	50	4	8	1,063	<1
P3	167	52	31	167	31
P4	344	142	41	350	41
P5	1,247	680	54	1,536	44
P6	113	63	56	144	44
Total	**4,225**	**1,327**		**15,372**	

14.3.2 Potential loss of conservation listed flora species

14.3.2.1 Threatened (Declared Rare) Flora

The design of the conceptual layout (**Figure 4**) has been cognisant of the presence of *Lepidium catapycnon* populations in the Proposal Area. *L. catapycnon* was recorded in areas that were originally designated for waste dumps in earlier versions of the conceptual design. However, the Proponent configured the waste dumps to avoid known and recorded populations of *L. catapycnon*. Further, all recorded populations of *L. catapycnon* have currently been designated as 'areas of special protection from ground disturbance' and therefore excised from the ground disturbance footprint.

L. catapycnon is known from a number of locations in the Hamersley Range and extends broadly from Tom Price across to Newman (Biota 2014a). There are over 30 known populations of *L. catapycnon* through this area, including one population in Karijini National Park. The populations recorded within the Proposal Area are within the known range of *L. catapycnon* and do not represent a range extension or edge of range population. Eleven separate populations of *L. catapycnon* have been recorded in the

wider Yandicoogina locality (Biota 2015a), all on hills and slopes. The populations within the Proposal Area are therefore unlikely to be either regionally or locally significant.

There is limited potential for *L. catapycnon* to be indirectly affected by changes to natural hydrological flows and runoff from waste dumps as the waste dumps are all on the downstream side of the recorded populations. Buffers of 50 m have been placed around populations to reduce the risk of accidental impacts from dumping of waste material.

14.3.2.2 Priority flora

Four records (37 individuals) of *Goodenia nuda* (Priority 4) will be impacted by the Proposal. *Goodenia nuda* is associated with clay substrates and has a broad distribution over a range of 500 km throughout the Pilbara bioregion and has been recorded from the broader Yandicoogina locality (190 individuals; Biota 2014a). Rio Tinto records show that *Goodenia nuda* has been recorded at 551 locations during Pilbara surveys, with 5,862 plants. The plant is a small, inconspicuous herb and it is therefore possible it occurs in other similar (floodplain) habitat elsewhere in the wider Yandicoogina locality. The loss of the individuals recorded from the Proposal Area is therefore not considered significant and would not alter the species' conservation status.

14.3.3 Effect of groundwater drawdown and discharge of surplus water on riparian vegetation

14.3.3.1 Existing altered hydrological environment

Riparian vegetation in the vicinity of the Proposal Area has been subject to the effects of groundwater drawdown and discharge of surplus groundwater by existing approved mining activities within the catchments of Marillana Creek since the mid 1990s and Weeli Wolli Creek since the mid 2000s. The presence of a permanent surface expression of discharge water in Weeli Wolli Creek (24-27 km downstream of the Hope Downs 1 discharge outlet) has in some sections of creek resulted in altered vegetation community structure, composition and health of the dominant riparian tree species *Eucalyptus victrix* and *E. camaldulensis* (Mattiske 2014; Rio Tinto 2015a; Eastham 2015). The surface water hydrology of Weeli Wolli Creek has changed from being an ephemeral system experiencing periodic (cyclonic) large flow events followed by extended dry periods to one of permanent surface flow, allowing increased recruitment, increased biomass and the establishment of riparian species (namely obligate phreatophytes such as *Melaleuca argentea*).

14.3.3.2 Drawdown

Groundwater modelling predicts that dewatering associated with the Proposal will lower the water table in the CID by approximately 50 m over two to three years (75 to 85 m bgl), with the water table remaining at that depth for the duration of mining (URS 2015). This drawdown would be below that of pre-mining levels and would translate to deficits in water availability for vegetation in the riparian zone (URS 2015). This will result in the disconnection of the current surface and groundwater systems within the low-flow channel of Weeli Wolli Creek, returning it to its more natural state (URS 2015). Perennial stream flow in the low-flow channel, and opportunities for flooding the adjacent riparian zone remain unchanged as a result of the Proposal (URS 2015). The low-flow channel was assumed to incorporate a 6 m zone that transmits perennial stream flow, and a 20 m corridor either side of this where the vegetation is able to access stream flow or pore water (46 m total corridor; URS 2015).

Groundwater monitoring data indicate that pre-mining depth to water tables within the Proposal Area CID occurred between 12 - 20 m below ground level, suggesting there

would have been low dependency of the vegetation in this area on groundwater, and most plants would have been reliant on soil (pore) water instead (URS 2015). Limited historical water level data exists within the adjacent riparian zone, however historical vegetation data (Integrated Environmental Services 1981) does not identify the presence of obligate phreatophytes (strictly groundwater dependent) species in the vicinity of the Proposal and recent vegetation mapping within this area has identified a predominance of young trees of the only obligate phreatophyte recorded, *Melaleuca argentea* (URS 2015; Rio Tinto 2015a). The vast majority of these trees are most likely to have established relatively recently, following commencement of discharge of surplus water into Weeli Wolli Creek from Hope Downs 1 operations upstream and discharge from Yandi JSE. Mature *Eucalyptus camaldulensis* and *E. victrix* (facultative phreatophytes; URS 2015) present as the dominant overstorey layer would have previously met their ecological water requirements from both soil and groundwater depending on its availability under pre-mining conditions.

Refined riparian vegetation mapping (Rio Tinto 2015a) revealed that three vegetation units contained a co-dominant component of *M. argentea* in the vicinity of the Proposal Area. Of these three units the C1B community was determined to contain *M. argentea* populations possessing a structure and size class range indicative of a community likely to have existed prior to discharge. Three small areas of this vegetation occupying a combined 420 m stretch of creekline (6.3 ha) were mapped in the Proposal Area, near the southern section of the proposed pit. The remaining two units (C1/C2A and C2/C1) were considered to contain *M. argentea* populations that had only established due to the increase in surface water availability as a result of Hope Downs 1 discharge. *M. argentea* populations have been interpreted by Rio Tinto (2015a) to be augmented by the presence of surplus discharge within Weeli Wolli Creek since late 2006 and the stem diameters (= size/age class) of the main population are considered representative of young recruits (ranging from 5-10 cm, with scattered individuals with stem diameters of 10-20 cm; Rio Tinto 2015a, see **Plate 3**).

Source: Rio Tinto (2015a)

Plate 3: Stands of young *Melaleuca argentea* fringing the low-flow channel within the Proposal Area and likely to have established since the commencement of surface water discharge at Hope Downs 1, Weeli Wolli Creek

As groundwater levels within Weeli Wolli Creek are lowered in response to the dewatering required for the Proposal, individuals of *M. argentea* outside the low-flow channel and immediate banks (a strip of approximately 10-20m either side of the 6m low-flow channel zone) are likely to lose condition and die unless their ecological water requirements are met through rainfall/cyclone events (to supplement the pore water radiating out from the low-flow channel; **Table 21**). The majority of the *M. argentea* populations interpreted to be present pre-discharge (associated with the C1B community) are contained within this zone and are unlikely to be impacted by dewatering. The *M. argentea* populations which extend outside this zone, and which are therefore most likely to see impact (the C1/C2A and C2/C1 communities), are those interpreted as not being present pre-discharge. **Figure 55** shows vegetation (including *Melaleuca* communities) in relation to high and low-flow channels adjacent to the mine pit and levee structures. Mine pits have been successfully developed next to riparian vegetation communities in the existing Yandi Operations; **Plate 4** shows a photo of the riparian vegetation associated with Marillana Creek adjacent to the existing JSW pit wall (~60 m bgl) in October 2015.

Despite the potential for the younger, post discharge C1/C2A and C2/C1 communities to experience mortality within *M. argentea* populations, only a small percentage of these communities are likely to occur within the impact zone (beyond the banks adjacent to the low-flow channel; **Figure 55**). Therefore, as the majority of the *M. argentea* populations most likely to experience decline or death as a result of drawdown are considered to have been established and augmented by discharge from other approved mining activities in the catchment, an impact to these populations brought about by a return to a more 'natural' hydrological regime is not considered significant and hence no active mitigation is proposed.

Plate 4: Marillana Creek riparian vegetation adjacent to the existing JSW pit wall.

Table 21: Possible responses of riparian tree species to groundwater drawdown associated with the Proposal

Change in depth to water table (m)	*Eucalyptus victrix*		*Eucalyptus camaldulensis*		*Melaleuca argentea*	
	Low-flow channel	**Incised channel**	**Low-flow channel**	**Incised channel**	**Low-flow channel**	**Incised channel***
<2	Little to no change	Little to no change	Little to no change	Little to no change	Little to no change	Reduced condition
2-5	Little to no change	Little to no change	Little to no change		Little to no change	Reduced condition and some potential for loss of foliage
5-10	Little to no change	Potential for reduced condition during extended periods without flood/overland flow	Little to no change	Potential for reduced condition during extended periods without flood/overland flow	Little to no change	Reduced condition, loss of foliage
10-15	Little to no change	reduced condition during extended periods without flood/overland flow	Little to no change	reduced condition with potential for foliage loss during extended periods without flood/overland flow	Little to no change	Complete loss of foliage, potential for fatality
15-20	Little to no change	reduced condition during extended periods without flood/overland flow	Little to no change	Loss of foliage, potential limb loss, and some potential for fatality during extended periods without flood/overland flow especially in enhanced vegetation	Little to no change	Fatality likely
>20	Little to no change	Reduced condition and foliage loss during extended periods without flood/overland flow	Little to no change	Loss of foliage, potential limb loss, and potential for fatality during extended periods without flood/overland flow especially in enhanced vegetation	Little to no change	Fatality likely

* If present

Adapted from URS (2015)

Eucalyptus camaldulensis and *E. victrix* woodland communities are considered to be facultative phreatophytes (relying on soil and groundwater to differing degrees depending on their availability and the local setting in which individual plants have become established). They are also likely to be impacted by groundwater drawdown associated with the Proposal if they have become dependent on surplus water associated with Hope Downs 1. The magnitude of this impact will depend on the rate of drawdown, the extent and frequency of surface water inputs and the ability of individual trees to access stored soil water as the groundwater declines. Monitoring of riparian eucalypts at Hope Downs 1 suggests the dominant riparian eucalypt species are resilient to drawdown if surface water (irrigation, rainfall, stream flow and overland flow) availability remains unaffected (Eastham 2015). Impacts are most likely to be seen once the water table drops below 5 m (the observed range of fluctuation after recharge events) and will be dependent on differences in adaptability of stands of vegetation to respond to sources and supply of water (URS 2015).

While flood regimes will be maintained in the creekline, overland flow within the floodplain zone will be diminished in an 8 km section adjacent to Weeli Wolli Creek where drainage tributaries from the east are being temporarily diverted around the Proposal mining operation via a diversion drain (that re-joins Weeli Wolli Creek further downstream). Modelling suggests that the baseline contribution of this surface flow amounts to approximately 2.5% of the local Weeli Wolli Creek catchment in the Proposal Area. Surface flow will be maintained on the western side of the creek and within the creek itself. Trees on the eastern side of Weeli Wolli Creek may experience increased drought stress as groundwater levels drop below pre-mining levels of 12 - 20 m with the reduction of overland surface water inputs. However, regular creekline flood events are more effective at supplying surface water inputs to this zone.

Figure 56 presents the risk (using the methodology outlined in URS, 2015) to the relevant riparian woodland communities of declining water availability within the riparian zone (based on 2019 drawdown predictions) and shows that an approximately 3 km stretch of vegetation is at medium – high risk and approximately 2.8 km at high risk of decline due to reduced water availability. A further 5 km is at medium risk. Within these stretches of creek it is expected that there will be deaths of *M. argentea* where it is present beyond the low-flow channel and immediately adjacent banks. Additionally, within these stretches of creek, it is expected that there will be decline of *E. camaldulensis* especially during periods of drought, with some deaths possible (beyond that typically expected to occur under natural climatic variability). *E. victrix* will decline in condition, again particularly during periods of drought where soil pore water is not being replenished as a result of rainfall and stream flow events.

The current health of some eucalypts due to waterlogging associated with surplus water discharge in Weeli Wolli Creek combined with additional stress of groundwater drawdown may cause rapid decline of some trees in this section of creek due to cumulative stresses (Eastham 2015). Similarly trees with enhanced canopies due to surplus water may be sensitive to groundwater decline; these localised impacts will depend on the position of individual trees in relation to the current and predicted water table depth. Areas of the creekline vegetation which have more recently established in areas of artificially elevated water table levels are generally immature and dominated by eucalypt and Melaleuca saplings and young individuals. These populations are expected to show significant decline and death as water levels are drawn down.

The dewatering activities associated with the Proposal are likely to produce losses of individual trees within the Weeli Wolli Creek riparian zone. It is expected that the potential for losses is greatest in those areas currently experiencing the greatest access to soil moisture, such as within and adjacent to the low-flow channel. However, the current perennial flow will be maintained within the low-flow channel of Weeli Wolli Creek in the vicinity of the Proposal by the continuation of discharge from Hope Downs 1 and is expected to circumvent a significant proportion of this potential for tree death. Recruitment within and adjacent to the perennial flow zone is likely to remain elevated for the duration of discharge and during wetter periods (cyclone/flood events), which may assist with offset the remaining losses which may be attributed to dewatering activities).

It is expected that the creek system will revert to a system similar to its ephemeral pre-mining state without active restoration through natural process such as cyclones and resultant flood events which provide optimum conditions for the establishment and survival of new propagules. Landscape-scale ecosystem processes such as nutrient cycling, flooding, fire and recruitment will remain unaffected by the Proposal.

14.3.3.3 Discharge

Approximately 50 GL/y of surplus water is proposed to be discharged from a new discharge outlet, adjacent to the existing discharge outlet (DO9) as a result of developing the Proposal, with the total discharge from the Revised Proposal being approximately 78 GL/y. Surface water modelling indicates that the alluvial aquifer and fractured Brockman Iron Formation bedrock in the downstream reaches of Weeli Wolli Creek could accommodate the maximum predicted discharge rate at DO9 without exceeding MS 914 condition 6-3, which limits the perennial surface water wetting front to 17 km downstream from the Marillana and Weeli Wolli Creek confluence.

Experience from the existing Yandi Operations and work undertaken by Eastham (2015) suggests that prolonged surface water discharge could result in:

- Artificial recruitment of riparian vegetation
- Increasing the leaf area index and biomass of vegetation exposed to higher water availability
- Decreasing biomass and waterlogging stress in areas exposed to prolonged soil saturation, resulting in tree health decline or death
- Drought stress in samplings unable to re-adjust to the withdrawal of artificial water supply on cessation of discharge
- Changes in vegetation structure including an enhanced potential for weed invasion

Discharge increases water availability in the unsaturated zone of the downstream creek bed alluvium, and can result in persistent waterlogged conditions in the soil profile within channel sections. The potential effects include tree health decline in established trees due to prolonged saturation of root systems, enhanced recruitment of new trees and the establishment of waterlogging tolerant species including sedges and rushes.

Monitoring of responses in eucalypt foliage cover to discharges into Weeli Wolli Creek indicate variable impacts of discharge on tree health. The Proponent's riparian vegetation health monitoring program suggests that individual tree responses range from no discernible impact to severe stress or tree death in extreme cases. Foliage cover has

displayed negative responses to discharge rates particularly at higher volumes at the existing Yandi Operations, with the greater impact on foliage cover related to shallower (artificially elevated) water tables in the alluvium (Eastham 2015).

Relationships between foliage cover and depth to water showed statistical reductions in foliage cover with rising water levels at some sites in Weeli Wolli Creek adjacent to the proposed pit, however, the response of individual trees at a site was not uniform, and at most of the sites there were some trees that increased their foliage cover. This finding indicates that a proportion of trees at each site likely occupy an ecological niche which has allowed them to maintain or increase their canopy (Eastham 2015). Trees occurring at higher elevations tended to maintain or increase foliage cover at some, but not all, sites.

Localised impacts around the discharge outlet and within the low-flow channel of the downstream reaches of Marillana Creek are most likely to experience waterlogging, which may result in declining health or death of some species, particularly *E. victrix,* and particularly if located within lower elevations of the creek bed such as directly within the low-flow or on lower elevations of the incised channel such as the scoured bed zones fringing the low-flow channel. Further downstream in Weeli Wolli Creek, the impacts will be largely restricted to the low-flow channel and lower scoured bed sections of the incised channel, and are likely to reduce with distance further downstream as surplus water infiltrates into the alluvial aquifer. Impacts will also include increased vegetation biomass as a result of increased vigour and associated recruitment by riparian species.

Hydrological modelling and infiltration tests predict that by maintaining the additional discharge from DO9, the surplus water wetting front will remain within the 17km footprint approved under MS914, and hence the impact footprint will be constrained to this section of the creekline. Given the wetting front is predicted to be within existing approved limits, it is considered that there will be negligible impacts on Fortescue Marsh due to a minor decrease in catchment area. However, if the discharge location were to be shifted further downstream, there is risk of extending the wetting footprint within Weeli Wolli Creek and towards the Fortescue Marsh.

14.3.3.4 Management of riparian systems

Drawdown can potentially reduce the availably of groundwater to species able to access this water source. Most Pilbara flora do not utilise groundwater but use stored soil moisture (derived from surface inputs) to meet their water use requirements. Riparian systems of the Pilbara bioregion are subjected to extremely seasonal and variable hydrologic regimes, in which stream flow typically occurs following cyclonic rainfall events. In the Proposal Area, the hydrological connection along Weeli Wolli Creek will be maintained throughout the development of the Proposal, which will allow the natural flood flows to persist and replenish the riparian system. Concurrently, discharge flows from Hope Downs 1 are modelled to continue to persist within the low-flow channel adjacent to the proposed PBS pit, which will assist in managing localised impacts from drawdown as a result of implementing the Proposal. As a result, additional long term supplementary irrigation of Weeli Wolli Creek adjacent to the Proposal is considered limited in its potential effectiveness to further mitigate potential groundwater drawdown impacts on the riparian system.

Historically, the Proponent and other mining companies in the region have sought to manage surplus water by discharging directly into creeklines. This approach has met with varying levels of success, and it can be argued that the approach has also generated

alternate ecosystem impacts, for example artificially generating permanent pools, waterlogging of existing healthy systems; and artificially enhancing biomass and recruitment. Permanent supplementary irrigation via discharge as an approach to negate the effects of groundwater drawdown during mining could result in the continuation of surface water flows along the low-flow channel of Weeli Wolli Creek and potentially maintain an artificially augmented system, which may not necessarily effectively mitigate the potential impacts on the riparian systems.

Creek ecosystem health observations at existing mining operations in the area suggest that local environmental conditions other than the groundwater level (i.e. topographic position, soil type and surface water runoff) can influence local soil water availability and thus offset the degree of impact experienced by individual vegetation communities due to dewatering. Consequently, managing the impact of dewatering on the environment through discharge spurs would is not proposed at this stage.

To enable the most effective management of the riparian system for the Proposal, a detailed study is being undertaken to further understand plant-water requirements, and refine appropriate management measures. Management measures may include forms of temporary irrigation within targeted mature parts of the riparian system, with the aim to allow the system to adapt and gradually return to the lower pre-mining water levels that are predicted to persist following cessation of mining and discharge in the area. It is considered that this approach will avoid unnecessarily maintaining younger (artificial) parts of the system by ongoing irrigation, which inevitably would not survive after cessation of mining and discharge. This approach aims to align with the adaptive management framework and includes:

- investigations to resolve local environmental (baseline) conditions;
- ongoing monitoring and investigations, until a causative link between dewatering drawdown and changes in ecosystem health can be determined; and
- design of mitigation solution options, targeted to deliver localised outcomes, to enable timely implementation if mining related water availability is determined to contribute to a significant decline in ecosystem health.

This approach was successfully applied for the management of potential impacts to the Mt Bruce Flats PEC as part of the Marandoo below water table operation; where, as a consequence of the management approach, it was demonstrated that water availability in the woodland was not linked to groundwater elevation and irrigation of the PEC was not required to maintain the persistence of the long term community.

The proposed program to determine appropriate management would include:

1. Investigative study to be undertaken as part of the Proposal Feasibility Study.

- Refined hydrogeological sampling and geochemical analysis.
- Installation of long term water monitoring bores at tree health monitoring sites and areas identified as higher risk.
- In situ neutron probe measurements to determine spatial and in situ variability in soil water content.
- Refined definition of baseline conditions.

- Riparian zone environmental risk assessment.

2. Development of mitigation solutions based on the findings of the investigation with a detailed plan for implementation should mitigation be necessary. This may include options for targeted irrigation in mature riparian areas considered to be of high local value and at high risk of impact due to groundwater drawdown.

3. Continuation and refinement of the existing operational monitoring network including:

- Ecosystem health.
- Groundwater levels.
- Ecological water availability.

Photo A: Typical Major Creekline Vegetation (low flow communities)

Photo B: Typical Floodplain Vegetation (high flow communities)

Photo C: Example of Augmented Vegetation

LEGEND

- Proposal Area
- Clearing Avoidance Area (MS914) (2012)
- Discharge Outlet
- Low Flow Channel
- High Flow Channel

Conceptual Mine Layout

- Mine Pit
- Topsoil Stockpile
- Office & Workshop
- Crossing Drainage Management
- Levee
- Pillar Levee
- HV & LV Road

Riparian Zone Vegetation

- Vegetation of Major Creeklines
- Vegetation of Minor Creeklines and Floodways

N

SCALE

0 250 500 750m

1:15 000 @ A4

RioTinto

Iron Ore (WA)

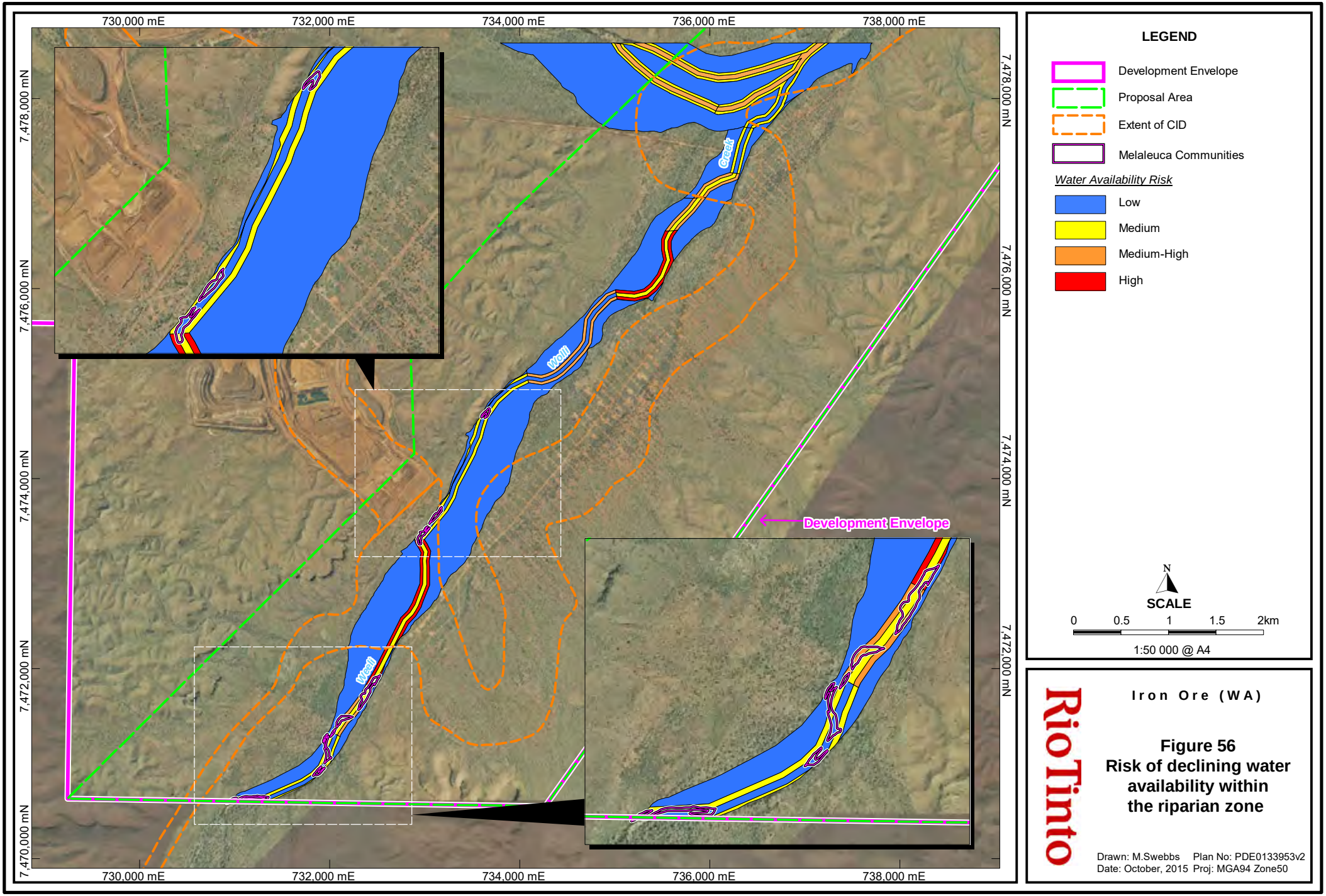
Figure 55

Broad Riparian vegetation associations in relation to high and low flow channels and mining infrastructure

Drawn: M.Swebbs
Date: Oct, 2015

Plan No: PDE0136053v1
Proj: MGA94 Zone50

Geospatial Information and Mapping


730,000 mE
732,000 mE
734,000 mE
736,000 mE
738,000 mE
7,478,000 mN
7,476,000 mN
7,474,000 mN
7,472,000 mN
7,470,000 mN
Creek
Wolli
Wolli
Development Envelope
LEGEND
Development Envelope
Proposal Area
Extent of CID
Melaleuca Communities
Water Availability Risk
Low
Medium
Medium-High
High
N
SCALE
0
0.5
1
1.5
2km
1:50 000 @ A4
Iron Ore (WA)
Figure 56
Risk of declining water availability within the riparian zone
Drawn: M.Swebbs
Plan No: PDE0133953v2
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping

14.3.4 Introduction and/or spread of weeds

Weeds can spread into natural environments by many vectors, including wind, water, and the movement of soils, people, vehicles, machinery and fauna (including native animals and livestock). The most relevant of these in relation to the Proposal is vehicle and earth movements, and discharge activities. Weeds are often able to rapidly invade locations subject to disturbance, land clearing and/or altered fire regimes, and altered hydrological regimes. This can result in smothering and replacement of native plants and domination and simplification of natural ecosystems.

The most common areas within the Proposal in which weeds were recorded were creeklines and floodplains. The most commonly recorded weeds were **Cenchrus ciliaris* and **C. setiger* which in many areas formed a continuous tussock grassland community resulting in low numbers of native understorey species along the banks of Weeli Wolli and Marillana Creeks. These species have the potential to spread further with cattle activity, water movement and clearing (Biota 2014a). Despite this fact it is noted that within the key habitats available on Marillana and Weeli Wolli Creeks, only a small areal extent remains un-colonised by these species.

Limited clearing will occur in these communities as part of the Proposal, however, weed management measures will be implemented in accordance with Yandicoogina Weed Action Plan **(Appendix 4**) to minimise the risk of weed introduction and spread. Some of the key actions that will be implemented are:

- Vehicle and equipment hygiene practices.
- Weed monitoring.
- Periodic weed control.

14.3.5 Effects of dust

Dust deposition on vegetation from the Proposal is likely to be restricted to immediately adjacent vegetation and will be mitigated by periodic high rainfall events, which would remove built-up materials on leaves. As per much of the vegetation in the Pilbara, native vegetation in the area is also expected to be reasonably tolerant to dust deposition and would not be at risk of significant physiological impacts. Research conducted at West Angelas mine site, 60 km to the west of the Proposal, showed no detectable negative impact of dust on plant function for a number of different leaf types (Butler 2009). Background dust levels in the vicinity of the Proposal Area are high relative to urban areas in the south west of WA. Located in the arid Pilbara region, dust lift off occurs naturally from sparsely vegetated landscapes.

Dust deposition on vegetation has not been identified as a key environmental issue in the wider Yandicoogina locality and to date management has been as per standard Rio Tinto practices. The ore being mined as part of the Proposal is below water table and as such has a high moisture content. Additionally, there is sufficient surplus water for dust suppression if required.

The Proposal will be managed in accordance with the Yandi Operations MMP and the E12 Standard (Air Quality Protection), which includes the following management measures:

- using existing tracks where possible;

- implementing speed limits to reduce dust generation;
- minimising clearing and conducting rehabilitation; and
- water application (heavily trafficked areas, stockpiles etc.).

14.4 Cumulative impacts

14.4.1 Cumulative impacts to riparian vegetation

A preliminary assessment of cumulative impacts to potentially groundwater dependent riparian vegetation (herein defined as vegetation supporting *Eucalyptus camaldulensis* and/or *E. victrix* and/or *Melaleuca argentea*) was conducted based on a review of the potential impacts of the Proposal (Rio Tinto), the existing Yandi Operations and 19 other projects identified as being potentially relevant based on their location in the Upper Fortescue River Catchment (three Rio Tinto and 17 third party projects; **Table 22**).

Of the projects reviewed, insufficient information was available in the documentation reviewed for some projects to enable their inclusion in the cumulative impact assessment (**Table 22**). Further, it was not possible based on the information available at the time of the review to determine the extent of overlap (if any) between areas of groundwater dependent vegetation mapped for different projects.

Of the approximately 14,946 ha of potentially groundwater dependent riparian vegetation mapped for the projects considered (including the Proposal), up to 2,159 ha will be disturbed (including areas cleared and areas subject to potentially significant impacts due to groundwater drawdown), which represents approximately 14% of the mapped extent (**Table 22**).

Table 22: Assessment of potential cumulative impacts to riparian vegetation in the Upper Fortescue River Catchment

Project	Baseline	Potential impact to riparian vegetation	Reference
Past and present actions			
FMG Christmas Creek Mine - Water Management Scheme (EP Act Assessment No. 1873; EPBC Act Ref. 2010/5706)	938 ha	82 ha	ENV (2010); FMG (2010a); FMG (2011)
FMG Cloudbreak Iron Ore Mine (EP Act Assessment No. 1577; EPBC Act Ref. 2005/2205)	824 ha	119 ha	Environ Australia (2005a)
FMG Cloudbreak Life of Mine (EP Act Assessment No. 1848; EPBC Act Ref. 2010/5696)	1,429 ha	473 ha	ENV (2010); FMG (2012)
Hamersley HMS's Hope Downs 1 Iron Ore Mine Expansion (EP Act Assessment No. 1308)	161 ha	10 ha	Ecologia (1997); Hope Downs Management Services Pty Ltd (2000)
Rio Tinto (managed) Hope Downs 4 Iron Ore Mine (EP Act Assessment No. 1738; EPBC Act Ref. 2008/4636)	914 ha	28 ha	This document

Project	Baseline	Potential impact to riparian vegetation	Reference
FMG IO Direct Shipping Iron Ore Project (Not Assessed – Public Advice Given under the EP Act)	NA	NA	Only the EPA (2012c) public advice was available at the time of assessment. Insufficient information was provided in that advice to enable the IO Direct Shipping Iron Ore Project to be included in the cumulative impact assessment
Iron Ore Holdings Iron Valley Iron Ore Project (EP Act Assessment No. 1905; EPBC Act Ref. 2012/6458)	114 ha	0 ha	URS (2012)
BHP Jinidi Iron Ore Mine (EP Act Assessment No. 1904; EPBC Act Ref. 2012/6299)	NA	NA	Both *E. camaldulensis* and *E. victrix* were present in the Jinidi Iron Ore Mine Project area (vegetation type 1a); however the area of vegetation supporting these species was not provided in the documentation reviewed (BHP 2011)
Rio Tinto Koodaideri Iron Ore Mine (EP Act Assessment No. 1933; EPBC Act Ref. 2012/6422)	543 ha	16 ha	ELA (2013)
BHP Marillana Creek (Yandi; EP Act Assessment No. 1555)	NA	NA	Groundwater dependent vegetation supporting *E. camaldulensis* and *E. victrix* was recorded in the Marillana Creek (Yandi) Project area; however, the area of such was not quantified in the documentation reviewed (EPA 2005)
Brockman Marillana Iron Ore Project (EP Act Assessment No. 1781; EPBC Act Ref. 2011/5892)	308 ha	19 ha	Brockman Resources (undated)
BHP Mining Area C (EP Act Assessment No. 1108)	NA	NA	Both *E. camaldulensis* and *E. victrix* were present in the Mining Area C Project area (vegetation type 13); however the area of vegetation supporting

Project	Baseline	Potential impact to riparian vegetation	Reference
			these species was not provided in the documentation reviewed (Woodward-Clyde 1997)
Mineral Resources Phil's Creek Iron Ore Mine (EPBC Act Ref. 2009/5107)	NA	NA	Vegetation type C1 supported both *E. camaldulensis* and *E. victrix*; however, details were not provided in the documentation reviewed on the area mapped and area proposed to be disturbed (Mattiske 2008c; URS 2009)
FMG Pilbara Iron Ore and Infrastructure Project - Railway Stage A (EP Act Assessment No. 1505)	NA	NA	Insufficient information was provided in the documentation reviewed to enable inclusion of this project in the cumulative impact assessment (FMG 2010b)
FMG Pilbara Iron Ore and Infrastructure Project - Railway Stage B (EP Act Assessment No. 1520; EPBC Act Ref. 2004/1897)	NA	NA	Both *E. camaldulensis* and *E. victrix* were present in the Pilbara Iron Ore and Infrastructure Project - Railway Stage B Project area; however, the area of vegetation types supporting these species was not provided in the documentation reviewed (Environ Australia 2005b)
Roy Hill Roy Hill 1 Iron Ore Mining Project Stage 1 (EP Act Assessment No. 1589; EPBC Act Ref. 2008/4624)	2,587 ha	568 ha	EPA (2009b); Roy Hill (2009)
Roy Hill Roy Hill 1 Iron Ore Mining Project Stage 2 (EP Act Assessment No. 1822; EPBC Act Ref. 2008/4624)	2,591 ha	353 ha	EPA (2009b)

Project	Baseline	Potential impact to riparian vegetation	Reference
Rio Tinto Yandicoogina Iron Ore Project, comprising: • Junction Central (EP Act Assessment No. 809 & 946) • Junction South East (EP Act Assessment No. 1590) • Junction South West and Oxbow (EP Act Assessment No. 1726; EPBC Act Ref. 2011/5815)	1,836 ha	67 ha	This document
Anticipated project actions			
Rio Tinto Proposal (this assessment)	791 ha	69 ha	This document
Reasonably foreseeable future actions			
FMG Christmas Creek Expansion Project (EP Act Assessment No. 1989; EPBC Act Ref. 2013/7055)	1,910 ha	355 ha	FMG (2015)
FMG Nyidinghu Iron Ore Project (EP Act Assessment No. 1068; EPBC Act Ref. 2013/6945)	NA	NA	FMG (2013)
Cumulative impact			
Refer above	14,946 ha	2,159	Refer above

* Area disturbed includes the area cleared and the area potentially significantly affected by groundwater drawdown. NA: Not available.

14.5 Key management actions

Flora and vegetation values in the Proposal Area will be protected through implementation of measures in accordance with the Yandicoogina Weed Action Plan; the E11 Standard: Water Quality Protection; the E14 Standard: Land Disturbance and Rehabilitation Control; the Yandicoogina Closure Plan; and the MMP which includes Water Discharge Management and Monitoring, as well as Vegetation and Groundwater Dependent Ecosystems Management and Monitoring. Key management measures include:

- Ongoing monitoring of the health and cover of riparian vegetation within the Revised Proposal Development Envelope and drawdown and discharge footprints using a number of techniques, along with their associated trigger and threshold levels including:
    - DCP monitoring; which measures canopy foliage density of mature riparian eucalypts. Foliage density in eucalypts is correlated with plant available water in accordance with the principle of ecological optimality (O'Grady et al. 2011; Ellis & Hatton 2008); and is regarded as a reliable indicator of water related stressors such as drought;

- Digital Multi-Spectral Imagery (DMSI) remote sensing of riparian vegetation; which provides a quantitative measure of change in vegetation condition based on a multiple spectral indexes;
- Riparian vegetation monitoring; involving direct measurement of vegetation attributes (*e.g.* structure and composition) in transects within the riparian vegetation communities;

- Ongoing monitoring and management of weeds, including established baseline and reference sites; implementing vehicle hygiene procedures; and targeted control.
- Maintaining a Clearing Restricted Area around the Marillana and Weeli Wolli Creeklines to limit clearing within riparian vegetation zones.
- Limiting the pit encroachment into edge of floodplain within less significant shrubland communities of the riparian zone and avoiding riparian woodland vegetation.
- Maintaining major creekline floodflows and minimising erosion on the creeklines by limiting the disturbance within the creeklines, and undertaking surface water modelling and geomorphological assessments on infrastructure required within the creeklines.
- Maintaining creekline discharge upstream of the Proposal to partially negate the potential impacts of groundwater drawdown.
- Monitoring surface water discharge extent within Weeli Wolli Creek.
- Monitoring discharge water quality, including pH, TDS, TSS and a range of analytes.
- Monitoring groundwater levels within monitoring bores to establish causative links between groundwater levels and tree health.
- Weed monitoring and management.

Disturbed areas will be rehabilitated following completion of mining. Refer to Section 17 for further details regarding rehabilitation and closure.

14.5.1 Status of existing Yandi Operations management

The ESD prepared by the EPA required provision of information on the current status and outcomes of the riparian vegetation management actions required by MS 914 Condition 7 – Riparian Vegetation, and Condition 8 – Weeds. A summary, based on the 2014 Annual Compliance Assessment Report, is outlined in the sections below.

14.5.1.1 Riparian vegetation

The Yandicoogina Surface Water Discharge and Groundwater Dependent Ecosystems Monitoring and Management Plan has been prepared and approved by OEPA. The outcome-based conditions identified in regard to riparian vegetation have been met, specifically:

- Water abstraction did not cause clearing or loss of vegetation or groundwater dependent ecosystems outside of prescribed zones.
- Dewatering discharge did not cause clearing or loss of vegetation or groundwater dependent ecosystems outside of prescribed zones.

- No irreversible impact occurred to riparian vegetation or groundwater dependent ecosystems within prescribed zones.

Monitoring and investigations using vegetation transects, visual qualitative assessments and a review of correlative environmental parameters confirmed that trigger levels for 'no impact' and 'no irreversible impact' had not been exceeded and therefore no contingency actions have been required to be implemented.

Overall, the Digital Canopy Photography and transect monitoring indicated some areas of riparian vegetation that were showing signs of stress (including foliage cover less than baseline data) while other areas showed increased foliage cover. The results from the DMSI align with DCP and vegetation transect results, showing variation in condition across both Marillana and Weeli Wolli Creeks. Some individual trees around the low-flow channels show reduced condition when compared to baseline, however, the overall green-ness indicates high recruitment rates of eucalypts and other strata.

14.5.1.2 Weeds

Weed monitoring sites have been developed in consultation with Parks and Wildlife and accepted by OEPA. Monitoring undertaken in 2014 showed that weed coverage in all monitored areas was lower than baseline cover.

14.6 Predicted outcome

A total of up to 1,800 ha of flora and vegetation will be required to be cleared for the Proposal. A range of measures have been or will be implemented to reduce potential impacts to flora and vegetation values (**Table 23**).

Table 23: **Mitigation hierarchy for flora and vegetation values**

Mitigation measure	Description
Avoidance	Re-designed waste rock dumps to avoid recorded *L. catapycnon* populations.
Minimisation	Clearing will be minimised to that required for safe construction and operation. Optimising waste dump designs and mine plan to minimise overall waste dump ex-pit clearing. Maintaining a Clearing Restricted Area which limits clearing of riparian vegetation, as far as practicable, to that required for key infrastructure to enable development of the Proposal (such as creek crossing points). Clearing of significant riparian vegetation communities containing mature Melaleuca communities avoided. Pit encroachment into edge of floodplain is located within less significant shrubland communities of the riparian zone. Limited physical disturbance to the low-flow channel (for infrastructure crossings only). Low flows in Weeli Wolli Creek will be maintained to support phreatophytic vegetation. Discharge location and wetting front extent designed to limit wetting front extent beyond existing approved 17km limit from the Marillana – Weeli Wolli confluence.
Rehabilitation	Disturbed areas will be rehabilitated using local native vegetation species, consistent with the Yandicoogina Closure Plan. Key functional creek elements retained (e.g. flood pathways, vegetation seed bank) to support natural rehabilitation upon closure.

After the mitigation hierarchy has been applied, it is expected that the Proposal will result in the following residual outcomes in relation to flora and vegetation:

- Clearing of up to 1,800 ha flora and vegetation (including 69 ha riparian zone vegetation).
- Stress and loss of some riparian vegetation associated with dewatering activities (drawdown), particularly more groundwater dependant vegetation and younger recruitment/augmented areas of riparian vegetation sustained by pre-existing discharge, with the vegetation expected to return to a more 'natural' state (i.e. pre-mining).
- Loss of some riparian vegetation associated with surplus water discharge, particularly waterlogging affects and the establishment of waterlogging tolerant species including sedges and rushes, though overall impacts will be limited to the currently approved footprint limit within MS 914 (17 km downstream from confluence of Marillana and Weeli Wolli Creeks).
- No loss of known and recorded individuals of *Lepidium catapycnon* (Hamersley Lepidium); redesign of the waste dumps has avoided recorded individuals and they have been designated 'areas of special protection from ground disturbance' and therefore excluded from the ground disturbance footprint.
- Removal of some individuals of Priority 4 flora species (*Goodenia nuda*), though it is recorded throughout the Pilbara and it is considered that this will not alter the species' conservation status.
- Rehabilitation of areas disturbed by the Proposal, consistent with the draft Yandicoogina Closure Plan.

Consistent with current guidelines and EPA approaches, the clearing of up to 1,731 ha of native vegetation in Good to Excellent condition and 69 ha riparian zone vegetation[4] within the Proposal Area will be offset as part of the Proposal (Section 18).

[4] For the purposes of the offset calculation, riparian zone vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

15. Terrestrial fauna

15.1 Key statutory requirements, environmental policy and guidance

15.1.1 EPA objective

The EPA has applied the following objective for the Proposal to its assessment of terrestrial vertebrate and short range endemic invertebrate fauna:

"To maintain representation, diversity, viability and ecological function at the species, population and assemblage level."

15.1.2 Regulatory framework

The following legislation is relevant to the Proposal with respect to the protection of terrestrial fauna values and the above EPA objective:

- *Wildlife Conservation Act 1950* (WA).
- *Conservation and Land Management Act 1984* (WA).
- *Environmental Protection Act 1986* (WA).
- *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth).

15.1.3 Relevant guidelines and policy

The following guidelines and international agreements are relevant to the Proposal with respect to the protection of terrestrial vertebrate, short range endemic invertebrate and aquatic fauna and the above EPA objective:

- EPA Position Statement No. 3: Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002).
- EPA Guidance Statement No. 20: Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in WA (EPA 2009a).
- EPA Guidance Statement No. 56: Terrestrial Fauna Surveys for Environmental Impact Assessment in WA (EPA 2004d).
- Technical Guide - Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment (EPA and DEC 2010).
- Survey Guidelines for Australia's Threatened Bats (DEWHA 2010).
- Survey Guidelines for Australia's Threatened Mammals (DSEWPaC 2011a).
- Survey Guidelines for Australia's Threatened Reptiles (DSEWPaC 2011b).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).
- Pilbara Water in Mining Guideline Report No.34 (DoW 2009).
- Japan-Australia (JAMBA), China-Australia (CAMBA) and Republic of Korea-Australia (ROKAMBA) Migratory Bird Agreements.

- The Convention on the Conservation of Migratory Species and Wild Animals (also known as the Bonn Convention).

15.2 Description of terrestrial vertebrate fauna

15.2.1 Terrestrial fauna surveys

There have been five previous vertebrate fauna and invertebrate SRE surveys overlapping or conducted in the Proposal Area (**Table 24** and **Figure 57**; surveys have been given codes for ease of recognition):

- Yandi Expansion Project - Conservation Significant Vegetation, Flora, Fauna and Fauna Habitat Assessment (JSE; Biota 2005).
- Yandicoogina Targeted Northern Quoll Survey (YNQ; Biota 2009).
- Yandicoogina Expansion Billiard Deposit Fauna Survey (BIL; Biota 2011).
- Pocket and Billiards South Level 2 Seasonal Fauna Survey (PBS; Biota 2014c, 2014e).
- Yandi Billiards Targeted Northern Quoll Survey (YBNQ; Biota 2014d).

Sampling methodology differed among the surveys, depending on the target fauna group. However, surveys typically included the following sampling methods:

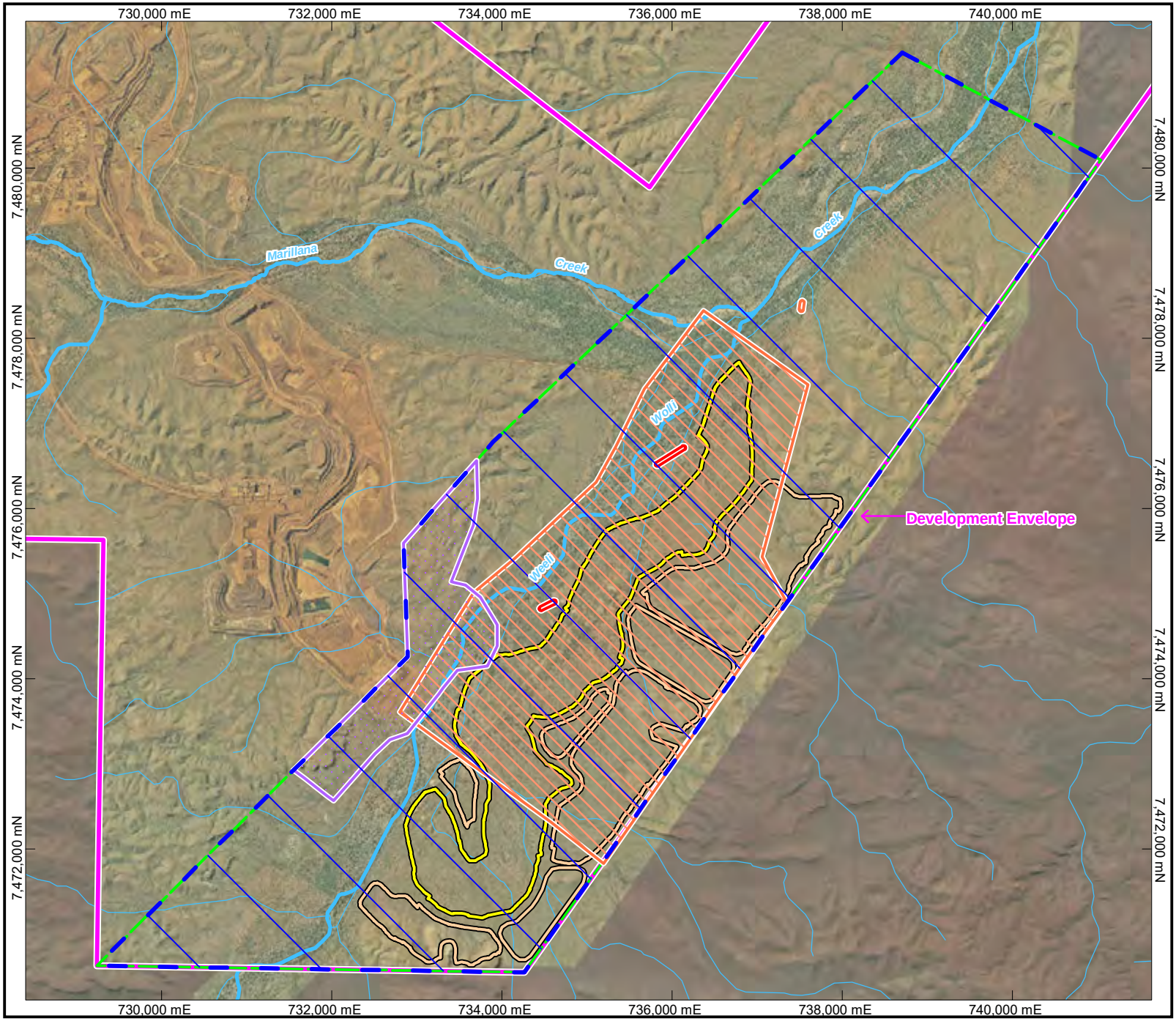
- Systematic sampling for non-volant mammals, reptiles, amphibians and SRE fauna via pitfall and funnel trapping grids and medium and large Elliott trap transects.
- Systematic volant mammal (bat) sampling via harp nets.
- Systematic avifauna surveys.

A range of non-systematic techniques were also used to identify animals not commonly recorded through trapping. These techniques included:

- Searching of specific habitats (targeted surveys).
- Identification of road kills and other animal remains.
- Opportunistic sightings and records.
- Secondary signs including tracks, scats and diggings.
- Motion camera trapping.
- Nocturnal searches.
- Echolocation call recorders such as Anabat SD2 and Song Meter SM2 for bat sampling.
- Audio recording for night birds and amphibian calls using the Song Meter SM2.

The location of systematic and non-systematic trapping sites within the Proposal Area is shown in **Figure 58**.

The description of fauna values has been adapted from the Biota survey reports (2005, 2009, 2011, 2014c, 2014d, 2014e) unless otherwise stated. Biota desktop reports (2010, 2013, 2014f, 2015b) have also been referenced.



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major; Minor Watercourse

Previous Fauna Surveys

- JSE Biota 2005b
- BIL Biota 2011a
- YNQ Biota 2009a
- YBNQ Biota 2014a, 2014h
  PBS Biota 2014a, 2014c

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Iron Ore (WA)

Figure 57
Previous terrestrial fauna surveys in the Proposal Area

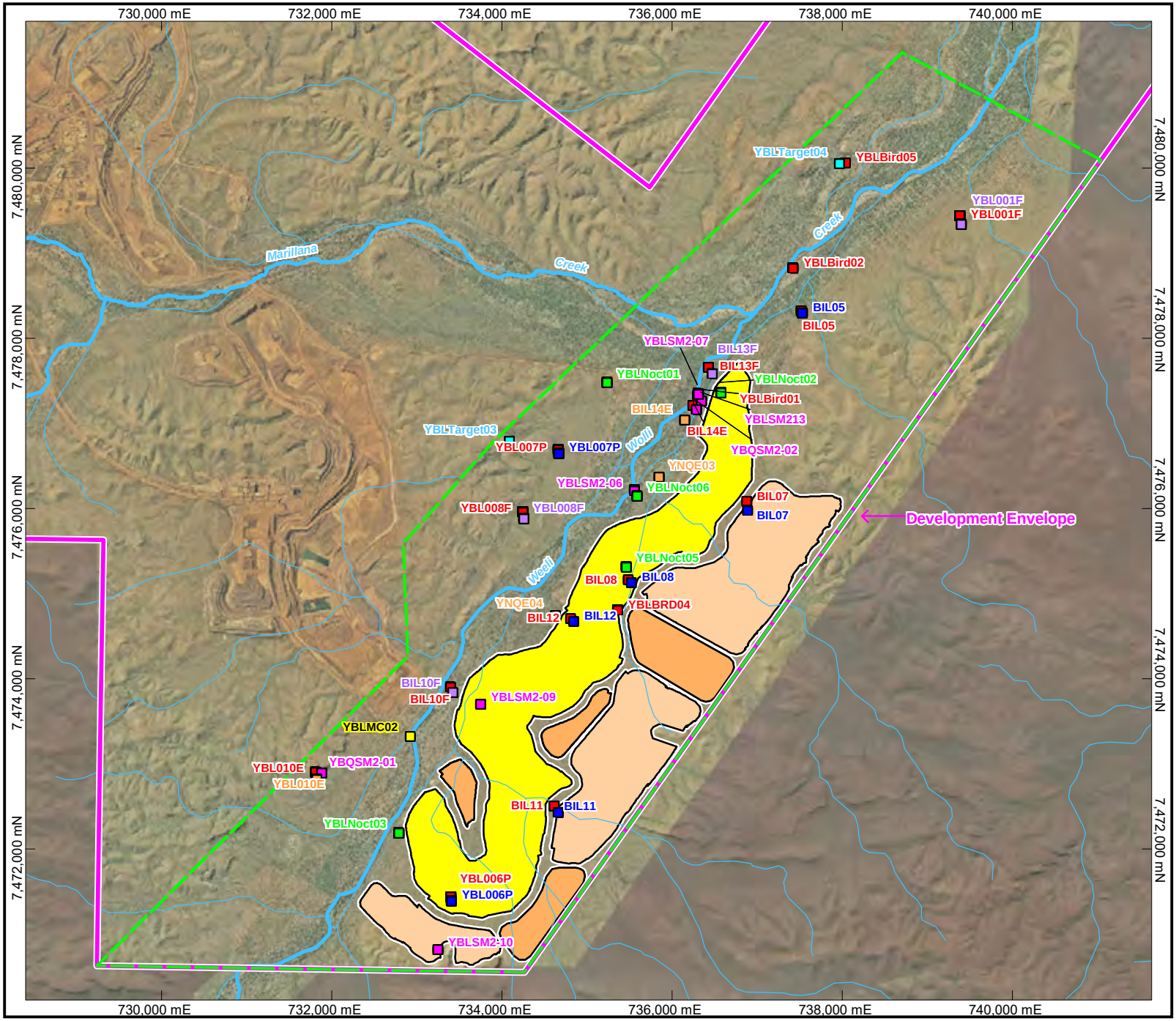
Drawn: M.Swebbs Plan No: PDE0133310v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Table 24: Summary of previous fauna surveys that overlap the Proposal Area

Survey (Reference)	Survey Code (from Biota 2015b)	Survey Dates	Fauna Groups Targeted	No. of Sampling Sites in Proposal Area	Conservation Significant Species Recorded During Survey (not necessarily in Proposal Area)	Survey Limitations and Constraints
Yandi JSE Project - Targeted Conservation Significant Vegetation, Flora, Fauna and Fauna Habitat Assessment (Biota 2005)	JSE	30/08/04-03/09/04	Invertebrate SRE	3 invertebrate (targeted)	• Nil.	• Single phase survey. • Large proportion of the study area was recently burnt. • Dry conditions discouraged activity in many invertebrate groups. • Vertebrate field survey was not conducted.
Yandicoogina Expansion Billiard Deposit Fauna Survey (Biota 2011)	BIL	05/07/08-12/07/08 04/03/10-07/03/2010 (invertebrate SRE only)	Vertebrate fauna Invertebrate SRE	8 vertebrate 8 avifauna 1 bat 9 invertebrate (4 targeted, 5 systematic)	• Rainbow Bee-eater (Sch 3, Migratory). • Western Pebble-mound Mouse (P4).	• Single phase vertebrate survey. • Not all sections of the study area could be sampled equally due to limited access.
Yandicoogina Targeted Northern Quoll Survey (Biota 2009)	YNQ	06/10/09-12/10/09	Northern Quoll	2 vertebrate	• Nil.	• Single phase survey. • Sampling was targeted at the Northern Quoll. • Collection of other taxa was mostly opportunistic.
Yandicoogina Pocket and Billiard South Level 2 Seasonal Fauna Survey (Biota 2014c,e)	PBS	Phase I: 08/03/14-18/03/14 Phase II: 10/09/14-19/09/14	Vertebrate fauna Invertebrate SRE	11 vertebrate 23 invertebrate (2 systematic, 21 targeted) 8 bat 10 avifauna	• Pilbara Olive Python, (Sch 1, V). • Fork-tailed Swift (Sch 3, Migratory). • Eastern Great Egret (Sch 3, Migratory). • Rainbow Bee-eater (Sch 3, Migratory). • Brush-tailed Mulgara (P4). • Western Pebble-mound Mouse (P4). • Chocolate Wattle Bat (no formal listing). • Three potential SREs: Idiopidae sp. I53, Nemesiidae sp. N42 and Nemesiidae sp. N44.	• Survey did not equally sample all areas of the target area, instead concentrated on areas that have previously been under represented during surveys. • Non-systematic sampling also undertaken.
Yandi Billiards Targeted Northern Quoll Survey (Biota 2014d)	YBNQ	05/08/14-13/08/14	Northern Quoll Invertebrate SRE Volant mammals	5 vertebrate 1 invertebrate (targeted) 6 bat	• A single potential Northern Quoll scat was found; however molecular sequencing was unable to determine its origin.	• Single phase survey. • Sampling was predominately targeted at the Northern Quoll.

***** Not necessary in the Proposal Area



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse

Vertebrate Trapping Sites

- Avifauna
- Elliott
- Funnel
- Motion Camera
- Nocturnal
- Pitfall
- Bat SongMeter
- Targeted

N

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RioTinto

Iron Ore (WA)

Figure 58
The location of systematic and non-systematic trapping sites within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133316v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

15.2.2 Terrestrial fauna habitats

Five fauna habitats were identified in the Proposal Area by Biota (2014c). These habitats were based on a combination of larger landform patterns (floodplains, hills etc.) and smaller landform elements (breakaways, slopes etc.), on the basis that fauna utilise many components of a landform, and are not specific to a certain element. Fauna habitats are described in **Table 25** shown in **Figure 59** and consist of:

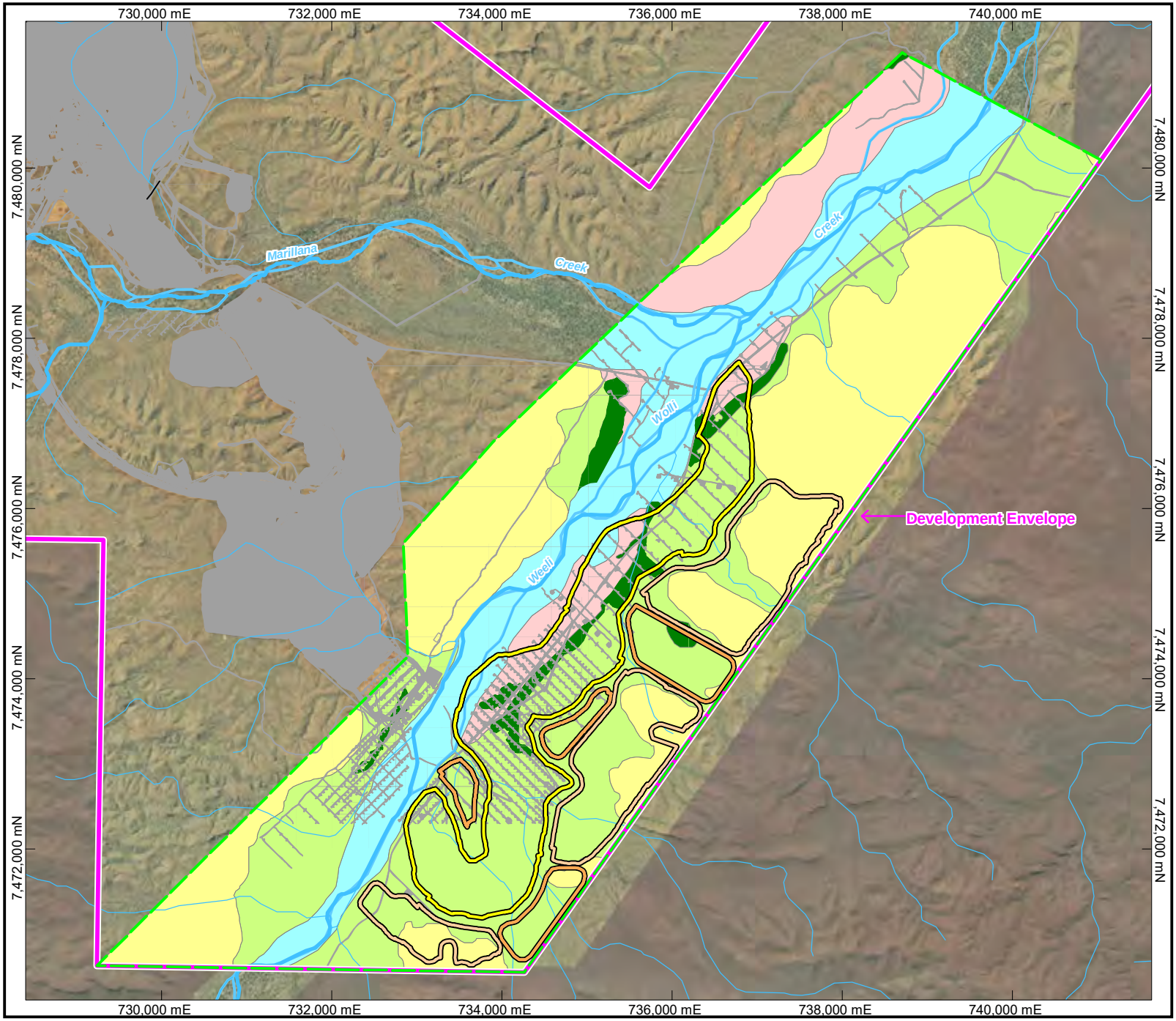
- Alluvial Plain (Flood Plain).
- Mulga woodland.
- Hilltops and Slopes.
- Pediment Slope.
- Major Drainage Line.

Disturbed areas within the Proposal Area were also mapped.

Table 25: Landforms and descriptions of fauna habitats mapped within the Proposal Area

Landform Pattern	Fauna Habitat	Description	Current Area within the Proposal Area (ha)
Flats	Alluvial Plain (Flood Plain)	An area of land adjacent to a drainage line that stretches from the banks of its channel to the base of the enclosing valley walls. It experiences flooding during periods of high discharge but does not experience a strong current.	402
Flats	Mulga Woodland	Mulga woodlands in Proposal Area occur on areas of alluvial plain. They are delineated as a discrete fauna habitat because they support a distinct fauna assemblage not present in other habitats within the Proposal Area.	111
Hilltops and Slopes	Hilltops and Slopes	Hilltops and slopes make up much of the Proposal Area and consist of a number of landform elements, notably (from highest to lowest elevation): Crests, Free Faces, Breakaways (not always present), Transitional Slopes and Foot Slopes.	1,434
Hilltops and Slopes	Pediment Slope	The large, gently inclined lower slopes below hills underlain by bedrock at varying depths. Pediments in the Proposal Area vary in width and exhibit sharp breaks of slope between the pediment and the steeper hillside above them. Water passes across the pediment by laminar sheet flow, but if this is disturbed, the flow becomes turbulent and gullies develop.	1,542
Drainage	Major Drainage Line	A linear, sinuous open depression forming the floor of the major drainage channel (Weeli Wolli Creek) that is eroded or aggraded (built-up) by stream flow. In the Proposal Area this supports taller eucalypts, dense shrublands and reedbeds around water pools that are semi-permanent due to upstream mine dewatering.	859
Disturbed		Areas of disturbed land originating from clearing.	138

Source: Biota (2014c)



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Existing Disturbance
- Major; Minor Watercourse

Fauna Habitat

- Alluvial plain
- Hilltops and slopes
- Major drainage line
- Mulga woodland
- Pediment slope

N

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Iron Ore (WA)

Figure 59
Fauna habitats within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133320v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

15.2.3 Terrestrial fauna occurrence

Of the 249 vertebrate fauna species that could potentially occur in the vicinity of the Proposal Area (based on a desktop review of database searches and the results of previous surveys in the general locality; Biota 2013), 147 species have been recorded within the Proposal Area (Biota 2015b, 2014c). The following numbers of species were recorded from each vertebrate fauna group:

- 10 native non-volant mammals;
- 3 introduced non-volant mammals;
- 5 volant mammals (bats);
- 78 birds;
- 48 reptiles; and
- 3 amphibians.

15.2.4 Terrestrial vertebrate fauna species of conservation significance

Six conservation listed species have been recorded in the Proposal Area, including four species listed under the EPBC Act and WC Act and one species listed in the Parks and Wildlife Priority Fauna List (**Table 26, Figure 60** and **Figure 61**). An additional species, the Chocolate Wattled Bat (*Chalinolobus morio*), while currently not conservation listed under Commonwealth or State legislation, is of regional significance as it is geographically restricted within the Pilbara region to Weeli Wolli Creek and Marillana Creek (Biota 2014c).

The locations of the records of these species within the Proposal Area are shown in **Figure 61**.

Table 26: Number of individuals of conservation significant terrestrial vertebrate fauna species found within the Proposal Area

Common Name	Species Name	Conservation Status		Number of individuals recorded/survey	
		State	Commonwealth	BIL	PBS
Pilbara Olive Python	*Liasis olivaceus barroni*	Schedule 1	Vulnerable	0	1
Fork-tailed Swift	*Apus pacificus*	Schedule 3	Migratory	0	9
Eastern Great Egret	*Ardea modesta*	Schedule 3	Migratory	0	1
Rainbow Bee-eater	*Merops ornatus*	Schedule 3	Migratory	21	42
Western Pebble-mound Mouse	*Pseudomys chapmani*	Priority 4	-	1	0 (9 mounds)
Chocolate Wattled Bat	*Chalinolobus morio*	-	-	0	1

Note: Survey codes are explained in Table 24.

Source: Biota (2015b). An additional seven Western Pebble-mound Mouse mound records were recorded in the Proposal Area opportunistically during a Rare Flora survey in 2014.

NatureMap, EPBC Act Protected Matters Search Tool (PMST) and Atlas of Living Australia (ALA), species distributions and habitat preference suggest a further 17 conservation significant species may potentially occur.

Species identified through these means have been further assessed to determine their likelihood of occurrence within the Proposal Area (**Table 27**). The assessment took into account results of field surveys undertaken within the Proposal Area and the wider Revised Proposal Development Envelope, along with existing data for the broader region; the habitat requirements and known distribution of each species and professional judgement from technical report authors. The likelihood of occurrence has been determined as follows (Biota 2014c):

Recorded: The species has been recorded in the Proposal Area during recent or previous surveys.

Likely: The species has a high probability of occurring in the Proposal Area based on records in the Revised Proposal Development Envelope or within 20 km to the Proposal Area. The specific or suitable habitat is present in the Proposal Area.

Has potential: The species has a medium probability of occurring in the Proposal Area based on existing records within 40 km. However, depending on the species habitat preferences:

- a small amount of the specific habitat is present in the Proposal Area;
- only some suitable general habitat is present; or
- suitable habitat is present, but the species is recorded infrequently in the locality.

Unlikely: The species has a low to very low probability of occurring in the Proposal Area based on its known distribution, habitat preference and/or historical records. Depending on the species habitat preferences:

- the specific habitat is absent from the Proposal Area;
- suitable habitat is present, however there are no existing records of the species from the locality; or
- some suitable habitat is present, however the species is recorded very infrequently in the locality.

Would not occur: The species would not occur in the Proposal Area. This is due to its restricted range, or absence of specific habitat that the species is linked to strongly.

Based on the likelihood of occurrence, the following species are considered likely to occur in the Proposal Area:

- Pilbara Leaf-nosed Bat, *Rhinonicteris aurantius* (Vulnerable, Schedule 1).
- Common Greenshank, *Tringa nebularia* (Migratory, Schedule 3).
- Peregrine Falcon, *Falco peregrinus* (Schedule 4).
- Blind Snake, *Anilios ganei* (Priority 1).
- Pilbara Barking Gecko, *Underwoodisaurus seorsus* (Priority 2).
- Brush-tailed Mulgara, *Dasycercus blythi* (Priority 4).

- Ghost Bat, *Macroderma gigas* (Priority 4).

The following species were considered to have potential to occur:

- Northern Quoll, *Dasyurus hallucatus* (Endangered, Schedule 1).
- Grey Falcon, *Falco hypoleucos* (Schedule 1).
- Australian Painted Snipe, *Rostratula australis* (Schedule 1).
- Cattle Egret, *Ardea ibis* (Migratory, Schedule 3).

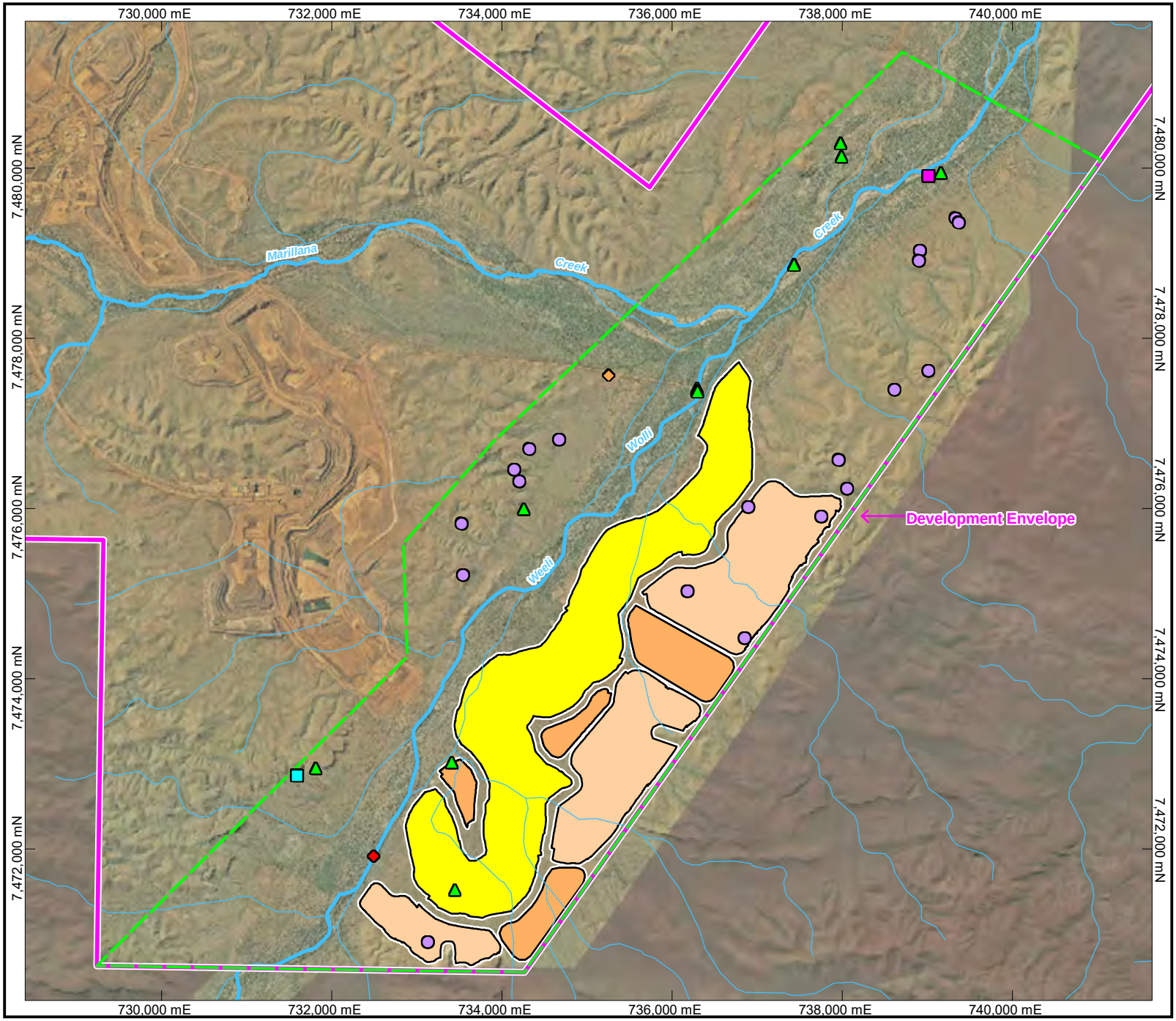
The following species were considered to be unlikely to occur:

- Night Parrot, *Pezoporus occidentalis* (Endangered, Schedule 1).
- Bilby, *Macrotis lagotis* (Vulnerable, Schedule 1).
- Oriental Plover, *Charadrius veredus* (Migratory, Schedule 3).
- Long-tailed Dunnart, *Sminthopsis longicaudata* (Priority 4).
- Short-tailed Mouse, *Leggadina lakedownensis* (Priority 4).

One species was considered to not occur in the Proposal Area:

- Northern Marsupial Mole, *Notoryctes caurinus* (Endangered, Schedule 1).

There is a history of taxonomic confusion regarding the genus *Dasycercus*. The most recent analysis has resulted in the recognition of two species in Australia, the Crest-tailed Mulgara (*D. cristicauda*) and the Brush-tailed Mulgara (*D. blythi*). Due to habitat preferences and distribution of Brush-tailed Mulgara, it was assumed that the burrows recorded in close proximity to the Proposal Area belonged to this species; however, the identification has yet to be confirmed due to a lack of direct captures (Biota 2014c). For the purposes of this PER, it has been assumed that Brush-tailed Mulgara is the species present in the vicinity of the Proposal Area.



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse

Conservation significant terrestrial vertebrate fauna

- Eastern Great Egret
- Pilbara Olive Python
- Rainbow Bee-eater
- Western Pebble-mound Mouse
- Chocolate Wattled Bat
- Fork-tailed Swift

N

SCALE

0 1 2 3km

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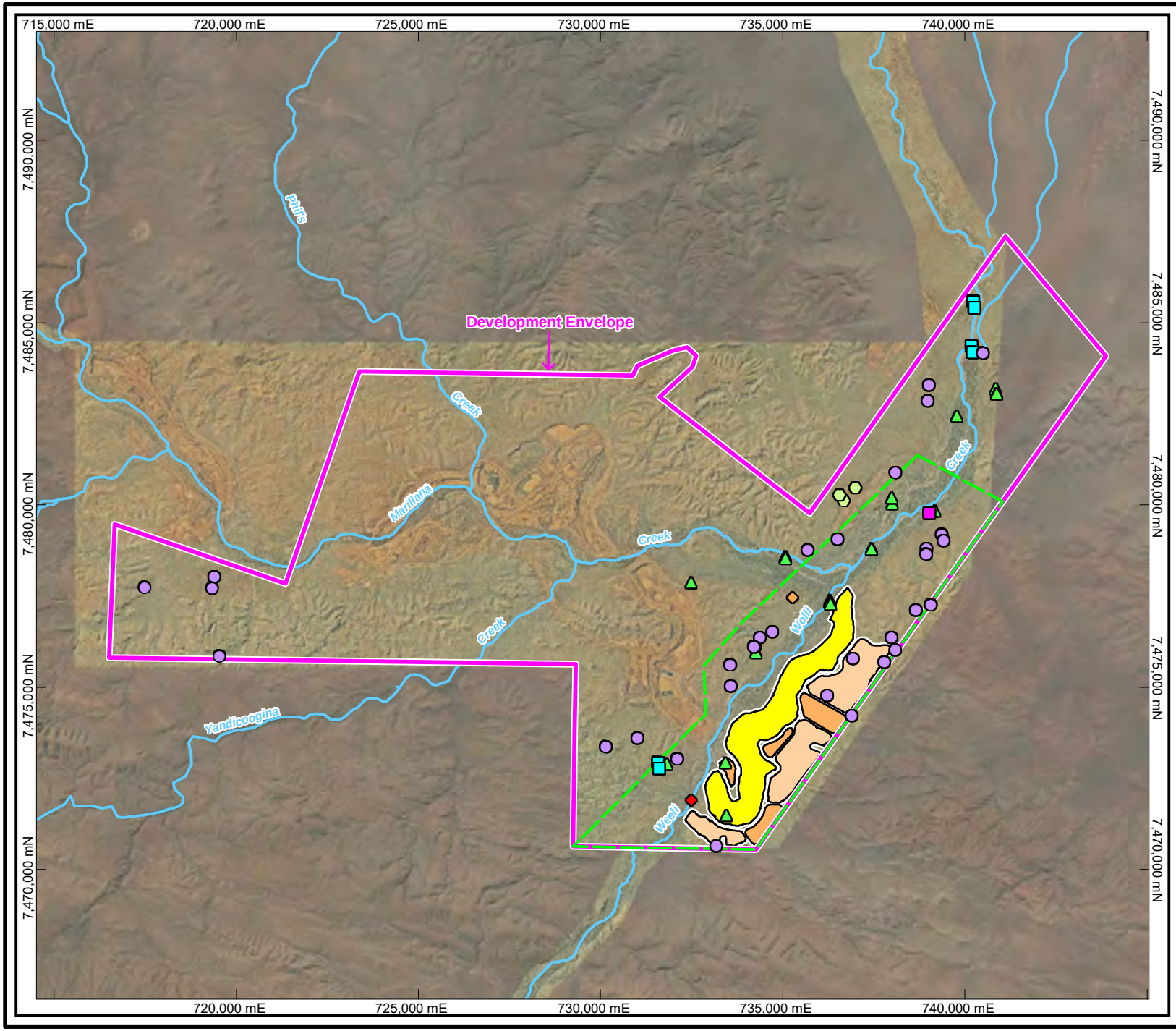
Iron Ore (WA)

Figure 60
Locations of conservation significant fauna records within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133323v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile

Conservation significant terrestrial vertebrate fauna

- Eastern Great Egret
- Pilbara Olive Python
- Rainbow Bee-eater
- Western Pebble-mound Mouse
- Chocolate Wattled Bat
- Brushed-tailed Mulgara
- Fork-tailed Swift

N

SCALE

0 2 4 6km

1:150 000 @ A4

Iron Ore (WA)

Figure 61
Locations of conservation significant terrestrial fauna in the Revised Proposal Development Envelope

Drawn: M.Swebbs Plan No: PDE0133381v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Table 27: Likelihood of occurrence of conservation significant terrestrial fauna in the Proposal Area based on database searches, known distribution and presence of potential habitat

Name	Conservation Status		Nature Map (<40 km)	PMST	ALA (<40 km)	Biota Records within 10 km (see Biota 2014c)	Preferred habitat	Habitat available in Proposal Area?	Likelihood of occurrence
	State	Commonwealth							
Night Parrot *Pezoporus occidentalis*	Schedule 1	Endangered	N	Y	N	No	Dense, low vegetation often associated with *Triodia* hummock grasslands and areas dominated by samphire	Y	Unlikely
Northern Marsupial Mole *Notoryctes caurinus*	Schedule 1	Endangered	N	Y	N	No	Well vegetated sand dunes and sandy soils	N	Would not occur
Northern Quoll *Dasyurus hallucatus*	Schedule 1	Endangered	Y	Y	N	Yes	Rocky habitats, ridges and free faces particular when in contact with dense vegetation along drainage area, and from boulder tours of the Abydos-Woodstock Plain	Y	Has potential
Bilby *Macrotis lagotis*	Schedule 1	Vulnerable	N	Y	N	No	Sandy soils covered with spinifex grassland (mainly *Triodia basedowii*), with an over-storey of low shrubs dominated by *Acacia* species	Y	Unlikely
Pilbara Leaf-nosed Bat *Rhinonicteris aurantius*	Schedule 1	Vulnerable	Y	Y	N	Yes	Breakaways adjacent to large drainage lines, deep caves in BIF ranges	Y (foraging)	Likely
Australian Painted Snipe *Rostratula australis*	Schedule 1	-	Y	Y	N	No	Wetland areas with dense screening vegetation	Y	Has potential
Grey Falcon *Falco hypoleucos*	Schedule 1	-	N	N	Y	No	Most common in lightly wooded coastal and riverine plains, although it is found in a wide range of arid zone habitats	Y	Has potential
Cattle Egret *Ardea ibis*	Schedule 3	Migratory	N	Y	N	No	Standing shallow freshwater	Y	Has potential
Common Greenshank *Tringa nebularia*	Schedule 3	Migratory	Y	N	N	Yes	Sheltered coastal habitats and terrestrial ephemeral wetlands	Y	Likely

Name	Conservation Status		Nature Map (<40 km)	PMST	ALA (<40 km)	Biota Records within 10 km (see Biota 2014c)	Preferred habitat	Habitat available in Proposal Area?	Likelihood of occurrence
	State	Commonwealth							
Oriental Plover *Charadrius veredus*	Schedule 3	Migratory	N	Y	N	No	Open plains, bare rolling country, muddy or sandy wastes near inland swamps or tidal mudflats, bare claypans, margins of coastal marshes, grassy airfields, lawns and coastal dunes	Y	Unlikely
Peregrine Falcon *Falco peregrinus*	Schedule 4	-	Y	N	Y	Yes	Wide range of habitats including forest, woodlands, wetlands and open country	Y	Likely
Blind Snake *Anilios ganei*	Priority 1	-	Y	N	Y	Yes	Occurs in a wide variety of habitats	Y	Likely
Pilbara Barking Gecko *Underwoodisaurus seorsus*	Priority 2	-	Y	N	N	Yes	Rocky ridges, slopes and gullies	Y	Likely
Brush-tailed Mulgara *Dasycercus blythi*	Priority 4	-	Y	N	N	Yes	Sand plain and gibber plain	Y	Likely
Ghost Bat *Macroderma gigas*	Priority 4	-	Y	N	Y	Yes	Breakaways adjacent to large drainage lines, deep caves in BIF ranges	Y (foraging)	Likely
Long-tailed Dunnart *Sminthopsis longicaudata*	Priority 4	-	N	N	N	Yes	Plateaux near breakaways and screes, and rugged boulder strewn screes, often in areas with little vegetation	Y	Unlikely
Short-tailed Mouse *Leggadina lakedownensis*	Priority 4	-	N	N	N	Yes	Cracking clay, native grasslands and surrounding habitat	N	Unlikely

Adapted from Biota (2014c)

15.3 Description of short range endemic invertebrate fauna

Short range endemic (SRE) species are those that display naturally restricted distributions (less than 10,000 km^2) and are therefore at greater risk of population extinctions than more widely distributed taxa (EPA 2009a). Taxa that exhibit short range endemism are generally characterised by poor dispersal, low growth rates and low fecundity. They are commonly reliant on habitat types that are discontinuous, and are often confined to fragmented 'refugial' habitats, having persisted from a time when moist conditions were more evenly distributed throughout the Australian landscape (Harvey 2002). SRE invertebrate species are historically poorly studied and, in many cases, lack formal descriptions or adequate taxonomic frameworks. Extensive, reliable taxonomic evaluations of many orders have only relatively recently commenced, and the availability of literature relevant to SREs is thus relatively scarce (Harvey 2002).

SRE invertebrate species are a relevant factor to consider during EIA, as their restricted distribution leaves them vulnerable to changes in conservation due to habitat loss (EPA 2009a).

Consultation was undertaken with the WA Museum to identify specific invertebrate groups to target in the area as those most likely to support SRE fauna (Biota 2015b). These comprised:

- Mygalomorphae (trapdoor spiders).
- Diplopoda (millipedes).
- Scorpionida (scorpions).
- Pulmonata (land snails).
- Pseudoscorpiones (pseudoscorpions).

15.3.1 Short range endemic invertebrate fauna surveys

Surveys and assessment of the SRE invertebrate fauna of the Proposal Area have been undertaken.

Field surveys were conducted in accordance with EPA Guidance Statement No. 20: "Guidelines for the Assessment of SRE Invertebrate Fauna for Environmental Impact in Western Australia" (EPA 2009a). SREs were systematically sampled via pit trap lines (seven study sites within the Proposal Area) during the Proposal surveys. Three non-systematic (targeted searching) invertebrate fauna surveys were also undertaken in the broader Revised Proposal Development Envelope, with 25 sites located within the Proposal Area. All surveys undertaken within the Proposal Area are summarised in **Table 24**. In addition, opportunistic searches were also undertaken during an earlier survey in the Proposal Area in 2009; the exact search effort was not recorded (Biota 2015b). Systematic and targeted sampling sites are presented in **Figure 62**. SRE data from a recent SRE survey conducted by Biota for BHP that overlapped the Proposal Area has also been included (records are lodged with the WAM; survey code JML; Biota 2015b).

Pit-trapping sites were selected to provide representative sampling for terrestrial fauna within the range of land systems and habitats present; SRE fauna were collected as by-catch (refer to Sections 5.4 and 6.3.1). In addition to pit-trapping, the surveys used a variety of targeted search methods to collect potential SREs (Biota 2014c, 2015b), including:

- overturning and searching under rocks and in rock crevices;
- raking soil and leaf litter;
- sieving soil and leaf litter;
- excavating leaf litter and soil around the base of spinifex (*Triodia* spp.) hummocks (land snails only);
- searching on trees and beneath bark (pseudoscorpions only); and
- visually locating burrows (mygalomorph spiders only).

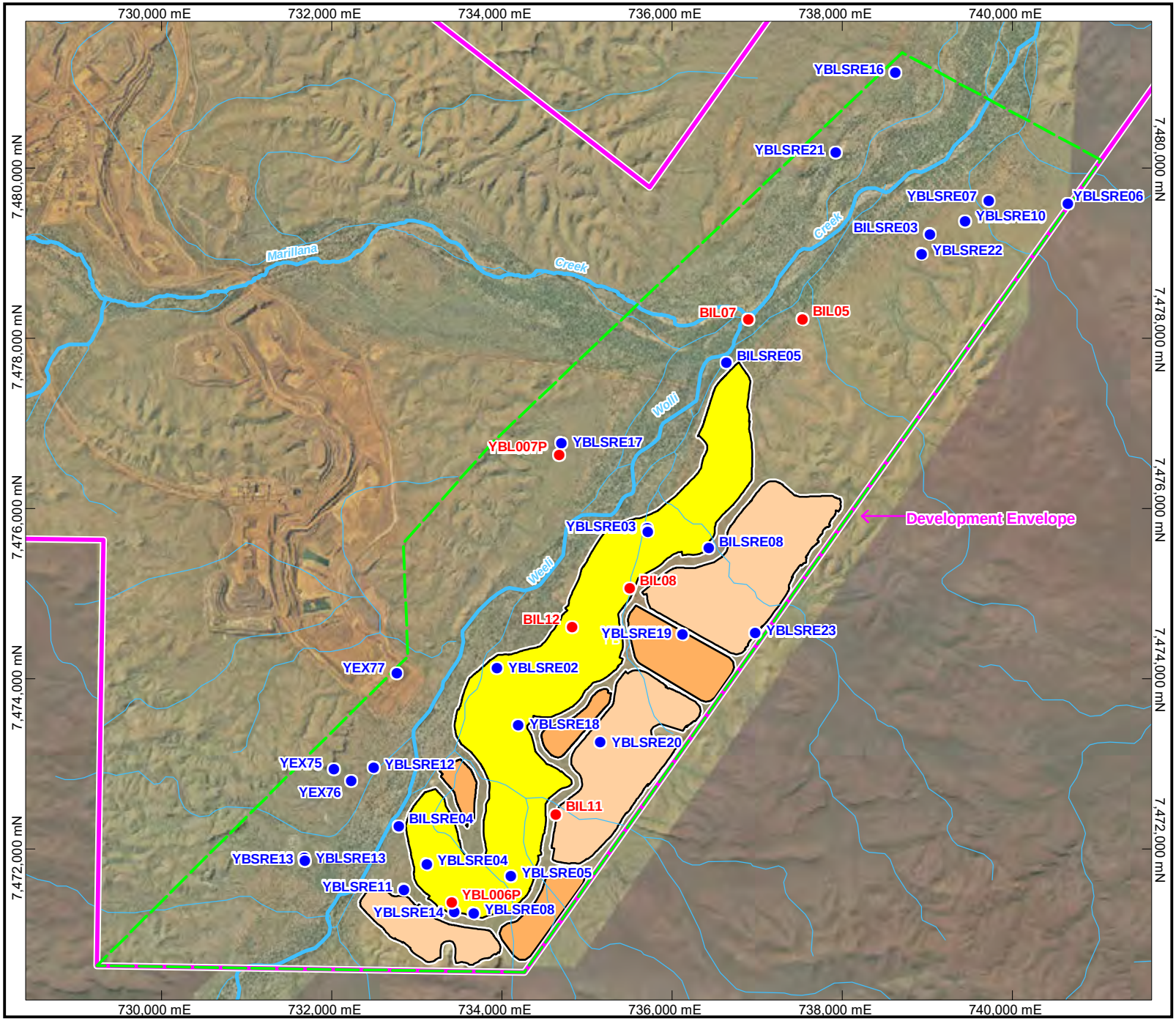
Specimens from all taxonomic groups were lodged with the WA Museum for morphological identification. Molecular (DNA) analysis was used to infer relationships within the mygalomorph spiders and putative species boundaries.

Species recorded in these surveys that have a known distribution exceeding 10,000 km^2 were considered to be non-SRE species, while those with a distribution of less than 10,000 km^2 were considered 'potential SREs'. The criteria used to determine the SRE status of putative species recorded are detailed in Biota (2014c). Some taxa were determined as being of uncertain SRE status due to a lack of available data and taxonomic framework.

15.3.2 Short range endemic invertebrate fauna habitats

Four land system units are found within the Proposal Area; the Newman, River, Boolgeeda and McKay (**Table 5**). All land systems were sampled for SREs during the targeted search surveys and by pit-trapping lines.

SREs were targeted in a variety of landforms (such as drainage lines, hills and slopes and flats) and microhabitats (like large spinifex hummocks, Mulga groves, bark, leaf litter, soil and rock piles) that are known to be prospective.



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse

SRE Sampling Sites

- Targeted
- Systematic

N

SCALE

0 1 2 3km

1:65 000 @ A4

Iron Ore (WA)

Figure 62
SRE targeted and systematic sampling sites within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133364v2
Date: October, 2015 Proj: MGA94 (Zone 50)

Geospatial Information and Mapping

15.3.3 Short range endemic invertebrate fauna occurrence

Twenty potential SRE specimens were collected from within the Proposal Area (Biota 2015b). Genetic analysis determined six putative species (**Table 28**); five from two families of mygalomorph spiders (Idiopidae and Nemesiidae), and one pseudoscorpion specimen from the genus *Beieroipium* (family Olpiidae). All species have been previously recorded outside the Proposal Area. Four of the mygalomorph spider putative species are considered potential SREs, as their known distribution is less than 10,000 km^2:

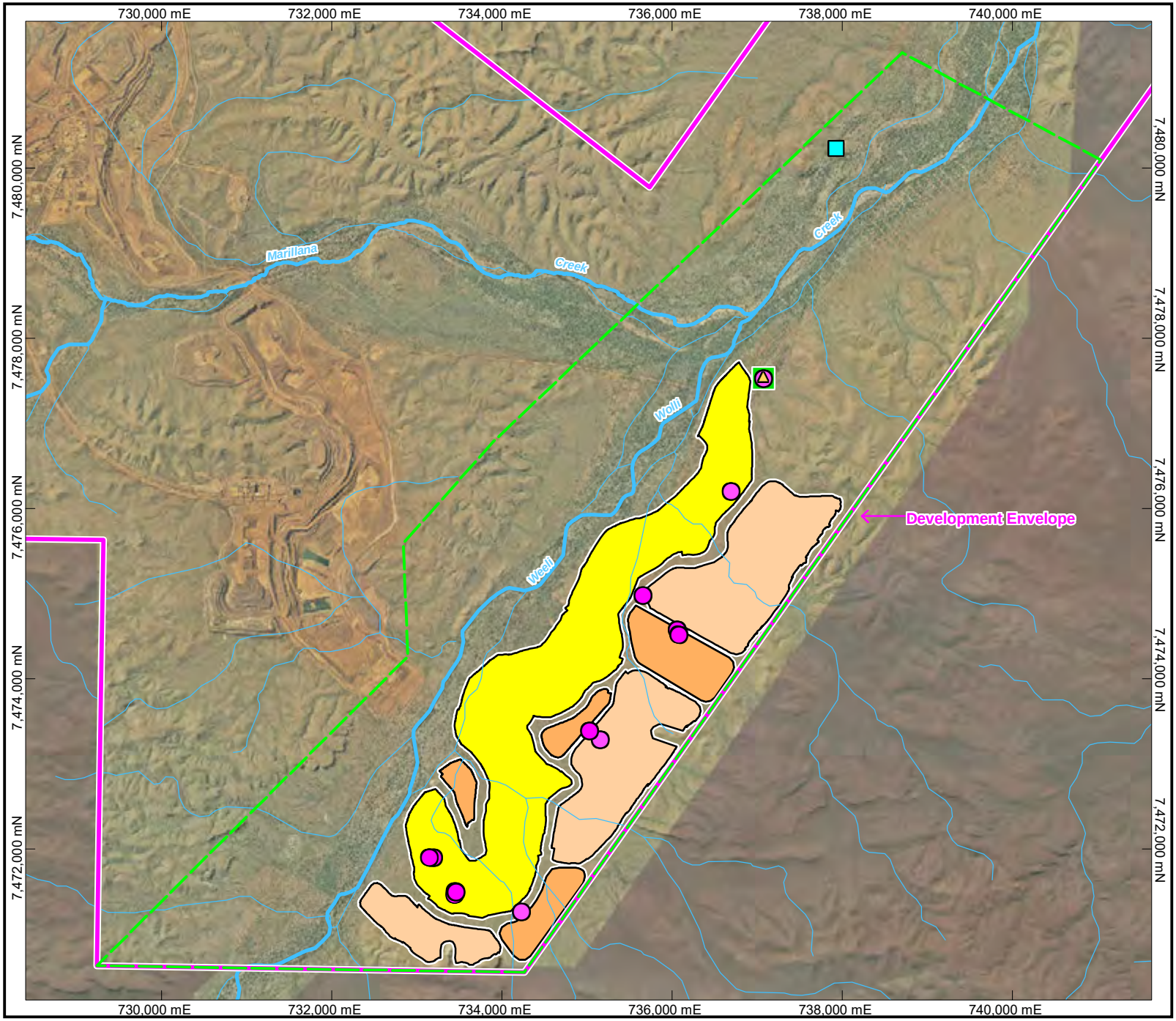
- Idiopidae sp.I1 and I9; and
- Nemesiidae sp. N42 and N44.

The distribution of some putative species is uncertain in olpiid pseudoscorpions due to limited taxonomic resolution. The SRE status of some Olpiidae taxa is therefore also uncertain, however the characteristics of this family's dispersal mechanism (phoretic, or animal-assisted dispersal) mean *Beierolpium* sp. is not considered likely to represent an SRE (Biota 2015b). **Figure 63** shows the locations of the potential SRE species within the Proposal Area. All four potential SRE species have been recorded outside of the Proposal Area (Biota 2015b).

Table 28: **Summary of potential SREs found within the Proposal Area**

Invertebrate Group Family	Taxon	No. of Specimens	Land Systems Represented	Survey Code	SRE Status	Occurs Outside Proposal Area?
Pseudoscorpions						
Olpiidae	*Beierolpium* sp.	1	River	PBS	Unlikely to be a SRE	Unknown
Mygalomorph Spiders						
Idiopidae	Idiopidae sp. I1	2	River	JML	Potential SRE	Yes
	Idiopidae sp. I9	1	River	JML	Potential SRE	Yes
Nemesiidae	Nemesiidae sp. N16	6	Boolgeeda, McKay, River	PBS/JML	Not an SRE	Yes
	Nemesiidae sp. N42	1	Boolgeeda, River	PBS/JML	Potential SRE	Yes
	Nemesiidae sp. N44	9	Boolgeeda, Newman, River	PBS/JML	Potential SRE	Yes

Table from Biota (2015b), adjusted with data from Biota (2014c)



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse

SRE Invertebrate Fauna

- Nemesiidae sp. N42
- Nemesiidae sp. N44
- Idiopidae sp.I1
- Idiopidae sp.I9

N

SCALE

0 1 2 3km

1:65 000 @ A4

Iron Ore (WA)

Figure 63
Distribution of potential SRE invertebrate species within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133368v2
Date: October, 2015 Proj: MGA94 (Zone 50)

Geospatial Information and Mapping

15.4 Description of aquatic fauna

15.4.1 Aquatic fauna surveys

Aquatic fauna surveys have been conducted biannually (wet and dry season) since September 2007 by Wetland Research and Management (WRM 2015a, 2015b) in Marillana Creek and Weeli Wolli Creek, with additional sites added in October 2008 and May 2009. The results of the September/October 2013 (late dry) and April/May 2014 (late wet) surveys are presented in Section 15.4.3 below. Fourteen sampling sites were located within the Proposal Area; three sites in Marillana Creek (MAR2-7 - MAR2-9) and ten sites in Weeli Wolli Creek (WW3-3 - WW3-6 and WW4-1, WW4-3 - WW4-6 and WW4-8; **Figure 64**).

The Marillana Creek sites (Marillana Reach Two; MAR-Two) were located downstream of the Yandi Operations D09, as far as the reach of the perennial surface water flows. The Weeli Wolli Creek Reach Three (WW-Three) sites were located upstream of the junction of Marillana Creek, as far as the Yandi Operations D06, with the Reach Four (WW-Four) sites located downstream of the Marillana Creek confluence, towards the Fortescue Marsh.

Aquatic microinvertebrates, macroinvertebrates and fish species were targeted, with survey methods including mesh pond netting, seine netting, gill nets, dip nets and electrofishing. Hyporheic fauna were sampled using the Karaman-Chappuis method. Fish were identified in the field, then released alive; aquatic invertebrates were preserved in 70% ethanol for later identification.

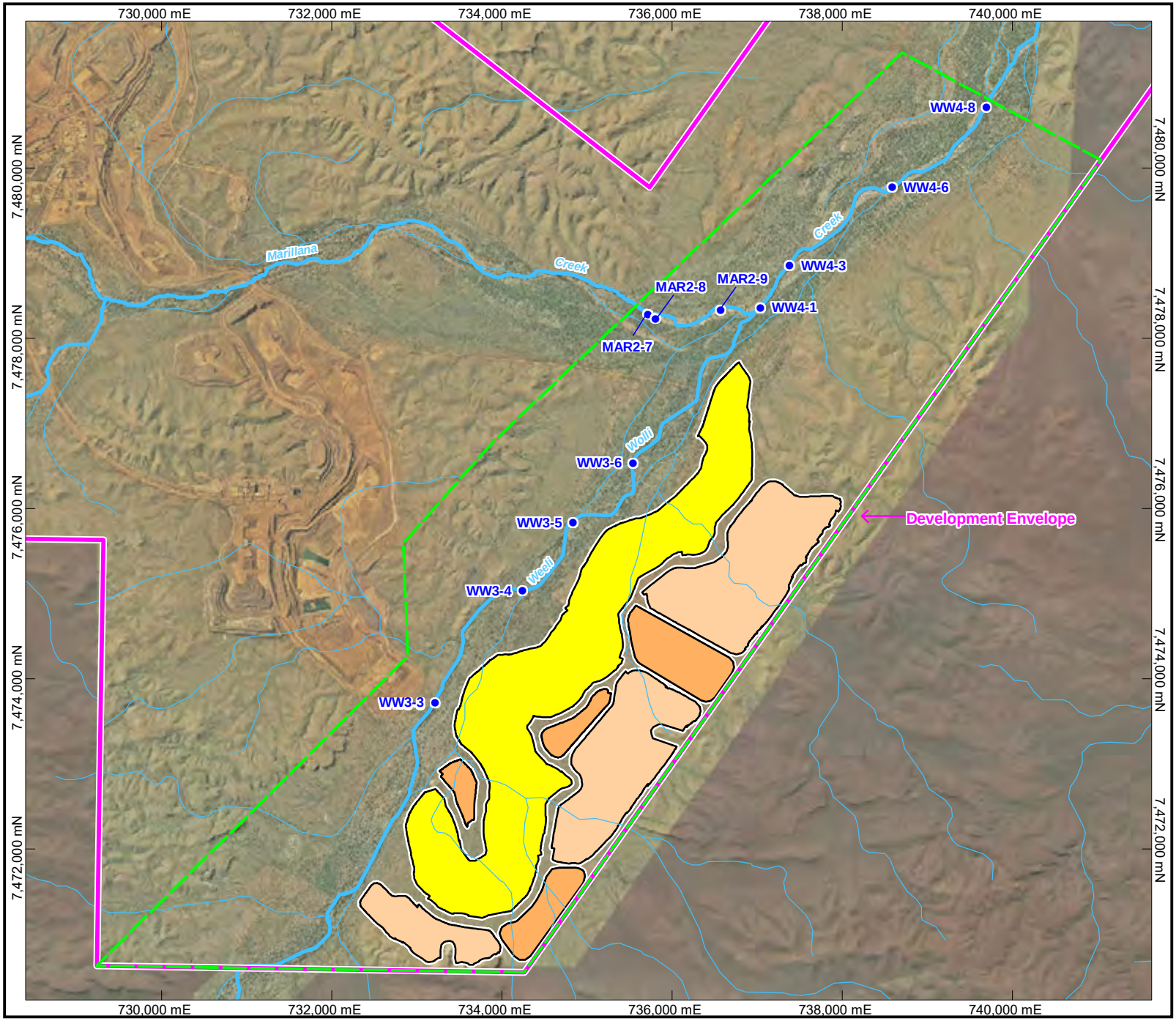
Dissolved oxygen, water temperature and pH were measured in the field, and water samples were collected for laboratory analysis to determine major ions, alkalinity, dissolved metals and nutrients.

15.4.2 Aquatic fauna habitats

The aquatic fauna were sampled from a variety of microhabitats (as per WRM 2015a, 2015b):

- Microinvertebrates (i.e. zooplankton); in the water column.
- Hyporheic fauna; in alluvial gravels adjacent to the water's edge.
- Benthic macroinvertebrates; riffle habitat (selected to allow comparisons between sites).
- Fish; in the water column, with shallow areas where there was little vegetation or large woody debris targeted for smaller species and juveniles.

During the field surveys, habitat characteristics of each site were recorded, including parameters such as substrate composition, cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation.



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse
- Aquatic Fauna Sampling Site

N

SCALE

0 1 2 3km

1:65 000 @ A4

Rio Tinto

Iron Ore (WA)

Figure 64
Location of September/October 2013 (late dry) and April/May 2014 (late wet) aquatic fauna sampling sites within the Proposal Area

Drawn: M.Swebbs Plan No: PDE0133375v2
Date: October, 2015 Proj: MGA94 (Zone 50)

Geospatial Information and Mapping

15.4.3 Aquatic fauna occurrence

15.4.3.1 Microinvertebrates

A total of 108 microinvertebrate taxa were recorded from the Marillana sites (n=70) and Weeli Wolli Creek Reach Three sites (n=40) and Reach Four sites (n=66) during the late dry and late wet surveys (WRM 2015a, 2015b). The microinvertebrate taxa consisted of Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp), and were more prolific during the wet season sampling.

Six endemic or rare microinvertebrate species were collected during the most recent surveys, and are summarised below (WRM 2015a,2015b).

- *Lecane noobijupi* is an endemic WA rotifer. It was originally described from specimens collected in south west WA, but has since been recorded from multiple locations within the Pilbara region. It was recorded at sites MAR2-8, WW3-3 and WW4-1.

- *Nebela penardiana* was recorded at all WW-Three sites within the Proposal Area. Weeli Wolli Creek is the only known location of this protist within WA, and the second record of this species in Australia.

- *Lecane* 'bulloid' n. sp. has similar morphology to *Lecane noobijupi*, but is larger than *L. bulla*. This morphotype is endemic to WA, and was recorded at site WW4-5.

- *Cephalodella* n. sp. did not conform to any described species and is likely to be a new species. It was collected from WW4-4, and represents the first record of this taxon.

- *Heterolepadella heterostyla* is a rarely collected rotifer, but is thought to have a cosmopolitan distribution. It is usually found in stagnant waters, and has also been collected from the nearby Mindy Mindy Creek. It was recorded at site MAR2-9.

- *Australoeucyclops karaytugi* is an endemic Australian cyclopoid copepod. It has previously been collected in the Pilbara from Fortescue Marsh and southern Weeli Wolli Creek, upstream of Hope Downs 1. It was collected from site MAR2-9.

15.4.3.2 Hyporheic fauna

The hyporheic zone is the region where riverine surface water and groundwater combine (Boulton 2001). Hyporheic fauna are aquatic invertebrates that reside in the alluvium below the streambed where water percolates through spaces between the rocks and cobbles (WRM 2015a). All taxa recorded from hyporheic samples were classified by WRM (2015a) using categories described by Boulton (2001):

- Stygobite: obligate groundwater species, with special adaptations to survive in this habitat.

- Permanent hyporheos stygophiles: species living on or near the surface of the ground that can occur in both surface and groundwater, but are a permanent inhabitant of the hyporheos.

- Occasional hyporheos stygophiles: these species use the hyporheic zone seasonally or during early life history stages.
- Possible hyporheic species: these species require further research to determine their status.

Stygoxene are species that appear rarely and apparently at random in groundwater habitats, either by accident or seeking refuge during flood or drought. They are not specialised for groundwater habitats, and are not considered to be part of hyporheos fauna.

A total of 113 taxa were recorded from hyporheic samples from the Marillana sites (n=52) and Weeli Wolli Creek Reach Three sites (n=62) and Reach Four sites (n=87) during the late dry and late wet surveys (WRM 2015a, 2015b). Of the 113 taxa collected, 6% were stygobites, 13% were considered occasional hyporheos stygophiles and 11% were considered to be possible hyporheic taxa. All sites within the Proposal Area were considered to support taxa that were restricted to the hyporheic zone; these taxa are described in WRM (2015a, b), and include a number of undescribed species that are new to science. Five stygobitic amphipod and isopod species were also considered to be potential SREs:

- Paramelitidae sp. D (equivalent to Paramelitidae Genus 2 sp. B3), recorded at MAR2-8 and WW3-4.
- Paramelitidae sp. B (equivalent to Paramelitidae Genus 2 sp. B2), recorded at all sites with the exception of WW4-4 and WW4-5.
- *Chydaekata* sp., recorded at sites WW3-3, WW3-4, WW3-5, WW4-1, WW4-3.
- *Maarrka weeliwolli*, recorded from sites WW3-5, WW3-6, WW4-1, WW4-3 and WW4-4.
- *Pygolabis weeliwolli*, recorded at site WW3-5.

The amphipod *Maarrka weeliwolli* and the isopod *Pygolabis weeliwolli* appear to be restricted to Marillana Creek and Weeli Wolli Creek (WRM 2015b). The other three taxa have been collected from outside these creek systems.

15.4.3.3 Macroinvertebrates

A total of 141 macroinvertebrate taxa were recorded were recorded from the Marillana sites (n=116) and Weeli Wolli Creek Reach Three sites (n=65) and Reach Four sites (n=87) during the late dry and late wet surveys (WRM 2015a, 2015b). Macroinvertebrate taxa richness was greatest at sites MAR2-9 during the late dry and WW4-8 during the late wet sampling (n=50), while site MAR2-8 recorded the least taxa (n=20; late dry sampling), and was correlated with stream size, flow duration, habitat heterogeneity and macrophyte abundance (WRM 2015a).

Recorded taxonomic richness in the wet season has increased at Marillana Creek since surveying began in 2008. This is likely to be due to surface water discharge from the existing Yandi Operations, which has altered the aquatic fauna habitat to increase habitat size, heterogeneity and flows (WRM 2015a).

Seven of the macroinvertebrate taxa from the Proposal Area are considered Pilbara endemics, including the four stygobitic amphipod species also recorded in the hyporheic

zone (see '*Hyporheic fauna*' above). The additional three species are summarised below.

- *Nannophlebia injibandi* (Pilbara Archtail Dragonfly); while this species has a relatively broad distribution throughout the Pilbara, it is not commonly recorded. It was observed at sites WW4-1, WW4-3, WW4-4, WW4-6 and WW4-8 during the most recent surveys.
- *Eurysticta coolawanyah* (Pilbara Pin Damselfly) is currently listed on the IUCN Redlist as Near Threatened (Hawking 2009); though WRM (2015a) suggest the conservation status of this species should be downgraded due to the addition of new records throughout the Pilbara. This species was recorded at site WW3-2.
- *Tiporus tambreyi*; a Pilbara endemic, this beetle appears to be common throughout the region. It was recorded at site MAR2-9.

15.4.3.4 Fish

A total of 4,455 freshwater fish samples were recorded from the Marillana sites (n=474) and Weeli Wolli Creek Reach Three sites (n=1297) and Reach Four sites (n=2684) during the late dry and late wet surveys (WRM 2015a, 2015b); 72% of these samples were recorded during the late wet survey.

Of the 12 known species of freshwater fish of the Fortescue River system, three were recorded in the Proposal Area:

- *Leiopotherapon unicolor* (Spangled Perch);
- *Neosilurus* sp. (Pilbara Tandan); and
- *Melanotaenia australis* (Western Rainbowfish).

The Western Rainbowfish was the most commonly observed species, consisting of 76% of all records. The Spangled Perch and Pilbara Tandan were recorded in lower numbers at Weeli Wolli Creek sites during the dry season (WW-Three, n=75; WW-Four, n=70) in comparison to the wet season (WW-Three, n=336; WW-Four, n=492), likely due to less suitable habitat being available during this season.

The sites at WW-Four appeared to be a nursery and recruitment zone for both Western Rainbowfish and Pilbara Tandan, as significantly higher proportions of new recruits recorded from these sites than in comparison to the WW-Three sites (WRM 2015b).

15.5 Assessment of potential impact, mitigation and residual impact

The EPA has listed the following potential impacts for the Proposal in relation to terrestrial fauna:

- habitat removal and fragmentation due to vegetation clearing; and
- indirect impacts that may occur through altered fire regimes, groundwater drawdown and discharge of surplus water, altered water regimes, changes to feral animal populations, the introduction or increase in spread of weed species, noise and light spill.

15.5.1 Impacts to fauna species of conservation significance

Five conservation listed species were recorded in the Proposal Area, with an additional 11 species assessed as likely, or potentially occurring. Impacts to these species are

discussed below. The Chocolate Wattled Bat (*Chalinolobus morio*), while currently not conservation listed under Commonwealth or State legislation, has also been included in the assessment. While common through much of its Australian range, the isolated Pilbara population is geographically restricted (Biota 2014c).

15.5.1.1 Threatened species (EPBC Act/WC Act Schedule 1 listed)

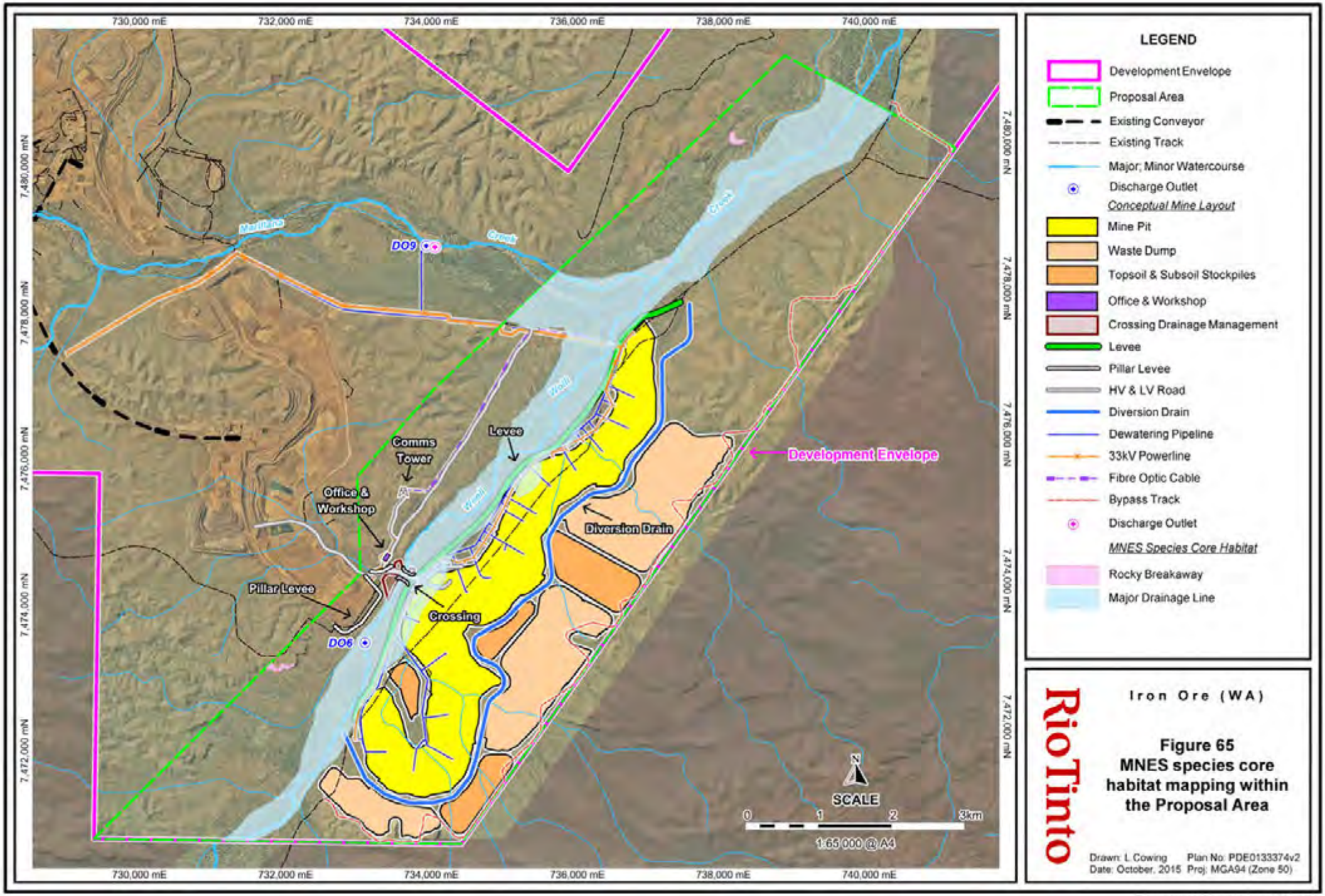
Pilbara Olive Python (*Liasis olivaceus barroni*) - Schedule 1, Vulnerable (Recorded)

A single Pilbara Olive Python was recorded opportunistically swimming downstream in Weeli Wolli Creek during a nocturnal search (site YBLNoct04) during the 2014 survey (Biota 2014c). This species is known from 17 locations in the Pilbara, and appears relatively common in the vicinity of the Proposal Area, with records from Hope Downs (21 km southwest), Flat Rocks (37 km west) and Koodaideri (38 km north west; Biota 2014c). This species has also been recorded in the Revised Proposal Development Envelope previously, with several sightings made at the existing Yandi Operations, and in Marillana Creek (Biota 2014c).

Core habitat for the Pilbara Olive Python includes gorges, escarpments, rocky outcrops and water holes where it may hunt and/or seek shelter in caves, beneath boulders, in pools of water and occasionally in trees overhanging water (DoE 2015b). It is often associated with ephemeral or permanent water, which is an indicator of high quality habitat for the species. However, the species may also be recorded in rocky habitats some distance from these features, especially during cooler months (Doughty et al. 2011). These landforms are not uncommon within the Pilbara bioregion. Pilbara Olive Pythons have also been observed using post-mining landforms and other man-made water sources, such as pit lakes, sewerage treatment ponds and recreational lakes. Individuals have been recorded utilising overburden heaps and railway embankments at mine sites (Pearson 2003).

This species may have a large home range, with estimations between 88 and 449 ha (DoE 2015b). Within the Proposal Area, its core habitat is likely to comprise of the major riverine systems of Marillana and Weeli Wolli Creeks. There is 872.8 ha of core habitat for the Pilbara Olive Python within the Proposal Area (Biota 2014f; **Figure 65**).

Habitat loss associated with mining developments is a recognised threat to the persistence of the Pilbara Olive Python (DoE 2015b). The Proposal has the potential to directly affect habitat utilised by the Pilbara Olive Python as a result of clearing and ground disturbance. The site of the recorded observation (see **Figure 60**) and the majority of this habitat occur outside the proposed mine pit and waste dump locations for the Proposal (Biota 2014f). Approximately 87 ha of Major Drainage Line habitat within the Proposal Area (10% of the core habitat available in the Proposal Area) is proposed to be cleared as part of the Proposal. While some core habitat will be removed, 90% of this habitat will remain undisturbed within the Proposal Area. Additional habitat is also available outside the Proposal Area to the north and south in Weeli Wolli Creek and nearby at Marillana Creek. The Pilbara Olive Python has also been observed utilising man-made habitats at Mesa J Iron Ore Mine near Pannawonica (Pearson 2003), and it is possible this species will utilise similar areas within the Proposal Area.



LEGEND

- Development Envelope
- Proposal Area
- Existing Conveyor
- Existing Track
- Major; Minor Watercourse
- Discharge Outlet

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil & Subsoil Stockpiles
- Office & Workshop
- Crossing Drainage Management
- Levee
- Pillar Levee
- HV & LV Road
- Diversion Drain
- Dewatering Pipeline
- 33kV Powerline
- Fibre Optic Cable
- Bypass Track
- Discharge Outlet

MNES Species Core Habitat

- Rocky Breakaway
- Major Drainage Line

Rio Tinto

Iron Ore (WA)

Figure 65
MNES species core habitat mapping within the Proposal Area

Drawn: L Cowing Plan No: PDE0133374v2
Date: October, 2015 Proj: MGA94 (Zone 50)

Geospatial Information and Mapping

Altered hydrological regimes as a result of the Proposal are not expected to result in a significant indirect loss of habitat for the Pilbara Olive Python. Perennial stream flow in the Weeli Wolli Creek low-flow channel will continue during the life of the Proposal, and opportunities for flooding the adjacent riparian zone remain unchanged as a result of the Proposal (URS 2015).

Vehicle movements associated with construction and operation phases of the Proposal have the potential to harm Pilbara Olive Python individuals or their prey (DoE 2015b). Speed limits will be enforced on all roads within the Proposal Area to reduce the risk of impact to Pilbara Olive Python individuals and other fauna. Training and induction of personnel will ensure that all staff are made aware of significant species at risk from vehicle strikes. Predation by feral foxes and cats are also a risk to the Pilbara Olive Python (particularly juveniles; DoE 2015b) and will be managed within the Proposal Area during construction and operation phases of the Proposal. These management actions will be in accordance with the Yandi SSMP addendum (**Appendix 4**).

While the Proposal will cause some loss of core habitat via vegetation clearing, and impacts to the local population via loss of individuals due to vehicle collisions and predation by feral animals, the overall impact to this species will be low. It is considered unlikely that the conservation status of the Pilbara Olive Python will be affected as a result of the Proposal. Potential cumulative impacts to the Pilbara Olive Python are discussed in Section 15.6.2.

Pilbara Leaf-nosed Bat (*Rhinonicteris aurantius*) – Schedule 1, Vulnerable (Likely)

The Pilbara Leaf-nosed Bat was not recorded in the Proposal Area (Biota 2015b). The closest record of this species is from a single call recorded approximately 7 km north west of the Proposal Area (Biota 2014c). The Pilbara Leaf-nosed Bat is the Pilbara form of the Orange Leaf-nosed Bat, which occurs as two disjunct populations in Australia – one only in the Pilbara bioregion and the other across northern Australia, from the Kimberley in Western Australia to western Queensland. In the Pilbara there are three sub-populations, the eastern Pilbara, Hamersley Range and upper Gascoyne.

The Pilbara Leaf-nosed Bat occurs in colonies, which vary in size from tens to thousands of individuals, concentrated around significant roosting sites, which are often associated with disused mining infrastructure. Most of the known natural roosting sites coincide with areas of current or future interest for mining development; hence mining activities are an identified threat to Pilbara populations of the species (DoE 2015b).

The occurrence of pools of water is a critical component of the Pilbara Leaf-nosed Bat's foraging habitat. Roosting sites may occur in rocky breakaways, scarps and gorges as these areas have the greatest potential to support relatively warm humid microclimates. Foraging habitats also include these habitats, and may also include riparian vegetation and hummock grasslands (DoE 2015b).

The major drainage channels of the Marillana-Weeli Wolli Creek system in the Proposal Area may provide foraging opportunities for the Pilbara Leaf-nosed Bat, although due to the absence of suitable roost caves in close proximity to the Proposal Area, this habitat is not considered core (Biota 2014c). A colony of Pilbara Leaf-nosed Bats occurs within the Koodaideri Iron Ore Mine area, approximately 40 km north west of the Proposal Area. It is assumed that individuals can move distances up to 60 km, although not necessarily overnight (DoE 2015b). Therefore the species is considered likely to occur within the

Proposal Area, but only on an occasional foraging basis. Changes to the groundwater regime as a result of the Proposal may alter the suitability of foraging habitat for the species, as some riparian tree species are expected to be lost over the life of the Proposal (see Section 14). The loss of some of this habitat through altered hydrological processes and clearing may have localised impacts to the Pilbara Leaf-nosed Bat, however, the Proposal is not anticipated to affect the conservation status of this species.

Northern Quoll (*Dasyurus hallucatus*) – Schedule 1, Endangered (Potential)

The Northern Quoll is the smallest quoll species. This species has been recorded in all four of the Pilbara subregions, with the majority of the records occurring in the north and north west of the bioregion, in the Hamersley and Chichester subregions (Biota 2010). The Northern Quoll is a short lived mammal, with both sexes maturing at 11 months of age. Males frequently do not survive after their first breeding season, and females usually do not live longer than 2-3 years. They are opportunistic omnivores, and have been recorded consuming invertebrates, fruit and flowers, mammals, birds, bird eggs, frogs, road kills and from rubbish bins (DoE 2015b).

There have been two anecdotal sightings of Northern Quoll individuals at the existing Yandi Operations warehouse over a one month period in 2009 (Biota 2009), and an individual found at the nearby Yandi Operations village in 2013. However, these represent the only sightings within the existing Yandi Operations in the past 19 years, and come from a nearby higher elevation area encompassing landforms more suitable for the species than the Proposal Area (Biota 2014d). It is thought these individuals may have been temporarily foraging in the Revised Proposal Development Envelope, or that this small local population may have declined (Biota 2009).

There are three records of the Northern Quoll within 15 km of the Proposal Area, which were recorded in 2010 (Biota 2013). Since then, surveys undertaken have not recorded the species, with over 10,000 Elliott trap nights in the Revised Proposal Development Envelope, and two Targeted Northern Quoll surveys within the Proposal Area (Biota 2014d). In addition, recent habitat mapping indicates there is very limited core habitat for the Northern Quoll in the Proposal Area (4.4 ha), consisting of two small areas of rocky breakaway habitat at the periphery of the Proposal Area, outside the proposed mine pit and waste dumps (Biota 2014f; **Figure 65**). Core habitat for the Northern Quoll is considered to be rocky gorges, rocky free face and hills usually of high relief, with secondary habitat associated with drainage lines used for denning (DoE 2015b).

It is considered extremely unlikely that a significant population of the Northern Quoll is present in the Proposal Area; and any interactions of this species within the Proposal Area would be limited to dispersing individuals (Biota 2014d). Habitat clearing and fragmentation as a consequence of mining is a threat to the Northern Quoll (DoE 2015), however, due to the limited core habitat and the low likelihood of Northern Quoll presence in the Proposal Area, the Proposal is not predicted to significantly affect the conservation status of this species.

Grey Falcon (*Falco peregrinus*) – Schedule 1 (Potential)

The Grey Falcon is endemic to Australia, typically found in the arid and semi-arid interiors. It is a wide-ranging species and hunts smaller birds in a range of habitats (Morcombe 2007). The Grey Falcon may occur within the Proposal Area; it has been recorded within 40 km (ALA database search). This species is not considered likely to

rely on any particular habitat type present within the Proposal Area. It may use the Proposal Area to hunt occasionally, and has the potential to breed in the taller eucalypts associated with the Weeli Wolli Creek (Biota 2014c). Potential breeding habitat may be reduced within the Proposal Area as a result of groundwater drawdown causing deaths to tree species within the riparian zone (see Section 14). As the Grey Falcon has a low density and broad distribution in the Pilbara, it is unlikely the Proposal will result in any significant impacts on the conservation status of this species.

Australian Painted Snipe (*Rostratula australis*) – Schedule 1 (Potential)

The Australian Painted Snipe is a wader, and has been recorded in wetlands across Australia. It is considered to occur in a single, contiguous breeding population, with population estimates ranging between a few hundred to five thousand individuals (DoE 2015b).

The Australian Painted Snipe has been observed within 40 km of the Proposal Area at the Fortescue Marsh (NatureMap database). This species may potentially occur within the Proposal Area as suitable shallow, fresh water wetlands are present year-round, however it has not been previously recorded (Biota 2014c).

The reduction of riparian habitat as a result of the Proposal could cause a local impact to individuals of this species if present within the Proposal Area. However, given the NatureMap record at the Fortescue Marsh is the only record of this species in this database within 400 km of the Proposal Area, and the availability of suitable habitat outside the Proposal Area in both creeks and the Fortescue Marsh, the conservation status of the Australian Painted Snipe is unlikely to be affected by the Proposal.

15.5.1.2 Migratory species (EPBC Act)

Eastern Great Egret (*Ardea modesta*) - Schedule 3, Migratory (Recorded)

The Eastern Great Egret is a migratory waterbird that is likely to utilise the Fortescue Marsh on an occasional basis, which is located 40 km north of the Proposal Area. In 2014 a single opportunistic observation of one individual flying near Weeli Wolli Creek was made outside of the proposed mine footprint (Biota 2014c). This species is widespread across Australia and occurs in a range of wetland habitats, predominately in shallow waters (DoE 2015b). The low number of observations of this species indicates the Eastern Great Egret only utilises the Proposal Area on an occasional, transient basis. As a result, it is considered unlikely the Proposal will affect the conservation status of this species.

Fork-tailed Swift (*Apus pacificus*) – Schedule 3, Migratory (Recorded)

The Fork-tailed Swift is a common migrant throughout the Pilbara between October and April (Morcombe 2007) and is exclusively aerial in Australia, occurring here as a non-breeding visitor (Johnstone and Storr 1998).

This species potentially utilises the Proposal Area for aerial foraging during the migratory period. An opportunistic observation of nine Fork-tailed Swift individuals flying overhead of the Proposal Area was recorded on one occasion (Biota 2014c). Due to the wide range of the Fork-tailed Swift and its aerial nature, it is unlikely that the Proposal will significantly affect the conservation status of this species.

Rainbow Bee-eater (*Merops ornatus*) - Schedule 3, Migratory (Recorded)

Rainbow Bee-eaters are commonly found during the summer throughout most of southern Australia excluding Tasmania (Barrett et al. 2003). They migrate north at the onset of cooler weather in autumn, spending the winter in northern Australia, New Guinea, and some of the southern islands of Indonesia. It is thought that many populations in northern Australia are sedentary (Boland 2004). They occur in a wide range of habitats including open woodlands, shrublands, beaches, dunes, cliffs, mangroves, woodlands and parks and private gardens (Boland 2004), preferring areas near water and sandy substrates. This species requires these sandy substrates to build nest burrows (Higgins 1999).

The Rainbow Bee-eater was observed on numerous occasions opportunistically and while conducting systematic avifauna surveys throughout the Proposal Area (Biota 2014c). This species is common in the Pilbara and is either a breeding resident or non-breeding visitor to the Proposal Area, with the tall trees of Weeli Wolli Creek providing suitable foraging habitat (Biota 2014c). Some of this habitat may potentially be affected as a result of clearing and groundwater drawdown and discharge caused by mine pit dewatering for the Proposal. This species nests in sandy soils in burrows; no evidence of nesting was found within the Proposal Area (Biota 2014c). This migratory species has a broad distribution across Australia, and has over 11,000 records within Western Australia on the NatureMap database. It is very common and widespread in the Pilbara bioregion and is unlikely to be reliant on the habitats within the Proposal Area. As such, it is unlikely that the Proposal will significantly affect the conservation status of this species.

Common Greenshank (*Tringa nebularia*) - Schedule 3, Migratory (Likely)

The Common Greenshank is a wader, and can be observed singly or in small to large flocks, occasionally numbering in the hundreds. This species occurs in all types of wetlands and has the widest distribution of any shorebird in Australia; however, it does not breed in Australia (DoE 2015b). It is likely to occur within the Proposal Area, as it has previously been recorded within 10 km (Biota 2014c). In Australia, threats to this species include habitat loss and modification, introduced species, pollution and disturbance by humans (DoE 2015b). Given the presence of suitable habitat outside the Proposal Area, the conservation status of this species is unlikely to be affected by the Proposal.

Cattle Egret (*Ardea ibis*) - Schedule 3, Migratory (Potential)

The Cattle Egret is a migratory waterbird that is considered widespread and common across its range (DoE 2015b). It is found in temperate and tropical grasslands, woodlands and terrestrial wetlands, and is likely to utilise the Fortescue Marsh on an occasional basis. Due to the proximity of the Proposal Area to the Marsh, it is possible that this species may occur, utilising the damp grasslands neighbouring Weeli Wolli Creek after flooding. However, this would only be on an occasional, transient basis and therefore the conservation status of this species is unlikely to be affected by the Proposal.

15.5.1.3 Schedule 4 species (WC Act)

Peregrine Falcon (*Falco peregrinus*) – Schedule 4 (Likely)

The Peregrine Falcon has an almost cosmopolitan distribution and inhabits a wide range of habitats, including cliffs, rocky outcrops and rocky coastal islands; however, it will use trees to nest where cliffs are not available. It is uncommon, and is usually found in pairs or as single individuals. This species has been recorded once inside the Revised Proposal Development Envelope, outside the Proposal Area; and the individuals

recorded were likely to have been transitory or foraging. It is considered likely to occur within the Proposal Area.

The large trees adjacent to Weeli Wolli Creek may provide potential habitat for nesting and foraging by the Peregrine Falcon (Biota 2014c). Some of this habitat may be affected by the Proposal as a result of groundwater drawdown, discharge and vegetation clearing. However, as suitable habitat for the Peregrine Falcon is present outside the Proposal Area, it is unlikely that the Proposal will significantly affect the conservation status of this species.

15.5.1.4 Priority listed species

Blind Snake (*Anilios ganei*) - Priority 1 (Likely)

The Blind Snake is distributed over much of the Pilbara region; however it is poorly collected (Biota 2014c), and is known only from 41 records in Western Australia on the NatureMap database. This species has been recorded in moist gorges and gullies, Mulga Woodlands and rocky scree slopes (Biota 2014c). It has been observed within 10 km of the Proposal Area and as suitable habitat is present, it is considered likely to occur within the Proposal Area (Biota 2014c).

Potential impacts to the Blind Snake as a result of the Proposal include habitat loss and direct mortality of individuals. Up to 1,138 ha of potentially suitable habitat, consisting of Mulga Woodlands, Slopes and Hills and Pediment Slope habitat within the Proposal Area is expected to be cleared as a result of the Proposal. There are few records of this species, which could be due to difficulties in successfully sampling individuals or a naturally low abundance despite their wide distribution in the region. If present in the Proposal Area, the Proposal could result in localised impacts to this species. However, given its wide distribution (over 400 km), and the low number of records in the vicinity of the Proposal Area, the conservation status of this species is unlikely to be significantly affected by the Proposal.

Pilbara Barking Gecko (*Underwoodisaurus seorsus*) - Priority 2 (Likely)

The Pilbara Barking Gecko is a Hamersley Range endemic that was recently discovered in 2006. It is a large carphodactylid gecko, with a large head, long slender limbs and digits, and long tail terminating in a point (Doughty and Oliver 2011). The known distribution of this species extends from north of Tom Price to West Angelas mine in the south east. The Pilbara Barking Gecko is found in rocky areas, with some observations associated with major gullies and rocky gorges (Doughty and Oliver 2011). This species is classified as Priority 2, based on its relatively small distribution and rarity. It has been recorded nearby to the Proposal Area (Biota 2014c), and as suitable rocky slope habitat is present, it is considered likely to occur (Biota 2014c).

A total of 1,075 ha of Slopes and Hills and Pediment Slope habitat within the Proposal Area may be cleared as a result of the Proposal; localised impacts to Pilbara Barking Gecko as a result of the Proposal include direct mortality and loss of habitat due to vegetation clearing. If present in the Proposal Area, the Proposal could result in localised impacts to this species. However, there is extensive habitat available to this species in the vicinity of the Proposal Area and in the wider locality, thus the Proposal is unlikely to significantly affect the conservation status of this species.

Western Pebble-mound Mouse (*Pseudomys chapmani*) - Priority 4 (Recorded)

The Western Pebble-mound Mouse is endemic to the central and eastern Pilbara; it has a broad distribution in within this area and is considered quite common. This species builds mounds of small stones covering 0.5-0.9 m^2, and frequents stony hillsides with hummock grasslands (Biota 2014c). The Western Pebble-mound Mouse was the most frequently recorded mammal during surveys in the Proposal Area, with pebble mounds recorded at 18 locations (Rio Tinto database). One individual was also trapped at site BIL07 (Biota 2011). The majority of mounds appeared active (Biota 2014c).

It is anticipated five known mounds will be directly impacted by clearing for the Proposal footprint (**Figure 60)**. Threats to the Pebble-mound Mouse as a result of the Proposal include direct mortality and habitat loss due to vegetation clearing. A total of 1,075 ha of Slopes and Hills and Pediment Slope habitat within the Proposal Area may be cleared as a result of the Proposal.

However, this species is broadly distributed in the Hamersley and Chichester subregions of the Pilbara bioregion and is commonly recorded, with over 850 records within the Pilbara Bioregion on NatureMap. Extensive suitable habitat is present outside of the Proposal Area, and it is unlikely that the Proposal will affect the conservation status of this species (Biota 2011).

Brush-tailed Mulgara (*Dasycercus blythi*) – Priority 4 (Likely)

The Brush-tailed Mulgara is a medium sized solitary carnivorous marsupial. It has a characteristic tail, with a fat base and black hairs, hence the common name 'Brush-tail'. This species is found in sand plain, sand dune and gibber plain (rock and pebble covered flat plains) habitat (Pavey et al. 2011). There is a history of taxonomic confusion between *Dasycercus cristicauda* and *D. blythi*; this is discussed further in Section 15.2.4.

Mulgara burrows were recorded at three sites in the north eastern section of the PBS study area (Biota 2014c), in close proximity to each other in Minor Alluvial Fans and Hills and Slopes habitat. The burrows were recorded approximately 800 – 960 m from the Proposal Area, however no animals were observed. These burrows were thought to be inactive, due to a lack of scats, tracks or fresh diggings. Despite the lack of recent activity, Biota (2014c) considers the Mulgara to have been recently present in the area; however the individuals may have relocated to areas with new resources. Previous surveys in this area have recorded live individuals (S Ford pers. obs., cited in Biota 2014c). No burrows or individuals of this species have been identified within the Proposal Area to date; however suitable habitat is present.

The Proposal has the potential to cause direct mortality to individuals and will result in potential habitat loss due to vegetation clearing. However, this species has a wide distribution across the Pilbara on NatureMap, and suitable habitat is present outside the Proposal Area. It is therefore unlikely the Proposal will affect the conservation status of this species.

Ghost Bat (*Macroderma gigas*) - Priority 4 (Likely)

The Ghost Bat occurs in a wide range of habitats and has a fragmented distribution caused by the availability of suitable roost sites in caves and mines. The transient day roosts or feeding sites of Ghost Bats are often shallow overhangs and crevices with microclimates similar to ambient conditions, whereas roosts for breeding activity (maternity roost) have a relative humidity of above 80% (Armstrong and Anstee 2000). For this bat species to persist, a productive foraging area (usually containing riparian

vegetation) within 5-10 km of their maternity roost site is preferable (Biologic 2014). The Ghost Bat occurs in all four Pilbara subregions, and McKenzie and Bullen (2009) suggest this species is more common that previously supposed.

This bat species is likely to utilise the Proposal Area for foraging. There has been one recorded sighting of an animal flying over the Revised Proposal Development Envelope in 1998 (Biota 2013), and a cave containing scats was recorded 9 km south of the Proposal Area (Biota 2014c). No potential roost caves for any conservation significant bat species were located within the Proposal Area. However, due to the presence of riparian vegetation and a nearby recorded sighting and scats, this carnivorous predator may utilise the Proposal Area occasionally for foraging on small mammals, birds, reptiles and insects. As the Proposal Area does not contain any known roost caves, and given the large home ranges of this species, it is unlikely the Proposal will significantly affect the Ghost Bat.

15.5.1.5 Other species

Chocolate Wattled Bat (*Chalinolobus morio*) - (Recorded)

The Chocolate Wattled Bat is a microbat that is found in a range of habitats throughout Australia. This species roosts in tree hollows, man-made structures and caves. They feed almost exclusively on moths, which they catch by flying below the tree canopy (ALA 2015).

The Chocolate Wattled Bat is not currently listed under Commonwealth or State legislation. While common through much of its range in southern and eastern Australia, it is currently only known in the Pilbara from the productive riparian environment of the Weeli Wolli-Marillana Creek System (McKenzie and Bullen 2009). Extensive sampling throughout this region and the neighbouring bioregions of the Gascoyne and Murchison have failed to detect it elsewhere (McKenzie and Bullen 2009). It is possible that the isolated Pilbara population is genetically distinct; however this has not been tested. The microbat assemblage of the Priority 1 Weeli Wolli Spring Community PEC, located upstream from the Proposal Area, has been identified as an environmental value for Weeli Wolli Creek in an Environmental Values Statement (**Appendix 1**) by the Proponent.

A Chocolate Wattled Bat was recorded from one survey site within the Proposal Area (site YBQSM2-05; **Figure 60)**. This record is adjacent to the south west border of the Proposal Area at the entrance of a small cave close to Weeli Wolli Creek (Biota 2014c). There are an additional two records of this species to the north of the Proposal Area.

The clearing and degradation of riparian vegetation within the Proposal Area could impact this species. Approximately 85.9 ha of Major Drainage Line habitat is anticipated to cleared due to the Proposal, with additional potential breeding habitat reduced within the Proposal Area as a result of groundwater drawdown and discharge causing stress or mortality to tree species within the riparian zone (see Section 14). It is possible that their range extent may be temporarily increased due to increased water availability from discharge. However, at a community level, these effects are unlikely to significantly affect the broader riparian habitat and suitable breeding and foraging habitat is present outside the Revised Proposal Development Envelope, including the Weeli Wolli Spring, and will not be threatened by the Proposal. Consequently, the Proposal is considered unlikely to significantly affect the Chocolate Wattled Bat population in Weeli Wolli and Marillana Creeks.

15.5.2 Habitat removal and fragmentation

15.5.2.1 Terrestrial vertebrate fauna

Clearing of terrestrial fauna habitat is required to facilitate construction of the mine and associated infrastructure. Clearing will result in up to 1,800[5] ha of terrestrial fauna habitat loss within the Proposal Area, including up to 69 ha of riparian zone vegetation. The proposed clearing will potentially result in the loss of the following fauna habitats:

- 85.9 ha of Major Drainage Line;
- 308.1 ha of Hilltops and Slopes;
- 767.0 ha of Pediment Slope;
- 102.4 ha of Alluvial Plain (Flood Plain); and
- 63.3 ha of Mulga woodland.

Approximately 87 ha of core habitat will be lost within the Proposal Area for the EPBC Act/WC Act Schedule 1 listed species the Pilbara Olive Python (**Figure 65**). Five additional conservation significant species have been recorded within the Proposal Area; aside from one record of a Rainbow Bee-eater at site YBL006P, the records of the Western Pebble-mound Mouse are the only species recorded within the proposed mine pit and waste dump locations (**Figure 60**).

Impacts to fauna habitats from vegetation clearing will be managed through the implementation of measures described in the Significant Species Management Guideline and in the Yandicoogina MMP (**Appendix 4**). Habitat clearing will be restricted to the Proposal Area and will be the minimum necessary for safe construction and operation of the Proposal. Clearing will be undertaken progressively to allow mobile fauna movement into contiguous habitat beyond the clearing area. Native fauna encountered on-site (including during clearing) will be avoided. A dedicated fauna relocation specialist/carer will be available on-site at all times to safely relocate any fauna encountered.

The proposed mine pit and waste dumps will fragment fauna habitat with the Proposal Area, with an approximate 8 km almost continuous stretch of habitat removed to the east of Weeli Wolli Creek, of up to 2.6 km in width. This habitat is primarily associated with the hills and slopes landform. Some fauna groups will be affected more than others based on their movement modes and patterns (flight versus ground moving and long versus short range movements), with the proposed mine pit and waste dumps potentially causing a barrier to dispersion for non-aerial species.

The Proposal Area contains fauna habitats that are consistent with the surrounding landscape. Based on the distribution of land systems, fauna habitats occurring in the Proposal Area are likely to be well represented in the surrounding area, and connectivity will remain with the intact habitats outside the Proposal Area.

[5] The total disturbance to fauna habitat is 1,327 ha, however the Proponent is seeking approval for overall disturbance of up to 1,800 ha to accommodate for detailed design of mining operations and infrastructure.

15.5.2.2 SRE invertebrate fauna

Loss of SRE invertebrate fauna habitat will occur as a result of clearing to facilitate construction of the mine pit, waste dumps and associated infrastructure. Clearing will result in the direct removal of up to 1,800[6] ha of fauna habitat within the Proposal Area. With the exception of one site, all recorded Nemesiidae sp. N44 locations within the Proposal Area will be disturbed (see **Figure 63**).

However, all four predicted SRE taxa, Idiopidae sp.I1 and I9 and Nemesiidae sp. N42 and N44, have been recorded outside the Proposal Area. These species have been recorded in multiple land systems and substrate types, suggesting they not restrained to a specific landscape-scale habitat unit. Therefore the probability that these mygalomorph spiders possess a narrow spatial distribution is lower, and thus it is less likely that vegetation clearing within the Proposal Area will adversely affect these species (Biota 2015b).

Habitat clearing will be restricted to the Proposal Area and will be the minimum necessary for safe construction and operation of the Proposal. Clearing areas are well-defined and demarcated on the ground to ensure that operators clear only what is necessary. Upon mine closure, the Proposal Area will be rehabilitated to contain a wide variety of fauna habitats, many that will be appropriate for SRE invertebrate fauna species.

15.5.2.3 Aquatic fauna

Minimal aquatic fauna habitat associated with Weeli Wolli and Marillana Creeks will be lost or fragmented as a result of the Proposal, as habitat and surface water flows will be retained. Therefore the associated aquatic fauna habitat and its ecological values will be retained.

15.5.3 Indirect impacts

Indirect impacts from the Proposal may modify or disturb fauna habitats leading to changes in fauna behaviour and movement patterns and/or disruption to nesting and roosting habitats. These potential modes of impact include light, dust and noise emissions, altered fire and water regimes, and the introduction and/or spread of weeds and feral animals.

15.5.3.1 Altered Hydrological Regime

Surface water will continue to be discharged as part of the Proposal and from Hope Downs 1 operations during the life of the Proposal, with the reach of the surface water footprint between 5 and 9 km downstream of the Weeli Wolli Creek and Marillana Creek confluence. Therefore the current perennial stream flow in the Weeli Wolli Creek low-flow channel will continue during the life of the Proposal, and opportunities for flooding the adjacent riparian zone remaining unchanged as a result of the Proposal (URS 2015).

However, the Proposal will alter the groundwater and surface water system, potentially resulting in degradation of fauna habitat. Up to 10 km of riparian vegetation will be exposed to the effects of groundwater drawdown, which is likely to cause some tree mortality in riparian zones adjacent to Weeli Wolli Creek during the mining operations (see Section 14 for further details).

[6] The total disturbance to fauna habitat is 1,327 ha, however the Proponent is seeking approval for overall disturbance of up to 1,800 ha to accommodate for detailed design of mining operations and infrastructure.

There is no evidence that current surface water discharges associated with the JSE, JSW and Oxbow development have adversely affected aquatic fauna taxa richness of microinvertebrates, hyporheic invertebrates or macroinvertebrates to date (WRM 2015a). Any changes to the surface water flows of Weeli Wolli Creek, such as water quality, flow velocity, increased turbidity and water depth, have the potential to cause local impacts to aquatic fauna. The Proposal will require direct disturbance to a section of the Weeli Wolli Creek floodplain adjacent to the pit, as well as the construction of flood protection levees within the floodplain of the creek. Disruption to the existing surface water flows along Weeli Wolli Creek due to the construction of the levee will be negligible during low-flow events.

As the magnitude of the flow increases, changes to the flow regime will increase due to greater constriction and obstruction of flows imposed by the infrastructure along the creek (URS 2015). This will reduce the width of the creekline floodflows, and may potentially cause increased erosion and turbidity downstream (WRM 2015a). Further details on the impacts and management of surface and groundwater are discussed in Section 13. Aquatic fauna will continue to be monitored over the life of the Proposal to quantify the impact, if any, from the Proposal (WRM 2015a, 2015b).

15.5.3.2 Altered Fire Regimes

Fire prevention measures will be implemented in accordance with the Proponent's standard operating procedures. Fire monitoring will be undertaken annually to assess the condition of firebreaks and the condition, layout and use of all hydrocarbon storage areas and other ignition sources, to identify any potential on-site fire risks.

15.5.3.3 Light, Dust and Noise

Light, dust and noise emissions from construction and mining activities can affect native fauna by deterring individuals from their habitats and subsequently altering species' foraging, roosting or breeding behaviour in the area immediately around the source of light, dust and noise. These impacts will be mitigated for EPBC Act listed threatened species in the SSMP and Yandi SSMP addendum (**Appendix 4**).

Impacts on fauna due to light emissions will be managed by implementing lighting controls, including, where appropriate, minimising light broadcast, installing sodium lights, using yellow-coloured lights at night, using motion sensors to limit the unnecessary light, and installing reflectors in strategic locations to deter bats from operational areas.

15.5.3.4 Introduced Species

Ground disturbance and poor waste management can result in the increase in numbers or introduction of weeds or feral animals, increasing predation of, or competition with, native fauna. These impacts will be mitigated in the Yandicoogina Weed Action Plan and for EPBC Act listed threatened species in the SSMP and Yandi SSMP addendum (**Appendix 4**).

15.6 Cumulative impacts

15.6.1 Cumulative impacts to the Chocolate Wattled Bat

A preliminary assessment of cumulative impacts to the Chocolate Wattled Bat was conducted based on a review of the potential impacts of the Proposal, the existing Yandi Operations and six other projects identified as being potentially relevant based on their location in the Weeli Wolli Creek or Marillana Creek sub-catchments of the Upper Fortescue River Catchment (**Figure 24**).

The Chocolate Wattled Bat is currently known to occur in the Pilbara only in the productive riparian environment of the Weeli Wolli-Marillana Creek System (McKenzie and Bullen 2009). Therefore, the preliminary assessment of cumulative impacts to this species has been based on potential impacts to riparian vegetation within the Weeli Wolli Creek and Marillana Creek sub-catchments.

The Chocolate Wattled Bat has been recorded at only one of the projects considered, being the Proposal (this Proposal; **Table 29**). The area of potential Chocolate Wattled Bat habitat (riparian vegetation) has been quantified for three of the projects considered (including this Proposal; **Table 29**). The three projects for which habitat has been quantified were included in this preliminary assessment of cumulative impacts to the Chocolate Wattled Bat.

Of the approximately 859 ha of potential Major Drainage Line habitat for the Chocolate Wattled Bat occurring in the Proposal Area, up to 85.9 ha will be cleared for the Proposal. This represents approximately 10% of the extent of this habitat in the Proposal Area. Taken together with the remaining projects for which habitat has been quantified, the cumulative impact is a loss of up to 1,463 ha of potential Chocolate Wattled Bat habitat, which represents approximately 5.6% of the 2,902 ha of riparian habitat mapped across the four projects (**Table 29**).

Table 29: Assessment of potential cumulative impacts to Chocolate Wattled Bat habitat

Project	Species occurrence	Area riparian habitat mapped	Area riparian habitat disturbed	Reference
Past and present actions				
Hamersley HMS's Hope Downs 1 Iron Ore Mine Expansion (EP Act Assessment No. 1308)	Not recorded	161 ha	10 ha	Ecologia (1997); Hope Downs Management Services Pty Ltd (2000)
Iron Ore Holdings Iron Valley Iron Ore Project (EP Act Assessment No. 1905; EPBC Act Ref. 2012/6458)	Not recorded	114 ha	0 ha	URS (2012)
BHP Jinidi Iron Ore Mine (EP Act Assessment No. 1904; EPBC Act Ref. 2012/6299)	Not recorded	NA	NA	Both *E. camaldulensis* and *E. victrix* were present in the Jinidi Iron Ore Mine Project area (vegetation type 1a); however the area of vegetation supporting these species was not provided in the documentation reviewed (BHP 2011; Biologic 2011)
BHP Marillana Creek (Yandi; EP Act Assessment No. 1555)	Unable to assess; insufficient	NA	NA	Groundwater dependent vegetation supporting *E.*

Project	Species occurrence	Area riparian habitat mapped	Area riparian habitat disturbed	Reference
	information provided in documentation reviewed			*camaldulensis* and *E. victrix* was recorded in the Marillana Creek (Yandi) Project area; however, the area of such was not quantified in the documentation reviewed (EPA 2005)
BHP Mining Area C (EP Act Assessment No. 1108)	Not recorded	NA	NA	Both *E. camaldulensis* and *E. victrix* were present in the Mining Area C Project area (vegetation type 13); however the area of vegetation supporting these species was not provided in the documentation reviewed (Woodward-Clyde 1997)
Mineral Resources Phil's Creek Iron Ore Mine (EPBC Act Ref. 2009/5107)	Not recorded	NA	NA	Vegetation type C1 supported both *E. camaldulensis* and *E. victrix*; however, details were not provided in the documentation reviewed on the area mapped and area proposed to be disturbed (Mattiske 2008c; URS 2009; Western Wildlife 2009)
Rio Tinto Yandicoogina Iron Ore Project, comprising: • Junction Central (EP Act Assessment No. 809 & 946) • Junction South East (EP Act Assessment No. 1590) • Junction South West and Oxbow (EP Act Assessment No. 1726; EPBC Act Ref. 2011/5815)	Not recorded	1,836 ha	67 ha	This document
Anticipated project actions				
Rio Tinto Yandi PBS Proposal (this assessment)	Recorded	859 ha	87 ha	This document

Project	Species occurrence	Area riparian habitat mapped	Area riparian habitat disturbed	Reference
Reasonably foreseeable future actions				
NA – none located in the Weeli Wolli Creek or Marillana Creek sub-catchments				
Cumulative impact				
Four projects: • Hamersley HMS's Hope Downs 1 Iron Ore Mine Expansion • Iron Ore Holdings Iron Valley Iron Ore Project • Rio Tinto Yandicoogina Iron Ore Project, comprising Junction Central, Junction south East, and Junction South West and Oxbow • Rio Tinto Yandi PBS Proposal (this assessment)	Refer above	2,902 ha	163 ha	Refer above

15.6.2 Cumulative impacts to the Pilbara Olive Python

A preliminary assessment of cumulative impacts to the Pilbara Olive Python was conducted based on a review of the potential impacts of the Proposal, the existing Yandi Operations and 19 other projects identified as being potentially relevant based on their location in the Upper Fortescue River Catchment (**Figure 24**).

The Pilbara Olive Python has been recorded at 12 of the projects considered (including this Proposal) and the area of potential Pilbara Olive Python habitat has been quantified for seven of the projects considered (including this Proposal; **Table 30**). The projects for which habitat has been quantified were included in this preliminary assessment of cumulative impacts to the Pilbara Olive Python.

Of the approximately 873 ha of potential habitat for the Pilbara Olive Python occurring in the Proposal Area, up to 87 ha will be cleared for the Proposal. This represents approximately 10% of the extent of this habitat in the Proposal Area. Taken together with the remaining projects for which habitat has been quantified, the cumulative impact is a loss of up to 5,447 ha of potential Pilbara Olive Python habitat, which represents approximately 15% of the 37,376 ha of habitat mapped across the seven projects (**Table 30**).

Table 30: Assessment of potential cumulative impacts to Pilbara Olive Python habitat

Project	Species occurrence	Area Pilbara Olive Python habitat mapped	Area Pilbara Olive Python habitat disturbed	Reference
Past and present actions				
FMG Christmas Creek Mine - Water Management Scheme (EP Act Assessment No. 1873; EPBC Act Ref. 2010/5706)	Not recorded	Not quantified	Not quantified	ENV (2010); FMG (2010a); FMG (2011)
FMG Cloudbreak Iron Ore Mine (EP Act Assessment No. 1577; EPBC Act Ref. 2005/2205)	Not recorded	Not quantified	Not quantified	Environ Australia (2005a)
FMG Cloudbreak Life of Mine (EP Act Assessment No. 1848; EPBC Act Ref. 2010/5696)	Not recorded	Not quantified	Not quantified	ENV (2010); FMG (2012)
Hamersley HMS's Hope Downs 1 Iron Ore Mine Expansion (EP Act Assessment No. 1308)	Recorded	11,348 ha	1,181 ha	Ecologia (1997); Hope Downs Management Services Pty Ltd (2000); this document
Rio Tinto (managed) Hope Downs 4 Iron Ore Mine (EP Act Assessment No. 1738; EPBC Act Ref. 2008/4636)	Not recorded	5,986 ha	914 ha	Mattiske (2008a; 2008b); Strategen (2010); this document
FMG IO Direct Shipping Iron Ore Project (Not Assessed – Public Advice Given under the EP Act)	Unable to assess; insufficient information provided in documentation	Unable to assess; insufficient information provided in documentation	Unable to assess; insufficient information provided in documentation	EPA (2012c)
Iron Ore Holdings Iron Valley Iron Ore Project (EP Act Assessment No. 1905; EPBC Act Ref. 2012/6458)	Not recorded	333 ha	105 ha	URS (2012)
BHP Jinidi Iron Ore Mine (EP Act Assessment No. 1904; EPBC Act Ref. 2012/6299)	Recorded	Not quantified	Not quantified	BHP (2011)

Project	Species occurrence	Area Pilbara Olive Python habitat mapped	Area Pilbara Olive Python habitat disturbed	Reference
Rio Tinto Koodaideri Iron Ore Mine (EP Act Assessment No. 1933; EPBC Act Ref. 2012/6422)	Recorded	729 ha	166 ha	ELA (2013)
BHP Marillana Creek (Yandi; EP Act Assessment No. 1555)	Recorded	Not quantified	Not quantified	EPA (2005)
Brockman Marillana Iron Ore Project (EP Act Assessment No. 1781; EPBC Act Ref. 2011/5892)	Recorded	Not quantified	Not quantified	Brockman Resources (undated)
BHP Mining Area C (EP Act Assessment No. 1108)	Not recorded	Not quantified	Not quantified	Woodward-Clyde (1997)
Mineral Resources Phil's Creek Iron Ore Mine (EPBC Act Ref. 2009/5107)	Recorded	Not quantified	Not quantified	Mattiske (2008c); URS (2009)
FMG Pilbara Iron Ore and Infrastructure Project - Railway Stage A (EP Act Assessment No. 1505)	Recorded	Not quantified	Not quantified	FMG (2010b)
FMG Pilbara Iron Ore and Infrastructure Project - Railway Stage B (EP Act Assessment No. 1520; EPBC Act Ref. 2004/1897)	Recorded	Not quantified	Not quantified	Environ Australia (2005b)
Roy Hill Roy Hill 1 Iron Ore Mining Project Stage 1 (EP Act Assessment No. 1589; EPBC Act Ref. 2008/4624)	Recorded	Not quantified	Not quantified	Roy Hill (2009)
Roy Hill Roy Hill 1 Iron Ore Mining Project Stage 2 (EP Act Assessment No. 1822; EPBC Act Ref. 2008/4624)	Recorded	Not quantified	Not quantified	EPA (2009b)
Rio Tinto Yandicoogina Iron Ore Project, comprising: • Junction Central (EP Act Assessment No. 809 & 946) • Junction South East (EP Act Assessment No. 1590) • Junction South West and Oxbow (EP Act Assessment No. 1726; EPBC Act Ref. 2011/5815)	Not recorded	9,434 ha	1,877	This document

Project	Species occurrence	Area Pilbara Olive Python habitat mapped	Area Pilbara Olive Python habitat disturbed	Reference
Anticipated project actions				
Rio Tinto Yandi PBS Proposal (this assessment)	Recorded	873 ha	87 ha	This document
Reasonably foreseeable future actions				
FMG Christmas Creek Expansion Project (EP Act Assessment No. 1989; EPBC Act Ref. 2013/7055)	Recorded	8,673 ha	1,117 ha	FMG (2015)
FMG Nyidinghu Iron Ore Project (EP Act Assessment No. 1068; EPBC Act Ref. 2013/6945)	Not recorded	Not quantified	Not quantified	FMG (2013)
Cumulative impact				
Seven projects: • Hamersley HMS Hope Downs 1 Iron Ore Mine Expansion • Rio Tinto (managed) Hope Downs 4 Iron Ore Mine • Iron Ore Holdings Iron Valley Iron Ore Project • Rio Tinto Koodaideri Iron Ore Mine and Infrastructure Project • Rio Tinto Yandicoogina Iron Ore Project, comprising Junction Central, Junction South East, and Junction South West and Oxbow • Rio Tinto Yandi PBS Proposal (this assessment) • FMG Christmas Creek Expansion Project	Refer above	37,376 ha	5,447 ha	Refer above

15.6.3 Cumulative impacts to potential Short Range Endemic invertebrates

A preliminary assessment of cumulative impacts was conducted for each of the four potential SRE invertebrate taxa recorded in the Proposal Area, being Nemesiidae sp. N42, Nemesiidae sp. N44, Idiopidae sp. I1 and Idiopidae sp. I9. Of these four taxa, only Nemesiidae sp. N44 has been recorded in the indicative disturbance footprint; the remaining three taxa have been recorded in the Proposal Area outside the indicative disturbance footprint.

The preliminary assessment of cumulative impacts to the four potential SRE invertebrate taxa was based on a review of the potential impacts of the Proposal and the existing Yandi Operations. The assessment considered each species' currently known distribution based on currently known records, and the extent of this distribution located in the Proposal Area and the Revised Proposal Development Envelope.

15.6.3.1 Nemesiidae sp. N42

The currently known distribution of Nemesiidae sp. N42 is approximately 11,300 ha. Of this, approximately 1,439 ha (13%) is located in the Revised Proposal Development Envelope, including less than 1 ha (<1%) in the Proposal Area.

15.6.3.2 Nemesiidae sp. N44

The currently known distribution of Nemesiidae sp. N44 is approximately 2,600 ha. Of this, approximately 1,638 ha (63%) is located in the Revised Proposal Development Envelope, all of which (63%) is in the Proposal Area.

15.6.3.3 Idiopidae sp. I1

The currently known distribution of Idiopidae sp. I1 is approximately 255,900 ha. Of this, approximately 18,606 ha (7%) is located in the Revised Proposal Development Envelope, including approximately 4,231 ha (2%) in the Proposal Area.

15.6.3.4 Idiopidae sp. I9

The currently known distribution of Idiopidae sp. I9 is approximately 6,500 ha. Of this, approximately 157 ha (2%) is located in the Revised Proposal Development Envelope, including approximately 50 ha (<1) in the Proposal Area.

15.7 Key management actions

Potential impacts to fauna values will be mitigated through the implementation of measures described in the SSMP and the E14 Standard (Land Disturbance and Rehabilitation Control). Measures relating to rehabilitation of disturbed areas will be implemented in accordance with the Yandicoogina Closure Plan.

Key measures in the SSMP (including the Yandi SSMP addendum) and Yandi Operations site measures include:

- Baseline surveys (following EPA Guidance Statements) will be completed in all areas with planned mining developments and infrastructure.
- Ensure any sightings or potential records of MNES encountered by the workforce during clearing operations are reported to site Environmental Advisors and are recorded in a register. Site environmental inductions and educational posters should include information to raise awareness of MNES species and specify protocols for reporting sightings.
- Location of MNES and their habitats identified within and adjacent to the Proponent's project boundaries will be recorded on the Rio Tinto GIS database.

- Targeted surveys will be undertaken to identify any significant species, habitat or communities for any new projects/developments. Methods will be investigated to minimise or avoid the clearing of significant species if identified. Riparian vegetation will be managed as per the Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.
- Proposed clearing and disturbance will be assessed through the internal approvals coordination process. This internal process will ensure:
    - disturbance remains within approved boundaries;
    - clearing is minimised to meet specific demands;
    - planned clearing is adjusted where possible to avoid disturbance of significant areas; and
    - planned clearing meets legal obligations.
- All areas to be cleared will be demarcated prior to disturbance.
- Rehabilitation success will be assessed through vegetation monitoring and monitoring for habitat use indicators, in accordance with the completion criteria established within the Yandicoogina Closure Plan.
- Weed management measures will be implemented in accordance with Yandicoogina Weed Action Plan and equipment hygiene procedures to ensure weeds are controlled and recorded and equipment is cleaned to minimise the spread of weeds.
- Feral animal control will be undertaken by:
    - prohibiting feeding animals;
    - prohibiting keeping pets;
    - appropriate waste disposal for food scraps and other wastes as per the Waste Management Guidelines; and
    - regular feral animal reduction programs.
- Dust control measures (including road watering, water sprays and dust suppression systems) will be used to minimise dust from sites.
- Native fauna encountered on-site will be given the opportunity to move on if there is no threat to personnel safety in doing so.
- Injured fauna encountered on-site will be handled and transported in accordance with the Proponent's Wildlife interaction guidelines.
- Feeding of native fauna, hunting, keeping of firearms or pets on-site will be prohibited.
- Appropriate speed limits for mining equipment and light vehicles will be implemented, sign-posted and enforced, and communicated via education of site personnel.
- Vehicles will remain on designated roads and will not be permitted off designated roads unless in the case of emergency.
- Animal strikes by vehicles will be recorded and documented.
- Control fires caused by operations.

Implementation of snake handling and relocation procedures as required (this includes Pilbara Olive Python relocation protocol for any individuals encountered within the Yandi operational area). The Yandi SSMP addendum (**Appendix 4**) addresses management measures specifically to relevant EPBC Act listed species occurring, or potentially occurring, in the Revised Proposal Development Envelope. It outlines key management actions and accountability for issues relating to clearing and direct disturbance, indirect disturbance and other operational issues and outlines survey/monitoring requirements. These management actions are already been successfully implemented for the existing Yandi Operations.

15.8 Predicted outcome

A range of measures have been or will be implemented to reduce potential impacts to terrestrial fauna values (**Table 31**).

Table 31: **Mitigation hierarchy for terrestrial fauna values**

Mitigation measure	Description
Avoidance	Clearing will only occur within the approved Revised Proposal Development Envelope.
	Modify land clearing plans and evaluate alternative mine plans to avoid impacts on the conservation significant fauna species.
	Pets will be prohibited within the Proposal Area.
Minimisation	Clearing will be minimised to that required for safe construction and operation.
	Modify land clearing plans and evaluate alternative clearing options to minimise impacts on conservation significant fauna species.
	Clearing of vegetation will be staged allowing for the progressive movement of fauna into areas outside the proposed disturbance areas
	Infrastructure in creeklines designed to avoid disruption of low-flow line and flood flows. Low flows will be maintained in the low-flow line to support vegetation habitat.
	Vehicles will remain on designated roads and will not be permitted off designated roads unless in the case of an emergency.
	Any native animals encountered on-site will be given the opportunity to move on if there is no threat to human safety.
	Potential noise impacts to fauna will be minimised by selecting and locating equipment start-up alarms so that they reduce noise impacts.
	Lighting and dust controls will be implemented.
Rehabilitation	Disturbed areas will be progressively rehabilitated.

After mitigation and management measures have been applied, the Proposal is expected to result in the following residual outcomes in relation to terrestrial fauna:

- Clearing of up to 1,800[7] ha of terrestrial fauna habitat over the life of the Proposal.
- Habitat degradation due to the altered surface water and groundwater regime (including stress and some deaths of trees within the riparian zone), which may lead to local reductions in fauna populations in the Proposal Area. The habitat types present in the Proposal Area are considered to be well represented in the

[7] The total disturbance to fauna habitat is 1,327 ha, however the Proponent is seeking approval for overall disturbance of up to 1,800 to accommodate for detailed design of mining operations and infrastructure.

local and regional area. It is considered likely that individuals will continue to forage in the remaining habitats within and adjacent to the Proposal Area.

- Clearing will result in the direct removal of up to 1,800 ha of vegetation that contains potential SRE habitat within Proposal Area; this habitat is considered widespread locally and regionally.
- Risk of alteration to aquatic fauna habitat in Weeli Wolli Creek (surface water flows); additional habitat is available to north and south of the Proposal Area.
- Fragmentation of fauna habitat caused by the pit, waste dumps and association infrastructure; the mine footprint may also cause a barrier to dispersion for non-aerial species.
- Direct loss of some individual fauna through impact with machinery and vehicles, particularly during vegetation clearing.
- Rehabilitation, with consideration given to restoring fauna habitat values where practicable.

Clearing of up to 1,731 ha of native vegetation in Good to Excellent condition and 69 ha of riparian zone vegetation[8], including fauna habitat, within the Proposal Area will be offset as part of the Proposal (Section 18).

[8] For the purposes of the offset calculation, riparian zone vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

16. Subterranean fauna

16.1 Key statutory requirements, environmental policy and guidance

16.1.1 EPA objective

The EPA has applied the following objective for the Proposal to its assessment of subterranean fauna:

"To maintain representation, diversity, viability and ecological function at the species, population and assemblage level."

16.1.2 Regulatory framework

The following legislation is relevant to the Proposal with respect to the protection of subterranean fauna values and the above EPA objective:

- *Wildlife Conservation Act 1950* (WA) *Environmental Protection Act 1986* (WA)
- *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)

16.1.3 Relevant guidelines and policy

The following guidelines are relevant to the Proposal with respect to the protection of subterranean fauna and the above EPA objective:

- EAG 12: Environmental Assessment Guideline for Consideration of subterranean fauna in Environmental Impact Assessment in Western Australia (EPA 2013b)
- EPA Guidance Statement No. 54a: Sampling Methods and Survey Considerations for Subterranean Fauna in WA (EPA 2007)

16.2 Description of stygofauna

16.2.1 Stygofauna surveys

A total of 13 stygofauna surveys have been undertaken in and around the Revised Proposal Development Envelope since 2003, including the Proposal Area (Biota 2010a, 2011b, 2011c, 2013b; as cited in Biota 2015c). A total of 139 drillhole/boreholes have been sampled to date, encompassing JC, JSE, JSW, Oxbow and PBS deposits. Stygobitic fauna sampling has been undertaken using modified plankton haul nets lowered to the bottom of the drillholes and bore holes. Each site has been sampled in this way five times, unless the site recorded high water turbidity, in which case the drillhole/borehole was only sampled two or three times. A full description of the sampling methodology is outlined in the Biota (2015c) report (**Appendix 3**).

Of the 139 drillhole/boreholes sampled, 62 sites are located within the Proposal Area, including the 29 sites located within the proposed pit boundary. Sampling effort differed over the 13 stygofauna surveys, depending on the deposit-specific focus of the surveys and the access to and condition of drillhole/boreholes. Many sites were sampled over multiple phases; some sites were sampled in up to 11 surveys, while others were only sampled during a single survey. **Figure 66** shows the locations of the drillhole/boreholes used for the stygofauna surveys.

The methodology and approach used in all surveys were consistent with those outlined in EPA Guidance Statement No. 54a and EAG No. 12.

16.2.2 Stygofauna habitat

Stygofauna habitat is characterised by groundwater environments including porous, karstic and fractured rock aquifers, springs and the hyporheric zone of streams (Eberhard et al. 2005). Stygofauna inhabit voids, cavities and fractures in groundwater aquifers and a correlation exists between interconnectivity and transmissivity of the aquifer and suitability for stygofauna. Calcrete and alluvium are considered to be productive habitats for stygofauna, and pisolite and banded iron formations also considered to be suitable (Halse et al. 2014). The geological units found in the Proposal Area and their potential suitability for stygofauna as defined by Biota (2015c) are listed in **Table 32**.

Table 32: Geological units in the Proposal Area and their suitability for stygofauna

Geological time scale	Geological Formation Code	Description	Potential Habitat Suitability
Quaternary Period	Qw	Alluvium and colluvium – red-brown sandy and clayey soil; on low slopes and sheetwash areas.	High
	Qa	Alluvium – unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains. **Superficial aquifer**.	High
Cenozoic Era	Czk	Calcrete – sheet carbonate; found along major drainage lines.	High
	Czp	Pisolite (CID) – Pisolitic limonite deposits developed along ancient river channels (Palaeo-channel). **Deeper aquifer.**	Mod*
Proterozoic Eon	PLHj	Weeli Wolli Formation: banded iron formation (commonly jaspilitic), pelite, and numerous matadolerite sills.	Low

Adapted from Biota (2015c) * Typically classified as High, but classified as Moderate based on depth of CID habitat in the Proposal Area and Biota assessment (Biota 2015c).

The pre-mining habitat has been modified as a result of discharge from the Hope Downs 1 mining operations upstream of the Proposal; discharge from the existing Yandi Operations at the upstream discharge point DO6; and surplus water re-injection into the Billiard South deposit from the existing Yandi Operations since late 2006. This change, coupled with seasonal variability from cyclones and flooding, has resulted in a shallow water table in the Proposal Area and superficial formations remaining saturated for extended periods compared to past (pre-mining) conditions (Biota 2015c).

The hydrogeology in the Proposal Area is generally well suited for stygobitic fauna utilisation, with the majority of the shallow stratigraphy comprised of saturated alluvium (**Figure 67**). This shallow alluvial aquifer overlays a deeper aquifer formed by the CID. These systems are recharged both directly and indirectly by rainfall, groundwater and surface water flow. The CID is primarily recharged by seepage in areas where the present day creek overlays the CID (**Figure 25**). The shallow water table and seasonally variable influx of water from storm events are also likely to aid in fauna dispersal and general hydraulic connectivity of subterranean habitats within the area (Biota 2015c).

16.2.3 Stygofauna occurrence

A total of 9,654 specimens of stygobitic fauna have been recorded from the Revised Proposal Development Envelope between 2003 and 2014 (Biota 2015c). These specimens were from eight phyla and at least nine classes. Specimens belonging to Gastropoda, Nematoda and Protozoa were unable to be classified beyond phylum, and turbellarian worms (phylum Platyhelminthes) could not be identified beyond class due to a lack of taxonomic framework for these groups in the Pilbara. Of the specimens that

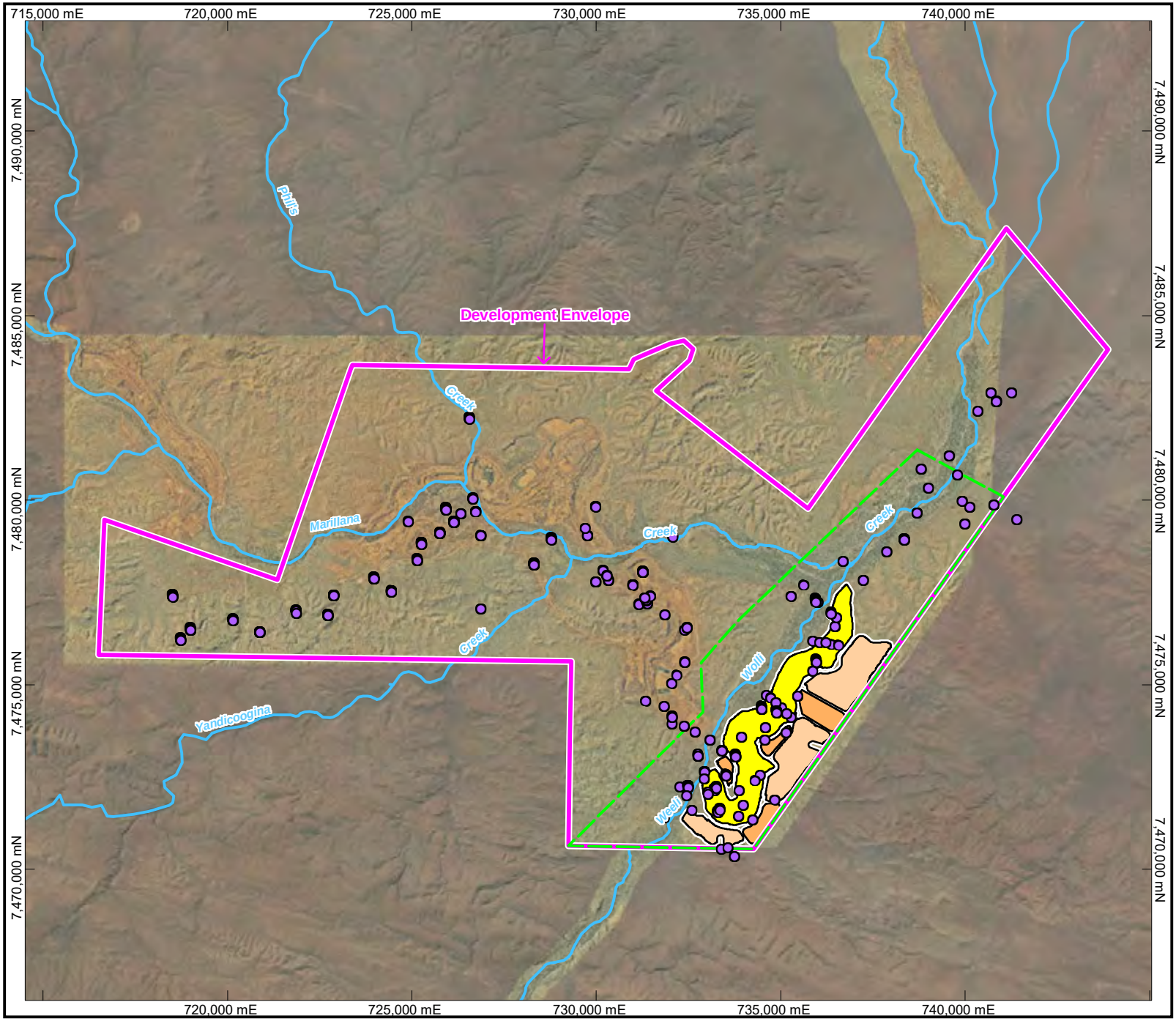
could be identified to lower taxonomic levels, Copepoda (copepods), Ostracoda (Seed Shrimp) and Amphipoda (Landhopper) were the most prolific, accounting for 77% of all specimens.

Approximately 64% of the total stygofauna species identified within the Revised Proposal Development Envelope have been recorded elsewhere in Australia or globally (Biota 2015c). The highest abundance of specimens was located in or adjacent to the Weeli Wolli and Marillana Creeks (Biota 2015c). Where the taxonomic framework is limited, identification of specimens beyond order can be difficult and results in limited conclusions for Environmental Impact Assessment at species level.

In the Proposal Area, 62 drillholes/boreholes have been sampled for stygofauna, with 42 sites yielding stygofauna specimens. In total there were 2,761 specimens from 62 taxa found in the Proposal Area since sampling commenced in 2003. The most abundant taxon was *Diacyclops humphreysi humphreysi* (918 specimens; 33% of records within the Proposal Area), followed by *Gordanitocrella trajani* (297 specimens; 11% of records within the Proposal Area) and *Notacandona boultoni* (270 specimens; 10% of records within the Proposal Area). Of the 29 sites within the proposed pit boundary, 21 of these sites contained stygofauna specimens (refer to **Figure 67**). From the sites that were sampled within the proposed pit boundary, Biota (2015c) identified 1,014 specimens from 39 individual taxa. Of these 39 taxa, three were only found within the proposed pit boundary and are not known from records outside this area:

- *Notobathynella* sp.;
- *Billibathynella* sp. B02; and
- *Brevisomabathynella* cf. *pilbaraensis.*

None of these species are currently Specially Protected, Schedule or Priority species or MNES. *Notobathynella* sp. and *Billibathynella* sp. B02 were only recorded as single specimens (singletons), while the two specimens of *Brevisomabathynella* cf. *pilbaraensis* were recorded from the same site. *Brevisomabathynella* cf. *pilbaraensis* is morphological similar to *Brevisomabathynella pilbaraensis* (type locality is 85 km away), however most Bathnellids have small distributions. *Brevisomabathynella* is known for its similarities between taxa, with two of the described species of this genus from the Pilbara (Ethel Creek and Millstream) also having only small morphological differences between them. **Table 33** provides a summary of the stygofauna survey results, including stygofauna recorded within the proposed pit boundary.



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Stygofauna Sampling Site

N

SCALE

0 2 4 6km

1:150 000 @ A4

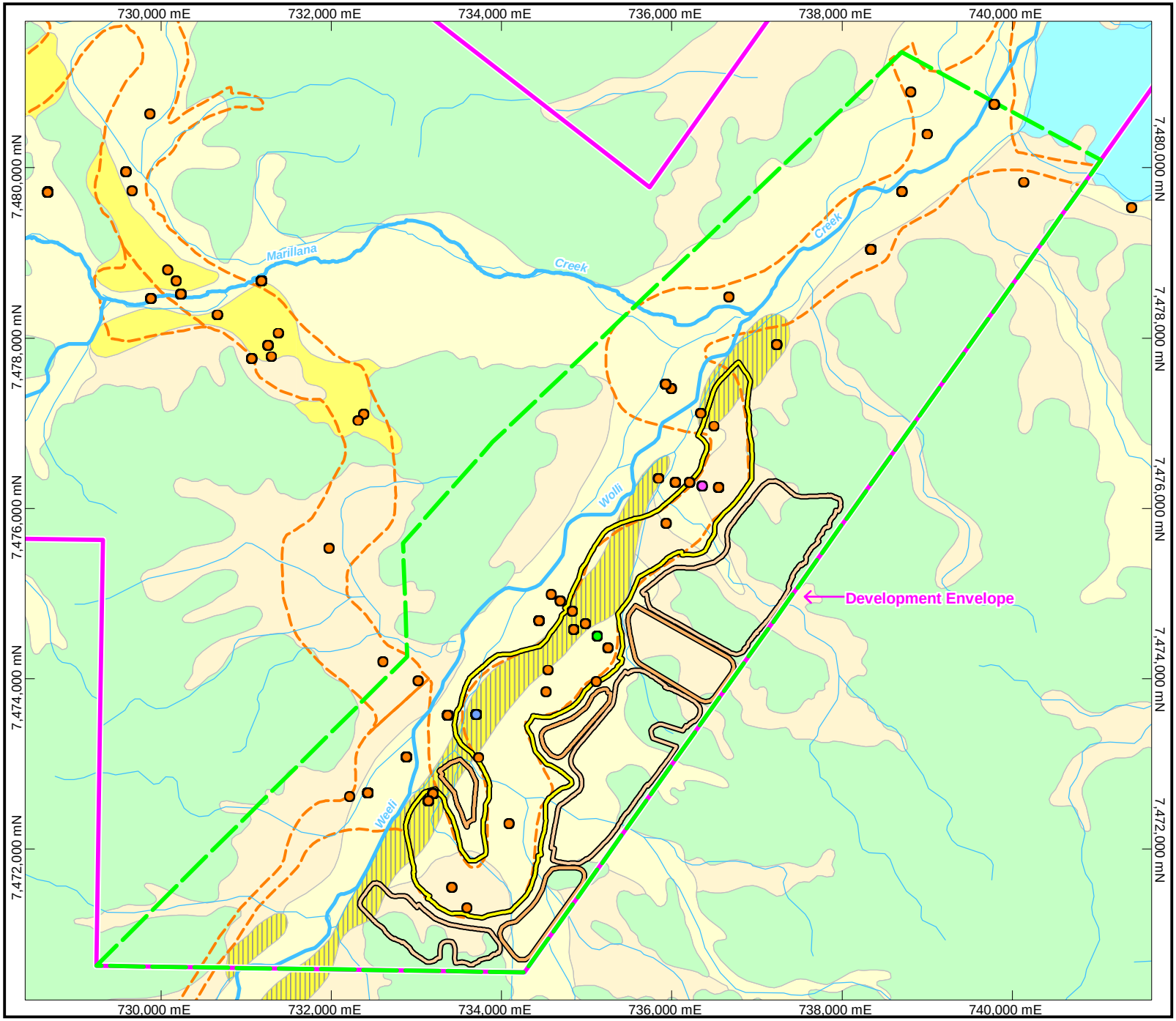
Iron Ore (WA)

Figure 66
Location of stygofauna sampling sites

Drawn: M.Swebbs
Date: Oct, 2015

Plan No: PDE0134734v3
Proj: MGA94 Zone50

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump
- Conceptual Topsoil / Subsoil Stockpile
- Major; Minor Watercourse
- Stygofauna Records
- *Brevisomabathynella cf. pilbaraensis*
- *Billibathynella sp. B02*
- *Notobathynella sp.*

Geology

- Colluvium
- Alluvium
- Pisolite and Limonite
- Calcrete

HAMERSLEY GROUP

- Brockman Iron
- Weeli Wolli
- Extent of CID

N

SCALE

0 1 2 3km

1:65 000 @ A4

Rio Tinto

Iron Ore (WA)

Figure 67
Stygofauna records and surface geology of the Proposal Area

Drawn: M.Swebbs Plan No: PDE0134741v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

Table 33: Stygofauna specimens recorded from the Proposal Area between 2003 and 2014

CLASS	ORDER	FAMILY	GENUS	SPECIES	No. of specimens found in the proposed pit	Total no. of specimens recorded elsewhere in the Proposal Area	Total no. of specimens recorded in the Proposal Area	Taxon only known from the proposed pit?
Kingdom: Protozoa				sp.	0	6	6	N
Phylum: Nematoda				sp.	2	2	4	N
Arachnida	Trombidiformes	Arrenuridae	*Arrenurus*	sp. 02	0	13	13	N
Arachnida	Trombidiformes	Arrenuridae	*Arrenurus*	sp. 03	0	4	4	N
Arachnida	Trombidiformes	Arrenuridae	*Arrenurus*	sp. indet	0	3	3	N
Arachnida	Trombidiformes	Aturidae	*Axonopsella*	sp. B1	0	1	1	N
Arachnida	Trombidiformes	Mideopsidae	*Guineaxonopsis*	sp. S1 (PSS)	3	4	7	N
Arachnida	Trombidiformes	Unionicolidae	*Recifella*	sp. "Yandi"	1	2	3	N
Gastopoda	Hypsogastropoda	Hydrobiidae		sp.	0	1	1	N
Malacostraca	Amphipoda			sp. indet	2	1	3	N
Malacostraca	Amphipoda	Paramelitidae		sp. (lineage YB3)	2	5	7	N
Malacostraca	Amphipoda	Paramelitidae		sp. (lineage YB4)	0	2	2	N
Malacostraca	Amphipoda	Paramelitidae		sp. B02	84	82	166	N
Malacostraca	Amphipoda	Paramelitidae		sp. B03	3	0	3	N
Malacostraca	Amphipoda	Paramelitidae		sp. B16	1	0	1	N
Malacostraca	Amphipoda	Paramelitidae		sp. H8	0	16	16	N
Malacostraca	Amphipoda	Paramelitidae		sp. indet	1	10	11	N
Malacostraca	Amphipoda	Paramelitidae		sp. WW-2C	5	12	17	N
Malacostraca	Amphipoda	Paramelitidae	*Chydaekata*	sp.	64	125	189	N
Malacostraca	Amphipoda	Paramelitidae	*Chydaekata*	sp. B01	6	0	6	N
Malacostraca	Amphipoda	Paramelitidae	*Chydaekata*	sp. E	15	28	43	N
Malacostraca	Amphipoda	Paramelitidae	*Maarka*	sp. MA1	3	0	3	N
Malacostraca	Amphipoda	Paramelitidae	*Maarka*	*weeliwolli*	5	18	23	N
Malacostraca	Amphipoda	Paramelitidae	*Pilbarus*	*millsi*	0	2	2	N

CLASS	ORDER	FAMILY	GENUS	SPECIES	No. of specimens found in the proposed pit	Total no. of specimens recorded elsewhere in the Proposal Area	Total no. of specimens recorded in the Proposal Area	Taxon only known from the proposed pit?
Malacostraca	Bathynellacea	Parabathynellidae	*Atopobathynella*	sp. indet	0	1	1	N
Malacostraca	Bathynellacea	Parabathynellidae	*Billibathynella*	sp. B02	1	0	1	**Y**
Malacostraca	Bathynellacea	Parabathynellidae	*Billibathynella*	sp. B03	0	1	1	N
Malacostraca	Bathynellacea	Parabathynellidae	*Brevisomabathynella*	cf. *pilbaraensis*	2	0	2	**Y**
Malacostraca	Bathynellacea	Parabathynellidae	*Chilibathynella*	sp. B06	0	1	1	N
Malacostraca	Bathynellacea	Parabathynellidae	*Notobathynella*	sp.	1	0	1	**Y**
Malacostraca	Isopoda	Tainisopidae	*Pygolabis*	sp.	1	5	6	N
Malacostraca	Isopoda	Tainisopidae	*Pygolabis*	*weeliwolli*	38	62	100	N
Maxillopoda				sp.	2	0	2	N
Maxillopoda	Cyclopoida			sp.	0	1	1	N
Maxillopoda	Cyclopoida	Cyclopidae	*Diacyclops*	*cockingi*	33	65	98	N
Maxillopoda	Cyclopoida	Cyclopidae	*Diacyclops*	*humphreysi humphreysi*	367	551	918	N
Maxillopoda	Cyclopoida	Cyclopidae	*Diacyclops*	*humphreysi unispinosus*	60	2	62	N
Maxillopoda	Cyclopoida	Cyclopidae	*Diacyclops*	*sobeprolatus*	55	49	104	N
Maxillopoda	Cyclopoida	Cyclopidae	*Paracyclops*	*chiltoni*	0	3	3	N
Maxillopoda	Harpacticoida	Ameiridae	*Gordanitocrella*	*trajani*	48	249	297	N
Maxillopoda	Harpacticoida	Canthocamptidae		sp. B1	7	6	13	N
Oligochaeta	Tubificida	Enchytraeidae		Pilbara sp. 1 (PSS)	36	0	36	N
Oligochaeta	Tubificida	Enchytraeidae		sp. indet	0	1	1	N
Oligochaeta	Tubificida	Enchytraeidae	*Enchytraeus*	Pilbara sp. 2 (PSS)	8	26	34	N
Oligochaeta	Tubificida	Naididae		sp.	0	3	3	N
Oligochaeta	Tubificida	Naididae	*Dero*	*furcata*	0	2	2	N
Oligochaeta	Tubificida	Naididae	*Pristina*	*aequiseta*	0	1	1	N
Oligochaeta	Tubificida	Naididae	*Pristina*	*longiseta*	2	0	2	N
Oligochaeta	Tubificida	Phreodrilidae		sp.	0	3	3	N
Oligochaeta	Tubificida	Phreodrilidae		sp. indet	0	1	1	N

CLASS	ORDER	FAMILY	GENUS	SPECIES	No. of specimens found in the proposed pit	Total no. of specimens recorded elsewhere in the Proposal Area	Total no. of specimens recorded in the Proposal Area	Taxon only known from the proposed pit?
Oligochaeta	Tubificida	Tubificidae		morphospecies 1/1a (pss)	1	0	1	N
Oligochaeta	Tubificida	Tubificidae		stygo type 5	0	1	1	N
Ostracoda	Podocopida	Candonidae	*Areacandona*	*mulgae*	1	0	1	N
Ostracoda	Podocopida	Candonidae	*Meridiescandona*	*facies*	47	54	101	N
Ostracoda	Podocopida	Candonidae	*Meridiescandona*	*lucerna*	0	53	53	N
Ostracoda	Podocopida	Candonidae	*Meridiescandona*	*marillanae*	1	79	80	N
Ostracoda	Podocopida	Candonidae	*Meridiescandona*	sp. BOS399	0	6	6	N
Ostracoda	Podocopida	Candonidae	*Notacandona*	*boultoni*	95	175	270	N
Ostracoda	Podocopida	Limnocytheridae	*Gomphodella*	*alexanderi*	5	4	9	N
Ostracoda	Podocopida	Limnocytheridae	*Gomphodella*	*hirsuta*	2	3	5	N
Ostracoda	Podocopida	Limnocytheridae	*Gomphodella*	sp. BOS200	2	0	2	N
Turbellaria				sp.	2	2	4	N
				TOTAL	**1,014**	**1,747**	**2,761**	N/A

Adapted from Biota (2015c)

16.3 Description of troglofauna

16.3.1 Troglofauna surveys

Two phases of troglobitic fauna surveys were undertaken across the Proposal Area. Phase one was undertaken in 2009 and sampled 52 sites across the Revised Proposal Development Envelope, with 34 of these sites located within the Proposal Area. Phase two, completed in 2014, sampled 32 sites across the Revised Proposal Development Envelope, with 26 of these sites located within the ProposalArea (**Figure 68**). In addition to these two phases, troglofauna were opportunistically collected from four sites during past stygofauna sampling of the Revised Proposal Development Envelope, three of these sites are within the Proposal Area (Biota 2015d).

The methodology and approach used in all surveys were consistent with those outlined in EPA Guidance Statement No. 54a and EAG No. 12.

16.3.2 Troglofauna habitat

The suitability of a geological formation as troglofauna habitat is predominantly determined by above water table environments, with availability and interconnectivity of void/cavity space; the potential for nutrient infiltration from the surface; and the ability of the inhabited substrate to maintain a stable humidity (Biota 2015d). The surface geological formations occurring within the Proposal Area (where troglofauna have previously been recorded) and their suitability for troglofauna is provided in **Table 34.**

Table 34: Geological units in the Proposal Area and their suitability for troglofauna

Geological Time Scale	Geological Formation Code	Description	Suitability
Quaternary Period	Qw	Alluvium and colluvium – red-brown sandy and clayey soil; on low slopes and sheetwash areas.	Low
	Qa	Alluvium – unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains.	Medium
Cenozoic Era	Czk	Calcrete – sheet carbonate; found along major drainage lines.	High
	Czp	Robe Pisolite (CID): Pisolitic limonite deposits developed along river channels.	Low*
Proterozoic Eon	PLHj	Weeli Wolli Formation: banded iron formation (commonly jaspilitic), pelite, and numerous matadolerite sills.	Medium

Adapted from Biota (2015d) * Typically classified as High, but classified as Low based on 99% of CID habitat in the Proposal Area being below the water table and Biota assessment (Biota 2015c).

The majority of the troglofauna specimens recorded within the Revised Proposal Development Envelope have been collected from shallow alluvium, colluvium and calcrete drill holes with less than 10 m to water table. The surface geology units therefore generally characterise the habitats that the fauna were using at that time, given that other geological formations at depth were below water table.

All troglofauna specimens were recorded from three surface geological units, alluvium (Qa), colluvium (Czc) and calcrete (Czk; **Figure 69**) and these represent habitats that the fauna currently utilise within the Proposal Area.

The unconsolidated alluvium, colluvium and calcrete geological units located adjacent to Weeli Wolli Creek can be seasonally inundated during flooding, periodically rendering areas of habitat unsuitable for use by troglofauna. Adjoining higher elevation landforms, such as the Brockman Iron Formation and the Weeli Wolli Formation, potentially represent an alternative refuge from inundation, and potentially provides refuge habitat over longer timeframes (Biota 2015d). Troglofauna has been

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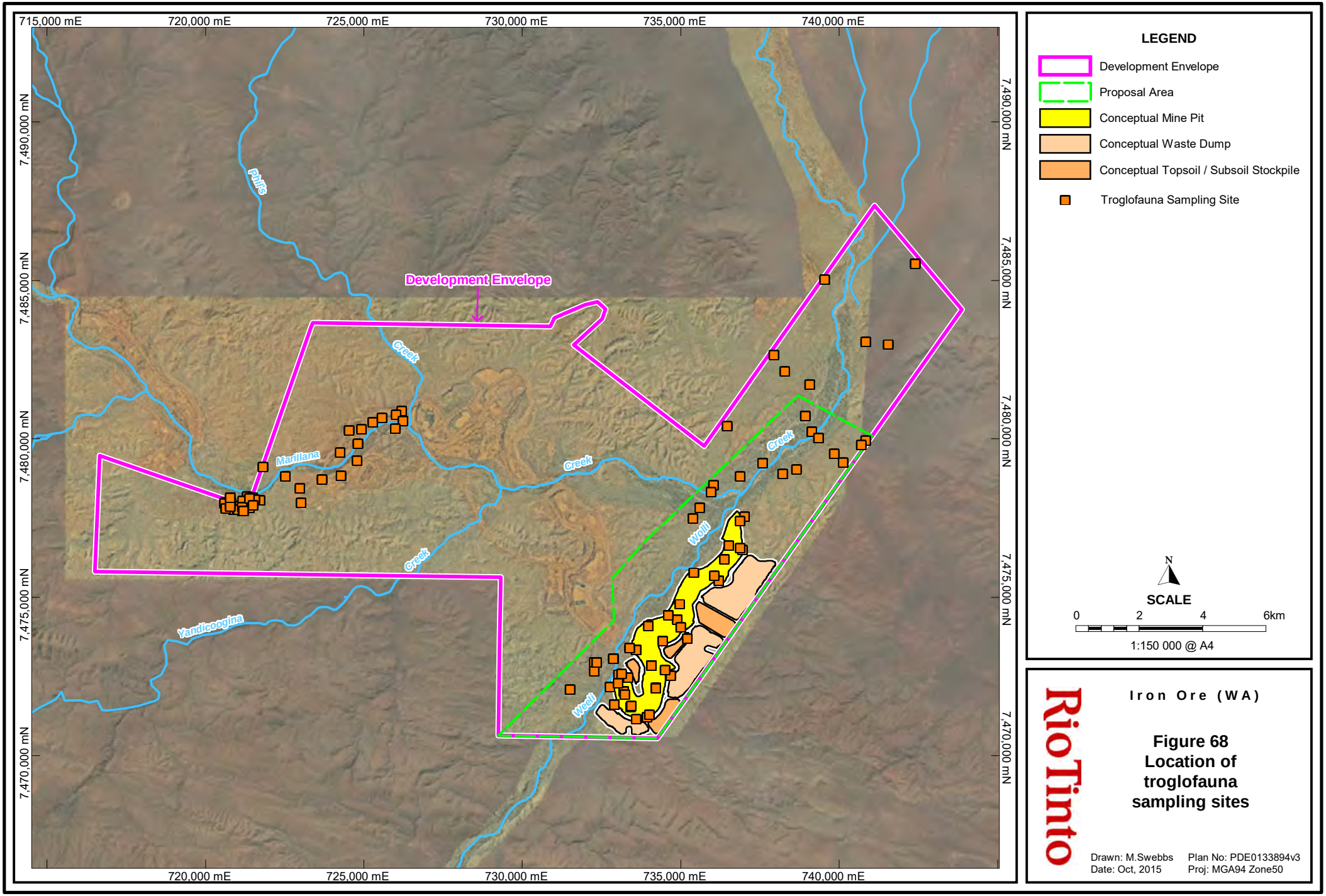
16.3.3 Troglofauna occurrence

Table 35 provides a summary of the troglofauna survey results, including troglofauna recorded within the proposed pit boundary. Six potential troglobitic fauna specimens have been recorded in the

Revised Proposal Development Envelope, three of which have been recorded within the Proposal Area (**Figure 69**):

- *Myrmopopaea* sp. nov;
- *Draculoides* sp. indet; and
- Pauropoda sp. indet.

Two of the specimens recorded within the Proposal Area are confirmed troglobites; *Myrmopopaea* sp. nov. and *Draculoides* sp. indet. The ecological status of the Pauropoda sp. indet is unconfirmed, as the distribution of this species is unknown (Biota 2015d). *Myrmopopaea* sp. nov. is the only taxon recorded from within the proposed pit boundary and it is not known from any other locations. *Draculoides* sp. indet and Pauropoda sp. indet were recorded from sites within 50 m from the proposed pit boundary.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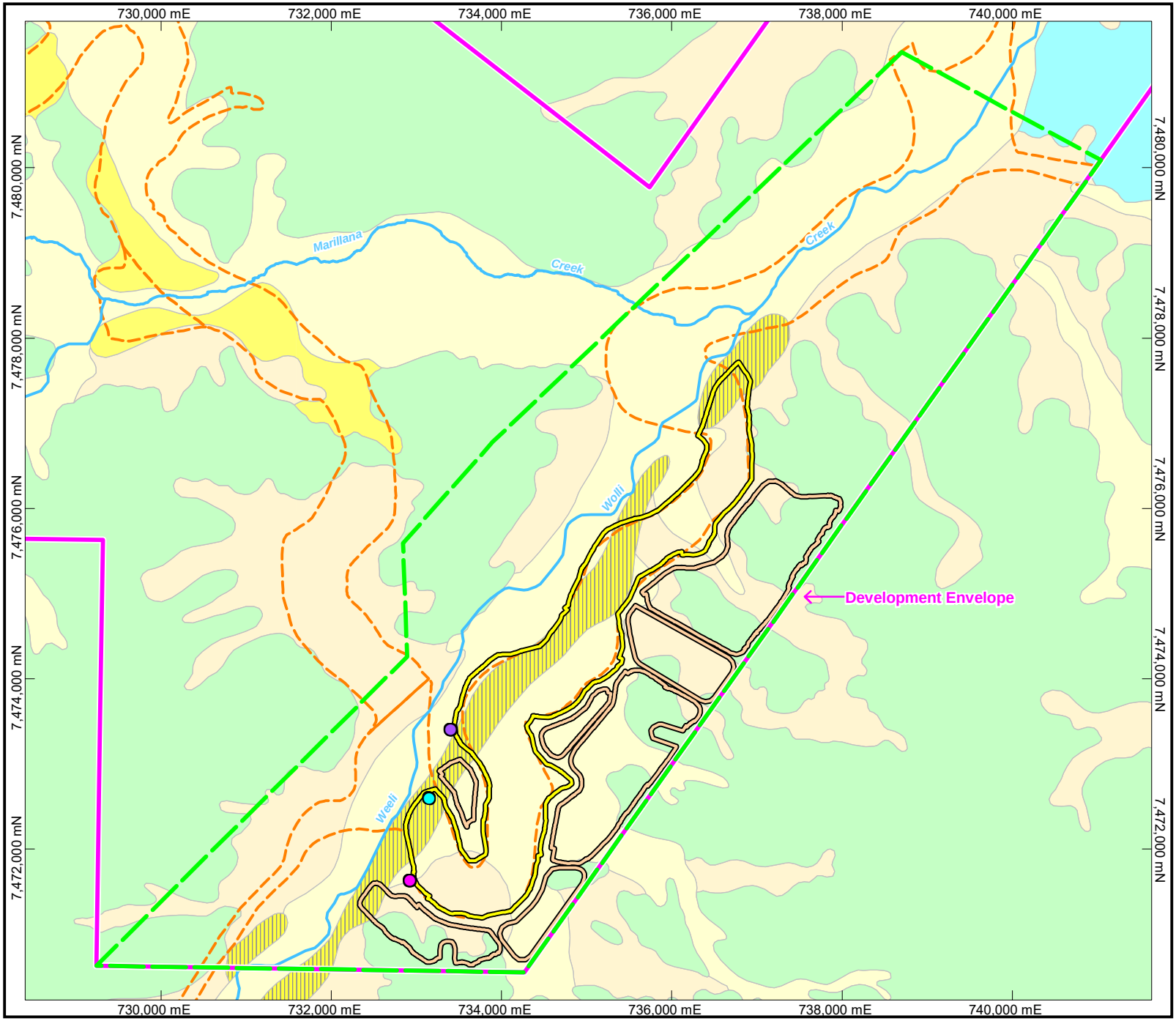
7,485,000 mN
7,480,000 mN
7,475,000 mN
7,470,000 mN
Development Envelope
Phillis Creek
Marillana Creek
Creek
Creek
Yandicoogina Creek
Woolli Creek
Weeli Creek
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump
Conceptual Topsoil / Subsoil Stockpile
Troglofauna Sampling Site
N
SCALE
0
2
4
6km
1:150 000 @ A4
Iron Ore (WA)
Figure 68
Location of troglofauna sampling sites
Drawn: M.Swebbs
Date: Oct, 2015
Plan No: PDE0133894v3
Proj: MGA94 Zone50
Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposal Area
- Conceptual Mine Pit
- Conceptual Waste Dump / Stockpile
- Major Watercourse

Troglofauna

- Pauropoda sp. indet
- *Myrmopopaea* sp. nov
- *Draculoides* sp. indet

Geology

- Colluvium
- Alluvium
- Pisolite and Limonite
- Calcrete

HAMERSLEY GROUP

- Brockman Iron
- Weeli Wolli
- Extent of CID

N

SCALE

0 1 2 3km

1:65 000 @ A4

Iron Ore (WA)

Figure 69
Troglofauna records and surface geology of the Proposal Area

Drawn: M.Swebbs
Date: Oct, 2015

Plan No: PDE0134739v2
Proj: MGA94 Zone50

Geospatial Information and Mapping

Table 35: Troglofauna collected within the Proposal Area

Class	Order	Family	Genus	Species	No. of specimens found in the proposed pit	Total no. of specimens recorded elsewhere in the Proposal Area	Total no. of specimens recorded in the Proposal Area
Arachnida	Araneae	Oonopidae	*Myrmopopaea*	sp. nov	1	0	1
Arachnida	Shizomida	Hubbardiidae	*Draculoides*	sp. indet	0	1	1
Insecta	Pauropoda			sp. indet	0	1	1

16.4 Assessment of potential impact, mitigation and residual impact

The EPA has listed the following potential impacts for the Proposal in relation to subterranean fauna:

- direct mortality and loss of habitat through subsurface disturbance; and
- loss of habitat through abstraction of groundwater for dewatering.

16.4.1 Stygofauna

Potential impacts on stygofauna arise from excavation of habitat and abstraction of groundwater for dewatering. Extraction of ore will result in the direct removal of stygofauna individuals and habitat and also reduces the ability to move around the system (i.e. reduces habitat connectivity). In the surrounding areas where there is no excavation, nutrient infiltration may be affected by stockpiling of overburden at the proposed waste dump locations.

As the proposed pit is located on the floodplain (with approximately 99% of the CID occurring below the water table), the taxa that are present in the proposed pit footprint, and directly adjacent to it, are most at risk from the Proposal. Almost half of the stygofauna assemblage recorded from the Revised Proposal Development Envelope is known from the wider region and the frequency of wider ranging taxa indicate there is unlikely to be geographically restricted taxa (Biota 2015c). Of the 39 taxa recorded within the proposed pit boundary, three species were only found within the proposed pit boundary and are not known from any other records outside this area: *Notobathynella* sp., *Billibathynella* sp. B02 and *Brevisomabathynella* cf. *pilbaraensis*. These species are not currently conservation listed. It is considered likely that the three taxa recorded only from the proposed pit would occur throughout the broader alluvial and CID aquifer and therefore would not be significantly impacted by the Proposal. The paucity of records may be an artefact of sampling, rather than an indication of an extremely restricted distribution (Biota 2015c).

The alluvial and CID aquifer in which the stygofauna occur is associated with the Weeli Wolli Creek system and extends north and south of the Proposal Area including northwards beyond the Marillana Creek confluence, which is further associated with alluvial units draining towards Fortescue Marsh (**Figure 67**). This extensive and hydrologically connected system of aquifers results in habitat that extends continuously beyond the predicted area of impact from pit excavation and groundwater drawdown. Seasonal flooding caused by cyclonic events may also assist in dispersing stygofauna taxa. This continuous aquifer linkage suggests that it is less likely that stygofauna species recorded in the proposed pit boundary and Proposal Area are restricted to this area (Biota 2015c). Potential stygofauna habitat and refuge areas within the local catchment are presented in **Figure 76**.

Figure 71 and **Figure 75** show the sequential modelled groundwater drawdown pattern during the life of the Proposal from 2017 to 2032. The peak dewatering period is predicted to occur within the first 6 years of dewatering in which the modelling shows the drawdown cone of depression would extend up to 85m bgl, encompassing the proposed pit area and extending to the mapped southern limit of the CID in the Proposal Area. This drawdown extent is modelled to continue from 2027 to 2031. Stygofauna that have been recorded within this drawdown area are likely to be affected.

While there will be a reduction in suitable habitat for stygofauna within the drawdown cone of depression, there is substantial habitat available within the adjacent alluvium (shallow aquifer) beneath Weeli Wolli Creek and also upstream and downstream both within the CID aquifer and shallow aquifer alluvium. The stygofauna habitat identification (Biota 2015d) was mapped and jointly considered with pre-mining depth to water table (Biota 2015e). This adopted a conservative approach of combining the most prospective geological units (**Table 32**), with areas where depth to water table was less than 40 m bgl. This is shown in **Figure 70**, along with the distribution of all stygofauna records from the Revised Proposal Development Envelope, which demonstrate the habitat mapping aligns with the known occurrence of this fauna.

Figure 70 also overlays the extent of predicted dewatering drawdown for the Proposal on the mapped stygofauna habitat. This illustrates that while sections of habitat in the Proposal Area may be effectively desaturated, equivalent and connected stygofauna habitat both upstream and downstream of the Proposal Area will remain suitable, allowing stygofauna to persist locally in the system over the life of the proposal. Reviews of stygofauna habitat indicate that there are no significant geological or hydrogeological barriers to dispersal within the broader Weeli Wolli – Marillana Creek system (Biota 2015d). This is consistent with both the habitat mapping shown in **Figure 70**, and reviews of the distributions of individual stygofauna species (Biota 2015d). Genetic and morphological determinations of stygofauna species, with representatives from most stygal orders, show that the same species occur within Weeli Wolli Creek and Marillana Creek, from higher in the catchment (e.g. Weeli Wolli Springs) to past the confluence of the two creeks (Biota 2015d, Finston and Johnson 2004). Sections of both Marillana Creek and Weeli Wolli Creek will remain unaffected by both the dewatering of the current Proposal, and that arising from other existing operations such as Hope Downs 1 and BHP's Yandi Operations, effectively representing habitat refugia for the stygal community that occurs within the local catchments (**Figure 76**).

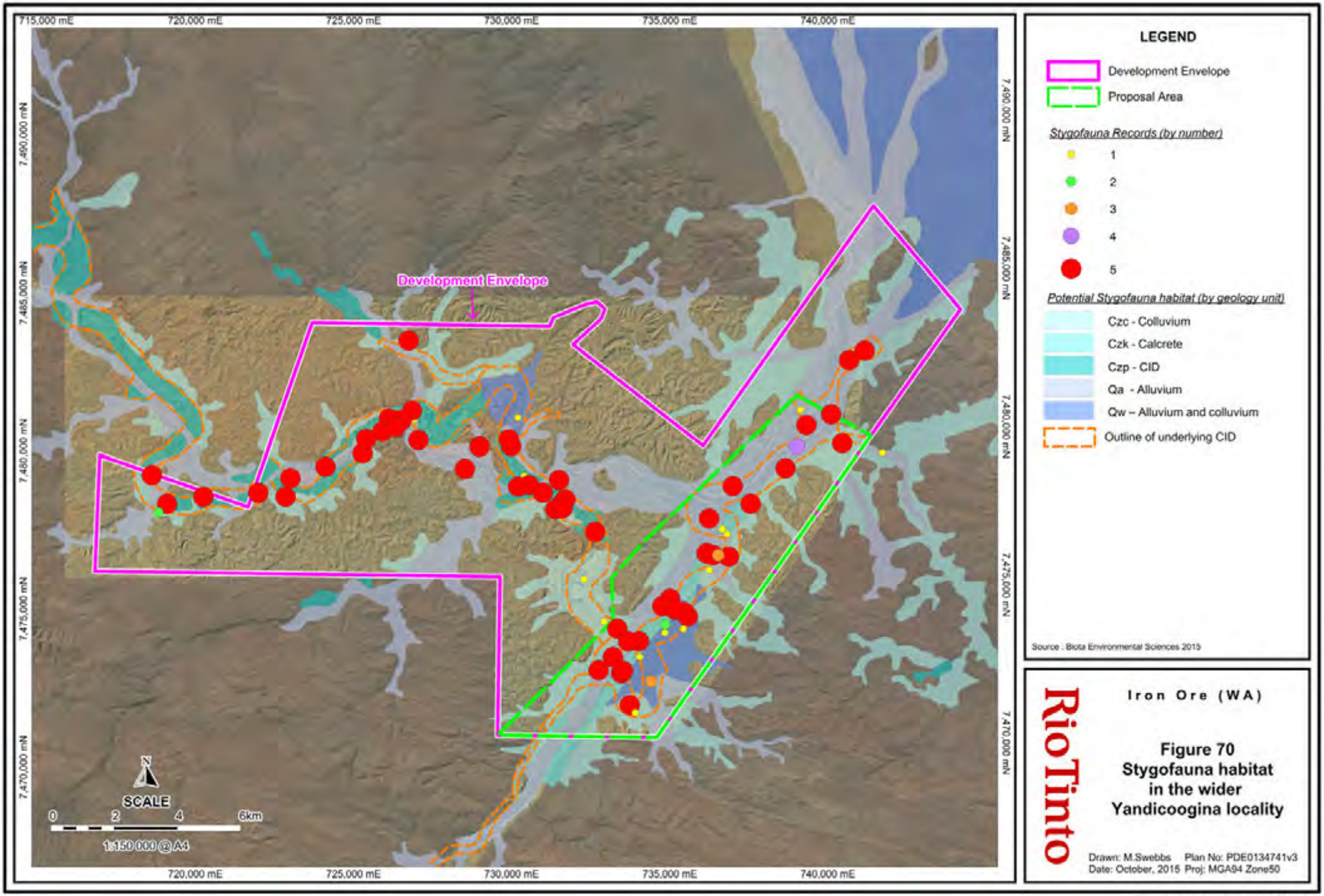
Discharge of surface water from other operations may also serve to offset any impacts from dewatering. While the peak dewatering periods may reduce the ability for stygofauna to move through the Proposal Area, restricting the ability for some dispersal through the groundwater system towards Fortescue Marsh, the continuation of upstream discharge from Hope Downs 1 maintaining flow within the low-flow channel combined with natural seasonal flooding events, is expected to largely reduce this impact. Discharge from DO9 will likely increase the extent of downstream saturation within the alluvial aquifer within the downstream extents of Marillana and Weeli Wolli Creeks and potentially extend the available habitat and dispersal range. During the majority of mining and following cessation of mining activities, it is likely that there will be continual habitat connection upstream and downstream of the Proposal, allowing the ongoing dispersal of the stygofauna. It is considered unlikely that there will be a substantial regional impact to stygofauna (Biota 2015c).

Overland surface water flows into the pit from the east will be diverted through the construction of roads, pit, dumps and via a surface water diversion drain. This construction will potentially reduce localised replenishment and nutrient flows into subterranean fauna habitat, however major flood flows in Weeli Wolli Creek will continue to deliver nutrients to the system.

Water quality monitoring to date at the existing Yandi Operations indicates some minor variation in water quality parameters, however this is considered to be within natural fluctuations and no significant effects on baseline water quality has occurred as a result

of abstraction and discharge activities. Given the abstraction and discharge of water from the Proposal is from the same water source as the existing Yandi Operations, it is expected that there will not be any significant effects on stygofauna due to water quality changes as a result of the Proposal operation.

The post-closure landform will include the development of permanent pit lakes, which will influence the way surface and groundwater inputs are redistributed within and released from the Proposal Area. This could potentially influence aquifer water quality and riparian environments within the Proposal Area and to some extent, downstream. The post-closure landform has been designed to enable periodic flushing of the pit voids, thereby reducing the potential for long term aquifer salinisation and minimising potential ongoing impacts to stygofauna. The post-closure landform is discussed further in Section 17.2.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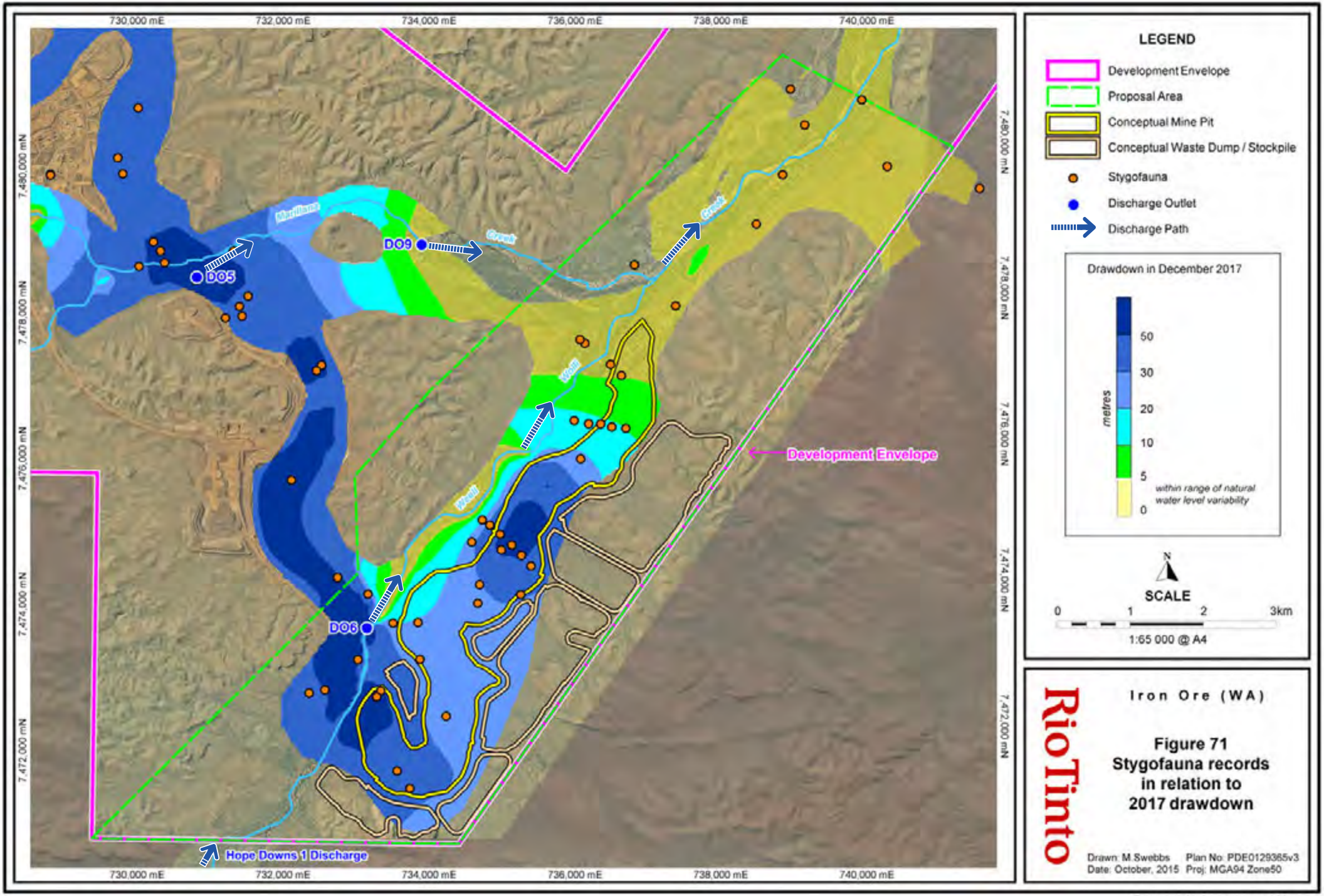
7,475,000 mN
7,470,000 mN
Development Envelope
N
SCALE
0
2
4
6km
1:150 000 @ A4
LEGEND
Development Envelope
Proposal Area
Stygofauna Records (by number)
1
2
3
4
5
Potential Stygofauna habitat (by geology unit)
Czc - Colluvium
Czk - Calcrete
Czp - CID
Qa - Alluvium
Qw – Alluvium and colluvium
Outline of underlying CID
Source : Biota Environmental Sciences 2015
RioTinto
Iron Ore (WA)
Figure 70
Stygofauna habitat
in the wider
Yandicoogina locality
Drawn: M.Swebbs Plan No: PDE0134741v3
Date: October, 2015 Proj: MGA94 Zone50
Geospatial Information and Mapping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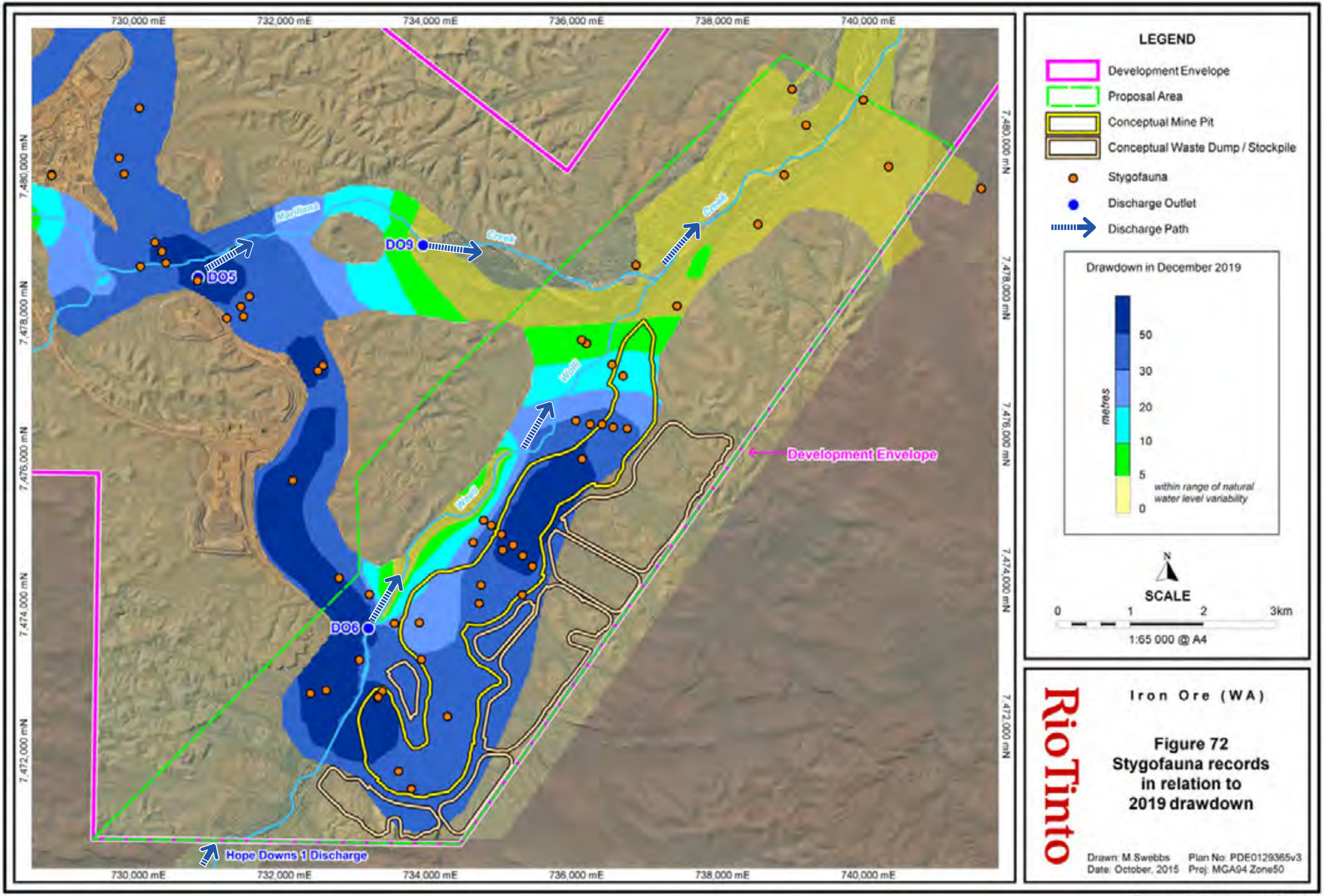
7,474,000 mN
7,472,000 mN
DO5
DO9
DO6
Development Envelope
Hope Downs 1 Discharge
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump / Stockpile
Stygofauna
Discharge Outlet
Discharge Path
Drawdown in December 2017
metres
50
30
20
10
5
0
within range of natural water level variability
N
SCALE
0
1
2
3km
1:65 000 @ A4
RioTinto
Iron Ore (WA)
Figure 71
Stygofauna records in relation to 2017 drawdown
Drawn: M.Swebbs
Plan No: PDE0129365v3
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping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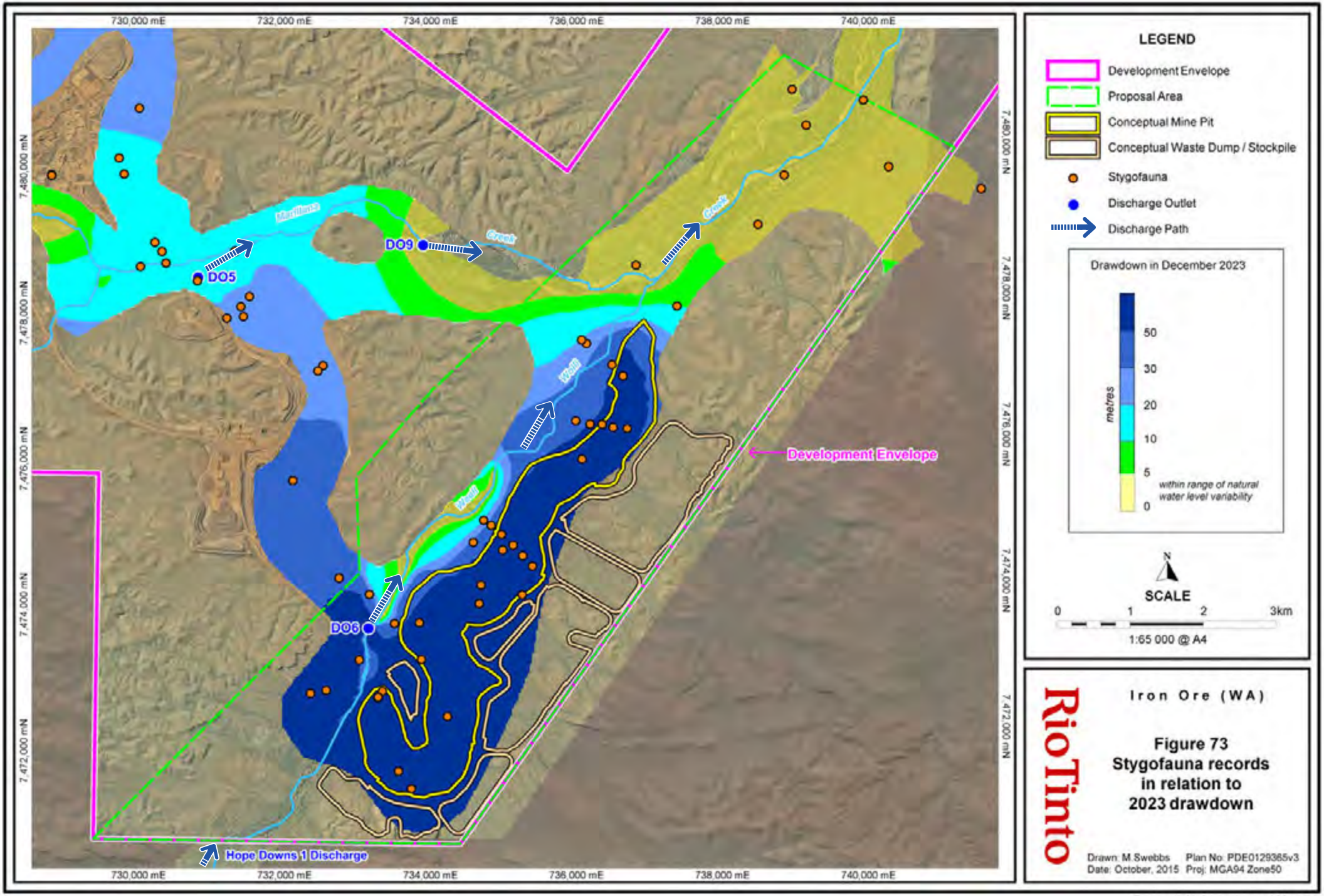
7,474,000 mN
7,472,000 mN
DO5
DO9
DO6
Development Envelope
Hope Downs 1 Discharge
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump / Stockpile
Stygofauna
Discharge Outlet
Discharge Path
Drawdown in December 2019
metres
50
30
20
10
5
0
within range of natural water level variability
N
SCALE
0
1
2
3km
1:65 000 @ A4
Iron Ore (WA)
Figure 72
Stygofauna records in relation to 2019 drawdown
Drawn: M.Swebbs
Plan No: PDE0129365v3
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping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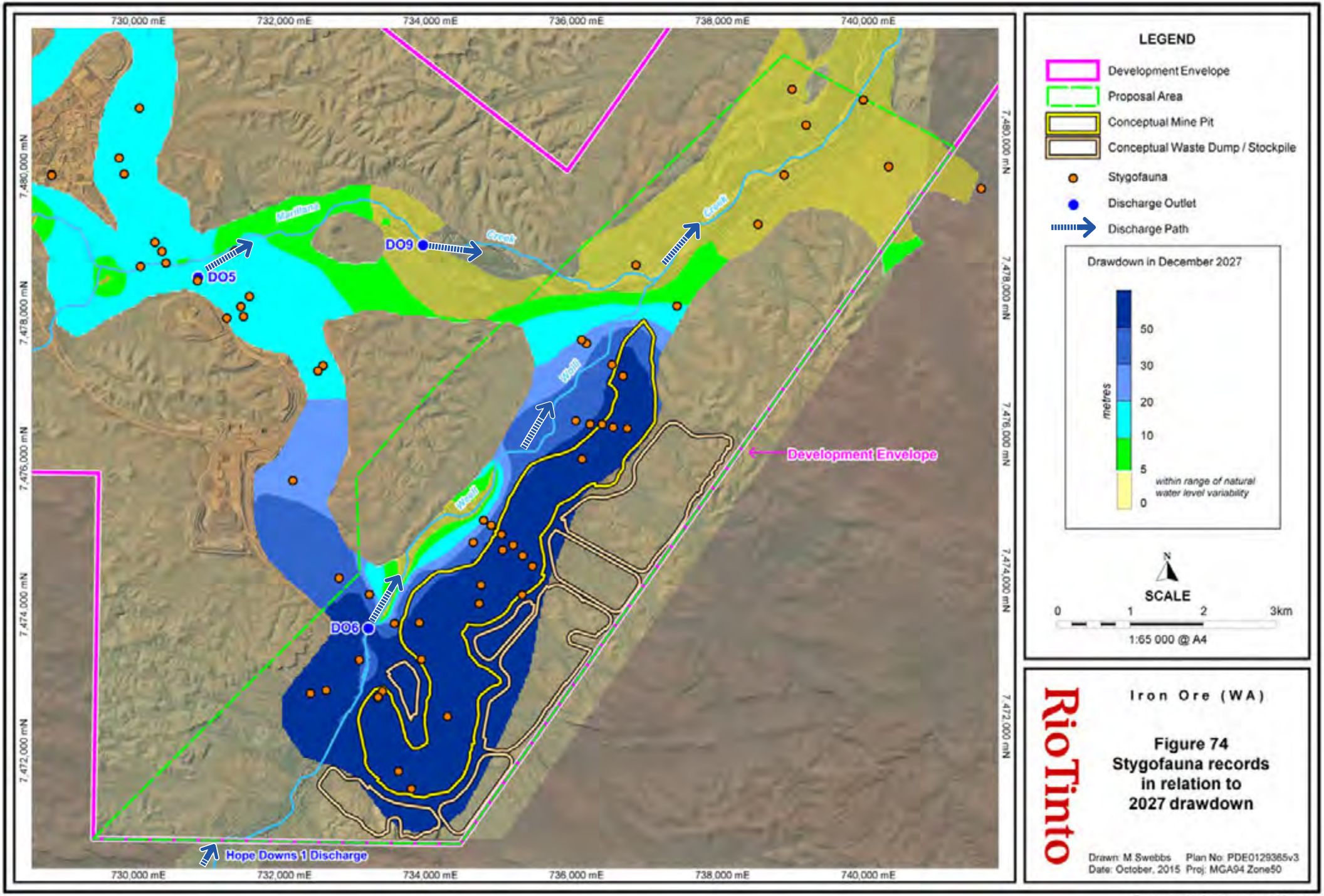
7,474,000 mN
7,472,000 mN
DO5
DO9
DO6
Development Envelope
Hope Downs 1 Discharge
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump / Stockpile
Stygofauna
Discharge Outlet
Discharge Path
Drawdown in December 2023
metres
50
30
20
10
5
0
within range of natural water level variability
N
SCALE
0
1
2
3km
1:65 000 @ A4
Iron Ore (WA)
Figure 73
Stygofauna records in relation to 2023 drawdown
Drawn: M.Swebbs
Plan No: PDE0129365v3
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping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738,000 mE
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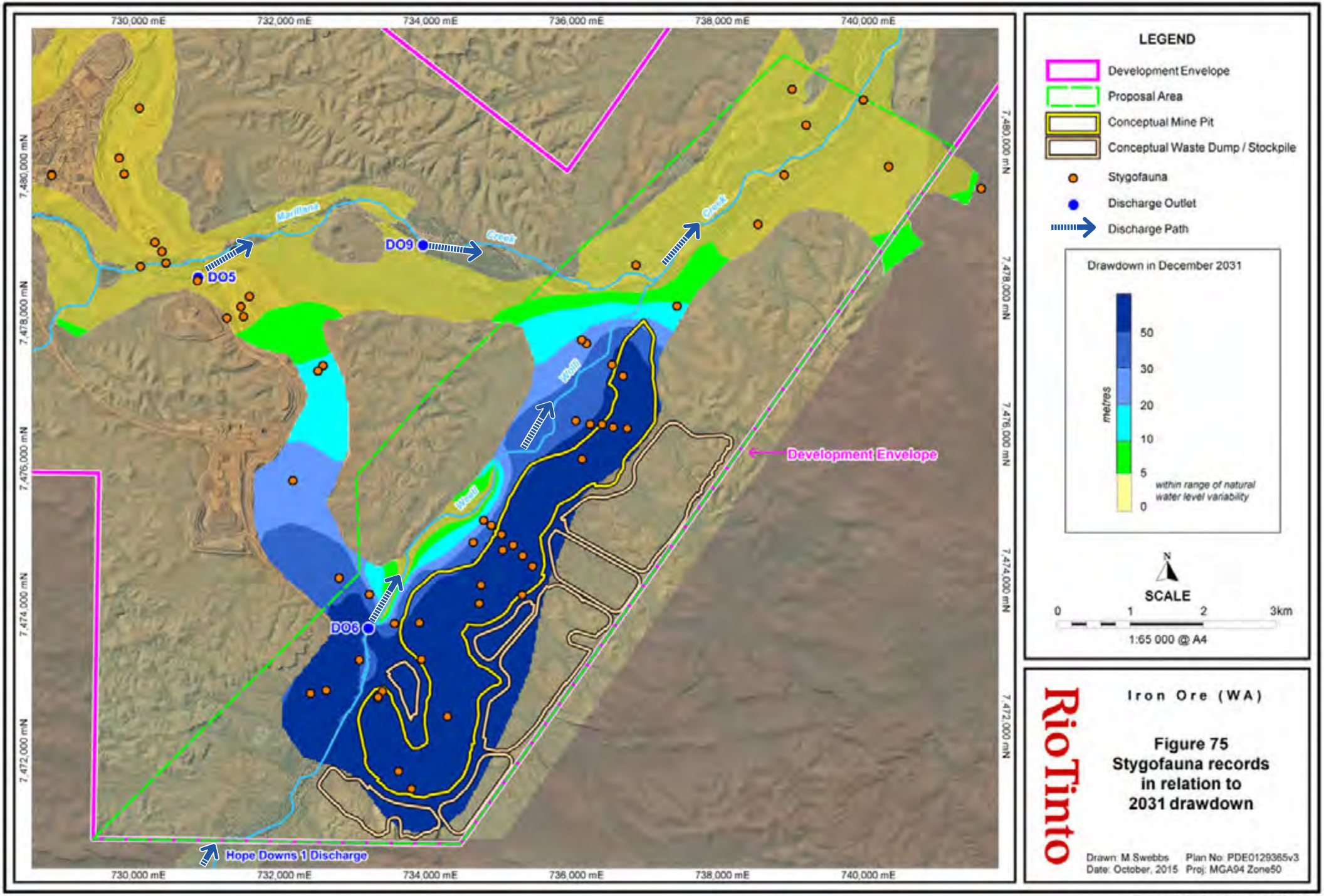
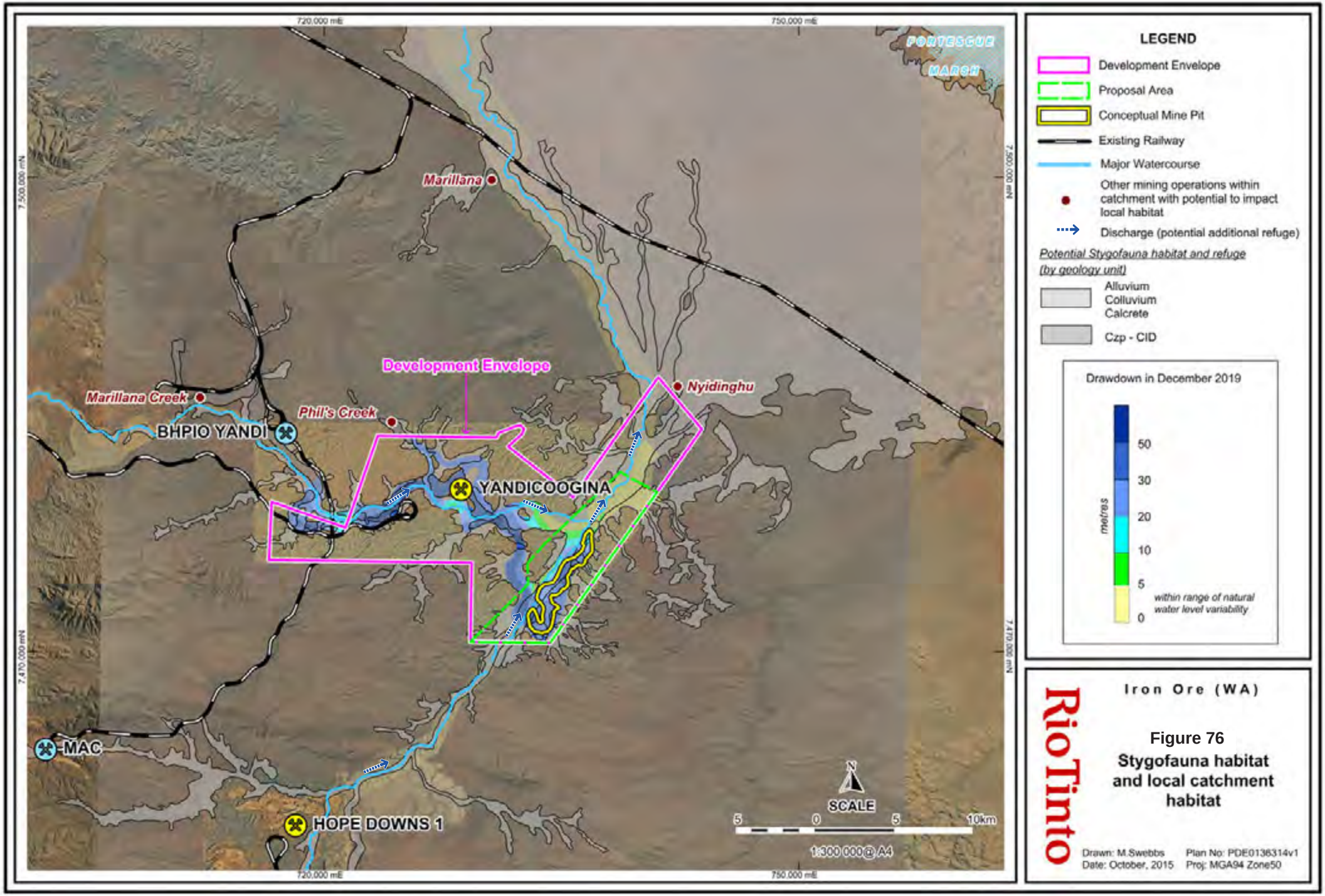
7,476,000 mN
7,474,000 mN
7,472,000 mN
DO5
DO9
DO6
Development Envelope
Hope Downs 1 Discharge
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump / Stockpile
Stygofauna
Discharge Outlet
Discharge Path
Drawdown in December 2027
metres
50
30
20
10
5
0
within range of natural water level variability
N
SCALE
0
1
2
3km
1:65 000 @ A4
Iron Ore (WA)
Figure 74
Stygofauna records in relation to 2027 drawdown
Drawn: M Swebbs
Plan No: PDE0129365v3
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping


730,000 mE
732,000 mE
734,000 mE
736,000 mE
738,000 mE
740,000 mE
7,480,000 mN
7,478,000 mN
7,476,000 mN
7,474,000 mN
7,472,000 mN
Marillana Creek
DO5
DO9
Creek
Wall
Development Envelope
DO6
Hope Downs 1 Discharge
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Conceptual Waste Dump / Stockpile
Stygofauna
Discharge Outlet
Discharge Path
Drawdown in December 2031
metres
50
30
20
10
5
0
within range of natural water level variability
N
SCALE
0
1
2
3km
1:65 000 @ A4
Iron Ore (WA)
Figure 75
Stygofauna records in relation to 2031 drawdown
Drawn: M.Swebbs
Plan No: PDE0129365v3
Date: October, 2015
Proj: MGA94 Zone50
Geospatial Information and Mapping


720,000 mE
750,000 mE
7,500,000 mN
7,470,000 mN
PORTESCUE MARSH
Marillana
Development Envelope
Nyidinghu
Marillana Creek
Phil's Creek
BHPIO YANDI
YANDICOOGINA
MAC
HOPE DOWNS 1
N
SCALE
5 0 5 10km
1:300 000 @ A4
LEGEND
Development Envelope
Proposal Area
Conceptual Mine Pit
Existing Railway
Major Watercourse
Other mining operations within catchment with potential to impact local habitat
Discharge (potential additional refuge)
Potential Stygofauna habitat and refuge (by geology unit)
Alluvium
Colluvium
Calcrete
Czp - CID
Drawdown in December 2019
metres
50
30
20
10
5
0
within range of natural water level variability
Iron Ore (WA)
Figure 76
Stygofauna habitat and local catchment habitat
Drawn: M.Swebbs
Date: October, 2015
Plan No: PDE0136314v1
Proj: MGA94 Zone50

16.4.2 Troglofauna

The excavation of ore and removal of overburden material will result in the direct removal of the habitat for troglobitic fauna. In addition, discharge of additional surplus water from DO9 is likely to broaden the lateral extent and height of perennial flow in the low-flow channel which may increase inundation of some areas of downstream habitats beyond natural seasonal durations.

The only confirmed troglobite specimen recorded from within the proposed pit area was *Myrmopopaea* sp. nov., which was recorded within interconnected calcrete and alluvium formations. These largely interconnected geological formations are located adjacent to, and extend parallel to Weeli Wolli Creek and contain sufficient interstitial spaces and cavities to allow movement of troglobitic fauna. This habitat continuity suggests that the single record of *Myrmopopaea* sp. nov. is likely to occur more widely than the current record and its distribution likely extends beyond the area of impact for the Proposal (Biota 2015d), see **Figure 69**.

The singleton records of *Draculoides* sp. indet (confirmed troglobite) and Pauropoda *s*p. indet. (unconfirmed troglobite) were recorded in calcrete from sites less than 50 m outside the proposed pit area. However, it is considered that these species will not be directly affected, they are likely to occur more widely than the current records, and their distribution is expected to extend beyond the area of impact for the Proposal (Biota 2015d).

Although the primary habitat for troglofauna in the area is currently poorly defined, the CID deposit proposed for excavation in the Proposal Area is located 99% below the water table, and is therefore not suitable for troglofauna habitat. The continuous nature of the alluvium, colluvium and calcrete units indicates that geology is not a limiting factor in the distribution of the taxa currently known from the area of impact for the Proposal (Biota 2015c). The long term persistence of the fauna in the riverine habitat setting of the Proposal Area suggests these habitats are well connected with other older geological units that provide refugia habitat over longer timeframes (Biota 2015d).

16.5 Key management actions

Potential impacts to subterranean fauna values will be mitigated through the implementation of measures described in the Yandicoogina MMP, the Yandicoogina GWOS; the E11 Standard: Water Quality Protection and Water Management; the E15 Standard: Hazardous Materials and Non-Mineral Waste Control and Minimisation; and the Yandicoogina Closure Plan. Key mitigation and management measures are:

- Maintaining viable habitat by maintaining groundwater levels within predicted ranges, including maintaining upstream surface water discharge (perennial flows) during drawdown to partially negate drawdown impacts;
- Maintaining surface water discharge quality by managing erosion and sedimentation; and
- Maintaining groundwater and surface water quality by managing contamination (eg. hydrocarbon spills).

16.6 Predicted outcome

Stygofauna and troglofauna habitat will be affected by implementation of the Proposal. A range of measures have been or will be implemented to reduce potential impacts to subterranean fauna values (**Table 36** and **Table 37**).

Table 36: Mitigation hierarchy for stygofauna values

Mitigation measure	Description
Avoidance	Direct physical disturbance (excavation) to Weeli Wolli Creek floodplain and shallow alluvial aquifer (core habitat) will largely be avoided Weeli Wolli Creek flood flows will be maintained.
Minimisation	Maintain discharge flows/water availability in the Weeli Wolli low-flow channel adjacent to the proposed pit for the duration of mining to partially negate drawdown impacts in the alluvial aquifer. Areas of saturated habitat for stygofauna will be preserved across the Revised Proposal Development Envelope from staged sequence of mining. Water quality, including pollution and salinisation (surplus discharge water quality and groundwater quality) will be maintained and managed in accordance with the Yandi MMP; GWOS; E11 Standard: Water Quality and Protection Standard; E15 Standard: Hazardous Materials and Non-Mineral Waste Control and Minimisation; and the Yandicoogina Closure Plan.
Rehabilitation	Disturbed areas will be rehabilitated consistent with the Yandicoogina Closure Plan. Key functional creek elements retained (e.g. flood pathways, vegetation seed bank) to support natural rehabilitation upon closure.

Table 37: Mitigation hierarchy for troglofauna values

Mitigation measure	Description
Avoidance	Direct disturbance to Weeli Wolli Creek will largely be avoided and low-flow lines will be maintained.
Minimisation	Clearing will be minimised to that required for safe construction and operation. Limited direct impact on creekline alluvial habitat.
Rehabilitation	Disturbed areas will be rehabilitated consistent with the Yandicoogina Closure Plan. Key functional creek elements retained (e.g. flood pathways, vegetation seed bank) to support natural rehabilitation upon closure.

After management and mitigation measures have been applied, it is expected that the Proposal will result in the following outcomes for subterranean fauna:

- Direct mortality and reduction in available subterranean habitats as a result of pit excavation and groundwater drawdown.
- Potential impacts will be localised to the proposed pit area and the groundwater drawdown zone during mining operations. However, it is not expected to significantly impact subterranean assemblages and species persistence.
- The risk of pollutants being transported into the subterranean habitats is likely to be low and restricted to localised areas. There is some risk of aquifer salinisation from the pit lakes after mine closure. This is further addressed in Section 17.2.4.
- The continuous nature of the alluvium, colluvium and calcrete units in which the subterranean fauna were predominately recorded indicates that geology is not a limiting factor in the distribution of the taxa currently known from the proposed pit area and the groundwater drawdown zone within the Proposal Area.

The Proponent considers that there are no significant residual impacts to subterranean fauna that require an offset.

17. Rehabilitation and closure

17.1 Key statutory requirements, environmental policy and guidance

17.1.1 EPA objective

The EPA has applied the following objective for the Proposal to its assessment of rehabilitation and closure:

"To ensure that premises can be closed, decommissioned and rehabilitated in an ecologically sustainable manner, consistent with agreed outcomes and land uses, and without unacceptable liability to the State."

17.1.2 Regulatory framework

Key legislation relevant to the Proposal with respect to rehabilitation and closure includes:

- *Environmental Protection Act 1986* (WA).
- *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth).
- *Contaminated Sites Act 2003* (WA).
- *Iron Ore (Yandicoogina) Agreement Act 1996* (WA).
- *Mining Act 1978 (WA).*

A more comprehensive list of legislation and closure obligations for the Proposal are set out in the Yandicoogina Closure Plan (**Appendix 4**).

17.1.3 Relevant guidelines and policy

The DMP and EPA have issued the *Guidelines for Preparing Mine Closure Plans – May 2015* (referred to herein as Closure Guidelines) which establish standards for closure plans being submitted to Government (DMP and EPA 2015). The *Mining Act 1978* (WA) has been amended to specifically require closure plans that comply with the Closure Guidelines to be submitted with mining proposals, and reviewed on a three-yearly basis. For projects subject to State Agreements rather than the Mining Act, such as the Proposal, the EPA will expect compliant closure plans to be submitted as part of the assessment under Part IV of the EP Act.

The following regulatory position and Guidance Statements set the framework for the management of rehabilitation and mine closure for the Proposal:

- Guidelines for Preparing Mine Closure Plans – May 2015 (DMP and EPA 2015).
- EPA Guidance Statement No. 6: Rehabilitation of Terrestrial Ecosystems (EPA 2006).
- Strategic Framework for Mine Closure (ANZMEC and MCA 2000).
- Mine Closure and Completion (DITR 2006a).
- Mine Rehabilitation (DITR 2006b).

17.2 Description of rehabilitation and closure

17.2.1 Mine Closure Plan

A Closure Plan for the existing Yandi Operation was approved by OEPA on 23 January 2015, in accordance with the existing decommissioning and rehabilitation condition (Condition 9) within MS 914. This Closure Plan has been updated, consistent with the

Guidelines for Preparing Mine Closure Plans (DMP and EPA 2015), to detail the closure requirements for the Proposal Area.

The updated Yandicoogina Closure Plan (**Appendix 4**) provides an integrated closure vision for the entire Yandicoogina mine lease, consistent with the agreed closure objectives:

(1) rehabilitated landforms are stable and designed to manage floodwater appropriately;

(2) the environmental and cultural heritage values associated with creek flows and function are maintained post-closure;

(3) environmental values of Fortescue Marsh are not compromised;

(4) water quality within pit lakes support natural ecosystems and are compatible with post-mining land use;

(5) alluvial groundwater systems support remnant phreatophytic vegetation;

(6) final landforms are rehabilitated to be compatible with post-mining land use; and

(7) public safety hazards have been addressed.

Closure completion criteria to support the closure objectives have been recommended within the Yandicoogina Closure Plan. The completion criteria include processes, evidence and metrics to assess:

- erosion of the constructed landforms;
- preservation of surface water hydrological regimes, considering flow volumes, levels and quality;
- pit lake salinity;
- groundwater salinity;
- phreatophytic vegetation health; and
- prevalence of invasive species in rehabilitated areas.

These completion criteria will be refined based on information developed during implementation of the Proposal, from baseline studies and rehabilitation trials. The completion criteria will also evolve and grow as the expectations of the stakeholders and probable environmental outcomes are clarified.

Post-closure, environmental and other site management activities will continue until it is determined that the closure objectives have been met or it is otherwise agreed with Government to allow relinquishment of the site.

The volume of overburden and waste material generated by implementing the Proposal is relatively low compared to the volume of ore extracted. As a consequence, there is insufficient overburden and waste material available to backfill into the pit to cover the groundwater table on closure. Proximity to Weeli Wolli Creek is also an important consideration in development of the closure. Removal of the flood protection levee of closure will reduce the stressors on the riparian floodplain vegetation, but will also enable flood water to interact with the final mine void.

The proposed closure strategy, described within the Yandicoogina Closure Plan, has been developed in consideration of the closure objectives and proposed mine activity, to create a safe, stable, non-polluting landform that supports a native ecosystem. A conceptual design of the post-closure landform for the Proposal Area is presented in **Figure 77**.

The closure strategy includes the development of a native, self-sustaining wetland ecosystem within the final mine void. The wetland ecosystem will comprise two groundwater dependent pit lakes located in the Weeli Wolli Creek floodplain, away from the low-flow channel of Weeli Wolli Creek proper. On closure, the available overburden and waste materials will be utilised to stabilise the pit walls adjacent to the floodplain and to create a spillway that will facilitate flood water ingress into the final mine void during the peak of large flood events. The spillway will be engineered to minimise erosion as floodwater flows into the lake system.

Once the groundwater table recovers, the pit lakes will have an average water depth of 35 m to 45 m, storing approximately 80 GL of water. During significant flood events, when the spillway activates, the lakes will combine and can hold an additional 70 GL of flood water, increasing water depth by 60 m to 70 m. The maximum total storage capacity of the mine void is approximately 150 GL, beyond that capacity the water will overtop the northern tip of the mine void and will be returned to the Weeli Wolli Creek floodplain.

17.2.2 Mineral waste geochemical characterisation

Static geochemical tests have been conducted on all waste types, with more comprehensive sequential leach and kinetic tests undertaken to confirm that materials had indeed low geochemical risk. All tests were conducted in accordance with the *Global Acid Rock Drainage (GARD) Guide.*

No sulphides, the primary source of acid drainage issues, have been identified in the host geology or mineral waste at Yandicoogina. The total sulphur concentration of the 99th percentile of all sampled processed ore and waste at Yandicoogina is less than 0.02%, suggesting the overall acid rock drainage risk is low to nil.

In the Proposal Area, mineral waste will be returned to the mine voids, where it will form part of the groundwater aquifer. Post-closure, groundwater will flow from the existing aquifer systems, through the mineral waste aquifer, into pit lakes and, where not lost to evaporative processes, will flow back into the groundwater aquifer beneath the Weeli Wolli Creek floodplain. Tailored sequential extraction and submerged column test work are being conducted to understand how water quality may change as a consequence of these interactions.

Standard leach tests conducted on waste rock and waste fines presented circum-neutral pH values between 6.5 to 8.5 and EC values of around 650 µS/cm for waste rock and 70 µS/cm for waste fines, regardless of test conditions. Sequential extraction test work demonstrated that trace elements like arsenic, selenium and antimony are incorporated in the crystalline structure of iron oxides and silicates resulting in a reduced potential for these elements to be released. The potential for contaminant release under slightly alkaline and saline conditions are currently being investigated.

Saline drainage conditions are anticipated to evolve at Yandicoogina post-closure. Based on preliminary lab test results, alkaline conditions may occur for very limited periods of time, e.g. during prolonged drought periods, but are not expected to be sustained over

the long term. Ion exchange reactions and the release of contaminants under saline conditions are expected to be limited due to the combined effects of the sorption capacity of iron and aluminium oxides and low mineral solubility expected to occur under neutral pH conditions.

Readily detectable elements within the waste rock included the major elements Ca, Mg, Na, K, Cl, Si and SO4 and the trace elements Al, B, Ba, F, Fe, Sr and Zn. The highest concentrations of elements were recorded in the low contact ratio leach tests. The majority of the elements were source term limited, such that low masses were present in the samples and would be completely dissolve during the test. The test work also indicated that elements Al, Ba, F and Si may be solubility controlled.

The characteristics of the waste fines materials are similar to the waste rock, with the exception that low contact ratio leach tests contained low but detectable concentrations of Cd, Cr, Cu, Pb, Mn and Ni. These elements were not detected in the 2:1 L:S leach.

17.2.3 Mineral waste physical characterisation and waste landforms

Mineral waste generated at the site consists largely of overburden material and CID fines. Characteristics of the material are summarised as presented in **Table 38** and **Table 39**.

Table 38: General properties of the alluvial overburden material at Yandicoogina

pH	$EC_{1:5}$	$EC_{1:2}$	ESP	Potentially Dispersive	Exchangeable Cations (m.eq./100g)					ECEC
(-)	(dS/m)	(dS/m)	(%)		K	Ca	Mg	Na	Al	
6.5	0.02	0.04	3.1	No	0.42	1.85	0.82	0.1	0	3.2

Table 39: Particle size distribution of the alluvial overburden material at Yandicoogina

Rock >45mm (%)	Pebbles 22-45mm (%)	Gravel 2-22mm (%)	Fine Fraction <2mm (%)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
1	0	18	81	40	44	4	12

The majority of the mineral waste is expected to be of high erodibility, and will require conservative landform design parameters (e.g. batter angles of 20 degrees, in 5 m lifts with 10 m berm widths) to be used in order to create stable slopes.

All mineral waste in the Proposal Area will be returned to the mine void on closure, where it will be used, primarily, to buttress (strengthen) the pit wall that intersects Weeli Wolli Creek floodplain. This same strategy will be implemented in the event of unexpected closure.

The design of the buttress will evolve over the life of the mine, in consideration of the shape of the final mine void, associated geotechnical stability and location of progressive backfill. The conceptual design for the buttress, is presented in **Figure 77**, includes:

- An in pit waste slope that extends from the pit floor to the pit crest at an angle of 20 degrees, in 5 m lifts with 10 m berm widths widths (commensurate with the mineral waste material properties); and
- A spillway and central island used, in combination, to control floodwater from Weeli Wolli Creek floodplain as it flows into the lake areas. The design will

minimise erosion inside the mine void and within Weeli Wolli Creek floodplain, to maintain the integrity of the Weeli Wolli Creek hydrological regime.

As discussed in Section 4.2.5, the existing in pit waste fines cells at JSE will be used for the disposal of waste generated by wet processing. Mineral waste will be used to cover the waste fines cell and raise the surface to above the long term projected groundwater elevation.

Monitoring and, if required, corrective actions will be undertaken to ensure erosion does not threaten the long term stability of the landform. Erosion monitoring will include visual and measured assessments of rill and gull formation over time. Flow over the spillway will also be monitored, to validate the spillway function.

17.2.4 Post-closure water quality

Groundwater recovery in the Proposal Area is predicted to occur within a few decades. As the groundwater table recovers, permanent lakes will be established in the Proposal Area mine voids.

Once the groundwater table is recovered, and the system reaches steady state conditions, these pit lakes are expected to have an average depth of 35 - 45 m, 20 m below the pit crest, with a surface area of 2 - 4 km^2 (depending on the final buttress design), storing approximately 80 GL of water. The lake geometry suggests the lake water column will be fully mixed, however, density driven flow may occur during long dry periods.

Although the pit lakes will be groundwater dependent, the lakes are expected to receive flood water when the Weeli Wolli Creek floodplain activates. These flood events will deliver nutrients and aquatic fauna/flora to the lakes, but will also result in rapid increases in the lake water levels. Three times in every 200 years, Weeli Wolli Creek is predicted to flood with such magnitude that the mine void, which has a maximum storage capacity of approximately 150 GL, will be completely filled with flood water. The mine void will overtop via the northern point of the pit, contributing flow back into Weeli Wolli Creek floodplain. During these events, salts and nutrients will be flushed from the pit lakes. The volume of overtopping water will be very small relative to the volume of the water flowing down Weeli Wolli Creek during these flood events; and as a consequence, the salts and nutrients are not expected to have a measurable impact on Weeli Wolli Creek water quality or, by extension, the downstream Fortescue Marsh.

A preliminary stochastic water balance model has been developed, based on the conceptual buttress landform and using estimated aquifer parameters, to predict how water levels (**Figure 78**) and salinity may change over time. The stochastic modelling showed that the pit lake water quality will be strongly influenced by the future climate conditions. The modelling suggests that, over a 1,000 year period, salinity is likely to follow an increasing trend. During periods of simulated prolonged drought, when water levels dropped to their lowest levels, up to 11,000 mg/L salt was modelled. However, during simulated wet periods, salinity could also be reduced to as low as 200 mg/L salt. The stochastic model suggests there is a 50 percent probability that after 75 years pit lake water salinity would still be fresh (<1000 mg/L), and that after 1,000 years there was a 50 percent probability that the average annual salinity would be 3,000 mg/L or less.

The stochastic water balance also shows that during periods of drought, resulting in high salinity, the pit lake water levels drop below downstream groundwater levels. When this occurs, the lake system will stop functioning as a through-flow system, and revert to groundwater ‘sink’. Lake water levels and water quality are not expected to be restored to

average until the next large magnitude flood event, when the salts will be flushed out of the lake during the overtopping and water quality salinity will be reduced.

The stochastic water balance suggests that the average downstream groundwater flow contribution from the pit lakes could be around 0.1 GL per year to the aquifer under Weeli Wolli Creek. This represents less than 10 percent of the upstream groundwater inflow into the pit lakes and significantly less than 10 percent of the total aquifer flow. The quality as it enters the groundwater aquifer is expected to be similar to that of the pit lakes, which will be saltier than the groundwater aquifer. This saltier water is expected to be denser than the downstream groundwater aquifer, and is unlikely to move towards the surface or interact with the environment.

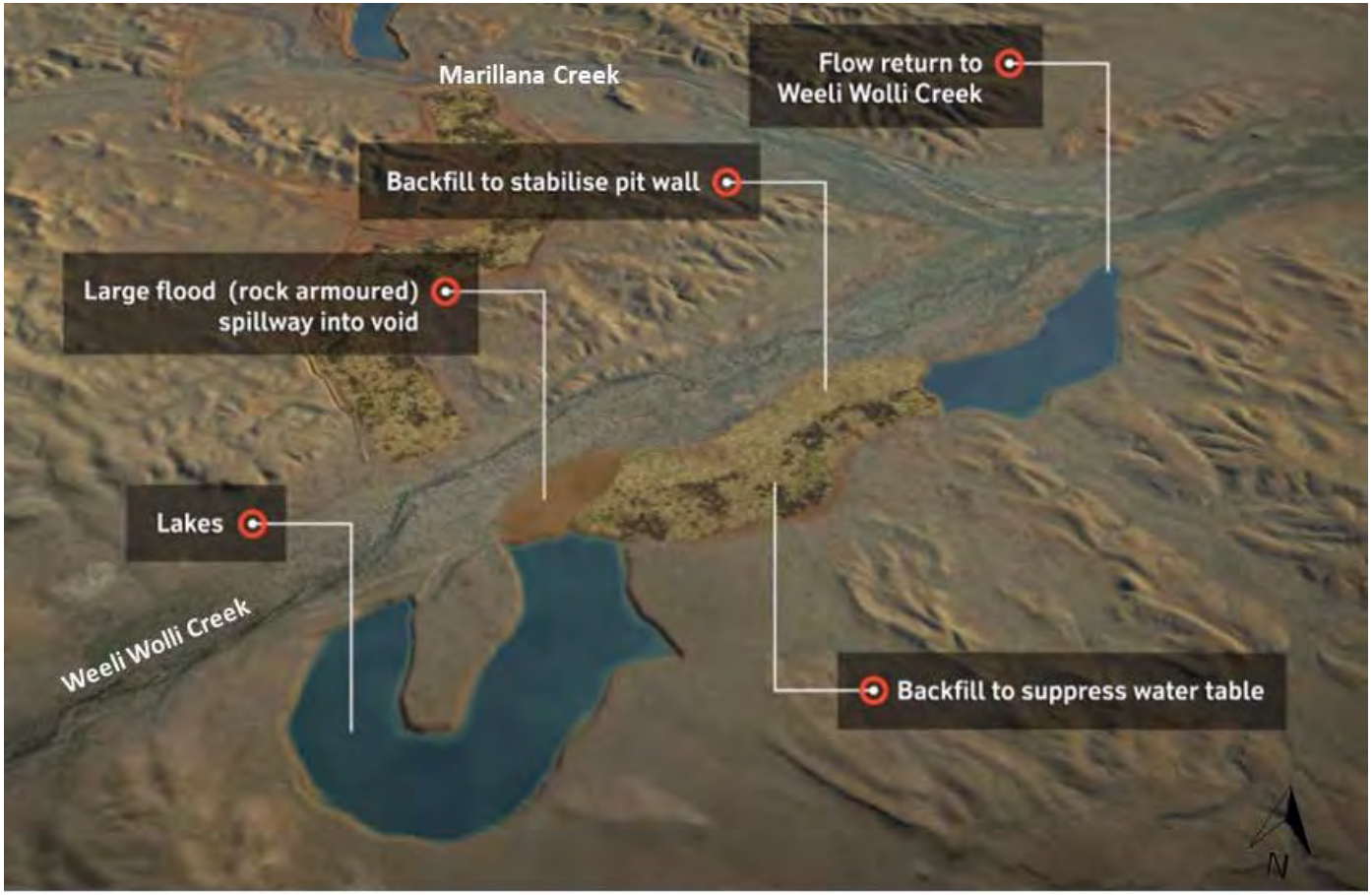


Figure 77: Post-closure landform of the Proposal

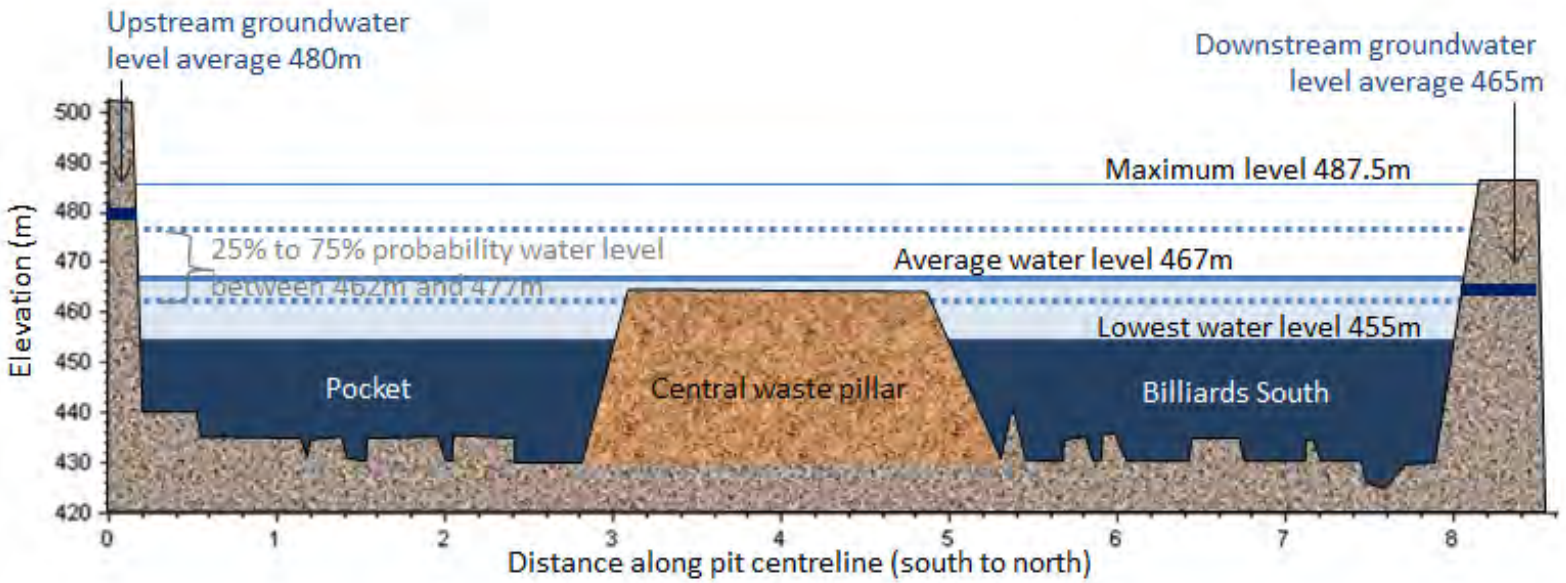


Figure 78: Proposal proposed pit lake cross-section

Rehabilitation strategies

17.2.4.1 Desktop Assessment of Rehabilitation

Rio Tinto has developed practice standards for rehabilitation, as described in the following standards:

- Iron Ore (WA) Rehabilitation Management Plan.
- Iron Ore (WA) Landform Design Guidelines.

The rehabilitation performance of Pilbara geologies and ecosystems that are similar to the Proposal Area were assessed via a desktop assessment to determine if Rio Tinto's standard practice would enable the Proposal's closure objectives to be met (**Table 40**; **Appendix 4**). The assessment was undertaken by comparing key indicators of rehabilitation success against benchmarks established in adjacent reference/control sites for different disturbance types, including:

- created landforms, e.g. the mineral waste buttress proposed to be developed within the mine void;
- long term disturbance areas, e.g. laydown areas, permanent facilities;
- short term disturbance areas, e.g. borrow pits and access tracks; and
- linear and fragmentation disturbances, e.g. road and powerlines.

Table 40: Examples of rehabilitation success across Rio Tinto's Pilbara operations

Rehabilitation Type	Key Similarities to the Proposal	Examples Reviewed	Applicability to Proposal
Created landforms (e.g. waste rock dump)	Channel Iron Style Deposit Detrital Ion Style Deposit	Mesa J Waste Dump S, Waste Dump T Brockman 2 Pit 2 Waste Dump	Rehabilitated mineral waste slopes within the pit area that are well above the water table
Short term disturbances (e.g. borrow pits and access tracks)	Minor earthworks in top few metres of the profile (topography), disturbed and rehabilitated in short time frames, minor earthworks in top few metres of the profile (topography),	Yandi Borrow Pits 363,374 & 417 Hope downs 4 Haul roads, Borrow Pits, Power Line & Railway construction rehabilitation	Borrow pits, access tracks
Long- term disturbances (e.g. construction camp, permanent accommodation villages)	Minor earthworks in top few metres of the profile (topography), generally flat areas, disturbed and rehabilitated in longer time frame	Yandi Landfill (disturbed for 3 and a half years prior to rehabilitation) Mesa A Fixed Plant	Laydown yards

Linear and/or fragmentation disturbances (e.g. roads, powerlines, bore fields)	Considered as similar to the short term disturbances – Minor earthworks in top few metres of the profile (topography), minor earthworks in top few metres of the profile (topography),	As per the short term disturbances examples	Roads, power lines

Created landforms are considered to be the most challenging areas to rehabilitate. Created landforms that will be developed as part of the Proposal's post-closure landform include rehabilitated slopes, associated with decommissioned infrastructure, and the development of the in pit buttress landform. There have been limited opportunities to undertake rehabilitation of created landforms at the existing Yandi Operations, as these features are used or modified as part of daily activities, e.g. in pit waste dumps are still under construction. However, mineral wastes with similar material type properties have been rehabilitated using the Proponent's standard practice at other Rio Tinto managed operations and provide a means of assessing expected rehabilitation performance for the Proposal Area (details are provided in **Appendix 4**).

In accordance with Rio Tinto's standard practice, created landforms and long term disturbances are rehabilitated by:

- considering the local climate conditions and physical properties of the soil and mineral waste properties when designing slopes;
- shaping the built or disturbed landform to blend with the surrounding topography;
- applying topsoil and salvaged vegetation, when available; and
- ripping along the contour then seeding.

Rehabilitation of the Dump S overburden waste dump at Robe River's Pannawonica Operation (a CID style deposit) was completed in 2001. Rehabilitation monitoring shows good perennial species diversity with 13 species present, which exceeds the slope benchmark of seven species. The lower storey vegetation, although present, was slow to develop and currently represents a very small proportion of the total cover. The cover composition differs across the rehabilitation area, and thus is slightly different to the reference sites. However, total plant cover percentages and density values are within or above the range exhibited within the reference sites, and rehabilitation is considered to be on track to provide a stable, native and self-sustaining ecosystem with habitat for native fauna present.

Overall, the Proponent's standard rehabilitation practices are considered sufficient to meet the Proposal's closure objectives for general created landforms, long term disturbance areas, short term disturbance areas and linear/fragmented disturbance area.

However, no rehabilitation activities have been completed adjacent to open water bodies on Rio Tinto managed operations, such as those proposed to be developed within the mine void post-closure (**Table 41**). These landforms, which form part of the dynamic wetland environment, will incorporate soil and water interactions that do not occur naturally in the neighbouring environment; although similar landforms are expected to be constructed throughout the Weeli Wolli Creek catchment as part of the existing Yandi Operations, and other mining company closure strategies.

Table 41: Rehabilitation types and gaps in knowledge

Rehabilitating Type	Applicability to Yandi	Knowledge Gaps
Created Landforms - backfilled alluvial waste that forms the pit lake fringes	Pit lake built edges (excludes pit walls)	• Landform design that will ensure alluvial materials will form stable slopes with undulating water levels. • Surface treatments required (if any) to enable vegetation growth and slope stability (eg. mulch, ripping, armouring, topsoil alone or rehab into alluvial materials with no treatment). • Species selection (what species will establish and grow with increased soil moisture, wet roots and survive with undulating water levels). • Species selection that are applicable to changing quality of water levels (increasing salinity and then flushes of fresh water).
Created Landforms - tailings storage facilities	In pit Tailings Storage Facility	• Landform design – particularly if capping is required and how much. • Species selection (what species will establish and grow with the growth medium which could be tailings and no capping, differing amounts of capping and topsoil).
Created Landform - backfilled pit large flat plains built of alluvial material	The backfilled pit areas that exist between the pit lakes	• Landform design to support stability and vegetation growth (e.g. gentle undulating peaks and troughs or very slight angle for drainage or completely flat). • Species selection (what species are best suited to flat alluvial areas that may be infrequently inundated).

The Proponent recognises the importance and challenges associated with creating these unusual habitats. In response, the Proponent has initiated research programs and rehabilitation trials, as described in the Yandicoogina Closure Plan, to investigate:

- how local creek species germinate, establish and grow in response to groundwater changes when grown in mineral waste (growth media);
- whether these species thrive post-germination with variable access to the groundwater table;
- which plant species combination(s) ensure wetland and floodplain vegetation communities are self-sustaining;
- what landform shapes support lake littoral zone development and other niche habitats; and
- what management is required to ensure water quality in the recovering lakes remain non-toxic and promotes ecosystem development.

The wetland rehabilitation trial at the existing Yandi Operations, which commenced in 2014, is an example of the ongoing research. This trial will establish how common Pilbara plant species of local provenance grow on sheltered lake fringes. The trial is being conducted on slopes created from mineral waste located on top of the exposed groundwater table, similar to the post-closure pit lake environment. Monitoring equipment has been installed to monitor moisture and temperature down the soil profile as the plants grow. The performance of mineral waste slope batter angles of 20 degrees and 10 degrees will also be reviewed as part of the study.

17.2.4.2 Rehabilitation Activities Undertaken to Date

Yandi Operations have completed 86 ha of rehabilitation since 1998. Rehabilitation opportunities have been limited as the majority of the disturbed areas are actively utilised as part of daily mining activities. Completed rehabilitation comprises of a small waste dump, numerous borrow pits and construction related rehabilitation, exploration related rehabilitation and completed landfill sites.

Borrow pits associated with the railway at the existing Yandi Operations were rehabilitated in the second half of 1998. In accordance with Rio Tinto's standard practice (applicable for short term disturbance and linear infrastructure) the borrow pits were rehabilitated by:

- re-shaping the disturbed area, where required, to ensure it is free draining and blends with surrounding topography;
- replacing stockpiled topsoil and salvaged vegetation; and
- ripping along the contour (no seed applied).

Monitoring completed in 2013 show that vegetation communities have similar number of species, plants per quadrant and percentage of perennial cover when compared to reference sites (**Table 42**), and are on target to achieve the closure objectives. Differences between the rehabilitated areas and reference sites are believe to result from changes to the vegetation communities after a bushfire. There is no evidence of erosion in any of the borrow pits.

Table 42: Selected monitoring results of the Borrow Pit rehabilitation areas and reference site values (shown in brackets).

Borrow Pit	Age of Rehabilitation (years)	Number of Species (Rehab)	Plants per Quadrant	% Perennial Cover	Summary
BP363	14	7 (8)	4.3 (4.2)	45 (64)	Site continues to compare favourably with the reference site
BP374	14	7 (13)	5.6 (20.3)	55 (53)	The 2007 burn in the reference site significantly changed a number of key parameters, making comparison of the two sites difficult. Overall, site is developing well.
BP417	14	7 (7)	3.3 (13.3)	49 (31)	Vegetation communities exhibiting similar trends to reference sites prior to a fire in 2010. Different trends apparent after fire. Overall, site is developing well.

17.2.4.3 Planned Progressive Rehabilitation at Yandicoogina

In 2017, the first substantive area of disturbance not required for future operational use is expected to be available for rehabilitation (subject to confirmation). Detailed rehabilitation designs for this area are expected to be included in the next update to the Yandicoogina Closure Plan.

17.2.5 Post-mining land use

Rehabilitation undertaken outside of the mine void is expected to be compatible with the pre-mining and adjacent (current) cattle grazing pastoral activities. However, the volume of overburden and waste material generated by implementing the Proposal is relatively low compared to the volume of ore extracted. As a consequence, there is insufficient overburden and waste material available to backfill into the pit to cover the groundwater table on closure or reinstate the natural surface, resulting in the creation of permanent pit lakes post-closure.

The mine void and resulting post-closure wetland, the pit lakes and the associated lake fringe proposed to be developed in the mine void of the Proposal Area, may not be compatible with cattle grazing pastoral activities. Alternatives to cattle grazing, for the created wetland, are under investigation in consultation with relevant stakeholders (including Pastoral Stations and Aboriginal Traditional Owners). Until an alternate land use is agreed for the pit lake areas, the Closure Plan has been prepared to ensure the area remains compatible with general Pilbara land uses, by:

- designing landforms that are stable for access by humans and native fauna;
- ensuring the water systems support existing riparian vegetation and are compatible with the natural system dynamics; and
- planning for a wetland ecosystem created from native vegetation that is compatible with the surrounding environment.

17.3 Assessment of potential impact, mitigation and residual impact

The impacts created by implementing the Proposal (beyond those generated by the existing Yandi Operations) include the loss of vegetation and habitat, soil disturbance, changes to the natural landforms and drainage features, and a lower groundwater table.

17.3.1 Post-mining land use

The values and constraints of the surrounding physical and biological environment need to be considered when selecting appropriate land use options for the Proposal Area post-mining. Heritage requirements and agreements with native title claimants, and other socio-economic aspects of the Proposal must also be taken into account.

Rehabilitation undertaken outside of the mine void is expected to be compatible with the pre-mining and adjacent (current) cattle grazing pastoral activities. However, the mine void resulting from implementation of the Proposal is not compatible with the pre-mining land use of cattle grazing pastoral activities. Other potential impacts could include unstable landforms, altered hydrology, changes to water chemistry, contamination and/or limited return of the native ecosystems.

17.3.2 Hydrological processes and inland environmental water quality

Groundwater modelling studies indicate that aquifer recharge and through-flow are important processes for maintaining water quality (principally low salinity), particularly for the Proposal.

The post-closure landform including the development of permanent pit lakes may influence the way surface and groundwater inputs are redistributed within, and released from, the Proposal Area. This in turn could influence aquifer water quality and riparian environments within the Proposal Area and to some extent, downstream. There is a risk that inappropriate landform design could result in increased salinity within the adjacent

aquifers, increased sediment load within the adjacent drainage network and subsequent ecosystem degradation.

Water quality will vary over time, depending on the different interactions between the groundwater source, surface water systems, the water levels, climatic conditions and whether groundwater or surface water can exit the pit lakes.

17.3.3 Vegetation

Disturbed areas, excluding the pit walls and pit lake water body, will be revegetated using locally occurring native species. The design of the final landform will influence its suitability for establishing particular vegetation communities and its long term persistence. Key factors include:

- Providing stable landforms with infiltration and runoff characteristics that support vegetation growth, reproduction and vegetation succession.
- Soil profiles with adequate water holding capacity and physiochemical characteristics, to enable plant root system development and access to water and nutrients.
- Minimising exposure to water quality conditions which may not support local vegetation, for example extremes of soil pH, salinity and exposure to toxic metal ions.
- Developing vegetation communities suited to the changed (wetland) environments.

Inappropriate landform construction may affect the rehabilitated area's ability to support native vegetation and meet revegetation completion criteria. Poorly designed and/or poorly implemented rehabilitation could also result in suboptimal vegetation re-establishment and increased numbers of weed species. Topsoil handling and storage practices are important for maintaining seed viability and enhancing rehabilitation success.

17.3.4 Fauna

17.3.4.1 Terrestrial Fauna

The final landform will be gradually recolonised by native fauna. The ability of fauna to use the area will be influenced by landform components and configurations, with some species being favoured and others disadvantaged. Inappropriately constructed habitat could lead to poor habitat use or favour undesirable species, such as feral animals.

17.3.4.2 Subterranean Fauna

Mining activities will result in the removal of subterranean habitat. The design of the post-mining landform will influence the amount of habitat retained in the Proposal Area, for the persistence of stygofauna assemblages post-mining. Factors that could detract from reinstating suitable habitat include:

- reduction of void space within the alluvials due to silt and sediment runoff from surrounding habitat;
- the development of saline pit lakes and saline groundwater aquifers;

- nutrient enrichment derived from the surface infiltration, e.g. due to a lack of buffering vegetation; and

- hydrology changes.

Aquatic fauna in Weeli Wolli Creek may also be impacted a result of changes to the hydrology of Weeli Wolli Creek system, development of a permanent pit lake and water quality (including salinity and nutrient enrichment).

17.3.5 Aboriginal Heritage

The post-mining landform could affect the accessibility of heritage sites and the ability of the Traditional Owners to use the Proposal Area for cultural and amenity purposes. These uses require safe and stable landforms that are suitably integrated with the wider landscape and environment.

17.4 Key management actions

Closure management, monitoring and mitigation measures required to achieve and demonstrate successful rehabilitation and closure of the Proposal Area are discussed within the Yandicoogina Closure Plan (**Appendix 4**).

Closure management includes regular review and update of the Yandicoogina Closure Plan, to account for changes resulting from:

- amendments to the mine plan;

- improvements of the site closure knowledge base (e.g. through daily activities, technical studies and research actions, progressive rehabilitation);

- new or amended regulation;

- changes to surrounding land uses; and

- evolving stakeholder expectations.

The review processes bring experts and stakeholders together to discuss current performance, proposed mine changes and opportunities to improve closure outcomes. A key aspect of the review process is the risk identification and management process. This process:

- Identifies hazards, aspects and opportunities, within the current closure strategy and associated with the current level of knowledge, that could influence the successful closure of Yandicoogina.

- Evaluates the hazards and opportunities with respect to the impact to people, property and / or the environment.

- Defines the actions required to improve knowledge, management guidance and / or the closure strategy.

Understanding of the local ecosystem will be advanced through implementation of the Proposal management programs and actions identified through the Closure Plan review process. As a result, the detail within the Yandicoogina Closure Plan will increase over the life of the Proposal.

The closure landform will be rehabilitated to include a wide variety of habitats, including:

- exposed bare rock areas, associated with the pit walls and rock armoured slopes;
- *Acacia* dominated plains-style habitat, similar to the pre-disturbance habitat;
- creek and floodplain habitat, similar to the pre-disturbance habitat; and
- created wetland habitats surrounding the pit lakes.

The mine void and post-closure landforms within the mine void, such as the fringe of the pit lakes, may not be compatible with cattle grazing activities that dominated the area prior to mining. Land capability assessments will be completed during the life of Proposal, based on post-closure ecosystem functionality, to guide discussions with key stakeholders on post-mining land use. Post-closure land uses will be resolved with key stakeholders prior to closure.

When the site approaches scheduled closure, location specific management plans will be finalised for each closure domain. These plans will detail the physical closure, dismantling and subsequent rehabilitation implementation, in accordance with the closure objectives and legal obligations. Stakeholder engagement and endorsement of the final completion criteria will be facilitated at this time, and the post-closure monitoring program will be finalised in alignment with the agreed completion criteria. These monitoring programs are expected to address:

- vegetation, erosion and ecological function;
- invasive species, including weeds and feral animals;
- terrestrial fauna and stygofauna;
- surface water and groundwater levels, quality and contaminants; and
- heritage.

Monitoring programs will define triggers and provide details of management actions and strategies to be implemented should the trigger levels be exceeded.

In the event of temporary closure, measures will be undertaken to transfer the site from operations into a care and maintenance regime and relevant authorities notified. A Care and Maintenance Plan will be developed prior to the care and maintenance period, which demonstrates how ongoing environmental obligations associated with the site will continue to be met during the period of care and maintenance. Social obligations and responsibilities will also be addressed in this plan.

17.5 Predicted outcome

Implementation of the Yandicoogina Closure Plan is expected to produce the following long term outcomes for the Proposal Area:

- Pit walls of the final mine void that are adjacent to Weeli Wolli Creek are stabilised in a way that prevents the creek from collapsing into the mine voids post-closure, ensuring continued function of Weeli Wolli Creek.
- All areas disturbed for mining (with the exception of pit walls) and infrastructure that are not required by the State (under conditions of applicable State

Agreements) are rehabilitated to a condition compatible with the post-mining land use following decommissioning.

- Creation of a dynamic wetland environment within the mine void, including two pit lakes and associated lake fringe, with water levels that will rise and fall in accordance with flooding of the creek systems.
- Regional hydrogeological impacts are minimised and adequately managed.
- Outside of the mining disturbance areas and more than 2 km from the Proposal mine voids, water levels are largely predicted to return to pre-disturbance levels.
- No impacts to the hydrological regime of the Fortescue Marsh as a result of closure of the site.

These outcomes suggest the Proposal is not likely to result in significant environmental impact. During the life of the Proposal, investigations and an adaptive management approach will be used to ensure that risks to closure are identified and addressed so as to meet the EPA's objective for rehabilitation and closure.

18. Offsets

18.1 Key statutory requirements, environmental policy and guidance

18.1.1 EPA objective

The EPA has applied the following objective for the Proposal to its assessment of residual risk management:

"To counterbalance any significant residual environmental impacts and/or uncertainty through the application of offsets."

18.1.2 Relevant guidelines and policy

Environmental offsets are "*actions that provide environmental benefits which counterbalance the significant residual environmental impacts or risks of a proposal. Unlike mitigation actions which occur on-site as part of the proposal and reduce the direct impact of that project, offsets are undertaken outside of the Proposal Area and counterbalance significant residual impacts*" (EPA 2014a).

The following guidelines and polices are relevant to the Proposal with respect to offsets and the above EPA objective:

- EPA Environmental Protection Bulletin No. 1 – Environmental Offsets – Biodiversity (EPA 2014a);
- WA Environmental Offsets Policy (Government of Western Australia 2011); and
- WA Environmental Offsets Guidelines (Government of Western Australia 2014).

18.2 Description of potential residual impacts

"*In general, significant residual impacts include those that affect:*

- *rare and endangered plants and animals (such as Declared Rare Flora and threatened species that are protected by statute);*
- *areas within the formal conservation reserve system;*
- *important environmental systems and species that are protected under international agreements (such as Ramsar listed wetlands); and*
- *areas that are already defined as being critically impacted in a cumulative context.*

Impacts may also be significant if, for example, they could cause plants or animals to become rare or endangered, or they affect vegetation which provides important ecological functions" (Government of Western Australia 2014).

The following elements are considered in quantifying the significant residual impact (Government of Western Australia 2014):

- extent of impact (hectares or numbers);
- quality of the environmental value;
- conservation significance of the environmental value;
- land tenure; and
- time scale.

Potential impacts associated with the Proposal in relation to offsets were identified by the EPA in the ESD as:

- Potential impacts on vegetation, flora, habitat and fauna species of State and National Significance.

Potential impacts for vegetation, flora, habitat and fauna species of State and National Significance are addressed in the following sections:

- Section 14 - Flora and vegetation; and
- Section 15 - Terrestrial fauna and habitat.

18.3 Residual impact evaluation for vegetation, flora, habitat and fauna species of State significance

Taking into account measures to avoid, minimise and rehabilitate impacts (**Table 43**), the following significant residual impact arising from the Proposal has been identified:

- Clearing of up to 1,731 ha of native vegetation in Good to Excellent condition within the Proposal Area, including fauna habitat (excluding riparian zone vegetation[9]).
- Clearing of up to 69 ha of native riparian zone vegetation[9] within the Proposal Area, including fauna habitat.

While 1,327 ha of vegetation is currently proposed to be cleared within the Proposal Area as part of the current mine layout (1,277 ha in Good to Excellent condition, which includes 2.9 ha of riparian zone vegetation), approval for clearing of up for 1,800 ha of the Proposal Area is being requested as part of the Proposal, to allow for flexibility with mine planning and development. As the location of up to 457 ha (excludes 16 ha of riparian zone vegetation) of this vegetation clearing is unconfirmed (and thus the condition of this vegetation is also unknown), it has been assumed this vegetation is in Good to Excellent condition; thus 1,731 ha of vegetation in Good to Excellent condition is proposed to be offset. A total of 69 ha of riparian zone vegetation is also proposed to be offset as good to excellent condition due to its local significance, irrespective of its actual condition.

The EPA has raised concerns regarding cumulative impacts on terrestrial biodiversity values in the Pilbara IBRA region (Government of Western Australia 2014). A number of recommendations have been made to improve management and monitoring of issues in the area, including the establishment of a strategic conservation initiative to coordinate delivery of offsets in the Pilbara.

Consistent with the WA Environmental Offsets Guidelines (Government of Western Australia 2014), it is considered that the residual impact of disturbance of vegetation in Good to Excellent condition is significant and will therefore require compensation via an offset. A standard offset approach has been developed by the EPA in regard to this residual impact and it has been applied consistently to projects in the Pilbara. As such, the Proponent is proposing to contribute funding of $1,500 (excluding GST) per hectare of native vegetation, and funding of $3,000 (excluding GST) per hectare of riparian

[9] For the purposes of the offset calculation, riparian zone vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

vegetation cleared to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.

Table 43: Quantification of significant residual impacts and proposed offsets

Existing environment /Impact	Mitigation			Significant Residual Impact	Offset Calculation Methodology				
	Avoid and minimise	Rehabilitation Type	Likely rehabilitation success		Type	Risk	Likely offset success	Time Lag	Offset Quantification
EPA objective: *To counterbalance any significant residual environmental impacts and/or uncertainty through the application of offsets.*									
Up to 1,800 ha of clearing of native vegetation, including fauna habitat, considered to be in Good to Excellent condition, including 69 ha of riparian zone vegetation	The Proposal has been designed to minimise the required amount of clearing; being an extension of an existing mine site enables utilisation of many existing facilities and reduces the footprint that would otherwise have been required.	Areas will be progressively rehabilitated with local native vegetation. The Yandicoogina Closure Plan will be implemented to ensure that the Proposal can be closed in an ecologically sustainable manner, consistent with agreed outcomes and land uses.	Can the environmental values be rehabilitated/ Evidence? Operator experience in undertaking rehabilitation? Yes – Rio Tinto has completed several areas of successful rehabilitation including examples within the Yandicoogina operation. What is the type of vegetation being rehabilitated? Assorted vegetation assemblages associated with plains, hills, flow lines and terminal basin habitat types. Time lag? Progressive rehabilitation where practicable; with mining of Proposal pit currently expected to be complete in 2032 (this timing may change). Credibility of the rehabilitation proposed (evidence of	Extent: 1,800 ha (1,731 ha Good to Excellent vegetation and 69 ha riparian zone vegetation) Quality: Vegetation is in Good to Excellent condition; provides fauna habitat. Riparian zone vegetation is in Very Poor to Excellent condition; provides fauna habitat. Conservation Significance: Local conservation significance for riparian vegetation Land Tenure: N/A Time Scale: N/A	Provision of funds to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.	N/A	N/A	N/A	$1,500 (excl. GST)/ha of native vegetation clearing of Good to Excellent condition vegetation; $3,000 (excl. GST)/ha of riparian zone vegetation.

			demonstrated success) See previous rehabilitation from Rio Tinto.						
DRF - *Lepidium catapycnon*	Reconfigured waste dumps to avoid all recorded *L. catapycnon* populations (as well as applying a 50 m buffer) within the Proposal Area; all populations identified as 'areas of special protection from ground disturbance'.	Rehabilitation of areas surrounding DRF locations will occur in accordance with the Yandicoogina Closure Plan.	Rio Tinto has completed several areas of successful rehabilitation including examples within the Yandicoogina operation.	No.	N/A	N/A	N/A	N/A	N/A
Priority flora – Four populations (37 individuals) of *Goodenia nuda* (P4) will be impacted	Impact on individuals within Proposal Area represents less than 1% of Rio Tinto records for the species within the Pilbara.	Rehabilitation of Proposal Area will occur in accordance with the Yandicoogina Closure Plan.	Rio Tinto has completed several areas of successful rehabilitation including examples within the Yandicoogina operation.	No.	N/A	N/A	N/A	N/A	N/A

Recorded Threatened fauna species: - Pilbara Olive Python (*Liasis olivaceus barroni*); Schedule 1, Vulnerable Recorded Migratory fauna species: - Eastern Great Egret (*Ardea modesta*); Schedule 3, Migratory - Fork-tailed Swift (*Apus pacificus*); Schedule 3, Migratory - Rainbow Bee-eater (*Merops ornatus*); Schedule 3, Migratory Recorded Priority fauna species: - Western Pebble-mound Mouse (*Pseudomys chapmani*); Priority 4	Approximately 90% of the core habitat identified for the Pilbara Olive Python within the Proposal Area will be retained; with the species recorded in the broader Yandicoogina area and throughout the Pilbara bioregion. Implementation of the Yandicoogina EMP will further reduce any impacts to the species from car collisions or feral animals. The recorded Migratory fauna species are considered transient, highly mobile, common and/or widespread in the Pilbara bioregion and are unlikely to be reliant on habitats within the Proposal Area. Eleven known mounds of the Western Pebble-mound Mouse will be removed as a result of the Proposal, however, the species is considered to be broadly distributed throughout the Pilbara bioregion.	Rehabilitation of Proposal Area will occur in accordance with the Yandicoogina Closure Plan.	Rio Tinto has completed several areas of successful rehabilitation including examples within the Yandicoogina operation.	No.	N/A	N/A	N/A	N/A	N/A

19. Other environmental factors

19.1 Aboriginal heritage

19.1.1 Assessment of potential impacts

The major risks to Aboriginal heritage are related to the disturbance of archaeological or ethnographic sites and impacts on the heritage values of sites and places. Aboriginal heritage sites could potentially be disturbed by proposed activities such as clearing, dewatering, excavation and surface water discharge, although it is Rio Tinto's policy to avoid heritage sites, wherever practicable. Aboriginal archaeological and ethnographic surveys have been completed for the majority of the Revised Proposal Development Envelope. Numerous Aboriginal archaeological sites have been recorded in the locality ranging from low to high in archaeological and cultural significance (Rio Tinto 2014b). A number of ethnographic sites have been identified in the Yandicoogina region in connection to the Marillana Creek and Weeli Wolli Creek. The creeks are recognised to have important links with camping activities, ceremonial activities and other cultural activities (Rio Tinto 2014b).

Section 18 approvals under the *Aboriginal Heritage Act 1972* will be required where disturbance to heritage sites cannot be avoided. All potential indirect impacts to heritage sites and cultural values are also considered prior to any works approvals being granted (e.g. relating to dust, blasting, dewatering, discharge and subsidence). These are often site and works specific, and as such mitigation measures may vary.

A heritage zone is currently delineated around Weeli Wolli Creek, due to the association of this site with camping activities, ceremonial activities and other cultural activities. However, it is noted that part of the proposed mining activities occur within this exclusion zone. Proposed mining activities include the clearing of up to 69 ha of riparian zone vegetation within the proposed Restricted Clearing Area, locating some infrastructure within the heritage zone, and alteration to the creek system by groundwater drawdown from the mine and surplus water discharge. Any long term alteration to the regional water regime is also considered to likely be of high cultural significance (Rio Tinto 2014b). Rio Tinto is required to consult with Traditional Owners prior to any disturbance within this exclusion zone and engage them in the approvals process. Consultations to date have been on both a broader level and a detailed level with the main concerns raised by Traditional Owners being in relation to cultural landscape changes as a whole. While there will be some disturbance to Weeli Wolli Creek, it has been identified that the pit lakes proposed to be present at closure do have the potential to provide for alternate land use (Rio Tinto 2014b).

19.1.2 Proposed mitigation and management measures

Management strategies to address the potential impacts identified are briefly summarised below. These strategies are in place to ensure identified significant areas are protected as much as possible, in accordance with the following Rio Tinto practices and procedures for protecting Aboriginal heritage sites:

- Rio Tinto Cultural Heritage Management Procedure.
- Rio Tinto Heritage Policy.

Rio Tinto also adheres to environmental legislation with relevance for managing potential impacts on heritage values (such as dust control), together with Rio Tinto's internal environmental and health compliance policies and procedures.

Specific strategies for mitigating impacts to heritage values include:

- Complying with the *Aboriginal Heritage Act 1972.*

- Seeking statutory heritage approvals.
- Continuing consultation with the Traditional Owners likely to be affected by the Proposal. Previous comments received from Traditional Owners during consultation are summarised in Section 3.
- Implementing the Aboriginal Heritage Management Guidelines, in conjunction with the Cultural Heritage Management Plan.
- Avoiding Aboriginal heritage sites whenever reasonably practicable in accordance with internal Rio Tinto guidelines and policies.
- Creation and implementation of a heritage drill and blast management plan, where applicable.
- Appropriately fencing/signposting or barricading key heritage sites outside the footprint area (where approval to disturb is not being sought under the *Aboriginal Heritage Act 1972)* to prevent inadvertent impacts to these sites, or alternative suitable approaches agreed with Traditional Owners.
- Stopping work immediately if human remains or archaeological material are accidentally uncovered during any ground-disturbing activity, and contacting the DAA and Rio Tinto's Heritage team.
- Requiring all personnel working in the Proposal Area to attend inductions for the area covering Health, Safety and Environmental requirements, of which Cultural Heritage Awareness is one component.
- Cultural heritage values associated with the Proposal Area to be maintained post-closure as per Yandicoogina Closure Plan.

19.1.3 Predicted environmental outcome

After mitigation and management measures have been applied, the Proposal is expected to have some effect on the ethnographic cultural values of Weeli Wolli Creek. Any disturbance within the Weeli Wolli Creek heritage zone or of other archaeological/ethnographic sites will be in accordance with the provisions of the *Aboriginal Heritage Act 1972* and will have the consent of the relevant Traditional Owners. Rio Tinto will maintain ongoing consultation with Aboriginal stakeholders over the life of the Proposal, in accordance with processes established for the existing Yandi Operations.

19.2 Air quality

19.2.1 Assessment of potential impacts

Air quality has the potential to be negatively impacted by dust created by the Proposal. Dust will be generated by construction and mining activities such as vegetation clearing, earthworks and mining (including blasting), vehicle movements and dry ore processing, stockpiling, reclaiming and transport. The potential impact of dust on native vegetation is discussed in Section 14.3.5.

As the majority of the Iron Ore at the Proposal is below watertable ore, the moisture content of the ore will reduce the likelihood of dust-related impacts from materials handling. Additionally, the Proposal is remote from sensitive air quality receptors, with other mining operations being the nearest premise. There have never been any complaints received in regard to dust emissions from the existing Yandi Operations, with existing mitigation measures to be implemented for the Proposal. Dust emissions are also an occupational health and safety risk for employees at the mine site, and as such are managed appropriately.

19.2.2 Proposed mitigation and management measures

Dust management procedures successfully employed at existing Rio Tinto mines will be used to control dust emissions. Potential dust emissions from processing facilities that are currently operational at the Yandi Operations, and will be utilised for processing of ore from the Proposal, may also be subject to controls imposed through an environmental licence required for such prescribed premises, in accordance with Part V of the EP Act. The strategies for minimising impacts from dust include:

- Clearing work areas only as they are required.
- Minimising exposed surfaces by progressively rehabilitating disturbed and available areas no longer in use.
- Applying water, or appropriate suppressants to haul roads, working surfaces and stockpiles as required.
- Implementing speed limits to minimise dust generation from roads.

19.2.3 Predicted environmental outcome

There is not expected to be a significant air quality impact as a result of the Proposal. Existing Rio Tinto procedures and practices used at the existing Yandi Operations to effectively prevent significant dust emissions will be applied to the Proposal and the ore is predominantly below the water table so presents a lower dust risk.

19.3 Amenity

19.3.1 Assessment of potential impacts

The Proposal is located within the south east corner of the Revised Proposal Development Envelope. The Revised Proposal Development Envelope is not located near any major population centres, with the closest town of Newman being located approximately 90 km to the south east. Tourism in the vicinity is very limited, with the only significant feature being the Weeli Wolli Spring, located approximately 7 km south of the Proposal Area.

The topography of the area around the Proposal range from hilly terrain to the northwest and southeast of the deposit, which descends into the Weeli Wolli Creek floodplain, where the Proposal pit lie. Through the life of the Proposal there will be changes in the immediate vicinity of the mine. Excavation of the mine pit will result in the creation of temporary waste dumps that will be approximately 80 m high, which may be higher in areas than the surrounding landscape which ranges from 50 – 80 m in height above the broader floodplain. These waste dumps will be utilised to backfill part of the mine pit during closure, so the predominantly flat floodplain landscape will be reinstated. There will be a range of other infrastructure and facilities constructed for the Proposal, however, these are not considered to be particularly prominent in the landscape given the proximity to the existing Yandi Operations. The Weeli Wolli Creek crossing will be a culvert bridge arrangement, and hence not an imposing feature on the landscape.

Drawdown of the groundwater associated with dewatering of the mine pit will reduce water available to riparian vegetation along Weeli Wolli Creek, resulting in the death of some native vegetation. Discharge of surplus water to Marillana Creek will also increase the current water available to riparian vegetation in this location, which is likely to cause waterlogging and death of some native vegetation. It is expected that the riparian vegetation will be returned to baseline conditions (i.e. pre-impact from dewatering or surplus water discharge) whereby the system is returned to an ephemeral system.

During mine closure, the maintenance of aesthetic values for cultural and amenity purposes are an important consideration. Creating suitable final landforms and maintaining ecological processes (such as water requirements for vegetation) are significant factors. It is expected that there will be two pit lakes established at the time of closure. These will be located adjacent to Weeli Wolli Creek and form part of the creek system in the long term.

19.3.2 Proposed mitigation and management measures

Proposal implementation will result in a change to visual amenity of the Yandicoogina area, particularly in regard to reduced riparian vegetation and the creation of pit lakes, and it should be considered during the life of the Proposal when possible.

The post-mining landform will affect the accessibility of heritage sites and the ability of the Traditional Owners to use the area for cultural and amenity purposes. These uses require safe and stable landforms that are suitably integrated with the wider landscape and environment. For example, when constructing waste dumps, in pit disposal of waste is preferable. The planned closure will use the waste dumps for infill to the pit. However, there will not be sufficient material to completely backfill the pit void, resulting in two pit lakes being formed in the northern and southern ends of the pit. This will allow for new ecosystems to develop. The measures implemented to maintain amenity upon mine closure are addressed in the Yandicoogina Closure Plan.

19.3.3 Predicted environmental outcome

There will be some temporary and permanent changes to the landforms and general landscape of the Proposal Area. There will be the temporary visual effects in the immediate region around the mine pit with the use of waste dumps and infrastructure/facilities. The extent and condition of riparian vegetation is also expected to be reduced in the long term as the creeks are ultimately returned to an ephemeral system. Through mine closure the visual amenity will be returned as much as possible to the original pre-disturbance landscape. However, two pit lakes will be created within the Proposal Area, which have the potential to create new ecosystems. Amenity will be considered where possible during the life of the Proposal, and the management measures outlined in the Yandicoogina Closure Plan should ensure the key amenity values are maintained after mine closure.

Part 6 – Summary of cumulative impacts

This part provides a summary of the cumulative impacts associated with hydrological processes; flora and vegetation; and terrestrial fauna.

The following factors were considered in regard to cumulative impacts as a key issue for the Proposal:

- Hydrological processes and Inland waters environmental quality:
  - Marillana and Weeli Wolli Creeks.
- Flora and vegetation:
  - Riparian vegetation.
- Terrestrial fauna:
  - Pilbara Olive Python.
  - Chocolate Wattled Bat.
  - Four mygalomorph SRE spiders.

20. Hydrological processes cumulative impacts

The key hydrological receptors near the Proposal are Marillana Creek, Weeli Wolli Creek and Fortescue Marsh. Of these, an assessment of potential cumulative impacts was conducted for Marillana and Weeli Wolli Creeks. Fortescue Marsh will not be affected by the Proposal and therefore was excluded from the CIA.

A preliminary assessment of cumulative impacts to surface water hydrology in the Marillana-Weeli Wolli Creek system was conducted based on a review of the potential impacts of the Proposal, the existing Yandi Operations and six other projects identified as being potentially relevant based on their location in the Weeli Wolli Creek or Marillana Creek sub-catchments of the Upper Fortescue River Catchment.

The average of existing discharge to the Marillana - Weeli Wolli Creek system is approximately 46 GL/y, with a peak of approximately 70 GL/y. Average discharge is expected to increase to approximately 111 GL/y and may reach a peak of approximately 144 GL/y. The existing Yandi Operations, including the Proposal (this assessment), is predicted to account for an average of 55 GL/y (approximately 50% of the total average discharge), with a peak of approximately 83 GL/y (approximately 57% of the total peak discharge).

21. Flora and vegetation cumulative impacts

A preliminary assessment of cumulative impacts to potentially groundwater dependent riparian vegetation (herein defined as vegetation supporting *Eucalyptus camaldulensis* and/or *E. victrix* and/or *Melaleuca argentea*) was conducted based on a review of the potential impacts of the Proposal (Rio Tinto), the existing Yandi Operations and 19 other projects identified as being potentially relevant based on their location in the Upper Fortescue River Catchment (three Rio Tinto and 17 third party projects).

Of the approximately 14,946 ha of potentially groundwater dependent riparian vegetation mapped for the projects considered (including the Proposal), up to 1,800 ha will be disturbed (including areas cleared and areas subject to potentially significant impacts due to groundwater drawdown), which represents approximately 14% of the mapped extent.

22. Terrestrial fauna cumulative impacts

A preliminary assessment of cumulative impacts to the Chocolate Wattled Bat, Pilbara Olive Python and four potential SRE invertebrate taxa was conducted based on a review of the potential impacts of the Proposal, the existing Yandi Operations and other projects identified as being potentially relevant.

Of the approximately 859 ha of potential habitat for the Chocolate Wattled Bat occurring in the Proposal Area, up to 85.9 ha will be cleared for the Proposal. This represents approximately 10% of the extent of this habitat in the Proposal Area. Taken together with the remaining projects for which habitat has been quantified, the cumulative impact is a loss of up to 1,463 ha of potential Chocolate Wattled Bat habitat, which represents approximately 5.6% of the 2,902 ha of habitat mapped across the four projects.

Of the approximately 873 ha of potential habitat for the Pilbara Olive Python occurring in the Proposal Area, up to 87 ha will be cleared for the Proposal. This represents approximately 10% of the extent of this habitat in the Proposal Area. Taken together with the remaining projects for which habitat has been quantified, the cumulative impact is a loss of up to 5,447 ha of potential Pilbara Olive Python habitat, which represents approximately 15% of the 37,376 ha of habitat mapped across the seven projects.

For the four potential SRE invertebrate taxa:

- Approximately 1,439 ha (13%) of the currently known distribution of Nemesiidae sp. N42 (11,300 ha) is located in the Revised Proposal Development Envelope, including less than 1 ha (<1%) in the Proposal Area.
- Approximately 1,638 ha (63%) of the currently known distribution of Nemesiidae sp. N44 (2,600 ha) is located in the Revised Proposal Development Envelope, all of which (63%) is in the Proposal Area.
- Approximately 18,606 ha (7%) of the currently known distribution of Idiopidae sp. I1 (255,900 ha) is located in the Revised Proposal Development Envelope, including approximately 4,231 ha (2%) in the Proposal Area.
- Approximately 157 ha (2%) of the currently known distribution of Idiopidae sp. I9 (6,500 ha) is located in the Revised Proposal Development Envelope, including approximately 50 ha (<1) in the Proposal Area.

Part 7 – Proposed environmental management program and environmental commitments

This part describes the environmental management framework for the Proposal, including management measures identified in Part 5, to prevent and mitigate potential impacts. This part also provides measures to offset significant residual impacts and proposes draft conditions to further ensure the environmental acceptability of the Proposal.

23. Environmental management framework

23.1 Overview

The Proponent is a member of the Rio Tinto Group, which has extensive experience in managing the development, operation and environmental compliance of iron ore mining projects similar to the Proposal. This experience, along with stakeholder consultation, has been used to define the potential environmental impacts from the Proposal, and the proposed mitigation and management measures. The Proponent aims to conduct its business in an efficient and environmentally responsible manner that is compatible with the expectations of stakeholders. A systematic process of environmental management has been adopted, which improves the likelihood that significant environmental impacts have been identified, investigated and mitigated, as far as practicable. As a result, there is greater certainty in achieving desirable environmental outcomes.

At a high level, the Proponent will manage environmental impacts through:

- Complying with environmental approval conditions.
- Maintaining an EMS and supporting business systems.
- Preparing and implementing the management plans for the Proposal as outlined in Section 12, and regularly reviewing the performance of the management plans that address specific environmental factors.
- Measuring energy use and calculating greenhouse gas emissions, and continually seeking opportunities to reduce emissions.
- Improving the efficiency of using natural resources.
- Regularly updating plans for ground disturbance and closure, progressively rehabilitating disturbed land and measuring success.
- Training staff and contractors in environmental requirements and considerations of their work.
- Seeking stakeholder views and ensuring they are respected and considered.
- Reporting regularly to stakeholders on performance.
- Aligning with the Proponent's Health, Safety, Environment, Community and Quality Policy (HSECQ Policy).

23.2 Environmental policies and codes

The Proponent operates under a HSECQ Policy, as all members of the Rio Tinto Group are required to do. The HSECQ Policy is the guiding document for environmental management and provides context and specific direction for continuous improvement.

Rio Tinto has also developed a set of environment standards which establishes Group wide expectations for environmental performance. These standards act to consolidate Group wide principles and guidelines, formalise external voluntary agreements and strengthen Rio Tinto's assurance processes. Operational sites are audited against the standards on a bi-annual basis by Rio Tinto.

Existing environment standards cover:

- Air quality control.
- Hazardous materials and contamination control.
- Mineral waste management (including acid rock drainage).
- Land use and rehabilitation.
- Water use and quality control.

23.3 Environmental Management System

Rio Tinto requires its operations to implement and maintain an EMS that provides a model for continuous improvement, the key elements of which include assessing environmental risk and legal requirements, developing objectives and targets for improvement, training, operational control, communication, emergency response, corrective actions, audits and reviews.

23.4 Sustainability

The Proponent will consider the Rio Tinto Sustainable Development Principles. These principles are applied to all proposals to ensure the sustainable development outcomes align with the sustainability principles stated in the WA State Sustainability Strategy and in the Rio Tinto 'The Way We Work' statement of business practice.

Policies detailed in 'The Way We Work' state that Rio Tinto businesses, projects, operations and products should contribute constructively to the global transition to sustainable development. This will be achieved by helping satisfy global and community needs and aspirations, whether economic, social or environmental. Sustainable development considerations have been made an integral part of business planning, decision making processes and operations.

The Rio Tinto Sustainable Development Principles cover the interrelated streams of environmental stewardship, social wellbeing, economic prosperity, governance and integrity systems. The ten principles are:

- Deliver economic value from our assets and resources.
- Ensure our communities benefit from the value generated by our operations.
- Contribute to the creation of resilient communities.
- Protect the health, safety and wellbeing of our employees, contractors, customers and host communities.
- Attract, develop and retain diverse people with diverse backgrounds and skills.
- Respect the cultures, customs, beliefs and values of our employees, contractors, customers and host communities.
- Demonstrate responsible biodiversity stewardship in the regions in which as operate.

- Improve energy efficiency and contribute to a reduction in greenhouse gas intensity over our product life cycle.
- Responsibly manage our water resources.
- Minimise all forms of environmental harm.

23.5 Summary of likely environmental control instruments

The Proponent has identified the regulatory controls that will ensure that environmental values are protected during implementation of the Proposal. The key controls include, but are not limited to:

- Environmental conditions in any Statement issued by the WA Minister for the Environment allowing the Proposal to be implemented.
- Environmental conditions in any approval conditions issued by the Australian Government Minister for the Environment allowing the Proposal to be implemented.
- Conditions of DER Native Vegetation Clearing Permits, if applicable.
- Conditions of DER Works Approval(s) (under Part V of the EP Act) for construction of works on prescribed premises.
- Conditions of DER Licence(s) (under Part V of the EP Act) for the operation of activities on prescribed premises.
- Conditions of the Licences and Permits for activities relating to the abstraction of groundwater and disturbance to river bed and banks (under the RIWI Act 1914).
- Conditions of any DMP Program of Works or Mining Proposal approvals, if applicable.
- As part of the Proposal, management controls will be implemented to ensure key environmental factors are managed. Other relevant measures and/or actions are also contained in the management plans outlined in Section 11.
-

Table 44: Principles of environmental protection

Principles of Environmental Protection	Relevant (yes/no)	If yes, consideration	Relevant sections of PER
The precautionary principle Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In application of this precautionary principle, decisions should be guided by: (a) careful evaluation to avoid, where practicable, serious or irreversible damage to the environment; and (b) an assessment of the risk – weighted consequences of various options	Yes	The Proponent uses a risk assessment process in the development of new projects to identify potential issues and management actions early in the study phase. Part of this process includes undertaking site investigations of the biological and physical environments to identify existing conditions and significance as part of a detailed environmental assessment of the Proposal. The risk assessment process used throughout the scoping process identified the environmental factors at risk from the Proposal. These factors and the potential environmental impact on these factors are addressed in this PER document. Scoping of relevant environmental factors was undertaken through the ESD process for the Proposal. The EPA prepared and issued the ESD in consultation with relevant decision making authorities and the Proponent. The EPA, in its development of the ESD, consulted with the Proponent on the details of the Proposal, its environmental setting and the environmental surveys and investigations required and expected outcomes.	Section 9
The principle of intergenerational equity The present generation should ensure that the health, diversity and productivity of the environment is maintained and enhanced for the benefit of future generations	Yes	The Proposal has been developed to align with the Proponent's sustainable development principles which seek to ensure that a balance is achieved between economic, environmental and social aspects of the Proposal activities. These principles are consistent with the intent of the WA State Sustainability Strategy and Rio Tinto's 'The Way We Work' statement of business practice. The Proposal incorporates progressive rehabilitation of disturbed areas through the Yandicoogina Closure Plan. The aim of closure and rehabilitation is to ensure that post-mining land uses are enabled to ensure that relevant areas of the Proposal Area retain enduring value for future generations.	Section 17
The principle of the conservation of biological diversity and ecological integrity Conservation of biological diversity and ecological integrity should be a fundamental consideration	Yes	Environmental studies have been conducted in the Proposal Area to identify environmental values and the risks of impact associated with proposed operations. The requirement and scope of the environmental studies was defined through preliminary risk assessment, stakeholder consultation and scoping of the Proposal as part of the ESD process. Results from these studies have been used in the Environmental Impact Assessment presented in this PER document. A number of biodiversity management measures have been developed. These will be put in place in accordance with the EMS, MMP, SSMP, Yandi SSMP addendum and Yandicoogina Closure Plan to prevent and mitigate potential impacts to local and regional biological diversity and ecological integrity.	Sections 11, 13, 14, 15 and 1
***Principles relating to improved valuation, pricing and incentive mechanisms*:** (a) Environmental factors should be included in the valuation of assets and services (b) The polluter pays principle – those who generate pollution and waste should bear the cost of	Yes	The Proponent conducted a pre-feasibility study of the Proposal, accounting for environmental, economic and social considerations. The full life cycle costs of the Proposal, including costs associated with decommissioning and closure will be re-estimated for internal purposes at various stages of the Proposal life. The importance of improved valuation, pricing and incentive mechanisms is recognised. The Proponent has committed significant human and financial resources to ensure that an environmental management program for the Proposal is well developed and implemented.	Appendix 4 (Yandi MMP)

Principles of Environmental Protection	Relevant (yes/no)	If yes, consideration	Relevant sections of PER
containment, avoidance and abatement (c) The users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any waste (d) Environmental goals, having been established, should be pursued in the most cost-effective way, by establishing incentive structure, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solution and responses to environmental problems		The Proponent recognises the polluter pays principle, and has designed the Proposal to ensure that pollution impacts are avoided. The potential pollution impacts of the Proposal have been identified and management measures to minimise these impacts developed. Pollution will largely be addressed through a combination of minimisation and on-site treatment, resulting in minimal export of pollutants off-site. Environmental goals will be pursued in the most cost-effective manner, using a combination of internal resources and external expertise where appropriate. A comprehensive approach for mine rehabilitation and closure has been developed in the Yandicoogina Closure Plan.	
The principle of waste minimisation All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment	Yes	Waste production will be minimised through the implementation of waste management approaches that apply the hierarchy of avoid, reduce, reuse, recycle and recover waste. The Proposal includes measures to minimise the generation of waste and reuse and recycle waste materials, wherever possible.	Appendix 4 (Yandi MMP)

Table 45: Statutory and environmental management controls for the Proposal

Factor	Proposed Statement Conditions	Yandi Operations management plans	Works Approval & licence (Part V, EP Act)	Other legislation and regulations
Key Environmental Factors				
Flora and Vegetation	x	x		x
Terrestrial Fauna	x	x		x
Subterranean Fauna	x	x		x
Hydrological Processes and Inland Waters Environmental Quality	x	x	x	x
Integrating Factors				
Rehabilitation and Closure	x	x		x
Residual Risk Management (Offsets)	x	x		x
Other Environmental Factors				
Aboriginal heritage		x		x
Air Quality		x	x	
Amenity		x		

24. Revised Proposal and proposed environmental conditions

The Revised Proposal will be implemented such that the resultant environmental effects will be as anticipated and assessed in this PER document, or as approved for the existing Yandi Operations based on MS 914.

The environmental footprint and other key characteristics of the Revised Proposal have been developed based on the description of the Proposal (Section 4) and MS 914 for the existing Yandi Operations (**Table 46**). A summary of the existing Yandi Operations and Proposal key characteristics, which together comprise the Yandicoogina Iron Ore Project – Revised Proposal, is outlined in **Table 1**, Section 1.4.1.

As the Proponent will be bound to implementing the Revised Proposal in accordance with technical specifications detailed in this PER document and as prescribed in any approval conditions (i.e. Schedule 1 of WA Ministerial Statement), only those elements of the Proposal that are significant from the point of view of environmental protection have been proposed as key characteristics.

The Proponent has also proposed environmental conditions for consideration by the State Minister (**Table 47**). These conditions are based on those outlined in MS 914, which would be superseded by a new Ministerial Statement pursuant to approval of the Revised Proposal. The changes made to MS 914 and the proposed new environmental conditions are also listed in **Appendix 6**.

The proposed Key Proposal Characteristics (**Table 46**) and Environmental Conditions (**Table 47**) have been developed to avoid duplication with other regulatory controls that can be applied under other existing legislation (Section 23.5). A condition relating to the management of a specific environmental factor has not been proposed if environmental impact can be, or is, adequately addressed by other environmental controls.

Table 46: Key Proposal Characteristics

Summary of the Proposal		
Proposal title	Yandicoogina Iron Ore Project – Revised Proposal	
Proponent name	Hamersley Iron – Yandi Pty Limited	
Short description	The proposal is to develop Iron Ore deposits Junction Central, Junction South East, Junction South West, Oxbow and Pocket and Billiard South, located in the central Pilbara region of Western Australia, on mining lease 274SA. Key aspects of the proposal include: • Ore transport and storage infrastructure (including rail link) –overland conveyors, stockyards, ore stackers and ore reclaimers, and storage infrastructure, rail loops. • Rail corridor allowing for rail lines and associated infrastructure. • Construction and operations support infrastructure. • 220kv power network including switchyard, back-up diesel power and transmission lines. • Dry and wet processing plants (including in pit waste fines storage facilities). • Flood protection structures and creek crossings. • Accommodation camps. • Access roads.	
Physical elements	**Location**	**Proposed Extent**
2. Mine and associated infrastructure	Figure 4 and Figure 79	Vegetation clearing up to 7,400 ha within Revised Proposal Development Envelope. Vegetation clearing up to 129 ha within the

		proposed Restricted Clearing Area.
Operational elements	**Location**	**Proposed Extent**
3. Dewatering	Figure 34	No more than 83 GL/year for entire Revised Proposal.
4. Surface water discharge	Figure 34	Up to 78 GL/year for entire Revised Proposal. No water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence.

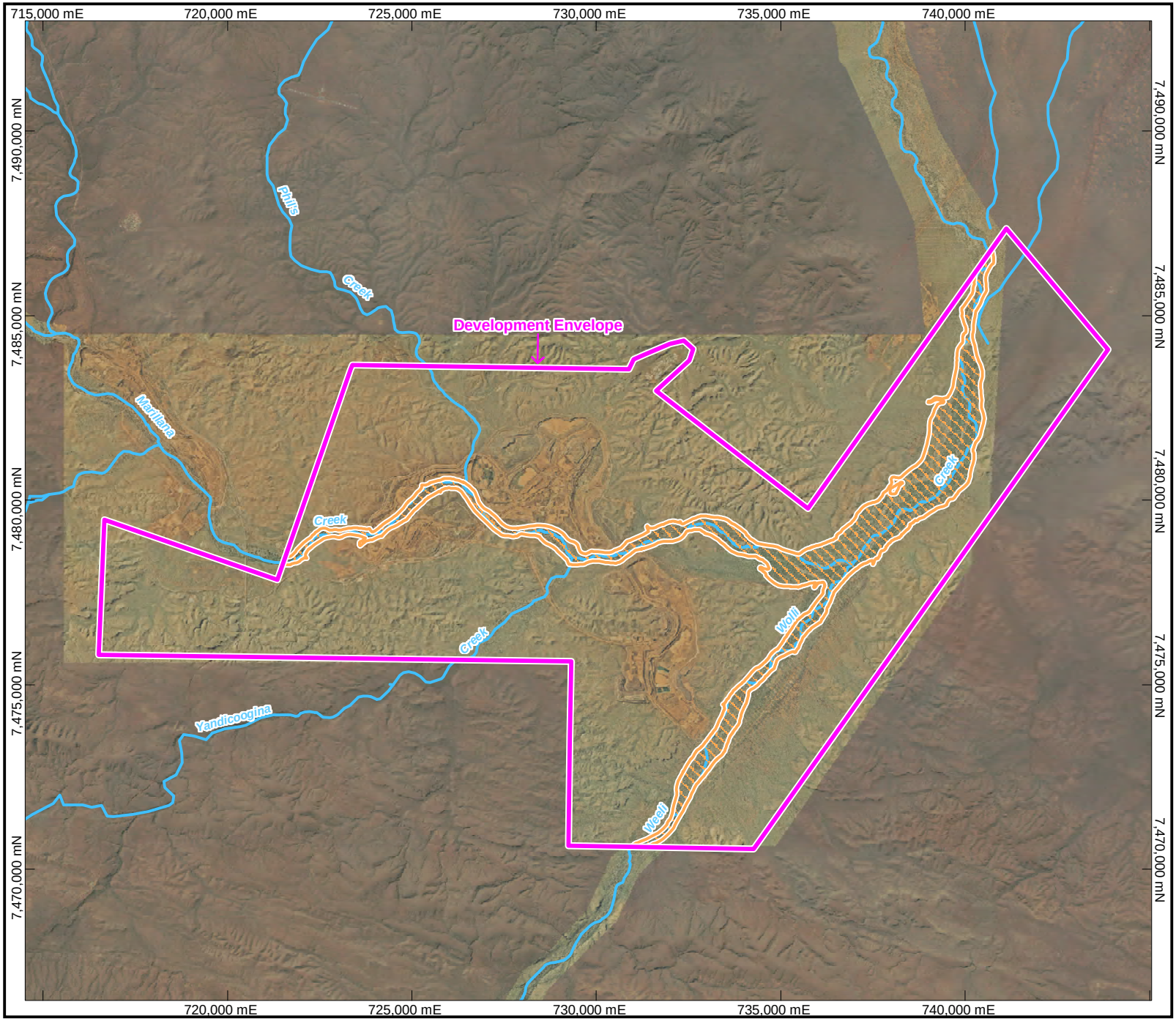
Table 47: Proposed environmental conditions for the Yandicoogina Iron Ore Project – Revised Proposal

Condition No.	Proposed condition
Proposal implementation	
1-1	When implementing the proposal, the proponent shall not exceed the authorised extent of the proposal as defined in Schedule 1, unless amendments to the proposal and the authorised extent of the Proposal have been approved under the EP Act.
Contact details	
2-1	The proponent shall notify the CEO of any change of its name, physical address or postal address for the serving of notices or other correspondence within 28 days of such change. Where the proponent is a corporation or an association of persons, whether incorporated or not, the postal address is that of the principal place of business or of the principal office in the State.
Compliance reporting	
3-1	The proponent shall prepare and maintain a compliance assessment plan to the satisfaction of the CEO at least six (6) months prior to the first compliance assessment report required by condition 3-6.
3-2	The compliance assessment plan shall indicate: (1) the frequency of compliance reporting; (2) the approach and timing of compliance assessments; (3) the retention of compliance assessments; (4) the method of reporting of potential non-compliances and corrective actions taken; (5) the table of contents of compliance assessment reports; and (6) public availability of compliance assessment reports.
3-3	After receiving notice in writing from the CEO that the compliance assessment plan satisfies the requirements of condition 3-2 the proponent shall assess compliance with conditions in accordance with the compliance assessment plan required by condition 3-1.
3-4	The proponent shall retain reports of all compliance assessments described in the compliance assessment plan required by condition 3-1 and shall make those reports available when requested by the CEO.
3-5	The proponent shall advise the CEO of any potential non-compliance within seven days of that non-compliance being known.
3-6	The proponent shall submit to the CEO a compliance assessment report by the end of April each year addressing compliance in the previous calendar year. The compliance assessment report must address compliance for the period from the date of issue of this statement, notwithstanding that the first report may cover a period less or more than 12 months. The compliance assessment report shall: (1) be endorsed by the proponent's Managing Director / General Manager / Chief Executive Officer or a person delegated to sign on the Managing Director's / General Manager's / Chief Executive Officer's behalf; (2) include a statement as to whether the proponent has complied with the conditions; (3) identify all potential non-compliances and describe corrective and preventative actions taken; (4) be made publicly available in accordance with the approved compliance assessment plan; and (5) indicate any proposed changes to the compliance assessment plan required by condition 3-1.
Public availability of data	
4-1	Subject to condition 4-2, within six months of the issue of this statement and for the remainder of the life of the proposal the proponent shall make publically available, in a manner approved by the CEO, all validated environmental data (including sampling

Condition No.	Proposed condition
	design, sampling methodologies, empirical data and derived information products [e.g. maps]) relevant to the assessment of this proposal and implementation of this statement.
4-2	If any data referred to in condition 4-1 contains particulars of: (1) a secret formula or process; or (2) confidential commercially sensitive information The proponent may submit a request for approval from the CEO to not make this data publically available. In making such a request the Proponent shall provide the CEO with an explanation and reasons why the data should not be made publically available.
Surface water discharge (protection of Weeli Wolli Creek)	
5-1	The proponent shall ensure that the discharge of excess water from the Yandicoogina Iron Ore Project – Revised Proposal as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek system.
5-2	To verify that condition 5-1 is being met, the proponent shall maintain an Environmental Values Statement for the Weeli Wolli Creek system that defines the environmental values of the Weeli Wolli Creek system to the satisfaction of the CEO in consultation with Parks and Wildlife.
5-3	The proponent shall ensure that dewatering discharge from the Yandicoogina Iron Ore Project – Revised Proposal does not cause water flow or pooling downstream from the Marillana Creek and Weeli Wolli Creek system Confluence further than the extent identified in Schedule 1 (under natural no flow conditions).
5-4	The proponent shall submit a revised Water Discharge Monitoring and Management Plan in consultation with the DoW, to the satisfaction of the CEO, to ensure that identified environmental values associated with the Weeli Wolli Creek system and any downstream ecosystems, including the Fortescue Marsh, are maintained. This plan shall: (1) describe the water discharge and monitoring program; (2) when implemented, demonstrate by monitoring, whether conditions 5-1 and 5-3 are being met; (3) when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of conditions 5-1 and 5-3; and (4) detail management actions and strategies to be implemented should the monitoring required by condition 5-4 (2) indicate that condition 5-1 or 5-3 may not be met.
5-5	The proponent shall implement the approved Water Discharge Monitoring and Management Plan required by condition 5-4, and any subsequent approved revisions.
Riparian vegetation	
6-1	The proponent shall ensure that surplus water discharge does not cause long term impacts on the health or cover of riparian vegetation or groundwater dependent ecosystems outside the management zones as shown in Figure 80.
6-2	The proponent shall ensure that dewatering discharge does not cause long term impacts on the health or cover of riparian vegetation or groundwater dependent ecosystems outside the management zones as shown in Figure 80.
6-3	The proponent shall manage the proposal in a manner that ensures there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems across the catchment as measured within the management zones shown in Figure 80.
6-4	The proponent shall submit a revised Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan to the satisfaction of the CEO.
6-5	The Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan required pursuant to condition 6-4 shall: (1) when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of conditions 6-1, 6-2, and 6-3; (2) when implemented, require the proponent to monitor to substantiate whether conditions 6-1, 6-2 and 6-3 are being met; (3) identify monitoring and control sites; (4) require the proponent to design a survey to acquire baseline biotic data, including health and abundance parameters and environmental data; (5) define health and cover parameters; (6) define monitoring frequency and timing; (7) identify criteria to measure any decline in health; (8) define critical correlative environmental parameters, including groundwater

Condition No.	Proposed condition
	drawdown; (9) define trigger and threshold levels for 'no irreversible impact'; (10) provide details of management actions and strategies to be implemented should trigger and threshold levels defined pursuant to condition 6-5(9) be exceeded within the management zones.
6-6	The proponent shall implement the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.
6-7	The proponent shall review and revise the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan at intervals not exceeding five years, to the approval of the CEO.
6-8	Commencing on the date of this statement and until it commences implementation of the revised Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan in accordance with condition 6-6, the proponent shall continue to implement the existing approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.
6-9	In the event that monitoring, undertaken pursuant to condition 6-6, identifies that trigger and threshold levels for no irreversible impact, defined pursuant to condition 6-5(9), have been or are being exceeded within the management zones, the proponent shall implement management actions and strategies defined in condition 6-5(10) to the satisfaction of the CEO.
Weeds	
7-1	The proponent shall ensure: (1) no increase in the species of weeds (including both declared weeds and environmental weeds) in the Proposal Area as a result of the implementation of the proposal; (2) the cover of weeds (including both declared weeds and environmental weeds) within the Proposal Area does not increase as a result of implementation of the proposal; and (3) identification and establishment of reference sites on nearby land outside the impact area shall be undertaken in consultation with the OEPA, on advice from Parks and Wildlife, to the satisfaction of the CEO. The reference sites are to be monitored biennially to determine whether changes in weed cover and type are as a result of proposal implementation or broader regional changes.
Decommissioning and rehabilitation	
8-1	The proponent shall ensure that the proposal is decommissioned and rehabilitated in an ecologically sustainable manner, consistent with agreed outcomes and land uses, and without unacceptable liability to the State of Western Australia, through the implementation of the Mine Closure Plan required by condition 8-2.
8-2	The proponent shall prepare the Yandicoogina Mine Closure Plan in accordance with the *Guidelines for Preparing Mine Closure Plans*, *June 2015* and any updates, to the requirements of the CEO on advice of the Department of Mines and Petroleum.
8-3	The proponent shall review and revise the Yandicoogina Mine Closure Plan required by condition 8-2 at intervals not exceeding three years, or as otherwise specified by the CEO.
8-4	The proponent shall implement the latest revision of the Yandicoogina Mine Closure Plan, which the CEO has confirmed by notice in writing, satisfies the requirements of condition 8-2.
Residual impact and risk management measures	
9-1	The 5,600 ha of clearing of native vegetation previously approved under Ministerial Statement 914 is exempt from the requirement to offset under condition 9-3.
9-2	In view of the significant residual impacts and risks as a result of implementation of the additional clearing for the Yandi PBS Proposal, the proponent shall contribute funds to offset the clearing of 'Good to Excellent' condition native vegetation, and calculated pursuant to condition 9-3. This funding shall be provided to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.

Condition No.	Proposed condition
9-3	The proponent's contribution to the initiative identified in condition 9-3 shall be paid biennially, the first payment due two years after commencement of the additional ground disturbance defined in Schedule 1. The amount of funding will be $1,500 AUD (excluding GST) per hectare of 'Good to Excellent' condition native vegetation and $3,000 AUD (excluding GST) per hectare of riparian zone vegetation cleared within the Development Envelope (delineated in Figure 1 and defined by the geographic coordinates in Schedule 2), within the Hamersley IBRA subregion.



LEGEND

- Development Envelope
- Proposed Restricted Clearing Area
- Major Watercourse

N

SCALE

0 2 4 6km

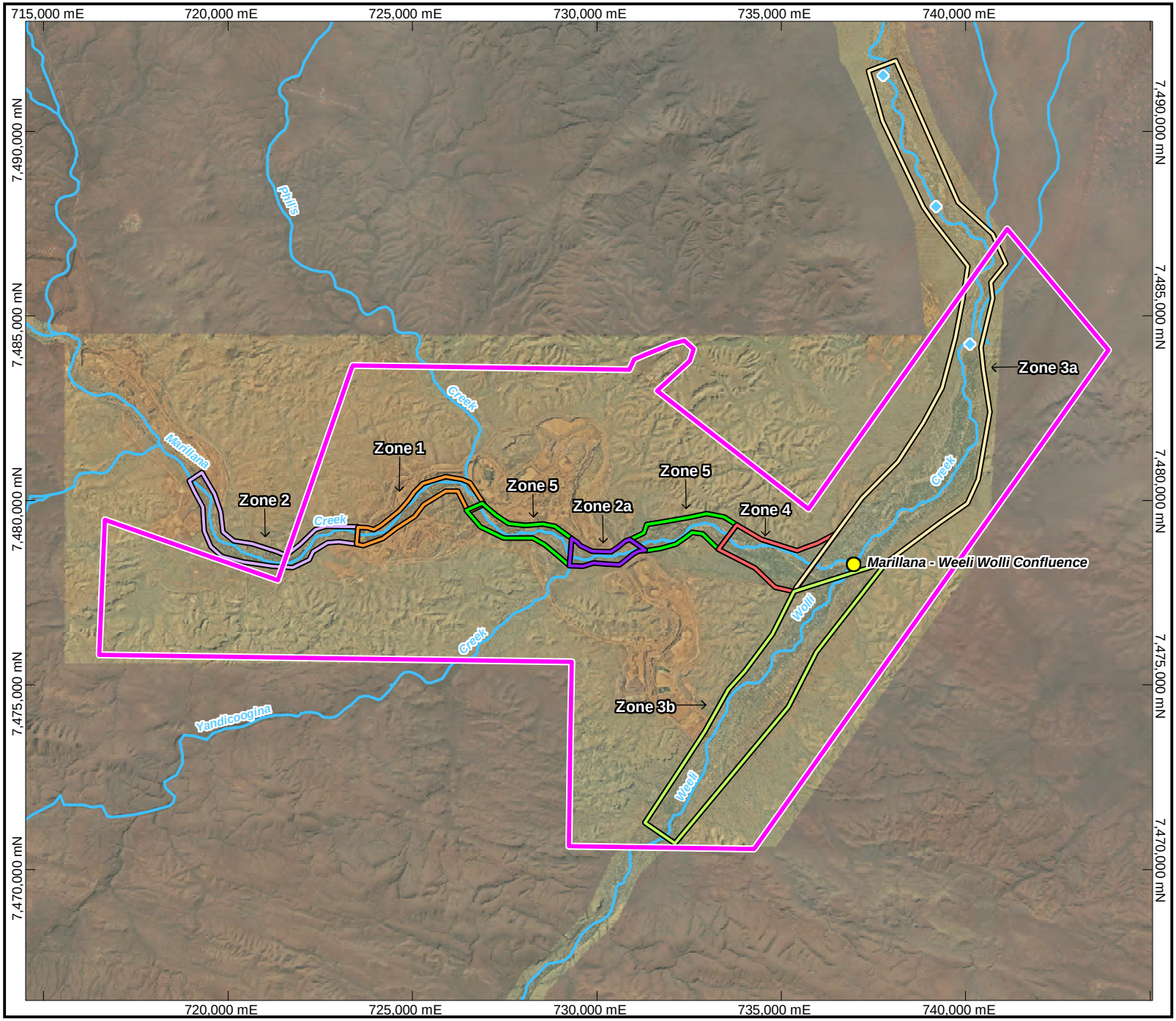
1:150 000 @ A4

Iron Ore (WA)

Figure 79
Yandicoogina Iron Ore Project - Revised Proposal Development Envelope and restricted clearing area

Drawn: M.Swebbs Plan No: PDE0133900v4
Date: October, 2015 Proj: MGA94 (Zone 50)

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Marillana - Weeli Wolli Confluence
- Wetting Footprint Extents
- Major Watercourse

Drawdown and or Discharge

- Zone 1 Impact Buffer
- Zone 2 Impact Buffer
- Zone 2a Impact Buffer
- Zone 3b Impact Buffer

Discharge Only

- Zone 3a Impact Buffer
- Zone 4 Impact Buffer
- Zone 5 Impact Buffer

N

SCALE

0 2 4 6km

1:150 000 @ A4

Iron Ore (WA)

Figure 80
Groundwater abstraction and dewatering discharge management zones

Drawn: M.Swebbs Plan No: PDE0133847v2
Date: October, 2015 Proj: MGA94 Zone50

Geospatial Information and Mapping

25. Conclusions

This PER provides:

- A description of the key components of the Revised Proposal.
- A summary of the important physical, biological and social factors of the existing environment.
- A discussion of the extent of stakeholder consultation.
- An evaluation of potential impacts of the Proposal to environmental factors, including cumulative impacts.
- Strategies and measures to ensure environmental factors and values are protected and managed to an appropriate level.

The PER has been prepared in accordance with the ESD developed by the EPA (**Appendix 2** and **Appendix 2**).

This PER document and all supporting biological survey reports have been prepared in line with the guidelines presented in the EPA checklist for documents submitted for Environmental Impact Assessment on marine and terrestrial biodiversity (**Appendix 5**).

25.1 Environmental impacts and mitigation

The key environmental factors identified by the EPA in the ESD for the Proposal were:

- Flora and vegetation.
- Terrestrial fauna.
- Subterranean fauna.
- Hydrological processes and Inland waters environmental quality.
- Rehabilitation and closure.
- Residual risk management (offsets).

Other environmental factors identified by the EPA in the ESD to be relevant to the Proposal were:

- Aboriginal heritage.
- Air quality.
- Amenity.

After mitigation and management measures have been applied, it is expected that the Proposal will result in the following residual outcomes in relation to the environmental factors identified by the EPA:

Hydrological processes and Inland waters environmental quality

- Natural surface water systems and flows – potential impacts likely to be minor and can be managed through typical stormwater management measures such as levees around the pit, diversion drains around waste dumps, and culverts under roads.

- Surface water resources including Weeli Wolli Creek due to surface discharge of surplus mine dewater – wetting front will be within existing approved limits, and therefore there will be negligible additional impacts on the downstream hydrological system of Weeli Wolli Creek.
- Altered flow regime to the Fortescue Marsh – surface water wetting front associated with the additional discharge from the Proposal is predicted to remain within existing approved limits of MS 914.
- Potential contamination of surface water and groundwater – acid rock drainage risk at the Revised Proposal has been assessed as low due to the geology of the area. Site drainage will be designed to minimise or eliminate surface runoff into areas where activities with a potential risk of hydrocarbon contamination occur. Management of waste dumps will ensure that risks of contamination of surface and groundwater are minimised.

Flora and vegetation

- Clearing of up to 1,800 ha flora and vegetation (including 69 ha riparian zone vegetation).
- Loss of some riparian vegetation associated with dewatering activities, with the vegetation expected to return to a more 'natural' state (i.e. pre-mining).
- Loss of some riparian vegetation associated with surplus water discharge, particularly waterlogging affects, though overall impacts will be limited to the currently approved limits of MS 914 (17 km downstream from confluence of Marillana and Weeli Wolli Creeks).
- No loss of known and recorded individuals of *Lepidium catapycnon* (Hamersley Lepidium); redesign of the waste dumps has avoided recorded individuals and they have been designated 'areas of special protection from ground disturbance' and therefore excluded from the ground disturbance footprint.
- Removal of some individuals of Priority 4 flora species (*Goodenia nuda*), though it is recorded throughout the Pilbara and it is considered that this will not alter the species' conservation status.
- Rehabilitation of areas disturbed by the Proposal, consistent with the Yandicoogina Closure Plan.

Terrestrial fauna

- Clearing of up to 1,800 ha of terrestrial fauna habitat over the life of the Proposal and habitat degradation due to the altered groundwater regime (some tree deaths within the riparian zone), which may lead to local reductions in fauna populations in the Proposal Area. The habitat types present in the Proposal Area are considered to be well represented in the local and regional area. It is considered likely that individuals will continue to forage in the remaining habitats within and adjacent to the Proposal Area.
- Clearing will result in the direct removal of up to 1,800 ha of potential SRE habitat within Proposal Area; this habitat is considered widespread locally and regionally.
- Risk of alteration to aquatic fauna habitat in Weeli Wolli Creek (surface water flows); additional habitat is available to north and south of the Proposal Area.

- Fragmentation of fauna habitat caused by the pit, waste dumps and association infrastructure; the mine footprint may also cause a barrier to dispersion for non-aerial species.
- Direct loss of some individual fauna through impact with machinery and vehicles, particularly during vegetation clearing.
- Progressive rehabilitation, with consideration given to restoring fauna habitat values where practicable.

Subterranean fauna

- Direct mortality and reduction in available subterranean habitats as a result of pit excavation and groundwater drawdown.
- Potential impacts will be localised to the proposed pit area and the groundwater drawdown zone during mining operations. However, it is not expected to significantly impact subterranean fauna assemblages and species persistence.
- The risk of pollutants being transported into the subterranean habitats is likely to be low and restricted to localised areas.
- The continuous nature of the alluvium, colluvium and calcrete units in which the subterranean fauna were predominately recorded indicates that geology is not a limiting factor in the distribution of the taxa currently known from the proposed pit area and the groundwater drawdown zone within the Proposal Area.

Rehabilitation and closure

- Pit walls of the final mine void that are adjacent to Weeli Wolli Creek are stabilised in a way that prevents the creek from collapsing into the mine voids post-closure, ensuring continued function of Weeli Wolli Creek.
- All areas disturbed for mining (with the exception of pit walls) and infrastructure that are not required by the State (under conditions of applicable State Agreements) are rehabilitated to a condition compatible with the post-mining land use following decommissioning.
- Creation of a dynamic wetland environment within the mine void, including two pit lakes and associated lake fringe, with water levels that will rise and fall in accordance with flooding of the creek systems.
- Regional hydrogeological impacts are minimised and adequately managed.
- Outside of the mining disturbance areas and more than 2 km from the Proposal mine voids, water levels are largely predicted to return to pre-disturbance levels.
- No impacts to the hydrological regime of the Fortescue Marsh as a result of closure of the site.

Offsets

Taking into account measures to avoid, minimise and rehabilitate impacts, the following significant residual impact arising from the Proposal has been identified:

- Clearing of up to 1,731 ha of native vegetation in Good to Excellent condition within the Proposal Area, including fauna habitat (excluding riparian zone vegetation[10]).
- Clearing of up to 69 ha of native riparian zone vegetation[10] within the Proposal Area, including fauna habitat.

The EPA has raised concerns regarding cumulative impacts on terrestrial biodiversity values in the Pilbara IBRA region. Consistent with the WA Environmental Offsets Guidelines, it is considered that the residual impact of disturbance of vegetation in Good to Excellent condition or riparian zone vegetation is significant and will therefore require compensation via an offset. As such, the Proponent is proposing to contribute funding of $1,500 (excluding GST) per hectare of native vegetation, and funding of $3,000 (excluding GST) per hectare of riparian zone vegetation cleared to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.

Aboriginal heritage

- Any disturbance within the Weeli Wolli Creek heritage zone or of other archaeological/ethnographic sites will be in accordance with the provisions of the *Aboriginal Heritage Act 1972* (WA) and will have the consent of the relevant Traditional Owners.

Air quality

- Existing Proponent procedures and practices used at Yandi Operations to effectively prevent significant dust emissions will be applied to the Proposal.

Amenity

- Through mine closure the visual amenity will be returned as much as possible to the original pre-disturbance landscape. However, two pit lakes will be created within the Proposal Area, which have the potential to create new ecosystems. Amenity will be considered where possible during the life of the Proposal, and the management measures outlined in the Yandicoogina Closure Plan should ensure the key amenity values are maintained after mine closure.

25.2 Environmental management framework

The Proposal will be subject to the Proponent's HSECQ Policy and operated under the company EMS.

Management controls to be implemented as part of the Proposal to ensure key environmental factors are managed as described in the PER include measures and/or actions contained within the following key documents:

[10] For the purposes of the offset calculation, riparian vegetation is classified as vegetation units within the riparian zone comprising C-coded and F2 coded vegetation located within the RCA.

- Yandicoogina MMP, which includes:
    - Yandicoogina Vegetation and Groundwater Dependant Ecosystems Monitoring and Management Plan.
    - Yandicoogina Surface Water Discharge Monitoring and Management Plan.
- Yandicoogina Weed Action Plan:
- SSMP, including Yandi Operations site specific addendum.
- Yandicoogina Closure Plan.

25.3 Environmental offsets

The Proponent recognises that an environmental offset will be required for significant residual impacts that remain after mitigation measures have been exhausted. An offset is proposed in regard to significant residual impacts on 'Good to Excellent' condition vegetation (Sections 18 and 24).

25.4 Environmental acceptability of the Proposal

The approach taken in this PER has been based on a risk assessment approach to characterise the environmental factors, determine potential impacts and develop mitigation measures.

The Proponent has extensive experience in managing the development, operation and environmental compliance of similar projects, particularly including the existing Yandi Operations. The knowledge and experience gained from the Yandi Operations to date is considered to have provided rigour to additional studies undertaken for the Proposal and is anticipated to lead to a greater certainty in achieving stated environmental outcomes.

The Proponent has consulted with key stakeholders to scope the potential impacts of the Proposal and to determine the significance of environmental issues and the acceptability of mitigation. This process substantially improves the likelihood that all significant environmental issues have been identified, investigated and mitigated as far as practicable.

On the basis of the findings of this PER, the Proposal is considered to be environmentally acceptable if implemented in accordance with the proposed management and mitigation measures, including proposed Ministerial Statement implementation conditions (which are based on the existing conditions in MS 914 for the Yandi Operations).

Part 8 – Abbreviations and references

26. Abbreviations

Abbreviation	Definition
%	Percent
°C	Degrees celsius
AEP	Annual Exceedance Probability
ALA	Atlas of Living Australia
ANZECC	Australian and New Zealand Environment and Conservation Council
ARI	Annual Recurrence Interval
AUD$	Dollars (Australian)
bgl	Below ground level
BHP	BHP Billiton Iron Ore
BIF	Banded Iron Formation
BWT	Below water table
CAA	Clearing Avoidance Area
CAMBA	China-Australia Migratory Bird Agreements
CID	Channel iron deposit
cm	Centimetre/s
CIA	Cumulative impact assessment
DAA	Department of Aboriginal Affairs
DCP	Digital canopy photography
DER	Department of Environment Regulation
DMAs	Decision making authorities
DMP	Department of Mines and Petroleum
DO	Discharge Outlet
DoE	Department of the Environment (Commonwealth)

Abbreviation	Definition
DoW	Department of Water
DSD	Department of State Development
EAG	Environmental Assessment Guideline
EIA	Environmental impact assessment
EMS	Environmental Management System
EPA	Environmental Protection Authority
EP Act	*Environmental Protection Act 1986*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ESD	Environmental Scoping Document
EVS	Environmental Values Statement
FIFO	Fly In-Fly Out
GIS	Geographic information system
GL	Gigalitre/s
GL/y	Gigalitre/s per year
ha	Hectare/s
Hamersley Iron	Hamersley Iron – Yandi Pty Limited
HSECQ	Health, Safety, Environment, Community and Quality Policy
IBRA	Interim Biogeographic Regionalisation for Australia
JAMBA	Japan-Australia Migratory Bird Agreements
JC	Junction Central
JSE	Junction South East
JSW	Junction South West (-A & C pits)
km	Kilometre/s
km^2	Square kilometre/s
kV	Kilovolt/s
m	Metre/s

Abbreviation	Definition
m^3	Cubic metre/s
Matters of NES	Matters of National Environmental Significance
mg/L	Milligrams per litre
mm	Millimetre/s
MMP	Monitoring and Management Plan
MS 914	Ministerial Statement No. 914
Mt	Million tonnes
Mtpa	Million tonnes per annum
MW	Megawatt/s
OEPA	Office of the Environmental Protection Authority
Parks and Wildlife	Department of Parks and Wildlife
PER	Public Environmental Review
Pilbara Iron	Pilbara Iron Company (Services) Pty Limited
RCA	Restricted Clearing Area
Revised Proposal	Yandicoogina Iron Ore Project – Revised Proposal; comprised of the existing Yandi Operations and Yandi PBS Proposal
RIWI Act	*Rights in Water and Irrigation Act 1914*
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreements
SRE	Short Range Endemic
SSMP	Significant Species Management Plan
TDS	Total Dissolved Solids
TEC	Threatened Ecological Community
Existing Yandi Operations	Existing Yandicoogina Operations
Proposal	Yandicoogina Pocket and Billiard South Iron Ore Development
YLUA	Yandicoogina Land Use Agreement
WA	Western Australia
WAM	Western Australian Museum

Abbreviation	Definition
WC Act	*Wildlife Conservation Act 1950*
WFSFs	Waste fines storage facilities

27. References

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Appendix 1: Yandicoogina Iron Ore Project – Revised Proposal Environmental Scoping Document

(Yandicoogina Iron Ore Project – Revised Proposal Environmental Scoping Document is contained on CD inside the back cover of the PER)

Appendix 2: Compliance checklist

Compliance checklist of work requirements for preliminary key environmental factors (and other environmental factors) stated in the ESD. For the EPA objective, relevant aspects and potential impacts, please see Appendix 1 (ESD).

Environmental factor	Work required	PER reference
Flora and Vegetation	1. Provide information on the current status and outcomes of the riparian vegetation management actions required by Ministerial Statement 914 Condition 7 - Riparian Vegetation, and Condition 8 - Weeds.	Section 14.5.1
	2. Provide a detailed description of the cumulative impacts associated with the proposal, including direct impacts from clearing, and indirect impacts such as groundwater drawdown, surface discharge of excess groundwater, altered drainage, changes in water quality, dust emissions and fragmentation of vegetation.	Section 14.4
	3. Provide figures showing the extent of clearing and indirect impact to vegetation and conservation significant flora species, including but not limited to threatened and/or Priority ecological communities, Declared Rare Flora, Priority flora and new flora species.	Figures 44 to 56
	4. Consolidate vegetation and flora reports incorporating information from all relevant previous and new studies, particularly for the Declared Rare Flora species *Lepidium catapycnon*.	Section 14.2.1; Appendix 3; Biota (2015a)
	5. Describe the environmental values and rational of the Clearing Avoidance Area identified in Ministerial Statement 914. Quantify the disturbance to this area as a result of implementing the proposal and describe how the environmental values of the Clearing Avoidance Area and Weeli Wolli Creek will be maintained.	Section 6.2.1.2 and 14.3.1
	6. Carry out Level 2 flora and vegetation surveys in areas that are likely to be directly or indirectly disturbed. Surveys are to be undertaken in accordance with Guidance Statement 51. Details of the scope, timing (survey season/s) and methodology for surveys used must be provided. Follow up targeted surveys may be required based on the results of the baseline survey for conservation significant flora and vegetation.	Section 14.2.1; Appendix 3; Biota (2015a)
	7. Analyse the extent of clearing and indirect impacts to assist in the determination of the significance of impacts, including impacts on: • vegetation units; • threatened and Priority ecological communities; • threatened and Priority flora; • species identified as significant consistent with Guidance Statement 51;	Section 14.3

Environmental factor	Work required	PER reference
	• vegetation units identified as significant consistent with Guidance Statement 51; and • groundwater dependent vegetation.	
	8. Undertake baseline mapping of weed affected areas in any area likely to be directly or indirectly impacted by the proposal.	Section 14.2.1; Appendix 3; Biota (2015a)
	9. Discuss potential direct/indirect (including downstream) and cumulative impacts to flora and vegetation as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance.	Section 14.3
	10. Discuss proposed management, monitoring and mitigation methods to be implemented. Also, discuss engineering solutions that could be implemented to redesign the waste rock dump locations to avoid impacts to *Lepidium catapycnon*.	Sections 14.3 and 14.5
	11. Demonstrate that all practicable measures have been taken to reduce both the area of the proposed disturbance footprint and the Development Envelope based on progress in the proposal design and understanding of the environmental impacts.	Sections 14.3 and 14.5
	12. Demonstrate that the mitigation hierarchy of avoid, minimise, rehabilitate and offset has been applied effectively during the mine planning and design stages of the project.	Sections 14.3 to 14.6, Section 17 and Section18
Terrestrial Fauna	1. Conduct desktop study of information available to provide a comprehensive listing of vertebrate fauna and SRE invertebrate fauna known or likely to occur in the habitats present, and identification of conservation significant fauna species likely to occur in the area. Consideration of species listed under both the WA *Wildlife Conservation Act 1950* and the *Environment Protection & Biodiversity Conservation Act 1999 (*EPBC Act), and species listed by the Department of Parks and Wildlife as Priority Fauna to include, but not necessarily be limited to, the following species of conservation significance have been recorded in the Yandicoogina PBS surveys: • Brush-tailed Mulgara (*Dasycercus blythi*) • Star Swift (*Neochmia ruficaudo*) • Fork-tailed Swift (*Apus pacificus)* • Western Pebble-mound Mouse (*Pseudomys chapman*) • Olive Python (Pilbara subspecies) (*Liasis olivaceus barroni*) • Rainbow Bee-eater (*Merops arnatus*) • Any other Priority fauna species identified in a Level 1 survey as likely to occur in the Proposal Area.	Sections 15.2 to 15.4; Appendix 3; Biota (2015b)
	2. For each relevant conservation significant species, provide baseline information on their abundance (including known occurrences), distribution, ecology, and habitat preferences at both the site and regional levels.	Sections 15.2 to 15.4; Appendix 3; Biota (2015b)
	3. Conduct a Level 1 reconnaissance vertebrate and SRE invertebrate fauna survey and mapping of habitats including specialised	Sections 15.2 to 15.4; Appendix 3; Biota

Environmental factor		Work required	PER reference
		habitats within the development envelopes, identification and mapping of important, rare or unusual habitat types within areas to be impacted, in accordance with Guidance Statements 56 and 20. This should also consider other areas outside the proposed disturbance footprint to determine whether the most suitable areas have been chosen for location of infrastructure.	(2015b)
	4.	Consider habitat types that provide important ecological function e.g. riparian vegetation, protected area buffer zones, refugia, important habitat corridors, wetlands, areas of conservation significance or geological features which may support unique ecosystems. Analyse the extent of clearing, including percentages of habitat types to be cleared or otherwise impacted, to assist in determination of significance of impacts. Information, including maps, must also differentiate habitat on the basis of use e.g. breeding habitat, migration pathways, feeding habitat. Consider whether the remaining habitat has adequate carrying capacity.	Sections 15.2 to 15.6
	5.	Conduct Level 2 fauna surveys in areas that are likely to be directly or indirectly impacted as a result of the proposal. Surveys are to be undertaken in accordance with Guidance Statements 20 and 56. Additional targeted surveys for conservation significant fauna that are known to or likely to occupy habitats in the Project area may be required based on the results of the survey.	Sections 15.2 to 15.4; Appendix 3; Biota (2015b)
	6.	For each relevant conservation significant species, provide: • information on the conservation value of each habitat type from a local and regional perspective, including the percentage representation of each habitat type on-site in relation to its local and regional extent; and • if a population of a conservation significant species is present on the site, its size and the importance of that population from a local and regional perspective and potential percentage loss of the conservation significant species locally due to loss of habitat.	Sections 15.2 to 15.6
	7.	Discuss known existing threats to the species, whether or not attributable to the proposed action with reference to relevant impacts from the proposed action (including taking into consideration any relevant guidelines, policies, plans and statutory provisions).	Sections 15.2 to 15.4
	8.	Discuss potential direct/indirect (including downstream) and cumulative impacts to fauna as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance.	Sections 15.5 and 15.6
	9.	Discuss proposed management, monitoring and mitigation methods to be implemented including an assessment of the effectiveness of the methods, any statutory or policy basis for the methods.	Section 15.7
Subterranean Fauna	1.	Conduct surveys within areas to be impacted and in surrounding areas in accordance with Guidance Statement 54a.	Sections 16.2 and 16.3; Appendix 3; Biota (2015c, 2015d)
	2.	Present the results of the subterranean fauna surveys and discuss the potential for direct and indirect impacts to subterranean fauna including consideration of altered water regimes and nutrient flows.	Sections 16.2 to 16.4
	3.	Assess any impacts to subterranean fauna in accordance with EAG 12. For species which are likely to be impacted, provide	Sections 16.2 to 16.4

Environmental factor		Work required	PER reference
		information, including detailed geological maps on habitat continuity and an appropriate explanation of the likely distribution of species within those habitats.	
	4.	Discuss proposed management, monitoring and mitigation methods to be implemented.	Section 16.5
Hydrological Processes and Inland Waters Environmental Quality	1.	Provide information on the current status and outcomes of surface water discharge management actions required by Ministerial Statement 914 Condition 6 - Surface Water Discharge (Protection of Weeli Wolli Creek).	Section 13.2.4
	2.	Provide a detailed description of the design and location of the proposal with the potential to impact surface water or groundwater.	Sections 13.2 and 13.3
	3.	Characterise baseline hydrological and hydrogeological regimes.	Section 13.2
	4.	Develop a conceptual model of the surface and groundwater systems, incorporating the extent of connectivity between surface and ground water systems.	Section 13.2; Appendix 3; URS (2015)
	5.	Discuss the effectiveness of the current water management scheme and provide a comparison of its actual operation versus what was predicted including discussion of accuracy. Also detail any problems with how the system has operated and what management measures have been taken when it is not operating as expected.	Section 13.2
	6.	Present information on predicted annual dewatering requirements and surplus water quantities over the life of the operations.	Sections 13.2 and 13.3
	7.	Provide a conceptual mine water balance over the life of the proposal to discuss the capacity to reuse surplus mine dewater.	Section 13.2.4
	8.	Discuss the potential environmental impacts and benefits of identified surplus water management options (i.e. reuse on-site, local water supply, aquifer recharge etc.) and discuss the most appropriate water management strategy for the proposal.	Sections 13.3 and 13.5
	9.	Discuss the impacts to Weeli Wolli Creek and the potential impacts on Fortescue Marsh considering worst case conditions, including natural flow conditions and maximum anthropogenic inputs. Describe methods used to minimise the impacts to Weeli Wolli Creek, including minimising the period of surface discharge. Quantify the period of surface discharge required, as well as the extent of surplus mine dewater release (wetting front) and changes to flows within Weeli Wolli Creek.	Section13.3
	10.	Model the impact of different flooding scenarios during operations and post- closure on infrastructure and final landforms. Note the for any storm water infrastructure on-site and provide an explanation, including reference to standards and guideline documents, for the chosen criteria.	Section13.3
	11.	Detail and assess the geotechnical criteria of the bund or levee that will be located next to Weeli Wolli Creek. Discuss the permanency of the bund or levee in the catchment. Identify the likely source of the material that will be used to build the bund or levee, and describe how the design and structural integrity will withstand large storm events. If the bund or levee is part of a closure strategy assess the Iona term integrity of the bund taking into consideration different flooding scenarios or a worst case	Section 4.2.8 and 13.3

Environmental factor	Work required	PER reference
	scenario.	
	12. Investigate groundwater drawdown due to ground water abstraction associated with the proposal. Analyse and discuss any impacts to groundwater levels and flows taking into consideration the cumulative impacts with other proposals.	Section13.3
	13. Develop a conceptual model of the surface and groundwater systems, incorporating groundwater quality and the extent of connectivity between surface and ground water systems and Fortescue Marsh.	Sections 13.2 and 13.3
	14. Have the surface and groundwater modelling for this assessment independently peer reviewed. Determine the scope, timing and the selection of the peer review in consultation with the Department of Water. The groundwater modelling should be consistent with Australian Government National Water Commission's Australian Groundwater Modelling Guidelines (2012). The surface water modelling should be in accordance with the Australian Rainfall and Runoff Guidelines.	Section 3; Appendix 3; WorleyParsons (2015) and Hydrogeologic (2015)
	15. Analyse, discuss and assess surface water and groundwater impacts, including changes in groundwater levels and changes to surface water flows associated with the proposal together with cumulative impacts with other projects and referred proposals (including the BHPBIO strategic proposal) for which relevant information is publicly available.	Sections 13.3 and 13.4
	16. Discuss the proposed management, monitoring and mitigation to prevent groundwater and surface water impacts as a result of implementing the proposal.	Section 13.5
	17. Characterise baseline water quality, including the analysis of groundwater quality that is proposed to be discharged into the surrounding environment.	Sections 13.2 and 13.3
	18. Develop a conceptual model of the surface and groundwater systems, incorporating groundwater quality and the extent of connectivity between surface and ground water systems and Fortescue Marsh (same requirement for hydrological processes).	Sections 13.2 and 13.3
	19. Undertake a hydrological investigation to determine what effect groundwater abstraction, and modified drainage will have on the surface water and groundwater quality and quantity of the area, including interactions between surface and groundwater.	Sections 13.2 and 13.3; Appendix 3; URS (2015)
	20. Have the surface and groundwater modelling for this assessment independently peer reviewed. Determine the scope, timing and the selection of the peer review in consultation with the Department of Water. The modelling should be consistent with Australian Government National Water Commission's Australian Groundwater Modelling Guidelines (2012) (same requirement for hydrological processes).	Section 3; Appendix 3; WorleyParsons (2015) and Hydrogeologic (2015)
	21. Undertake a comprehensive review of surface water and groundwater quality collected from the existing mining operation at the site. Identify any adverse changes caused by the mining operation and outline avoidance, minimisation and management methods to be used to prevent further impacts.	Sections 13.2 and 13.5
	22. Undertake waste characterisation studies of waste rock and other materials and carry out an acid and metalliferous drainage risk	Sections 13.3.7 and 17.2.2

Environmental factor	Work required	PER reference
	assessment. Detail where Potentially Acid Forming (PAF) material will be located and discuss stored and containment options, including sub-aqueous storage.	
	23. Provide a description of the design, location and extent of discharges of the proposed waste facilities, and any other elements of the proposal with the potential to impact surface water or groundwater quality.	Sections 13.3 and 13.5
	24. Model cumulative impacts with other mines in the catchment (currently operating and referred proposed mines, including the BHPBIO strategic proposal, where information is publicly available). Develop strategies and controls to minimise the impacts.	Sections 13.3 to 13.6
	25. Confirm whether or not pit lakes may form and provide details of potential backfill options. If pit lakes may form, provide an assessment of the long term contamination of any pit lakes and the potential impact on groundwater and surface water quality with particular attention to possible impacts on Fortescue Marsh. In addition, undertake a risk assessment in accordance with the most recent version of the joint DMP/EPA Mine Closure Guidelines and provide details of mitigation measures undertaken to reduce the risk of any pit lakes.	Section 17
	26. Discuss proposed management , monitoring and mitigation methods, including the identification of water quality trigger levels, to be implemented during construction, operation and following closure to ensure that the EPA's objective for this factor is met.	Section 13.5.
Rehabilitation and Closure	1. Provide information on the current status of Yandicoogina Decommissioning and Rehabilitation Plan required by Ministerial Statement 914 Condition 9 - Decommissioning and Rehabilitation.	Section 17.2.1
	2. Undertake a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including any rehabilitation that has been conducted to date within the Development Envelope. Including a discussion of the different methodology and success rates for the various proposed disturbance types including: • created landforms (e.g. waste rock dump, tailings storage facility); • short term disturbances (e.g. borrow pits and access tracks); • long term disturbances (e.g. construction camp, permanent accommodation village and administration buildings); and • linear and/or fragmentation disturbances (e.g. roads, power lines, bore fields).	Appendix 4; Rio Tinto (2015c)
	3. Provide waste characterisation work including static, short term leaching and kinetic test results, and water quality monitoring results for drainage from existing waste storage facilities to enable a thorough assessment of acid and metalliferous drainage risk posed by the project. If PAF material is identified, provide mine scheduling detail to demonstrate that PAF material is not disturbed during mining and/or that effective strategies will be in place to ensure PAF material is adequately managed should it be exposed and/or disturbed.	Sections 13.3.7 and 17.2.2
	4. Provide the physical characteristics of the waste materials and proposed locations and geotechnical design detail (including slope	Section 17.2.3

Environmental factor	Work required	PER reference
	stability) for the waste landforms, including the WFSFs. Identify proposed management and monitoring for the waste landforms. Describe contingencies to make landforms secure and non-polluting in the event of unexpected or temporary closure.	
	5. Prepare a Rehabilitation and Mine Closure Plan consistent with the current version of the Department of Mines and Petroleum (DMP) and EPA Guidelines for Preparing Mine Closure Plans. Include completion criteria and closure objectives addressing native vegetation and habitat for significant flora and fauna and base the conclusions on the availability of suitable substrates and landform design. Establish and measure vegetation and fauna reference sites to inform completion criteria. Determine requirements for, and sources of, soil and seed for rehabilitation. A conclusive discussion on backfill options (including 'worst case scenario') is also required.	Appendix 4; Rio Tinto (2015c)
	6. Discuss proposed management, monitoring and mitigation methods to be implemented including post-mining land use and areas to be rehabilitated.	Section 17.4
	7. Discuss proposed monitoring of linkages of specialised habitats to demonstrate that rehabilitated areas function as ecological corridors for conservation significant fauna.	Section 17.4; Appendix 4; Rio Tinto (2015c)
Offsets (Residual Risk Management)	1. Examine residual impacts and, if required, develop a draft program of environmental offsets that adheres to the relevant policy/guidance document listed below.	Section 18
	2. Include the completed Environmental Offsets Reporting Form and any offsets required and proposed in the PER.	Section 18
Heritage (Indigenous)	Not stated (other environmental factor)	NA
Air Quality	Not stated (other environmental factor)	NA
Amenity	Not stated (other environmental factor)	NA

Appendix 3: Supporting studies

The following supporting documents are contained on CD inside the back cover of the PER:

Biota Environmental Sciences (Biota) 2011. *Yandicoogina Expansion Billiard Deposit Fauna Survey*. Report prepared for Rio Tinto, January 2011.

Biota Environmental Sciences (Biota) 2014. *Pocket and Billiard South Level 2 Seasonal Fauna Survey*. Report prepared for Rio Tinto, November 2014.

Biota Environmental Sciences (Biota) 2014. *Yandi Billiards – Interim Report on Conservation Significant Terrestrial Fauna.* Report prepared for Rio Tinto, September 2014.

Biota Environmental Sciences (Biota) 2014. *Yandi Billiards Targeted Northern Quoll Survey.* Report prepared for Rio Tinto, September 2014.

Biota Environmental Sciences (Biota) 2014. *Yandi Billiards Vegetation and Flora Survey – Phase 1 and Phase 2*. Report prepared for Rio Tinto, October 2014.

Biota Environmental Sciences (Biota) 2015. *Yandi Billiards Troglobitic Fauna Assessment*. Report prepared for Rio Tinto, April 2015.

Biota Environmental Sciences (Biota) 2015. *Yandi Operations Stygofauna Data Consolidation 2003 – 2014.* Report prepared for Rio Tinto, April 2015.

Biota Environmental Sciences (Biota) 2015. *Yandi Terrestrial Fauna Integration Report*. Report prepared for Rio Tinto, January 2015.

Biota Environmental Sciences (Biota) 2015. *Yandi Vegetation and Flora Integration Report*. Report prepared for Rio Tinto, March 2015.

Eastham J. 2015. *Understanding riparian vegetation responses to groundwater drawdown and discharge from below water table mining in the Pilbara*. Report prepared for Rio Tinto, July 2015.

Hydrogeologic Pty Ltd (Hydrogeologic) 2015. *Rio Tinto Yandi Mine Groundwater Flow Model Independent Review*. Report prepared for Rio Tinto, February 2015.

Rio Tinto Pty Ltd (Rio Tinto) 2014. *Revised discharge extent modelling in Weeli Wolli Creek based on measured channel loss rates*. Report prepared by Rio Tinto, December 2014.

Rio Tinto Pty Ltd (Rio Tinto) 2014. *Yandicoogina Billiard acid and metalliferous drainage risk*. Report prepared by Rio Tinto, June 2014.

Rio Tinto Pty Ltd (Rio Tinto) 2014. *Yandicoogina – Pocket and Billiards South model setup, calibration and estimation of dewatering requirements*. Report prepared by Rio Tinto, November 2014.

Rio Tinto Pty Ltd (Rio Tinto) 2015. *Riparian Vegetation of Marillana and Weeli Wolli Creeks: Mapping refinement and assessment of values and significance*. Report prepared by Rio Tinto, October 2015.

Rio Tinto Pty Ltd (Rio Tinto) 2015. *Supporting document for the Yandi Pocket and Billiard South Project Public Environmental Review (PER), Yandi Rehabilitation Review*. Report prepared by Rio Tinto, March 2015.

Rio Tinto Pty Ltd (Rio Tinto) 2015. *Weeli Wolli Creek Ecohydrology – Yandicoogina Pocket and Billiard South Pre-Feasibility Study.* Report prepared by Rio Tinto, April 2015.

RPS 2015. *Yandicoogina Billiard South Water Balance*. Report prepared for Rio Tinto, April 2015.

URS Australia Pty Ltd (URS) 2015. *Environmental risk assessment for riparian zones on Weeli Wolli Creek*. Report prepared for Rio Tinto, June 2015.

Wetland Research & Management (WRM) 2015. *Yandicoogina: Cumulative impacts of mining on Marillana and lower Weeli Wolli Creeks, Dry 2013 and Wet 2014 sampling*. Report prepared for Rio Tinto, July 2015.

WorleyParsons 2015. *Billiards South Pre-feasibility Study, Review of surface water modelling*. Report prepared for Rio Tinto, March 2015.

Appendix 4: Environmental management documents

The following environmental management documents are contained on CD inside the back cover of the PER:

- Yandicoogina Monitoring and Management Plan (MMP) (October 2015), which includes:
  - Yandicoogina Vegetation and Groundwater Dependant Ecosystems Monitoring and Management Plan; and
  - Yandicoogina Surface Water Discharge Monitoring and Management Plan;
- Yandicoogina Weed Action Plan (July 2012); and
- Rio Tinto Significant Species Management Plan (including Yandicoogina Significant Species Management Plan addendum) (September 2014).
- Yandicoogina Closure Plan (August 2015).

Appendix 5: EPA checklist for documents submitted for EIA on marine and terrestrial biodiversity

Checklist Item	Completed	PER reference
PART 1 – GENERAL QUALITY OF DOCUMENTS		
Ensure that the following standard elements are present in all documentation (including appendices):		
A clear and concise title that outlines basic information about the proposal and purpose of the document.	✓	Cover page
Date and document revision number.	✓	Cover page
Information identifying the document's author and publishing entity.	✓	Cover page
All issues identified in a scoping guideline or scoping document have been addressed and covered in the report.	✓	**Appendix 2**
Complete and correct tables of contents, maps, tables and figures.	✓	Table of Contents; Figure 1 to **Figure 80**; **Table 1** to **Table 47**
Suitably-sized scale maps placing the proposal into both a regional and local context.	✓	Figure 1 and **Figure 2**
Figures, plates, maps, technical drawings or similar including scale bar, legend, informative caption, labels identifying important or relevant locations/features referred to in the document text.	✓	Figure 1 to **Figure 80**
All survey site locations and derived data products (e.g. benthic habitat maps, vegetation maps) have been provided in map and appropriate GIS-based electronic database forms.	✓	GIS-based electronic data contained on CD inside back cover of PER
All survey data from terrestrial biological surveys have been provided in electronic database form (Access/Excel).	✓	Contained on CD inside back cover of PER

Checklist Item	Completed	PER reference
Proposed infrastructure is shown on scale maps and associated spatial data and are provided in an appropriate GIS-based electronic database form.	✓	**Figure 4**; GIS-based electronic data contained on CD inside back cover of PER
A list of references that have been cross-checked to ensure that all references in the Reference list are cited in the text (and vice versa).	✓	Section 27
All information based on 'expert' opinion/judgement are explicitly attributed, by name and qualification, to a person/s or organisation.	✓	Entire document
Where relevant, appendices are attached to the main EIA document that describe the details of technical work undertaken to underpin the content of the main document, and explicitly attributed by name to the author/s and (if applicable) their organisation.	✓	**Appendix 3**
Description(s) of the proposal are internally consistent throughout all documentation and are couched to allow potential environmental impacts to be placed in local and regional contexts, including cumulative impacts of existing and approved developments.	✓	Section 4
Descriptions of the local and regional environmental features most likely to be directly or indirectly affected by the proposal.	✓	Sections 5 to 7
PART 3 – TERRESTRIAL BIODIVERSITY ISSUES		
For proposals likely to impact on native flora and vegetation/plant communities, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 51, *Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment* (June 2004), including:		
Determining the level of flora and vegetation survey consistent with that expected in Table 3 of Guidance Statement No. 51 (Appendix 2);	✓	**Appendix 3**; Biota (2015a)
Describing the survey area and methodologies, including reference to timing, duration, survey effort, any survey limitations, and the nomenclature used (WA Herbarium);	✓	**Appendix 3**; Biota (2015a)
Maps and text describing the survey area/plot sites, location of significant species, vegetation mapping, vegetation condition assessment and predicted extent of impact on the vegetation;	✓	**Figure 43** to **Figure 56**; Sections 14.2 and 14.3
A comprehensive list of flora species identified and assessment of threatened, Priority or other significant flora / Ecological Communities (TECs, PECs) known or reasonably expected to occur in the area (as defined in Guidance Statement 51);	✓	Sections 14.2 and 14.3; further detail provided in **Appendix 3**, Biota (2015a)
Evaluating the impact of the proposal on the species/communities, including reference to the extent of regional clearing of the vegetation complex/type and ecological linkage; and	✓	Sections 14.3 and 0

Checklist Item	Completed	PER reference
All quadrat data used in reporting provided as electronic database in raw form, in addition to hardcopy reports.	✓	Contained on CD inside back cover of PER
For proposals likely to impact on vertebrate fauna or fauna habitat, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 56, *Terrestrial Fauna Surveys for Environmental Impact Assessment* (June 2004) and *Technical Guide Terrestrial Fauna Surveys for Environmental Impact Assessment* (EPA and Department of Environment and Conservation 2010), including		
Determining the level of fauna survey consistent with that expected in Table 3 (Appendix 2) of Guidance Statement No. 56;	✓	**Appendix 3**; Biota (2015b)
Describing the survey methodologies in the context of EPA and DEC (2010), including reference to timing, duration and survey effort used to sample each of the fauna groups sampled, any survey limitations and the nomenclature used (WA Museum checklist except for birds which should follow Christidis and Boles 2008);	✓	**Appendix 3**; Biota (2015b)
Maps and text describing the survey area, sampling locations and fauna habitats; and	✓	**Figure 57** to **Figure 61**, **Figure 64** and **Figure 65**; Sections 15.2 and 15.4; further detail available in **Appendix 3**, Biota (2015b)
A comprehensive list and assessment of fauna known or reasonably expected to occur in the area, including Specially Protected and other significant fauna (as defined in Guidance Statement No. 56), and an evaluation of the impact of the proposal on the species and key habitat/s.	✓	Sections 15.2, 15.4 and 15.5; further detail available in **Appendix 3**, Biota (2015b)
For proposals with the potential to impact on short range endemic (SRE) invertebrate fauna or SRE habitat, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 20, *Sampling of Short Range Invertebrate Fauna for Environmental Impact Assessment in Western Australia* (May 2009), including:		
Early initial assessment for restricted habitat types that have potential to support SRE fauna, including advice from the WA Museum and the DEC/OEPA.	✓	**Appendix 3**; Biota (2015b)
Maps and text describing the survey area, potential SRE habitats and regional context and extent of predicted impact on the habitat.	✓	**Figure 62** and **Figure 63**; Sections 15.3, 15.5.2.2 and 1.1.1; further detail available in Appendix 3, Biota (2015b)
Describing the survey methodologies, including reference to timing, duration and survey effort used to sample each of the SRE groups sampled, and any survey limitations.	✓	**Appendix 3**; Biota (2015b)
A survey report with assessment of SRE fauna found or reasonably expected to occur in the area, including any Specially Protected and other significant fauna, their known occurrence/habitats locally and their wider status if known, and an evaluation of the risk of the proposal to long term survival of the species and community.	✓	**Appendix 3**; Biota (2015b)

Checklist Item	Completed	PER reference
For proposals with the potential to impact on subterranean (stygofauna and troglofauna) fauna, the EIA document describes how potential impacts have been addressed in the context of EPA Guidance Statement No. 54 *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia* (2003) and 54a, *Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia* (Draft 2007), including:		
Early initial desktop review to determine if the site has potentially suitable geology /substrate habitat that could support subterranean fauna, including advice from the WA Museum and the DEC/OEPA and a pilot study, if appropriate;	✓	**Appendix 3**; Biota (2015c,d)
A subterranean fauna survey report, if the site has a very high or high likelihood of supporting subterranean fauna, or a pilot study indicated that the site supports a significant subterranean fauna;	✓	**Appendix 3**; Biota (2015c,d)
Maps and text identifying and describing the survey sites/area, and the geology/ habitat supporting subterranean fauna, and extent of predicted impacts on the habitat (Note the survey area should extend beyond the predicted impact zone);	✓	further detail available **Appendix 3** Biota (2015c,d)
Describing the survey methodologies (see Guidance Statement No. 54a), including reference to timing, duration and survey effort used to sample each of the fauna groups sampled, species identification, and any survey limitations; and	✓	**Figure 66** to **Figure 76;** Sections **16.2** and **16.4;** further detail available **Appendix 3**; Biota (2015c,d)
A comprehensive list and assessment of subterranean fauna recorded or reasonably expected to occur in the area, including any Specially Protected and other significant fauna and their known occurrence/habitats locally and their wider status if known, and an evaluation of the risk of the proposal to long term survival of the species and community.	✓	Section 16.2, further detail available **Appendix 3**; Biota (2015c,d)

Appendix 6: Existing Ministerial Statement 914 environmental conditions and proposed environmental conditions for the Yandicoogina Iron Ore Project – Revised Proposal

Condition No.	Existing Condition	Proposed Condition	Reason for change
Proposal implementation			
1-1	When implementing the proposal, the proponent shall not exceed the authorised extent of the proposal as defined in Column 3 of Table 2 in Schedule 1, unless amendments to the proposal and the authorised extent of the Proposal has been approved under the EP Act.	When implementing the proposal, the proponent shall not exceed the authorised extent of the proposal as defined in Schedule 1, unless amendments to the proposal and the authorised extent of the Proposal **have** been approved under the EP Act.	Removal of Column 3 of Table 2. Update based on new Schedule 1
Contact details			
2-1	The proponent shall notify the CEO of any change of its name, physical address or postal address for the serving of notices or other correspondence within 28 days of such change. Where the proponent is a corporation or an association of persons, whether incorporated or not, the postal address is that of the principal place of business or of the principal office in the State.	The proponent shall notify the CEO of any change of its name, physical address or postal address for the serving of notices or other correspondence within 28 days of such change. Where the proponent is a corporation or an association of persons, whether incorporated or not, the postal address is that of the principal place of business or of the principal office in the State.	No Change
Time limit for proposal implementation			
3-1	The proponent shall not commence implementation of the proposal after the expiration of five years from the date of this statement, and any commencement, within this five year period, must be substantial.	**Remove**	Yandicoogina Operations is currently a brownfields site and substantially commenced operations in 1996. Consistent with other Brownfields operations contemporised Ministerial Statements (e.g. MS 1000).

3-2	Any commencement of implementation of the proposal, within five years from the date of this statement, must be demonstrated as substantial by providing the CEO with written evidence, on or before the expiration of five years from the date of this statement.		
Compliance reporting			
4-1	The proponent shall prepare and maintain a compliance assessment plan to the satisfaction of the CEO.	The proponent shall prepare and maintain a compliance assessment plan to the satisfaction of the CEO at least six (6) months prior to the first compliance assessment report required by condition 4-6. ~~**or prior to implementation, whichever is sooner.**~~	Condition contemporised between split of 4-1 and 4-2. The proposal is already implemented and hence the prior to implementation (of the proposal) is not possible.
4-2	The proponent shall submit to the CEO the compliance assessment plan required by condition 4-1 at least six months prior to the first compliance report required by condition 4-6, or prior to implementation, whichever is sooner. The compliance assessment plan shall indicate: (1) the frequency of compliance reporting; (2) the approach and timing of compliance assessments; (3) the retention of compliance assessments; (4) the method of reporting of potential non-compliances and corrective actions taken; (5) the table of contents of compliance assessment reports; and (6) public availability of compliance assessment reports.	The compliance assessment plan shall indicate: (1) the frequency of compliance reporting; (2) the approach and timing of compliance assessments; (3) the retention of compliance assessments; (4) the method of reporting of potential non-compliances and corrective actions taken; (5) the table of contents of compliance assessment reports; and (6) public availability of compliance assessment reports.	
4-3	The proponent shall assess compliance with conditions in accordance with the compliance assessment plan required by condition 4-1.	**After receiving notice in writing from the CEO that the compliance assessment plan satisfies the requirements of condition 4-2** the proponent shall assess compliance with conditions in accordance with the compliance assessment plan required by condition 4-1.	Condition contemporised to reflect more recent Ministerial Statements.
4-4	The proponent shall retain reports of all compliance assessments described in the	The proponent shall retain reports of all compliance assessments described in the	No Change

	compliance assessment plan required by condition 4-1 and shall make those reports available when requested by the CEO.	compliance assessment plan required by condition 4-1 and shall make those reports available when requested by the CEO.	
4-5	The proponent shall advise the CEO of any potential non-compliance within seven days of that non-compliance being known.	The proponent shall advise the CEO of any potential non-compliance within seven days of that non-compliance being known.	No Change
4-6	The proponent shall submit to the CEO a compliance assessment report by the end of April each year addressing compliance in the previous calendar year. The first compliance assessment report must be submitted by 30 April 2013 addressing compliance for the period from the date of issue of this statement, notwithstanding that the first reporting may be less than 12 months. The compliance assessment report shall: (1) be endorsed by the proponent's Managing Director / General Manager / Chief Executive Officer or a person delegated to sign on the Managing Director's / General Manager's / Chief Executive Officer's behalf; (2) include a statement as to whether the proponent has complied with the conditions; (3) identify all potential non-compliances and describe corrective and preventative actions taken; (4) be made publicly available in accordance with the approved compliance assessment plan; and (5) indicate any proposed changes to the compliance assessment plan required by condition 4-1.	The proponent shall submit to the CEO a compliance assessment report by the end of April each year addressing compliance in the previous calendar year. The compliance assessment report must address compliance for the period from the date of issue of this statement, notwithstanding that the first report may cover a period less or **more** than 12 months. The compliance assessment report shall: (1) be endorsed by the proponent's Managing Director / General Manager / Chief Executive Officer or a person delegated to sign on the Managing Director's / General Manager's / Chief Executive Officer's behalf; (2) include a statement as to whether the proponent has complied with the conditions; (3) identify all potential non-compliances and describe corrective and preventative actions taken; (4) be made publicly available in accordance with the approved compliance assessment plan; and (5) indicate any proposed changes to the compliance assessment plan required by condition 4-1.	Minor change if compliance assessment report covers 13 months if approval granted 1 month or less prior to compliance assessment reporting period.
Public availability of data			

5-1	Subject to condition 5-2, within six months of the issue of this statement and for the remainder of the life of the proposal the proponent shall make publicly available, in a manner approved by the CEO, all validated environmental data (including sampling design, sampling methodologies, empirical data and derived information products [e.g. maps]) relevant to the assessment of this proposal and implementation of this statement.	Subject to condition 5-2, within six months of the issue of this statement and for the remainder of the life of the proposal the proponent shall make publically available, in a manner approved by the CEO, all validated environmental data (including sampling design, sampling methodologies, empirical data and derived information products [e.g. maps]) relevant to the assessment of this proposal and implementation of this statement.	No Change
5-2	If any data referred to in condition 5-1 contains particulars of: (1) a secret formula or process; or (2) confidential commercially sensitive information The proponent may submit a request for approval from the CEO to not make this data publically available. In making such a request the Proponent shall provide the CEO with an explanation and reasons why the data should not be made publically available.	If any data referred to in condition 5-1 contains particulars of: (1) a secret formula or process; or (2) confidential commercially sensitive information The proponent may submit a request for approval from the CEO to not make this data publically available. In making such a request the Proponent shall provide the CEO with an explanation and reasons why the data should not be made publically available.	No Change
Surface water discharge (protection of Weeli Wolli Creek)			
6-1	The proponent shall ensure that the discharge of excess water from the Yandicoogina Iron Ore Project - Expansion to Include Junction South West and Oxbow Deposits as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek System.	The proponent shall ensure that the discharge of excess water from the Yandicoogina Iron Ore Project – **Revised Proposal** as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek system.	Change to reflect Revised Proposal name.
6-2	To verify that condition 6-1 is being met, the proponent shall develop an Environmental Values Statement for the Weeli Wolli Creek System that defines the environmental values of the Weeli Wolli Creek System to the satisfaction of the CEO in consultation with the DEC.	To verify that condition 6-1 is being met, the proponent shall **maintain** an Environmental Values Statement for the Weeli Wolli Creek system that defines the environmental values of the Weeli Wolli Creek system to the satisfaction of the CEO in consultation with **Parks and Wildlife**.	DEC changed to Parks and Wildlife.

6-3	The proponent shall ensure that dewatering discharge from the Yandicoogina Iron Ore Project - Expansion to Include Junction South West and Oxbow Deposits does not cause water flow or pooling further than 17 kilometres downstream from the Marillana Creek and Weeli Wolli Creek System Confluence.	The proponent shall ensure that dewatering discharge from the Yandicoogina Iron Ore Project – Revised Proposal does not cause water flow downstream from the Marillana Creek and Weeli Wolli Creek system Confluence further than the extent identified in Schedule 1 (under natural no flow conditions)	Contemporised condition in line with more recent Ministerial statements, with discharge extent included in proposed Schedule 1. Inclusion of 'under natural no flow conditions' to meet the intent of the condition and reflect the wording in Schedule 1. Removal of 'pooling' as localised natural pools can be created during rainfall events and can persist for extended periods due to variable basement geology.
6-4	The proponent shall ensure that any dewater discharged to the environment does not exceed whichever is greater of the following: (1) the default trigger for the protection of marine and freshwater ecosystems as per the Australian and New Zealand Environmental and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ (2000)) Australian Water Quality Guidelines for Fresh and Marine Waters and its updates; or (2) baseline levels identified pursuant to condition 6-6(3). (3) other criteria agreed by the CEO on the advice of the Department of Environment Regulation.	**Remove**	Condition contemporised to match more recent Ministerial Statements (e.g. MS 1000) and management under Part IV of the EP Act (by DER).
6-5	The proponent shall prepare a Water Discharge Monitoring and Management Plan.	**Remove**	Original condition is redundant as a Water Discharge Monitoring and Management Plan has been developed and implemented for the existing Yandicoogina Operations

6-6	The Water Discharge Monitoring and Management Plan required pursuant to condition 6-5 shall: (1) when implemented, require the proponent to monitor to substantiate whether condition 6-1, 6-3 and 6-4 are being met; (2) (when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of condition 6-1, 6-3 and 6-4; (3) identify water quality baseline levels at the Western tenement boundary for the criteria measured under the Australian and New Zealand Environmental and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ (2000)) Australian Water Quality Guidelines for Fresh and Marine Waters and its updates; (4) require the proponent to monitor the hydrology, extent of discharges and ecology of the Weeli Wolli Creek System; (5) include provisions for remediating the Weeli Wolli Creek System to ensure that identified environmental values associated with the Weeli Wolli Creek System and any downstream ecosystems, including the Fortescue Marsh, are maintained.	**<u>New Condition 6-4</u>** **The proponent shall submit a revised** Water Discharge Monitoring and Management Plan **in consultation with the DoW, to the satisfaction of the CEO, to ensure that identified environmental values associated with the Weeli Wolli Creek system and any downstream ecosystems, including the Fortescue Marsh, are maintained. This plan shall:** **(1) describe the water discharge and monitoring program;** **(2) when implemented, demonstrate by monitoring, whether conditions 6-1 and 6-3 are being met;** **(3) when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of conditions 6-1 and 6-3; and** **(4) detail management actions and strategies to be implemented should the monitoring required by condition 6-4 (2) indicate that condition 6-1 or 6-3 may not be met.**	Condition updated to reflect a revision of the existing approved and implemented Water Discharge Monitoring and Management Plan. Condition contemporised to match more recent Ministerial Statements.
6-7	Prior to commencing groundwater abstraction from or excavation below the water table at Junction South West A, Junction South West C and Oxbow and until advised otherwise by the CEO, the proponent shall implement the approved Water Discharge Monitoring and Management Plan.	**<u>New Condition 6-5</u>** The proponent shall implement the approved Water Discharge Monitoring and Management Plan **required by condition 6-4, and any subsequent approved revisions.**	Condition updated to reflect the updated Proposal and the existing approved and implemented Water Discharge Monitoring and Management Plan.

6-8	Commencing on the date of this statement and until it commences implementation of the approved Water Discharge Monitoring and Management Plan in accordance with condition 6-7, the proponent shall implement Section 1 Groundwater Management Plan and Section 2 Surface Water Management Plan of Part 3 - Management Plans of the *Yandicoogina Iron Ore Environmental Management Program (March 2011*).	**Remove**	Redundant as covered by the requirements of Condition 6-5.
6-9	The proponent shall annually submit the results of monitoring required by condition 6-6, in the compliance assessment report required by condition 4-6.	**Remove**	Redundant as covered by the requirements of Condition 4.
Riparian vegetation			
7-1	The proponent shall ensure that groundwater abstraction does not cause clearing or loss of vegetation or groundwater dependent ecosystems outside Zones 1, 2, 2a, 3, 3a, 4 and 5 as shown in Figure 1.	The proponent shall ensure that groundwater abstraction does not cause **long term impacts on the health or cover of riparian** vegetation or groundwater dependent ecosystems outside the **management** zones **as shown in Figure 80.**	Reference to clearing removed as condition relates to impacts of groundwater abstraction. Clearing of vegetation is managed under Schedule 1. Condition updated to reflect: • objectives in relation to riparian vegetation; • contemporised conditions. • the impacts recognised in the original MS914 approval (Report 1448) • impacts predicted to riparian vegetation (particularly artificially augmented vegetation); and • abundance changed to cover – to more accurately reflect measurable tree health monitoring parameters; and • new impact management zones.

7-2	The proponent shall ensure that dewatering discharge does not cause clearing or loss of vegetation or groundwater dependent ecosystems outside Zones 1, 2, 2a, 3, 3a, 4 and 5.	The proponent shall ensure that **surplus** water discharge does not cause **long term impacts on the health or cover of riparian** vegetation or groundwater dependent ecosystems outside the **management** zones **as shown in Figure 80**.	Reference to clearing removed as condition relates to impacts of surplus water discharge. Dewatering discharge changed to surplus water discharge as dewatering is a generic term covering both abstraction and discharge. Clearing of vegetation is managed under Schedule 1. Condition updated to reflect: • objectives in relation to riparian vegetation; • contemporised conditions; • the impacts recognised in the original MS914 approval (Report 1448); • impacts predicted to riparian vegetation (particularly artificially augmented vegetation); • abundance changed to cover – to more accurately reflect measurable tree health monitoring parameters; and • new impact management zones.
7-3	The proponent shall manage the proposal in a manner that ensures there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems within Zones 1, 2, 2a, 3, 3a, 4 and 5.	The proponent shall manage the proposal in a manner that ensures there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems **across the catchment as measured** within the **management** zones **as shown in Figure 80.**	Condition updated to reflect predicted localised impacts to riparian vegetation *within* the management zones, but no irreversible impact to the local catchment functioning (*across* the management zones).
7-4	The proponent shall prepare a Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.	The proponent shall **submit a revised** Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan to the satisfaction of the CEO.	Revision only: the current Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan for Yandicoogina Operation has been approved and implemented.
7-5	The Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan required pursuant to condition 7-4 shall: (1) when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of conditions 7-1, 7-2, and 7-3; (2) when implemented, require the proposal to monitor to substantiate whether conditions 7-	The Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan required pursuant to condition 7-4 shall: (1) when implemented, require the proponent to manage the implementation of the proposal to meet the requirements of conditions 7-1, 7-2, and 7-3; (2) when implemented, require the	Condition contemporised to match more recent Ministerial Statements. Clause (3) – (5) covered by conditions 7-1, 7-2, 7-3 and Condition 6. As per comments in Condition 7-1 & 7-2

1, 7-2 and 7-3 are being met;

(3) require the proponent to minimise impact to riparian Vegetation and Groundwater dependent ecosystems from groundwater abstraction and dewatering discharge;

(4) require the proponent to maintain the abundance, diversity, geographical distribution and productivity of vegetation communities through the avoidance or management of adverse impacts and improvement in knowledge;

(5) require the proponent to maintain the flow paths, quantity and quality of water within Marillana, Yandicoogina and Weeli Wolli Creeks and the underlying aquifers to protect the surface water and groundwater dependent ecological systems;

(6) identify potential impact monitoring and control sites between the Oxbow pit and the Fortescue Marsh;

(7) require the proponent to design a survey to acquire baseline biotic data, including health and abundance parameters and environmental data;

(8) define health and abundance parameters;

(9) define monitoring frequency and timing;

(10) identify criteria to measure any decline in health;

(11) define critical correlative environmental parameters, including groundwater drawdown;

(12) define trigger levels for no impact;

(13) define trigger levels for no irreversible impact;

(14) provide details of management actions and strategies to be implemented should trigger levels defined pursuant to condition 7 -5(12) be exceeded outside Zones 1, 2, 2a, 3, 3a, 4 and 5; and

(15) provide details of management actions and strategies to be implemented should trigger

proposal to monitor to substantiate whether conditions 7-1, 7-2 and 7-3 are being met;

(3) identify monitoring sites;

(4) require the proponent to design a survey to acquire baseline biotic data, including health and abundance parameters and environmental data;

(5) define health and cover parameters;

(6) define monitoring frequency and timing;

(7) identify criteria to measure any decline in health;

(8) define critical correlative environmental parameters, including groundwater drawdown;

(9) define trigger **and threshold** levels for 'no irreversible impact';

(10) provide details of management actions and strategies to be implemented should trigger **and threshold** levels defined pursuant to condition 7-5(9) be exceeded within the management zones.

	levels defined pursuant to condition 7-5(13) be exceeded within Zones 1, 2, 2a, 3, 3a, 4 or 5.		
7-6	Prior to commencing groundwater abstraction from or excavation below the water table at Junction South West A, Junction South West C and Oxbow and until advised otherwise by the CEO, the proponent shall implement the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.	The proponent shall implement the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.	Condition revised to reflect that an existing approved and implemented Groundwater Dependent Ecosystems Monitoring and Management Plan exists for the Yandicoogina Operations and that Yandicoogina Operations already implements dewatering activities.
7-7	The proponent shall review and revise the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan at intervals not exceeding five years, to the approval of the CEO.	The proponent shall review and revise the approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan at intervals not exceeding five years, to the approval of the CEO.	No Change
7-8	Commencing on the date of this statement and until it commences implementation of the approved Vegetation and Groundwater. Dependent Ecosystems Monitoring and Management Plan in accordance with condition 7-6, the proponent shall implement Section 6 Riparian vegetation management Plan Part 3 - Management Plans of the Yandicoogina Iron Ore Environmental Management Program (March 2011).	Commencing on the date of this statement and until it commences implementation of the **revised** Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan in accordance with condition 7-6, the proponent shall **continue to** implement **the existing approved Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan.**	Condition revised to reflect that an existing approved and implemented Groundwater Dependent Ecosystems Monitoring and Management Plan exists for the Yandicoogina Operations and that Yandicoogina Operations already implements dewatering activities.
7-9	In the event that monitoring, undertaken pursuant to condition 7-6, identifies that trigger levels for no impact, defined pursuant to condition 7-5(12), have been or are being exceeded outside Zones 1, 2, 2a, 3, 3a, 4 and 5, the proponent shall implement management actions and strategies defined in condition 7-5(14) to the satisfaction of the CEO.	In the event that monitoring, undertaken pursuant to condition 7-6, identifies that trigger **and threshold** levels for no **irreversible impact,** defined pursuant to condition 7-5**(9)**, have been or are being exceeded **within the management** zones, the proponent shall implement management actions and strategies defined in condition 7-5**(10)** to the satisfaction of the CEO.	Condition is not feasible to measure outside of the management zones as monitoring extends only to the limit of conservative predicted impact extents. Impacts to riparian vegetation have been predicted in the original MS914 approval and the current approval. Intent of the condition is that there are no irreversible impacts.

7-10	In the event that monitoring, undertaken pursuant to condition 7-6, identifies that trigger levels for no irreversible impact, defined pursuant to condition 7-5(13), have been or are being exceeded within Zones 1, 2, 2a, 3, 3a, 4 or 5, the proponent shall implement management actions and strategies defined in condition 7-5(15) to the satisfaction of the CEO.	Remove	Captured in proposed Condition 7-9.
Weeds			
8-1	The proponent shall ensure: (1) no increase in the species of weeds (including both declared weeds and environmental weeds) in the Proposal Area as a result of the implementation of the proposal; (2) the cover of weeds (including both declared weeds and environmental weeds) within the Proposal Area does not exceed that on comparable, nearby land, determined by the CEO which has not been disturbed during implementation of the proposal; and (3) reference sites on nearby land are to be chosen in consultation with the OEPA, on advice from Parks and Wildlife and established within the Proposal Area and outside the impact area to the satisfaction of the CEO. The reference sites are to be monitored biennially to determine whether changes in weed cover and type are as a result of proposal implementation or broader regional changes.	The proponent shall ensure: (1) no increase in the species of weeds (including both declared weeds and environmental weeds) in the Proposal Area as a result of the implementation of the proposal; (2) the cover of weeds (including both declared weeds and environmental weeds) within the Proposal Area does **not increase as a result of** implementation of the proposal; and (3) **identification and establishment of** reference sites on nearby land **outside the impact area shall be undertaken** in consultation with the OEPA, on advice from Parks and Wildlife ~~and established within the Proposal Area and outside the impact area~~ to the satisfaction of the CEO. The reference sites are to be monitored biennially to determine whether changes in weed cover and type are as a result of proposal implementation or broader regional changes.	Condition revised to reflect the current weed baseline knowledge.
Decommissioning and rehabilitation			
9-1	Within 12 months following commissioning of the Junction South West or Oxbow pits, whichever is first, the proponent shall prepare and implement a Yandicoogina Decommissioning and Rehabilitation	**The proponent shall ensure that the proposal is decommissioned and rehabilitated in an ecologically sustainable manner, consistent with agreed outcomes**	Condition contemporised to match more recent Ministerial Statements (e.g. MS 1000)

	Plan in accordance with the *Guidelines for Preparing Mine Closure Plans, June 2011* and any updates to the requirements of the CEO on advice of the Department of Mines and Petroleum.	**and land uses, and without unacceptable liability to the State of Western Australia, through the implementation of the Mine Closure Plan required by condition 9-2.**	
9-2	The Yandicoogina Decommissioning and Rehabilitation Plan required pursuant to condition 9-1 shall ensure that closure planning and rehabilitation are carried out in a coordinated, progressive manner and are integrated with development planning, consistent with current best practice, and the agreed land uses.	**The proponent shall prepare the Yandicoogina Mine Closure Plan in accordance with the *Guidelines for Preparing Mine Closure Plans*, *June 2015* and any updates, to the requirements of the CEO on advice of the Department of Mines and Petroleum.**	Condition contemporised to match more recent Ministerial Statements (e.g. MS 1000)
9-3	The Yandicoogina Decommissioning and Rehabilitation Plan required pursuant to condition 9-1 shall set out procedures to: (1) manage long term hydrogeological impacts of mining the channel iron deposit; (2) model the long term hydrological impacts, particularly the water levels and quality both in the pit void and downstream of waste material landforms; (3) manage over the long term the surface water systems affected by the open pit; (4) progressively rehabilitate all disturbed areas to a standard suitable for the agreed end land use(s), with consideration and incorporation of: (a) the characteristics of the pre-mining ecosystems within the Project area (through research and baseline surveys); (b) the performance of previously rehabilitated areas within the mining lease; (c) the performance of rehabilitation areas at the proponent's other operations in the Pilbara; and (d) best practice rehabilitation techniques used elsewhere in the mining industry. (5) develop and identify completion criteria; (6) monitor rehabilitation to assess the performance of all rehabilitated areas against the completion criteria;	The proponent shall review and revise the Yandicoogina Mine Closure Plan required by condition 9-**2** at intervals not exceeding three years**, or as otherwise specified by the CEO.**	Condition modifies 9-4 and contemporised to match more recent Ministerial Statements (eg. MS 1000)

	(7) report on the rehabilitation and monitoring results; (8) remove all infrastructure; (9) develop management strategies and/or contingency measures in the event that operational experience and/or monitoring identify any significant environmental impact as a result of the proposal; (10) manage and monitor mineral waste including physical characteristics and acid or neutral metalliferous drainage using national and international standards and updates; and (11) develop a 'walk away' solution for the decommissioned mine site.		
9-4	The proponent shall review and revise the Yandicoogina Decommissioning and Rehabilitation Plan required by condition 9-1 at intervals not exceeding three years.	**The proponent shall implement the latest revision of the Yandicoogina Mine Closure Plan, which the CEO has confirmed by notice in writing, satisfies the requirements of condition 9-2.**	Condition contemporised to match more recent Ministerial Statements (eg. MS 1000)
9-5	The proponent shall make revisions of the Yandicoogina Decommissioning and Rehabilitation Plan required by condition 9-1 publicly available.	**Remove**	Addressed by Condition 4 and 5.
Residual impact and risk management measures			
10-1	In view of the significant residual impacts and risks (permanent and temporary) to native vegetation including riparian vegetation as a result of the implementation of the proposal, the proponent shall contribute three million dollars ($AUD) to a strategic regional conservation initiative for the Pilbara as determined by the Minister for Environment on advice of the Environmental Protection Authority and the DEC.	**The 5,600 ha of clearing of native vegetation previously approved under Ministerial Statement 914 is exempt from the requirement to offset under condition 10-3.**	The previous approval under MS914 was subject to an upfront contribution of $AUD 3 Million to a strategic regional conservation initiative as agreed by the CEO.
10-2	The contribution shall be paid in full by 31 December 2013, unless otherwise agreed by the CEO.	**Remove**	

10-3	**New Condition 10-2** **In view of the significant residual impacts and risks as a result of implementation of the additional clearing for the Yandi PBS Proposal, the proponent shall contribute funds to offset the clearing of 'Good to Excellent' condition native vegetation, and calculated pursuant to condition 10-3. This funding shall be provided to a government-established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.**	Condition contemporised to match more recent Ministerial Statements (e.g. MS 1000)
10-4	**New Condition 10-3** **The proponent's contribution to the initiative identified in condition 10-3 shall be paid biennially, the first payment due two years after commencement of the additional ground disturbance defined in Schedule 1. The amount of funding will be $1,500 AUD (excluding GST) per hectare of 'Good to Excellent' condition native vegetation and $3,000 AUD (excluding GST) per hectare of riparian zone vegetation cleared within the Development Envelope (delineated in Figure 1 and defined by the geographic coordinates in Schedule 2), within the Hamersley IBRA subregion.**	Condition contemporised to match more recent Ministerial Statements (e.g. MS 1000)

GOVERNMENT OF
WESTERN AUSTRALIA

Environmental Protection Authority

Ms Hermione Scott
Manager, Government Approvals
Hamersley Iron – Yandi PTY Limited
152-158 St Georges Terrace
PERTH WA 6000

Our Ref: *AC01-2014-0123*
Enquiries: *Matt Spence, 6145 0819*
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Dear Ms Scott

YANDICOOGINA IRON ORE PROJECT – REVISED PROPOSAL - ENVIRONMENTAL SCOPING DOCUMENT (Assessment No. 2017)

As you are aware the Environmental Scoping Document (ESD) for the Yandicoogina Iron Ore Project – Revised Proposal was considered by the Environmental Protection Authority (EPA) at meeting number 1073 on 11 December 2014. The approved ESD is enclosed.

In considering the scoping document the EPA had some significant concerns about the potential environmental impacts associated with disturbing the riparian vegetation of Weeli Wolli Creek, which is the subject of a Clearing Avoidance Area delineated in Ministerial Statement 914 (MS 914). The EPA was also concerned about the potential for long term impacts that proposed infrastructure would have on the hydrology of Weeli Wolli Creek, as well as the aesthetic value of infrastructure left in perpetuity within the catchment.

In addition to the requirements outlined in the scoping document the EPA would like to draw your attention to the following points:

- **Clearing Avoidance Area** – The EPA is particularly concerned about the proposed disturbance within the Clearing Avoidance Area to accommodate a bridge/floodway and levee structure. Considering that this area has been delineated for protection in accordance with MS 914, and an Environmental Values Statement has been developed, Hamersley Iron will be required to demonstrate how the environmental values of Weeli Wolli Creek will be maintained and protected during the implementation of this proposal.

- **Hydrological Impacts** – The EPA has identified as a key issue cumulative impacts on Weeli Wolli Creek and potentially Fortescue Marsh considering this proposal together with other existing and proposed projects in the catchment. Considering this, the EPA will expect Hamersley Iron to

demonstrate that any potential impacts to the Fortescue Marsh are minimised and managed to ensure the protection of the Marsh and its environmental values.

- **EPA Board Meeting** – The EPA encourages Hamersley Iron to attend the February EPA Board Meeting to discuss these key concerns.

If you have any queries please contact Matt Spence on 9145 0816.

Yours sincerely

Dr Paul Vogel
CHAIRMAN

31 December 2014

Encl. Environmental Scoping Document

ENVIRONMENTAL SCOPING DOCUMENT

PROPOSAL NAME:	**YANDICOOGINA IRON ORE PROJECT – REVISED PROPOSAL**
ASSESSMENT NUMBER:	**2017**
LOCATION:	**APPROXIMATELY 90 KILOMETRES (KM) NORTH-WEST OF NEWMAN**
LOCAL GOVERNMENT AREA:	**SHIRE OF EAST PILBARA**
PROPONENT:	**HAMERSLEY IRON – YANDI PTY LIMITED**
PUBLIC REVIEW PERIOD:	**6 WEEKS**

1. Introduction

The above proposal is being assessed by the Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act 1986* (EP Act) at the level of Public Environmental Review (PER). This Environmental Scoping Document (ESD) sets out the requirements for the environmental review of the proposal. The purpose of an ESD is to:

- provide proposal-specific guidelines to direct the proponent on the preliminary key environmental factors or issues that are to be addressed during the environmental review and preparation of the environmental review report;
- identify the required work that needs to be carried out; and
- timing of the environmental review.

The proponent must conduct the environmental review in accordance with this ESD and then report to the EPA in an environmental review report (PER document). As well as the proposal-specific requirements for the environmental review identified in this ESD, the PER document must also address the generic information requirements listed in section 10.2.4 of the EPA's *Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2012* (Administrative Procedures). When the EPA is satisfied that the PER document adequately addresses both of these requirements, the proponent will be required to release the document for a public review period of 6 weeks.

This ESD has been prepared by the EPA in consultation with the proponent, decision-making authorities and interested agencies consistent with EPA Environmental Assessment Guideline (EAG) 10 – *Scoping a proposal.* ESDs prepared by the EPA are not subject to public review. The ESD will be available on

the EPA website (www.epa.wa.gov.au) upon endorsement and must be appended to the PER document.

2. The proposal

The subject of this ESD is Hamersley Iron – Yandi Pty Limited's (Hamersley's) proposed Yandicoogina Pocket & Billiard South Iron Ore Mine. The proposal is located approximately 90 km north-west of the town of Newman. The regional location of the proposal is shown in Figure 1.

The revised proposal includes the development of the ore bodies known as Pocket and Billiard South which are located within the south-eastern corner of the development envelope of the existing Yandicoogina operations, approved under Ministerial Statement 914 (Figure 2). The revised proposal (including existing Yandicoogina operations and the Pocket and Billiard South deposits) is likely to have a combined total throughput of up to 70 Mtpa over a mine life of approximately 16 years.

The Pocket and Billiard South deposits occur at the eastern extents of an extensive 80 km long Channel Iron Deposit (CID) palaeochannel. This extension of the Yandicoogina operations is proposed to consist of a single below water table open-cut pit along the CID palaeochannel, temporary and permanent surface waste dumps and the following major infrastructure (Figure 3):

- **one flood protection levee** along the eastern bank of Weeli Wolli Creek;
- **Weeli Wolli creek crossing** - either a floodway or bridge-type structure;
- **ore-handling and processing infrastructure** including dry crushing and potentially future wet-processing facilities;
- **in-pit waste fines storage facilities** (WFSFs) when wet processing is undertaken; and
- **supporting mine infrastructure** including haul roads and ramps, mine access and internal road network, and conveyors.

In addition, a number of the Yandicoogina operation's existing facilities will be upgraded or integrated, including:

- **a land bridge** across Junction South East pit;
- **a levee** along the southern edge of Junction South East pit;
- **trucking or conveying ore** back to the existing Yandicoogina Plant;
- **a water management system** including on-site reuse of water abstracted from pit dewatering, and discharge of surplus volumes into creek systems. Discharge infrastructure servicing the existing Yandicoogina operations will be used; and
- **mine support facilities** (power supply infrastructure, communications infrastructure, offices, explosives storage, waste water treatment plants etc).

Waste rock material from the mine will be stored in waste dumps with some progressive backfilling once individual mine pits (including those from the approved Yandicoogina operations) are exhausted.

As this proposal is a sustaining extension of the existing Yandicoogina operations, the proponent has requested that this referral be treated as a revised proposal and a new statement be issued superseding the existing Ministerial Statement (MS914). Figure 2 shows the proposal area approved under Ministerial Statement 914.

The key characteristics of the proposal are set out in Table 1, in accordance with EAG 1 – *Defining the key characteristics of a proposal*. The development envelope encompassing the physical elements of the proposal is delineated in Figure 2.

It should be noted that the key proposal characteristics may change as a result of implementation of the mitigation hierarchy by the proponent on account of the findings of studies and investigations conducted as part of the environmental review.

Table 1 – Key Characteristics Table

Summary of the proposal			
Proposal Title	Yandicoogina Iron Ore Project – Revised Proposal		
Proponent Name	Hamersley Iron – Yandi Pty Limited		
Short Description	The proposal includes the existing Hamersley Yandicoogina iron ore project and proposed sustaining operations. The existing project includes open pit mining at the Junction Central, Junction South East, Junction South West and Oxbow operations and associated waste landforms, infrastructure, rail, dewatering activities and disposal activities. The proposed sustaining operations includes the development of new pits at Pocket and Billiard South and associated additional temporary and permanent waste landforms, infrastructure, additional dewatering activities and water disposal activities.		
Physical Elements			
Element	**Location**	**Existing Authorised Extent (Ministerial Statement 914)**	**Proposed Extent**
Mine and associated infrastructure	Figure 4	Up to 5,600 ha within Restricted Clearing Area 1. Up to 60 ha within Restricted Clearing Area 2.	Within the Mine Development Envelope of 19,351 ha: • Clearing no more than 8,400 ha within Clearing Area 1; • Clearing no more than 60 ha within Restricted Clearing Area 2; • Clearing no more than 60 ha within Restricted Clearing Area 3; and • No clearing (0 ha) within the Clearing Avoidance Area.

Railway and associated infrastructure	Figure 5		Clearing no more than 300 ha within the Infrastructure Development Envelope of 605 ha.

Operational Elements			
Element	**Location**	**Existing Authorised Extent** **(Ministerial Statement 914)**	**Proposed Extent**
Dewatering	Dewatering Zones	No more than 35 GL/a from Junction South East and Junction Central operations. Up to 18 GL/a from Junction South West A, Junction South West C and Oxbow operations.	Groundwater abstraction of no more than 83 GL/a for the entire Yandicoogina Operations.
Surplus dewater water	Weeli Wolli Creek		Controlled surface discharge of no more than 80 GL/a for the entire Yandicoogina Operations.

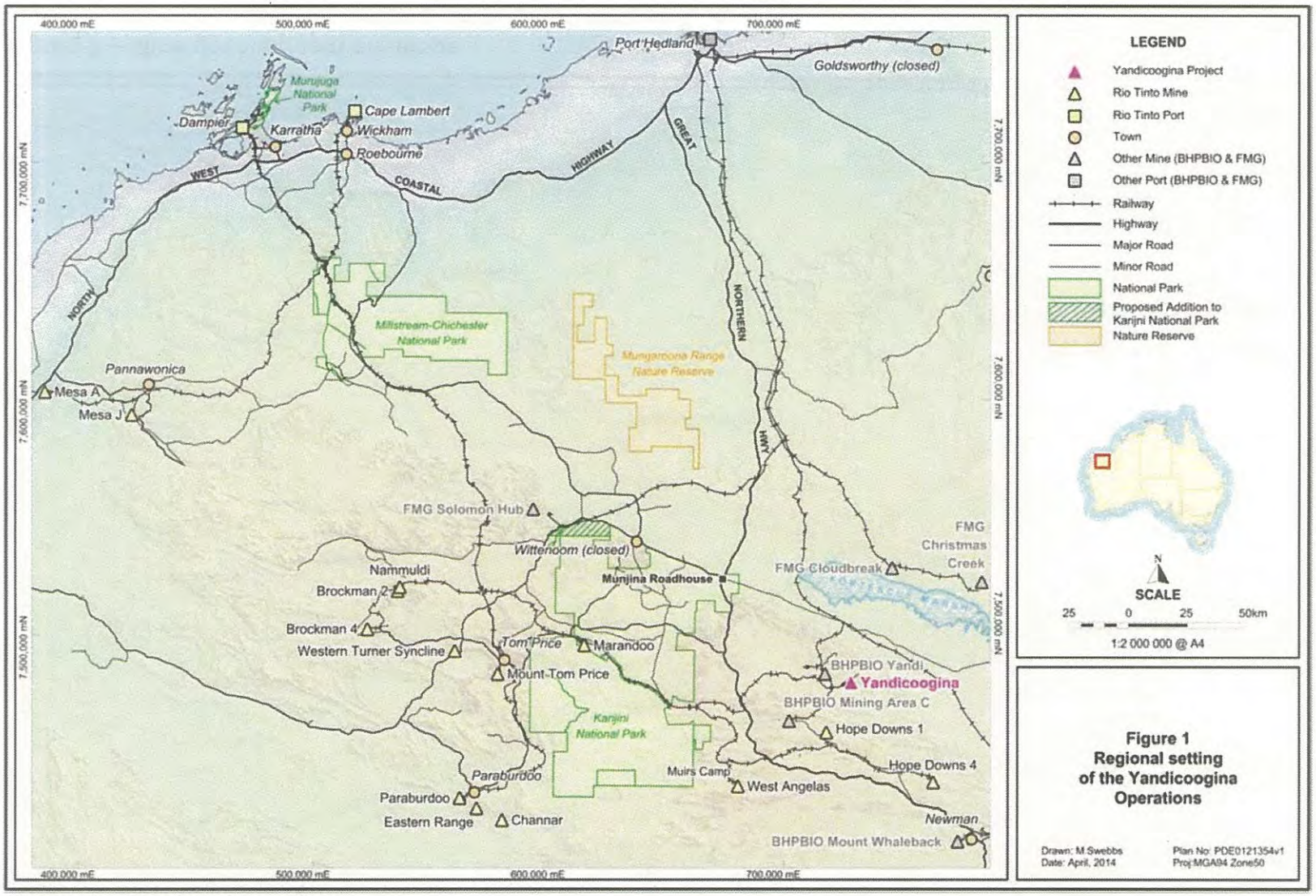

Figure 1 – Regional location

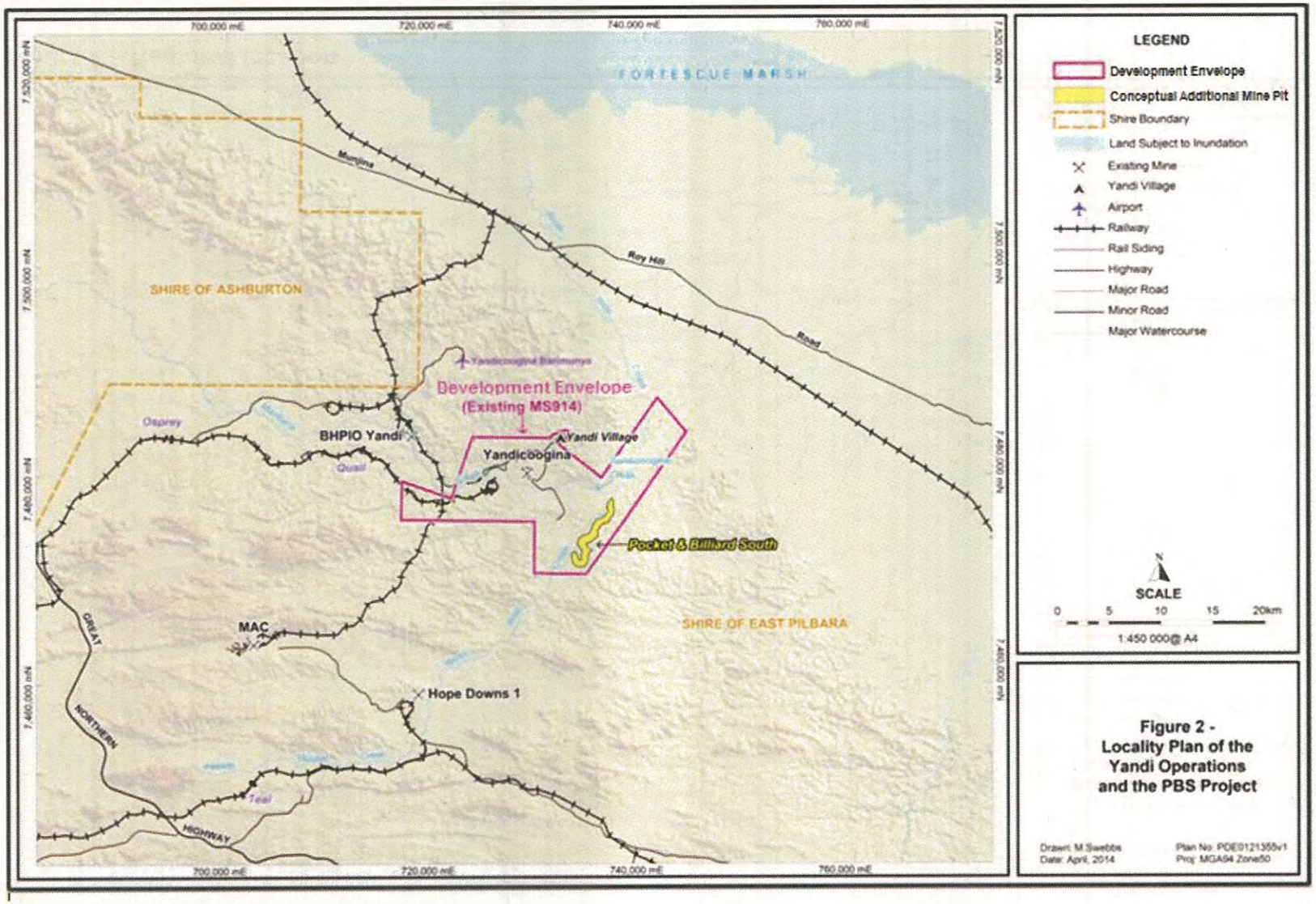

Figure 2 – Mine development envelope

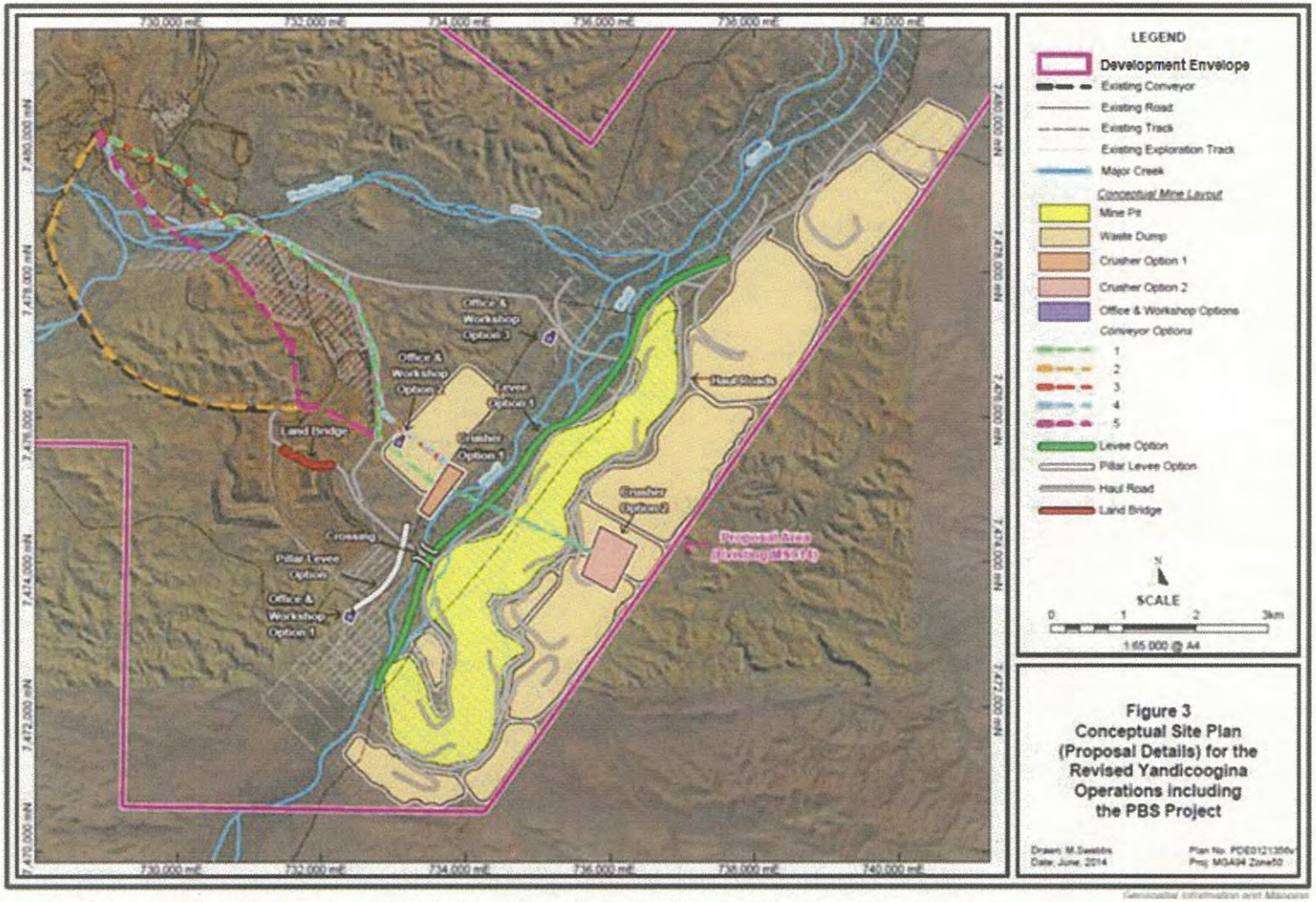

Figure 3 – Conceptual mine layout of the Pocket and Billiard South Extension

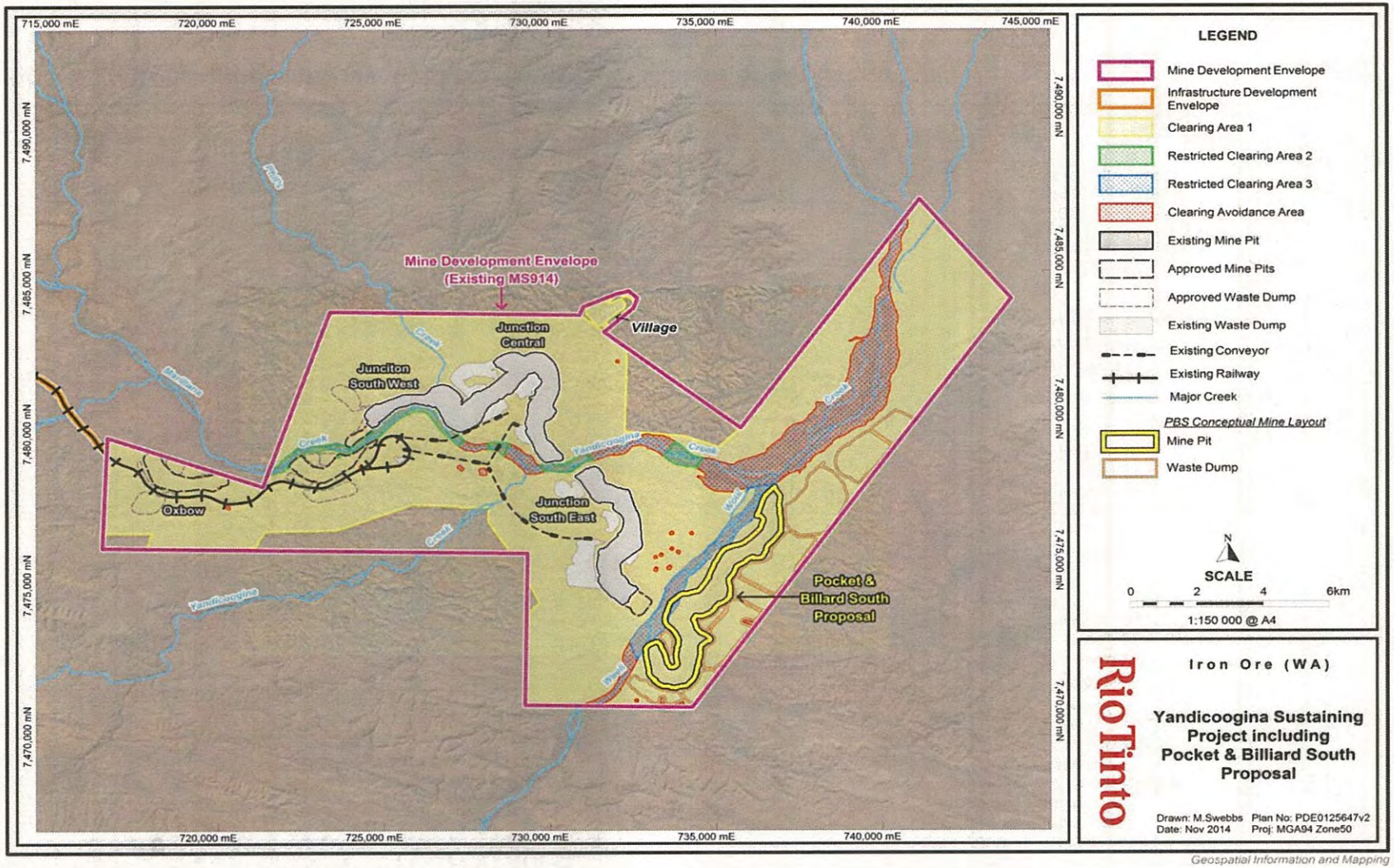

Figure 4 – Avoidance and clearing areas

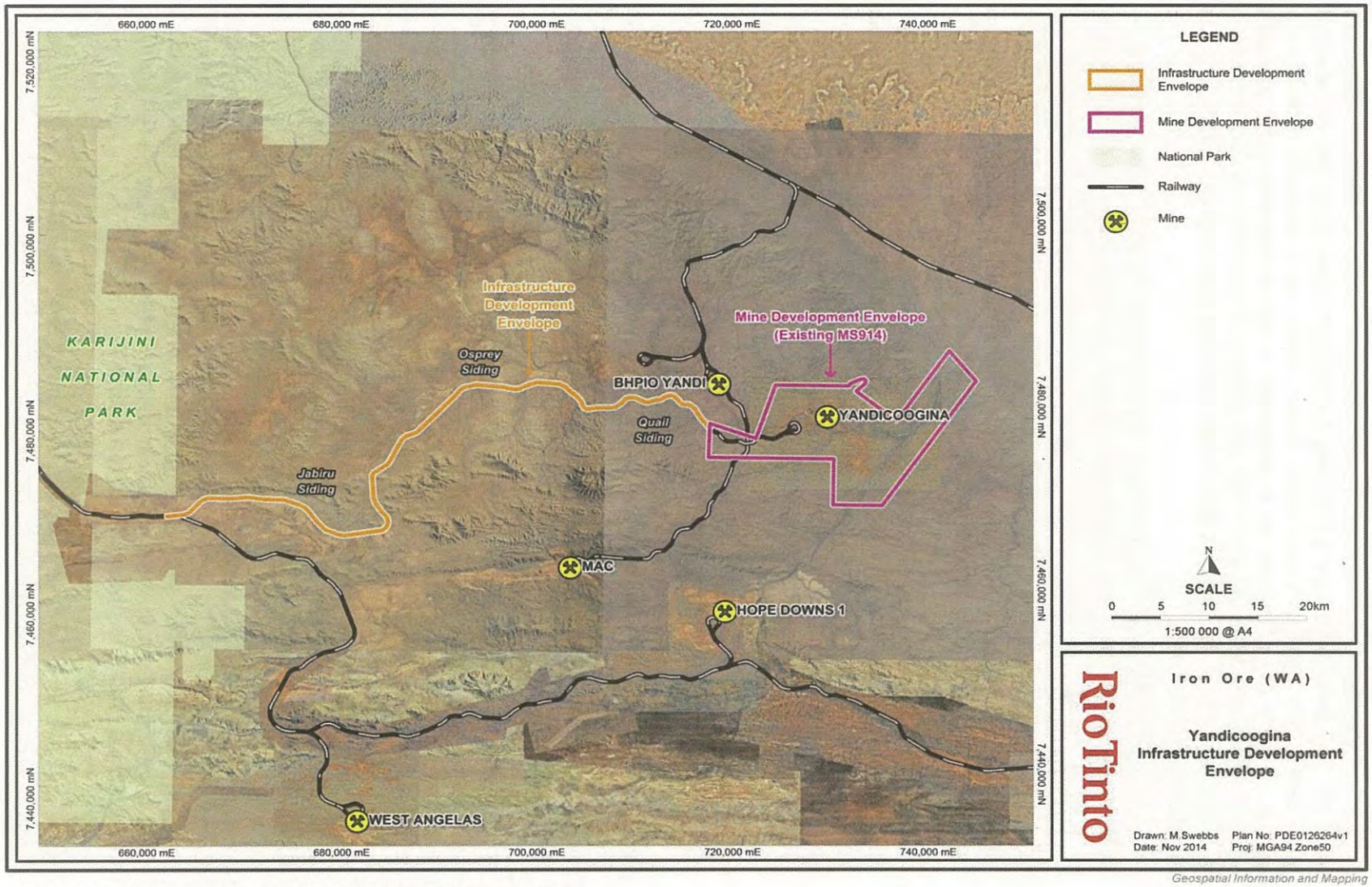

Figure 5 – Infrastructure Development Envelope

3. Assessment context

The current Yandicoogina Iron Ore Project was approved by the Minister for the Environment in October 2012 and currently operates under Ministerial Statement 914 (MS 914). MS 914 delineated a Clearing Avoidance Zone along the entire length of riparian vegetation zone of Weeli Wolli Creek within the proposal's development envelope to protect an area that is considered to be environmentally sensitive. Furthermore, Condition 6-2 required the proponent to develop an Environmental Values Statement (EVS) for Weeli Wolli Creek, defining the environmental values of the system, which included:

- **Value 1 - Hydrology:** the proposal area includes major creek systems that ultimately drain into the Fortescue Marsh Priority Ecological Community (PEC);

- **Value 2 - Flora and Vegetation:** the proposal area includes individuals of *Lepidium catapycnon* (Declared Rare Flora) and a riparian vegetation community of elevated conservation significance;

- **Value 3 - Fauna:** the project area contains a number of stygofauna species known only from the Marillana-Weeli Wolli Catchment. Riparian habitat provides a conduit for the movement of microbats and other fauna. In the wider catchment, the Weeli Wolli Spring (upstream from the proposal area) is known to support a significant microbat species assemblage; and

- **Value 4 - Heritage and Social:** the local creek systems have cultural significance for traditional owners.

The EVS was developed in consultation with the former Department of Environment and Conservation and approved by the CEO on 14 September 2012. The EVS confirmed that the riparian vegetation community of Weeli Wolli Creek was of elevated conservation significance and required protection.

The EPA understands that this revised proposal proposes changes to the Clearing Avoidance Area delineated in MS 914 (shown by the proposed Restricted Clearing Area 3 in Figure 4). The proponent proposes to clear 60 ha within this area to accommodate a bridge/floodway and levee structure that will traverse Weeli Wolli Creek. The EPA is particularly concerned about the disturbance within this area and will require the proponent to demonstrate how the above environmental values would be maintained and protected during the implementation of any revisions to the currently approved proposal.

Furthermore, the EPA has identified as a key issue cumulative impacts on Weeli Wolli Creek and potentially Fortescue Marsh considering this proposal together with other existing and proposed projects in the catchment. The EPA will expect the proponent to demonstrate that any impacts to the Fortescue Marsh are minimised and managed to ensure the protection of the wetland.

4. Preliminary key environmental factors and scope of work

The key proposal characteristics in Table 1 have informed the identification of the preliminary key environmental factors for the proposal, in accordance with EAG 8 – *Environmental factors and objectives*. The preliminary key environmental factors for this proposal and the EPA's objective for each of those factors are identified in Table 2.

To provide context to the preliminary key environmental factors, Table 2 also identifies the aspects of the proposal that cause the factors to be preliminary key factors, and the potential impacts and risks likely to be relevant to the assessment. All of this in turn has informed the work required to be conducted in the environmental review.

Finally, Table 2 identifies the policy documents that establish how the EPA expects the environmental factors to be addressed in the environmental review and the PER document that follows. Impacts associated with proposals are to be considered at a local and regional scale, including evaluation of cumulative impacts, and provide details of proposed management/mitigation measures. This includes whether environmental offsets are required by application of the mitigation hierarchy, consistent with the WA Environmental Offsets Guidelines.

Table 2 Preliminary key environmental factors and required work

Flora and Vegetation	
EPA objective	To maintain representation, diversity, viability and ecological function at the species, population and community level.
Relevant aspects	Clearing, dewatering, alterations to surface water flows and rehabilitation activities.
Potential Impacts	• The proposal involves additional clearing that will increase the disturbance footprint from 5,600 ha to 8,520 ha for the mine and supporting infrastructure. • The clearing includes up to 60 ha of riparian vegetation within Weeli Wolli Creek. There are potential for impacts on Priority Flora species and *Lepidium catapycnon,* which is Declared Rare Flora. • Groundwater drawdown from the mine has the potential to impact on the health of riparian vegetation along an 8 km stretch of Weeli Wolli Creek. • Discharge of surplus water from mine pit dewatering has the potential to impact on riparian vegetation along Marillana and Weeli Wolli creeks. • There is the potential for the introduction of weeds through vehicle movements and earthworks. • There is also the potential to impact on vegetation through the generation of dust from mining operations.
Work required	1. Provide information on the current status and outcomes of the riparian vegetation management actions required by Ministerial Statement 914 Condition 7 – Riparian Vegetation, and Condition 8 - Weeds. 2. Provide a detailed description of the cumulative impacts associated with the proposal, including direct impacts from clearing, and indirect impacts such as groundwater drawdown, surface discharge of excess groundwater, altered

	drainage, changes in water quality, dust emissions and fragmentation of vegetation. 3. Provide figures showing the extent of clearing and indirect impact to vegetation and conservation significant flora species, including but not limited to threatened and/or priority ecological communities, declared rare flora, priority flora and new flora species. 4. Consolidate vegetation and flora reports incorporating information from all relevant previous and new studies, particularly for the Declared Rare Flora species *Lepidium catapycnon*. 5. Describe the environmental values and rational of the Clearing Avoidance Area identified in Ministerial Statement 914. Quantify the disturbance to this area as a result of implementing the proposal and describe how the environmental values of the Clearing Avoidance Area and Weeli Wolli Creek will be maintained. 6. Carry out Level 2 flora and vegetation surveys in areas that are likely to be directly or indirectly disturbed. Surveys are to be undertaken in accordance with Guidance Statement 51. Details of the scope, timing (survey season/s) and methodology for surveys used must be provided. Follow up targeted surveys may be required based on the results of the baseline survey for conservation significant flora and vegetation. 7. Analyse the extent of clearing and indirect impacts to assist in the determination of the significance of impacts, including impacts on: - vegetation units; - threatened and priority ecological communities; - threatened and priority flora; - species identified as significant consistent with Guidance Statement 51; - vegetation units identified as significant consistent with Guidance Statement 51; and - groundwater dependent vegetation. 8. Undertake baseline mapping of weed affected areas in any area likely to be directly or indirectly impacted by the proposal. 9. Discuss potential direct/indirect (including downstream) and cumulative impacts to flora and vegetation as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance. 10. Discuss proposed management, monitoring and mitigation methods to be implemented. Also, discuss engineering solutions that could be implemented to re-design the waste rock dump locations to avoid impacts to *Lepidium catapycnon*. 11. Demonstrate that all practicable measures have been taken to reduce both the area of the proposed disturbance footprint and the Development Envelope based on progress in the proposal design and understanding of the environmental impacts. 12. Demonstrate that the mitigation hierarchy of avoid, minimise, rehabilitate and offset has been applied effectively during the mine planning and design stages of the project.
Relevant policy/guidance documents	• Position Statement 2 *Environmental Protection of Native Vegetation in Western Australia*. • Position Statement 3 *Terrestrial Biological Surveys as an Element of Biodiversity Protection*.

	• Guidance Statement No. 51 *Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia* June 2004. • EPA (2013) *Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986*. EPA Report 1484. July 2013. • EPA (2014) *Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986.* • Checklist for documents submitted for EIA on marine and terrestrial biodiversity.
Terrestrial Fauna	
EPA objective	To maintain representation, diversity, viability and ecological function at the species, population and assemblage level.
Relevant aspects	Clearing, dewatering, alterations and disruptions to surface water flows and pools, vehicle movement.
Potential impacts	• Habitat removal and fragmentation due to vegetation clearing. • Indirect impacts may occur through altered fire regimes, groundwater drawdown and discharge of surplus water, altered water regimes, changes to feral animal populations, the introduction or increase in spread of weed species, noise and light spill.
Work required	1. Conduct desktop study of information available to provide a comprehensive listing of vertebrate fauna and SRE invertebrate fauna known or likely to occur in the habitats present, and identification of conservation significant fauna species likely to occur in the area. Consideration of species listed under both the WA *Wildlife Conservation Act 1950* and the *Environment Protection & Biodiversity Conservation Act 1999 (*EPBC Act), and species listed by the Department of Parks and Wildlife as Priority Fauna to include, but not necessarily be limited to, the following species of conservation significance have been recorded in the Yandicoogina PBS surveys: - Brush-tailed Mulgara (*Dasycercus blythi*) - Star Swift (*Neochmia ruficaudo*) - Fork-tailed Swift (*Apus pacificus)* - Western Pebble-mound Mouse (*Pseudomys chapman*) - Olive Python (Pilbara subspecies) (*Liasis olivaceus barroni*) - Rainbow Bee-eater (*Merops arnatus*) - Any other priority fauna species identified in a Level 1 survey as likely to occur in the proposal area. 2. For each relevant conservation significant species, provide baseline information on their abundance (including known occurrences), distribution, ecology, and habitat preferences at both the site and regional levels. 3. Conduct a Level 1 reconnaissance vertebrate and SRE invertebrate fauna survey and mapping of habitats including specialised habitats identified within the development envelopes, identification and mapping of important, rare or unusual habitat types within areas to be impacted, in accordance with Guidance Statements 56 and 20. This should also consider other areas outside the proposed disturbance footprint to determine whether the most suitable areas have been chosen for location of infrastructure.

	4. Consider habitat types that provide important ecological function e.g. riparian vegetation, protected area buffer zones, refugia, important habitat corridors, wetlands, areas of conservation significance or geological features which may support unique ecosystems. Analyse the extent of clearing, including percentages of habitat types to be cleared or otherwise impacted, to assist in determination of significance of impacts. Information, including maps, must also differentiate habitat on the basis of use e.g. breeding habitat, migration pathways, feeding habitat. Consider whether the remaining habitat has adequate carrying capacity. 5. Conduct Level 2 fauna surveys in areas that are likely to be directly or indirectly impacted as a result of the proposal. Surveys are to be undertaken in accordance with Guidance Statements 20 and 56. Additional targeted surveys for conservation significant fauna that are known to or likely to occupy habitats in the project area may be required based on the results of the survey. 6. For each relevant conservation significant species, provide: - information on the conservation value of each habitat type from a local and regional perspective, including the percentage representation of each habitat type on site in relation to its local and regional extent; and - if a population of a conservation significant species is present on the site, its size and the importance of that population from a local and regional perspective and potential percentage loss of the conservation significant species locally due to loss of habitat. 7. Discuss known existing threats to the species, whether or not attributable to the proposed action with reference to relevant impacts from the proposed action (including taking into consideration any relevant guidelines, policies, plans and statutory provisions). 8. Discuss potential direct/indirect (including downstream) and cumulative impacts to fauna as a result of the proposal, and provide quantitative data on impacts of the proposal to species of conservation significance. 9. Discuss proposed management, monitoring and mitigation methods to be implemented including an assessment of the effectiveness of the methods, any statutory or policy basis for the methods.
Relevant policy/guidance documents	• Guidance Statement No. 20 *Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment* in Western Australia. • Guidance Statement No. 56 *Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia* June 2004. • Position Statement 3 *Terrestrial Biological Surveys as an Element of Biodiversity Protection.* • Technical Guide – *Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment* September 2010. • Department of Water (2009) Pilbara Water in Mining Guideline Report No.34 • EPA (2013) *Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986.* EPA Report 1484. July 2013. • EPA (2014) *Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for*

	Environment under Section 16(e) of the Environmental Protection Act 1986. • Checklist for documents submitted for EIA on marine and terrestrial biodiversity.
Subterranean Fauna	
EPA objective	To maintain representation, diversity, viability and ecological function at the species, population and assemblage level.
Relevant aspects	Excavation for mining activities. Dewatering groundwater for mining activities.
Potential impacts	Direct mortality and loss of habitat through sub-surface disturbance and abstraction of groundwater for dewatering.
Work required	1. Conduct surveys within areas to be impacted and in surrounding areas in accordance with Guidance Statement 54a. 2. Present the results of the subterranean fauna surveys and discuss the potential for direct and indirect impacts to subterranean fauna including consideration of altered water regimes and nutrient flows. 3. Assess any impacts to subterranean fauna in accordance with EAG 12. For species which are likely to be impacted, provide information, including detailed geological maps on habitat continuity and an appropriate explanation of the likely distribution of species within those habitats. 4. Discuss proposed management, monitoring and mitigation methods to be implemented.
Relevant policy/guidance documents	• Environmental Assessment Guideline 12 Consideration of subterranean fauna in environmental impact assessment in Western Australia June 2013. • Guidance Statement No. 54a Sampling methods and survey considerations for subterranean fauna in Western Australia July 2007. • Department of Water (2009) Pilbara Water in Mining Guideline Report No.34 • EPA (2013) Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. EPA Report 1484. July 2013. • EPA (2014) Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. • Checklist for documents submitted for EIA on marine and terrestrial biodiversity.
Hydrological processes	
EPA objective	To maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance are protected.
Relevant aspects	Altered hydrological regimes. Dewatering groundwater for mining activities.
Potential impacts	• Impacts to natural surface water flows as a result of placement, design and operation of new mine and associated infrastructure.

	• Impacts to surface water resources including Weeli Wolli Creek due to surface discharge of surplus mine dewater. • Altered flow regime to the Fortescue Marsh due to groundwater drawdown and discharge of surplus water into Weeli Wolli and Marillana creeks. Cumulative impact due to similar activities of other mines operating in the area. • Impacts to any groundwater dependent ecosystems and subterranean fauna, as a result of groundwater drawdown.
Work required	1. Provide information on the current status and outcomes of surface water discharge management actions required by Ministerial Statement 914 Condition 6 – Surface Water Discharge (Protection of Weeli Wolli Creek). 2. Provide a detailed description of the design and location of the proposal with the potential to impact surface water or groundwater. 3. Characterise baseline hydrological and hydrogeological regimes. 4. Develop a conceptual model of the surface and groundwater systems, incorporating the extent of connectivity between surface and ground water systems. 5. Discuss the effectiveness of the current water management scheme and provide a comparison of its actual operation versus what was predicted including discussion of accuracy. Also detail any problems with how the system has operated and what management measures have been taken when it is not operating as expected. 6. Present information on predicted annual dewatering requirements and surplus water quantities over the life of the operations. 7. Provide a conceptual mine water balance over the life of the proposal to discuss the capacity to reuse surplus mine dewater. 8. Discuss the potential environmental impacts and benefits of identified surplus water management options (i.e. reuse on site, local water supply, aquifer recharge etc.) and discuss the most appropriate water management strategy for the proposal. 9. Discuss the impacts to Weeli Wolli Creek and the potential impacts on Fortescue Marsh considering worst case conditions, including natural flow conditions and maximum anthropogenic inputs. Describe methods used to minimise the impacts to Weeli Wolli Creek, including minimising the period of surface discharge. Quantify the period of surface discharge required, as well as the extent of surplus mine dewater release (wetting front) and changes to flows within Weeli Wolli Creek. 10. Model the impact of different flooding scenarios during operations and post-closure on infrastructure and final landforms. Note the design criteria for any storm water infrastructure on site and provide an explanation, including reference to standards and guideline documents, for the chosen criteria. 11. Detail and assess the geotechnical criteria of the bund or levee that will be located next to Weeli Wolli Creek. Discuss the permanency of the bund or levee in the catchment. Identify the likely source of the material that will be used to build the bund or levee, and describe how the design and structural integrity will withstand large storm events. If the bund or levee is part of a closure strategy assess the long term integrity of the bund taking into consideration different

	flooding scenarios or a worst case scenario. 12. Investigate groundwater drawdown due to ground water abstraction associated with the proposal. Analyse and discuss any impacts to groundwater levels and flows taking into consideration the cumulative impacts with other proposals. 13. Develop a conceptual model of the surface and groundwater systems, incorporating groundwater quality and the extent of connectivity between surface and ground water systems and Fortescue Marsh. 14. Have the surface and groundwater modelling for this assessment independently peer reviewed. Determine the scope, timing and the selection of the peer review in consultation with the Department of Water. The groundwater modelling should be consistent with Australian Government National Water Commission's Australian Groundwater Modelling Guidelines (2012). The surface water modelling should be in accordance with the Australian Rainfall and Runoff Guidelines. 15. Analyse, discuss and assess surface water and groundwater impacts, including changes in groundwater levels and changes to surface water flows associated with the proposal together with cumulative impacts with other projects and referred proposals (including the BHPBIO strategic proposal) for which relevant information is publicly available. 16. Discuss the proposed management, monitoring and mitigation to prevent groundwater and surface water impacts as a result of implementing the proposal.
Relevant policy/guidance documents	• Rights in Water and Irrigation Act (1914). • Department of Water (2009) Pilbara Water in Mining Guideline. Report No 34. • Department of Water (2013) Western Australian Water in Mining Guideline. Water licensing delivery report series. Report No. 12. • Department of Water (2013) Pilbara Groundwater Allocation Plan. Water resource allocation and planning report series. Report No 55, October 2013. • EPA (2013) Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. EPA Report 1484. July 2013. • EPA (2014) Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. • Australian Government National Water Commission's Australian Groundwater Modelling Guidelines (2012). • Australian Rainfall and Runoff Guideline.
Inland Waters Environmental Quality	
EPA objective	To maintain the quality of groundwater and surface water, sediment and/or biota so that the environmental values, both ecological and social, are protected.
Relevant aspects	Temporary stockpiling of waste material on the surface, storage and use of hazardous materials and hydrocarbons. Legacy of mine pit lakes.

Potential impacts	• Disruption of surface drainage systems in the Fortescue Marsh catchment by mine pits, surface waste dumps and stock piles, and drainage structures. • Potential changes to the ground water quality over time from pit lakes left by the proposal. • Potential contamination of surface water and groundwater, if management of waste dumps containing at-risk material (material with potential for acid or metalliferous drainage) is not appropriate.
Work required	1. Characterise baseline water quality, including the analysis of groundwater quality that is proposed to be discharged into the surrounding environment. 2. Develop a conceptual model of the surface and groundwater systems, incorporating groundwater quality and the extent of connectivity between surface and ground water systems and Fortescue Marsh (same requirement for Hydrological Processes). 3. Undertake a hydrological investigation to determine what effect groundwater abstraction, and modified drainage will have on the surface water and groundwater quality and quantity of the area, including interactions between surface and groundwater. 4. Have the surface and groundwater modelling for this assessment independently peer reviewed. Determine the scope, timing and the selection of the peer review in consultation with the Department of Water. The modelling should be consistent with Australian Government National Water Commission's *Australian Groundwater Modelling Guidelines (2012)* (same requirement for Hydrological Processes). 5. Undertake a comprehensive review of surface water and groundwater quality collected from the existing mining operation at the site. Identify any adverse changes caused by the mining operation and outline avoidance, minimisation and management methods to be used to prevent further impacts. 6. Undertake waste characterisation studies of waste rock and other materials and carry out an acid and metalliferous drainage risk assessment. Detail where Potentially Acid Forming (PAF) material will be located and discuss stored and containment options, including sub-aqueous storage. 7. Provide a description of the design, location and extent of discharges of the proposed waste facilities, and any other elements of the proposal with the potential to impact surface water or groundwater quality. 8. Model cumulative impacts with other mines in the catchment (currently operating and referred proposed mines, including the BHPBIO strategic proposal, where information is publicly available). Develop strategies and controls to minimise the impacts. 9. Confirm whether or not pit lakes may form and provide details of potential backfill options. If pit lakes may form, provide an assessment of the long term contamination of any pit lakes and the potential impact on groundwater and surface water quality with particular attention to possible impacts on Fortescue Marsh. In addition, undertake a risk assessment in accordance with the most recent version of the joint DMP/EPA Mine Closure Guidelines and provide details of mitigation measures undertaken to reduce the risk of any pit lakes. 10. Discuss proposed management, monitoring and mitigation methods, including the identification of water quality trigger levels, to be implemented during construction, operation and following closure to ensure that the EPA's objective

	for this factor is met.
Relevant policy/guidance documents	• ANZECC and ARMCANZ (2000) Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting. • Government of WA (2004) State Water Quality Management Strategy Document No. 6. • Department of Water (2009) Pilbara Water in Mining Guideline. Report No 34. • Department of Water (2013) Western Australian Water in Mining Guideline. Water licensing delivery report series. Report No. 12.EPA (2013) • EPA (2013) Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. EPA Report 1484. July 2013.
Rehabilitation and Closure (Integrating factor)	
EPA objective	To ensure that premises can be closed, decommissioned and rehabilitated in an ecologically sustainable manner, consistent with agreed outcomes and land uses, and without unacceptable liability to the State.
Relevant aspects	Excavation and earthworks resulting in changed landforms, disposal of waste material and clearing of large areas requiring rehabilitation.
Potential impacts	• The proposal is under a State Agreement Act (Iron Ore (Yandicoogina) Agreement Act 1996) and as such rehabilitation and closure cannot be regulated and managed by the Department of Mines and Petroleum. • The proposal may impact on Fortescue Marsh Management Zones listed in the EPA's strategic advice on mining-related assessments in the Fortescue Marsh area (EPA, 2013). • Should there be poor rehabilitation and mine closure planning and management practices there could be a number of undesirable impacts to the receiving environment, such as: - unauthorised vegetation disturbance; - depletion of topsoil resources; - compacted soil layers with poor infiltration rates; - the formation of pit lakes which may attract and harm wildlife, birds or stock; - the introduction of weeds to rehabilitated areas; - landscape modification, altered hydrology and other ecosystem impacts; - unstable landforms and adverse dust impacts; - poor return of native vegetation and flora species; and - contamination.
Work required	1. Provide information on the current status of Yandicoogina Decommissioning and Rehabilitation Plan required by Ministerial Statement 914 Condition 9 –

	Decommissioning and Rehabilitation. 2. Undertake a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including any rehabilitation that has been conducted to date within the development envelope. Including a discussion of the different methodology and success rates for the various proposed disturbance types including: - created landforms (e.g. waste rock dump, tailings storage facility); - short-term disturbances (e.g. borrow pits and access tracks); - long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings); and - linear and/or fragmentation disturbances (e.g. roads, power lines, bore fields). 3. Provide waste characterisation work including static, short term leaching and kinetic test results, and water quality monitoring results for drainage from existing waste storage facilities to enable a thorough assessment of Acid and Metalliferous Drainage risk posed by the project. If PAF material is identified, provide mine scheduling detail to demonstrate that PAF material is not disturbed during mining and/or that effective strategies will be in place to ensure PAF material is adequately managed should it be exposed and/or disturbed. 4. Provide the physical characteristics of the waste materials and proposed locations and geotechnical design detail (including slope stability) for the waste landforms, including the WFSFs. Identify proposed management and monitoring for the waste landforms. Describe contingencies to make landforms secure and non-polluting in the event of unexpected or temporary closure. 5. Prepare a Rehabilitation and Mine Closure Plan consistent with the current version of the Department of Mines and Petroleum (DMP) and EPA *Guidelines for Preparing Mine Closure Plans.* Include completion criteria and closure objectives addressing native vegetation and habitat for significant flora and fauna and base the conclusions on the availability of suitable substrates and landform design. Establish and measure vegetation and fauna reference sites to inform completion criteria. Determine requirements for, and sources of, soil and seed for rehabilitation. A conclusive discussion on backfill options (including 'worst case scenario') is also required. 6. Discuss proposed management, monitoring and mitigation methods to be implemented including post-mining land use and areas to be rehabilitated. 7. Discuss proposed monitoring of linkages of specialised habitats to demonstrate that rehabilitated areas function as ecological corridors for conservation significant fauna.
Relevant policy/guidance documents	• DMP and EPA (2011) Guidelines for Preparing Mine Closure Plans or its revisions. • EPA (2006) Guidance Statement No 6: Rehabilitation of Terrestrial Ecosystems. • EPA (2013) Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986. EPA Report 1484. July 2013. • EPA (2014) Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986.

Offsets (Integrating factor)	
EPA objective	To counterbalance any significant residual environmental impacts and/or uncertainty through the application of offsets.
Relevant aspects	Clearing of native vegetation including conservation significant flora, 'good to excellent' condition vegetation, habitat for conservation significant fauna species.
Potential impacts	Potential impacts on vegetation, flora, habitat and fauna species of State and National significance.
Work required	1. Examine residual impacts and, if required, develop a draft program of environmental offsets that adheres to the relevant policy/guidance documents listed below. 2. Include the completed Environmental Offsets Reporting Form and any offsets required and proposed in the PER.
Relevant policy/guidance documents	• EPA (2008) *Environmental Protection Bulletin No 1 – Environmental Offsets – Biodiversity*. • Govt of WA (2011) *WA Environmental Offsets Policy*. • Govt of WA (2014) *WA Environmental Offsets Guidelines*. • EPA (2014) *Cumulative environmental impacts of development in the Pilbara region. Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986*. • EPA Offsets Reporting Form.

5. Stakeholder consultation

The EPA expects that the proponent will consult with stakeholders who are interested in, or affected by, the proposal. This includes decision-making authorities (DMAs), other relevant State government departments and local government authorities, environmental non-government organisations and the local community.

The proponent must document the stakeholder consultation undertaken and the outcomes, including any adjustments to the proposal and any future plans for consultation. This is to be addressed in a specific section of the PER document and, in addition, key outcomes of consultation are to be reported against the preliminary key environmental factors as relevant.

It is expected that as a part of the consultation with DMAs there will be discussion around each agency's specific regulatory approvals, and a demonstration that other factors can be managed by another regulatory body.

6. Other factors or matters

During assessment of proposals, other factors or matters will be identified as relevant to the proposal, but not of significance to warrant further assessment by the EPA, or impacts can be regulated by other statutory processes to meet the EPA's objectives.

These factors do not require further work as part of the environmental review, or detailed discussion and evaluation in the PER document, although they must be

included in the PER document in a summarised, tabular format noting that the PER document will be subject to public review.

In some circumstances other factors, while not being considered as preliminary key environmental factors, may require greater emphasis in the PER document. This may be due to high public interest or at the request of another stakeholder, so that the potential impacts and management measures associated with the other factor are sufficiently articulated for the public review. For this assessment, the other factors that need to be concisely described and discussed in the PER document, are:

- Air quality;
- Amenity; and
- Heritage.

It is also important that the proponent be aware that other factors or matters may be identified during the course of the environmental review that were not apparent at the time that this ESD was prepared. If this situation arises, the proponent must consult with the EPA to determine whether these factors and/or matters are to be addressed in the PER document, and if so, to what extent.

7. Agreed assessment timeline

Table 3 sets out the timeline for the assessment of the proposal agreed between the EPA and the proponent. Proponents are expected to meet the agreed timeline, and in doing so, provide adequate, quality information to inform the assessment.

Table 3 Assessment Timeline

Key Stages of Assessment	Agreed Completion Date
EPA approval of ESD Document	December 2014
Proponent submits first adequate draft of PER Document	March 2015
OEPA provides comment on first draft PER Document	6 weeks Mid May 2015
Proponent submits adequate revised draft PER Document	4 weeks Mid June 2015
EPA authorises release of PER Document	2 weeks End June 2015
Proponent releases approved PER Document	1 Week Early July 2015
Public Review of PER Document	6 weeks Mid August 2015
EPA provides Summary of Submissions	3 Weeks

	Early September 2015
Proponent provides adequate Response to Public Submissions	4 Weeks Early October 2015
OEPA reviews Response to Submissions	4 weeks Early November 2014
OEPA assesses proposal for consideration by EPA	7 weeks End December 2015
Preparation and finalisation of EPA Report (including 2 weeks consultation on draft conditions with proponent and key Government agencies)	5 weeks (+2 weeks for Christmas) End February 2016

If any stage in the agreed timeline is not met or inadequate information is submitted by the proponent, the timing for the completion of subsequent stages of the process will be revised. Equally, where the EPA is unable to meet an agreed completion date in the timeline, the proponent will be advised and the timeline revised.

The proponent should refer to EPA's EAG 6 – *Timelines for environmental assessment of proposals* for information regarding the responsibilities of proponents and the EPA for achieving timely and effective assessment of proposals.

8. Decision-making authorities

At this stage, the EPA has identified the authorities listed in Table 4 as DMAs for the proposal. Additional DMAs may be identified during the course of the assessment.

Table 4 Decision-making authorities

Decision-making authority	Relevant legislation
Minister for Environment	*Wildlife Conservation Act 1950*
Minister for Water	*Rights in Water and Irrigation Act 1914*
Minister for State Development	*Iron Ore (Yandicoogina) Agreement Act 1996*
Minister for Aboriginal Affairs	*Aboriginal Heritage Act 1972*
Minister for Lands	*Lands Administration Act 1997*
Department of Environment Regulation	Part V of the *Environmental Protection Act 1986*
Department of Mines and Petroleum	*Mining Act 1978* <u>Dangerous Goods</u> *Dangerous Goods Safety Act 2004* Storage and handling of hazardous materials Chief Dangerous Goods Officer

	Mine Safety *Mines Safety and Inspection Act 1994* District Inspector, Resources Safety Branch

9. Parallel processing

The EP Act constrains DMAs from making any decision that could have the effect of causing or allowing the proposal to be implemented. However, the proponent is encouraged to pursue other approvals in parallel with the EPA's assessment noting that the constraint only relates to making an approval decision.

10. PER document

When the EPA is satisfied with the standard of the PER document (refer to section 4.4 of EAG 6) it will provide written authorisation for the release of the document for public review. The proponent must not release the PER document for public review until this authorisation is provided.

The proponent is responsible for advertising the release and availability of the PER document in accordance with instructions that will be issued to the proponent by the EPA. The EPA must be consulted on the timing and details for advertisement.

RIO TINTO YANDI MINE
GROUNDWATER FLOW MODEL
INDEPENDENT REVIEW

Prepared for:	**Pilbara Iron Company Services Pty Ltd**	24 February 2015

hydrogeologic

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Table 1 – Groundwater Model Compliance Checklist: 10-point essential summary 1

hydrogeologic

Prepared by	Hydrogeologic Pty Ltd (ABN 51 877 660 235) PO Box 383, Highgate, South Australia 5063 M: +61 438 983 005 E: hugh@hydrogeologic.com.au
Author	Hugh Middlemis (Principal Groundwater Engineer, Hydrogeologic)
Recommended citation	Middlemis, H. (2015). Rio Tinto Yandi Mine Groundwater Flow Model Independent Review. Prepared by Hydrogeologic Pty Ltd for Pilbara Iron Company Services Pty Ltd. 24 February 2015.

1. Overview

This report summarises the outcomes of an independent review of the Yandi Mine numerical groundwater flow model developed by the Water Resource Evaluation (Projects and Development) business unit of Rio Tinto (on behalf of Pilbara Iron). The review was conducted in accordance with the principles of the Australian Groundwater Modelling Guidelines issued by the National Water Commission (NWC) in June 2012 (Barnett et al., 2012), as well as the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (Middlemis et al, 2001), which was the foundation for the 2012 guidelines. The 2012 guideline suggests a compliance checklist suitable for high-level appraisals, which can also be used to summarise the outcomes of a review. The completed summary checklist is presented at Table 1, and justifications for the opinions indicated are summarised in the comments field, with key elements explored/detailed further in later sections.

In summary, it is my professional opinion that the model has been developed in a manner that is broadly consistent with basic practice, but does not yet achieve best practice. The review confirmed good overall model calibration performance has been achieved, but also identified weaknesses in certain elements of the model design, surface and groundwater interaction features and parameter values. Such weaknesses/inconsistencies are not necessarily fatal flaws as such, but they could potentially form easy targets for unwarranted criticism, and many (if not all) could be readily addressed with refinements in the next modelling work program.

The main weakness is that the model design process has not thoroughly optimised all the issues of model functionality required to support a high model confidence classification in relation to the 2012 guideline (e.g. the layer structure is a little too complex and the calibration performance could be improved in the JSE Southern area). This does not mean that the model is technically flawed; simply that it is not a good example of best practice in its design and execution (i.e. the model could be described as somewhat over-designed). While the transient calibration performance is generally very good, it should be improved in the key area of the JSE Southern borefield and Weeli Wolli Creek intersection, which may require some additional data to validate the stream-aquifer interaction performance. The exploration of model uncertainty in structural and parameter value terms is basic and needs improvement under future work programs, notably in relation to stream-aquifer interaction.

This independent review finds that a Class 2 model confidence level classification (Barnett et al, 2012) has been achieved, meaning that this model is suitable for mining project impact prediction purposes.

Table 1 – Groundwater Model Compliance Checklist: 10-point essential summary

Question	Yes/No	Comments re Rio Tinto Yandi Mine groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	**Yes**	• As part of the PFS, dewatering requirements and potential environmental impacts of dewatering are needed for the Public Environmental Review. • A numerical groundwater model was selected as the tool to predict the dewatering requirements to meet the A8 mine schedule released in August 2014 and demonstrate the potential cumulative impacts of increased dewatering.
2. Are the objectives satisfied?	**Yes**	The general aims are satisfied via a generally good model calibration performance, and the prediction results provide data on dewatering needs and related impacts that are basically suitable for the PER purpose.
3. Is the conceptual model consistent with objectives and confidence level classification?	**Yes**	The close-coupled aquifer and creek system involves many complexities but the conceptualisation appears to be sound, representing the key features in quite some detail. The 15-layer model design is arguably too complex, but that does allow for a detailed spatial distribution of aquifer properties.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	**Yes**	Critical /fatal model flaws have not been identified during this review, but some weaknesses and minor inconsistencies identified have the potential to form easy targets for unwarranted criticism. Many (if not all) should be addressed in the next model work program. A multi-disciplinary team at Rio Tinto has clearly been involved in the hydrological and hydrogeological investigations and data analysis, with collaboration and review evidenced by acknowledgements in reports and papers, reinforced during discussions undertaken for this review.

5. Does the model design conform to best practice?	**Yes**	The model design, software, extent, cell size, boundaries and parameters are generally consistent with best practice (with some minor issues). The 15 layers are arguably too many (5 layers would be a bare minimum; perhaps 10 layers might be optimal?). The 15 layers do allow for a detailed representation of the spatial distribution of aquifer properties (especially helpful where the CID and alluvium are contiguous). However, this also results in a large model (>3 million cells) and thus long run times (around 2 days), which makes scenario modelling inefficient (e.g. the running of many scenarios to assess uncertainty, alternative mine plans, closure options, or climate variability would be ideal but not feasible in this case). This indicates that the model design process has not, in fact, optimised all the issues of model functionality required to support a high model confidence level classification. This does not mean that the model is technically flawed; simply that it is not a good example of best practice in its design and execution.
6. Is the model calibration satisfactory?	**Yes**	Model calibration performance is very good in terms of time series matches to measured groundwater levels at most bores (statistical measures are superfluous in this case). One area of relatively poor (but still adequate) performance is actually in a key area where good performance is required: near the JSE Southern borefield and where Weeli Wolli Creek crosses the CID for the first time, upstream from Billiard. Many processes are concentrated here: dewatering, reinjection, Discharge Outlet #6, creek interaction, and there is a complex distribution and wide range of parameter values. There are good matches pre-2006 to bores JSE31, JSE32, JSE39 and WB02, but then variable subsequent performance (model sometimes high and/or low at various times, with no obvious systematic trend). The next model refinement work program should focus on this area to improve calibration performance.
7. Are the calibrated parameter values and estimated fluxes plausible?	**Yes**	An appropriate level of complexity in parameter distributions has been applied to achieve overall good calibration performance. The parameter values and fluxes are plausible and generally consistent with site-specific testing and also literature values. Calibration uses measured data on groundwater levels, fluxes for bore extraction and injection, and stream flow volumes. There is an acknowledged level of uncertainty on some elements of the mine water balance volumes, which makes robust calibration performance difficult to achieve. Improved metering & monitoring will provide data for future model improvements. There is room for improvement on validation of stream-aquifer interactions, which form the major water balance volumes and thus strong performance is required. The review identified that the data available near discharge outlets 1 and 5 is not suitable for validating stream-aquifer interactions (i.e. these DO's are not active when groundwater monitoring was active). However, suitable data is available in the area of JSE Southern and DO6, an area where model validation is critical and must be demonstrated. The relatively poor (but still adequate) calibration performance here must be improved in the next work program.
8. Do the model predictions conform to best practice?	**Yes**	The methods applied were generally consistent with best practice. For example, the predictions conservatively accounted for the effects of BHP Billiton mining operations upstream, and scenarios were run to evaluate the effect of replacing DO9 by DO10 (demonstrating a reduction in dewatering). Other model predictions are adequate, but certain scenarios should be updated in the next work program; for example: • monthly creek flows over the quite dry 2009-2013 period were averaged and applied to the Marillana Ck and Weeli Wolli Ck boundary inputs for prediction scenarios; this approach should be improved to help evaluate climate variability effects, for example, a simple method would be to apply a repeated historical sequence of flows from wet/dry periods (e.g. 1998-2008) • the post-closure aquifer parameters are unchanged from in-situ values, which would over-estimate aquifer recovery rates & groundwater levels.
9. Is the uncertainty associated with the predictions reported?	**Yes**	Aquifer parameter sensitivity was analysed and the results used to evaluate related uncertainties in the model predictions, and this was executed very well. However, parameters relating to key processes including stream-aquifer interaction (streambed conductance) and evapotranspiration were not tested, and this should be a focus for the next work program to update the model.
10. Is the model fit for purpose?	**Yes**	My professional opinion is that the model has been developed in a manner consistent with basic practice, but not achieving best practice. The model design process has not optimised all the issues of model functionality required to support the PER purpose (e.g. the layer structure is too complex). This does not mean that the model is technically flawed; simply that it is not a good example of best practice in its design and execution. The transient calibration performance is generally very good, but is poor in the key area of the JSE Southern borefield and Weeli Wolli Creek traverse, where data is available to validate the stream-aquifer interaction performance.

2. Review Approach

For the record, the reviewer (Hugh Middlemis) is an independent groundwater modelling specialist with more than 25 years' experience in this field, including eight years based in Perth working mainly on mining projects, notably the Marillana Creek groundwater model for BHP (Middlemis et al, 1998). Hugh is principal author of the MDBA groundwater modelling guidelines (Middlemis et al, 2001) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling against international best practice.

The review was undertaken at Rio Tinto offices in Perth on Friday, January 23, 2015, when discussions were held with various staff, notably Eddy Lim (Senior Modeller), Keith Brown (Superintendent Hydrogeology) and Shawan Dogramaci (Principal Hydrogeologist). Mr Lim gave a presentation of various model details on that morning, and a brief question and answer session ensued regarding certain model specifics, with interrogation of some of the model data files facilitated by Eddy Lim. There was some subsequent provision of certain model information via email and discussion on certain model details via telephone. Dr Dogramaci provided copies of several published papers on research into stream-aquifer interactions and isotope analysis, and one Rio Tinto report for background purposes.

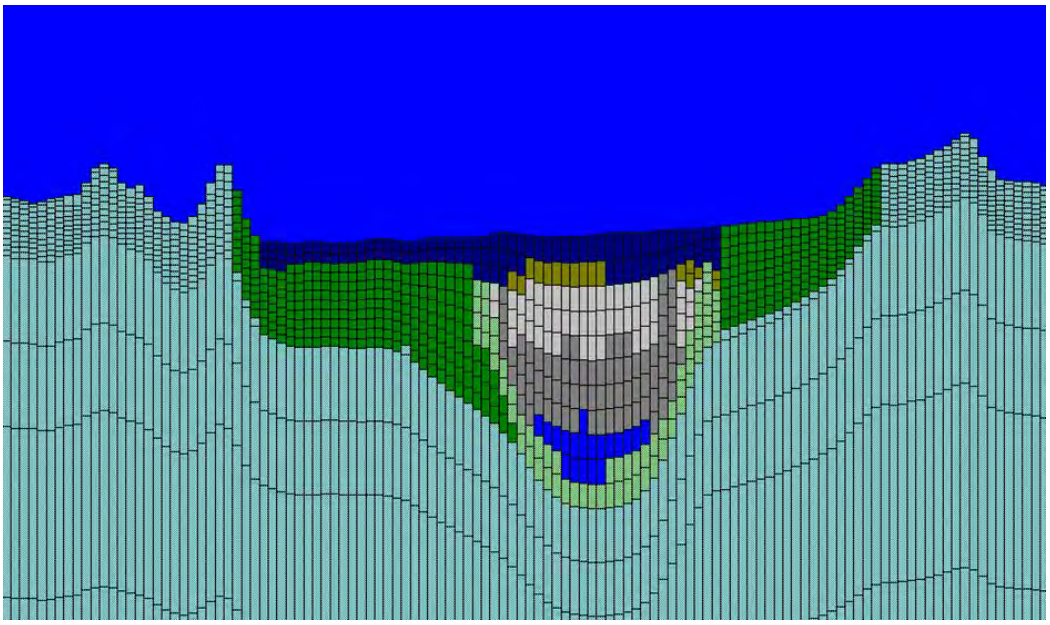
It was not possible to evaluate comprehensively the entire range of hydrogeological data nor every element of the gigabytes of model data files, nor indeed all the background reports and papers. While this review does not consider or address all uncertainties and risks, it aims to investigate any weaknesses relating to the model design and implementation, based on application of the review protocols in modelling guidelines.

Given the aim to identify weaknesses, this review process tends to focus on negative aspects. However, it is acknowledged that many elements of the technical modelling process have been very well executed.

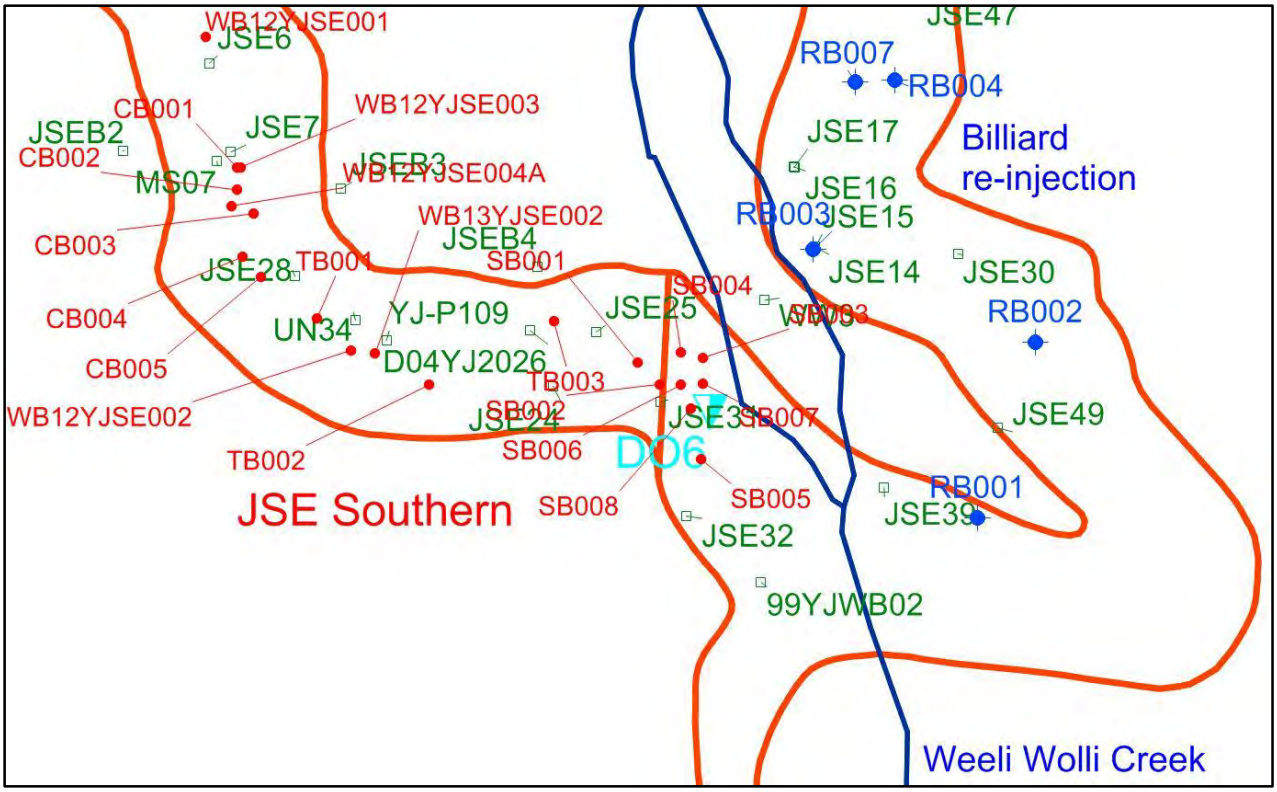
3. Impact Assessment Modelling Approach

The following points summarise the model design, calibration, sensitivity testing and prediction approach undertaken, with comments added to confirm where the work forms a sound basis for impact assessment, or to outline where/why it may be deficient:

- **conceptual model** is summarised adequately in geological terms and is based on substantial investigations over the many years that Rio Tinto has operated the Yandi mine;
- **25 x 30 km model extent** with maximum cell size of 509 x 750 m provides adequate regional extent (boundaries remote from mine area with intervening low permeability units); minimum cell size of 31 x 32 m provides adequate detail internally where needed;
- **15-layer regional model** with model layer elevations based on geological structure/mapping, validated against drill logs; 15 layers is arguably too many (5 layers would be a bare minimum; perhaps 10 layers might be optimal?); but the approach does allow for a detailed representation of the spatial distribution of aquifer properties (e.g. see screen grab of model cross section west-east at Billiard, showing aquifer parameter distribution consistent with hydrogeological understanding, including basal clay conglomerate forming lateral separation of thick alluvium from CID, validated by pumping test);



- **modelling software is Modflow-Surfact** (industry-leading and suitable); model comprises 3.3 million cells, or three times larger than what the industry regards as a large model of 1 million cells; long run times result (around 2 days), which make for inefficient scenario modelling; this indicates that the model design process has not, in fact, optimised all the issues of model functionality required to support the PER purpose; it does not mean that the model is technically flawed, simply that it is not a good example of best practice in its design and execution;
- **model boundaries**: western boundary is specified head plus stream discharge from BHPB discharge point (i.e. reasonable in principle, but conservatively assumes no groundwater level impact from BHPB dewatering, although ongoing BHPB stream discharge outlet volumes are applied); northern boundary is drain cells, whereas it would be expected that the same (fixed head) boundary type as for the western boundary would be adopted and another calibration parameter (drain conductance) would not be introduced without suitable justification (this is not a fatal flaw as such, simply an example of inelegant design); southern boundary is no flow (not unreasonable given lack of CID in this area) plus stream discharge based on Tarina gauging station flows, which includes the effects of dewatering discharge from mining operations south of Weeli Wolli Spring;
- **steady state calibration**: groundwater contours appear acceptable across almost all areas, but show some perturbations on the northern boundary, which the on-site review identified as being related to a localised active evapotranspiration process that may not be realistic due to the (low) topographical data in that area; this is not material to overall model performance (other than in this unimportant area on the northern model boundary), and should be addressed in the next model update;
- **transient calibration performance** is demonstrated by generally good time series matches at most bores; there is one area of relatively poor performance: near the JSE Southern borefield and Discharge Outlet 6, close to where Weeli Wolli Creek crosses the CID for the first time, and upstream from Billiard (see sketch below); many processes are concentrated here: dewatering, reinjection, Discharge Outlet #6, creek interaction, and there is a complex distribution and wide range of parameter values; there are good matches pre-2006 to bores JSE31, JSE32, JSE39 and WB02, but then variable performance (model high and/or low at various times, with no obvious systematic trend); further calibration effort at the next modelling work program is required to improve model performance in this key area;



- **stream-aquifer interactions** are a key element of the model design and execution and form the major water balance volumes, but more effort is required on the validation of this key process; this could be demonstrated by interrogating model output data to show that the persistence of stream flows downstream of discharge outlets matches the observable stream leakage characteristics, and is consistent with published information on stream aquifer interactions (e.g. Dogramaci et al, 2015); the Q&A review session identified that the data available at DO1 and DO5 is not suitable for such validation (i.e. DO's are not active when groundwater monitoring was active); however, it was identified that DO6 is a site where model validation could be demonstrated, including information from published papers;

- **transient prediction simulations of mine dewatering** are well executed; however, the climate variability effects of wet and dry periods were not comprehensively assessed, as the predictions used the averaged monthly creek flows 2009-2013 (a relatively dry period) to specify the Marillana Creek and Weeli Wolli Creek boundary inputs; this is an arguably conservative approach that is suited to mining project impact prediction purposes; a better approach (albeit very simple) that does consider climatic variability would be to apply a repeated historical sequence of flows from a period with wet and dry sequences (e.g. 1998-2008); future model updates should consider the need for assessment of the effects of climatic variability;
- **post-closure model scenarios** assumed in situ parameters, which would have the effect of over-estimating the rate of aquifer recovery, and the assumed climatic inputs have not considered variability effects.

4. Model Conceptualisation and Complexity

The overall modelling approach applied is reasonable for the mining project impact assessment purpose. In terms of the 2012 guideline (Barnett et al, 2012), this review has found that a model confidence level 2 classification would be justified for the Yandi model (or medium complexity in terms of the 2001 guideline).

5. References

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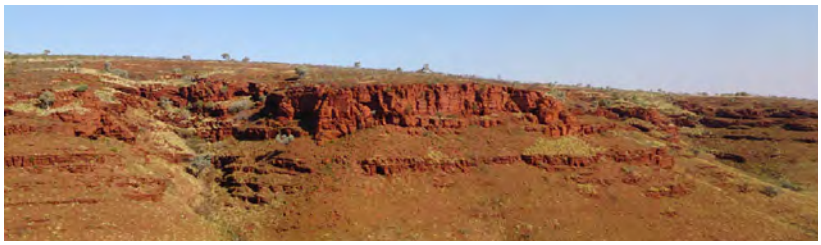
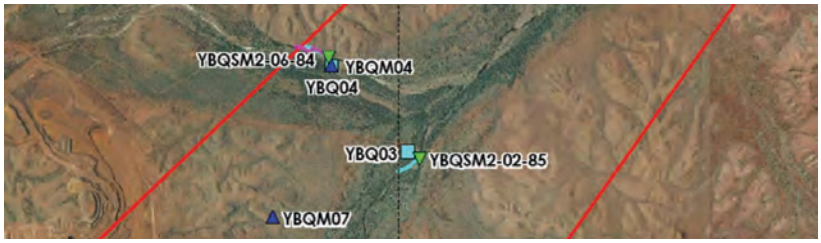
Biota Environmental Sciences

Yandi Billiards Targeted Northern Quoll Survey





Prepared for Rio Tinto Pty Ltd

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Yandi Billiards Targeted Northern Quoll Survey

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1.0 Introduction

1.1 Project Background

Rio Tinto (Pty Ltd) (Rio Tinto) currently operates the Yandicoogina (Yandi) iron ore mine as part of its Pilbara Iron operations. Yandi is located approximately 90 km northwest of Newman in the Pilbara region of Western Australia. Rio Tinto is currently conducting a Pre-feasibility Study for development of two channel-iron deposits at Yandi Billiards, Pocket and Billiards South, located approximately 7 km east of the existing Yandi mine.

It is anticipated that the future development of Yandi Billiards will be formally assessed under both the State *Environmental Protection Act 1986* and the Federal *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Any potential impacts on fauna species listed as Threatened under the *EPBC Act 1999* have potential to constitute a Matter of National Environmental Significance (MNES) and in cases where threatened fauna are recorded, would require referral to the Department of the Environment (DotE) under the Federal act. A key threatened fauna species that is likely to be relevant at both State and Federal levels is the Northern Quoll (*Dasyurus hallucatus*).

To address this, Biota Environmental Sciences (Biota) was commissioned to undertake a targeted Northern Quoll (*Dasyurus hallucatus*) survey at Yandi Billiards, an area approximately 8,640 ha in size. The polygon defining this Yandi Billiards survey extent is hereafter referred to as the 'study area' (see Figure 1.1)

1.2 Scope and Objectives of this Study

In preparation for forthcoming environmental assessment, Rio Tinto required a single-phase survey specifically targeting the Northern Quoll (*Dasyurus hallucatus*), in order to address anticipated MNES species requirements and demonstrate compliance with relevant Federal referral guidelines (DSEWPaC 2011).

The work also addresses the key gaps relating to Northern Quoll studies as identified by the Yandi Billiards desktop assessment (Biota 2013a), including a requirement for increased sampling effort and to further assess the likelihood of the Northern Quoll occurring within the study area.

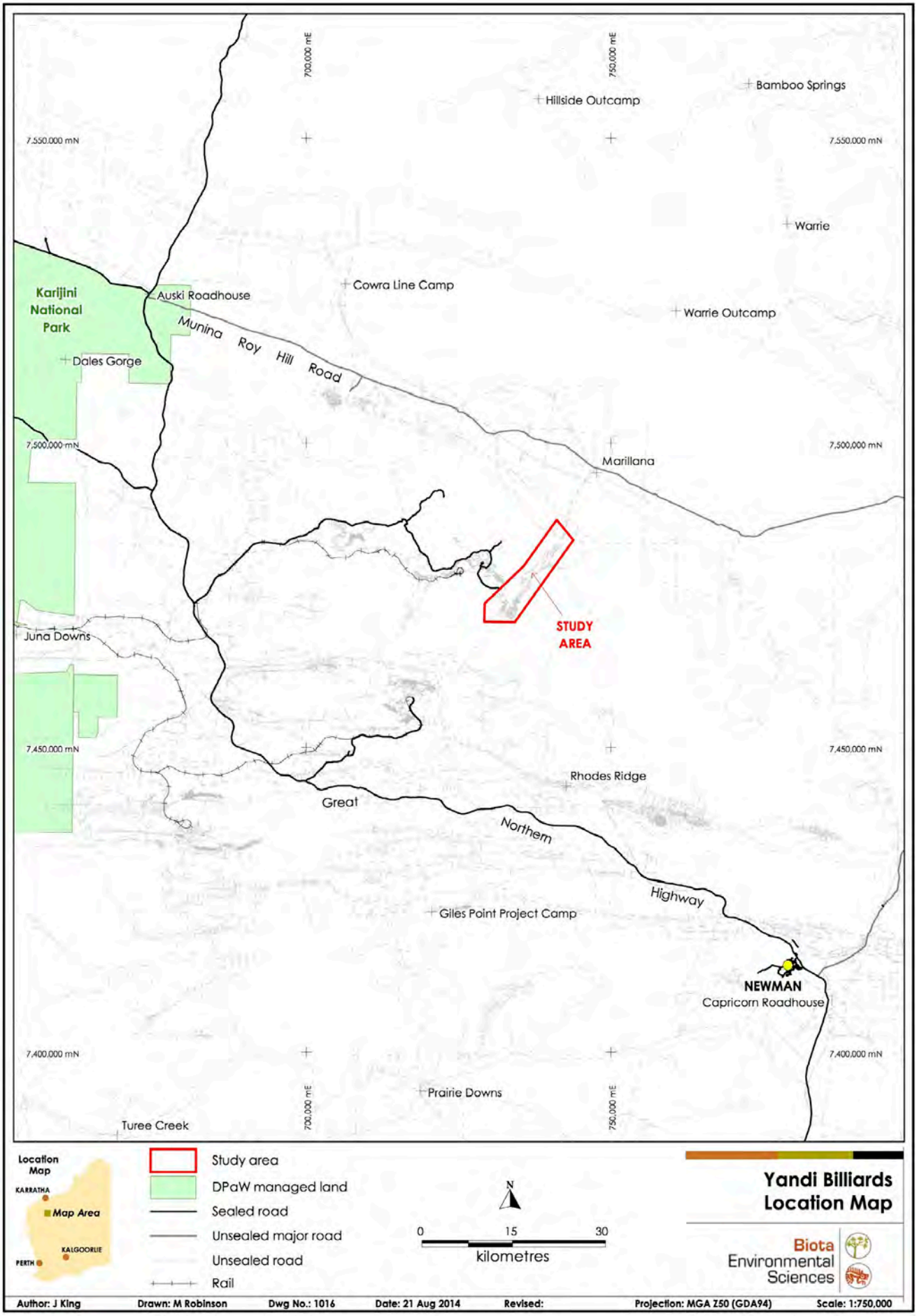

Figure 1.1: Location of the study area.

2.0 Background on the Northern Quoll

2.1 Ecology

The Northern Quoll is specially protected under both State and Federal legislation. It is listed as Schedule 1 ('Endangered') under the Western Australian *Wildlife Conservation Act 1950* and is listed as "Endangered" under the Federal *EPBC Act 1999.* It is a medium-sized dasyurid marsupial, with adult weight ranging from 300 to 1,200 g. It is considered a partially arboreal and aggressive carnivore, preying on a varied diet of small invertebrates and vertebrates, including lizards, birds, snakes, small mammals and frogs (Oakwood 1997), and is also known to feed on fleshy fruit and carrion. The Northern Quoll is mostly nocturnal, although crepuscular (dusk and dawn) activity also occurs.

The Northern Quoll formerly occurred across much of northern Australia but is now restricted to six main areas: the north and western top end of the Northern Territory, north of Cape York, the Atherton-Cairns area, the Carnarvon Range-Bowen area of Queensland (Menkhorst and Knight 2011), and the northwest Kimberley and Pilbara regions of Western Australia (Braithwaite and Griffiths 1994). The species is most abundant in open, rocky habitat and is also commonly found in gorges, rocky freefaces and hills, particularly for denning purposes (van Dyck and Strahan 2008, DEWHA 2010, DSEWPaC 2011). It also occurs near creek lines and drainage lines, where adjacent plains and vegetated areas provide habitats for foraging and dispersal of young (van Dyck and Strahan 2008).

Northern Quoll populations fluctuate on both annual and inter-annual cycles. This variability is driven by both the reproductive biology of individuals and longer-term cycles in response to regional stochastic processes such as rainfall, fire and related changes of prey populations (How et al. 2009). They are short-lived mammal, with both sexes maturing at 11 months. Females reproduce only once each year and almost all males die shortly after reproducing (Dickman and Braithwaite 1992, Oakwood 2000). The extent of this semelparity in the Pilbara is not well documented however, and there are suggestions that some males may survive more than one season (How et al. 2009).

The discrete male cohorts that arise within populations can make quolls more susceptible to local population extinctions. If no juvenile male quolls survive to adulthood, there will be no males available for mating the following year and the local population will rapidly decline (Braithwaite and Griffiths 1994, Oakwood 2000).

2.2 Desktop Assessment

A total of 105 land systems have been identified and mapped in the Pilbara bioregion[1], with 63 land systems occurring in the Hamersley subregion. Land systems mapping covering the study area has been prepared by van Vreeswyk et al. (2004).

Several recent studies have examined the regional relationship between Northern Quoll records and land systems in the Pilbara (Biota 2009a, 2010, 2013b). Compiled Northern Quoll records for the region show a wide distribution across the Pilbara, with records from locations across the extent of the bioregion (NatureMap database and Biota 2010), represented within a wide range of land systems.

In the Pilbara, more than half of all Northern Quoll records have come from within the Rocklea, Macroy, Robe and Newman land systems. These land systems contain rocky hills, gorges, rocky free faces, plateaus, drainages and granite tor fields, representing core Northern Quoll habitat (DEWHA 2010, DSEWPaC 2011). Northern Quolls have also been recorded relatively frequently

[1] This information was obtained by merging the Ashburton land system mapping (Payne et al. 1988) and Pilbara land system mapping (van Vreeswyk et al. 2004) and intersecting this with the Pilbara bioregion (Environment Australia 2000) in ArcView (v. 3.2).

from the Capricorn and River land systems, which also include incised terrain and major drainage habitats (Table 2.1). Together, these six land systems account for 77% of the Northern Quoll records from the region (Table 2.1).

Table 2.1: Relationship between Northern Quoll records and land systems in the Pilbara bioregion (land systems in grey contain core habitats for the Northern Quoll; Table modified from Biota (2010); six additional land systems with less than two records not shown).

Land System	No. of Records	Description
Rocklea	49	Basalt hills, plateaux, lower slopes and minor stony plains supporting hard spinifex (and occasionally soft spinifex) grasslands.
Macroy	42	Stony plains and occasional tor fields based on granite supporting hard and soft spinifex grasslands.
Robe	36	Low plateaux, mesas and buttes of limonites supporting soft spinifex (and occasionally hard spinifex) grasslands.
Newman	24	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands.
Capricorn	17	Hills and ridges of sandstone and dolomite supporting low shrublands or shrubby spinifex grasslands.
Wona	10	Basalt upland gilgai plains supporting tussock grasslands and minor hard spinifex grasslands.
River	8	Active flood plains, major rivers and banks supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.
Horseflat	7	Gilgaied clay plains supporting tussock grasslands and minor grassy snakewood shrublands.
McKay	5	Hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands.
Boolgeeda	5	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands or mulga shrublands.
Calcrete	5	Low calcrete platforms and plains supporting shrubby hard spinifex grasslands.
Uaroo	5	Broad sandy plains supporting shrubby hard and soft spinifex grasslands.
Boolaloo	3	Granite hills, domes and tor fields and sandy plains with shrubby spinifex grasslands.
Taylor	3	Stony plains and isolated low hills of sedimentary rocks supporting hard and soft spinifex grasslands.
Urandy	3	Stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands.

The Yandi Billiards study area intersects three land systems, Newman, River and McKay (Biota 2013a). Regional analysis indicates the Northern Quoll could occur in all these land systems, with the Newman land system most likely to provide habitat for the species.

In addition, there have been a small number of anecdotal sightings of Northern Quolls at the existing Yandi operations to the northwest (Biota 2009b, 2010) (M. Brand, Rio Tinto, pers. comm. 2014), and two individuals were recently trapped 10 km to the northwest in the Koodaideri project area (Biota 2013c). There are also three other records of the Northern Quoll within 15 km of the study area, which were recorded in 2010 (NatureMap database). Given the presence of Weeli Wolli Creek, riparian vegetation and rocky habitat along the study area periphery, it is possible that the Northern Quoll occurs in the study area. However, if present, it is likely to be at low density, as appears to be typical for the eastern Pilbara (Biota 2009b, 2010).

3.0 Methodology

3.1 Survey Design

The survey trapping locations were selected to sample the most prospective habitats for Northern Quolls available within the study area. These were determined based on examination of land systems data (Section 2.2), vegetation types (Biota 2014a) and aerial imagery. Consideration was also given to spatial distribution of trapping sites within the study area, with most effort apportioned to the south of the study area where the Pocket and Billiards South deposits are located. Five nominal trapping sites were selected within the study area prior to the field survey, with the exact locations being determined by confirmation of habitats on-site on commencement of the field work.

3.1.1 Timing and Personnel

The project was co-ordinated by Garth Humphreys of Biota. The field survey team consisted of Michael Greenham and Jacinta King, both from Biota. The survey ran from August 5th to 13th, 2014 with each sampling site being open for a minimum of seven nights, such that duration and seasonal timing were consistent with Federal referral guidelines (DSEWPaC 2011).

3.1.2 Climate and Weather

Minimum temperatures during the survey ranged from 5.3°C to 15.3°C and maximum temperatures ranged from 30.3°C to 22.2°C (Table 3.1). No rain was recorded for the duration of the sampling.

Table 3.1: Daily meteorological observations for Newman Airport during the survey period.

	5/08	6/08	7/08	8/08	9/08	10/08	11/08	12/08	13/08
Minimum Temperature (°C)	8.0	6.1	5.3	7.7	9.8	15.3	9.5	10.2	12.0
Maximum Temperature (°C)	23.5	23.5	26.0	27.6	30.3	29.4	28.2	26.6	22.2
Daily Rainfall (mm)	0	0	0	0	0	0	0	0	0

Data obtained from Bureau of Meteorology Newman Airport, BOM (station 007176)

Long-term climatic data for Newman Airport indicate that the mean minimum and maximum temperatures for the six months leading up to the survey were close to the long term average (Figure 3.1). Monthly rainfall for the six months leading up to the survey was below average, wuth the exception of May and July (Figure 3.1).

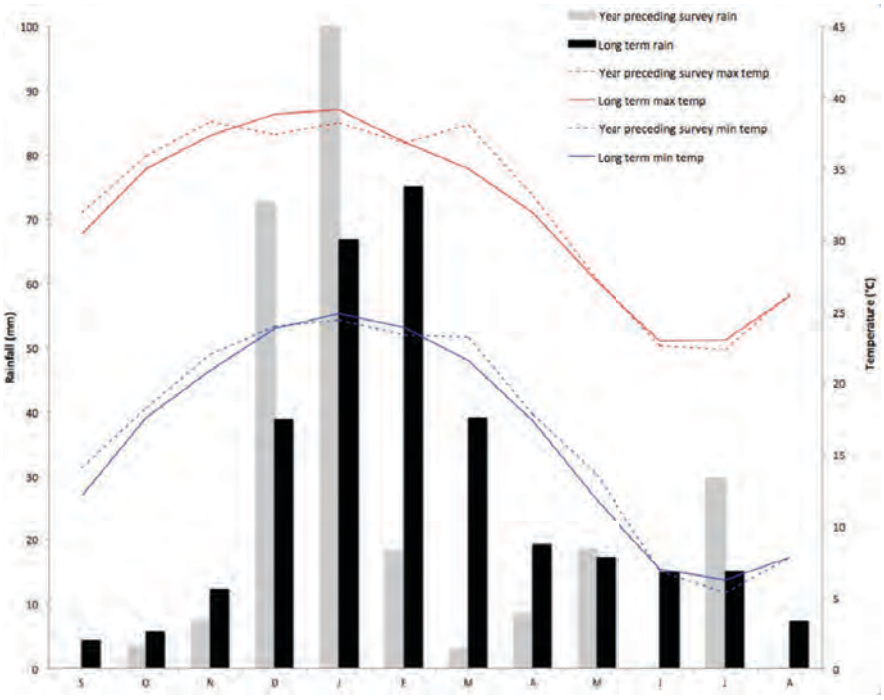

Figure 3.1: Long-term and recent climatological averages recorded at Newman Airport. Data supplied by BOM: long-term rainfall data (1996-2014); long-term temperature data (1971-2014); year preceding the survey (September 2013-August 2014).

3.2 Sampling Techniques and Effort

3.2.1 Systematic Northern Quoll Sampling

Targeted trapping for the Northern Quoll was carried out in accordance with the Federal referral guidelines (DSEWPaC 2011). The survey consisted of a combination of systematic fauna sampling and targeted searches. Systematic sampling was centred on five main trapping sites, each consisting of four cage traps and 20 large Elliott traps (see Figure 3.2). Individual traps were placed in specifically targeted microhabitats and were suitably spaced to maximise the likelihood of encountering Northern Quolls. Traps were baited with a mixture of peanut butter, rolled oats, bacon and sardines, which was placed at the back of each trap, with rebaiting with fresh bait conducted every second day. Each trapping site was open for seven consecutive nights, translating to a total of 840 trap nights (Table 3.2).

Table 3.2: Trapping site locations and effort (coordinates in zone 50, GDA94).

Site Name	Easting (mE)	Northing (mN)	Date Opened	Date Closed	Number of Traps		Nights Open	Trap Nights
					Elliott	Cage		
YBQ01	731811	7472976	5/08/14	12/08/14	20	4	7	168
YBQ02	733147	7471040	6/08/14	13/08/14	20	4	7	168
YBQ03	736109	7477362	6/08/14	13/08/14	20	4	7	168
YBQ04	735098	7478519	6/08/14	13/08/14	20	4	7	168
YBQ05	740190	7484499	6/08/14	13/08/14	20	4	7	168
				Total large Elliott trapping effort				700
				Total cage trapping effort				140
				Total trapping effort				840

Automatic infrared motion cameras were deployed in rocky overhangs between boulders and within other habitat that Northern Quolls might be expected to utilise. The majority of the cameras were placed in areas close to the Elliott/cage trapping sites (Figure 3.2). However, other suitable locations within the study area were also utilised. Bait was placed on the ground in order to attract animals to within the camera's field of view. Each motion camera was deployed for a minimum of three nights, comprising a combined total of 22 camera-trap nights (Table 3.3).

Table 3.3: Automatic camera locations and effort (coordinates in zone 50, GDA94).

Site Name	Easting (mE)	Northing (mN)	Date Opened	Date Closed	Nights open	Trap Nights
YBQM01	732013 mE	7473157 mN	6/08/14	9/08/14	3	3
YBQM02	733224 mE	7470635 mN	7/08/14	10/08/14	3	3
YBQM03	732210 mE	7473433 mN	6/08/14	9/08/14	3	3
YBQM04	735089 mE	7478526 mN	6/08/14	9/08/14	3	3
YBQM05	742423 mE	7482645 mN	9/08/14	13/08/14	4	4
YBQM06	731692 mE	7472970 mN	9/08/14	12/08/14	3	3
YBQM07	734302 mE	7476490 mN	10/08/14	13/08/14	3	3
				Total Trap Nights		22

3.2.2 Non-systematic Sampling

Non-systematic observations of vertebrate fauna were also recorded during the survey. This included observations made during routine trap checks and timed, targeted searches in various other suitable parts of the Yandi Billiards study area (Figure 3.2). Targeted searches focussed on the detection of trace records such as tracks and scats.

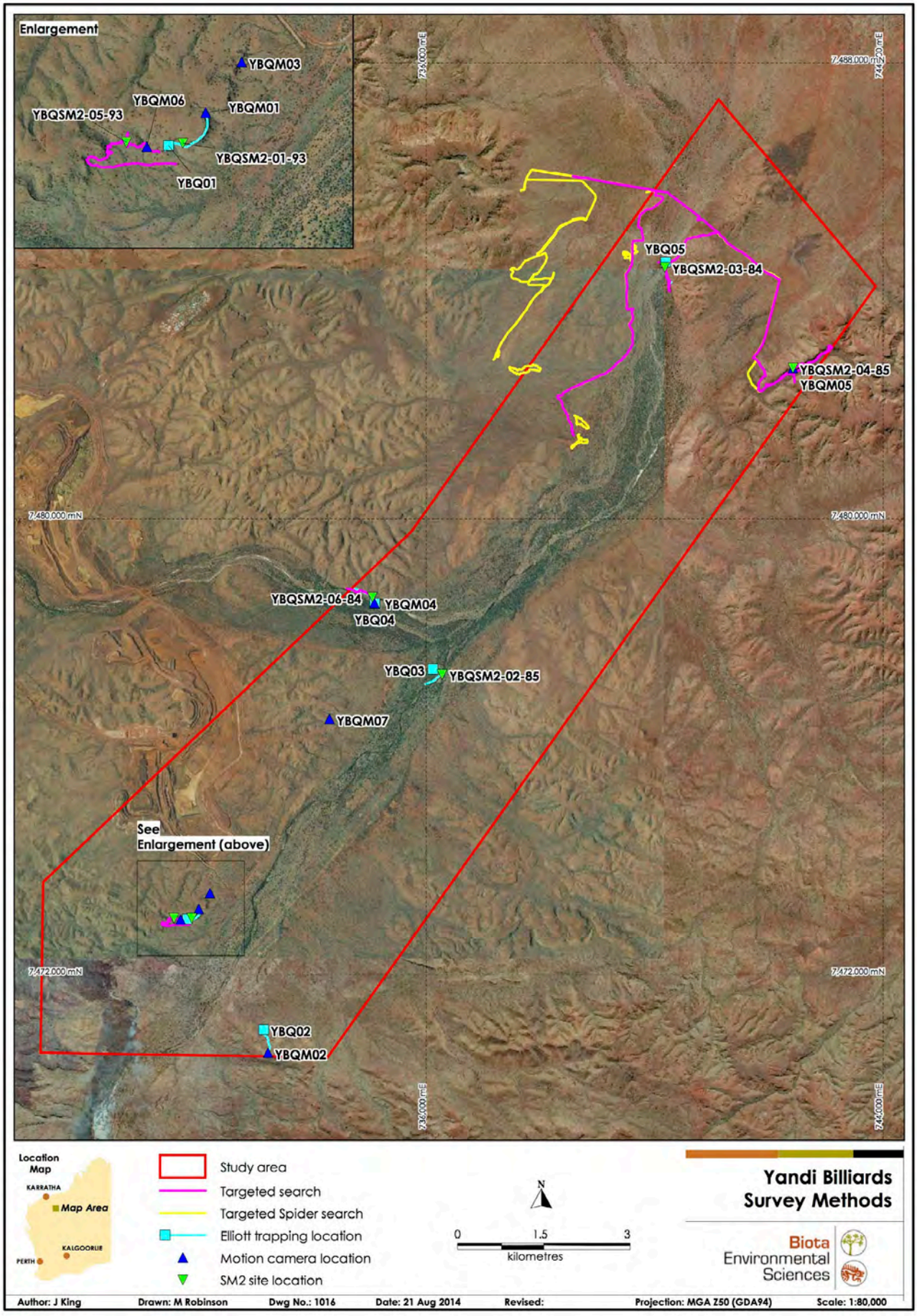

Figure 3.2: Targeted sampling effort in study area.

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4.0 Results

4.1 Habitats

The study area comprised three, well defined landscapes, each containing specific landforms (Table 5.1). Within each functional landform, habitats were identified on the basis of geomorphology, geology, vegetation and ecological niches relevant to fauna (see Table 4.1 and Table 4.2). Much of the Newman land system present in the study area contained hillslope land units rather than gorges suitable for Northern Quoll. Sampling effort was deployed in the optimal habitats available in the study area based on field confirmations (Table 4.1 and Table 4.2).

Table 4.1: Landscapes and landforms present in the study area.

Landscape	Landform
LANDSCAPE 1: contemporary drainage systems and flood plains of alluvial deposits.	• river channel; and • gently sloping plain with adjacent stream channel.
LANDSCAPE 2: gently sloping to level alluvial/colluvial plain.	• plain; and • minor drainage lines.
LANDSCAPE 3: Incised hills comprising ridges and rocky free faces.	• hills; • free face and debris slope; and • minor drainage lines.

Table 4.2: Elliott/cage transect site descriptions.

Site	Site Description	Photo
YBQ01	Landform: Rocky free face. Vegetation: *Eucalyptus leucophloia* and *E. ferriticola* low open woodland over *Triodia wiseana* hummock grassland over *Themeda* sp., *Cenchrus* sp., tussock grassland. Land system: McKay	
YBQ02	Landform: Rocky free face. Vegetation: *Eucalyptus leucophloia* open woodland over *Goodenia* sp., open shrubland over *Triodia wiseana* hummock grassland over *Eriachne* sp., tussock grassland. Land system: Newman.	

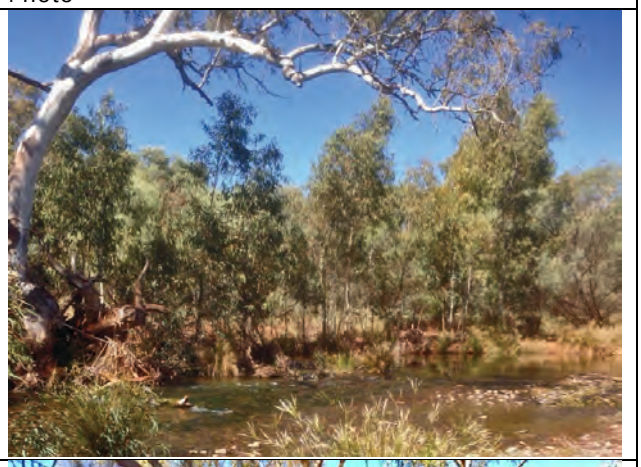
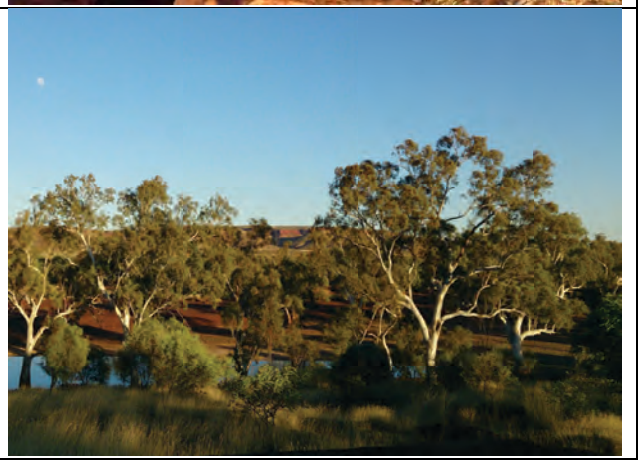
Site	Site Description	Photo
YBQ03	Landform: Major drainage line bed. Vegetation: *Eucalyptus camaldulensis* low open forest over *Acacia pyrifolia* and *Acacia* sp., open shrubland over *Triodia wiseana* open hummock grassland over **Cenchrus* sp., tussock grassland over *Papyrus* sp. and *Typha* sp. sedgeland. Land system: River.	
YBQ04	Land form: Major drainage line bed. Vegetation: *Eucalyptus camaldulensis* open woodland over *Acacia* sp., scattered shrubs over **Cenchrus* sp. open tussock grassland. Land system: River.	
YBQ05	Land form: Major drainage line bed. Vegetation: *Eucalyptus camaldulensis* woodland over **Cenchrus* sp. tussock grassland. Land system: River.	

Table 4.3: Motion camera site descriptions.

Site	Site Description	Photo
YBQM01	Land form: Rocky free face Vegetation: E*ucalyptus leucophloia* and *E. ferriticola* low open woodland over *Triodia wiseana* hummock grassland over *Themeda* sp. and **Cenchrus* sp. tussock grassland. Land system: McKay	
YBQM02	Landform: Cave/overhang Vegetation: *Eucalyptus leucophloia* open woodland over *Goodenia* sp. open shrubland over *Triodia wiseana* hummock grassland over *Eriachne* sp. tussock grassland. Land system: Newman	
YBQM03	Landform: Rocky free face Vegetation: *Eucalyptus leucophloia* and *E. ferriticola* low open woodland over *Triodia wiseana* hummock grassland over *Themeda* sp, **Cenchrus* sp., tussock grassland. Land system: McKay	

Site	Site Description	Photo
YBQM04	Landform: Minor drainage line. Vegetation: *Eucalyptus camaldulensis* open woodland over *Acacia* sp. scattered shrubs over **Cenchrus* sp. open tussock grassland. Land system: River	
YBQM05	Landform: Cave Vegetation: *Eucalyptus leucophloia* open woodland over *Solanum* sp. scattered low shrubs, over *Themeda* sp,.and **Cenchrus* sp. open tussock grassland. Land system: Newman	
YBQM06	Landform: Rocky free face Vegetation: *Eucalyptus* sp. scattered low trees over *Triodia* sp. hummock grassland. Land system: McKay	

Site	Site Description	Photo
YBQM07	Landform: Rocky free face Vegetation: *Eucalyptus leucophloia* and *E. ferriticola* low open woodland over *Acacia inaequilatera* and *Gossypium robinsonii*, over *Triodia wiseana* hummock grassland and *Themeda* sp. and **Cenchrus* sp. tussock grassland. Land system: McKay	

4.2 Trapping and Targeted Search Results

No specimens of Northern Quoll were collected during the survey. A single potential *Dasyurus hallucatus* scat was collected during a targeted search, close to site YBQ01 (Plate 4.1; Figure 3.2). However, molecular sequencing was unable to confirm its origin.

Plate 4.1: Typical cylindrical shaped scat typical of Northern Quolls (reference image from Biota (2014b)).

Three other fauna species were recorded during the survey (Table 4.4). The Common Rock-Rat, *Zyzomys argurus* was frequently caught at the two rocky freeface sites (YBQ01 and YBQ02). The Sandy Inland Mouse, *Pseudomys hermansburgensis* was frequently captured at two of the grass-dominated riverine locations (YBQ03 and YBQ04). A single individual of Woolley's False Antechinus, *Pseudantechinus woolleyae*, was captured on four occasions at YBQ02. None of these species are of elevated conservation significance.

4.3 Automatic Motion Camera Results

The automatic cameras did not record the presence of Northern Quolls during the survey period. However, four native mammal species, one introduced mammal and one bird species were recorded at the various automatic camera locations (Table 4.4).

Table 4.4: Fauna recorded during the survey.

Order Species	Elliott/Cage Transect Sites					Automatic Motion Camera Sites							Opportunistic Sightings	Total
	YBQ01	YBQ02	YBQ03	YBQ04	YBQ05	YBQ M01	YBQ M02	YBQ M03	YBQ M04	YBQ M05	YBQ M06	YBQ M07		
Felis catus House Cat	-	-	-	-	-	-	-	-	-	-	-	12M	-	12
Macropus robustus Euro	-	-	-	-	-	-	-	-	-	3M	-	-	-	3
Petrogale Rothschild Rothschild's Rock Wallaby	1	-	-	-	-	-	-	-	-	2M	-	-	-	3
Pseudantechinus woolleyae Woolley's False Antechinus	-	4	-	-	-	-	-	-	-	-	-	-	-	4
Pseudomys hermannsburgensis Sandy Inland Mouse	-	-	20	4	2	-	-	-	-	-	-	-	-	26
Zyzomys argurus Common Rock Rat	21	4	-	-	-	-	-	-	-	1M	-	23M	-	49
Ardeotis australis Australian Bustard	-	-	-	-	-	-	-	-	-	-	-	-	3	3
Dromaius novaehollandiae Emu	-	-	-	-	-	-	-	-	-	-	-	-	3	3
Corvus orru Torresian Crow	-	-	-	-	-	7M	25M	-	-	-	-	-	-	32
Pseudechis australis Mulga Snake	1*	-	-	-	-	-	-	-	-	-	-	-	-	1
Total	*23*	8	18	3	2	7	25	0	0	6	0	35	4	131

*M indicates video records from motion cameras.

5.0 Discussion and Conclusions

The targeted survey of the Billiards study area recorded no evidence of *Dasyurus hallucatus* from any of the 120 traps or seven automatic cameras deployed. The only potential evidence of the species presence was a single possible scat belonging to the species located during a traverse, but confirmation of this is currently pending (Section 4.2).

These findings are generally consistent with the outcomes of past biological survey effort in the vicinity of the study area. Numerous targeted and general terrestrial fauna surveys have been undertaken in the wider Yandi locality over many years and seasons with a combined total trap effort of over 10,000 Elliott traps (Biota 2010). Past work in similar landscapes to the current study area has also specifically targeted *Dasyurus hallucatus* with cage and Elliott traps, without any record of the species' presence (Biota 2009b). While the species' life history also plays a role, with significant natural population fluctuations influencing the ability to detect individuals in an area (Biota 2009a, 2010), it is unlikely that a significant Northern Quoll population occurs within the study area. This is also consistent with the small proportion of the study area mapped as potential NES species habitat by the field zoological interpretation of Biota (2014c).

The only evidence of *D. hallucatus* from the Yandi locality in the past 15 years remains the anecdotal observations of individuals around the warehouse and camp of the existing Yandi operations. This may be partially attributable to the lack of good quality suitable habitat for the species within the generally lower elevation habitats of the study area, and that better quality habitat for the species occurs further northwest where the camp is sited (G. Humphreys, Biota, pers. obs. 2014). Individual Northern Quoll may be foraging from core habitat in gorges further north of the camp and warehouse and becoming habituated to human activity in the area. This and other past studies, however, show no evidence that a population of the species currently occurs as far southwest as Yandi Billiards.

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6.0 Glossary and Acronyms

Biota	Biota Environmental Sciences.
EPA	Environmental Protection Authority of Western Australia.
EPBC	Federal *Environmental Protection and Biodiversity Conservation Act 1999.*
NES	National Environmental Significance.
Elliott Trap	A collapsible aluminium box trap.
Land system	Repeated patterns of topography, soils and vegetation.
Landform	A geomorphological unit that is largely defined by its surface form and location in the landscape.
Semelparity	A species characterised by a single reproductive episode prior to death.

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Rio Tinto

Supporting document for the Yandi Pocket and Billiard South Project Public Environmental Review (PER)

Yandicoogina Rehabilitation Review

31 March 2015

This document addresses the PER item "*Undertake a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including a discussion of the different methodology and success rates for the various proposed disturbance types including:*

- *created landforms (e.g. waste rock dump, tailings storage facility)*
- *short-term disturbances (e.g. borrow pits and access tracks)*
- *long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings); and*
- *linear and/or fragmentation disturbances (e.g. roads, power lines, bore fields)"*

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Context and Purpose

This document provides the information to address the following requirement of the Yandicoogina PER.

Undertake a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including a discussion of the different methodology and success rates for the various proposed disturbance types including:

- created landforms (e.g. waste rock dump, tailings storage facility)
- short-term disturbances (e.g. borrow pits and access tracks)
- long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings); and
- linear and/or fragmentation disturbances (e.g. roads, power lines, bore fields)

The Yandicoogina ore body is a specific type of paleochannel[1] known as a Channel Iron Deposit (CID). The CID mined at Yandicoogina consists of three main layers the overburden material (a mixture of lateritic pisolite, poorly sorted angular to sub-rounded BIF, chert and dolomite gravels in a sandy matrix), the iron deposit and the basement rocks and altered basement rocks.

The key waste types that will result from mining at Yandicoogina are referred to as Channel Iron Deposit (CID) waste and Alluvials. The erodibility potential of these waste types at Yandicoogina has been assessed with the majority of waste classified as high erodibility when utilised in final landform design at Yandicoogina.

Rio Tinto Iron Ore aims to create landforms that are safe and stable, considered aesthetically compatible with the surrounding landscape, supportive of native vegetation, and are non-polluting

[1] Paleochannels are remnants of ancient streams cut into old rocks and filled with sediments from younger rocks; such that they reflect historical drainage lines. The contemporary equivalent is called an alluvial channel.

Assessment of Rehabilitation Strategies

To enable a discussion of the "success" or otherwise of past rehabilitation strategies and outcomes a review of rehabilitation monitoring results that compares rehabilitation areas to "similar" reference or control sites has been undertaken. Reference sites can be described as an unmined site, usually representative of the 'natural' landscape surrounding the mine site or rehabilitated area. The reference site generally consists of the target vegetation community, soil type and terrain and provides an example of what the rehabilitated area should achieve. For example to determine the success of waste dump slope rehabilitation it has been compared to a reference site that has been established on an undisturbed slope in the surrounding environment. Similarly rehabilitation of flat areas has been compared to reference sites established in an area of flat undisturbed vegetation, with the vegetation being typical of the surrounding area. By comparing rehabilitated areas to undisturbed reference areas (with similar terrain and topography) effectively it is answering the question as to whether the rehabilitated areas have similar biodiversity to surrounding communities. This aligns with the overall closure and rehabilitation strategy outlined in the Yandicoogina Closure Plan (2013) that is to establish ecosystems with similar biodiversity and cultural heritage values as surrounding reference sites.

Whilst this is a high level approach, it is suitable for getting a general understanding of the success of a rehabilitation area (regardless of site specific completion criteria which might apply). As rehabilitation (and related closure strategies and outcomes might differ between sites depending on the site based risks and environmental values) comparing rehabilitation to similar reference sites also allows us to understand how the rehabilitation is performing against the general objective of creating a stable, non-polluting landform, that comprises local native vegetation that is self-sustaining and compatible with the surrounding environment.

It is acknowledged that Yandicoogina has specific objectives and completion criteria proposed in its current Closure Plan including those listed relating to stability and biodiversity in ***Table 1***.

Table 1: Yandicoogina objectives and completion criteria relating to biodiversity and landform stability.

Function	Objective	Indicative Completion Criteria
Landform Stability	Rehabilitated landforms are stable and designed to manage floodwater appropriately.	Erosion does not threaten the long term stability of the landform.
Biodiversity	Final landforms are rehabilitated to be compatible with post-mining land use.	Vegetation on rehabilitated land is native and self-sustaining. Habitat for native fauna is provided in appropriate rehabilitated areas. The prevalence of invasive species (weeds, feral animals) is similar to that in nearby reference site.

By reviewing previously completed rehabilitation areas on similar geologies in Pilbara ecosystems (against adjacent similar reference/control sites), we can get an understanding of what rehabilitation methods might be transferable and utilised at Yandicoogina to help Yandicoogina achieve its objectives and completion criteria.

As the rehabilitated areas assessed in this discussion are located at numerous locations and terrains across the Pilbara, a range of vegetation types will be assessed (by default). It is acknowledged that some of the vegetation communities proposed to exist following rehabilitation and closure at Yandicoogina are considered new types of rehabilitation for RTIO such as wetland habitat within mine voids. As a result, examples of this disturbance type and proposed rehabilitation are not included in this discussion. Whilst general methodologies are likely to be transferable to implement this type of new rehabilitation (such as waste characterisation and resulting landform design and shaping, topsoil application, ripping and seeding) there is a recognised knowledge gap as to the details for the rehabilitation methods such as topsoil application rates, surface water controls required and species mix to utilise.

Created Landforms (Waste Rock Dumps, Tailings Storage Facilities)

The proposed final landform at Yandicoogina on closure will not result in any external waste dumps. There will however be rehabilitated slopes external to the pit areas, such as where current infrastructure has been decommissioned and removed. In addition the edge of the backfilled waste within the pit areas that will slope down into what will eventually be pit lakes will also be rehabilitated. It is therefore important to review successful and unsuccessful rehabilitation strategies of slopes built of similar materials to what is predicted to be encountered at Yandicoogina. This rehabilitation type (built slopes) may be present in the rehabilitated land and wetland habitats that are likely to be introduced at Yandicoogina at closure.

At present, as there are no rehabilitated slopes at Yandicoogina with sufficient monitoring data to enable a review and discussion of rehabilitation success, rehabilitated slopes at Pannawonica Operations and Brockman Two Operations have been reviewed. The Pannawonica Operations in the Robe Valley are situated in a similar geology to Yandicoogina, with the mining of Iron Ore from a channel iron style deposit. In addition Brockman 2 Pit 2 deposit was mined in the late 1990's and involved the mining of ore and waste from a detrital iron ore deposit. The resultant single waste dump from the mining of ore from Brockman 2 Pit 2 deposit is comprised primarily of a erodible waste type considered similar (in terms of physical characteristics and erodibility) to the CID and alluvial wastes that are encountered as a result of mining ore at Yandicoogina from the Channel Iron Deposit.

This section will therefore focus on different strategies utilised for rehabilitated slopes at the Pannawonica Operations by reviewing rehabilitation success at Mesa J Waste Dump S and Mesa J Waste Dump T and Brockman 2 pit 2 Waste Dump 1. The strategy utilised to rehabilitate a tailings storage facility located at Pannawonica's Mesa J operation and early monitoring results will also be discussed.

Successful and Unsuccessful Rehabilitation Strategies

Mesa J Operations Waste Dump S

Waste Dump S at Mesa J Operations had rehabilitation of its slopes completed between 2002-2004 and these have a monitoring transect located on them. The same dump had further slopes rehabilitated in 2007 and has a monitoring transect located on it. Both areas were battered to 15 degrees slopes, comprise of a 12-15m lift height and had 150mm of topsoil applied and ripped into the surface and seed was applied. Approximately 90% of the single lift dump was rehabilitated as at 2007 (~40Ha). The monitoring transects on the slope of Waste Dump S are positioned where the lift height is approximately 8-10m.

The most recent monitoring of these areas, completed in in 2013 showed both areas had good perennial species diversity with 13 species present (higher than the slope control sites that had seven species present). The 2002-2004 rehabilitation, lower storey vegetation was absent until 2013, and then only represented a very small proportion of the total cover. The lower storey vegetation at this site was primarily made up of a mixture of *Triodia* and small or juvenile shrubs and the upper storey dominated by *Acacia* shrubs. The 2007 rehabilitation dominant stratum was the upper storey of *Acacia* shrubs, including *Acacia bivenosa* and *Acacia ancistrocarpa.*

Landscape function indices for stability were 61% for the slope reference sites while the rehabilitate sites were 59% (in 2013). The nutrient cycling and infiltration values for the

rehabilitation sites were also higher than the values measured in the slope reference site in 2013. All three indices compared favourably to the average scores achieved by the sloping reference sites. Due to the mature stage of ecosystem development these scores are not expected to change substantially in the future until *Acacia* senescence, or a disturbance event occurs, such as fire.

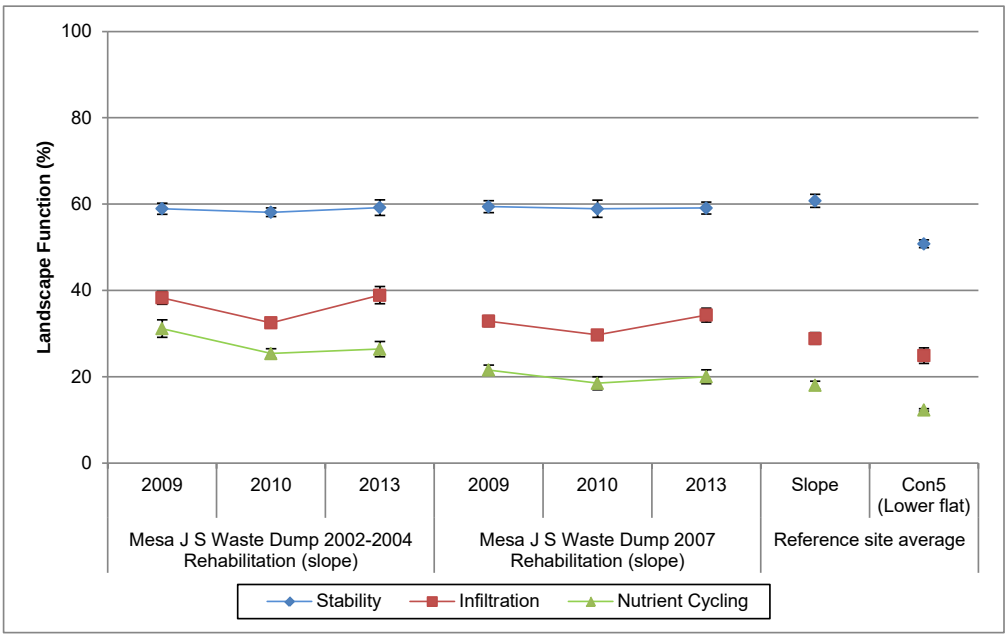

Figure 1: Changes in landscape function of the 2002-2004 and 2007 rehabilitation on the Mesa J S Waste dump (slope), in comparison with the sloping reference sites (Con7 and Con10) average, and Con5.

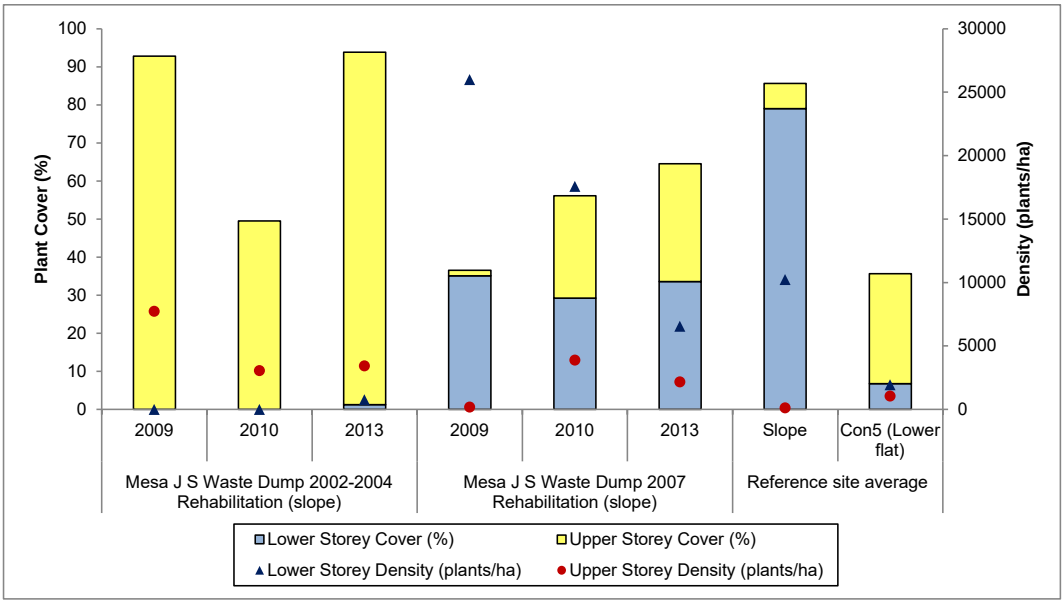

Figure 2: Changes in the plant cover index and density (lower and upper storey) of the 2002-2004 and 2007 rehabilitation on the Mesa J S Waste dump (slope), in comparison with the sloping reference sites (Con7 and Con10) average, and Con5.

The plant cover percentage was 63% and 93% for the two rehabilitation areas which was both higher and lower than the slope reference site which had 85% vegetation cover. The density of the cover was dominated by upper storey plants in both rehabilitation sites whilst the reference site was dominated by a lower story (refer to ***Figure 1*** and ***Figure 2***).

In terms of habitat complexity (which is used as an indicator of suitability of habitat for fauna) of the Waste Dump S rehabilitation areas several faunal niches were available such as litter, logs and rocks. Kangaroo scats were observed at both transects providing evidence that native fauna were utilising the rehabilitation area.

Since this site was first monitored in 2009, the proportion of the slope eroded has decreased on the 2002-2004 rehabilitation area from 14% to less than 9% in 2013. On the 2007 rehabilitation area, erosion increased slightly but the overall proportion of slope eroded was low. The vast majority of the erosion that was present was on the lower slope of the transect; erosion present on the upper slopes of both transects was minor.

Rehabilitation monitoring data to date suggests that the rehabilitation on Waste Dump S at Mesa J Operations is on track to achieving a stable, self-sustaining native vegetation community similar to the control sites. Whilst total plant cover percentages and density values are within or above the range of the combined slope and flat reference sites the composition/breakdown of this cover is different to the reference sites at the older (2002-2004) Mesa J S Waste Dump rehabilitation. A large proportion of the vegetation on the rehabilitation comprises of upper story cover (*Acacia's*) as opposed to lower story cover (*Spinifex sp*.) which is the dominant strata in the reference sites. The importance of this composition of species and how it may affect the achievement of completion criteria will be further clarified and refined as the site progresses towards closure and site specific completion criteria are established. Whilst erosion is present it appears to be either stabilising over time or only on a small proportion of the slope that was assessed.

Overall the few indicators of rehabilitation monitoring discussed here suggest that the right species are present (albeit in different proportions to the reference sites), the cover is adequate, and a number of landscape function indices are within the range of (or above) the reference sites indicating that this rehabilitation is heading in the direction of being considered stable, native and self-sustaining with habitat for native fauna present.

Brockman 2 Pit 2 Waste Dump 1

Pit 2 Waste Dump 1 at Brockman 2 Operations is comprised of waste that came from the adjacent Pit 2 deposit (detrital iron ore deposit) and is considered a similar waste type (in terms of physical characteristics and erodibility) to the alluvial and CID wastes that are encountered as a result of mining ore at Yandicoogina from the Channel Iron Deposit. The Pit 2 Waste Dump 1 is built with a single lift with the total dump height ranging from 8-20m and 15-20 degree outer slopes and was rehabilitated in 1999. It is assumed the dump had topsoil applied and was ripped and seeded (no records have been found to confirm this although evidence of cross ripping can be seen on aerial photos). The last monitoring of this rehabilitation was completed in 2012 (via a transect established on the waste dump slope where the lift height is ~8m) and the results are discussed below.

The total species number recorded in the rehabilitation was six which was within the range of values recorded in the three reference sites (six to nine species). *Spinifex, Acacias* and several other native perennial species were identified in the rehabilitation as well as the reference sites. The density of the S*pinifex* and native perennial plants was lower in the rehabilitation at 2.7 plants per quadrant than the range of the reference sites which were 5.8 – 19.4 plants per quadrant. Despite this the percentage perennial cover of the rehabilitation (53%) was within the range of the reference sites (38-70%).

In terms of habitat complexity *Spinifex species*, grass, shrub and litter cover were all comparable to or higher than values recorded in the reference sites, and good numbers of logs and rocks were present. Overall, the fauna habitat could be considered good, with the range of vegetation strata present suggesting that the site is likely to support a diversity of small mammal, reptile, bird and invertebrate species. Erosion monitoring of Pit 2 Waste Dump 1 described the site as very stable, with minimal erosion and no measurements provided for gullies (suggesting they were too small for measurement or that no gullies were located along the monitoring transect). No landscape function measures were completed during this monitoring.

Overall monitoring in 2012 showed that relatively good rehabilitation has developed after 14 years with species diversity and cover similar to reference sites, fauna habitat considered good and the rehabilitated slope in a stable condition. It was noted that the density of the *Spinifex* was lower than in reference sites although this is likely to improve in time (given that the species are present in the rehabilitation area).

Mesa J Operations Waste Dump T

A different rehabilitation strategy was applied at Mesa J operations in 2007 that involved a single lift waste dump having subsoil applied (as opposed to topsoil). The T Waste Landform was reworked in 2007, the slopes were battered to 15 degrees and stockpiled subsoil (less than five years old) was applied, prior to the area being ripped and seeded. The total lift height of the waste dump is 22-25m whilst at the area of monitoring the lift height is 20m. Due to the sloping gradient of the rehabilitation, monitoring results for the rehabilitation slopes were compared to the average achieved by the sloping reference sites.

Rehabilitation monitoring of the T waste landform in 2013 found there were seven species recorded, the same number as both sloping reference sites. Despite the similar number of species present native perennial plants have established poorly and between 2010 and 2013, plant cover and density only slightly improved (***Figure 3***). The rehabilitation had minimal vegetation compared to the average of the sloping reference sites. The lower storey contributed two thirds of the cover with *Triodia pungens* the most frequently sampled species. The upper storey contributed less than 1% cover with only four *Acacia* individuals sampled.

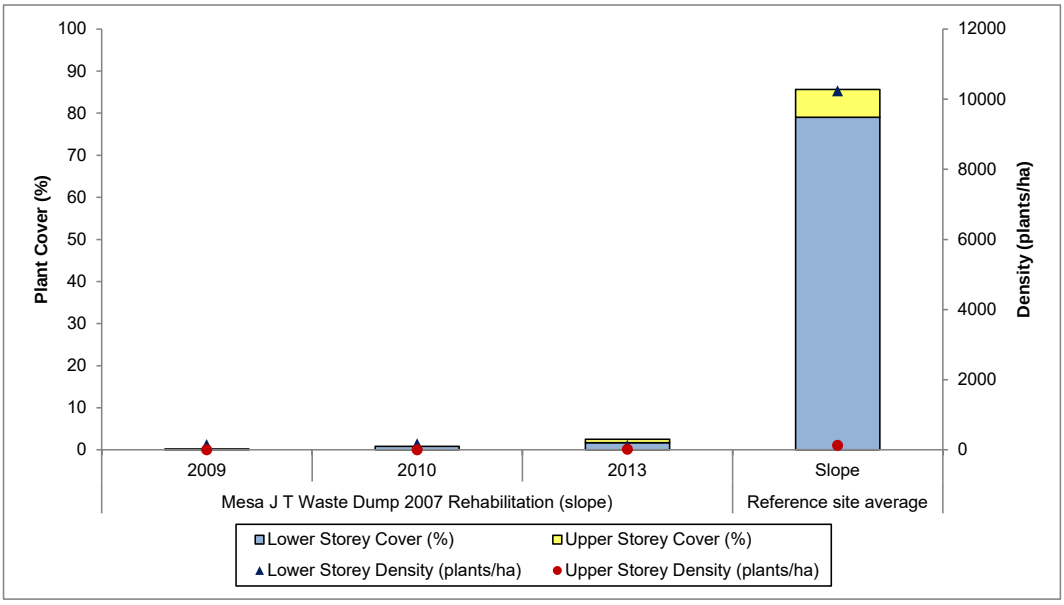

Figure 3: Changes in the plant cover index and density of the 2007 rehabilitation on the Mesa J T Waste Landform (slope), in comparison with sloping reference site (Con7 and Con10) average

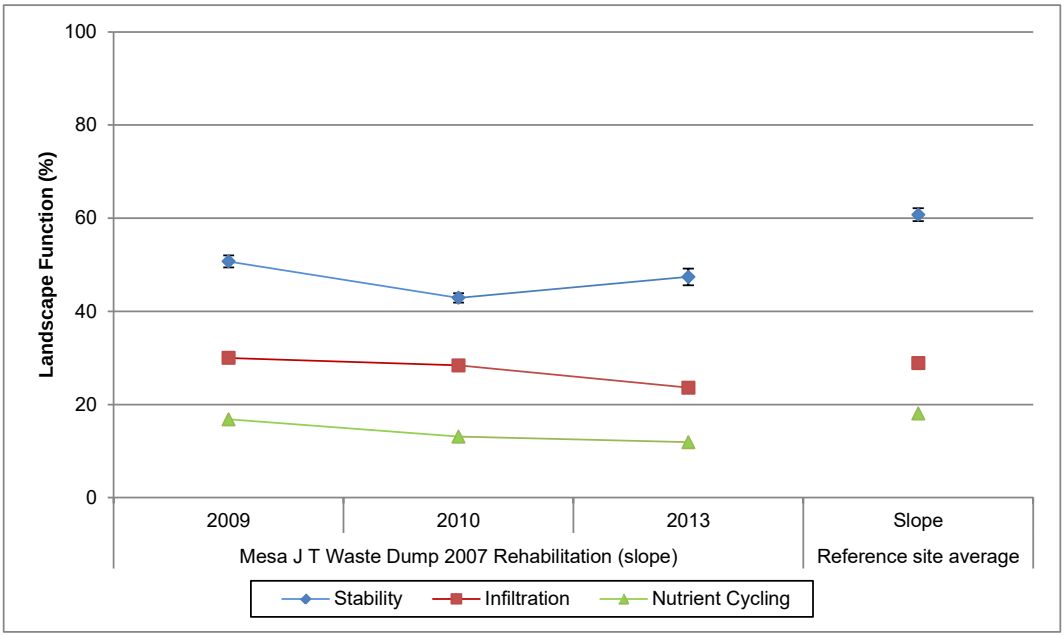

Figure 4: Changes in landscape function of the 2007 rehabilitation on the Mesa J T Waste Landform (slope), in comparison with sloping reference site (Con7 and Con10) average

In terms of landscape function all three indices achieved scores substantially lower than the average scores achieved by the sloping reference sites (refer to ***Figure 4***). The low scores can be attributed to a lack of rocky material on the soil surface and poor vegetation establishment.

A moderate degree of habitat complexity was present with numerous vegetation strata present from grasses to a few shrubs taller than three metres. Faunal habitat was available in the form of grass litter and rocks.

Erosion was a significant issue affecting the performance of the rehabilitation on the T Waste Landform. Since 2009 monitoring the proportion of the slope eroded doubled to 30%. Both the upper and lower slope was substantially eroded, indicating substantial loss of water resources and therefore reduced potential productivity of the ecosystem.

At the same time as the T waste landform slope rehabilitation was completed, a flat section (on the top of the dump) was also completed. The rehabilitation involved flattening the area, applying subsoil then ripping and seeding. The landscape function scores of this flat area of rehabilitation compare favourably with those achieved by similar flat reference sites. Despite this the vegetation has not established well on the flat rehabilitation with total native perennial cover and density substantially lower than that of the reference sites and the habitat complexity was considered moderate (similar to the slope rehabilitation). There was no erosion (as expected as the area was flat).

The monitoring results to date of the T waste landform slope rehabilitation suggest that while the utilisation of subsoil may assist rehabilitation in achieving some of the rehabilitation indices considered important, in this example it is unlikely to lead to successful rehabilitation. The utilisation of the subsoil on the flat area and slope and resultant low vegetation cover and density suggest the application of subsoil may have contributed to these low values (and not the values being a result of rehabilitation being on a slope versus on a flat area).

The evidence of extensive erosion also suggests that the subsoil used (and underlying waste type) may not be suitable for use in lift heights of 20m even when battered to 15 degrees.

Mesa J Operations Tailings Storage Facility 1 (Mesa J TSF1)

RTIO has only rehabilitated one tailings storage facility which was completed in 2014 at Mesa J Operations. The Mesa J TSF1 operated as a tailings storage facility between 1999 and 2004. It was decommissioned in 2004 and upon rehabilitation consisted of two low-lying areas that covered ~20% of the surface and an upper, dryer area that covered the remaining 80%. The tailings on the surface of TSF1 had been investigated in 2009 and it was determined it was suitable for plant growth with few potentially restrictive properties; in addition the TSF already supported regrowth of native vegetation. As a result no topsoil was added during the rehabilitation process to trial whether successful rehabilitation could be achieved on the surface of tailings storage facilities without the utilisation of capping and topsoil.

The TSF rehabilitation commenced in December 2013 and was finished in February 2014 and involved the rehabilitation of the northern two thirds of the facility (~45Ha).

Rehabilitation involved ripping and seeding the surface of the TSF and trees that were present prior to rehabilitation works were retained (and worked around). Contour ripping was conducted to a depth of 600 to 800mm in all areas. Two seed mixes were utilised (with seed collected the year prior to rehabilitation) with one seed mix used for the lower lying potentially wet areas and a second seed mix for the remainder of the TSF. Species were selected specifically to be able to germinate and grow in "wet" inundated clays or water logged soils such as *Cyperus vaginatus.*

Monitoring of Mesa J TSF1 conducted mid 2014 showed that whilst the number of species present in the rehabilitation was within the range of the reference sites the density of lower storey plants (which represents germination) in the rehabilitation was very low. There was less than 1% cover of lower storey perennial vegetation at the time of the 2014 assessment of the dryer areas, whilst the pre-existing upper story contributed up to 10% cover in some areas. Whilst it is expected the density and cover would be lower than reference sites given the young age of the rehabilitation these are particularly low numbers. The landscape function indices and habitat complexity measures were also lower than references sites, which was to be expected given the young age of the rehabilitation. There was a large amount of the weed species *Acetosa vesicaria* (ruby Dock) and cattle present at the time of monitoring. Ruby Dock had been noted on the tailings dam prior to the rehabilitation commencing.

In regards to stability and erosion while no rill or gully formations were present at the three low-lying monitoring transects, some low lying areas at TSF1 were showing signs of subsidence and erosion. A small but deep cavity (sinkhole) and other cavities were present adjacent to one of the monitoring transects and contoured rip-lines appeared to be deepening into gully-like flow lines in some areas.

Initial monitoring results of the rehabilitation suggest that the rehabilitation was showing signs of developing an ecosystem comprising of local native species although the rehabilitated area was threatened by the spread of ruby dock and disturbance by cattle. In addition early signs of erosion suggest that this needs to be monitored to determine if it will result in long term stability concerns.

It is too early to determine if tailings storage facilities similar to the Mesa J TSF1 can be successfully rehabilitated without the use of capping and topsoil. Continued monitoring of this rehabilitation will be undertaken to assess the ongoing development of the vegetation and rehabilitation success.

Early learnings from the rehabilitation methodology used for the TSF1 indicate that for future areas with Ruby Dock infestations it is worth considering completely eradicating Ruby Dock prior to commencing rehabilitation works. This could be achieved through an aggressive and long term spraying program. RTIO has examples of borrow pits along the Tom Price Rail Line located in a national park that are undergoing such a program and have almost eradicated the Ruby Dock.

The other critical learning from the TSF1 rehabilitation that is critical for rehabilitation success related to the post rehabilitation management of cattle (as opposed to rehabilitation methodology). Stray cattle accessed the rehabilitated TSF1 and during monitoring negative impacts on the vegetation and surface of the TSF1 from the cattle were evident. This highlights the need to exclude cattle (and potentially other grazing animals as far as possible such as goats) from rehabilitated areas to assist in the initial establishment of vegetation and long-term success of the areas. Grazing of historically rehabilitated areas can be seen across the Pilbara and anecdotally it appears the vegetation and ecosystems continue to survive. However areas of young rehabilitation (that have not yet become a self-sustaining ecosystem) appear to require protection from grazing animals during the early years of vegetation establishment. This is an important consideration for closure and particularly rehabilitation planning and implementation at Yandicoogina where areas of the operations co-exist with pastoral leases and areas of rehabilitation may be utilised post closure for grazing purposes.

Methodology and Success Rate

Based on the above examples at Mesa J and Brockman of rehabilitation of created landforms comprising of erodible material, the success rates to date indicate the use of topsoil enhances rehabilitation success. Whilst the use of subsoil may assist in improving certain parameters of rehabilitation success (such as habitat complexity and functional indices and does enable some native species germination) it has proven less effective and in some places (such as on slopes) problematic for use in rehabilitation. Whilst this is a limited review of only a few rehabilitated slopes it confirms that topsoil management and the ultimate use of topsoil in rehabilitation greatly enhances rehabilitation success (when compared to subsoil). It also indicates that subsoil may assist in rehabilitation success but should be prioritized for use in flat areas and would require a review of the subsoil properties and seed mixes utilized (to try and improve germination success and ultimately vegetation establishment).

A review of the three sloped rehabilitation areas comprised of CID or similar waste types Waste Dump S, Pit 2 Waste Dump 1 and T waste landform has indicated that it is possible to achieve a stable, non-polluting landform, that comprises local native vegetation that is self-sustaining and compatible with the surrounding environment containing these waste types if appropriate landform design is utilised and topsoil and seed are applied.

The performance of the rehabilitation area that utilized subsoil suggests that any subsoil proposed for utilization in rehabilitation should have material testing (physical and chemical properties relevant to plant growth) completed to determine its applicability as a growth medium and that if subsoil is to be used it may be better placed on flat areas (as opposed to slopes).

The fact that significant erosion was evident on the slopes utilised in a 20m lift, only minor erosion was noted on the lower slopes of the 8-10m lift and no erosion was noted on the 8m lift suggest that CID and alluvial waste if utilising a 15 degree slope should be built with a maximum 8-10m lift height.

The slope stability results seen in the three rehabilitation examples is further supported by testing on CID waste and alluvial materials completed in more recent years that indicate the appropriate maximum lift heights (when using a 15 to 20 degree slope) is from 0m to 10m (depending on the location of the site and associated climate). By 0m lift height testing of some waste type and climate combinations suggest that some wastes will not be stable enough for use in final outer slopes.

The single review of a tailings storage facility highlights that whilst rehabilitation can be completed and germination can be achieved on a tailings storage facility surface without capping and topsoil application, the success of this is yet to be proven. The need for the exclusion of cattle in the immediate years post rehabilitation is also highlighted as a recommendation for at Yandicoogina and the control and eradication of Ruby Dock prior to rehabilitation should be considered.

Short-term disturbances and Linear and/or fragmentation disturbances

In addition to created landforms such as built slopes the proposed final landform at Yandicoogina on closure will also have rehabilitation that was completed on short term disturbances. Examples of short term disturbances include borrow pits, access tracks, clearing for power line and railway construction and are assumed as any disturbance that is rehabilitated within a short time frame following disturbance.

This disturbance can also regularly encompass disturbance described as linear and or fragmentation disturbances such as rehabilitation completed for the construction or removal of pipelines, roads, power lines and bore fields. Whilst a majority of this disturbance is often narrow long areas of disturbance adjacent to undisturbed vegetation with minor earthworks, it can also include significant earthworks and is likely to range from short term to longer term disturbance timeframes.

The short-term disturbance type often occurs on the surface of the landscape and often involves only minor earthworks. Minor earthworks may include clearing topsoil and using an area as a laydown, or following topsoil removal excavating a shallow pit and utilising the material as borrow resulting in a borrow pit that requires rehabilitation. As a result of this disturbance type occurring often at the surface of the landscape, the material types intersected are usually restricted to the first few metres from surface. This material (first few metres from surface) is generally comprised primarily of topsoil and subsoil (as opposed to alluvial and CID materials). Therefore in discussing rehabilitation methodologies and successful completion of this type of rehabilitation a range of examples from across the Pilbara of different ages have been reviewed and not just examples from Yandicoogina and Pannawonica Operations.

Rio Tinto regularly complete this type of rehabilitation and have refined methodologies over many years of learning and generally achieve rehabilitation success for this type of rehabilitation. In addition the ability to utilise relatively fresh (young) topsoil, these disturbance areas are usually small or narrow and adjacent to undisturbed vegetation, which greatly enhances the ability to achieve successful rehabilitation.

Successful and Unsuccessful Rehabilitation Strategies

Yandicoogina Borrow Pits

Borrow pits associated with the railway at Yandicoogina were rehabilitated in the second half of 1998 and rehabilitation monitoring commenced in 1999. Monitoring of these borrow pits completed in 2013 suggest that vegetation communities, in general, are similar to that of reference sites and differences appear to be a result of some reference sites being burnt during the monitoring period.

The rehabilitation methodology for these borrow pits is consistent with methodology used in current borrow pit rehabilitation and includes battering of all slopes, ensuring the borrow pits are free draining and pulling back salvaged vegetation and topsoil across the disturbed area at completion of the rehabilitation, no seed was applied. All borrow pits reviewed appear to have had topsoil replaced and were ripped. There is no evidence of erosion in any of the borrow pits. Monitoring results from three of the borrow pits are shown in ***Table 2*** below to give an indication of rehabilitation success as at 2013.

Table 2: Selected monitoring results of the Borrow Pit rehabilitation areas and reference site values (shown in brackets).

Borrow Pit	Age of Rehabilitation (years)	No Species (Rehab)	Plants/ Quadrant	% Perennial Cover	Summary (sourced from the rehabilitation monitoring report)
BP363	14	7 (8)	4.3 (4.2)	45 (64)	The rehabilitated site continues to compare favorably with the reference site
BP374	14	7 (13)	5.6 (20.3)	55 (53)	The 2007 burn in the reference site significantly changed a number of key parameters, making comparison of the two sites difficult, overall, the rehabilitation appears to be developing well
BP417	14	7 (7)	3.3 (13.3)	49 (31)	Results in 2003 indicated that the vegetation communities of the reference and rehabilitated sites had become similar in most regards, a fire in 2010 has since altered this trend.

In addition to the above results all borrow pits were found to have an abundance of *Spinifex* species and *Acacia* species, which were the species dominant in the reference sites they were being compared to.

Figure 5 below show as an example BP374 monitoring transect at the start and end of the transect and the reference site it is being compared to.

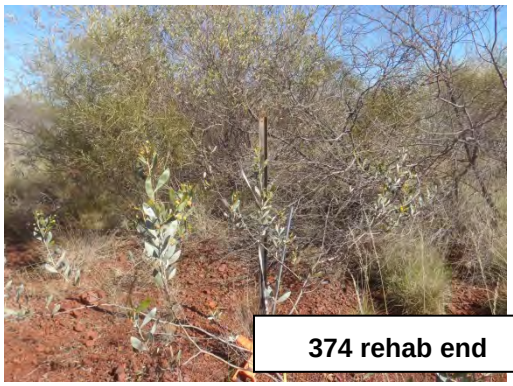

Figure 5: The start and end of the monitoring transect on borrow pit 374 at Yandicoogina and the start and end of the relative reference site transect (in undisturbed vegetation).

Hope Downs 4 Haul Roads, Borrow Pits, Power Line and Railway Rehabilitation

To further review rehabilitation strategies and success relating to short term disturbances the 2014 rehabilitation monitoring conducted across Hope Downs 4 is discussed. The monitoring completed at Hope Downs 4 involved assessing 35 locations across a range of rehabilitated disturbance types and associated reference sites. These included the mine access road (1 site), disturbance for power line construction (4 sites), borrow pits (11 sites), camps (4 sites), railway construction (15 sites) and mine disturbance (5 sites). All of this rehabilitation was completed during 2013 and resulted from disturbance to enable the establishment of the new Hope Downs 4 Mine. The rehabilitation methods utilised included reprofiling areas, replacing topsoil and salvaged vegetation and shallow or deep ripping of areas (dependent on compaction), no seed was applied.

The executive summary from the Hope Downs 4 2014 Rehabilitation Monitoring Final Report (Environmental Management and Research Consultants, 2014) states that *"Vegetation in most of the Railway sites has established well, with good species establishment, species/q and density comparable to that of the reference sites. Spinifex was present in all sites."* The summary goes on to state *"All Railway and Powerline rehabilitated sites appeared to be stable. Weeds were only present in four of the 19 Railway and Powerline sites, with weed abundance (mostly Buffel Grass) low in all apart from 2014_HD4_Powerline_T2 where Spiked Malvastrum was abundant across the whole transect"*. The report stated that the *"Vegetation in many of the Mine Access Road, Camp and Mine rehabilitated sites has also established well, with total species numbers, species/q and native plant density comparing favourably with the reference sites. Spinifex was establishing in most rehabilitated sites".* Results are shown in ***Table 3*** and ***Table 4***.

Table 3: Rehabilitation monitoring results of the Railway line sites, with green shading indicating values within or above the reference site range which indicate rehabilitation heading in the right direction given its young age.

	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	Reference Site Range
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	
Total Spp	10	13	10	6	13	11	7	11	13	19	17	12	9	12	15	14-26
Species/q	2.9	3.4	3	2.2	3.6	1.9	1.2	2.5	2.9	4.9	3.9	2.1	1.5	2.7	3.8	1.8-2.5
Plants/q	8.4	6	7	15.9	11.5	3.1	2	5.9	6.3	30.5	7.4	3.4	1.7	3.2	6.8	5.4-14.2
Spinifex/q	6.9	3.2	4.8	14	8.4	1.5	1	3.1	0.1	18.8	1.2	1	0.3	0.1	4.3	0.5-7.3
% Perenn Cover	30	32	20	11	24	21	1	6	36	19	27	12	7	20	13	44-63

Table 4: Rehabilitation monitoring results of camp, mine access road and mine disturbance sites, with green shading indicating values within or above the reference site range which indicate rehabilitation heading in the right direction given its young age.

	2014_HD4_Mine_Access_Road_T1	2014_HD4_Camp_T1	2014_HD4_Camp_T2	2014_HD4_Camp_T3	2014_HD4_Camp_T4	2014_HD4_Mine_T1	2014_HD4_Mine_T2	2014_HD4_Mine_T3	2014_HD4_Mine_T4	2014_HD4_Mine_T5	Reference Site Range
Total Spp	20	20	14	18	2	6	2	11	6	15	14-26
Species/q	5.5	3.9	2.9	4	0.2	0.9	0.2	2.1	1.4	3.7	1.8-2.5
Plants/q	14.3	7.8	7.3	5.4	0.2	1.7	0.2	3.3	4.8	6.1	5.4-14.2
Spinifex/q	6.5	1	0.4	0.6	0	0.3	0.1	1.5	4.3	3.2	0.5-7.3
% Perenn Cover	25	33	16	15	0.5	6	0.1	8	1.3	4	44-63

In terms of Fauna habitat the report states that fauna habitat assessment showed that fauna habitat is beginning to develop well in many sites, though more time is needed to assess this.

Methodology and Success Rate

The methodology utilised for rehabilitating short term disturbances in general appears to be working to achieve successful rehabilitation (stable, non-polluting landform, that comprises local native vegetation that is self-sustaining and compatible with the surrounding environment) and is proposed for use to rehabilitate similar types of disturbance at Yandicoogina. This methodology involves salvaging and stockpiling vegetation and salvaging and stockpiling topsoil prior to disturbance, then reprofiling areas, returning the stockpiled topsoil and vegetation and deep or shallow ripping along the contour as appropriate. With regard to borrow pits the initial placement of them on the landscape and resultant excavation is critical to enabling the borrow pits to be free draining following rehabilitation.

Long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings)

In addition to created landforms and short term disturbances the proposed landform at Yandicoogina on closure will also have rehabilitation that was completed on long-term disturbances. Examples of long- term disturbances include construction camps, landfill sites, accommodation villages and are considered in this discussion as any generally flat disturbance that is rehabilitated within a medium to longer time frame following disturbance. The discussion of rehabilitation strategies and success rates for long-term disturbance will involve a review of monitoring results for a rehabilitated landfill at Yandi and fixed plant rehabilitation completed at Mesa A.

Landfill Sites at Yandicoogina

Two landfill sites (adjacent to each other) that were rehabilitated in 2009 after being disturbed (active) at Yandicoogina for three and a half years and last monitored in 2014 are considered examples of longer term disturbance and discussed below.

The decommissioned landfill had clean fill imported to cover the pits, then it had topsoil applied, was ripped and seeded and monitored for the first time in 2013, then again in 2014.

Numbers of total species in the two landfill sites were nine and 11 which was similar to those in the two reference sites (11 and 12 species), with a range of *Acacia species* as well as *Spinifex species*, native grasses, and various other native shrub and herb species identified at the rehabilitated site. Species per quadrant values showed no clear separation between the reference site and the Landfill sites. Native plant density in the two landfill sites had changed very little since 2013, and was comparable to or higher than those in the reference sites. Mean bare areas values (which provides an indication of cover values) in the two landfill sites and the reference sites were similar to each other, with no significant differences.

Results for the two landfill sites show that rehabilitation has established and developed well, with most measured and calculated parameters similar to values recorded in the two reference sites and in some cases higher. No weeds were recorded in either landfill site, and both sites are stable, with no erosion recorded. Field notes for both sites describe the rehabilitation as excellent. Fauna habitat of the two sites is likely to be good for any small reptiles, mammals, birds and invertebrates that utilise spinifex and shrubs, but less suitable for ground dwelling species that utilise litter and logs.

Mesa A Fixed Plant Rehabilitation

A nine hectare area previously utilised as a laydown area for approximately three years by the fixed plant personnel at Mesa A operations was rehabilitated in 2012. The area had topsoil applied, was ripped and seeded. Monitoring of the area in 2013 showed the total numbers of species in the two rehabilitated sites were comparable to or greater than those recorded in the reference sites, species present in the rehabilitation included a number of *Acacia species* and other shrub, herb and grass species as well as *Spinifex species*. The plant density values were lower in the rehabilitated site at 2.3 and 2.3 plants per quadrant as compared to the reference sites (5.3 and 6.4 plants per quadrant), which is expected given the young age of the rehabilitation. The percentage of perennial cover was also very low in the rehabilitated sites (1% and 4%) as compared to the reference sites (43% and 51%).

There were no signs of erosion in the rehabilitated sites and it was too early to do an assessment of habitat diversity (to determine appropriate habitat for fauna). It is too early to determine if the rehabilitation is on track to be successful. The early indicators of the rehabilitation certainly show it is not doing as well as some other shorter term rehabilitated areas such as the areas reviewed at Hope Downs 4. This may be a result of weather and rainfall received at the two sites or as a result of the disturbance being longer term (which may lead to reduced quality of topsoil). The other factor that may be contributing to the rehabilitation success at the Mesa A Fixed plant area is that it is surrounded by disturbed areas (and not immediately adjacent to undisturbed native vegetation).

Methodology and Success Rate

The two examples for longer term disturbance reviewed suggest that it may be more difficult to achieve rehabilitation success in areas of longer term disturbance (than short term disturbance areas). In both cases the rehabilitation methodology has shown that the areas are stable and have native species present, with the landfill indicating density and cover is similar to the reference sites whilst further monitoring of the Mesa A rehabilitation will determine if cover values will be achieved in time. Whilst only a review of two areas the rehabilitation methodology of landform shaping, topsoil application, ripping and seeding appears to support the development of successful rehabilitation in longer term disturbance. An important step of the rehabilitation of the longer term disturbance (as opposed to short term disturbance) is the addition of seed. The addition of seed in the rehabilitation process should be considered regardless of the disturbance type but based on the likely viability of the seed bank with the topsoil utilised in the rehabilitation. In addition the germination of seed in rehabilitation areas may also assist if the proposed rehabilitation habitat being established is different to the habitat from which the topsoil was sourced, which may be the case in Yandicoogina where some wetland habitats will be developed as a part of the closure of the site.

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Yandicoogina Pocket and Billiards South Proposal

Billiards Acid and Metalliferous Drainage Risk

RTIO-PDE-0122966

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30 June 2014

FINAL Draft

Rio Tinto

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This report has been prepared by Rio Tinto Iron Ore (Rio Tinto), on behalf of Hamersley Iron Yandi Pty Limited, specifically for the Yandicoogina Pocket and Billiards South Proposal. Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

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1. BACKGROUND

An acid and metalliferous drainage (**AMD**) risk assessment for the Billiard deposits at Yandicoogina has been undertaken and takes into account: total sulfur concentrations within rock types; the sample location with respect to the proposed pit shell; and geochemical data to identify enriched elemental concentrations which may pose an environmental risk. This data, along with site specific baseline information can be used to generate a conceptual site model to describe mechanisms by which acid and metals/metalloids may mobilise and interact with environmental receptors.

The Yandicoogina Billiard deposits are located approximately 100 km north-west of Newman and approximately 3 km south-east of the existing JSE crusher at Yandicoogina (Figure 1-1). Yandicoogina is a large pisolitic iron deposit that follows a winding palaeochannel approximately 80 km long. Much of the area is covered by alluvial gravels overlying a lateritic clay unit known as the Eastern Clay. The Channel Iron Deposit (**CID**) palaeochannel is saucer-shaped with a simple structure exhibiting no folds or faults, with the main ore zone approximately 40 – 50 m thick in the centre and thins towards the channel margins. The current production from Yandicoogina is 53 Million tonnes per annum (**Mt/a**) with the Billiard deposits being the last developed to sustain this rate.

The Yandicoogina area is a semi-arid to arid environment, characterised by hot summers and warm winters. The region experiences climate extremes, where severe droughts and major floods can follow in close succession. The Billiard deposits runs parallel to the Weeli Wolli Creek, and encroach into the floodplain.

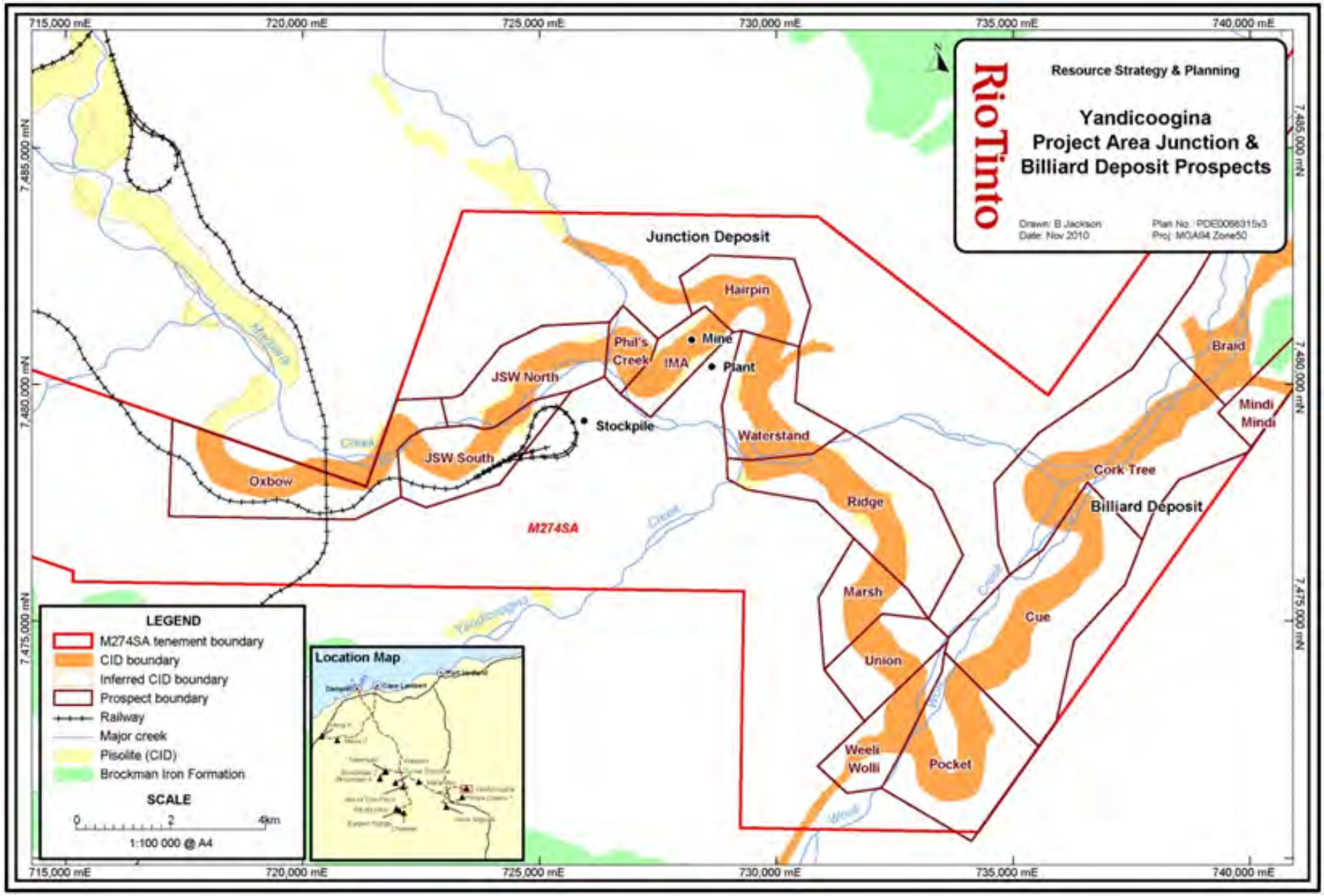

Figure 1-1: Yandicoogina Project Area Junction and Billiard Deposit Prospects

2. SULFUR ANALYSIS

A summary of the risk assessment process followed here is detailed in *Geochemical Risk Assessment Process for Rio Tinto's Pilbara Iron Ore Mines* (Green and Borden 2011) and in *Mineral Waste Management in the Pilbara: A Position Statement* (Brown 2012).

The Proponent has undertaken static acid base accounting (**ABA**) and kinetic characterisation on different lithologies to identify the potential for these rock types to generate acidity. ABA data for sulfidic black shale confirms a value of 0.1% total sulfur can be adopted as the boundary to delineate potentially acid forming (**PAF**) material from inert/non-acid forming (**NAF**) material. For other lithologies such as banded iron formation (**BIF**) and detrital rock types, a value of 0.3% total sulfur concentration is the most appropriate boundary. In oxidised material it has been shown that sulfur may be in the form of the hydroxysulfate mineral alunite (KAl3(SO4)2(OH)6) (RTIO 2011). There is the potential for relatively low levels of acid generation from elevated-sulfur samples that contain alunite (when compared against acid generation from sulfide minerals), since the low solubility of alunite may result in a low flux of acid release (and contaminant release). A sulfur cut-off of both 0.1% and 0.3% are considered for the purpose of this assessment.

It is recognised that sulfur-related AMD includes acid drainage and neutral drainage, with both potentially containing elevated concentrations of contaminants (INAP 2010; DITR 2007). Brown (2012) has summarised geochemical data from the Proponents drillhole database showing that contaminants predominately become soluble when associated with material containing elevated sulfur (i.e. pyrite and alunite). If there is sufficient neutralising capacity in the acid-generated rock then any acid generated at the microscopic scale is subsequently neutralised; however as a result, concentrations of some contaminants which do not precipitate at circumneutral pH, may remain in solution and result in poor-quality drainage (DITR 2007). For this reason, analysis of total sulfur in rock types will identify those with the propensity to generate acid and lead to poor quality drainage characterised at both low-pH and circumneutral pH conditions.

Poor quality drainage may also result from contaminants soluble at neutral pH (and not related to sulfur). Many minerals are unstable when exposed to the atmosphere after disturbance; elevated concentrations of dissolved minor and trace elements in surface water runoff may result from the dissolution of readily soluble salts (being a source of such elements). The potential for this risk is assessed by considering the oxidation state of minerals characterising the rock types likely to be exposed, and by also considering the average concentration of elements relative to the average crustal abundance for that element, as well as ecological toxicity trigger values.

3. ACID BASE ACCOUNTING AND GEOCHEMICAL CHARACTERISATION

Although no geochemical characterisation has been undertaken on Billiard samples, it is expected that the Billiard material will be similar to other Yandicoogina materials. A total of 90 samples from the Junction Central, Junction SE and Junction SW deposits and 13 tailings samples were submitted for ABA and geochemical characterisation. All samples were classified as either NAF or Uncertain-NAF (**UC-NAF**). The samples were enriched (when compared to the average crustal abundance) in As, Au, B, Bi, Sb, Se, Tl and Hg; however the static leach testing indicated that these elements were not readily leached.

To determine how the elements are distributed among mineral hosts, a multi stepped leach regime using different leachants, each more aggressive than the last were selected to target different mineral components of the samples. The tests indicated that Sr, Mn and Ba were either labile

(loosely bound), adsorbed, exchangeable or associated with carbonates. Lead was found to be associated with crystalline iron oxyhydroxides. The bulk of the elements were not leached until the final steps indicating that they are strongly bound and unlikely to be leached under the expected geochemical conditions.

The Proponent has also commissioned studies into leaching under saline conditions. Leaching was undertaken at two different levels to represent saline groundwater and possible brines that develop in pit voids due to evapoconcentration. Overall, the results indicate the mass of Ca, Mg, K, Sr, Cu, Ba, Mn and Zn leached increased as salinity increased. These increases can be explained by cation exchange processes, desorption or increased formation of aqueous complexes. For all other elements there appeared to be no increase or decrease in leached concentration as a function of the differing salinity levels.

4. TOTAL DRILLHOLE SULFUR ANALYSIS

An analysis of sulfur values in drillhole data (to the end of April 2014) was undertaken to identify those rock types that require further investigation relating to acid-forming potential (and any related metalliferous drainage). An outcome of this analysis includes the likelihood that a particular rock type will pose an acid drainage risk. For the purpose of this assessment, the rock types, or "strand-tag groups" comprise like-material assigned the same "geozone" code based upon their sub-divided stratigraphies (strands) and further differentiated based on dominant material type (tag).

It should be noted that the following factors may also influence the interpretations within this assessment:

- Negative assay results represent concentrations below the detection limit. The assay value for the element or oxide was taken to be the absolute value (i.e. the detection limit). This approach is conservative, as the true values for these assays may be below the detection limit value.
- Total sulfur was measured using the XRF method rather than the LECO method. The XRF method may underestimate the total sulfur concentration when sulfur values are high.
- The logging code pyrite (**PYT**) can be used where it is readily identifiable. However logging codes either do not exist or are not readily used for the sulfate minerals gypsum and alunite as these minerals are less identifiable.
- The drillhole data for the ore body is extensive with less data collected for waste rock types.
- Assay values of "-99" or "zero" indicate that the element was not assayed and were deleted and not considered in this assessment.
- Some intervals had incomplete stratigraphy, strand or tag information. These samples were grouped into and UNKNOWN strand-tag category.
- Limited information exists related to the neutralising potential of the rock type; the presumed risk of acid drainage may be over-stated if the available neutralising capacity of that rock type is unaccounted for.
- The drillhole spacing varies across the deposit.

Table 4-1 shows a summary of the total sulfur analysis performed using the drillhole sample assays extracted from the acQuire database in April 2014, and filtered by the "YBIL" "PROJECTCODE". The average sulfur value for those samples with elevated-sulfur (i.e. sulfur values greater than 0.1%) is

also tabulated and considered in the analysis. Drillhole samples represent rock types associated with the Billiard deposits, and that not all rock types drilled and listed in the table are expected to be mined.

Three samples from the Billiard deposits had pyrite visibly identified. The samples were from the Pocket and Braid areas with one sample being located in the Weeli Wolli (**WW**) and the two others located in the basal clay conglomerate (**BCC**). The sulfur levels for the samples were 0.075% for the WW sample and 3.15% and 1.89% for the BCC samples. These three samples were logged as having lignite.

For the Billiard deposits approximately 0.25% of more than 61,000 samples have sulfur levels greater than 0.1%. Approximately 0.7% of all the waste samples have sulfur levels greater than 0.1%. When a 0.3% sulfur filter is applied, 0.07% of all samples have sulfur levels greater than 0.3%, and 0.23% of waste samples have sulfur values greater than 0.3%. The elevated sulfur samples come from the detrital ore (**DET ORE**), Joffre Member Hydrated (**JOF HYD**) and the Mount McRae Shale (**MCS WASTE**). The maximum sulfur content measured from the Billiard deposit is from a Weeli Wolli sample with a measured sulfur content of 3.65%. The sample is associated with lignite and clay; however no pyrite was identified in the core sample.

Almost 5.9% of DET ORE samples have sulfur levels greater than 0.1%; however none of these samples have sulfur levels greater than 0.3%. These elevated sulfur samples are located in one drillhole, and are associated with samples with Fe values greater than 56%. Based on the low sulfur values associated with the elevated-sulfur samples (i.e. average of 0.19%) and that these samples are located in one drillhole, **DET ORE is expected to pose a low acid drainage risk**.

Almost 24% of JOF HYD samples have sulfur levels greater than 0.1%, with 6.9% with sulfur levels greater than 0.3%. The 48 elevated-sulfur samples are located within two drillholes; 47 were from one drillhole. Although there was no pyrite visibly identified in the elevated sulfur-samples, the majority of samples were identified as having siderite which has been known to be associated with pyrite at other Proponent deposits. Based on the high number of elevated-sulfur samples, the moderate sulfur values associated with these samples (i.e. average of 0.29%), **JOF HYD is expected to pose a moderate acid drainage risk**. The distribution of this material with respect to the pit shell should be investigated further.

A total of five or 10.4% of MCS WASTE samples have sulfur levels greater than 0.3%. All five samples were from the same drillhole and consecutive intervals. Given the relatively high sulfur values associated with these samples (i.e. average of 0.92%), **MCS WASTE is expected to pose a moderate acid drainage risk**, and further analysis of the MCS material with respect to the pit shell should be undertaken.

Table 4-1: Total Sulfur Analysis for the Billiard Deposit Samples

Strand-tag group	Number of Samples assayed for S	Number of samples with S>0.1%	Percentage of samples with S>0.1%	Number of samples with S>0.3%	Percentage of total with S>0.3%	Average S for samples with S>0.1%
ALLUVIUM	4823	36	0.75	11	0.23	0.31
DET WASTE	66	1	1.52	0	0.00	0.13
DET ORE	**68**	**4**	**5.88**	0	0.00	0.19
ECC	735	0	0.00	0	0.00	-
WCH	3793	1	0.03	0	0.00	0.13
GVU	15762	0	0.00	0	0.00	-
GVC	151	0	0.00	0	0.00	-
GVL	21743	6	0.03	0	0.00	0.16
LGC	4204	7	0.17	3	0.07	0.34
BCC	2906	12	0.41	5	0.17	0.78
DOR	43	0	0.00	0	0.00	-
WOONGARRA RHYOLITE	21	0	0.00	0	0.00	-
WW WASTE	1922	24	1.25	4	0.21	0.33
WW ORE	7	0	0.00	0	0.00	-
YS WASTE	111	0	0.00	0	0.00	-
YS ORE	57	0	0.00	0	0.00	-
JOF WASTE	624	1	0.16	1	0.16	1.33
JOF ORE	894	0	0.00	0	0.00	-
JOF HYD	**203**	**48**	**23.65**	**14**	**6.90**	0.29
WS WASTE	15	0	0.00	0	0.00	-
WS ORE	103	0	0.00	0	0.00	-
DG WASTE	73	0	0.00	0	0.00	-
DG ORE	130	0	0.00	0	0.00	-
FWZ WASTE	4	0	0.00	0	0.00	-
MCS WASTE	**48**	**5**	**10.42**	**5**	**10.42**	0.92
UNKNOWN	2578	5	0.19	1	0.04	0.28

Total number of samples assayed for S	**61084**	**61084**
Total number of samples with S>0.1/0.03%	**150**	**44**
Percentage of total with S>0.1/0.3%	**0.25%**	**0.07%**
Total number of waste samples assayed for S**	**11391**	**11391**
Total number of waste samples with S>0.1/0.3%	**79**	**26**
Percentage of total waste samples with S>0.1/0.3%	**0.69%**	**0.23%**

5. TOTAL SULFUR ANALYSIS CONSIDERING THE PROPOSED FINAL PIT SHELLS

The proposed final pit design (bill_pkt_cf_v05.00t) was used to filter the drillhole data according to which samples are located within the final pit shell. A summary is provided in Table 5-1. Approximately 0.25% of all in-pit samples (including all waste samples) have sulfur levels greater than 0.1%. Approximately 0.07% of all in-pit samples have sulfur levels greater than 0.3%. The DET ORE, JOF HYD and MCS WASTE rock-types identified as having greater than 3% of samples greater than 0.1%, are not present within the pit shell. It is unlikely that acid drainage will be an issue in material mined from the Billiard pit.

Table 5-1: Total Sulfur Analysis for Drillholes Located within the Billiard Pit Shell

Strand-tag group	Number of Samples assayed for S	Number of samples with S>0.1%	Percentage of samples with S>0.1%	Number of samples with S>0.3%	Percentage of total with S>0.3%	Average S for samples with S>0.1%
ALLUVIUM	3488	41	1.18	13	0.37	0.31
ECC	306	0	0.00	0	0.00	-
WCH	3064	1	0.03	0	0.00	0.13
GVU	14924	0	0.00	0	0.00	-
GVL	18750	1	0.01	0	0.00	0.16
LGC	453	0	0.00	0	0.00	-
BCC	469	0	0.00	0	0.00	-
WW WASTE	196	0	0.00	0	0.00	-
UNKNOWN	2059	8	0.39	2	0.10	0.28
Total number of samples assayed for S		**43709**		**43709**		
Total number of samples with S>0.1/0.03%		**51**		**15**		
Percentage of total with S>0.1/0.3%		**0.12%**		**0.03%**		
Total number of waste samples assayed for S**		**4459**		**4459**		
Total number of waste samples with S>0.1/0.3%		**41**		**13**		
Percentage of total waste samples with S>0.1/0.3%		**0.92%**		**0.29%**		

6. TOTAL SULFUR ANALYSIS IN THE MINING MODEL

The mining model for Billiard was used to predict the amount of material with elevated sulfur likely to be encountered during the life of the deposit. This is undertaken by looking at the sulfide_risk variable and the block sulfur grade. Sulfur grades are estimated into the blocks using the available surrounding data (i.e. assay values of nearby drillhole samples). The method used includes Ordinary Kriging for ore blocks and is more reliable than the inverse distance method used for the estimation of waste blocks. It should be noted that the sulfur grades may be over- or under-estimated; and this exercise identifies the presence of mining blocks in proximity to elevated-sulfur drillhole samples that may have the potential to generate acidity.

Blocks have been assigned to the rock type air. This is due to the sub-blocked model being regularised (aggregating data for the selected mining unit size). The dominant rock type in the sub-blocked model is assigned as the rock type in the regularised mining model. Therefore where blocks are close to the surface such that air is the dominant rock type it will be assigned as air in the regularised model.

Based on the mining model yndapr_bil_20130821_003, the estimated tonnes of elevated-sulfur material is given in Table 6-1, and summarised below.

All material within the Billiard pit shells have been assigned a sulfide_risk variable of 0 (no risk, material classified as non-acid forming). When the mining model is filtered by the s_bin variable it

can be seen that the bulk of the material is expected to have sulfur levels less than 0.1%, and is consistent with the inpit drillhole analysis. The only material that is expected to have sulfur levels greater than 0.1% is waste material and in particular the ALL and WW. Approximately 94,000 t of elevated-sulfur material is expected, however none of this material is expected to have sulfur levels greater than 0.3%. From this it can be seen that elevated-sulfur material comprises a very small part of the material to be encountered at Billiard and therefore it is unlikely that acid drainage will be a problem.

Table 6-1: Breakdown of Quantities of Material by mp_dest and sulfur bin

mp_dest	s_bin (%)				Grand Total (Mt)
	<0.1	0.15	0.20	0.25	
hg	379				379
lga	351				651
bla	48				48
lgs	64				64
w	613	0.07	0.01	0.01	614
Grand Total (Mt)	1,455	0.07	0.01	0.01	1,456

7. GEOCHEMICAL ENRICHMENT

Understanding the geochemistry of rock types can assist with more environmentally sound management of waste rock and low-grade stock piles. Drillholes are regularly analysed for the main chemical element suite of Fe, Si, Al, P, Ti, Ca, Mg, S and Mn. Occasionally there have been full chemical suite analyses of As, Ba, Bi, Cl, Co, Cr, Cu, K, Na, Ni, Pb, Sn, Sr, V, Zn, and Zr. The assay results are determined using XRF and it is now common practice to analyse for the full chemical suite as part of ore body evaluation.

The extent of enrichment of a drillhole sample can be reported as the Geochemical Abundance Index (**GAI**), which relates the actual concentration with average crustal abundance on an adjusted log 2 scale (Bowen 1979). The GAI is expressed in integer increments where a GAI of zero indicates the element is present at a concentration similar to, or less than, median crustal abundance, and a GAI of 6 indicates approximately a 100 fold enrichment above median crustal abundance. The main purpose of the GAI is to provide an indication of any elemental enrichment. As a general rule, a GAI of 3 or greater (more than 12-times the average crustal abundance) signifies enrichment that warrants further examination, while a GAI of 1 or 2 indicates that the element may be elevated.

The GAI values from the drillhole samples were contrasted with Ecological Investigation Levels (EILs) and Health Investigation Levels (**HILs**) provided in the Contaminated Sites Management Series Assessment Levels for Soil, Sediment and Water (DEC 2010), as well as US EPA Ecological Soil Screening Levels (Eco-SSLs) (US EPA 2005, 2010). These various screening levels identify contaminants of potential concern in soils and sediments, which can then be evaluated through site specific assessments. The comparison of the GAI trigger concentrations used in this assessment are

lower than the EILs, HILs and Eco-SSL values with the exception of Ba, Cd, Co, Cr, Cu, Mn, Ni, P, Pb, S, Sb, V and Zn. The GAI trigger is generally higher than the Eco-SSLs in the US EPA report with the exception of As and Se, for which the crustal abundance values are lower than the most conservative Eco-SSL values.

The most conservative Eco-SSLs were considered for the purpose of this comparison, however these values may not be the most appropriate for Pilbara-specific receptors.

Some potential issues are that:

- Material mined on the Proponents mine sites is mostly rock and not soil, and therefore whilst EILs, HILs and Eco-SSLs are useful for screening, they may not be the most appropriate to use as management triggers; and
- Concentrations of some trace elements of environmental concern (e.g. As) may be enriched in some of the sampled material, but these elements may not necessarily mobilise into groundwater.

8. ANALYSIS OF DRILLHOLE SAMPLES FOR THE BILLIARDS DEPOSITS

The multi-element analysis of all drillhole assay data (derived from the full chemical suite) for the Billiard deposits and the corresponding GAI values are summarised in Table 8-1, with the full details given in Appendix 1. The same factors outlined earlier may also influence the interpretations. Most rock types are either enriched or elevated in Fe, as correlated with the iron mineralisation associated with the ore body. Arsenic (**As**) is enriched in most rock types while tin (**Sn**), Th and U are generally elevated. MCS also had elevated levels of Mn and S, while JOF HYD had elevated levels of S and Cl.

Table 8-1: Geochemical Enrichment Summary for the Billiards Deposits

Yandi Rock Type	Enriched (GAI >=3)				Elevated
	Fe	As	Sn	U	(GAI = 1 or 2)
ALLUVIUM		3		3	Fe, Sn, Th
DET WASTE		3			Fe, Sn, Th, U
DET ORE	3	3			Sn, Th, U
ECC		3		3	Fe, Sn, Th
WCH	3	3			Sn, Th, U
GVU	3	3			Sn, U
GVC	3	3			Sn, Th, U
GVL	3	3			Sn, U
LGC		3			Fe, Sn, Th, U
BCC		3			Fe, Sn, Th, U
DOR		3	3	3	Fe, Ti, Th
WOV		3	3	3	Fe, Th
WW WASTE		3		3	Fe, Sn, Th
WW ORE	3	3			Fe, Sn, Th
YS WASTE		4			Fe, Sn, Th, U
YS ORE	3	3			Sn, U
JOF WASTE		3			Fe, Sn, Th, U
JOF ORE	3	3			Sn, U
JOF HYD	3	3			S, Cl, Th, U
WS WASTE		3			Fe, Th, U
WS ORE	3	3			Sn, U
DG WASTE		3			Fe, Sn, U
DG ORE	3	3			Fe, Sn, U
FWZ WASTE	3	4			
MCS WASTE		3		3	Fe, S, Mn, Sn, Th

For the standard suite of element suite including Ba, Co, Cr, Cu, Mn, Ni, P, Pb, S, V and Zn the GAI triggers are higher than the standard DEC/US EPAA EILs, HILs and Eco-SSL triggers (see Green 2011). An analysis comparing the lower triggers against the average concentration of those elements in each rock type (Table 8-2) indicates that:

- the majority of rock types have values lower than the DEC/EPA triggers for Ba, Cu, Ni, P, S and Zn;
- most rock types have relatively high concentrations of Mn, V and Pb; and
- generally the dominant rock types to be encountered in the Billiard pit have relatively high levels of Co, Mn, Pb and V.

In general, whilst concentrations of some trace elements of potential environmental concern (e.g. As, Pb) were enriched in some of the sampled ore and waste materials, these elements will not necessarily mobilise into groundwater. Arsenic in particular is commonly enriched in ore and waste for many Hamersley Group deposits. Iron oxy-hydroxides such as hematite and magnetite have high sorption capacities for As (e.g. Zhang *et. al*. 2004), and consequently these materials have been used around the world for treating water enriched in arsenic.

In summary, the following elements have been identified as being enriched in the Billiard deposits: **Fe, As, Sn, Th and U (based on GAI triggers) and Mn, V, Pb and Co (based on DEC/EPA triggers)**. Although these elements were found to be enriched, the results of static and sequential leach extractions indicated that elements other than Mn and Pb are unlikely to leach at appreciable levels; however these enriched elements should be monitored in groundwater to ensure that geochemical conditions do not change.

Table 8-2: Analysis of Billiard Drillhole Mean Concentrations Compared to the Lowest DEC/EPA Trigger Values

	Ba (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Mn (%)	Ni (mg/kg)	P (%)	Pb (mg/kg)	S (%)	V (mg/kg)	Zn (mg/kg)
GAI Trigger	6000	240	1200	600	1.14	960	1.2	168	0.31	1920	900
DEC/EPA Trigger	330	13	26	28	0.022	38	0.2	11	0.06	7.8	46
Alluvium	81	20	74	20	0.06	18	0.03	22	0.01	146	24
DET WASTE	49	15	57	21	0.03	19	0.05	16	0.02	101	27
DET ORE	122	12	41	27	0.12	21	0.10	18	0.03	76	32
ECC	83	13	33	17	0.04	22	0.02	22	0.01	190	17
WCH	42	16	26	14	0.05	16	0.04	14	0.01	112	13
GVU	34	16	15	11	0.05	12	0.05	13	0.01	44	10
GVC	91	12	25	18	0.12	26	0.08	13	0.01	39	20
GVL	28	18	18	11	0.07	12	0.07	13	0.01	56	10
LGC	45	21	28	17	0.10	16	0.07	13	0.01	80	12
BCC	55	18	43	19	0.09	16	0.06	14	0.02	194	14
DOR	274	23	101	19	0.03	18	0.13	32	0.01	304	43
WOV	364	11	38	14	0.03	21	0.06	24	0.00	45	63
WW WASTE	169	19	34	23	0.10	16	0.05	23	0.01	168	39
WW ORE	73		73	20	0.01	30	0.12		0.01	64	28
YS WASTE	99	27	121	47	0.06	27	0.18	34	0.01	109	47
YS ORE	82	11	61	29	0.04	28	0.27	28	0.01	47	55
JOF WASTE	84	13	22	14	0.07	18	0.10	17	0.01	30	24
JOF ORE	93	14	24	16	0.07	23	0.17	15	0.01	25	28
JOF HYD	111	11	35	26	0.05	26	0.13	13	0.09	49	23
WS WASTE	54		26	20	0.04	12	0.10	13	0.00	24	32
WS ORE	68	12	39	13	0.08	25	0.19	13	0.01	37	35
DG WASTE	36	43	16		0.08	15	0.12	12	0.00	27	26
DG ORE	45	10	20	14	0.07	18	0.16	10	0.00	19	28
FWZ WASTE	63	20	30	20	0.18	30	0.19		0.00	15	28
MCS WASTE	48	21	26	17	0.76	24	0.07	15	0.10	19	33

9. AMD RISK ASSESSMENT AND CONCLUSION

The risk associated with AMD for the Billiard deposits has been investigated and takes into account: total sulfur concentrations within rock types; the sample location with respect to the proposed pit shell; the estimated tonnes expected during mining; and geochemical data to identify enriched elemental concentrations which may pose an environmental risk. The results of this assessment, taking into account background information related to mining of the deposit, as well as environmental factors which may be impacted are presented in the AMD Hazard Scorecard.

The Billiard deposit is expected to pose a low AMD risk based on the current pit design. Approximately 0.12% of all in-pit samples have sulfur levels greater than 0.1%, with 0.03% with sulfur levels greater than 0.3%. From the mining model it can be seen that elevated sulfur (i.e. S greater than 0.1%) material makes up a very small proportion of material to be encountered during mining, with this material likely to be sulfate minerals.

The following elements were found to be enriched in samples from the Billiard samples and should be monitored in groundwater: Fe, As, Sn, Th, U, Mn, V, Pb and Co, though these elements are not expected to leach from waste material in appreciable levels.

10. REFERENCES

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INAP (2010). Global Acid Rock Drainage (GARD) Guide. The International Network for Acid Prevention (INAP), Salt Lake City; available at http://www.gardguide.com/index.php/Main_Page

RTIO (2011). Brockman 2 Detrital Iron Ore Mine Extension Phase 2B AMD Risk Assessment

11. APPENDICES

Appendix 1: ARD Hazard Score

Project Name	Yandi Billiard
Assessment Date	4/06/2014
Compiled by	Steven Lee
Final ARD Hazard Assessment	**LOW**

Version Date: 11/06/14
Version Number: 3

RTIO ARD Hazard Score

1. Preliminary Assessment (Order of Magnitude/Exploration)

A. Preliminary Geology Hazard

	Select Relevant Option Below	Score	Option Details
Ore Deposit Type	C) Enriched Marra Mamba Formation and Joffre Member, and/or channel and detrital ore bodies mined below the water table (un-oxidised lignite and black shales other than Mt McRae may be present). Enriched Dales Gorge Member mined above the water table only	14	Moderate / moderate
Host & Country Rock Neutralising Potential	None (<5%)	10	
Brownfield's / Greenfields	Greenfield		
Known ARD Issues on Site	No	0	
	Geology Hazard Score		**26**

Complete following sections

B. Incipient ARD Risk

	Select Relevant Option Below	Score
Operation Age	< 5 years	5

**By default, all new projects should receive a <5 years value*

C. Scale of Disturbance

	Select Relevant Option Below	Score
Total Waste Stored	250 - 1 billions tonnes	10
Footprint	250 - 1000 hectares	6

D. Transport Pathways

	Select Relevant Option Below	Score
Project / Exploration?	No	
Precipitation / Areal Potential Evapo-transpiration Ratio	1/10 to 1/3 ratio_mining below the water table in a rock mass that is connected to a regionally significant aquifer	3

**All new projects should respond Yes to Project / Exploration*

E. Sensitivity of Receiving Environment

	Select Relevant Option Below	Score
Distance to Perennial/Ephemeral Water Bodies	500 - 2000 metres	1
Alkalinity	>35 mg/L	1
Distance to closest protected / permanently inhabited area	>10000 metres	0

Preliminary Hazard Assessment

Preliminary Hazard Score	52
Preliminary Risk Assessment	**MODERATE**

2. Detailed Assessment (Pre Feasibility/ Feasibility/Mining)

This assessment should be completed by an ARD expert

Pit	Yandi Billiard

F. Geochemical Hazard (Interrogate the drill hole database)

	Select Relevant Option Below	Score	Option Details
Waste sulfur risk	Total number of waste samples with S>0.1% is less than 3%	0	0.9% of waste samples with sulfur greater than 0.1%
Ore grade sulfur risk	Total number of ore grade samples with S>0.1% is less than 3%	0	0.03% of ore samples with S>0.1
Spatial distribution of sulfur	Sulfur scattered throughout the pit and through numerous lithologies (AWT and close to surface)	1	
Chemical enrichment	Enrichments of contaminants that are unlikely to mobilise into groundwater	1	

G. Mine Planning Hazard

	Select Relevant Option Below	Score	Option Details
PAF material management	No special waste management needed	0	No sulfidic material
Bulk NPR (Mass of neutralising material x mean ANC) / (Percent of lithology greater than 0.1%x tonnes of lithology x mean sulfur concentration for all data greater than 0.1 x 30.6 + repeat for each PAF lithologies)	>3	0	No sulfidic material
PAF rock mass disturbed or exposed (waste tonnes with S>0.1%)/(total tonnes of waste)*100	< 3% of the total disturbed mass	0	No sulfides expected to be mined
Pit backfilling	Pit will not be backfilled	5	

H. Water Management Hazard

	Select Relevant Option Below	Score	Option Details
Dewatering volume	80-160 ML/day	2	
Surface water	Creek flow	7	Weeli Wolli & Marillana Creeks
Water treatment during Operation	No water treatment or special management for ARD needed	0	No PAF material
Final void management	No PAF rock exposures likely on final pit shell	0	No PAF material

Combined Hazard Assessment

Preliminary Assessment Score	52
Detailed Assessment Score	16
Combined Hazard Score	29
Risk Ranking	**LOW**

This risk ranking score card is relevant for Pilbara based iron ore operations and the ranking system can be used to assess the relative risk of each .operation. The ranking system is likely to overestimate the risk if compared to porphry copper or some coal deposits

. For RTIO internal distribution only. The manager of Technical Projects and Development will need to review and approve this prior to external release
This risk assessment should be read in conjunction with the detailed ARD Risk Assessment

| Element/oxide_ | Alluvium | | | | | DET WASTE | | | | | DET ORE | | | | | ECC | | | | | WCH | | | | | GVU | | | | | GVC | | | | | GVL | | | | | LGC | | | | | BCC | | | | | DOR | | | | | WOV | | | | | WW WASTE | | | | |
|---|---|---

Rio Tinto

Water Resource Evaluation / Projects & Development

Revised Discharge Modelling in Weeli Wolli Creek based on measured channel loss rates

December 2014

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Introduction

1. Overview

Surplus water discharge into Weeli Wolli Creek is one of the water disposal options currently in place at Hope Downs 1 (HD1) and Yandicoogina mine sites, and is subject to condition 6-3 of Ministerial Statement 914, which limits the wetting front to 17 km downstream from the confluence of Marillana and Weeli Wolli Creek. To ensure compliance, Mine Operations at Yandicoogina are required to monitor the extent of surplus discharge on a regular basis and recent measurements suggest that the wetting front has travelled 7 km downstream from the confluence.

A baseline hydrologic assessment was completed in 2010 to evaluate the response of Weeli Wolli Creek to increased artificial discharge associated with the development of the JSW and Oxbow deposits within the Yandicoogina mine (RTIO, 2010). The assessment has since been updated to incorporate the potential increase in surplus water generation as a result of dewatering at Pocket and Billiard South (RTIO, 2013).

The main uncertainty associated with the current approach of estimating creek response and subsequently the extent of surplus water discharge is the channel loss rate[1], which is influenced by the alluvial characteristics, the underlying geology, the depth to groundwater table, and the seasonal variation in evaporation and transpiration. Previous modelling attempts utilised regional values for the channel loss rates due to the lack of localised information for the catchment. These values do not sufficiently capture the variations in losses along the creek, due to changes in catchment characteristics, which are considered important in assessing the reaction and impact of dewatering discharge in a creek system in a local scale. In order to improve the estimation of the discharge footprint along Weeli Wolli Creek, more representative values of channel loss rates are required in the model simulations.

Discharge measurements were carried out at various locations along Weeli Wolli Creek to quantify the channel loss rates in reaches of the creek system. These measurements were complemented by infiltration testing to better understand the rates of infiltration, in particular along the section downstream of the current discharge extent. Channel loss rates were estimated based on these field measurements (RTIO, 2014a), and were subsequently incorporated into the discharge extent modelling for Weeli Wolli Creek. Specific objectives of this assessment were:

- To calibrate the existing steady state discharge extent model using the field-derived channel loss rates for Weeli Wolli Creek.
- To predict the response of Weeli Wolli Creek, using the calibrated loss parameters, from the potential increase in surplus water discharge associated with the development of the Pocket and Billiard South deposits.
- To assess the sensitivity of the loss rates on the predicted wetting front along Weeli Wolli Creek.

2. Model Calibration

Detailed description of the rationale behind the development of the discharge extent model is provided in the Yandicoogina discharge baseline hydrology report (RTIO-PDE-0074001/RTIO, 2013). In brief, the wetting front of the artificial discharge is estimated based on a water balance approach, which calculates the length of the creek over which the discharge is lost to the environment. A short section of Marillana Creek was modelled

[1] The channel loss rate is the rate of total loss/gain of discharge to the environment via evaporation, infiltration, recharge and transpiration from riparian vegetation.

from DO8 to the catchment outlet and a 51 km section of Weeli Wolli Creek was modelled from the HD1 outlet to the BHP rail that runs across the Weeli Wolli Creek alluvial plain. Both creeks were divided into reaches based on creek morphology, vegetation type/pattern and the field-derived channel loss rates.

2.1.1 Existing discharge regime

The existing regime of surplus water discharge from the Yandicoogina and HD1 mine operations between 2007 and September 2014 is shown in Figure 1. This is compared with the movement of the wetting front for the same period downstream from the confluence of Marillana and Weeli Wolli Creek. The period saw a steady increase in total discharge, predominantly from water released from the HD1 operation. A sudden increase in discharge was observed in February 2009, which was associated with the activation of DO8 at Marillana Creek. This resulted in a dramatic response in the creek, where the wetting front migrated 6 km downstream from the confluence. The footprint receded quickly following the peak, which mirrored the sudden drop in total discharge in mid-2009 and early 2010. The wetting front remained fairly consistent at 5 km downstream from the confluence in 2012 where HD1 discharge stabilised at approximately 100 ML/day (37 GL/year). However, an increase in footprint distance was observed from 2013, which coincided with the activation of DO9 in April of the same year. DO9 was to replace all discharge outlets along Marillana Creek as the main point of discharge at Yandicoogina. Its location, downstream from the current mine operations, was chosen to prevent re-circulation from dewatering, thus water released from this outlet has the tendency to travel further down the creek. The maximum recorded wetting front was 7.7 km downstream from the confluence in June/July 2014.

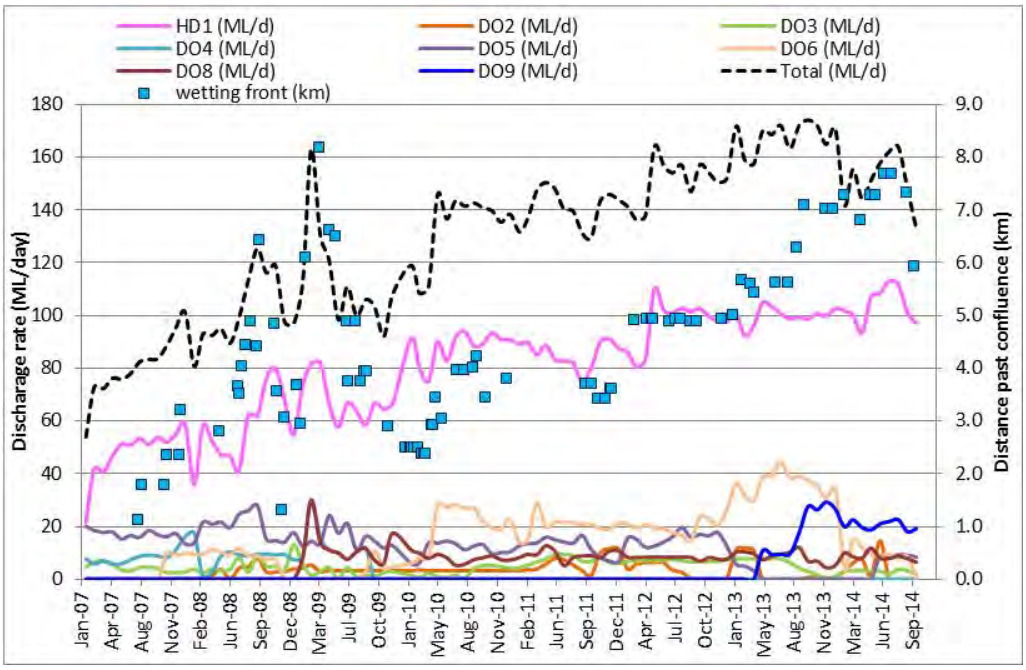


Figure 1: Existing discharge regime from Yandicoogina and Hope Downs 1 between 2007 and September 2014.

2.1.2 Calibration results

The most recent measurements of the wetting front from January to September 2014 were used to calibrate the discharge extent model. This was achieved by adjusting the channel loss rates to match the model results of the observed footprints along Weeli Wolli Creek. A comparison of the observed and estimated wetting front is provided in Table 1,

and the calibrated loss rates for each of the modelled reaches, together with the field-derived loss rates, are presented in Figure 2.

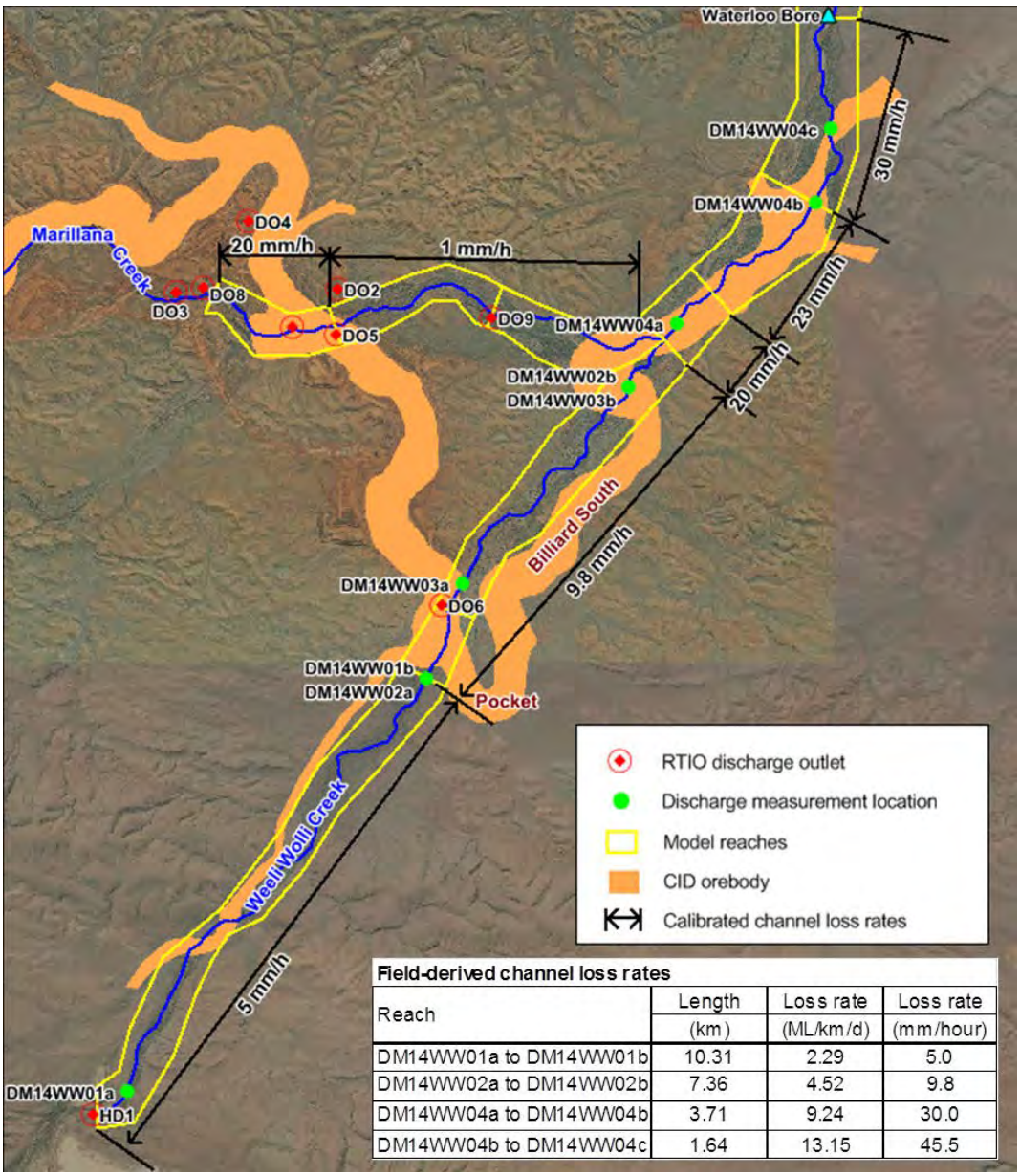
Minimal adjustments were made to the field-derived loss rates for Weeli Wolli Creek reaches upstream of the confluence, which range from approximately 5 to 10 mm/hour. A significant increase in losses is observed downstream from the confluence, where the rates increase from 20 mm/hour to approximately 30 mm/hour towards Waterloo Bore[2]. These findings are consistent with those of the study conducted by Dogramaci et al, who identifies Weeli Wolli Creek as a groundwater-connected system, with minimal losses, upstream of the confluence, and a disconnected creek downstream as the unsaturated zone increases. This transition also coincides with where the creek is underlain by the CID orebody, which has a high hydraulic conductivity (K) of approximately 10 m/day (Dogramaci et al., 2014). This change in understanding of the hydrogeological properties has resulted in the substantial increase in channel loss rates, predominately via infiltration, in the disconnected section of the creek.

Greater uncertainty is associated with the channel loss rates for Marillana Creek, but model calibration indicates a very small value of 1 mm/hour for reaches underlain by the impermeable Weeli Wolli Formation, which has the potential to restrict water loss via infiltration and/or recharge. On the other hand, due to the presence of the CID orebody, a high loss rate of 20 mm/hour was used for the first reach of Marillana Creek.

Table 1: Comparison of the observed and estimated wetting front distances along Weeli Wolli Creek downstream from the Marillana and Weeli Wolli Creek confluence.

Date	Discharge (GL/year)	Wetting front past the confluence (km)		Error (%)
		Observed	Estimated	
30/01/2014	52	7.3	6.6	-9.3
19/02/2014	57	7.3	7.5	2.3
24/03/2014	53	6.8	6.8	-0.2
29/04/2014	55	7.3	7.1	-2.9
14/05/2014	58	7.3	7.6	4.9
11/06/2014	59	7.7	7.8	1.1
9/07/2014	60	7.7	7.8	1.5
26/08/2014	54	7.3	7.0	-5.0
20/09/2014	48	6.0	6.3	5.4

[2] Waterloo Bore is a Department of Water (DoW) rainfall and streamflow gauging site.



Field-derived channel loss rates

Reach	Length (km)	Loss rate (ML/km/d)	Loss rate (mm/hour)
DM14WW01a to DM14WW01b	10.31	2.29	5.0
DM14WW02a to DM14WW02b	7.36	4.52	9.8
DM14WW04a to DM14WW04b	3.71	9.24	30.0
DM14WW04b to DM14WW04c	1.64	13.15	45.5

Figure 2: Calibrated and field-derived channel loss rates for Marillana and Weeli Wolli Creek.

2.2 Model prediction

With future expansion and development of the Pocket and Billiard South deposits, the total groundwater abstraction and the rate of surplus water discharge will increase for the Yandicoogina operation. Due to the close proximity of the deposits to Weeli Wolli Creek, discharge from HD1 will be re-circulated through the CID and back to the surface when dewatering begins. Results from the latest groundwater modelling indicates that all potential discharge from HD1 will be abstracted by dewatering, hence surface water flow will likely be terminated along the section of the creek parallel to Pocket and Billiard South. The abstracted water will be pumped to DO9 and released into Marillana Creek and subsequently into Weeli Wolli Creek downstream of the confluence.

Results from the water balance and groundwater modelling suggest that the total volume of water likely to be released from DO9 between 2017 and 2032 will range from 46 GL/year to maximum 84 GL/year (RTIO, 2014b). These predicted rates include abstraction from JSE, JSW, Pocket/Billiard South, as well as HD1 discharge re-circulation. This assessment investigates the response of the wetting front through

continual discharge of 46 GL/year, 58 GL/year and 84 GL/year at DO9, the minimum, average and maximum rate of discharge predicted for the outlet from 2017 to 2032, respectively. Discharge footprints were determined based on the assumption that steady state conditions were established.

The channel loss rates for Weeli Wolli Creek, down gradient from the current observed wetting front (down gradient from Waterloo Bore), cannot be definitively estimated in the field (RTIO, 2014a). However, the extensive layer of unsaturated surficial alluvium (> 40 m in thickness) that characterises the very downstream of Weeli Wolli Creek is highly conductive, K= ~ 1000 m/day, which allows rapid recharge to occur during creek flows; the underlying Brockman Iron Formation is also relatively permeable with a K value of approximately 5 m/day (Dogramaci et al., 2014). Based on these hydrogeological properties, it is expected that the channel loss rates for the downstream reaches will be as high as 30 mm/hour (the calibrated value of the last reach where the wetting front was observed) if not greater due to the increasing thickness of the unsaturated creek alluvium. However, to be conservative in the model predictions, the channel loss rate of 30 mm/hour was adopted for all reaches downstream of Waterloo Bore.

2.2.1 Model results

Model results for the proposed discharge rates and the associated contiguous surface water footprint distances, measured from the confluence of Marillana and Weeli Wolli Creek, are detailed in Table 2 and Figure 3, respectively.

Table 2: Estimated footprints for Weeli Wolli Creek for different discharge rates at DO9

Discharge rate at DO9 (GL/year)	**Footprint distance (km)**	
	From DO9	From confluence
46	13.6	10.7
58	15.3	12.3
84	18.5	15.5

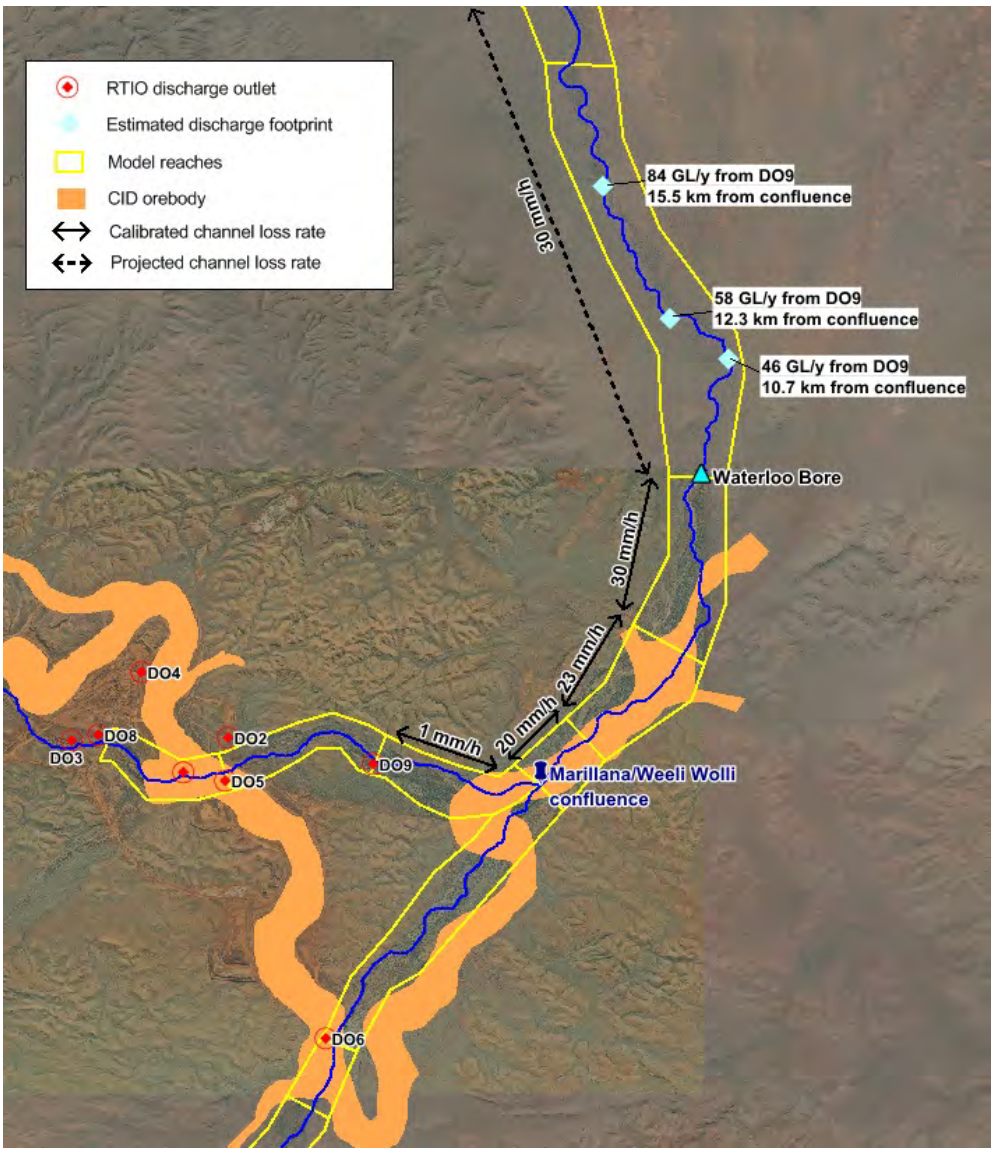


Figure 3: Estimated discharge footprints for Weeli Wolli Creek and the channel loss rates used in the model simulations.

Based on a constant loss rate of 30 mm/hour for the creek section downstream of Waterloo Bore, the modelled footprint for discharge rates 46 GL/year to 84 GL/year at DO9 would extend approximately 11 km to 16 km downstream from the confluence of Marillana and Weeli Wolli Creek. However, due to the lack of actual measurements, the level of uncertainty associated with the channel loss rate for the downstream reaches is high. Hence sensitivity analysis was undertaken to assess the response of Weeli Wolli Creek, beyond Waterloo Bore, to varying channel loss rate (± 20%).

Table 3 illustrates the results of the sensitivity analysis. It can be seen that modifying the channel loss rate by 20%, in general, resulted in less than 10% change in the discharge extent. Of exception is the 84 GL/year (- 20% loss rate) case where the modelled footprint was increased by 12%. The sensitivity analysis also shows that the creek is less responsive to the increase in channel loss rate than the decrease in rate for reaches downstream of Waterloo Bore, which suggests the nonlinearity of the relationship between footprint distance and channel loss rate for the Weeli Wolli Creek system.

The results of this assessment indicate that Weeli Wolli Creek could potentially accommodate the maximum predicted discharge rate of 84 GL/year at DO9, which incorporates surplus water generated from both HD1 and Yandicoogina mine operations, without breaching condition 6-3 of the existing Ministerial Statement 914. Continuous monitoring and discharge measurements are required and recommended to ensure compliance.

Table 3: Results of the sensitivity analysis of the channel loss rate for Weeli Wolli Creek downstream of Waterloo Bore

Discharge rate at DO9 (GL/year)	**Channel loss rate beyond Waterloo Bore (mm/hour)**	**Footprint distance from confluence (km)**
46	30 (base case)	10.7
58		12.3
84		15.5
46	24 (- 20 %)	11.4 *(6 %)*
58		13.4 *(9 %)*
84		17.4 *(12 %)*
46	36 (+ 20 %)	10.2 *(- 4 %)*
58		11.6 *(- 6 %)*
84		14.3 *(- 8 %)*
(x %) is the percentage difference in footprint distance compared with the base case.		

3. Conclusion

The existing discharge extent model for Weeli Wolli Creek has been reviewed and calibrated, based on field-derived channel loss rates, to improve the estimation of the wetting front associated with the potential increase in surplus water discharge from dewatering at Pocket and Billiard South. It can be concluded that:

- The channel loss rate for Weeli Wolli Creek increases from approximately 5 mm/hour at the HD1 discharge outlet to 30 mm/hour at Waterloo Bore, in association with the changes in hydrogeological properties of the creek as it transitions from a groundwater-connected system upstream of the confluence with Marillana Creek to a disconnected system downstream.

- The calibrated channel loss rates for the last two reaches of Marillana Creek are very small, which may be related to the impermeable Weeli Wolli Formation that underlays the creek alluvium restricting water loss via infiltration.

- The modelled footprint for discharge rates 46 GL/year to 84 GL/year (maximum predicted based on recent water balance and groundwater modelling) at DO9 would extend approximately 11 km to 16 km downstream from the confluence of Marillana and Weeli Wolli Creek, based on a constant loss rate of 30 mm/hour for the creek section downstream of Waterloo Bore.

- Varying the channel loss rate by ± 20% for Weeli Wolli Creek, downstream of Waterloo Bore, would result in less than 10% change in the footprint distance.

- Weeli Wolli Creek could potentially accommodate the maximum predicted discharge rate of 84 GL/year at DO9 without breaching condition 6-3, which limits the wetting front to 17 km downstream from the Marillana and Weeli Wolli Creek confluence, of the existing Ministerial Statement 914.

4. Reference

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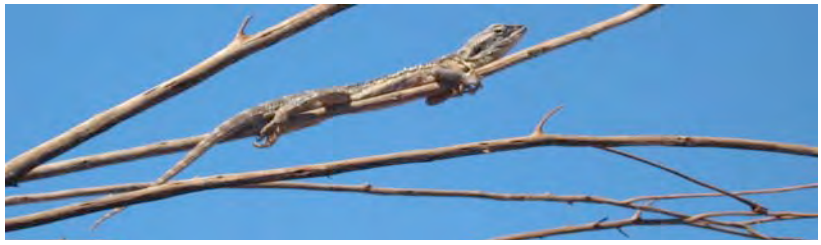
Biota Environmental Sciences

Yandicoogina Expansion Billiard Deposit Fauna Survey



Prepared for Rio Tinto Iron Ore

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1.0 Summary

1.1 Background

The Yandicoogina iron ore mine is located approximately 75 km north-west of Newman, in the Pilbara region of Western Australia (Figure 2.1). This mine site is owned and operated by Rio Tinto Iron Ore (RTIO).

Rio Tinto is seeking to expand their current mining operations at Yandicoogina. This involves a development site at Billiard, located to the east of the existing mine. A further two expansion sites, Junction South West and Oxbow are located to the west of the existing Yandicoogina operation. These two sites are the subject of a related, but separate, report.

Biota Environmental Sciences (Biota) was commissioned to complete a fauna survey of the proposed the Billiard project area, which is currently intended for use as a dewatering site. The survey was planned and implemented in accordance with the EPA Position Statement No. 3 "Terrestrial Biological Surveys as an Element of Biodiversity Protection" (EPA 2002) and Guidance Statement No. 56 "Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia" (EPA 2004).

The scope of the study was to:

- identify the fauna habitats, particularly those with conservation significance, within the study area;
- document the vertebrate and SRE invertebrate fauna assemblage within the study area; and
- identify fauna (particularly Schedule and Priority listed fauna as well as potential short-range endemic taxa) of particular conservation significance occurring within the area.

1.2 Methods

The initial survey took place during a single phase conducted in July 2008. This was followed in March 2010 by a four-day survey phase specifically targeting invertebrate SRE (Short-range endemic) fauna.

Systematic censusing of terrestrial fauna assemblages, including avifauna, mammals and herpetofauna, was carried out at nine sites, each located within defined habitats. The central component of the censusing consisted of trapping grids at six sites comprising 10 pit-fall traps (alternating 20 litre buckets and 20 cm diameter PVC tubes) spaced at 10 m intervals and connected by a single length (90 m) of 30 cm high flywire fence. One further sampling site exclusively comprised 50 Elliott traps, while two funnel trap sites were also utilised.

Seventeen avifauna censuses were conducted during the surveys across eight sites. Censuses were conducted between approximately 7:10 am and 12:00 pm, and were supplemented by opportunistic sightings of birds while traversing the study area.

Invertebrates were collected from both systematic sampling sites and opportunistic sampling sites. Groups targeted during these activities included:

- mygalomorph (trap-door) spiders;
- pseudoscorpions;
- scorpions;
- millipedes; and
- terrestrial snails.

Additional non-systematic collection techniques were undertaken by the survey team to supplement trapping efforts, and to investigate habitats not sampled using systematic methods.

1.3 Fauna

The single phase survey of vertebrate taxa in the Billiard study area yielded a total of 62 species, comprising 44 avifauna species, 18 mammals and 10 herpetofauna species: two frogs and eight reptiles (Table 1.1; Section 5.0).

Table 1.1: Number of vertebrate fauna species recorded during the fauna survey of the study area.

Fauna Group	Number of Species	Number of Individuals
Avifauna	44	860
Non-volant mammals	5	15
Bats	3	-
Amphibians	2	2
Reptiles	8	29
Total	62	906

One Priority 4 listed species was recorded by Biota from the survey area (Table 1.2). A further seven Schedule and six Priority listed species have either previously been recorded or may occur in the region (as determined by a search of the DEC Threatened Fauna Database and the WAM FaunaBase; Appendix 1 and Appendix 2). The Northern Quoll and the Night Parrot are listed as Endangered at the Federal level, while the Bilby, Pilbara Orange Leaf-nosed Bat and Pilbara Olive Python are listed as Vulnerable under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. The Rainbow Bee-eater was also recorded during the survey and is listed as Migratory under the *EPBC Act 1999*. These species are discussed further in Section 6.4.

Table 1.2: Fauna of conservation significance recorded during the fauna survey, or with the potential to occur within the study area (* denotes recorded during the survey).

Threatened Fauna Species	Status	
	State	Federal
Pezoporus occidentalis Night Parrot	Schedule 1	Endangered
Dasyurus hallucatus Northern Quoll	Schedule 1	Endangered
Macrotis lagotis Bilby	Schedule 1	Vulnerable
Rhinonicteris aurantius Pilbara Orange Leaf-nosed Bat	Schedule 1	Vulnerable
Lerista olivaceus barroni Pilbara Olive Python	Schedule 1	Vulnerable
Falco peregrinus Peregrine Falcon	Schedule 4	
Ramphotyphlops ganei	Priority 1	
Neochmia ruficauda subclarescens Star Finch	Priority 4	
Falco hypoleucos Grey Falcon	Priority 4	
Ardeotis australis Australian Bustard	Priority 4	
Burhinus grallarius Bush Stone-curlew	Priority 4	
**Pseudomys chapmani* Western Pebble-mound Mouse	Priority 4	
Leggadina lakedownensis Short-tailed Mouse	Priority 4	
Macroderma gigas Ghost Bat	Priority 4	

Only one Priority 4 species, the Western Pebble-mound Mouse, was confirmed from the study area (Table 1.2). This species is not restricted to the study area and is well represented in similar habitats across the Pilbara bioregion. The conservation status of this species is not expected to change as result of the Billiard development.

Searches for invertebrates during the initial survey phase, as well as during the targeted effort in 2010, yielded no taxa considered likely to represent potentially SREs

2.0 Introduction

2.1 Project Background and Study Area

The Yandicoogina iron ore mine is located approximately 75 km north-west of Newman, in the Pilbara region of Western Australia (Figure 2.1). This mine site is owned and operated by Rio Tinto Iron Ore (RTIO).

A further two expansion sites; Junction South West (JSW) and Oxbow are located to the west of the existing Yandicoogina operation. These two sites are the subject of a related, but separate, report.

Rio Tinto is seeking to expand their current mining operations at Yandicoogina. This involves a development site at Billiard, located to the east of the existing mine. The site at Billiard is intended for use as a dewatering area. The other two study areas, JSW and Oxbow, are located to the west of the existing Yandicoogina operation. These two study areas are the subject of a related, but separate report.

The project footprint was altered subsequent to the field survey and reduced in extent (see Section 4.0). For the purposes of this report, the original extent has been referred to as the 2007 survey boundary and the modified footprint the 2009 survey boundary.

2.2 Study Objectives and Scope

Biota Environmental Sciences (Biota) was commissioned to complete a fauna survey of the proposed Billiard project area. The survey was planned and implemented in accordance with the EPA Position Statement No. 3 "Terrestrial Biological Surveys as an Element of Biodiversity Protection" (EPA 2002) and Guidance Statement No. 56 "Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia" (EPA 2004).

The scope of the study was to:

- identify the fauna habitats, particularly those with conservation significance, within the study area;
- document the vertebrate and SRE invertebrate[1] fauna assemblage within the study area; and
- identify fauna (particularly Schedule and Priority listed fauna as well as potential short-range endemic taxa) of particular conservation significance occurring within the area.

2.3 Purpose of this Report

This report describes the methodology employed for the fauna survey of the Billiard project area. It documents the methods and results of the survey and identifies potential fauna of conservation significance occurring within the project area. Its intended use is as a supporting document for the environmental assessment of the project. Both the survey and report are subject to specific limitations that are discussed in detail in Section 4.5.

[1] Note that the survey referred to here was completed prior to publication of SRE survey guidelines (EPA 2009).

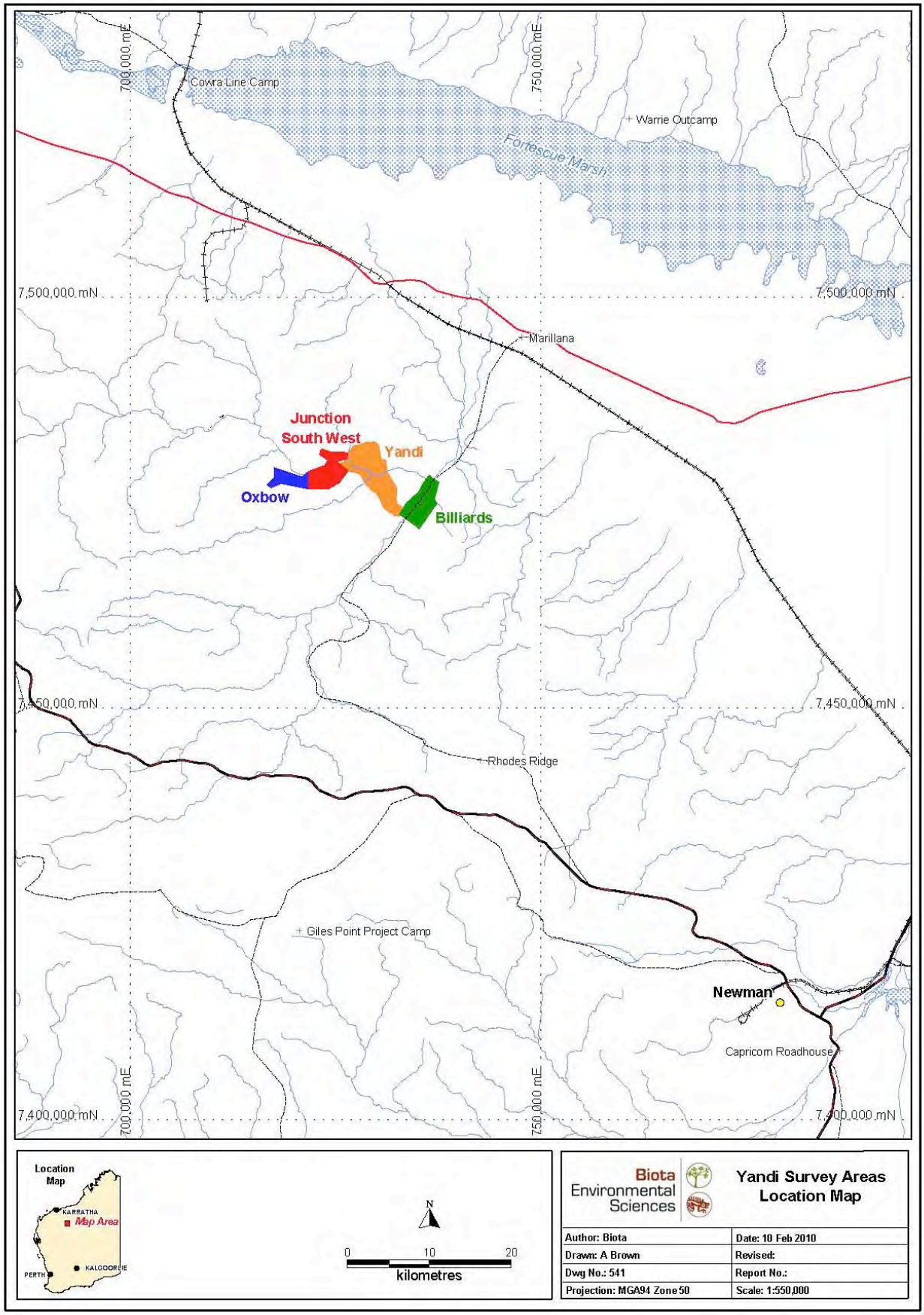

Figure 2.1: Location Map for the Yandicoogina Expansion fauna survey.

3.0 Existing Environment

3.1 Geological and Physiographic Context of the Study Are

3.1.1 Geology

Thorne and Trendall (2001) surveyed the geological units present within the proposed Yandicoogina Expansion study area, as part of a wider Pilbara project. There are six of their geological units present within the study area (Table 3.1; Figure 3.1).

Table 3.1: Geological units present in the study area.

Unit	Description
Czk	Calcrete - sheet carbonate, found along major drainage lines
Qw	Alluvium and colluvium - red-brown sandy and clayey soil; on low slope and sheetwash areas
PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills
Czc	Colluvium - partly consolidated quartz and rock fragments in silt and sand matris; old valley-fill deposits, locally derived
Qa	Alluvium - unconsolidated silt, sand, and gravel; in drainage channels and adjacent floodplains
PLHb	Brockman Iron Formation: banded iron-formation, chert, and pelite

3.1.2 Land Systems

Land Systems (Rangelands) mapping covering the study area has been prepared to a draft stage by the Western Australian Department of Agriculture (van Vreeswyk et al. 2004). Land Systems are comprised of repeating patterns of topography, soils, and vegetation (Christian and Stewart 1953) (i.e. a series of "land units" that occur on characteristic physiographic types within the Land System).

A total of 107 Land Systems occur in the Pilbara bioregion. [This information was obtained by combining the Land System mapping for the Pilbara (van Vreeswyk et al. 2004) and Ashburton (Payne et al. 1988), and intersecting this with the Pilbara bioregion in ArcView 3.2.]

Land Systems mapped by the Department of Agriculture (van Vreeswyk et al. 2004) for the region including the Billiard study area are shown in Figure 4.3. Descriptions for each Land System within the project area are provided in Table 3.2.

Table 3.2: Land systems present in the study area (based on the 2009 survey boundary).

Land System	Description	Extent within bioregion (ha)	Extent within study area (ha)	% of total within bioregion
Boolgeeda (RGEBGD)	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.	961,635	587	0.06
McKay (RGEMCK)	Hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands.	426,142	29	0.007
Newman (RGENEW)	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands.	1,993,742	390	0.02
River (RGERIV)	Active flood plains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.	482,176	506	0.1
		3,863,695	1,512	

3.2 Biological Context of the Study Area

3.2.1 IBRA Bioregions and Subregions

The Interim Biogeographic Regionalisation for Australia (IBRA) recognises 85 bioregions (Environment Australia 2000). The Billiard study area lies entirely within the Pilbara bioregion.

The Pilbara bioregion is divided into four subregions, described in Environment Australia (2000) as the four major components of the Pilbara Craton. The Billiard study area is located within a crossover section between the east of the Hamersley subregion and the Fortescue subregion (Figure 4.3):

- Fortescue Plains (PIL2): alluvial plains and river frontages with salt marsh, Mulga-bunch grass and short grass communities on alluvial plains and River Gum (*Eucalyptus camaldulensis*) woodlands fringing drainage lines; and
- Hamersley (PIL3): mountainous area of Proterozoic ranges and plateaux with low Mulga (*Acacia aneura*) woodland over bunch grasses on fine textured soils, and Snappy Gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on the skeletal sandy soils of the ranges.

3.2.2 Previous Fauna Surveys

Numerous surveys have been undertaken adjacent to the proposed project area, or are otherwise relevant because they have been undertaken nearby in the same sub-region of the Pilbara Craton. These include:

- Yandi (HI) biological survey (Ninox Wildlife Consulting 1995);
- BHPIO Yandi Stage II biological survey (Ecologia 1995);
- Mining Area C biological survey (see Woodward-Clyde 1997);
- Seasonal survey of the Hope Downs mine area (Ecologia 1997);
- Weeli Wolli Springs biological survey (Ecologia 1998a);
- West Angelas biological survey (Ecologia 1998b);
- BHPIO Marillana Creek biological surveys (summarised in Halpern Glick Maunsell 1999);
- BHPIO Marillana Creek rare fauna survey (Bamford and Associates 2003);
- Western Rail Corridor survey from the Hope Downs mine to the vicinity of Coondewanna Flats (Halpern Glick Maunsell 2000);
- Eastern Rail Corridor survey from the Hope Downs mine to Weeli Wolli siding (Halpern Glick Maunsell 2000);
- Vertebrate fauna survey of the proposed Hope Downs rail corridor from Weeli Wolli Siding to Port Hedland (Biota 2002a);
- Mulgara *Dasycercus cristicauda* and Bilby *Macrotis lagotis* surveys completed in late October 2001 (Biota 2002b);
- Vertebrate fauna survey of a proposed extension to the Hope Downs rail corridor through the Hamersley Range (Biota 2004a);
- Vertebrate fauna survey of a proposed addition to the Hope Downs rail corridor through the Chichester Range (Biota 2004b);
- An assessment of the fauna habitats and fauna assemblage of the proposed Fortescue Metals Group (FMG) Stage A rail corridor (Biota 2004c);
- An assessment of the fauna habitats and fauna assemblage of the proposed FMG Stage B rail corridor and mine areas (Biota 2004d);

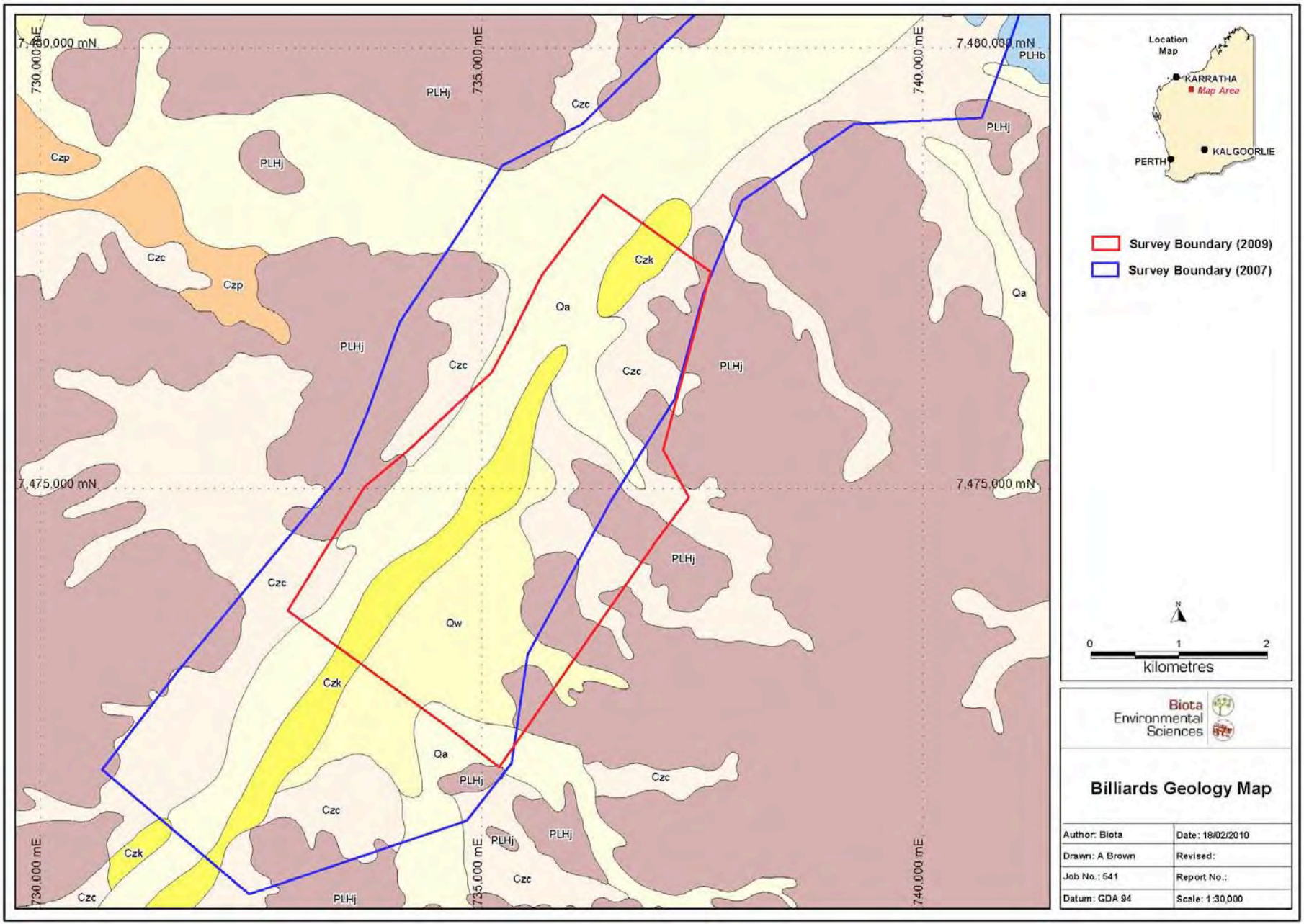

Figure 3.1: Geology mapping for the Billiard study area.

- A desktop fauna assessment and targeted invertebrate survey of the Yandi Expansion (Biota 2004e); and
- Yandicoogina Targeted Northern Quoll Survey (Biota 2009).

3.2.3 Conservation Reserves in the Locality

The main conservation reserve in the locality is the A-class Karijini National Park, approximately 100 km to the west-northwest of the study area.

While not listed as a conservation reserve the area known as Fortescue Marshes, approximately 45 km northeast of the study area, is listed as a Wetland of National Significance (Figure 2.1).

The Pilbara bioregion is listed as a medium priority for funding for land purchased under the National Reserves System Co-operative Program due to the limited representation of the area in conservation reserves. Portions of various pastoral leases in the region have been nominated for exclusion for public purposes in 2015, when the leases come up for renewal. Many of the submissions are from the Department of Environment and Conservation (DEC), with the intention of adding these areas to the existing conservation estate in order to provide a comprehensive, adequate and representative reserve system. None of these proposed exclusions are located in the vicinity of the expansion areas.

4.0 Study Methodology

4.1 Database Searches

Database searches were conducted of the DEC Threatened Fauna database (Appendix 1), the WA Museum FaunaBase (Appendix 2), and the *EPBC Act 1999* Protected Matters database (Appendix 3). These were completed using a point search utilising a 50 km buffer on the study area. The central coordinates for this search were:

- 22º47'5.61"S and 119º13'18.62"E

4.2 Survey Timing and Weather

The initial survey was conducted over a 7-day period between 5th July and 12th July 2008. Minimum temperatures during the survey ranged from 2.3°C to 11.5°C and maximum temperatures ranged from 20.4°C to 26.6°C (Table 4.1). No rainfall was recorded in Newman during the survey (Table 4.1).

The weather experienced during the fauna survey was comparable to the long-term climatic averages for Newman (Figure 4.1). The long-term averages for July include a maximum temperature of 22.3°C and a minimum temperature of 8.1°C. While the average rainfall for the month is 12.6 mm, rainfall events are typically only recorded sporadically at this time of year.

An additional survey phase targeting only invertebrate SRE taxa was completed between March 4th and 7th 2010.

Table 4.1: Daily meteorological observations at Newman Airport for July 2008 during the fauna survey (data provided by the Western Australian Bureau of Meteorology).

	5/07	6/07	7/07	8/07	9/07	10/07	11/07	12/07	Average
Min. Temp. (°C)	11.5	7.9	6.7	2.6	4.0	2.3	3.5	8.1	5.8
Max. Temp. (°C)	23.7	21.1	20.4	23.8	24.7	24.8	26.6	22.4	23.4
Rainfall (mm)	0	0	0	0	0	0	0	0	

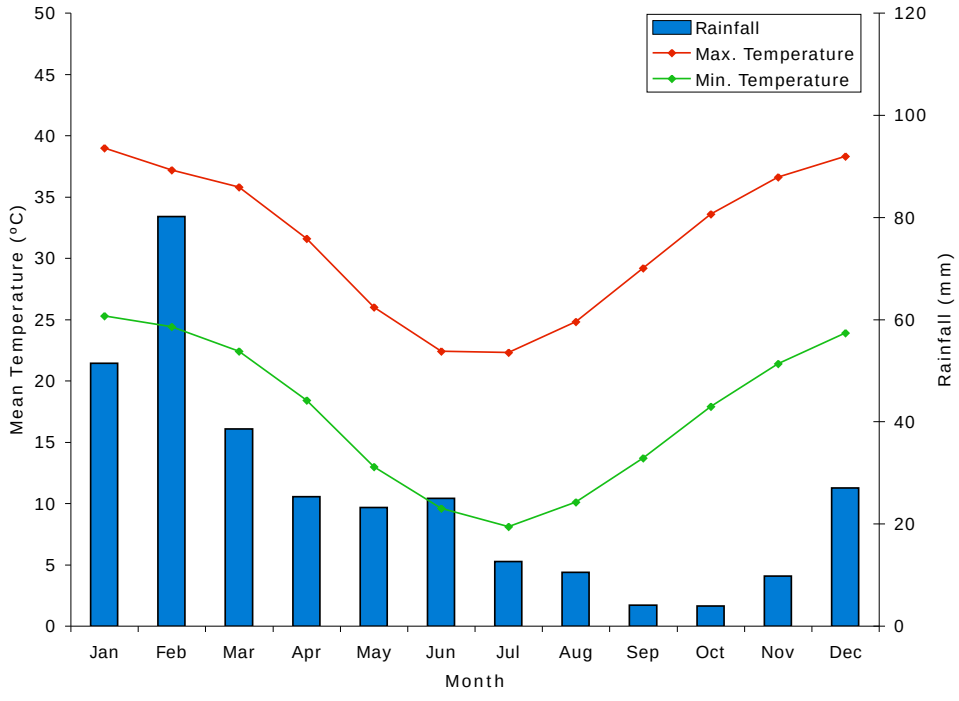

Figure 4.1: Long-term climatic averages for Newman (data provided by the Bureau of Meteorology).

4.3 Fauna Survey Team

The vertebrate fauna sampling for the field survey component of this study in 2008 was conducted under "Licence to Take Fauna for Scientific Purposes" No. SF006426 issued to Dr Phil Runham (Appendix 4). The fauna survey team comprised Dr Phil Runham, Mr Dan Kamien, Ms Erin Harris and Ms Jessica Cairnes (all of Biota Environmental Sciences). Mr Michael Greenham and Mr Ashley Johnsen participated in the set-up process for the fauna survey. The targeted SRE survey phase in 2010 was completed by Dr Phil Runham and Ms Erin Harris.

4.4 Systematic Censusing

4.4.1 Selection and Location of the Survey Sites

The principal component of the field survey consisted of systematic fauna sampling centred on a total of nine trapping sites, including six grids of 10 pit-traps in environments considered to represent the range of habitats available within the study area. Two funnel trap sites, each with 20 traps, and one site of 50 Elliott traps were also utilised.

Each survey site was installed within a defined habitat and was selected such that equal weight was given to accessibility of the sites in terms of regular inspection of traps (Plate 5.1 - Plate 5.9). Locations of trapping sites are presented in Table 4.2 and Figure 4.3.

4.4.2 Trapping Effort and Layout of the Trapping Grids

The trapping effort at each of the systematic trapping sites is detailed in Table 4.2. The locations of the trapping sites are shown in Figure 4.3.

During the fauna survey, pit-traps at six sites were arranged in a single row of ten traps, alternating between 20 litre buckets (~40 cm diameter) and PVC tubes (~20 cm diameter). Pit-traps were spaced at ~10 m intervals and connected with a single length of 30 cm tall flywire fence (Figure 4.2). Funnel traps were placed in a layout similar to that used for pit-traps, whilst Elliott traps were spaced at 5 - 10 m intervals along the base of breakaways or other suitable landscape features.

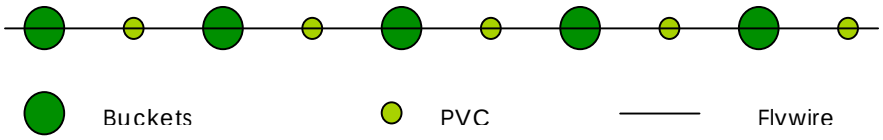

Figure 4.2: Indicative layout of trapping grids for the fauna survey.

Table 4.2: Trapping effort and trap location (WGS84, Zone 50) for the fauna survey.

Site	Location	Trap Type	Date Opened	Date Closed	Nights Open	No. of Traps	Total Trapping Effort
BIL02	740112mE; 7480997mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL05	737520mE; 7478340mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL07	736885mE; 7476102mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL08	735490mE; 7475184mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL10F	733398mE; 7473929mN	Funnel traps	6/07/08	12/07/08	6	20	120
BIL11	734617mE; 7472530mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL12	734812mE; 7474730mN	Pit-traps	6/07/08	12/07/08	6	10	60
BIL13F	736431mE; 7477689mN	Funnel traps	6/07/08	12/07/08	6	20	120
BIL14E	736249mE; 7477246mN	Elliott traps	7/07/08	12/07/08	5	50	250
					Pit-trapping Nights		360
					Funnel Trap Nights		240
					Elliott Trap Nights		250
					Total Trap Nights		850

4.4.3 Avifauna Sampling

The avifauna of the project area was sampled using a combination of techniques, which included:

- unbounded area searches conducted at the systematic sampling grids (Table 4.3);
- unbounded area searches conducted at opportunistic locations containing habitats or microhabitats likely to support previously unrecorded species; and
- opportunistic observation of birds while driving around the study area.

A total of 17 avifauna censuses were completed across eight sites during the survey period (Table 4.3). Avifauna were sampled using 30 or 40-minute censuses comprising a total of 10 hours of dedicated avifauna sampling.

Censuses were supplemented by recording avifauna species observed opportunistically within the study area.

Table 4.3: Timing of avifauna censuses during the fauna survey.

Site	7/7/08	8/7/08	9/7/08	10/7/08	11/7/08	Total (min)
BIL02		0715 - 0745				30
BIL05	1500 - 1530	0800 - 0830				60
BIL07			0825 - 0905	1010 - 1050		80
BIL08		1130 - 1200	0920 - 1000			70
BIL10F		0930 - 1000		0720 - 0800	0731 - 0811	110
BIL11	*	0840 - 0910	1010 - 1050			70
BIL12		1040 - 1110		0825 - 0905		70
BIL13F & BIL14E			0725 - 0805	0910 - 0950	0947 - 1027	110
					Total	600 min

4.4.4 Bat Sampling

Bats were sampled at one site using an Anabat echolocation call detector (Table 4.4 and Figure 4.3; Plate 4.1).

Table 4.4: Location of bat sampling during the Billiard fauna survey.

Site	Location	Structure	Type	Date Opened	Date Closed	No. of Nights
BILANA01	736435mE; 7477590mN	Creekline	Anabat	8/07/08	12/07/08	4
					Total Bat Sampling Nights	4

Plate 4.1: Site BILANA01.

4.4.5 Non-systematic Sampling of Vertebrate Fauna

A range of non-systematic fauna survey activities was also undertaken by the Biota survey team to supplement the trapping and investigate additional habitats identified during the course of the survey. These included:

- habitat-specific searches for Schedule and Priority listed fauna species;
- searching of microhabitats for reptile, frog and small mammal species;
- opportunistic sightings and records;
- identification of road kills and other animal remains; and
- recording and identification of secondary signs including tracks, scats and diggings.

4.4.6 Invertebrate Sampling

Hand foraging was undertaken for pseudoscorpions, involving peeling bark and lifting rocks. The latter technique was also used to search for scorpions, with additional specimens collected from pit traps. Millipedes were searched for whilst raking leaf litter and other debris and whilst searching for land snails. Representative samples of other invertebrates from pit traps were collected, sorted to morphotype, placed in 70% ethanol and lodged with the WA Museum."

Groups targeted during these activities included:

- mygalomorph (trap-door) spiders;
- pseudoscorpions;
- scorpions;
- millipedes; and
- terrestrial snails.

Invertebrates were collected from systematic sampling sites in the course of removing vertebrates from traps, as well as searches being conducted in these habitats. Additional non-systematic sampling for invertebrate groups supporting potential short-range endemic (SRE) taxa was also conducted across four sites (Table 4.5) through bulk sampling of leaf litter under vegetation.

Table 4.5: SRE sampling sites within the Billiard study area.

Site	Easting (mE)	Northing (mN)
BIL SRE03	739 019	7 479 322
BIL SRE04	732 777	7 472 371
BIL SRE05	736 627	7 477 820
BIL SRE08	736 422	7 475 639

4.5 Survey Limitations

The following limitations should be recognised by the reader of this report:

- The Billiard fauna survey represents a single phase of sampling with an additional phase targeting SRE taxa. It is probable that a broad seasonal survey would augment the number of species recorded from the study area.
- Not all sections of the study area were ground-truthed or equally sampled for fauna. Parts of the study area were inaccessible by vehicle hence regular checking of fauna traps in these areas would not have been possible. However, systematic fauna sampling was completed on the basis of trapping grid installation in habitats considered to be representative of the range of units present within the development area.
- It should be noted that nightspotting was not undertaken during the survey in accordance with site operational and safety procedures.

- Terrestrial invertebrate sampling was targeted at a small number of specific groups that are known to potentially harbour SRE taxa. Whilst the survey guidelines for SRE sampling were not published prior to completion of the survey, retrospective analysis has demonstrated that the sampling techniques utilised are in accordance with the EPA Guidelines for this type of work (EPA 2009).

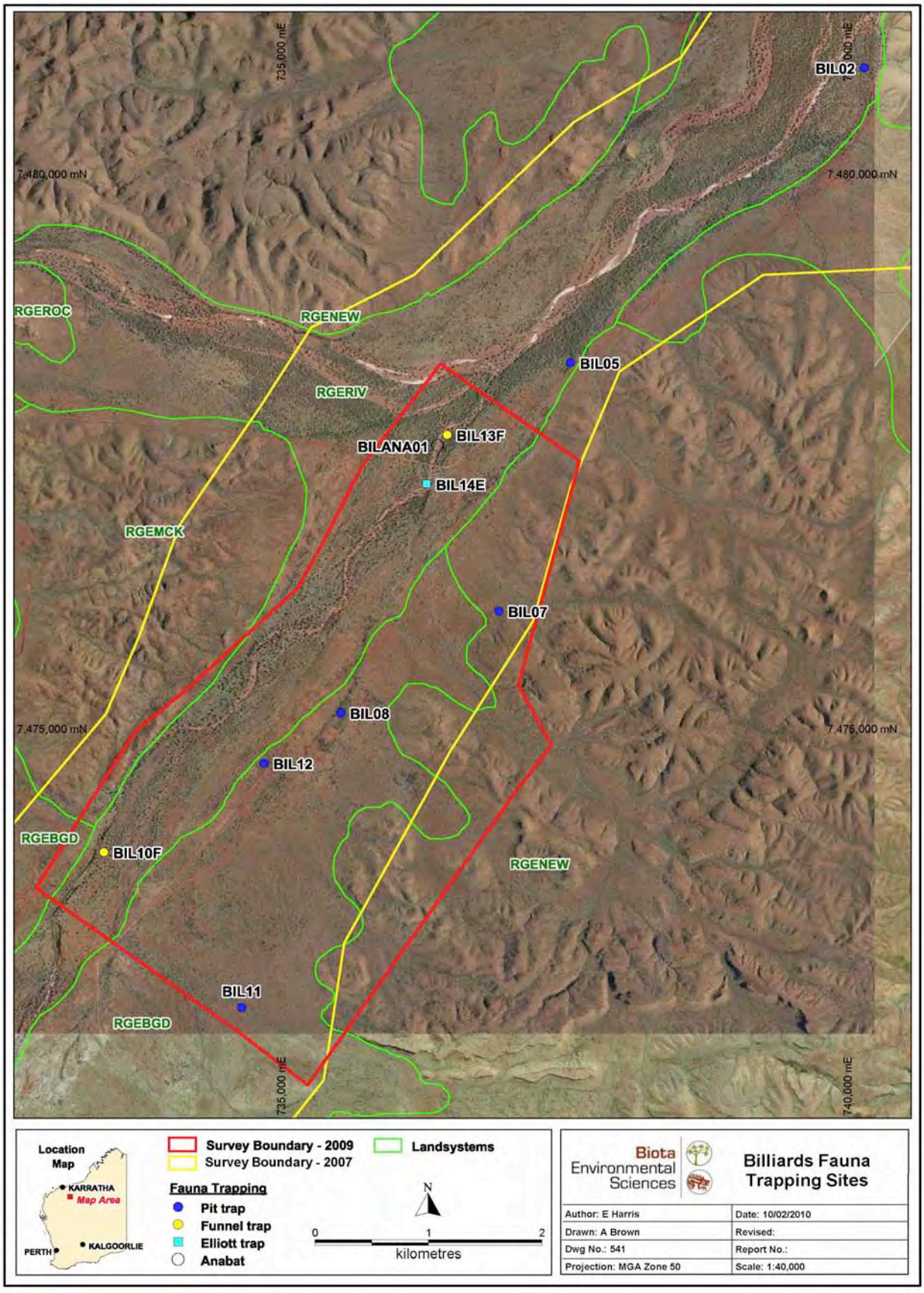

Figure 4.3: Fauna trapping site locations in the Billiard study area.

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5.0 Results

5.1 Fauna Habitats

Six separate fauna habitat units were identified during the Billiard fauna survey (Table 5.1). The fauna habitats were distinguished primarily on the basis of landforms, but also on their associated vegetation and soil types.

Table 5.1: Fauna habitats utilised during the Billiard fauna survey, distinguished by landform.

Vegetation Description and Substrate	Site	Plate
MAJOR DRAINAGE LINE		
Eucalyptus victrix. over *Acacia citrinoviridis* and *A. pruinocarpa*. over mixed shrubs over *Triodia* spp. and tussock grasses on river gravel.	BIL14E	Plate 5.9
	BIL10F	Plate 5.5
	BIL13F	Plate 5.8
MAJOR DRAINAGE LINE		
Eucalyptus and *Corymbia* spp. woodland over *Cenchrus ciliaris* (Buffel Grass) on stony loam.	BIL05	Plate 5.2
MINOR DRAINAGE LINE		
Eucalyptus spp. over *Acacia* spp. over *Triodia* spp. and grasses on stony loam.	BIL11	Plate 5.6
PLAIN		
Acacia aneura (Mulga) over *Eremophila forrestii* and small mixed shrubs on loam.	BIL08	Plate 5.4
Acacia sp. woodland over *Cenchrus ciliaris* (Buffel Grass) on loam.	BIL02	Plate 5.1
PLAIN		
Scattered *Eucalyptus* spp. over *Acacia* spp. over *Triodia* spp. on gravelly loam with calcrete.	BIL12	Plate 5.7
LOW STONY HILL SLOPE		
Scattered *Corymbia* spp. over *Acacia* spp. shrubland over *Triodia* on stony slope.	BIL07	Plate 5.3

Plate 5.1: Site BIL02.

Plate 5.2: Site BIL05.

Plate 5.3: Site BIL07.

Plate 5.4: Site BIL08.

Plate 5.5: Site BIL10F.

Plate 5.6: Site BIL11.

Plate 5.7: Site BIL12.

Plate 5.8: Site BIL13F.

Plate 5.9: Site BIL14E.

5.2 Overview

The fauna survey of the Billiard project area yielded a total of 62 vertebrate fauna species representing 33 families (Table 5.2). Forty-four species of avifauna, eight species of mammals and 10 species of herpetofauna were recorded during the survey (Table 5.2).

Table 5.2: Vertebrate Fauna Groups recorded during the fauna survey.

Fauna Group	Number of Species	Number of Individuals
Avifauna	44	860
Non-volant mammals	5	15
Bats	3	-
Amphibians	2	2
Reptiles	8	29
Total	62	906

5.3 Avifauna

5.3.1 The Assemblage

A total of 44 species of birds was recorded during the Billiard fauna survey, comprising 23 families. This included 14 non-passerine species and 30 passerine species (Table 5.3).

The most commonly recorded species was the Zebra Finch *Taeniopygia guttata* with a total of 176 records, representing 20.5% of all avifauna records. The Masked Woodswallow *Artamus personatus* was also relatively common, with 14.0% of the total of all avifauna records for the survey. The most abundant family was the Estrildidae (finches) with 176 records accounting for 20.5% of all records (it should be noted these are all Zebra Finch records). The Meliphagidae (honeyeaters) was also an abundant family with 158 records representing 18.4% of the total avifauna records. The Meliphagidae was also the most speciose family with six species recorded (Table 5.3).

The most species rich sites were BILF13 with 28 species, followed by BILF10 (both situated on major drainage lines) with 27 species (Table 5.3).

5.3.2 Avifauna of Conservation Significance

One Migratory species, the Rainbow Bee-eater *Merops ornatus* was recorded during the Billiard fauna survey (Table 5.3).

A further five avifauna species of elevated conservation significance may occur within the study area.

Further information on these species of elevated conservation significance can be found in Section 6.4.

5.4 Mammals

5.4.1 The Assemblage – Non-volant mammals

A total of five species of non-volant mammals was recorded during the survey, comprising four families. This total includes four native mammal species and one non-native species (a total of 46.7% of all non-volant mammal records for the survey). The most commonly recorded native species was the Red Kangaroo Macropus rufus, with a total of four records, representing 26.7% of all non-volant mammal records.

Table 5.3: Avifauna species recorded during the Billiard fauna survey.

FAMILY Common Name	Species Name	BIL02	BIL05	BIL07	BIL08	BILF10	BIL11	BIL12	BILF13	TOTAL
ARDEIDAE										
White-faced Heron	*Ardea novaehollandiae*					1				1
ACCIPITRIDAE										
Black-breasted Buzzard	*Hamirostra melanosternon*						2			2
Whistling Kite	*Haliastur sphenurus*					1				1
FALCONIDAE										
Brown Falcon	*Falco berigora*		1							1
CHARADRIIDAE										
Black-fronted Dotterel	*Charadrius melanops*					6				6
COLUMBIDAE										
Crested Pigeon	*Ocyphaps lophotes*					15	3			18
Peaceful Dove	*Geopelia striata*	6							2	8
PSITTACIDAE										
Little Corella	*Cacatua sanguinea*					53		1	31	85
Australian Ringneck	*Platycercus zonarius*	4				8			5	17
CUCULIDAE										
Pallid Cuckoo	*Cuculus pallidus*			1	1		1			3
Horsfield's Bronze Cuckoo	*Chrysococcyx basalis*					2			1	3
HALCYONIDAE										
Blue-winged Kookaburra	*Dacelo leachii*		1			2			1	4
Red-backed Kingfisher	*Todiramphus pyrrhopygia*							1	2	3
MEROPIDAE										
Rainbow Bee-eater	*Merops ornatus*		7			9			5	21
MALURIDAE										
Variegated Fairy-wren	*Malurus lamberti*		7			3		7		17
PARDALOTIDAE										
Red-browed Pardalote	*Pardalotus rubricatus*					2			6	8
Striated Pardalote	*Pardalotus striatus*	2				3				5
ACANTHIZIDAE										
Weebill	*Smicrornis brevirostris*	2	10	3	2	9	1	7	9	43
Western Gerygone	*Gerygone fusca*				2	3		1	1	7
MELIPHAGIDAE										
Brown Honeyeater	*Lichmera indistincta*		2	8		5	1	9	1	26
Singing Honeyeater	*Lichenostomus virescens*			1	5	3	9	6	1	25
Grey-headed Honeyeater	*Lichenostomus keartlandi*					1				1

FAMILY Common Name	Species Name	BIL02	BIL05	BIL07	BIL08	BILF10	BIL11	BIL12	BILF13	TOTAL
White-plumed Honeyeater	*Lichenostomus penicillatus*	11	8			22			20	61
Yellow-throated Miner	*Manorina flavigula*			9	11		4	16		40
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*					1		3	1	5
PETROICIDAE										
Red-capped Robin	*Petroica goodenovii*				1				1	2
POMATOSTOMIDAE										
Grey-crowned Babbler	*Pomatostomus temporalis*	3		1		2			11	17
PACHYCEPHALIDAE										
Crested Bellbird	*Oreoica gutturalis*	1			1	1	2	2	1	8
Rufous Whistler	*Pachycephala rufiventris*	2	3		1				4	10
Grey Shrike-thrush	*Colluricincla harmonica*					3			1	4
DICRURIDAE										
Grey Fantail	*Rhipidura fuliginosa*	1								1
Willie Wagtail	*Rhipidura leucophrys*		2	3		11			5	21
Magpie-lark	*Grallina cyanoleuca*		1	1	1	12		1	6	22
CAMPEPHAGIDAE										
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*						2		7	9
ARTAMIDAE										
Masked Woodswallow	*Artamus personatus*				50				70	120
Black-faced Woodswallow	*Artamus cinereus*			7			4			11
Little Woodswallow	*Artamus minor*								2	2
CRACTICIDAE										
Grey Butcherbird	*Cracticus torquatus*				4					4
Pied Butcherbird	*Cracticus nigrogularis*						2		1	3
Australian Magpie	*Cracticus tibicen*					1				1
CORVIDAE										
Torresian Crow	*Corvus orru*	6	1	1	1	6		1	4	20
Little Crow	*Corvus bennetti*								1	1
DICAEIDAE										
Mistletoebird	*Dicaeum hirundinaceum*	13	4							17
ESTRILDIDAE										
Zebra Finch	*Taeniopygia guttata*	3				137	22		14	176
	Total Number of Individuals	54	47	35	80	322	53	55	214	860
	Total Number of Species	12	12	10	12	27	12	12	28	44

The most abundant family was the Macropodidae, with six records accounting for 40.0% of all records. The most speciose family observed was also the Macropodidae, which comprised two species (Table 5.4).

The most speciose site during the fauna survey was BIL07 (low stony hill slope), recording three species.

5.4.2 The Assemblage – Bats

Three species of bats were identified on the basis of ultrasonic call analysis from one site within the Billiard project area (Appendix 5). These comprised one Emballonuridae and two Vespertilionidae (Table 5.5).

5.4.3 Mammals of Conservation Significance

One mammal species of elevated conservation significance was recorded during the fauna survey; this was the Western Pebble-mound Mouse *Pseudomys chapmani* (see Section 6.4).

A further five mammal species of elevated conservation significance may occur within the study area, but were not recorded during the survey (see Section 6.4).

Table 5.4: Non-volant mammal species recorded during the Billiard fauna survey.

FAMILY Common Name	Species Name	BIL07	BILF10	BILF13	Total
DASYURIDAE					
Little Red Kaluta	*Dasykaluta rosamondae*	1			1
MACROPODIDAE					
Euro	*Macropus robustus*	2			2
Red Kangaroo	*Macropus rufus*		4		4
MURIDAE					
Western Pebble-mound Mouse	*Pseudomys chapmani*	1			1
BOVIDAE					
European Cattle	*Bos taurus*		6	1	7
	Total Number of Individuals	4	10	1	15
	Total Number of Species	3	2	1	5

Table 5.5: Bat species recorded during the Billiard fauna survey.

FAMILY Common Name	Species Name	BILANA01
EMBALLONURIDAE		
Yellow-bellied Sheathtail-bat	*Saccolaimus flaviventris*	C
VESPERTILIONIDAE		
Gould's Wattled Bat	*Chalinolobus gouldii*	C
Finlayson's Cave Bat	*Vespadelus finlaysoni*	C
	Total Number of Species	3

5.5 Herpetofauna

5.5.1 The Assemblage

A total of 10 species of herpetofauna were recorded during the fauna survey, comprising four families (Table 5.6). This total comprised two tree frogs (Hylidae), two dragons (Agamidae), five skinks (Scincidae) and two front-fanged snakes (Elapidae).

The most commonly recorded species was the dragon *Amphibolurus longirostris* with a total of 13 records, representing 42.0% of all herpetofauna records. The most abundant herpetofauna families were the Agamidae and the Scincidae; each with 14 records each accounting for 45.2% of all herpetofauna records. The most speciose family observed was the Scincidae, which comprised five species.

The most speciose site was BILF10 (major drainage line) with five species recorded (Table 5.6).

5.5.2 Herpetofauna of Conservation Significance

Two herpetofauna species of elevated conservation significance may occur within the study area, but were not recorded during the survey (see Section 6.4).

Table 5.6: Herpetofauna species recorded during the Billiard fauna survey.

FAMILY Species Name	BIL02	BIL05	BIL07	BILF10	BIL11	BIL12	BILF13	Total
HYLIDAE								
Cyclorana maini				1				1
Litoria rubella				1				1
AGAMIDAE								
Ctenophorus caudicinctus			1					1
Amphibolurus longirostris	1	1		5			6	13
SCINCIDAE								
Carlia munda	1	3						4
Ctenotus duricola			1		2			3
Ctenotus leonhardii				1				1
Ctenotus pantherinus			1		1	1		3
Menetia greyii		2			1			3
ELAPIDAE								
Demansia psammophis		1						1
Parasuta monachus				1				
Total Number of Individuals	2	7	3	9	4	1	6	31
Total Number of Species	2	4	3	5	3	1	1	10

5.6 Short-range Endemic (SRE) Taxa

A total of only three invertebrate taxa were collected from one site during the survey phases. None of these represented taxa considered to contain potential SRE fauna (Section 4.4.6). A further three sites (see Section 4.4.6) from which leaf litter samples were taken yielded no invertebrates at all. This result was probably attributable to the general lack of suitable microhabitats in the study area.

Site	Location		Habitat Type	Taxon	Specimen Number
	Easting (mE)	Northing (mN)			
BILSRE04	736 627mE	7477 820mN	Colluvial drainage line	Diplopoda	3
				Coleoptera	1
				Blattodea	1
				Total	5

6.0 Discussion

The discussion following provides a synopsis of the significance of the fauna habitats and assemblages documented in the Billiard study area in the context of both the Pilbara Bioregion and the local area. The fauna assemblage is discussed predominantly in terms of the vertebrate families recorded and later in terms of fauna of elevated conservation significance.

6.1 Fauna Habitats

The survey of the Billiard study area identified six primary habitat types on the basis of landform, substrate types and vegetation assemblages (see Section 5.1). These six habitat types can be simplified into four habitat types based solely on landform:

- Major Drainage Line;
- Minor Drainage Line;
- Plain; and
- Low Stony Hill Slope.

This compares favourably with the previously available data, which indicate the potential for six habitat types (Biota 2004e). The four habitat types identified within the Billiard study area broadly comprise spinifex hummock grasslands on low stony hills, with open Eucalypt woodlands and *Acacia* shrublands over spinifex on valley floors, and Eucalypt woodlands along creeks. Creeklines were divided into the major creek habitat of Weeli Wolli and Marillana Creeks, and smaller secondary creeklines. The two habitat types not represented within the Billiard study area were low stony hills comprising areas of Mulga on hillcrests and rocky ridges / breakaways.

These habitats represent a small subset of the available habitats within the Pilbara and are largely considered to be ubiquitous throughout the Bioregion.

It should be noted here also that the habitats identified in the Billiard study area were characterised by high levels of degradation due to the presence of cattle and the frequency of fires. Relatively small, regenerating plants dominated much of the Triodia hummock grassland habitat, while the open areas between plants were frequently disturbed by cattle tracks. The dominant trees present in the *Acacia* groves close to the drainage line appeared largely intact, but understoreys were significantly impacted by cattle and / or the native vegetation replaced with *Cenchrus ciliaris*.

6.2 Fauna Assemblage

The fauna assemblage recorded during the survey of the Billiard study area comprised a total of 62 species, representing 33 families. This assemblage is considered to represent a subset of the vertebrate taxa that might be expected to occur in the study area, which has previously been estimated at 147 species across 51 families (Biota 2004e). For the greater part, the absence from the current study of families included in the earlier list can be attributed to factors including disturbed or unsuitable habitats, seasonality or the vagaries of species biologies.

Comparison of the avifauna assemblage with that compiled earlier (Biota 2004e) reveals the absence of nine families from the assemblage documented during this study. The absence of many of these species can be related to the state and/or availability of suitable habitat.

For instance, it is likely that members of avifauna families such as the Casuariidae (Emu), Otididae (Australian Bustard) and Turnicidae (Little Button-quail) were absent due to the extent of habitat that were highly degraded due to the presence of cattle. These areas were vegetated with only very small *Triodia* in most places and would have offered little foraging for frugivorous or

insectivorous species, and little protection for taxa reliant on *Triodia* respectively (Johnstone and Storr 1998). Portions of Weeli Wolli Creek influenced by existing dewatering activity (Figure 2.1) provide standing water within the study area, which accounts for the presence of the Ardeidae and Charadriidae (Table 5.3), however other water dependant taxa that may have been expected (Anatidae, Phalacrocoracidae, Threskiornithidae etc.) were not observed. Night birds (Tytonidae, Strigidae etc.) were not observed during the survey, this is likely due to nightspotting not occurring in accord with site operational procedures (see Section 4.5).

Amongst the mammals, there were only minor differences in the families recorded during the survey and those appearing in the earlier list (Biota 2004e). The sole native mammal family appearing in other documents (Biota 2004e) not documented by the current survey was the Molossidae. The one species representing this family in the vicinity of Billiard is the Northern Free-tail Bat *Chaerephon jobensis*. While this species may forage within the study area, it requires a core habitat that includes caves, this habitat is not available within the Billiard study area.

Although the herpetofauna documented during the current survey comprised representatives of four of the families, represented by 31 individuals, expected to occur in the Billiard study area, the numbers of both species and individuals were significantly below what might be expected for the area. However, this result is unsurprising given the low temperatures (both minima and maxima) experienced during the survey.

6.3 Fauna of Conservation Significance

6.3.1 Threatened Fauna Statutory Framework

Native fauna species that are rare, threatened with extinction, or have high conservation value are specially protected by law under the Western Australian *Wildlife Conservation Act 1950-1979*. In addition, many of these species are listed under the Federal *EPBC Act 1999*.

6.3.1.1 *EPBC Act 1999*

Fauna species of national conservation significance are listed under the *EPBC Act 1999*, and may be classified as 'critically endangered', 'endangered', 'vulnerable' or 'conservation dependent' (consistent with IUCN categories: http://www.iucn.org/themes/ssc/redlist2006/categories.htm).

Migratory wader species are also protected under the *EPBC Act 1999*. The national List of Migratory Species consists of those species listed under the following International Conventions:

- Japan-Australia Migratory Bird Agreement (JAMBA);
- China-Australia Migratory Bird Agreement (CAMBA); and
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

6.3.1.2 *Wildlife Conservation Act 1950-1979*

Classification of rare and endangered fauna under the *Wildlife Conservation (Specially Protected Fauna) Notice 2010* recognises four distinct schedules of taxa:

1. Schedule 1 taxa are fauna which are rare or likely to become extinct and are declared to be fauna in need of special protection;
2. Schedule 2 taxa are fauna which are presumed to be extinct and are declared to be fauna in need of special protection;
3. Schedule 3 taxa are birds which are subject to an agreement between the governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction, which are declared to be fauna in need of special protection; and
4. Schedule 4 taxa are fauna that are in need of special protection, otherwise than for the reasons mentioned in paragraphs (1), (2) and (3).

In addition to the above, fauna are also classified under five different Priority codes:

Priority One Taxa with few, poorly known populations on threatened lands.
Taxa which are known from a few specimens or sight records from one or a few localities on lands not managed for conservation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Two Taxa with few, poorly known populations on conservation lands, or taxa with several, poorly known populations not on conservation lands.
Taxa which are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Three Taxa with several, poorly known populations, some on conservation lands.
Taxa which are known from few specimens or sight records from several localities, some of which are on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Four Taxa in need of monitoring.
Taxa which are considered to have been adequately surveyed or for which sufficient knowledge is available and which are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. Taxa which are declining significantly but are not yet threatened.

Priority Five Taxa in need of monitoring.
Taxa which are not considered threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

6.4 Threatened Fauna Species from the Study Area

Two species of elevated conservation significance were recorded during the Billiard fauna survey during (Table 6.1). The Western Pebble-mound Mouse *Pseudomys chapmani* is listed as Priority 4 species under State legislation. The Rainbow Bee-eater *Merops ornatus* is listed under Federal legislation as Migratory.

A further five species listed under Federal legislation as either Endangered or Vulnerable (and as Schedule 1 under State legislation) may also occur in the study area (Table 6.1). One Schedule 4 State-listed species may be present. A further seven Priority listed species under State legislation may also be present within the study area.

Table 6.1: Threatened Fauna Species possibly occurring within the Yandicoogina vicinity (* denotes species recorded during the Billiard fauna survey).

Threatened Fauna Species	Status	
	State	Federal
Pezoporus occidentalis Night Parrot	Schedule 1	Endangered
Dasyurus hallucatus Northern Quoll	Schedule 1	Endangered
Macrotis lagotis Bilby	Schedule 1	Vulnerable
Rhinonicteris aurantius Pilbara Orange Leaf-nosed Bat	Schedule 1	Vulnerable
Lerista olivaceus barroni Pilbara Olive Python	Schedule 1	Vulnerable
Falco peregrinus Peregrine Falcon	Schedule 4	
Ramphotyphlops ganei	Priority 1	
Neochmia ruficauda subclarescens Star Finch	Priority 4	
Falco hypoleucos Grey Falcon	Priority 4	
Ardeotis australis Australian Bustard	Priority 4	
Burhinus grallarius Bush Stone-curlew	Priority 4	
**Pseudomys chapmani* Western Pebble-mound Mouse	Priority 4	
Leggadina lakedownensis Short-tailed Mouse	Priority 4	
Macroderma gigas Ghost Bat	Priority 4	

6.4.1 Schedule Fauna Species

Pezoporus occidentalis Night Parrot
State: Schedule 1 'Critically Endangered'
Federal: Endangered

Distribution: Night Parrots have been reported from every state on the Australia mainland. Suitable habitat occurs, or has occurred, across most of the inland, covering at least half of the continent. Records are sparsely distributed through this area, however there do appear to be concentrations of records in western Queensland and the eastern Pilbara (Higgins 1999). There is a confirmed record from Minga Well north of the Fortescue Marsh (approx. 100 km north of Newman, and 250 km east of Brockman) and an unconfirmed sighting from near Yandicoogina on the edge of the Marshes (Mr Roy Teale, Biota, pers. obs.).

Ecology: Night Parrots inhabit areas where there is dense, low vegetation, which provides them shelter during the day. Most records come from hummock grasslands with spinifex (*Triodia*), from areas dominated by samphire, or particularly, where these two habitats are juxtaposed. It has been suggested that birds move into the grasslands when *Triodia* is seeding. They have also been reported in low chenopod shrublands with saltbush and bluebush, and from areas of Mitchell grass (*Astrebla*) with scattered chenopods.

Many records have come from waterholes, and almost all reports from areas of *Triodia* have noted the presence of nearby water. The species is secretive and almost all confirmed sightings of feeding or drinking birds have come after dark. Sightings during the day have almost always been of birds flushed from hiding places by herds of stock, dogs or fire. Birds typically sit very tight, flushing only if the disturbance is very close, actually affecting the clump of vegetation in which they are hiding. Early observers stressed the dependence of the parrot upon dense spinifex or samphire for daytime roosting spots and for nesting.

The Night Parrot is presumably like other arid zone birds in being markedly nomadic. The extent of the movements and the possibility of some seasonality in any part of the range are unknown. Several possible reasons have been proposed for the decline of this species in recent years, including (1) habitat loss through clearing, (2) changes in habitat from burning practices, (3) changes in habitat caused by or competition from stock, (4) reduced availability of water holes or surrounding suitable food plants and (5) predation from feral animals, particularly cats and foxes (cats were mentioned as a major problem by several early observers).

Likelihood of occurrence: While the proposed expansion areas contain areas of dense *Triodia*, this habitat is not restricted to these areas. Additionally, there are no areas vegetated with samphire in the vicinity of the study area.

Potential Impacts: As a Schedule 1 and federally listed species the Night Parrot is considered fauna in need of special protection. However the Night Parrot is considered unlikely to occur within the study area, and therefore the conservation status of this species would not be altered by the current proposal.

Dasyurus hallucatus Northern Quoll
State: Schedule 1 'Endangered'
Federal: Endangered

Distribution: The Northern Quoll was originally recorded across Northern Australia from the Northwest Cape, Western Australia to south-east Queensland but has declined in recent years. Its distribution is now restricted to six main areas: the north and western top end of the Northern Territory, north of Cape York, the Atherton-Cairns area, the Carnarvon Range-Bowen area of Queensland (Menkhorst and Knight 2001), and the northwest Kimberley and Pilbara regions of Western Australia (Braithwaite and Griffiths 1994). It also occurs on numerous islands off the Australian coast (Abbott and Burbidge 1995, Burbidge and McKenzie 1978).

Ecology: The Northern Quoll, *Dasyurus hallucatus*, is classed as a medium-sized marsupial, with adult weight ranging from 300 g up to 1,200 g. It is considered a partially arboreal and aggressive carnivore, preying on a varied diet of small invertebrates and vertebrates, including lizards, birds, snakes, small mammals and frogs (Oakwood 1997).

The Northern Quoll is a short-lived mammal with both sexes maturing at 11 months. Females reproduce only once each year, and all males die shortly after reproducing (Dickman and Braithwaite 1992, Oakwood 2000). The discrete male cohorts that arise within populations make quolls vulnerable to extinction. If no juvenile male quolls survive to adulthood, there will be no males for females to mate with the following year, and the local population will rapidly become extinct (Braithwaite and Griffiths 1994, Oakwood 2000). Therefore, any factor that results in significant increases in mortality rates of female and juvenile quolls could cause local extinction of quoll populations. This species is most abundant near major creek lines and rivers and in open, rocky habitat and is also commonly found in gorges, where breeding is successful (Oakwood 2008).

Likelihood of Occurrence: The Northern Quoll may occur in the rocky gorge located in the nearby Oxbow study area (OXB06E), as suitable habitat is available. However it is unlikely to occur within the Billiard project area due to a lack of suitable habitat.

Potential Impacts: Under the *EPBC Act 1999*, an action requires referral to the Federal Environment Minister if it is deemed likely to have a significant impact on a matter of national environmental significance (eg. a listed threatened species such as the Northern Quoll *Dasyurus hallucatus*). Given the apparently broad distribution of the Northern Quoll in the Pilbara bioregion, the relatively small scale of clearing required for the current proposal, and the lack of suitable habitat for this species in the current study area, it is considered that the action will not result in a significant impact to the Northern Quoll.

Macrotis lagotis Bilby
State: Schedule 1 'Vulnerable'
Federal: Vulnerable

Distribution: The former range of the Bilby included most of the semi-arid areas of mainland Australia, however, it is now confined to *Triodia* hummock grassland and *Acacia* scrub across parts of northern Australia. It has been reintroduced to parts of the south-west of Western Australia (eg. Dryandra Woodlands).

Ecology: The Bilby *Macrotis lagotis* is a medium sized ground mammal, ranging in weight from 1.0 - 2.5 kg. The species is apparently strictly nocturnal and constructs a substantial burrow system, which may be up to 3 m in length (Flannery 1990; Strahan 1995). Similar to the Mulgara, the species has been documented as holding temporary home ranges and showing relatively rapid changes in distribution in response to variation in habitat resources (Johnson 1995).

Likelihood of Occurrence: This species is considered unlikely to occur within the study area due to a lack of suitable habitat. It has never been recorded during any previous surveys in the vicinity of the Yandicoogina operations (see Section 3.2.2).

Potential Impacts: As a Schedule 1 and federally listed species the Bilby is considered fauna in need of special protection. However, the proposed development is not considered likely to have a significant impact upon this species.

Rhinonicteris aurantius Pilbara Orange Leaf-nosed Bat
State: Schedule 1 'Vulnerable'
Federal: Vulnerable

Distribution: The Pilbara Orange Leaf-nosed Bat is a relictual monotypic genus of the family Hipposideridae. It occurs in the Pilbara region of Western Australia, through the Kimberley and across the Top End into north-western Queensland (Churchill 1991).

Ecology: Occurrence of this species is influenced by the availability of suitable roost caves (Churchill 1998). That is, deep caves offering suitable humidity and a stable temperature. In the Pilbara, they are thought to be restricted to caves where at least semi-permanent water is nearby (Dr Kyle Armstrong, Kyoto University Museum, pers. comm. 2005).

Likelihood of Occurrence: The gorge located in the nearby Oxbow study area (OXB06E) may provide foraging opportunities for this species, but does not contain core roosting habitat. The Billiard study area does not contain suitable habitat for this species, and it is considered unlikely to occur.

Potential Impacts: As a Schedule 1 and federally listed species the Pilbara Orange Leaf-nosed Bat is considered fauna in need of special protection. However, the proposed development is not considered likely to have a significant impact upon this species.

Liasis olivaceus barroni Pilbara Olive Python
State: Schedule 1 'Vulnerable'
Federal: Vulnerable

Distribution: Regarded as a Pilbara endemic, this subspecies has a known distribution that coincides roughly with the Pilbara bioregion (Environment Australia 2000).

Ecology: The Pilbara Olive Python occurs in rocky areas within the Pilbara, showing a preference for rocky habitats near water, particularly rock pools.

Likelihood of Occurrence: This species may occur within the study area, as suitable habitat is available along the drainage lines.

Potential Impacts: As a Schedule 1 and federally listed species the Pilbara Olive Python is considered fauna in need of special protection. However, while the proposed development may impact on individuals it is not considered likely to have a significant impact upon this species.

Falco peregrinus Peregrine Falcon
State: Schedule 4

Distribution: The Peregrine Falcon has an almost cosmopolitan distribution, but is absent from most deserts and the Nullarbor Plain (Johnstone and Storr 1998). The only subspecies in Australia, *F. p. macropus*, is widespread throughout Australia and Tasmania (Marchant and Higgins 1993). The Australian population has been estimated at 3,000 to 5,000 pairs (Cade 1982). Whilst its status is difficult to determine in the Pilbara, it is certainly more common than its Priority 4 listed cogener *Falco hypoleucos*.

Ecology: This species inhabits a wide range of habitats including forest, woodlands, wetlands and open country (Pizzey and Knight 1997). The availability of prey is apparently more important than habitat in determining its distribution. Home ranges are probably defended year round and are variable in size, though typically not less than 480 ha (Marchant and Higgins 1993).

This species typically nests on cliffs (81% of nests Australia-wide) but also on stick nests (11%) and in tree hollows (8%). Breeding typically occurs from August to November (Johnstone and Storr 1998). Food is almost exclusively birds such as pigeons, parrots and passerines, which are captured in flight (Johnstone and Storr 1998). Mammals such as possums and rabbits have been recorded as rare prey items (Marchant and Higgins 1993).

Likelihood of Occurrence: This species may occur within the study area, as suitable habitat is available.

Potential Impacts: Loss of potential nesting and foraging habitat. With its cosmopolitan distribution, the conservation status of this species is unlikely to be affected by the proposal. The reason for initially listing this species was a global decline associated with the use of DDT.

6.4.2 Priority Fauna Species

Ramphotyphlops ganei
State: Priority 1

Distribution: This blind snake is poorly collected, being represented by just 15 specimens in the WA Museum collection. This distribution places them across the Pilbara Bioregion from Pannawonica in the west, to Millstream in the north, to Newman in the east.

Ecology: This species is poorly known, but as for most blind snakes, individuals are likely to mostly inhabit the topsoil, termitaria and ant nests. Blind snake diet typically consists of the eggs, larvae and pupae of ants (Storr et al. 2002). A single specimen (R151749) of this species was recorded from a pitfall trap in *Triodia epactia* hummock grassland on a scree slope of the Chichester Range near Redmont Camp (22°01'02"E, 118°58'57"E; Biota database).

Likelihood of Occurrence: There is insufficient data known about the ecology of this species to determine whether it may occur within the habitats available within the study area.

Potential Impacts: Some potential habitat loss and possible direct mortality associated with construction of mines and infrastructure. The conservation status of this species is difficult to ascertain from the small number of known records. However, the records of the species suggest that it does not have a restricted distribution, and therefore its conservation status is unlikely to be affected by the proposal.

Neochmia ruficauda subclarescens Star Finch
State: Priority 4

Distribution: This species is endemic to Australia where it is found from the Pilbara to south-eastern Australia. It remains most common in the tropics. Its population has not been estimated but the species is typically patchy and highly variable in abundance.

Ecology: This species is typically confined to reedbeds and adjacent vegetation communities along permanent waterways in the Pilbara. It is considered to be resident in most of its range but, as with all finches, the species can wander widely. Its ecology in the Pilbara is not well known but it has been observed feeding on the seed of sedges (*Cyperus* spp.) and Buffel Grass (*Cenchrus ciliaris*) (Dr Mike Craig, pers. obs.). In other parts of its range it feeds mainly on seeds, but insects are a common part of the diet during the breeding season. It typically nests in March and April, as seeds are maturing after summer cyclones, and its domed nest is usually built in reeds up to several metres from the ground. The clutch is between three and six and the young usually fledge after about 16 days. In captivity, Star Finches may produce as many as three broods per year.

The main threat to the species is considered to be overgrazing by stock along waterways, which destroys the riparian vegetation on which they depend (Garnett and Crowley 2000).

Likelihood of occurrence: This species was recorded during the Yandicoogina Expansion survey, at the nearby Junction South-West project area (Biota Internal Database). This species is likely to be found throughout the study area where suitable habitat is available.

Potential Impacts: Impacts would include loss of habitat and deaths of individuals, but are unlikely to make an impact on the conservation status of this species.

Falco hypoleucos Grey Falcon
State: Priority 4

Distribution: The Grey Falcon is endemic to Australia, where it is widespread but rare throughout the arid zone. Occurs in the northern half of Western Australia (Johnstone and Storr 1998). The Grey Falcon is a resident or nomadic visitor to inland parts of Australia (Pizzey and Knight 1997), but its movements are poorly understood. Its population has been estimated at 1,000 pairs, with about 5,000 individuals present post-breeding (Marchant and Higgins 1993).

Ecology: This species inhabits a wide range of habitats in the arid zone but appears to be least rare in lightly wooded coastal and riverine plains (Johnstone and Storr 1998). In the Pilbara, the Grey Falcon is mostly recorded from the coastal plain between the de Grey and Ashburton Rivers (Storr 1984). Little is known of the ecology of the species but it appears to feed primarily on birds, with mammals and insects forming variably important parts of the diet depending on season and location (Marchant and Higgins 1993; Johnstone and Storr 1998). It breeds in trees, such as *Eucalyptus* spp., typically in the abandoned nests of crows and butcherbirds (Marchant and Higgins 1993; Johnstone and Storr 1998). Eggs have been recorded in July and August but its breeding season is not certain.

Likelihood of Occurrence: This species may occur within the study area, as suitable habitat is available.

Potential Impacts: Potential impacts are likely to be similar to that of the Peregrine Falcon, such as loss of potential nesting and foraging habitat. The conservation status of this species, if present in the study area, is unlikely to be affected by the proposal.

Ardeotis australis Australian Bustard
State: Priority 4

Distribution: The Australian Bustard occurs over much of Western Australia, with the exception of the more heavily wooded southern portions of the state (Johnstone and Storr 1998). Its wider distribution includes eastern Australia and New Guinea. This species is classified as Near Threatened by Garnett and Crowley (2000).

Ecology: This species prefers open or lightly wooded grassland including Triodia sandplains (Johnstone and Storr 1998) and is considered scarce to common depending on season and habitat. It has an omnivorous diet and occurs in a relatively broad range of habitats, but appears to have some preference for grasshoppers and is often attracted to recently burnt areas (Marchant and Higgins 1993). This species is typically nomadic and has a large home range (Marchant and Higgins 1993). This species breeds from March to September and the eggs are laid on bare, preferably stony, ground (Johnstone and Storr 1998), which makes the eggs and young vulnerable to predation by foxes and cats.

Likelihood of Occurrence: This species has previously been recorded in the vicinity of the study area (Ecologia 1995 and Ecologia 1998a), and is likely to occur periodically within the study area as suitable habitat is available.

Potential Impacts: Impacts would include loss of habitat and deaths of individuals, but are unlikely to make an impact on the conservation status of this species.

Burhinus grallarius Bush Stone-curlew
State: Priority 4

Distribution: This species is widespread in Australia and southern New Guinea. It remains common in tropical Australia, but has declined alarmingly in temperate Australia and has disappeared from many regions (Marchant and Higgins 1993). It is found in the Kimberley and western portion of the remainder of the state west of a line joining Port Hedland, Leonora and Albany.

Populations are apparently secure in the Pilbara (Ron Johnstone, WA Museum, pers. comm. 2003). The Australian population has been estimated at c. 15,000 individuals.

Ecology: The nocturnal Bush Stone-curlews inhabit sparsely grassed, lightly timbered forest or woodland. In southern Australia, they persist most often where there is a well-structured litter layer and fallen timber debris. Individuals have an estimated home range of about 250 ha (Johnson and Baker-Gabb 1993). Foxes are usually considered to be the primary cause for their decline, hence their relative abundance in the tropics, but habitat clearance has also been identified as a threatening process (Garnett and Crowley 2000).

Likelihood of Occurrence: This species may occur within the study area, as suitable habitat is available.

Potential Impacts: Impacts would include loss of habitat and deaths of individuals, but are unlikely to make an impact on the conservation status of this species.

Pseudomys chapmani Western Pebble-mound Mouse
State: Priority 4

Distribution: *Pseudomys chapmani* is confined to the central and eastern Pilbara including Karijini National Park (Menkhorst and Knight 2001). This species is found on stony hillsides with hummock grasslands (Menkhorst and Knight 2001) and is common to very common in suitable habitat within the Hamersley and Chichester subregions of the Pilbara bioregion.

Ecology: The Western Pebble-mound Mouse is well known for its behaviour of constructing extensive mounds of small stones covering areas from 0.5 to 9.0 square meters (Start 2008). This mound formation is most common on spurs and gentle slopes with suitable size class stones.

Likelihood of Occurrence: This species was recorded during the Billiard fauna survey. This species is likely to be found throughout the study area where suitable habitat is available.

Potential Impacts: Impacts would include loss of habitat and deaths of individuals, however given the broad distribution of the Western Pebble-mound Mouse and the habitats occupied by the species in the Pilbara, it is unlikely that the conservation status of this species will be affected by the current proposal.

Leggadina lakedownensis Short-tailed Mouse
State: Priority 4

Distribution: Since 1997, the number of records of this species has increased substantially, such that it has now been recorded from over 20 locations (Armstrong et al. in prep). In Western Australia the distribution includes the Pilbara and Kimberley regions (Menkhorst and Knight 2001). We have recorded this species on cracking clay communities from Cape Preston (60 km west of Dampier) in the west to the northern flanks of the Fortescue Marshes in the east (Halpern Glick Maunsell and Biota 2000).

A recent taxonomic revision of *Leggadina* (Cooper et al. 2003) found that despite morphological variation, *L. lakedownensis* are genetically similar across their range and the variation is insufficient to warrant subspecific status for any regional populations.

Ecology: Regional records suggest that the primary mainland habitat comprises areas of cracking clay and adjacent habitats, although this species has also been recorded from hill tops (Dr Peter Kendrick, DEC Karratha, pers. comm. 2003) and sandy coastal areas near Onslow (Mr Garth Humphreys, Biota, pers. obs.). At Cape Preston this species was recorded from *Acacia xiphophylla* open shrubland over a mosaic of *Triodia wiseana* and *Eragrostis xerophila* mixed hummock and tussock grassland (Halpern Glick Maunsell and Biota 2000). At the Southern Plains study site (near Tom Price), numerous individuals were recorded from *Acacia xiphophylla* shrubland over *Triodia longiceps* and annual grasses (Biota 2002a). Along the proposed Hope Downs rail alignment, this species was recorded from *Astrebla pectinata* tussock grassland (Biota 2002b). During the FMG Stage A rail corridor survey (Biota 2004), this species was recorded from

Astrebla pectinata, *Aristida latifolia* tussock grassland on the self-mulching clays at a similar location in the Chichester Range.

Likelihood of occurrence: Not recorded to date and considered unlikely to occur within the study area due to a lack of suitable habitat.

Potential Impacts: The conservation status of this species is unlikely to be affected by the proposal.

Macroderma gigas Ghost Bat
State: Priority 4

Distribution: Previously distributed across most of inland and northern Australia, but now restricted to the tropical north of the continent (Churchill 1998). Occurs in a broad range of habitats, with their distribution being influenced by the availability of suitable caves and mines for roost sites (Churchill 1998). The distribution of Ghost Bats is fragmented, with each population showing some genetic differentiation (Armstrong and Wilmer 2004; Biota 2004f; and Dr. Kyle Armstrong, pers. comm. 2004). Populations in the Pilbara bioregion appear to be isolated from those in the Kimberley and Northern Territory.

Ecology: Ghost Bats are efficient predators of small birds, mammals and reptiles, and large insects, and they have highly developed echolocation, visual and hearing systems (Churchill 1998). Vocalisations audible to humans are used in their complex social interactions (Churchill 1998). Bats forage over large distances (ranges of ~ 60 ha; Churchill 1998), and the size of their foraging area is probably inversely related to the productivity of their landscape. Bats are known to have overlapping ranges (Churchill 1998).

Scat material from *M. gigas* is quite distinctive and can be used to identify temporary roosts or feeding sites. Fairy Martin (*Hirundo ariel*) nests within culverts provide a roosting substrate for *M. gigas* and culverts may function either as a night or feeding roost or (probably less commonly) as a temporary day roost. This is an example of where man-made habitat has benefited bats (Biota 2002c).

Likelihood of Occurrence: As for the Pilbara Orange Leaf-nosed Bat, the gorge located in the Oxbow study area (OXB06E) may provide foraging opportunities for this species, but does not contain core roosting habitat. This species is unlikely to occur within the Billiard study area as suitable habitat is not available.

Potential Impacts: Possible loss or disturbance of roosting sites and foraging habitat. No effect on the conservation status of the species is expected.

6.4.3 Migratory and Marine Avifauna Species

Avifauna species can be listed as migratory and/or marine species under the *EPBC Act 1999*. Database searches completed for this study indicate the following species listed as Migratory under the act could occur in the study area: Rainbow Bee-eater, Night Parrot, Great Egret and Cattle Egret. The following species listed as Marine could also be present: Fork-tailed Swift, Great Egret, Cattle Egret, Oriental Plover and Rainbow Bee-eater. Of these taxa, only the Rainbow Bee-eater has been confirmed as occurring in the study area.

The proposed Yandicoogina Expansion is unlikely to adversely affect the conservation status of any of these species. Therefore they would not require further specific consideration as part of the assessment process.

6.5 Short-range Endemic (SRE) Fauna

The small number of invertebrate taxa collected during the survey may be considered indicative of the suitability of the available microhabitats for potential SRE taxa. A large proportion of the

study area comprising loamy substrates adjacent to the drainage line exhibited the detrimental effects of cattle.

The lack of ground level vegetation due to grazing or trampling by cows corresponds with low levels of leaf litter, which may otherwise provide habitat for such groups as millipedes (Diplopoda) and some trapdoor spiders (Mygalomorphae). Additionally, the high quantity of disturbance to open ground, and to vegetation by frequent burning, reduce the faunal values of the available habitats for target groups.

6.6 Conclusions

The fauna habitats and assemblages recorded for the Billiard study area during this fauna survey represent a subset of those that might be expected to occur across the Pilbara Bioregion. The fauna habitats in particular are considered to be widespread and common throughout the local area and within the wider region. Additionally, the relatively poor quality of the available habitats due to the presence of cattle and the frequency of fires reduces the value of the habitats for fauna that might typically be adversely affected by the proposed expansion.

On this basis, the expansion of existing operations at Yandicoogina is unlikely to adversely affect the conservation value of the fauna habitats and assemblages in the local area or wider Bioregion. Similarly, the development is not considered likely to detrimentally alter the conservation significance of those fauna species having elevated conservation significance, including Schedule and Priority listed fauna as well as SRE invertebrate fauna.

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Appendix 1

DEC Threatened Fauna Database Search Results

Threatened and Priority Fauna Database Page 1 of 2

22.3436 °S 118.7243 °E / 23.2377 °S 119.7228 °E Yandi area (plus ~50km buffer)

#	Date	Certainty	Seen	Location Name	Method

Schedule 1 - Fauna that is rare or is likely to become extinct

Dasyurus hallucatus **Northern Quoll** *1 records*

This carnivorous marsupial occurs across much of northern Australia with a disjunct population in the Pilbara. Occurs in a wide range of habitats but most suitable habitat appear to be rocky areas.

1980	1		NULLAGINE	

Liasis olivaceus barroni **Pilbara Olive Python** *1 records*

2004	1	1	Newman	Caught or trapped

Priority Two: Taxa with few, poorly known populations on conservation lands

Ctenotus uber johnstonei *1 records*

This species of skink is associated with small rock outcrops on open sandy and stony plains.

2001	1	2	Fortescue Valley	Caught or trapped

Priority Four: Taxa in need of monitoring

Macroderma gigas **Ghost Bat** *2 records*

This species is Australia's only carnivorous bat and has a patchy distribution across northern Australia. It shelters in caves, mine shafts and deep rock fissures and is sensitive to disturbance.

1998	1	1	West Angela Hill	Caught or trapped
2007	1	1	Newman	Caught or trapped

Pseudomys chapmani **Western Pebble-mound Mouse, Ngadji** *30 records*

This species is well-known for the characteristic pebble-mounds which it constructs over underground burrow systems. These mounds are most common on spurs and lower slopes of rocky hills.

1979	1	2	West Angela Hill	Caught or trapped
1979	1	2	West Angela Hill	Caught or trapped
1980	1	1	Marillana	Caught or trapped
1992	1	1	Packsaddle Hill	Caught or trapped
1993	1	1	The Governor	Caught or trapped
1994	1	0	Rhodes Ridge	Definite signs
1994	1	0	The Governor	Definite signs
1994	1	0	Weeli Wolli Creek	Definite signs
2001	1	1	Hamersley Range	Caught or trapped
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs
2006	1	0	Marillana	Definite signs

Friday, 3 October 2008

Department of Environment and Conservation

Threatened and Priority Fauna Database

22.3436 °S 118.7243 °E / 23.2377 °S 119.7228 °E Yandi area (plus ~50km buffer)

*	Date	Certainty	Seen	Location Name	Method
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs
	2008	1	0	Newman	Definite signs

Ardeotis australis **Australian Bustard** *3 records*

This species is uncommon and may occur in open or lightly wooded grasslands.

	2007	1	1	Newman	Day sighting
	2007	0	1	Newman	Day sighting
	2008	1	1	Newman	Day sighting

Burhinus grallarius **Bush Stonecurlew** *1 records*

A well camouflaged, ground nesting bird which prefers to 'freeze' rather than fly when disturbed. It inhabits lightly timbered open woodlands.

	2007	1	2	Newman	Day sighting

Neochima ruficauda subclarescens **Star Finch (western)** *1 records*

A nomadic species inhabiting grasslands and eucalypt woodlands near water.

	2008	1	1	Newman	Day sighting

Leiopotherapon aheneus **Fortescue Grunter** *1 records*

A species of freshwater fish restricted to the Prince Regent and Roe River systems of the Kimberley region of Western Australia. Inhabits open rocky pools with minimal aquatic vegetation.

		1		Karijini NP	

* Information relating to any records provided for listed species:-
Date: date of recorded observation
Certainty (of correct species identification): 1=Very certain; 2=Moderately certain; and 3=Not sure.
Seen: Number of individuals observed.
Location Name: Name of reserve or nearest locality where observation was made
Method: Method or type of observation

Department of Environment and Conservation

Appendix 2

WA Museum FaunaBase Search Results

Amphibia collected between
-22.5018, 118.8420 and -23.0666, 119.5959

Hylidae
Cyclorana maini
Litoria rubella

Myobatrachidae
Uperoleia russelli

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Birds collected between
-22.5018, 118.8420 and -23.0666, 119.5959

Acanthizidae
Gerygone fusca mungi

Caprimulgidae
Eurostopodus argus

Columbidae
Geopelia striata placida
Phaps chalcoptera

Pachycephalidae
Pachycephala rufiventris rufiventris

Ptilonorhynchidae
Ptilonorhynchus maculatus guttatus

Strigidae
Ninox connivens connivens
Ninox novaeseelandiae boobook

Turnicidae
Turnix velox

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Mammals collected between
-22.5018, 118.8420 and -23.0666, 119.5959

Dasyuridae
Dasykaluta rosamondae
Ningaui ridei
Ningaui timealeyi
Planigale sp
Pseudantechinus woolleyae
Sminthopsis macroura
Sminthopsis ooldea
Sminthopsis youngsoni

Emballonuridae
Saccolaimus flaviventris
Taphozous hilli

Macropodidae
Macropus robustus erubescens

Molossidae
Chaerephon jobensis
Mormopterus beccarii
Tadarida australis

Muridae
Mus musculus
Notomys alexis
Pseudomys chapmani
Pseudomys desertor
Pseudomys hermannsburgensis
Zyzomys argurus

Vespertilionidae
Chalinolobus gouldii
Chalinolobus morio
Nyctophilus bifax daedalus
Nyctophilus geoffroyi
Scotorepens greyii
Vespadelus finlaysoni

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Reptiles collected between
-22.5018, 118.8420 and -23.0666, 119.5959

Agamidae
Caimanops amphiboluroides
Ctenophorus caudicinctus caudicinctus
Ctenophorus isolepis
Ctenophorus isolepis gularis
Ctenophorus isolepis isolepis
Ctenophorus nuchalis
Ctenophorus reticulatus
Diporiphora valens
Lophognathus longirostris
Pogona minor
Pogona minor minor

Boidae
Antaresia perthensis
Liasis olivaceus barroni

Elapidae
Acanthophis wellsi
Brachyurophis approximans
Demansia psammophis cupreiceps
Parasuta monachus
Pseudechis australis
Pseudonaja modesta
Pseudonaja nuchalis
Suta fasciata

Gekkonidae
Diplodactylus conspicillatus
Diplodactylus pulcher
Diplodactylus savagei
Diplodactylus stenodactylus
Diplodactylus wombeyi
Gehyra pilbara
Gehyra punctata
Gehyra purpurascens

Gehyra variegata
Heteronotia binoei
Heteronotia spelea
Nephrurus wheeleri cinctus
Oedura marmorata
Rhynchoedura ornata
Strophurus elderi
Strophurus jeanae

Pygopodidae
Delma haroldi
Delma nasuta
Delma pax
Delma tincta
Lialis burtonis

Scincidae
Carlia munda
Cryptoblepharus carnabyi
Cryptoblepharus plagiocephalus
Ctenotus ariadnae
Ctenotus duricola
Ctenotus grandis titan
Ctenotus hanloni
Ctenotus helenae
Ctenotus pantherinus ocellifer
Ctenotus rubicundus
Ctenotus rutilans
Ctenotus saxatilis
Ctenotus schomburgkii
Ctenotus serventyi
Cyclodomorphus melanops melanops
Egernia depressa
Egernia formosa
Lerista bipes
Lerista labialis
Lerista muelleri
Lerista neander
Lerista zietzi
Menetia greyii
Menetia surda surda
Morethia ruficauda exquisita
Proablepharus reginae
Tiliqua multifasciata

Typhlopidae
Ramphotyphlops ammodytes
Ramphotyphlops ganei
Ramphotyphlops grypus
Ramphotyphlops waitii

Varanidae
Varanus acanthurus
Varanus brevicauda
Varanus caudolineatus
Varanus giganteus
Varanus gouldii
Varanus panoptes rubidus
Varanus pilbarensis
Varanus tristis tristis

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Appendix 3

EPBC Act 1999 Protected Matters Report

Matters of National Environmental Significance		
Threatened Species	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot	Endangered	Species or species habitat likely to occur within area
Mammals		
Dasyurus hallucatus Northern Quoll	Endangered	Species or species habitat may occur within area
Macrotis lagotis Greater Bilby	Vulnerable	Species or species habitat may occur within area
Rhinonicteris aurantius (Pilbara form) Pilbara Leaf-nosed Bat	Vulnerable	Community likely to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies)	Vulnerable	Species or species habitat may occur within area
Migratory Species	Status	Type of Presence
Migratory Terrestrial Species		
Birds		
Merops ornatus Rainbow Bee-eater	Migratory	Species or species habitat may occur within area
Pezoporus occidentalis Night Parrot	Migratory	Species or species habitat likely to occur within area
Migratory Wetland Species		
Birds		
Ardea alba Great Egret	Migratory	Species or species habitat may occur within area
Ardea ibis Cattle Egret	Migratory	Species or species habitat may occur within area

Other Matters Protected by the EPBC Act		
Listed Marine Species	Status	Type of Presence
Birds		
Apus pacificus Fork-tailed Swift	Listed – overfly marine area	Species or species habitat may occur within area
Ardea alba Great Egret	Listed – overfly marine area	Species or species habitat may occur within area
Ardea ibis Cattle Egret	Listed – overfly marine area	Species or species habitat may occur within area
Charadrius veredus Oriental Plover	Listed – overfly marine area	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater	Listed – overfly marine area	Species or species habitat may occur within area

Appendix 4

DEC Regulation 17 “Licence to take fauna for scientific purposes” SF006426

DEPARTMENT OF ENVIRONMENT AND CONSERVATION

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PAGE 1
NO. SF006426

RECEIPT NO. **AMOUNT**
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WILDLIFE CONSERVATION ACT 1950
REGULATION 17

LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

DIRECTOR GENERAL

CONDITIONS

1 THE LICENSEE SHALL COMPLY WITH THE PROVISIONS OF THE WILDLIFE CONSERVATION ACT AND REGULATIONS AND ANY NOTICES IN FORCE UNDER THIS ACT AND REGULATIONS.

2 UNLESS SPECIFICALLY AUTHORISED IN THE CONDITIONS OF THIS LICENCE OR OTHERWISE IN WRITING BY THE DIRECTOR GENERAL, SPECIES OF FAUNA DECLARED AS LIKELY TO BECOME EXTINCT, RARE OR OTHERWISE IN NEED OF SPECIAL PROTECTION SHALL NOT BE CAPTURED OR OTHERWISE TAKEN.

3 NO FAUNA SHALL BE TAKEN FROM ANY NATURE RESERVE, WILDLIFE SANCTUARY, NATIONAL PARK, MARINE PARK, TIMBER RESERVE OR STATE FOREST WITHOUT PRIOR WRITTEN APPROVAL OF THE DIRECTOR GENERAL. NO FAUNA SHALL BE TAKEN FROM ANY OTHER PUBLIC LAND WITHOUT THE WRITTEN APPROVAL OF THE GOVERNMENT AUTHORITY MANAGING THAT LAND.

4 NO ENTRY OR COLLECTION OF FAUNA TO BE UNDERTAKEN ON ANY PRIVATE PROPERTY OR PASTORAL LEASE WITHOUT THE CONSENT IN WRITING OF THE OWNER OR OCCUPIER, OR FROM ANY ABORIGINAL RESERVE WITHOUT THE WRITTEN APPROVAL OF THE DEPARTMENT OF INDIGENOUS AFFAIRS.

5 NO FAUNA OR THEIR PROGENY SHALL BE RELEASED IN ANY AREA WHERE IT DOES NOT NATURALLY OCCUR, NOR HANDED OVER TO ANY OTHER PERSON OR AUTHORITY UNLESS APPROVED BY THE DIRECTORGENERAL, NOR SHALL THE REMAINS OF SUCH FAUNA BE DISPOSED OF IN SUCH MANNER AS TO CONFUSE THE NATURAL OR PRESENT DAY DISTRIBUTION OF THE SPECIES.

6 THIS LICENCE AND THE WRITTEN PERMISSION REFERRED TO AT CONDITIONS 3 & 4 MUST BE CARRIED BY THE LICENSEE OR AUTHORISED AGENT AT ALL TIMES FOR THE PURPOSE OF PROVING THEIR AUTHORITY TO TAKE FAUNA WHEN QUESTIONED AS TO THEIR RIGHT TO DO SO BY A WILDLIFE OFFICER, ANY OTHER STATE OR LOCAL GOVERNMENT EMPLOYEE OR ANY MEMBER OF THE PUBLIC.

**********ANY INTERACTION INVOLVING GAZETTED THREATENED FAUNA THAT MAY BE HARMFUL AND/OR INVASIVE MAY REQUIRE APPROVAL FROM THE COMMONWEALTH DEPT OF THE ENVIRONMENT AND WATER RESOURCES, PHONE 02 6274 1900. INTERACTION WITH SUCH SPECIES IS CONTROLLED BY THE COMMONWEALTH GOVERNMENT'S "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999" & "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION REGULATIONS 2000" AS WELL AS DEC'S WILDLIFE CONSERVATION ACT & REGULATIONS.**********

8 NO BIOPROSPECTING INVOLVING THE REMOVAL OF SAMPLE AQUATIC AND TERRESTRIAL ORGANISMS (BOTH FLORA AND FAUNA) FOR CHEMICAL EXTRACTION AND BIOACTIVITY SCREENING IS PERMITTED TO BE CONDUCTED WITHOUT SPECIFIC WRITTEN APPROVAL BY THE DIRECTOR GENERAL OF DEC.

9 FURTHER CONDITIONS (NUMBERED TO) ARE ATTACHED.

PURPOSE BASELINE FAUNA INVENTORY SURVEY OF YANDI JUNCTION SW AND BILLIARDS FOR IMPACT ASSESSMENT.

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DATE OF ISSUE 30/06/2008
VALID FROM 01/07/2008
DATE OF EXPIRY 30/06/2009

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Appendix 5

Bat Call Identifications

Specialised Zoological

Bat call identification

from Yandi, WA

Type:	Bat Call Analysis
Prepared for:	Biota Environmental Sciences
Date:	10 April 2009
Job No.:	SZ098
Prepared by:	Specialised Zoological Kyle Armstrong and Yuki Konishi ABN 92 265 437 422 0404 423 264 kyle.armstrong@graduate.uwa.edu.au kyle.n.armstrong@gmail.com

SZ098: *Bat call identification from Yandi, WA*

SUMMARY

Bat identifications from Anabat echolocation call recordings are provided from Yandi, Western Australia. Six species were identified as being present (Table 1).

The calls of the yellow-bellied sheath-tailed bat *Saccolaimus flaviventris* can sometimes be confused with those of the northern free-tailed bat *Chaerephon jobensis*. In all cases the calls appeared to be from *S. flaviventris*.

Details supporting the identifications are provided, as recommended by the Australasian Bat Society (ABS 2006). A summary of pulse parameters is provided in Table 2, and representative call sequences are illustrated in Figure 1. Further data is available should verification be required.

METHODS

Signals as recorded with Anabat SD1 and Anabat II – CF-ZCAIM units were supplied as downloaded sequences, which were examined in AnalookW 3.7a software. Three call variables were measured on good quality search phase pulses in representative call sequences: pulse duration (milliseconds), maximum frequency (kHz) and characteristic frequency (equivalent to minimum frequency; kHz). Species were identified based on information in McKenzie and Muir (2000). Nomenclature follows Armstrong and Reardon (2006).

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Armstrong, K. and Reardon, T. (2006). Standardising common names of bats in Australia. *The Australasian Bat Society Newsletter* 26: 37–42.

McKenzie, N.L. and Muir, W.P. (2000). Bats of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement 61: 465–477.

TABLE 1. Species identifications, with the degree of confidence indicated by a code. Date correlates with site; see Table 2 for full species names.

Date	Site	*C. gouldii*	*S. flaviventris*	*S. greyii*	*T. australis*	*T. georgianus*	*V. finlaysoni*
Serial 683							
8/07/2008	BILANA01	H	H	—	—	—	H
Serial 3709							
8/07/2008	YANBAT01	H	H	—	—	—	H
9/07/2008	YANBAT01	H	H	—	H	—	H
10/07/2008	YANBAT01	H	H	—	H	H	H
11/07/2008	YANBAT01	H	—	—	—	H	H
Serial 3726							
8/07/2008	OXBANA01	—	—	—	—	H	H
9/07/2008	OXBANA01	—	—	—	—	H	H
10/07/2008	OXBANA01	H	—	H	—	H	H

Definition of confidence level codes:

H High. Unambiguous identification of the species at the site based on measured call characteristics and comparison with available reference material. Greater confidence in this ID would come only after capture and supported by morphological measurements or submission of a specimen/tissue to a museum.

NC Needs Confirmation. Either call quality was poor, or the species cannot be distinguished reliably from another that makes similar calls. Alternative identifications are indicated in the Summary section of this report. If this is a species of conservation significance, further survey work might be required to confirm the record.

TABLE 2. Summary of variables from representative call sequences.

Species	s,p[1]	Duration (msec)[2]	Max Frequency (kHz)[2]	Char frequency (kHz)[2]
Gould's wattled bat *Chalinolobus gouldii*	1,8	6.5 ± 2.3 3.2 – 10.3	35.8 ± 0.7 34.8 – 37.0	31.8 ± 1.5 30.3 – 34.6
Yellow-bellied sheath-tailed bat *Saccolaimus flaviventris*	2,18	9.1 ± 2.6 2.3 – 12.5	20.1 ± 2.4 16.2 – 23.3	17.9 ± 1.3 15.6 – 20.8
Little broad-nosed bat *Scotorepens greyii*	2,25	3.5 ± 0.8 1.6 – 4.8	59.0 ± 5.1 47.3 – 66.7	36.5 ± 1.1 34.9 – 38.7
White-striped free-tailed bat *Tadarida australis*	1,10	8.1 ± 1.5 5.9 – 9.9	19.0 ± 1.7 16.5 – 21.2	13.7 ± 1.0 11.9 – 15.2
Common sheath-tailed bat *Taphozous georgianus*	3,22	9.0 ± 2.1 5.7 – 13.5	25.9 ± 1.0 24.5 – 28.1	23.8 ± 0.3 23.3 – 24.4
Finlayson's cave bat *Vespadelus finlaysoni*	4,100	4.8 ± 0.8 0.4 – 7.6	65.1 ± 5.0 54.8 – 83.3	54.3 ± 0.7 52.6 – 55.9

[1] s,p: number of sequences measured, combined total number of pulses measured;

[2] Mean ± SD; range.

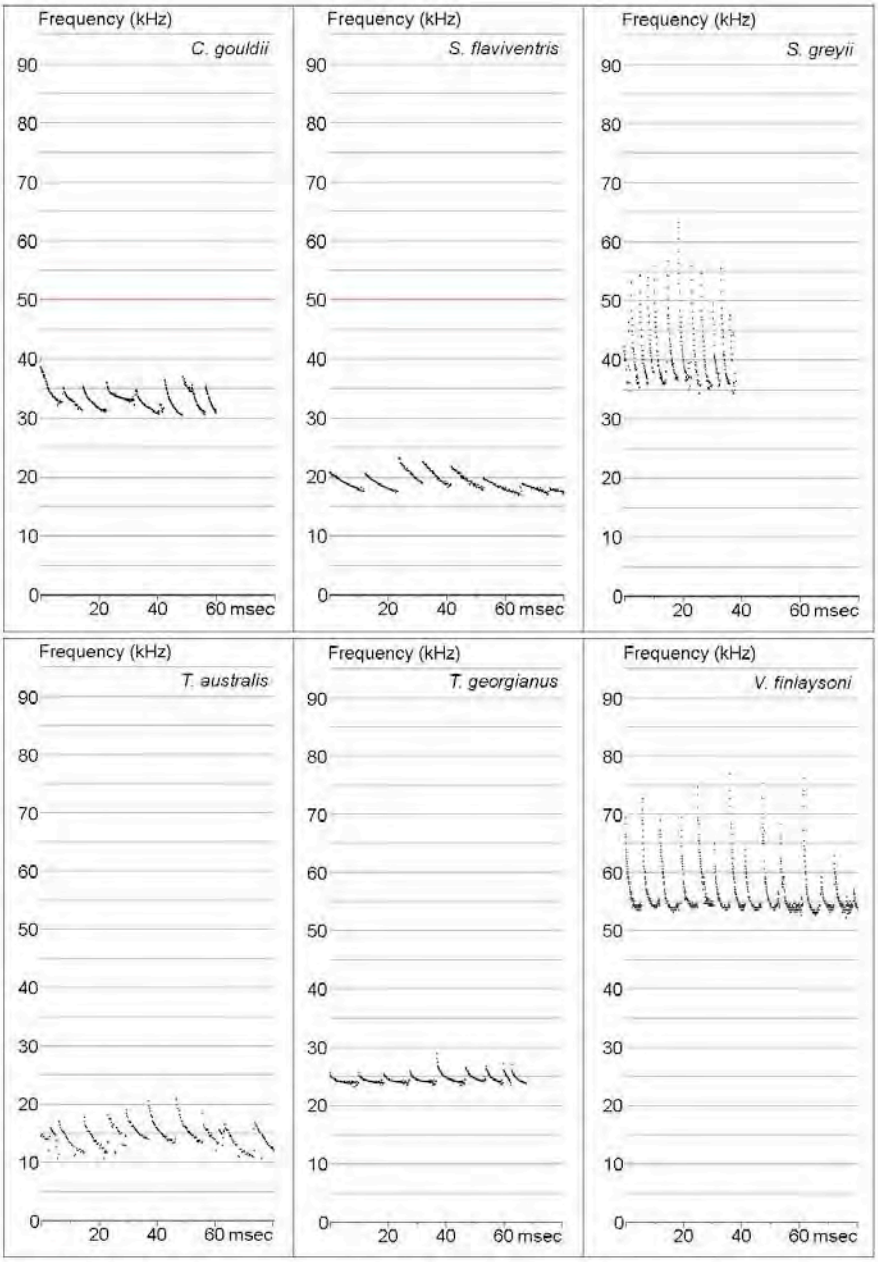

FIGURE 1. Representative call sequences of the six species identified (time is compressed between pulses).

Understanding Riparian Vegetation Responses to Groundwater Drawdown and Discharge from Below Water Table Mining in the Pilbara

Report for Rio Tinto Iron Ore

July 2015

Judy Eastham

Understanding Riparian Vegetation Responses to Groundwater Drawdown and Discharge from Below Water Table Mining in the Pilbara

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		Method	Date
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Final	Judy Eastham	email	28th July 2015

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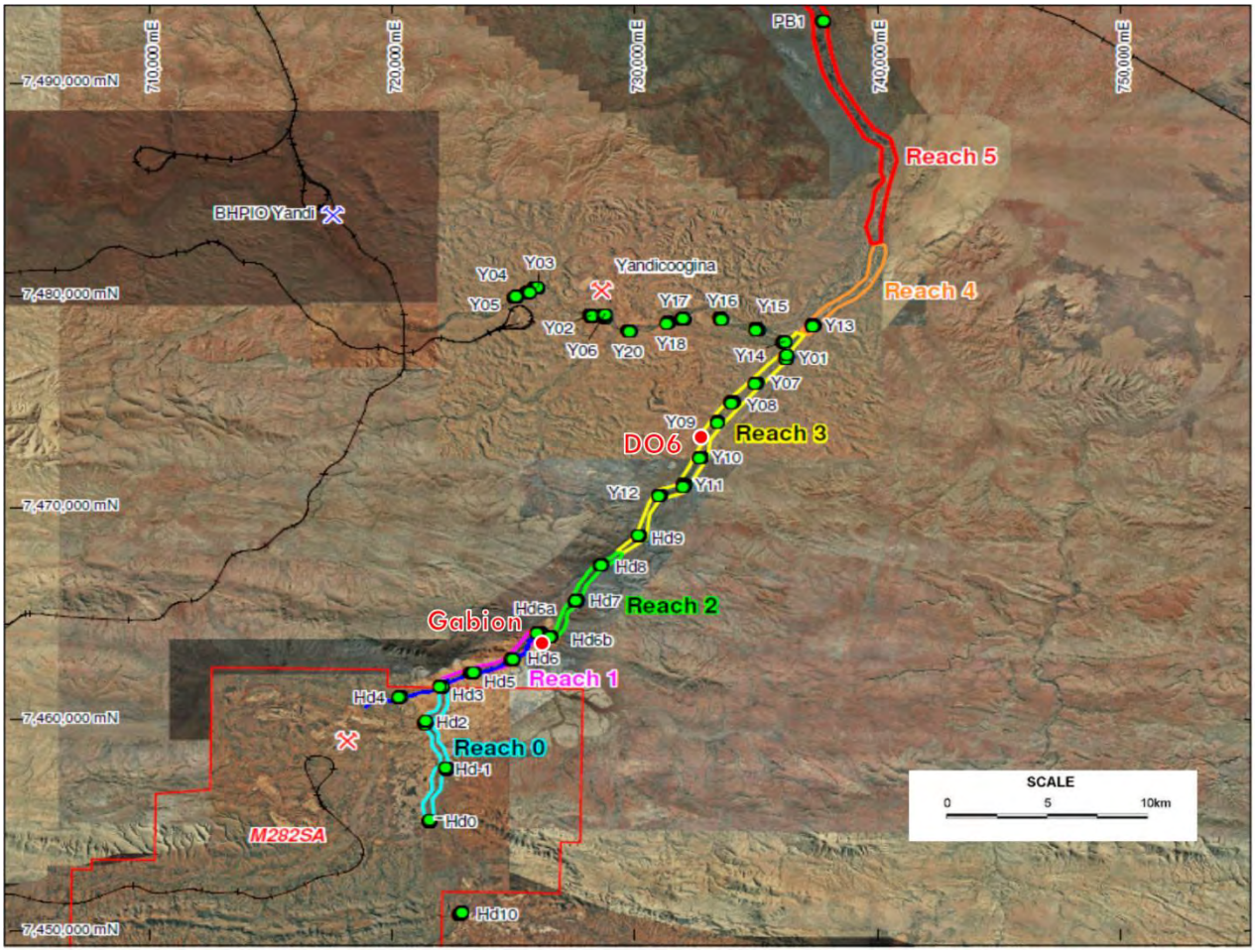
SUMMARY

This study collated and analysed relevant data and information on the response of riparian vegetation along Weeli Wolli Creek to drawdown and discharge associated with below water table mining activities at the Hope Downs 1 (HD1) and Yandicoogina (Yandi) mine sites (Figure 1). The aim was to undertake a comprehensive study to identify and better understand the mechanisms underlying the system's response to dewatering, and water discharges based on the integration of existing data. Understanding of these mechanisms and where they are operating in different parts of the system are important for predicting and managing the short and long-term impacts of dewatering and discharge.

Quarterly tree health monitoring data collected by digital canopy photography monitoring of crown and foliage cover was used to assess vegetation responses between October 2006 and December 2014. Data was collected at 26 sites distributed along Weeli Wolli Creek, including 3 reference sites assumed unaffected by drawdown or discharge (Figure 1). Some sites were located within the zone experiencing groundwater drawdown due to dewatering operations at HD1 and Yandi. Others were located downstream of two discharge outlets into Weeli Wolli Creek, the gabion and discharge outlet six (DO6, Figure 1). The species monitored were *Eucalyptus camaldulensis* and *victrix,* the most common tree species along the creek. More limited foliage and crown cover data was also available for *Melaleuca argentea* collected between June 2010 and December 2014.

Long-term rainfall and streamflow data sourced from the Department of Water (DoW) was collated and analysed to context post-impact rainfall and flows against historical norms. Discharge and reinjection data was sourced from Rio Tinto and analysed to quantify discharge rates and cumulative volumes for intervals between tree health monitoring. Transects of bores relevant to understanding the hydrological impacts of dewatering, discharge and reinjection on water levels beneath tree health monitoring sites were identified and all available data was accessed and collated. For sections of Weeli Wolli Creek where bore data was unavailable, water levels were estimated using river stage data from DoW. Since bores and river gauges were generally not located at tree health monitoring sites, estimated levels beneath these sites were derived by interpolation between adjacent monitoring points. These interpolations enabled estimation of depth to water at monthly intervals for the majority of tree health monitoring sites. Depth to water wasn't estimated for sites between the Tarina gauging station and bores at Yandi, because of the large distance between these monitoring points which increased uncertainty over the validity of interpolations. Relationships between foliage cover and rainfall, streamflow, discharge and depth to water were investigated using linear regression analyses.

Figure 1: Location of reaches and tree health monitoring plots on Weeli Wolli Creek. The figures also shows the location of discharge outlets at the gabion and DO6



Operations at both HD1 and Yandi mine sites impacted on hydrological parameters significant for riparian vegetation along Weeli Wolli Creek. Drawdown associated with dewatering at both sites reduced both groundwater levels and water levels in the alluvium. The disposal of water extracted by dewatering by reinjection into a borefield at Yandi and as discharge into Weeli Wolli Creek from the gabion and DO6 increased levels in the alluvium.

Substantial variation in foliage cover found between sites prior to the start of dewatering and discharge are indicative of the inherent variability of the riparian vegetation associated with Weeli Wolli Creek. Initial foliage covers in October 2006 ranged from 0.33 to 0.61 with a coefficient of variation of 14.7%. Foliage cover also exhibited temporal variation associated with seasonal conditions. For example, foliage cover at reference site HD0 ranged from 0.41 and 0.54 with a coefficient of variation of 8.5% for the period of monitoring.

Impacts of dewatering on groundwater levels at HD1 were observed to extend about 6.5 km downstream along Weeli Wolli Creek and about 6.4 km upstream. The significance and extent of influence of drawdown at Yandi on levels relevant for riparian vegetation along

Weeli Wolli Creek couldn't be readily assessed because impacts were confounded by discharge and reinjection.

Analyses of long-term rainfall and streamflow data downstream of the gabion at the Tarina station suggest that streamflow has increased disproportionately in years after the start of discharge. However streamflow at Waterloo Bore, downstream of both discharge outlets and the Marillana Creek confluence, remains unaffected by cumulative impacts of discharge from BHP Billiton and Rio Tinto Iron Ore operations at HD1 and Yandi. This supports the thesis that cumulative impacts of mining operations in Weeli Wolli catchments have not altered hydrological conditions at the Fortescue Marsh further downstream.

At sites closest to the dewatering bore field at HD1, groundwater was found to be at depths ranging from 3.7 to 11.5 m prior to dewatering, potentially accessible to tree roots. In response to dewatering at these sites, groundwater levels fell by more than 30 m. Foliage cover responses to drawdown were quite site-specific and confounded in places by changes in surface water hydrology. It was concluded that the *Eucalyptus* species studied were resilient to drawdown if surface water availability was maintained. Foliage cover of eucalypts in areas of drawdown was responsive to supplemental irrigation via a spur system. However, the data suggests that spur discharge may have over-compensated for any reduced water availability caused by drawdown. It is possible that *Eucalyptus* species have been over-irrigated such that enhanced foliage cover is in disequilibrium with water available under undisturbed conditions. This has implications for the cessation of spur discharge and the transition back to an unmanaged system.

A preliminary analysis of water levels in the alluvial aquifer suggests that both the frequency and duration of streamflow in unirrigated parts of Weeli Wolli Creek upstream of the gabion were reduced by drawdown. Thus falling water levels exert a dual influence through decreasing the accessibility of water from the saturated zone, and decreasing availability from unsaturated alluvium. Given this significance, an important consideration in understanding impacts of drawdown on vegetation health is adequate monitoring of depth to water as well as streamflow responses and water availability in the unsaturated zone.

Responses in eucalypt foliage cover to discharge indicate variable impacts of discharge on tree health. Foliage cover at sites downstream of the gabion showed statistically significant negative responses to gabion discharge rates or to cumulative discharges. Impacts extended as far as site HD9, approximately 6.2 km downstream of the gabion. However, sites beyond this point remained unaffected by impacts of HD1 discharge from the gabion. Closer to Yandi operations, foliage cover at all sites downstream of DO6 to Y13 were negatively impacted by discharge. Foliage cover showed statistically significant negative

responses to discharge rates and cumulative volumes. The greater impact on foliage cover of discharges at Yandi results from generally shallower water tables in the alluvium compared with sites impacted by HD1 discharge alone. Relationships between foliage cover and depth to water showed statistically significant reductions in foliage cover with rising levels at sites Y08 and Y01. However, the response of individual trees at a site wasn't uniform, and at most of the sites there were some trees that increased their foliage cover. This finding has significance since it suggests that a proportion of trees at each site occupy an ecological niche which has allowed them to maintain or increase their canopy. Trees maintaining or increasing foliage cover tended to be at higher elevations at some, but not all, sites.

The negative impacts of discharge on foliage cover of *Eucalyptus* species at some sites was supported by other responses observed in this study. In contrast with the generally positive responses in foliage cover to annual rainfall and streamflow observed for reference and drawdown sites, foliage cover at discharge sites was not enhanced in years with greater annual rainfall or streamflow. Foliage cover was either unresponsive or showed trends of declining foliage cover as annual rainfall and streamflow increased, suggesting conditions of water excess could be detrimental to cover. Lower foliage cover found at the start of this study for eucalypts at sites with perennial flow compared with annual sites was also indicative of negative responses to shallow water tables.

In contrast to the decline in foliage cover with cumulative discharge, a stress index calculated from qualitative assessments of tree condition for *Eucalyptus* species on vegetation survey transects at discharge sites showed no decrease with cumulative discharge. Where monitoring sites were in close proximity, there was no correlation between foliage cover and stress index parameters. These findings suggest that eucalypts selected for foliage cover monitoring may not be representative of trees across the riparian zone at each site location. Trees monitored for foliage cover may represent the more severely-affected trees, with vegetation monitoring transects better capturing responses of eucalypts across the riparian zone.

In this study, the trend in decreasing foliage cover with cumulative discharge observed for several discharge sites cannot be consistently attributed to rising water levels. Further investigation to establish with greater certainty the water levels at each site may confirm whether or not this is the key factor causing decline. Foliage cover responses to cumulative discharge may not be simply due to waterlogging, but could also relate to indirect effects of discharge e.g. through increasing disease, unknown impacts of precipitate or changing soil

chemistry and plant nutrition. If waterlogging isn't identified as the key determinant of foliage cover decline, further studies are warranted to understand the underlying mechanisms behind the decrease in foliage cover with cumulative discharge. Improved understanding of factors contributing to foliage cover decline will both inform management decisions and facilitate the prediction of discharge impacts from future below water table operations.

There is little evidence from this study to support differential responses of *E. victrix* or *E. camaldulensis* to drawdown, discharge or to rising water levels. However, the capacity to undertake a systematic comparison of their respective responses in this study was limited by the small number of trees of a species sampled at some sites (ie unequal replication).

Understanding responses of *Melaleuca argentea* to drawdown is limited in this study by the short timeframe of monitoring (June 2010 to December 2014) and the minimal drawdown (< 0.7 m) experienced over the monitoring period. Responses to irrigation by spur discharge may have also confounded melaleuca foliage cover response to drawdown. None of the components of melaleuca health monitored by digital canopy photography (foliage cover, crown cover and canopy cover) were found to be responsive to changing depth to water. The significance of discharge for the health of *Melaleuca argentea* is also unclear from this study, principally because of contrasting responses in foliage cover, crown cover and canopy cover to discharge. Further studies are warranted to understand the responses in foliage cover, crown cover and canopy cover of Melaleucas and to identify which parameter best represents their condition.

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1. INTRODUCTION

Dewatering and discharge to allow mining below the water table has been implemented at Rio Tinto Hope Downs 1 mine site since 2007. In subsequent years, substantial bodies of data relating to vegetation health, ground and surface water hydrology has been collected for compliance and other purposes. Further relevant datasets include long-term rainfall and streamflow records collected for catchments of Marillana and Weeli Wolli Creeks by the Department of Water (DoW).

This investigation integrates relevant existing data and information to identify and better understand the mechanisms underlying ecosystem response to dewatering, and water discharges. Understanding of these mechanisms and where they are operating in different parts of the ecosystem are important for predicting the short and long-term impacts of discharges in Weeli Wolli, Yandi and other river systems associated with below water table deposits. It is also important for managing water discharges as effectively as possible to meet the constraints of mining below the water table, whilst minimising impacts to the environment, including cumulative impacts.

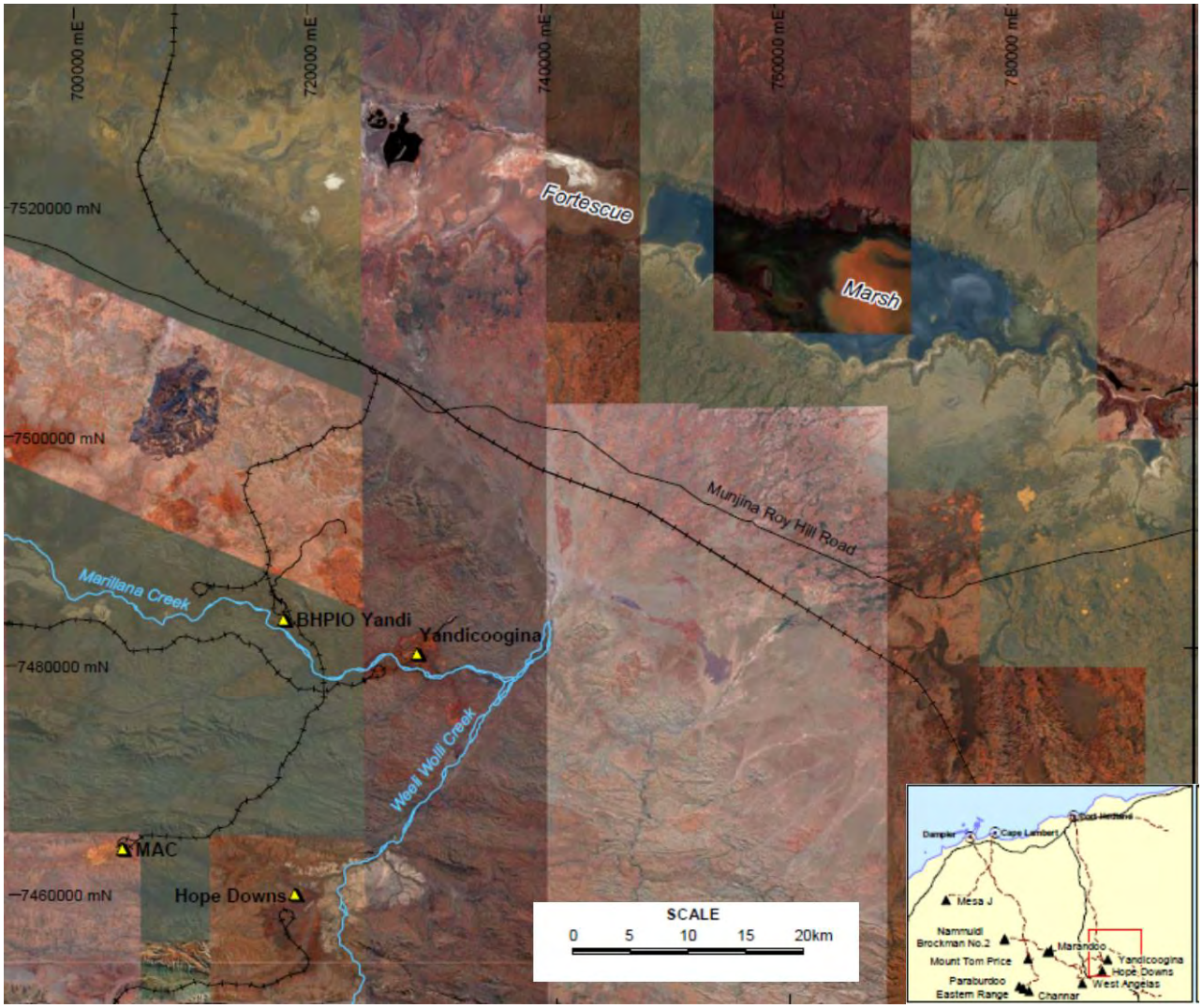
2. METHODOLOGY

2.1. Study location and background

Potential impacts of groundwater drawdown associated with mine site dewatering were investigated at the Hope Downs 1 (HD1) and Junction South East (JSE) deposit of the Yandicoogina (Yandi) mine site in the Eastern Pilbara (Figure 2). At these sites, water extracted and not used on site is discharged into the Weeli Wolli Creek system. At Yandi, a portion of this surplus water is disposed of through aquifer reinjection. Long-term discharge of water into tributaries of Weeli Wolli Creek has occurred since BHP Billiton commenced discharging into Marillana Creek as early as 1998. Dewatering associated with mining of various deposits associated with Rio Tinto's Yandi mine site has also resulted in discharges into Marillana Creek in subsequent years.

Weeli Wolli Creek has particular ecological significance in the arid Pilbara region because of the occurrence of Weeli Wolli Springs. These groundwater springs generate perennial streamflow which extends downstream of the creek for a distance of approximately 4 km. Flow in the creek is ephemeral upstream of the spring and beyond the zone of persistent groundwater discharge. Following intense, cyclonic rainfall events, flow from Weeli Wolli Creek extends north where it drains into the Fortescue River via Fortescue Marsh approximately 40 km downstream of the source of the spring.

Figure 2: Location of the study on Weeli Wolli Creek and Hope Downs 1 and Yandicoogina mine sites



Other than groundwater drawdown and discharge, open pit mining and the diversion of Pebble Mouse Creek, a tributary of Weeli Wolli Creek, away from the mine pit will impact on the hydrology of the creek.

2.2. Dewatering and Discharge at Hope Downs 1 and Yandi

This study investigated potential impacts of discharges from two separate locations associated with HD1 and Yandi dewatering. Surplus volumes of water generated by dewatering at HD1 are discharged from a discharge outlet at the gabion downstream of the mine site on Weeli Wolli Creek (Figure 1). Discharge from dewatering of Junction South East (JSE) flows from discharge outlet 6 (DO6) into Weeli Wolli Creek upstream of the confluence with Marillana Creek (Figure 1).

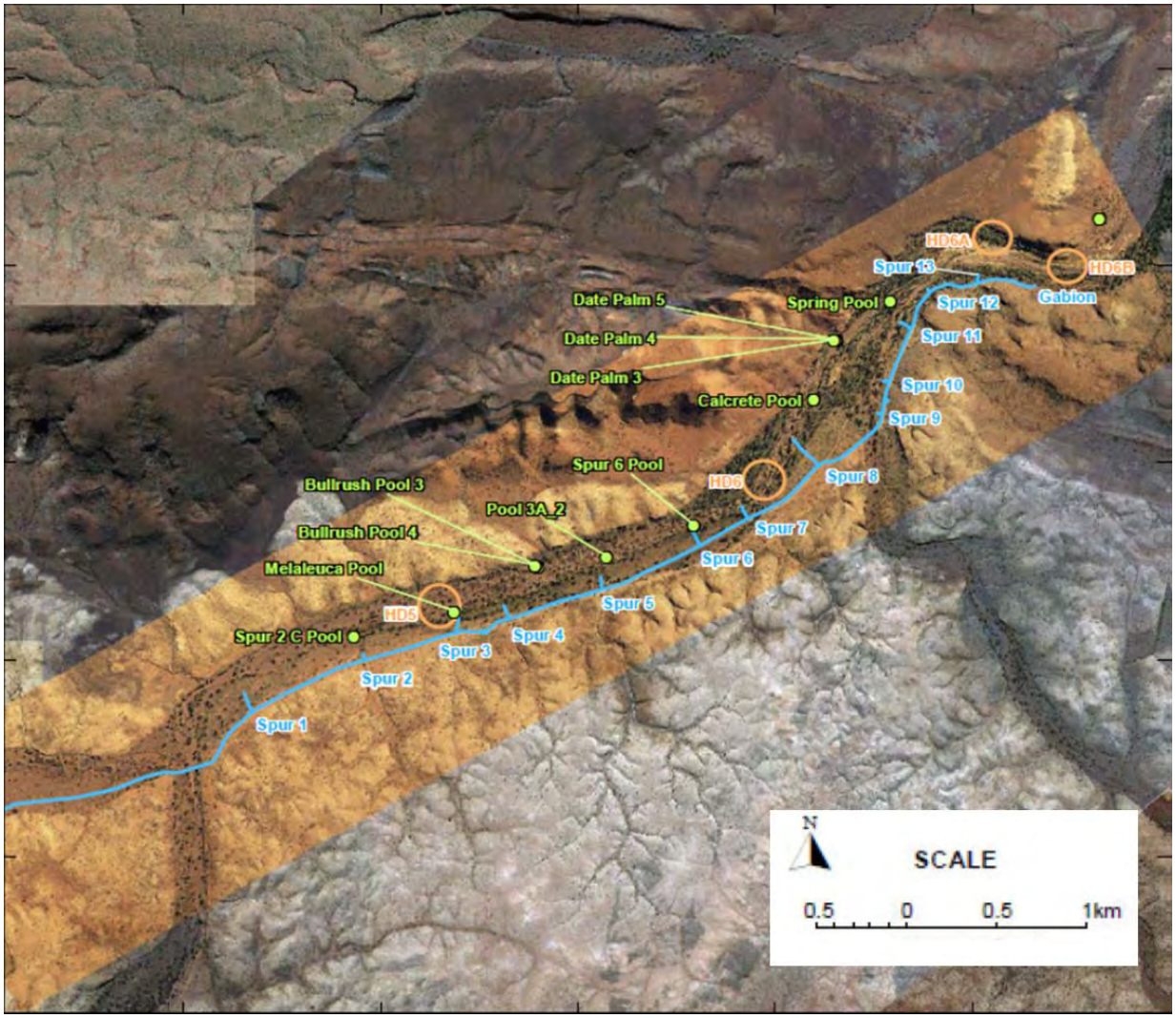
Rio Tinto Iron Ore have delineated sections of Weeli Wolli Creek into 6 separate reaches characterised by differences in their original flow regime and potential impacts of groundwater drawdown, discharge or supplemental irrigation (Figure 1). Reach 0 includes

the ephemeral section of the creek upstream of Weeli Wolli Springs, and potentially affected by groundwater drawdown from the adjacent HD1 mine. Reach 1 and 2 comprise sections of the creek encompassing the springs and pools which generally experienced perennial flows. Reach 1 is also potentially affected by groundwater drawdown, and contains the spur discharges to apply supplemental irrigation. Reach 2 is downstream of Weeli Wolli Springs and potentially affected by HD1 discharge from the gabion. Reach 3 formerly experienced ephemeral flows. For the purposes of this study, Reach 3 was subdivided into 2 sections to delineate sites subject to HD1 discharge only (Reach 3a), and sites downstream of DO6 which also received Yandi discharge (Reach 3b). Parts of Reaches 3a and 3b in proximity to the southern dewatering bore field of JSE were also potentially affected by dewatering. Reach 4 comprises a section of creek downstream of the confluence with Marillana creek. This reach would have historically experienced ephemeral flows, but has also been subject to potential impacts of long-term discharges into Marillana creek. This reach is also subject to potential impacts of combined discharges from HD1 and Yandi including those into both Weeli Wolli and Marillana Creeks. Reach 5 comprises a section of the creek extending beyond the surface expression of discharge and extending downstream towards the Fortescue Marsh.

A series of spurs were installed in the vicinity of Weeli Wolli Spring to provide supplemental irrigation to vegetation which included species assumed groundwater dependent. Water from the spurs also maintained the presence of pools and spring flow (Figure 3). The system discharges water from 13 spurs which can be controlled separately to vary flow rates or to stop discharging. The spurs became operational and water was discharged from February 2007.

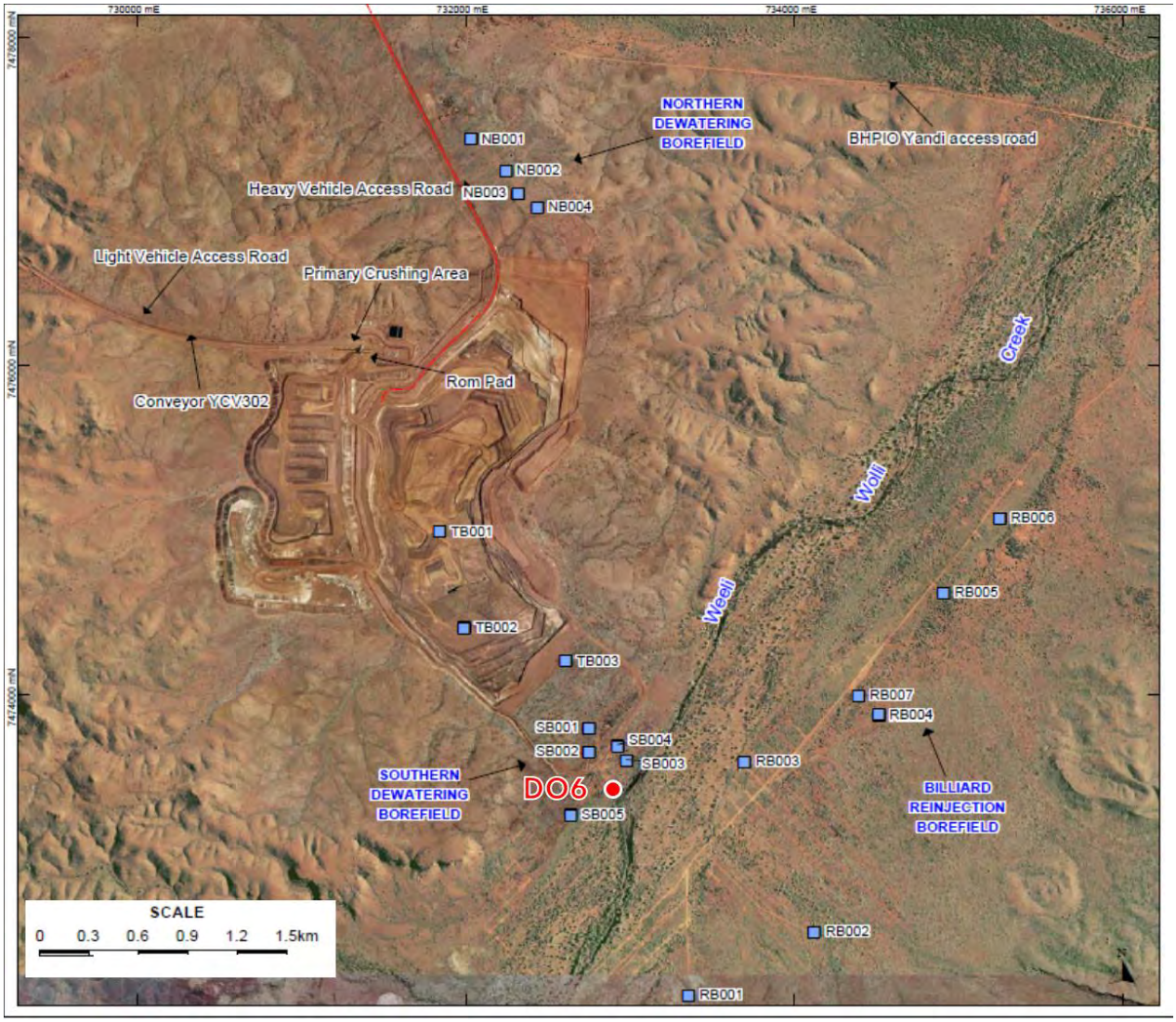
Monthly discharge from the gabion, DO6 and spurs were collated into total wet (October-April) and dry (May-September) season discharge volume for each year.

Figure 3: Location of the gabion discharge outlet and spurs in the springs area of Weeli Wolli Creek. The location of pools and tree health monitoring plots HD5, HD6, HD6a, HD6b, HDM1 and HDM2 are also shown



Bore fields installed at Yandi to dewater Junction South East (JSE) were located in the vicinity of Weeli Wolli Creek, with the Southern Borefield located immediately adjacent to the creek to the northwest (Figure 4). On the opposite side of the creek to the southeast, the Billiard Reinjection borefield was installed to reinject surplus water into the aquifer. DO6 was also located in the vicinity, adjacent to the Southern Borefield. Thus dewatering, reinjection and discharge operations at Yandi each occurred in close proximity to Weeli Wolli Creek.

Figure 4: Location of dewatering bore fields and Billiard Reinjection bore field in the vicinity of Weeli Wolli Creek at Yandi. The location of discharge outlet 6 into Weeli Wolli Creek (DO6) is also shown.

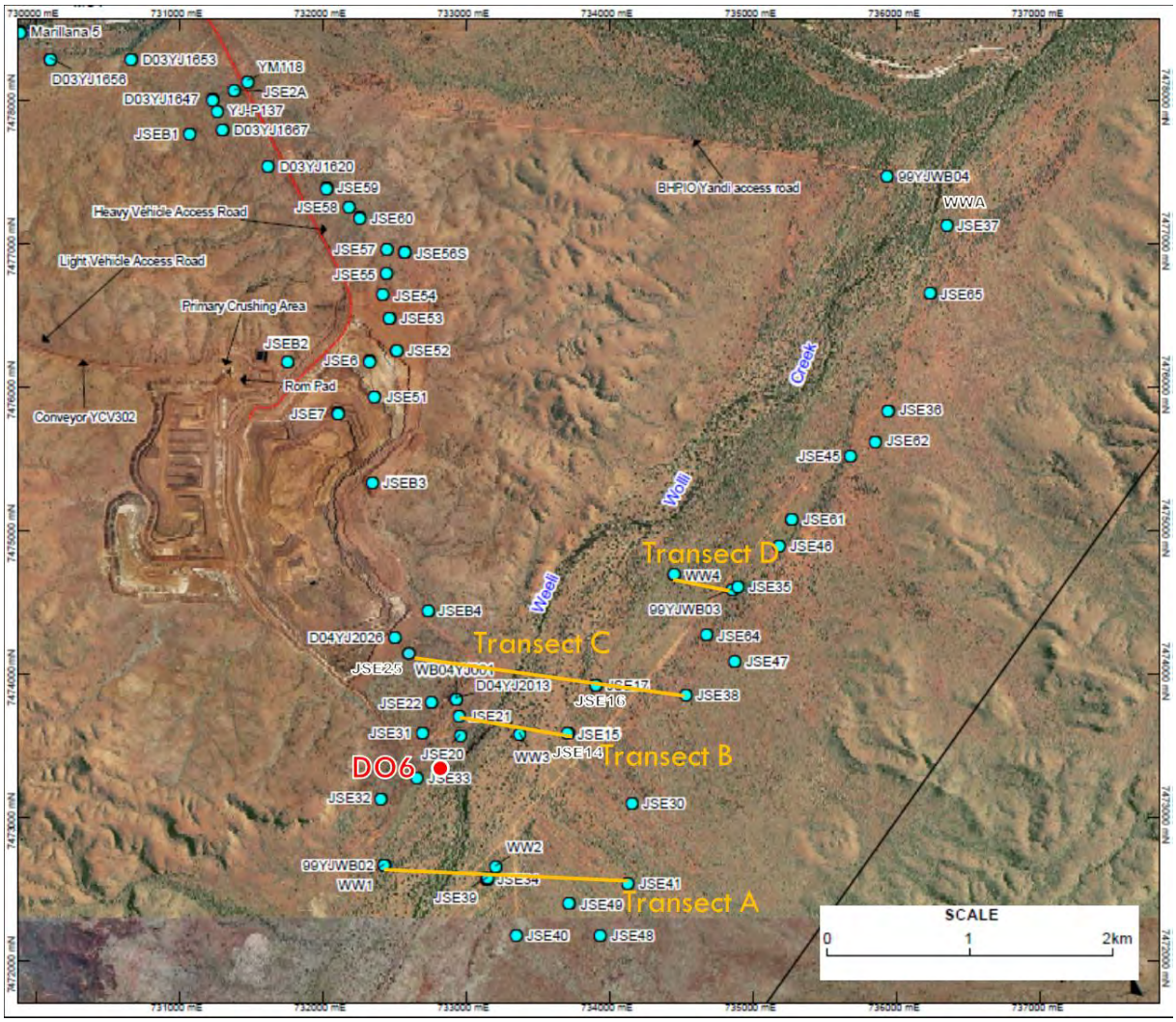


To investigate whether water levels in the alluvium experienced by riparian vegetation were primarily influenced by reinjection, dewatering or discharge, differences between relative levels in the alluvials and CID were examined for four transects across the creek (Transects A, B, C and D) at different locations (Figure 5). Where reinjection caused relative levels to be higher in the CID than in the alluvium, it was concluded that the hydraulic gradient was towards the creek, and that water from reinjection was influencing creek levels. Conversely where levels were higher in the alluvium than the CID as a result of dewatering of the CID or discharge into the creek (or both), it was concluded that hydraulic gradients were away from the creek and that discharge was influencing creek levels.

This analysis of the influence of reinjection, discharge and dewatering on levels in the alluvium is intended to be indicative only. Transects of bores investigated weren't formally installed for the purpose, and thus aren't perfectly aligned on a straight line, normal to the

creek. As a result of any misalignment some will be slightly further up- or downstream than others, possibly resulting in small differences in levels unrelated to any management impacts. So the analysis below generally disregards small differences in levels. Any inference that hydraulic gradients generate flows into or out of the alluvium assumes that the CID and alluvial aquifers are hydraulically connected. Assessing the magnitude and hence the significance of any flows towards or away from the creek would also require knowledge of the hydraulic conductivities of each aquifer, and a reliable estimation of the gradient. Such an analysis is beyond the scope of the present study.

Figure 5: Location of transects of bores in the CID and alluvial aquifers examined to assess the influence of dewatering, discharge and reinjection on water levels in the alluvium along Weeli Wolli Creek at Yandi.



2.3. Vegetation monitoring

Two key vegetation monitoring datasets were used to evaluate the impacts of groundwater drawdown and discharge on vegetation health. These included digital canopy photography (DCP) monitoring of crown and foliage cover by Rio Tinto staff, and vegetation survey data collected by Mattiske Consulting.

2.3.1. Digital Canopy Photography

Data from digital canopy photography (DCP) monitoring of crown and foliage cover by Rio Tinto staff was used to evaluate the impacts of groundwater drawdown and discharge on vegetation health. Foliage and crown cover data was available for *eucalyptus* species at 19 sites distributed along Weeli Wolli Creek (HD1 to HD9; Y07 to Y12, Y01 and PB1, Figure 1), and at 3 reference sites assumed unaffected by drawdown or discharge (HD0, HD10 and PB1). The species monitored were *E. camaldulensis* and *E. victrix,* selected at random when monitoring sites were established. For 14 of the eucalypts monitored, trees were identified as either *E. camaldulensis* or *E. victrix*, but the particular species remained unconfirmed. Foliage cover data was also available for *Melaleuca argentea* collected at 3 sites on Weeli Wolli Creek (HDM1 to HDM3) and at another reference site (HDM0).

When plots were established, 2 permanent photo locations were selected for each sample tree and marked by stakes. The monitoring technique and methods for image analysis are described more fully in McFarlane *et al*. (2007). Analyses of digital images allowed estimation of crown cover (Crc, defined as % of ground area covered by the vertical projection of crowns, assuming the crowns to be solid) and foliage cover (Fc, defined as the percentage of ground area covered by the vertical projection of foliage and branches). Canopy cover (Cc, defined as the percentage of ground area covered by the vertical projection of foliage and branches within the perimeter of crowns of individual plants) for canopies within each image each was subsequently calculated from Crc and Fc.

Monitoring commenced in October 2006 for all eucalypt monitoring sites and was subsequently carried out at approximately quarterly intervals in February/March; May/June; September/October and November/December each year until December 2014. Exceptions were the reference sites HD10 and PB1 which began in June 2009, and Y12 which began in February 2007. Monitoring at Melaleuca sites began in June 2010. Ten trees were typically monitored at sites associated primarily with Hope Downs 1 operations HD0 to HD9; HDM1 to HDM3 and at reference sites HDM0, HD10 and PB1. The exceptions were sites HD6a and HD6b where 5 trees were monitored until June 2010 when an additional 5 trees were included for monitoring. Twelve trees were typically monitored at sites associated with Yandi operations Y07 to Y12 and Y01. Exceptions were sites Y09 and Y01 where 6 and 15 trees, respectively, were monitored. No data for any sites were available for quarter 4 2008.

During the course of the monitoring period, stakes marking photo points were occasionally lost due to flood events or other disturbances, resulting in missing data points. In order to minimize the impact of missing data on the calculated mean, data was infilled where possible. When only one monitoring point was missing from a particular tree, missing data was infilled assuming the same percentage change measured for the other monitoring point for that tree over the time interval. Where both monitoring points were missing, data was infilled assuming a percentage change equivalent to the average change measured for the remaining live trees monitored at that site over the same time interval.

This study primarily sought to investigate changes with time in foliage cover in response to natural variation and management impacts, so data from the additional 5 trees at sites 6a and 6b monitored in June 2010 were excluded from all analyses to avoid any influence of a change in sampling regime on mean foliage cover for the sites. For the same reason, data for the entire monitoring period was excluded when sample trees were occasionally lost or badly damaged due to fire or clearing. Data for 3 sample trees from site HD2 and 4 from HD7 were excluded because of impacts of fire at these sites in March 2007 and February 2009 respectively. Data from three sample trees which were inadvertently felled in HD1 were also excluded. Data for one tree from Y10 and for 3 trees from Y13 were missing from the entire dataset without explanation.

When a tree died without any obvious cause other than potential impacts, the cover value for the image containing only branches and stems, measured at the next monitoring date, was entered for all subsequent monitoring dates.

2.3.2. Vegetation survey data collected by Mattiske consulting

Vegetation survey data from Mattiske consulting was used to investigate changes in foliage cover for different lifeforms, and changes in the degree of stress experienced by eucalypts at sites exposed to discharge. Site locations, sampling frequency and methods are described in Mattiske consulting reports (Mattiske, 2014). The different categories used for the qualitative assessment of tree stress were assigned numerical values. These were dead = 1; very stressed = 2; stressed = 3; slightly stressed = 4 and healthy = 5. A mean stress index for eucalypt species in each transect was subsequently calculated from the mean of these numerical values at each monitoring date. Stress indices for *E. camaldulensis* or *E. victrix* at sites subject to HD1 and Yandi discharge and for regional reference sites on Weeli Wolli Creek, Coondiner Creek and Mindy Mindy Creek were subsequently calculated from the mean of relevant vegetation transects.

2.3.3. Elevation of tree sites

The co-ordinates and elevation of stakes installed to map photo points for each of the trees monitored was downloaded from the Tree health monitoring Mapinfo layer. The data was used to calculate a mean elevation for each site.

2.3.4. Statistical analyses

The statistical significance of impacts on tree health under conditions of varying water availability due to drawdown or discharge was investigated by statistical analyses. 2-way Repeated Measures Analysis of Variance (RM ANOVA) was used to assess whether foliage cover responses differed significantly between sites or whether temporal changes observed were significant. Data was tested for sphericity and the Greenhouse and Geisser correction applied. Since RM ANOVA revealed statically significant responses, further 2-way and 1-way ANOVAs were used to investigate these differences in more detail. Where ANOVA revealed factors as significant, Tukey-testing was used to test the significance of differences between individual means.

To investigate the impacts of management, sites were grouped according to the water management regime applied (drawdown or discharge) and whether flow was historically typically ephemeral or perennial. The treatment groupings were sites HD1, HD2, HD3 & HD4 (drawdown ephemeral); HD5, HD6, HD6a (drawdown perennial); HD6b, HD7, HD8 (HD1 discharge perennial); HD9, Y12, Y11, Y10 (HD1 discharge ephemeral); Y09, Y08, Y07, Y01 (Yandi discharge ephemeral).

Analyses were also carried out to investigate whether differences in the distribution of *E. victrix* and *E. camaldulensis* between ephemeral and perennial sections of the creek were statistically significant. 2 sample T-tests were carried out using data on the number of each species sampled at THM sites located in each section.

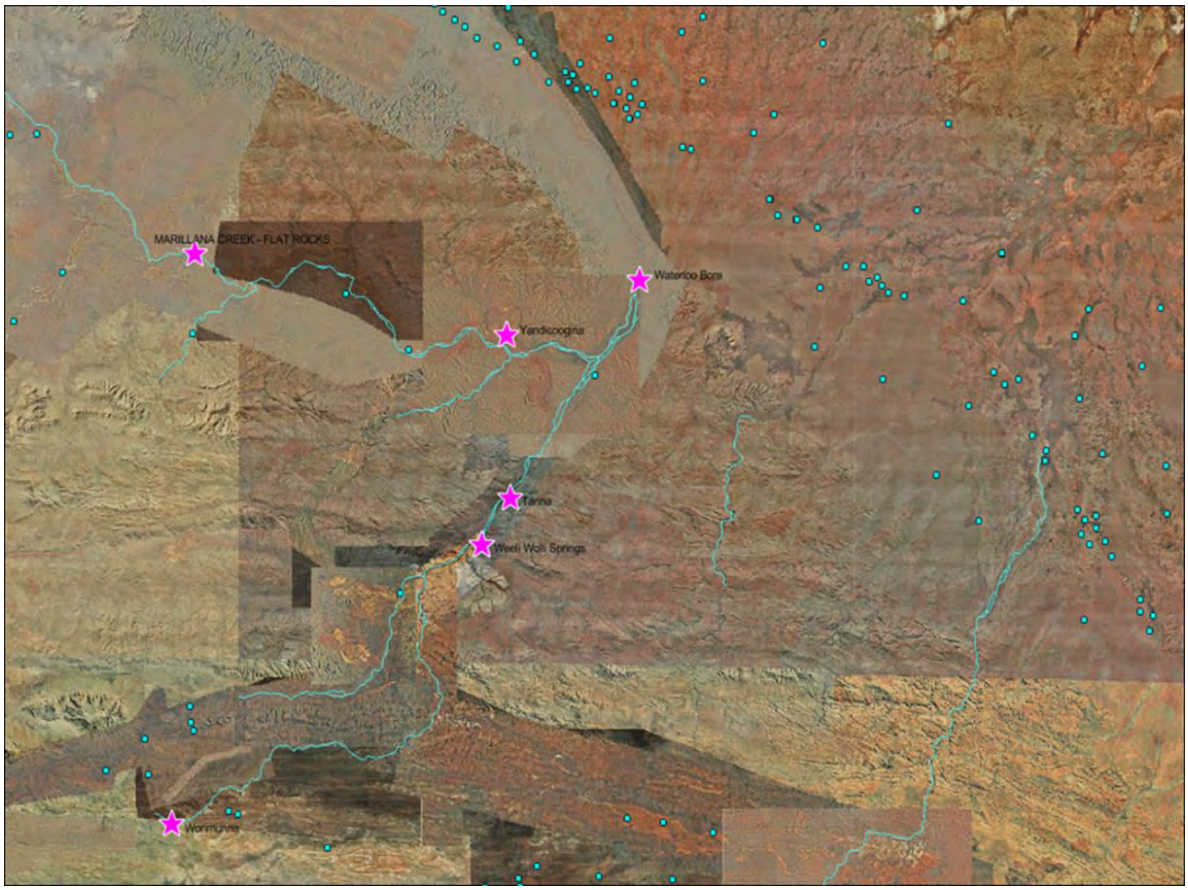
All differences reported following statistical analyses were significant at the 5% probability (or greater) level of significance.

2.4. Rainfall and streamflow

All daily rainfall, river stage and streamflow data available to December 2014 for the Weeli Wolli Springs, Tarina, Waterloo Bore and Flat Rocks stations (Figure 6) were accessed from the Department of Water (Hydstra database - time-series data accessed 31/01/2015. Department of Water (DoW), Water Information section, Perth, Western Australia). Streamflow is estimated from water level elevation (stage) at these stations. Some of the

recent data accessed had not been validated by DoW, but was assumed of adequate quality for the purposes of this study. Data was analysed to derive monthly and annual totals for rainfall and streamflow for each of the catchments. Wet and dry season rainfall and streamflow totals were also calculated, assumed to comprise the months of October to April (wet season) and May to September (dry season). These intervals were selected to be synchronous with quarterly vegetation monitoring. Annual rainfall and streamflow data for all years available without missing data were ranked for each year from 2006. Annual streamflow was plotted as a function of annual rainfall for the Tarina and Waterloo Bore catchments. Data from prior to and post 2006 were plotted separately to investigate any potential impacts of discharge or groundwater drawdown on rainfall-runoff relationships.

Figure 6: Location of Department of Water rainfall and streamflow monitoring stations on Weeli Wolli and Marillana Creeks.



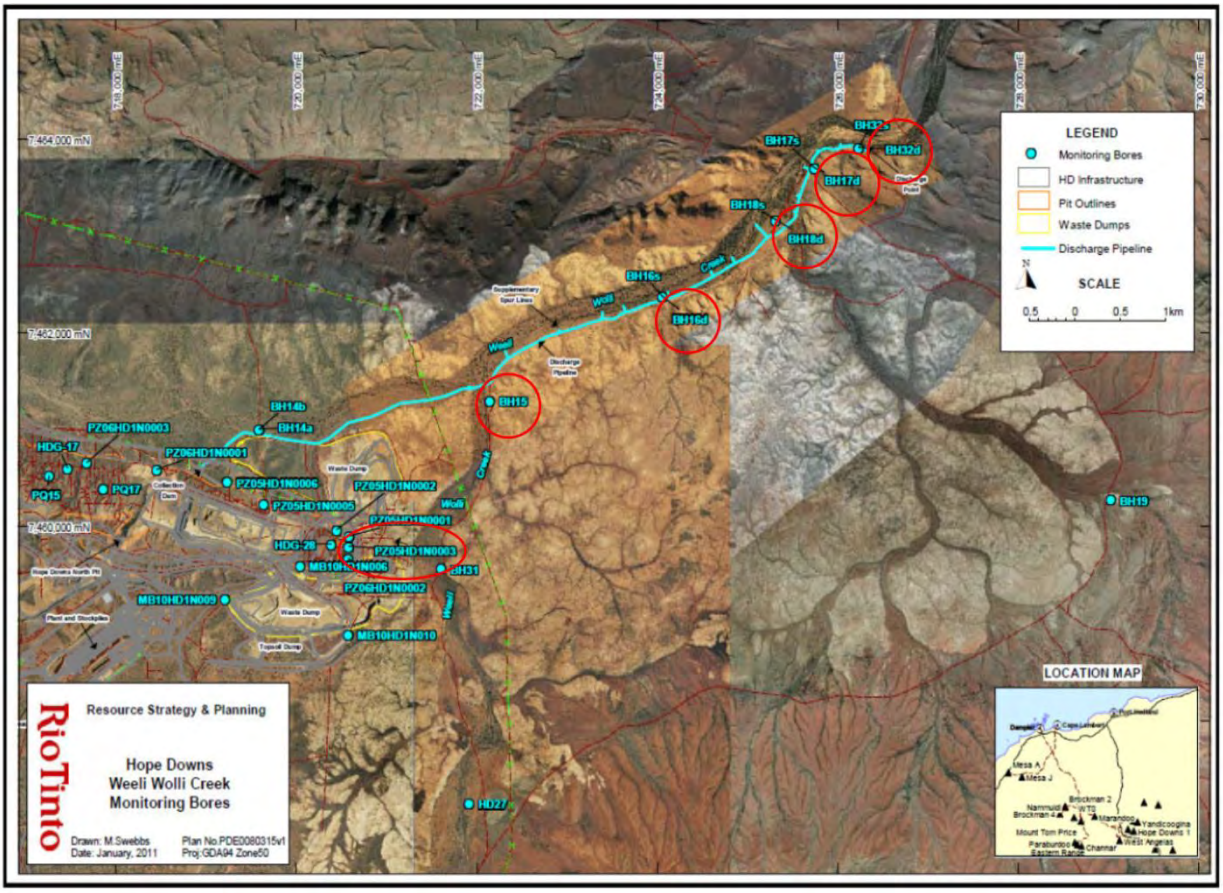
2.5. Surface and groundwater levels at vegetation monitoring sites

We used water levels from bore data and estimated from DoW river stage data to estimate the depth to water for each of the vegetation monitoring sites. Since water level generally wasn't measured at each site, this required interpolation between water levels measured on transects along the creek at varying distances from dewatering and discharge. The bore and river data used for these interpolations is described below.

2.5.1. Bore selection

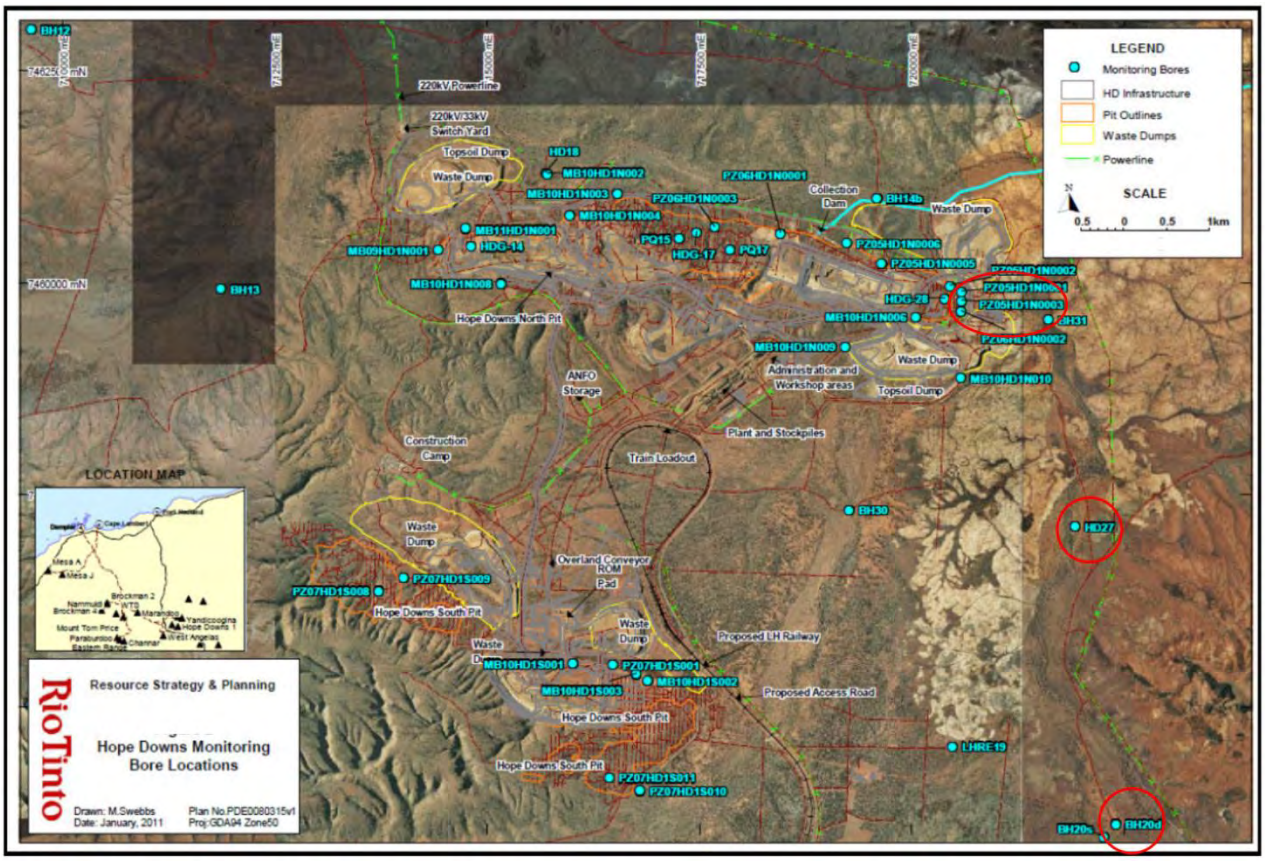
Rio Tinto's Mapinfo layer showing bore locations was scrutinised to identify bores in the proximity of Weeli Wolli Creek relevant to investigating the impacts of groundwater drawdown and discharges on vegetation health. Once potential bores were identified, data from all these bores were downloaded from EnviroSys, and examined to check for data availability extending over the study period from October 2006 to December 2014. A transect of bores (Transect 1, Figure 7) was identified that extended upstream along Weeli Wolli Creek from adjacent to dewatering at HD1 to close to the gabion. The transect included bores PZ05HD1N0003; BH15; BH16d; BH18d; BH17d and BH32d.

Figure 7: Location of bores on Transect 1 from adjacent to the dewatering borefield at PZ05HD1N0003 to just upstream of the gabion at BH32d. Transect bores are circled in red.



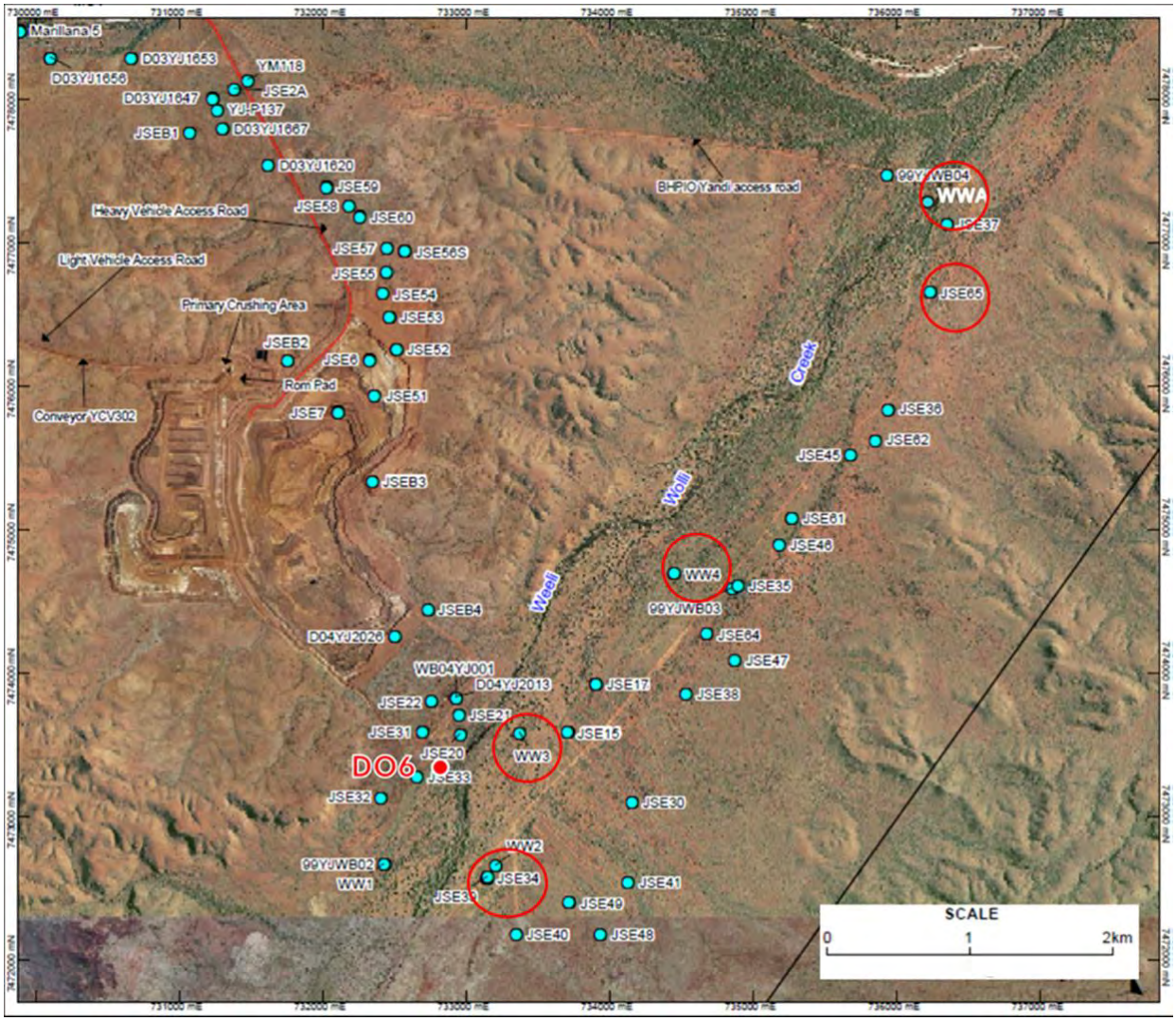
A second transect of bores extending south from dewatering along the creek (Transect 2) was identified including bores PZ05HD1N0003; HD27 and BH20d (Figure 8). There were no bores available between the gabion and just upstream of DO6 discharges at Yandi (Figure 1). However, there were a large number of bores associated with the dewatering of JSE to the northwest of the creek and the reinjection borefield to the southeast which were examined for data availability.

Figure 8: Location of bores on Transect 2 from PZ05HD1N0003 extending south upstream along Weeli Wolli Creek and including bores HD27 and BH20d. Transect bores are circled in red.



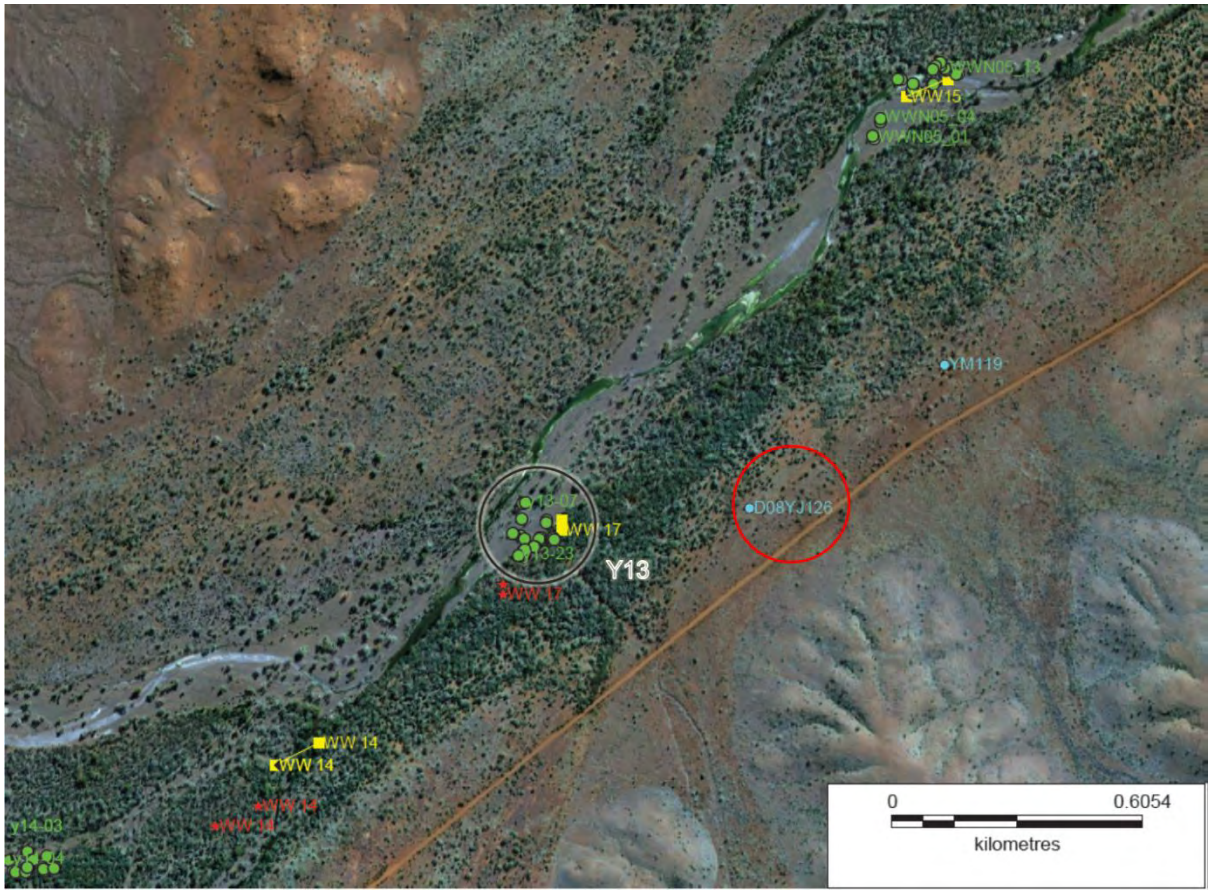
A series of alluvial bores extended along this section of the creek to the confluence with Marillana Creek. Bores (WW1; JSE14; JSE16; JSE34; WW2, WW3, WW4, JSE65; and WWA) were located at varying distances from and on both sides of the creek. Bores closest to the creek with adequate data availability over the study period were selected for further analyses to estimate water levels at monitoring sites (JSE34; WW3, WW4, JSE65 and WWA, Figure 9).

Figure 9: Location of alluvial bores at Yandi selected for inclusion on Transect 3. Transect bores are circled in red.



No alluvial bores were identified downstream of the confluence with Marillana Creek. Levels in CID bore D08YJ126 were used to represent levels relevant for tree health monitoring site Y13 downstream of the Marillana confluence (Figure 10). The CID and alluvial aquifers were assumed hydraulically connected at this location, since levels in D08YJ126 responded to discharge and to the passage of surface water expression of water in the creek.

Figure 10: Location of bore D08YJ126 (circled in red), adjacent to tree health monitoring site Y13.



2.5.2. Water levels at river gauging stations

In the absence of bores between the gabion and JSE34, stage levels from DoW gauging stations at Tarina and Weeli Wolli springs were used to estimate surface water levels for this section of the creek. Water levels at these gauges were surveyed on 17/04/2015 and are shown in Table 1. The stage reading for the Tarina gauge was simultaneously accessed from the DoW website which provides real time monitoring of water level and stage data for the Tarina station. (http://kumina.water.wa.gov.au/waterinformation/telem/stage.cfm). Stage data was not available online for the decommissioned Weeli Wolli Springs gauge, so this stage was estimated from a relationship between Weeli Wolli Springs and Tarina stage data derived for times when Tarina stage readings were close to 10.602 m in February 2008.

Table 1: River stage and water level at Tarina and Weeli Wolli Springs on 17/04/2015

	Surveyed Level (mAHD)	*Stage (m)*
Tarina	522.071	10.602
Weeli Wolli Springs	544.798	10.466

Establishing an elevation datum for Tarina and Weeli Wolli Springs river stages on 17/04/2015 allowed estimation of water levels from all stage data available for these stations. The relationship between water levels at Tarina and Weeli Wolli Springs was used to estimate water levels at Weeli Wolli Springs from Tarina levels for dates after the decommissioning of the station. A combination of bore and river level data was used to estimate water levels on Transect 3 which extended from a bore immediately upstream of the gabion (BH32s) to the confluence with Marillana Creek (WWA). Transect 3 incorporated bores BH32s; JSE34; WW3, WW4, JSE65 and WWA (Figure 9) as well as Weeli Wolli Springs and Tarina levels (Figure 6).

2.5.3. Estimating water levels at vegetation monitoring sites

For Transects 1 & 2, the distance from dewatering was estimated as the distance from the bore PZ05HD1N0003 immediately adjacent to dewatering bores. Distance from dewatering was estimated for all bores and vegetation monitoring sites on these transects. Distance from the gabion was estimated for all bores, river stations and vegetation monitoring sites on Transect 3.

Mean monthly water level (mAHD) was calculated from data from each of the bores or river stations along Transects 1 to 3. Where water level data was missing for a bore in any month, water levels were estimated from the level measured in a bore from a similar locality demonstrating a similar response. To do this, relationships between water levels measured in each of the bores over periods with concurrent data were derived by regression analyses. Only regressions with a correlation coefficient significant at the 5% probability level (or greater) were used to estimate missing data. Once datasets of monthly water levels were complete, monthly (2-dimensional) water level contours were originally derived by cubic spline interpolation of water level (mAHD) as a function of distance from dewatering (Transects 1 and 2) or distance from the gabion (Transect 3). However this method of interpolation did not appear to represent well water levels of some sites close to existing bores. Linear interpolation was subsequently used to estimate monthly water levels beneath each vegetation site. The mean elevation of each vegetation site was then used to estimate monthly values for depth to the water table beneath each site. Temporal means in depth to water table for months between each monitoring date were calculated for each site from monthly estimates. For example, the mean of monthly depth to water table for September, October and November was used to represent depth to water for the period between September and November monitoring.

2.5.4. Hydrological Modelling

A simple spreadsheet model was used to simulate streamflow in Weeli Wolli catchments using monthly climate and streamflow data (Kirby *et al.* 2010). A preliminary calibration of the model was undertaken and results presented below.

2.5.5. Relationships between vegetation health and water availability parameters

Relationships between foliage cover and different parameters relating to water availability were investigated using linear regression analyses. Parameters investigated were rainfall, streamflow, discharge and depth to water where these data were available and relevant to conditions at the site. Linear regression was used simply to identify whether or not the response in foliage cover to any of these variables was statistically significant at each site. Where correlation coefficients were statistically significant, the r^2 value shown with the regression equation on the appropriate figure below was annotated with an asterisk (*). Where the correlation coefficient wasn't found to be statistically significant, the r^2 value was annotated with NS (not significant).

3. RESULTS

3.1. Rainfall and streamflow

3.1.1. Rainfall

Annual rainfall for DoW Flat Rocks, Tarina and Waterloo Bore stations are shown below in Figure 11. Mean annual rainfall is also shown for each station for comparison with annual totals. Gaps in the data for any year imply missing data for part of that year making an annual total unavailable. Rainfall records were longest for the Flat Rocks station with the first complete year of data collected in 1974, and complete records available from 1986 for Waterloo Bore and Tarina stations.

As would be expected in Pilbara region, annual rainfall was highly variable for all 3 stations. Annual trends were generally similar for all stations with high or low rainfall conditions experienced in the same years at each station. Vegetation monitoring by DCP commenced in October 2006. That year represented a very high rainfall year at all stations, being the highest on record at Tarina. This was followed by a 4-year period of below-average rainfall from 2007 to 2010, with Tarina rainfall in 2010 being the lowest on record.

Figure 11: Annual rainfall for DoW stations Flat Rocks, Tarina and Weeli Wolli Bore

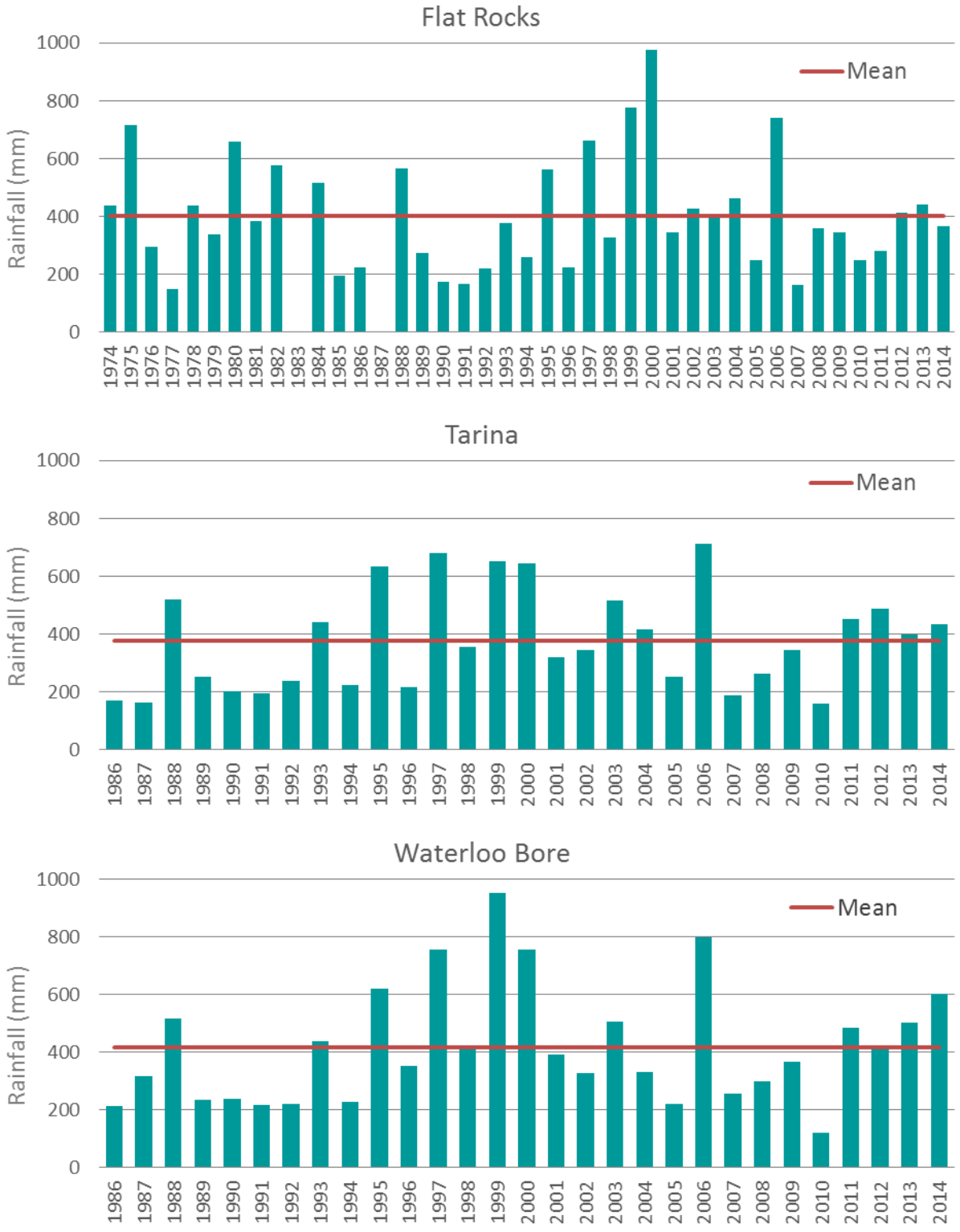
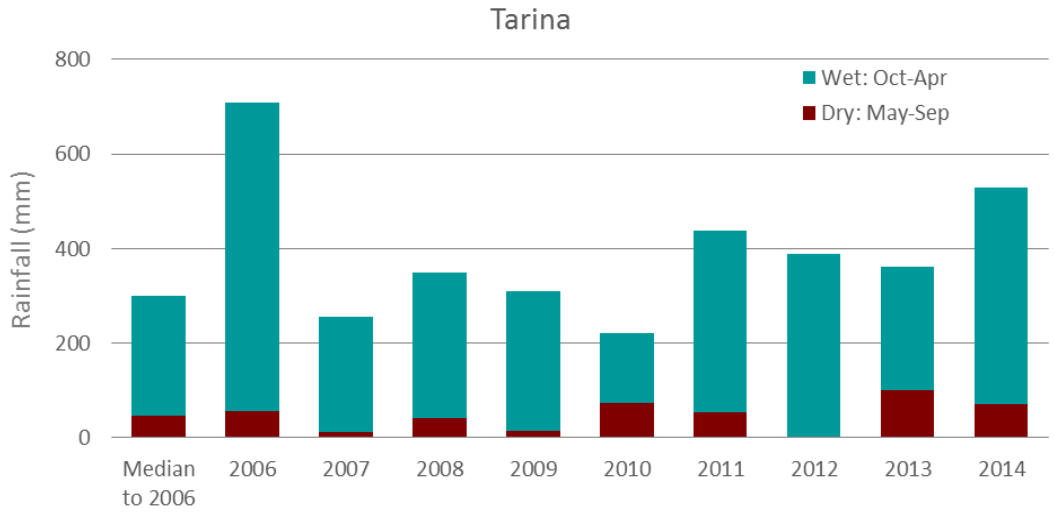


Figure 12 shows the wet and dry season rainfall at Tarina for the years of vegetation monitoring from 2006 to 2014. Wet season rainfall in any year includes rainfall measured from October of the previous year to April of that year. Mean wet and dry season rainfall for all rainfall years on record at Tarina are also shown for comparison in Figure 12. Similar to the trend in annual rainfall, wet season rainfall was high in 2006 compared with the long-term average at Tarina. Both wet and dry season rainfall was below average for the years 2007 to

2009, and wet season rainfall was also below average in 2010. Dry season rainfall in 2012 was the lowest on record, with a 5 month drought period between April and September with only 2.3 mm of rainfall received. This followed a wet season of above average rainfall in 2012.

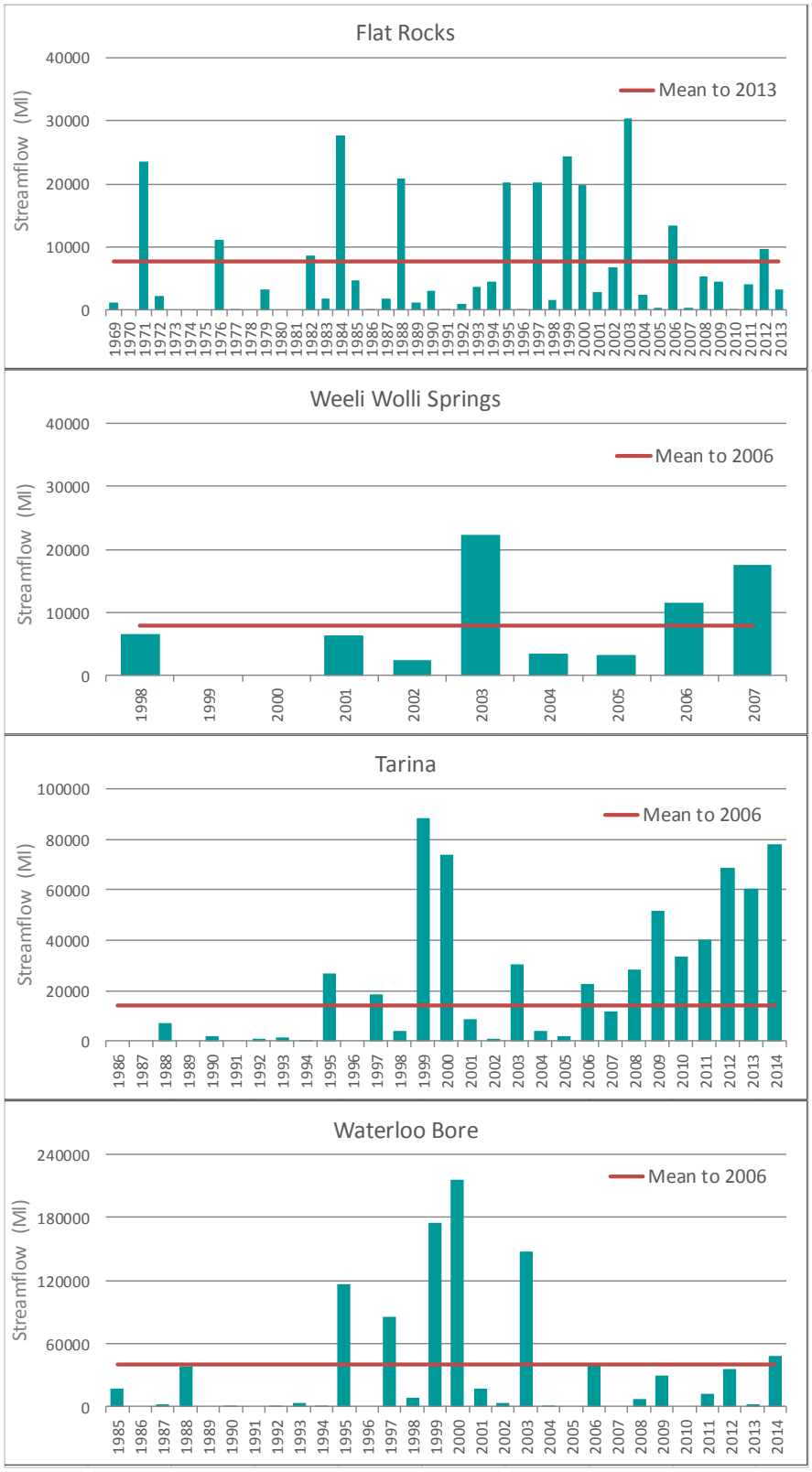
Figure 12: Wet and dry season rainfall during years of vegetation monitoring at Tarina



3.1.2. Streamflow

Consistent with annual rainfall, annual streamflow showed large year to year variation at the Flat Rocks, Weeli Wolli Springs, Tarina and Waterloo Bore stations (Figure 13).

Figure 13: Annual streamflow measured at Flat Rocks, Weeli Wolli Springs, Tarina and Waterloo Bore stations



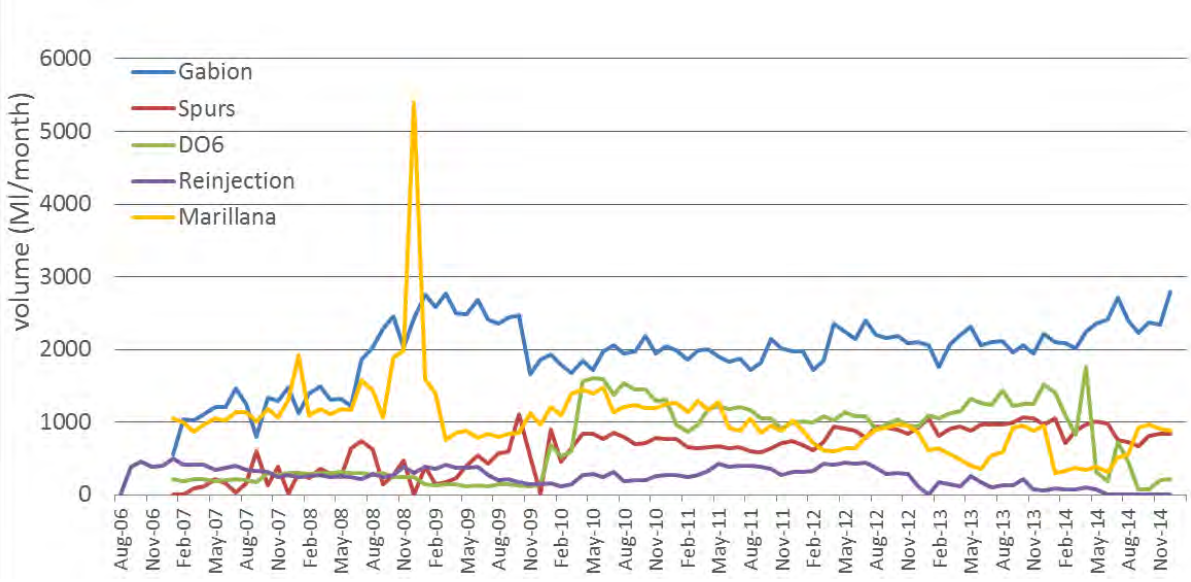
3.2. HD1 and Yandi discharge and reinjection

Dewatering at HD1 and discharge from the gabion commenced in February 2007 (Figure 14). Spur discharges applied to maintain pool levels and as supplementary irrigation for riparian vegetation also began in February 2007. Dewatering of JSE at Yandi and reinjection began in August 2006. Discharge from DO6 into Weeli Wolli Creek began in January 2007.

3.2.1. Reinjection and discharge volumes

Volumes of reinjection and discharge for HD1 and Yandi are shown in Figure 14. Discharge from the gabion was generally greater than all other discharges into the system, except for throughout 2007 and 2008 when gabion discharge was periodically similar to or smaller than discharges into Marillana Creek (Figure 14). Spur discharges at HD1 were initially relatively small in proportion to discharge from the gabion. From 2010 spur discharges increased and volumes subsequently formed a greater proportion of discharges from HD1. Spur discharge from 2010 to 2014 was 39.5 % of the gabion discharge over the same period.

Figure 14: Volumes discharged into Weeli Wolli Creek from the spurs and gabion at HD1 and DO6 at Yandi. Volumes reinjected adjacent to the creek at Yandi, and the total discharge into Marillana Creek are also shown.

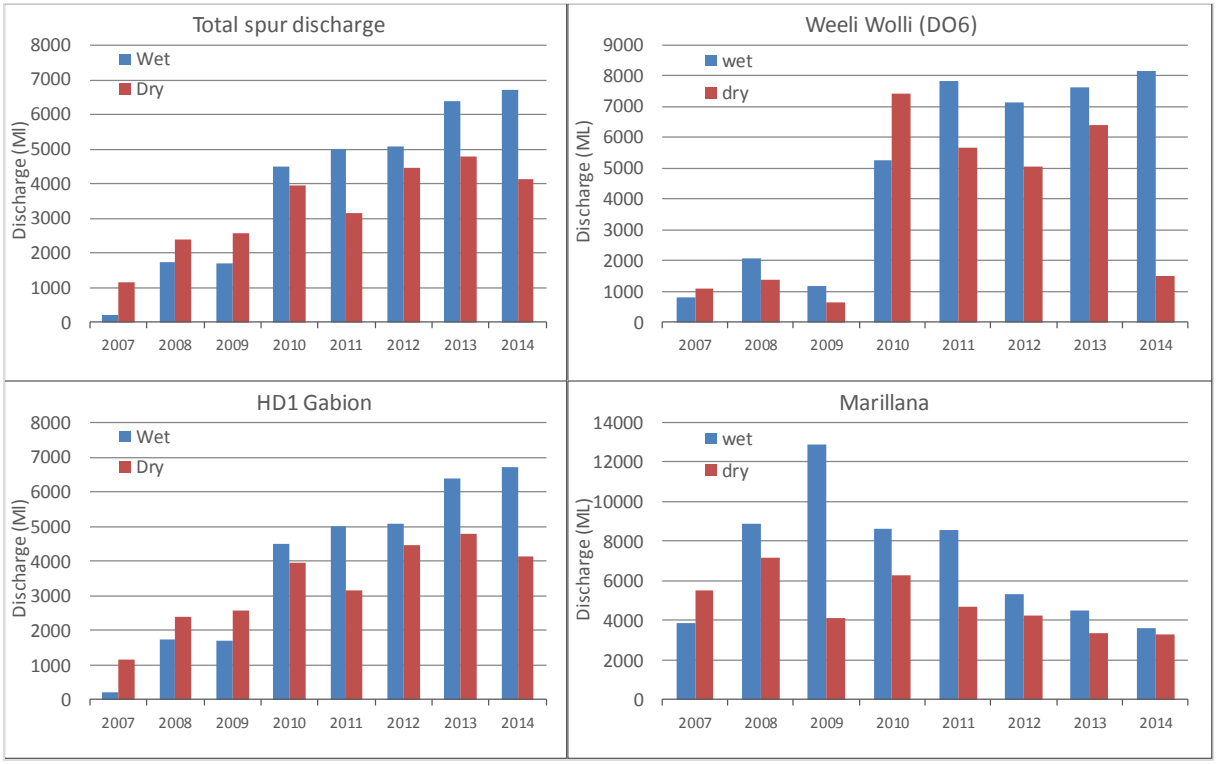


Reinjection volumes (Figure 14) at Yandi were either greater than or similar to discharges from DO6 until the end of 2009. From 2010, discharges from DO6 increased substantially and remained close to or greater than 1000 Ml/month throughout 2010 to 2013. Both reinjection and DO6 discharge volumes tended to decrease in 2014, with reinjection ceasing from July 2014. Discharges into Marillana Creek were consistently greater than both reinjection volumes and DO6 discharges until April 2010 when volumes from DO6 increased. Discharges into Marillana and from DO6 remained high throughout 2010 to 2012, and

subsequently increased from DO6 in 2013. There is little data available to interpret the combined impact of these discharges on levels and flows in Weeli Wolli Creek beyond the confluence with Marillana Creek.

Collation of discharge data into totals for the wet (October-April) and dry (May-September) season each year (Figure 15) revealed a trend for wet season discharge from the spurs, gabion and DO6 to increase with time, but wet season discharges into Marillana Creek decreased from 2009. Although dry season discharges at all locations except Marillana were generally greater from 2010 onwards than in earlier years, they didn't show the consistently increasing trend with time found for wet season discharges. There appeared to be no direct relationship between rainfall and discharge volumes each year (Figure 12)

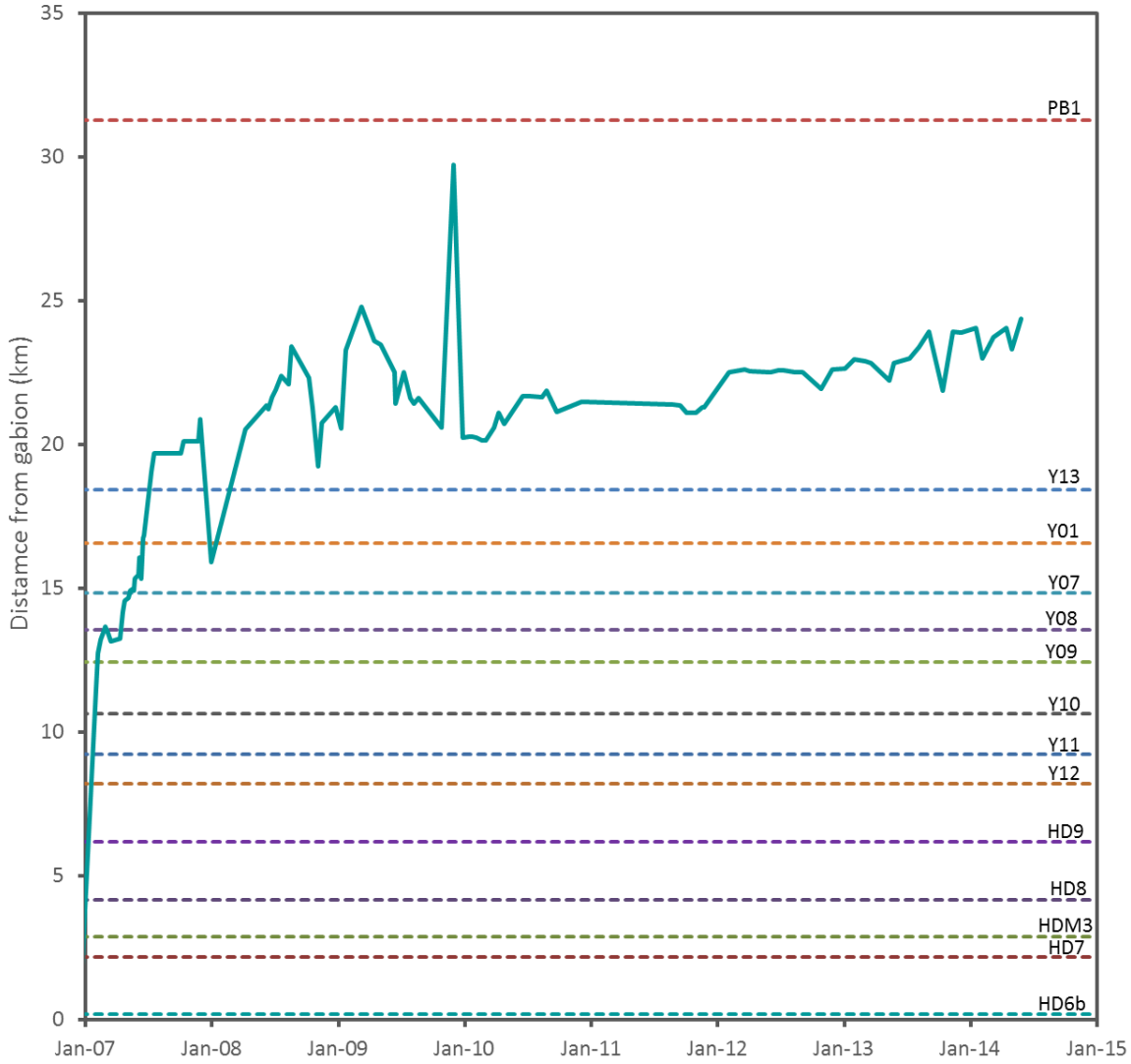
Figure 15: Wet and dry season discharges from the gabion, spurs, DO6 and total Rio Tinto discharge into Marilla Creek from 2007 to 2014.



3.2.2. Surface expression of discharge

The surface expression of discharge progressed rapidly down Weeli Wolli Creek after discharge from the gabion began (Figure 16). The first available data is for 17/02/2007 when the extent of the surface expression had already extended a distance of 11.5 km downstream of the gabion. Thus THM sites HD6b, HD7, HDM3, HD8, HD9, Y12, Y11 and Y10 were experiencing surface expression of discharge within 3 months of discharge commencing. By 23/02/2007, the wetting front had progressed past DO6 and YO9. Since discharge from DO6 had already started by this date, it isn't possible to determine the respective influences of discharge from DO6 and the gabion on the advancing wetting front.

Figure 16: Progression of surface expression of discharge past Tree Health Monitoring sites downstream of the gabion.



The front reached Y08, Y07, Y01 and Y13 by approximately 15 March, 26 May, 4 July and 26 July, respectively. By December 2014, the surface expression of discharge hadn't reached the THM site PB1 which lay > 31 km downstream. Although progression of the wetting front was slower from the start of 2009, it continued to extend to greater distances throughout subsequent years. This trend continued to the end of the study period in December 2014.

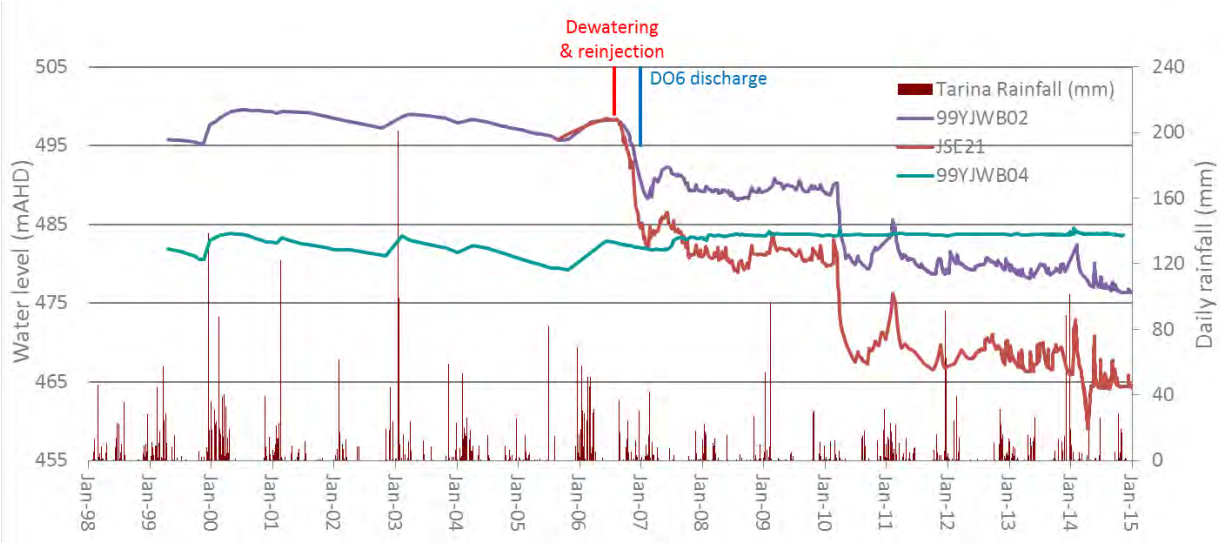
3.3. Water levels

3.3.1. Water level response to dewatering, reinjection and discharge at Yandi

Bores 99YJWBO2, JSE21 and 99YJWBO4 (Figure 17) reveal variable responses to dewatering and discharge in the CID aquifer to the northwest of Weeli Wolli Creek at Yandi

(Figure 17). Bore 99YJWBO2 is upstream of the DO6 discharge outlet, and both JSE21 and 99YJWBO4 lie downstream of it (Figure 9). Longer-term records for 99YJWBO2 and 99YJWBO4 show the natural variation in levels since 1999 in response to seasonal rainfall and streamflow. Prior to the start of dewatering in 2006, variation was generally less than 5m. However water levels in the bores closest to the dewatering bore field 99YJWBO2 and JSE21, showed rapid responses to dewatering that weren't mitigated by reinjection on the other side of the creek. By early February 2007, levels had fallen by approximately 10 m and 16 m respectively in 99YJWBO2 and JSE21, but there was no response to dewatering further downstream in bore 99YJWBO4.

Figure 17: Water levels in the CID to the northwest of Weeli Wolli Creek at Yandi and daily rainfall at Tarina



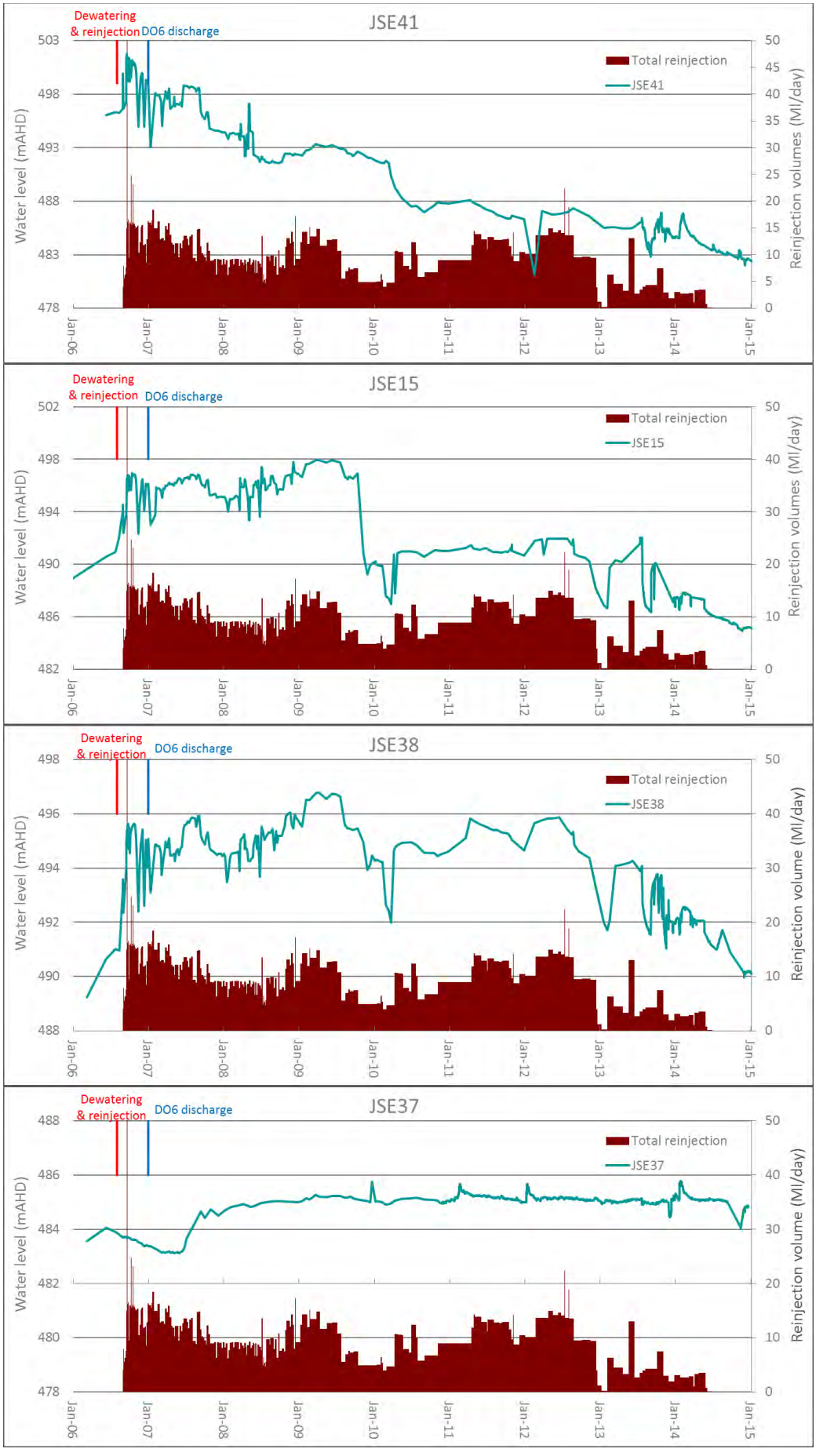
All three bores showed apparent responses to the start of discharge into Weeli Wolli Creek, with levels increasing in both 99YJWBO2 and JSE21 by approximately 4 m. The rise may also be partly in response to wet season rainfall, but since both rainfall and streamflow were below median in 2007, it seems unlikely that it could be fully attributed to wet season flows. A more muted response to discharge is discernible in bore 99YJWBO4 further downstream, which began to rise in June 2007, with levels increasing by about 2 m in subsequent months. The response of water levels in CID bores corresponded with the passage of surface expression of discharge in the adjacent creek. This occurred in February 2007 at both 99YJWBO2 and JSE21, and in early July at 99YJWBO4. Since 99YJWBO2 lies upstream of the DO6 outlet, the surface expression of water and bore response may be related to discharges from the gabion at HD1.

Throughout 2008 and 2009, levels in all three bores were largely stable, showing responses to seasonal rainfall. However, from March 2010 levels in 99YJWBO2 and JSE21 declined rapidly, falling by about 13 m and 11 m respectively by September 2007. Levels continued to

respond to seasonal rainfall, but showed evidence of a more gradual decline until the end of 2014. There was no impact of dewatering on water levels further downstream at bore 99YJWBO4 which remained very stable throughout 2008 to 2014.

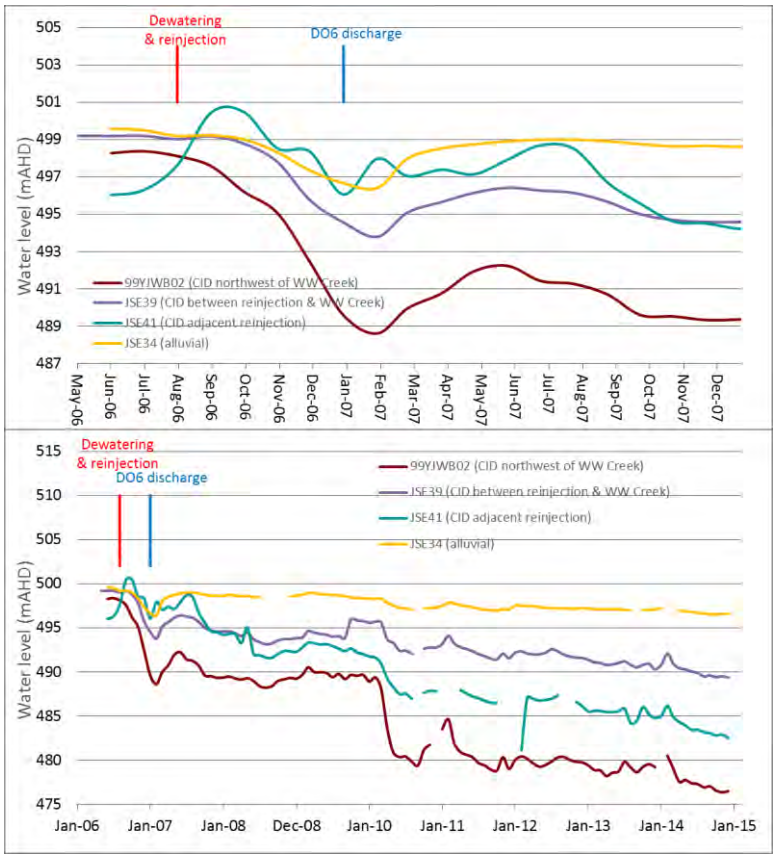
Water levels in the CID to the southwest of Weeli Wolli Creek responded to reinjection of water, but levels in some of these bores also declined in response to dewatering (Figure 18). Levels in each of the bores JSE41, JSE15 and JSE38 rose by 4 to 6 m after the start of reinjection in August 2006. All of these bores responded to reinjection, showing peaks and troughs in synchrony with increasing and decreasing reinjection volumes and a reduction in levels throughout 2013 and 2014 as volumes decreased. Dewatering of the CID on the other side of Weeli Wolli Creek had the greatest impact on water levels in the CID bores further upstream, with decreases of 19 m and 13 m from maximum levels observed in JSE41 and JSE15 respectively by December 2014. This represented a 5 m reduction in water levels from those measured in January 2006. In contrast, levels in JSE38 reflected a closer correlation with reinjection volumes, and water levels in December 2014 were approximately 1m higher than levels measured in March 2006. None of these bores showed a discernible response to the start of discharge in January 2007 (Figure 18). Further downstream at bore JSE 37, levels were less responsive to reinjection volumes. Levels here were more responsive to discharge, showing an immediate rise after April 2007 when the discharge wetting front passed this section of the creek.

Figure 18: Water levels in the CID to the southeast of Weeli Wolli Creek in response to re-injection and dewatering.



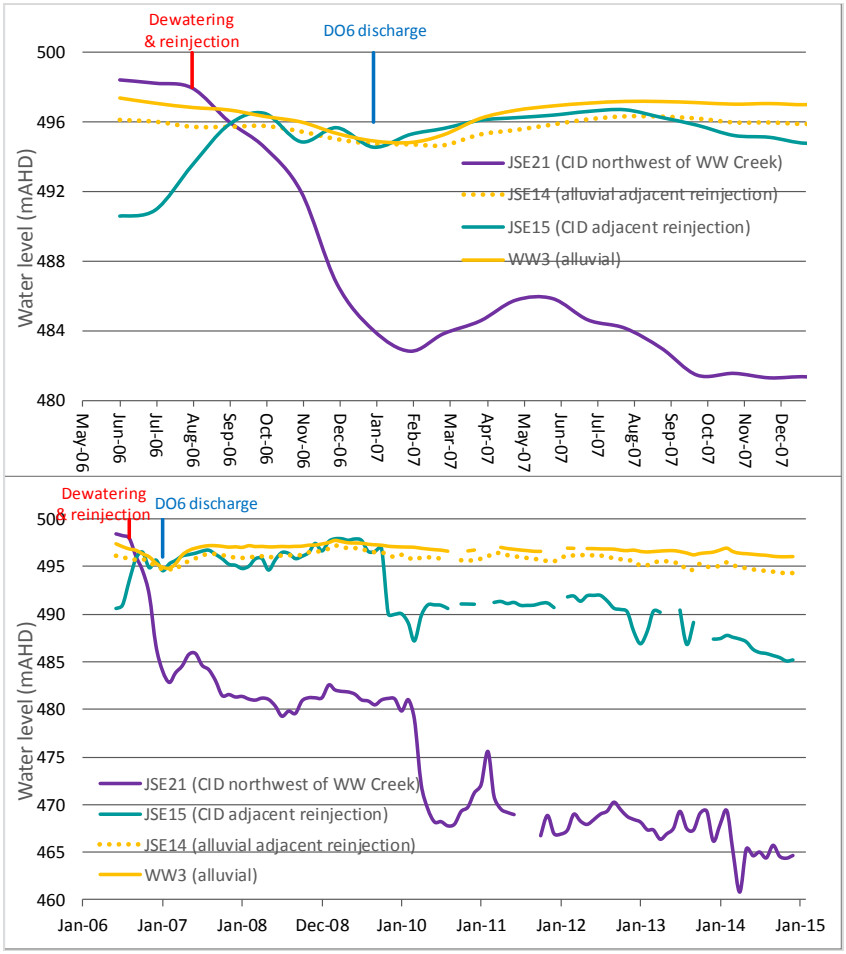
Factors influencing water levels in the alluvium at tree health monitoring plot Y10 may be inferred from the response in bores in the nearby Transect A (Figure 5). In June 2006, prior to the start of the dewatering, levels at Transect A upstream of DO6 were highest in the alluvial aquifer JSE34 (Figure 19). Hydraulic gradients were away from the creek with lower relative levels in the CID adjacent to the creek to the northwest (99YJWBO2) and the southeast (JSE39). Levels were lower again in the CID further from the creek in bore JSE41 close to a reinjection bore. Following the start of dewatering in August 2006, water levels decreased in the CID bores 99YJWBO2 and JSE39 adjacent to the creek, whilst reinjection caused levels in JSE41 to increase. By October 2006, levels were higher in JSE41 than in other CID and alluvial bores in the transect, and hydraulic gradients were towards the creek from the reinjection borefield to the southeast, and away from the creek towards dewatering to the northwest. Water levels increased in the alluvial aquifer after the surface expression of discharge from HD1 passed this point in February 2007. From March 2007 to December 2014, water levels were consistently greater in the alluvial bore JSE34 than in CID bores on both sides of the creek where dewatering caused a continuing decline in levels. The increasing difference in water levels in JSE34 and the adjacent CID bore JSE39 suggest the hydraulic connection between alluvial and CID aquifers is poor in this vicinity.

Figure 19: Mean monthly levels measured in a transect of bores (Transect A) across Weeli Wolli Creek, upstream of DO6 at Yandi. The upper figure shows short-term responses from May 2006 to December 2007, and the lower figure the longer-term responses through to December 2014.



Further downstream and past DO6 at Transect B (Figure 5), June 2006 levels prior to dewatering in the CID aquifer were 8 m higher at bore JSE21 to the northwest of the creek than at JSE15 adjacent to reinjection (Figure 20). Levels in the alluvial bores WW3 and JSE14 were consistent with a declining gradient along the transect from the northwest.

Figure 20: Mean monthly levels measured in a transect of bores (Transect B) across Weeli Wolli Creek, downstream of DO6 at Yandi. The upper figure shows short-term responses from May 2006 to December 2007, and the lower figure the longer-term responses through to December 2014.

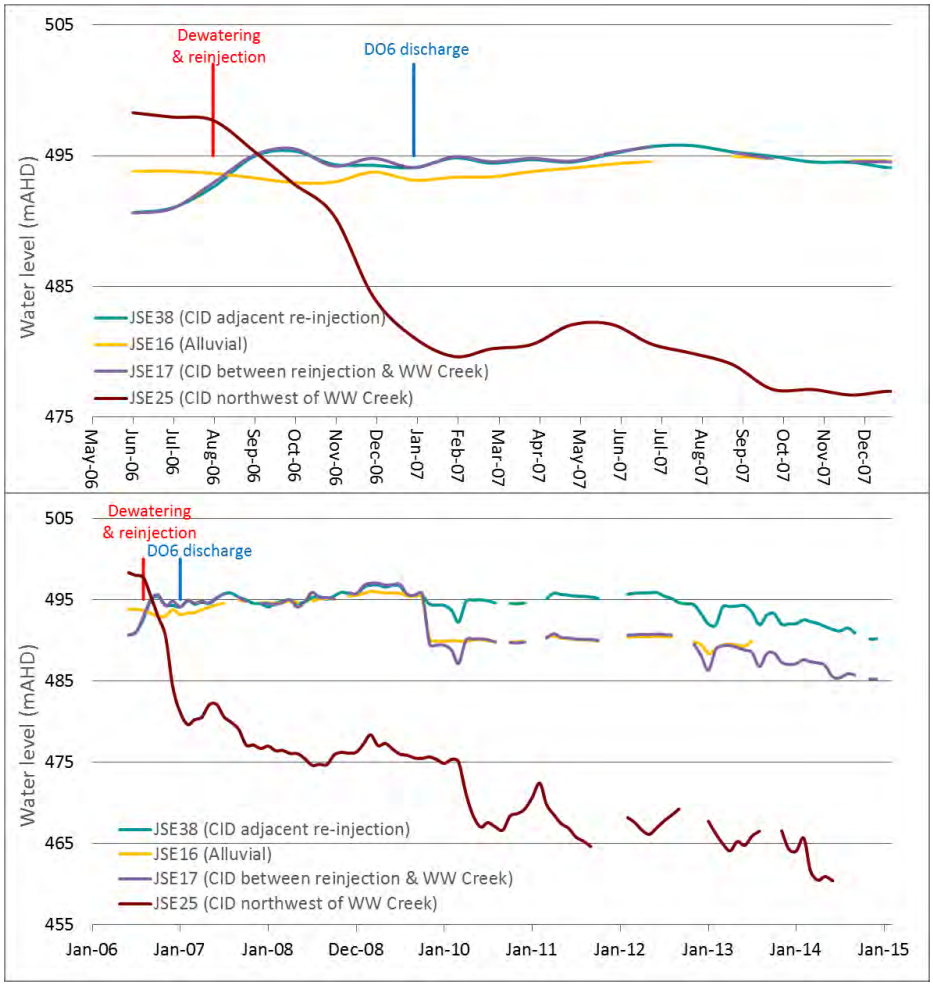


Following the start of dewatering in August 2006, water levels declined in the CID at JSE21, but rose in JSE15 adjacent to reinjection, and by November 2006, the hydraulic gradient in the CID had reversed. Levels in the alluvial bores JSE14 and WW3 were influenced more by dewatering than reinjection, decreasing from August 2006 to February 2007. The decline in levels was less at JSE14 adjacent to reinjection than at WW3 which was closer to the creek and to dewatering. Over the 6 month period between the start of dewatering and the first discharge from DO6, levels at WW3 declined by 2 m. Levels in the alluvium recovered in subsequent months after discharge commenced, and there are indications that reinjection may have also contributed to this recovery as levels in the CID at JSE15 were intermittently higher for intervals than in alluvial bores when reinjection volumes were high. However, reinjection volumes were insufficient to maintain these levels as the spatial extent of dewatering impacts increased and levels in JSE15 fell in November 2009. Levels in the

alluvial aquifer were maintained by discharge with hydraulic gradients away from the creek until the end of the study in December 2014.

Further downstream at Transect C (Figure 5) water levels in the CID in June 2006 were higher to the northwest of the creek in JSE25 than in CID bores JSE17 and JSE38 to the southeast (Figure 21). Levels in the alluvial aquifer at JSE16 were 3.2 m higher than in the CID at the adjacent bore JSE16 in June 2006.

Figure 21: Mean monthly levels measured in a transect of bores (Transect C) across Weeli Wolli Creek, downstream of DO6 at Yandi. The upper figure shows short-term responses from May 2006 to December 2007, and the lower figure the longer-term responses through to December 2014.

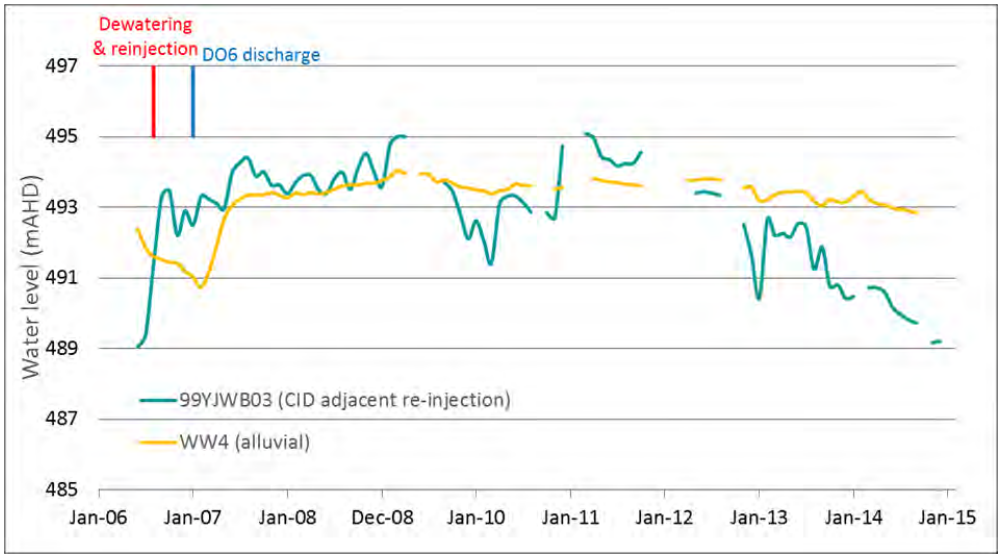


At the start of dewatering, levels in JSE25 began to fall, but levels in JSE17 and JSE38 rose in response to reinjection. By November 2006 the direction of the hydraulic gradient reversed, and levels in the CID to the southeast became higher than in the alluvium. These higher levels in the CID at JSE17 and JSE38 were sustained by reinjection through to October 2009, and the hydraulic gradient remained predominantly towards the creek. Over this period, levels in the alluvium reflected small variations in the CID bores JSE17 and

JSE38, suggesting hydraulic connectivity between the two aquifers in this vicinity and a contribution from reinjection to levels in the alluvium. From November 2009, the impact of the increasing spatial extent of dewatering caused a rapid decrease in levels in JSE17 and in the alluvium at JSE16, but little response in JSE38. Levels in all these bores were subsequently largely maintained until June 2012, after which they began to decline, with the alluvial bore JSE16 becoming dry in August 2013. This decline could relate to impacts of dewatering and/or a reduction in reinjection volumes from 2013.

Further downstream there are few bores to consider in evaluating the potential contribution of re-injection and discharge. However, differences between levels in bores 99YJWBO3 and WW4 (Transect D, Figure 5) provide indications of the responses there (Figure 22). Levels in 99YJWBO3 show fluctuations in response to reinjection volumes, consistent with other CID bores. Levels in the alluvial bore WW4 respond to the start of dewatering in 2006, and to discharge from DO6 in early 2007. The differences between levels in the CID and alluvium suggest the direction of hydraulic gradient changes with time as levels in the CID fluctuate in response to changing reinjection volumes. The gradient was predominantly towards Weeli Wolli Creek from August 2006 to April 2009, and away from the creek from May 2012 until December 2014.

Figure 22: Mean monthly levels measured in CID bore 99YJWBO3 and WW4 in the alluvium at Weeli Wolli Creek.

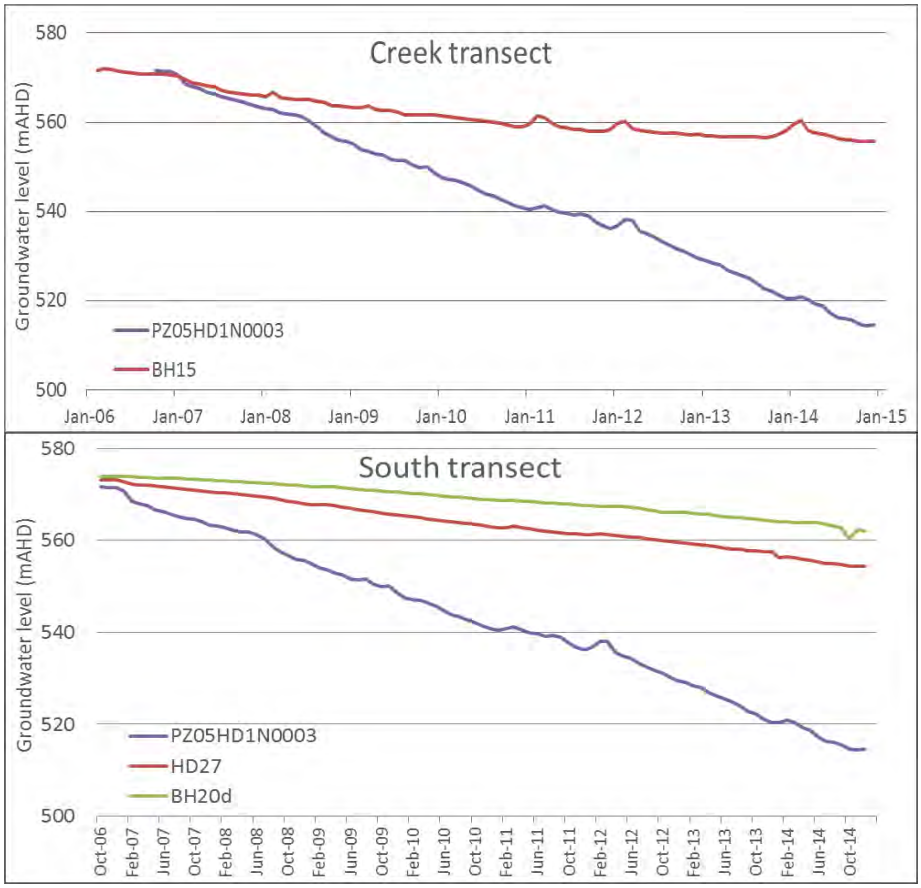


Thus the influence of dewatering, reinjection and discharge on water levels in the alluvium at Yandi varied at different positions along Weeli Wolli Creek, and conditions at tree health monitoring plots varied accordingly.

3.3.2. Water level response to dewatering at HD1

Responses in water levels of bores on Transect 1 (Figure 7) and Transect 2 (Figure 8) in ephemeral sections of Weeli Wolli Creek in response to dewatering at HD1 are shown in Figure 23. Levels in bore PZ05HD1N0003 adjacent to dewatering showed an immediate response to groundwater pumping, and declined progressively throughout the study period from 2007 to December 2014. Levels fell from 570.7 m to 514.6 m (56.1 m) over this period, a mean rate of 7.01 m/year. The rate of fall was relatively uniform with time, although levels increased slightly in response to wet season rainfall and streamflow events. Further from dewatering at bores BH15, HD7 and BH20d, levels also responded to dewatering. As may be expected, the rate of fall and change in water levels between 2007 and 2014 was smaller at locations further from dewatering.

Figure 23: Mean monthly water levels in bores on Transect 1 (Creek transect) and Transect 2 (South transect) in response to dewatering at HD1. Bores are located in ephemeral reaches of Weeli Wolli Creek.

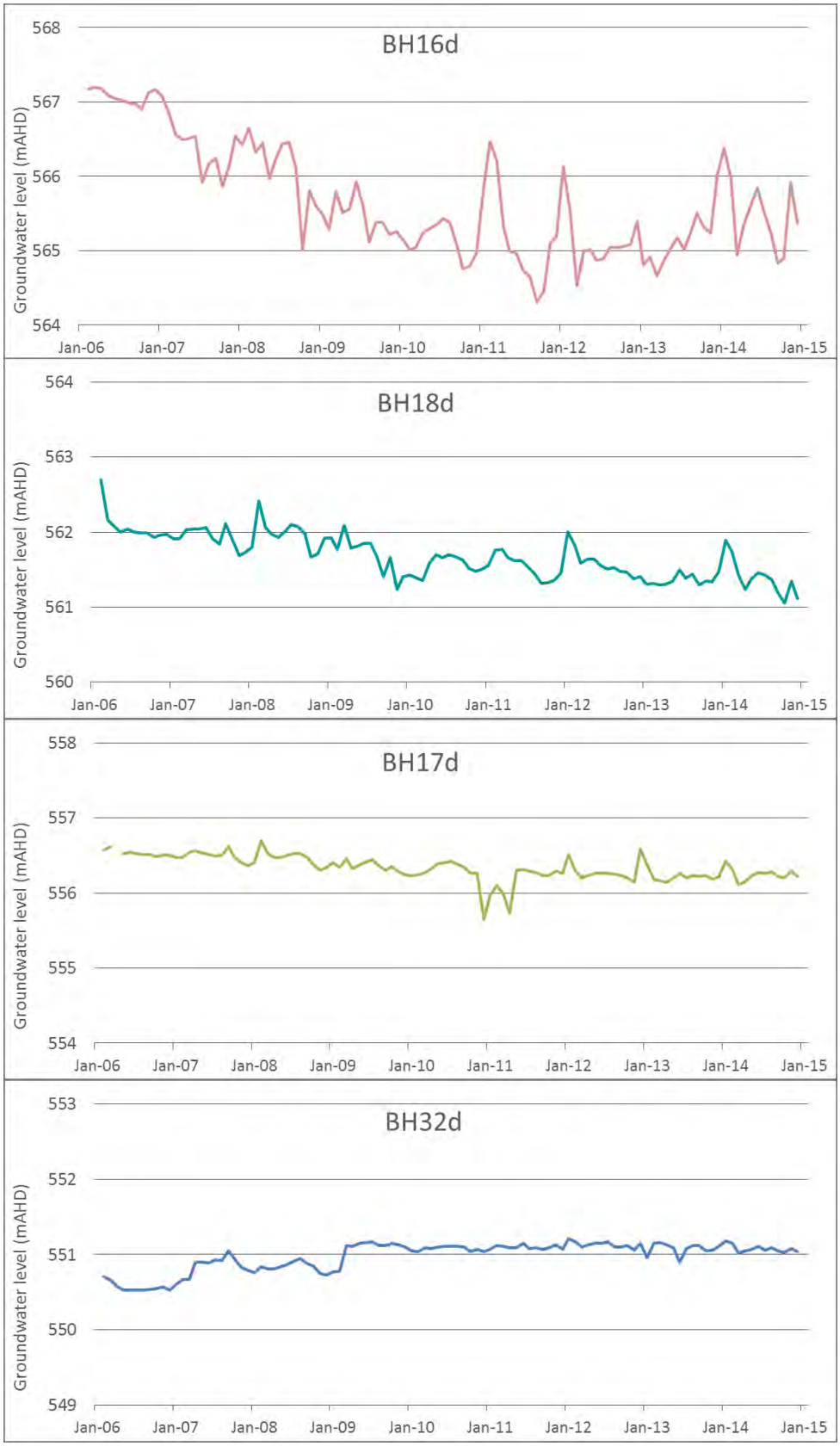


Water levels in the majority of the bores on the previously perennial section of Weeli Wolli Creek along Transect 1 also declined in response to dewatering (Figure 24).

The magnitude of the decline was greatest at BH16d (2.9m), becoming progressively smaller at BH18d (1.7 m), and BH17d (0.9m) further downstream. At the bore on the transect furthest from dewatering (BH32d), water levels tended to increase from February 2007 to

March 2009, and subsequently remained relatively constant until December 2014. The water level here increased by about 0.4 m from its value at the start of dewatering.

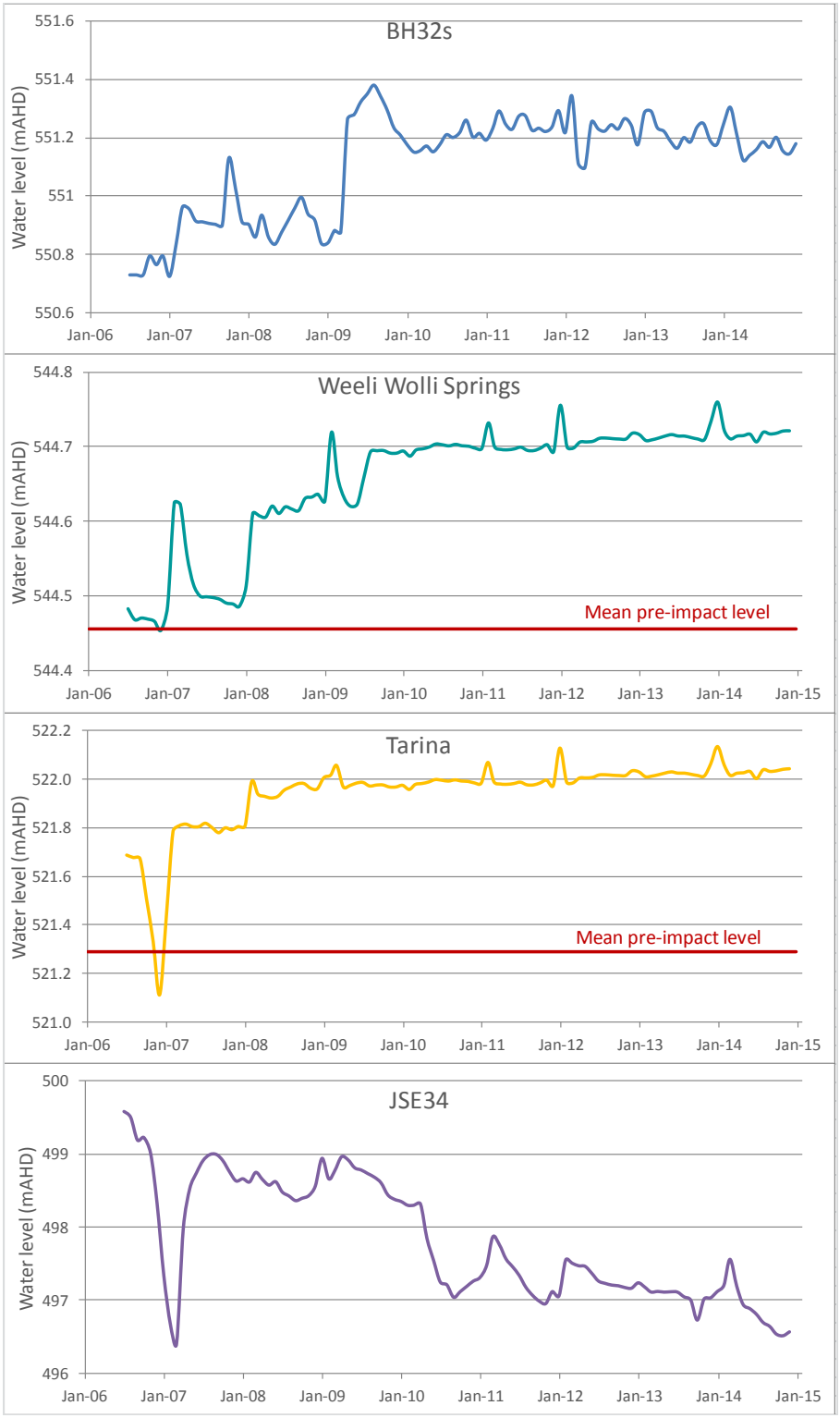
Figure 24: Mean monthly water levels in bores BH16d; BH18d; BH17d and BH32d on Transect 1 (Creek transect) at HD1. Bores are located in the sections of Weeli Wolli Creek receiving supplemental irrigation from spurs and with largely perennial flows prior to dewatering.



3.3.3. Water level responses downstream of the gabion to Yandi

Water levels responses on Transect 3 from bore BH32s and downstream of the gabion to Yandi are shown in Figure 25.

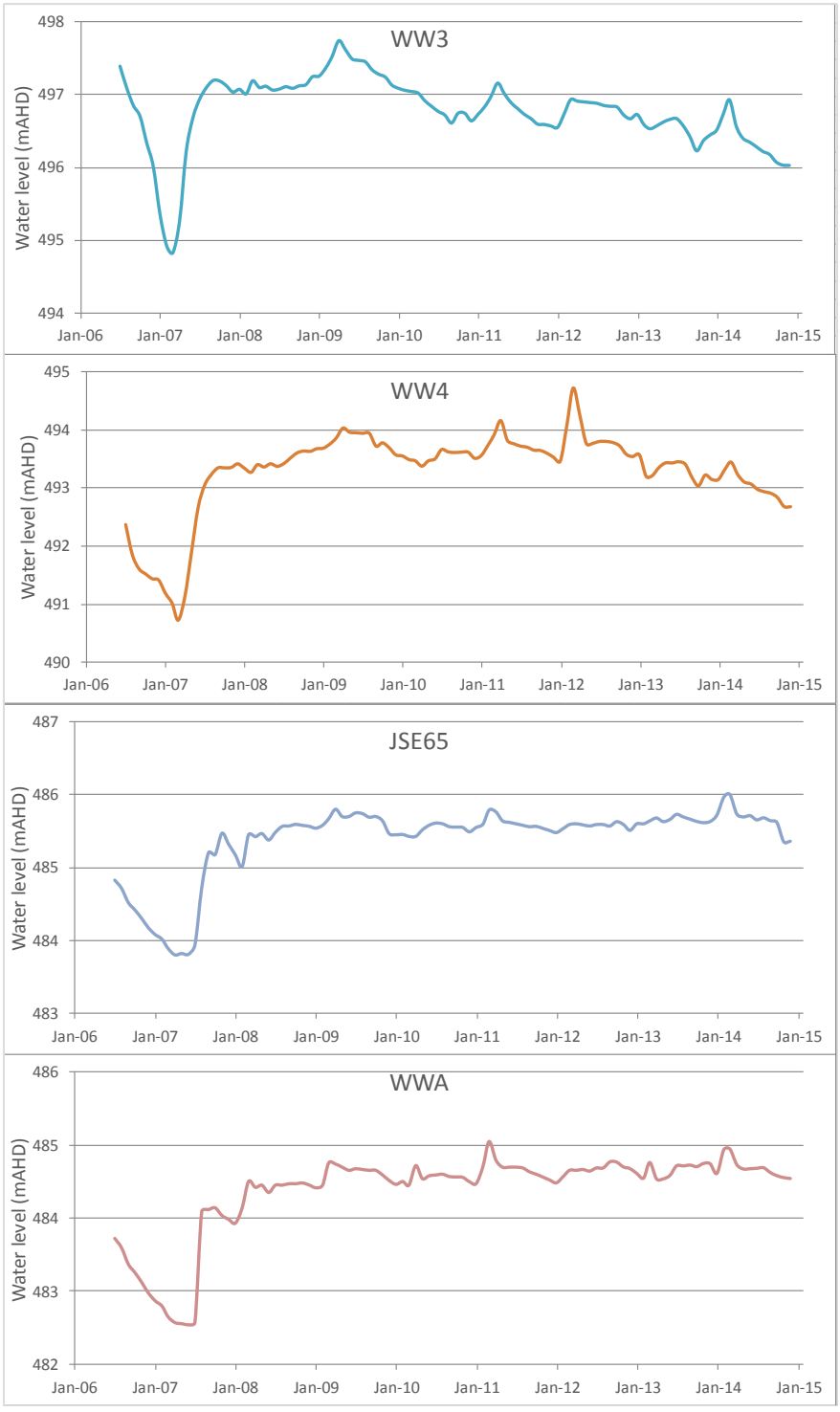
Figure 25: Mean monthly water levels on Transect 3 from bore BH32s and downstream of the gabion to JSE34 at Yandi.



Trends in the response of water levels are different depending on the location on Weeli Wolli Creek as sites are differentially impacted by discharge, drawdown and re-injection. Water

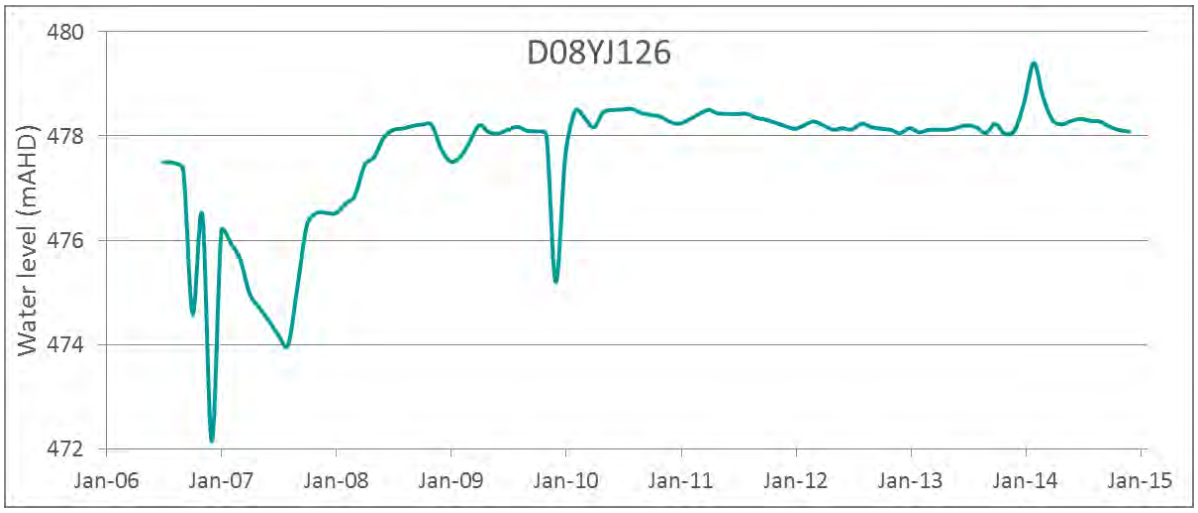
levels at BH32s, Weeli Wolli Springs and Tarina increased in response to discharge from HD1. Increases in levels were initially relatively rapid, but became more gradual from 2009, with indications in December 2014 that the upward trajectory was increasing. Levels at Weeli Wolli Springs and Tarina had increased by 0.26 m and 0.75 m respectively by December 2014 compared with mean levels prior to the start of discharge. In contrast, further downstream at JSE34 (Figure 25) and WW3 (Figure 26) water levels in the alluvium decreased with time in response to dewatering of JSE.

Figure 26: Mean monthly water levels on Transect 3 from bore WW3 to WWA at Yandi.



Further downstream, the influence of dewatering was progressively diminished, and levels increased at WW4, JSE5 and WWA due to differential impacts of discharge and reinjection (Figure 26). Past the confluence with Marillana at bore DO8YJ126 water levels also increased due to impacts of combined discharges into Marillana and Weeli Wolli Creeks (Figure 27).

Figure 27: Mean monthly water levels past the confluence of Marillana Creek at DO8YJ126



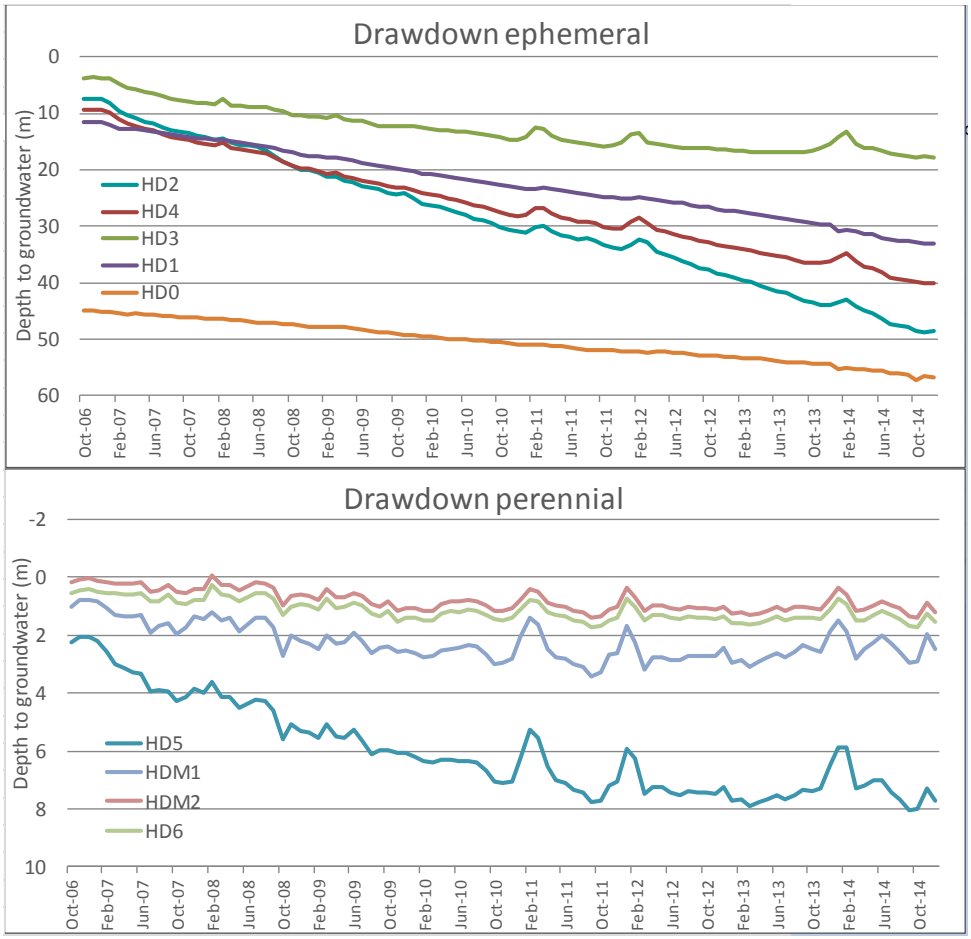
3.3.4. Depth to water table responses in tree health monitoring plots

HD1 drawdown sites

Groundwater levels at each of the THM sites upstream of the gabion were impacted by dewatering (Figure 28). Impacts were greater at ephemeral sites closer to the dewatering than further downstream at the previously perennial sites, which also received supplementary water from the spurs. Prior to the start of dewatering, depth to groundwater at ephemeral sites HD1, HD2, HD3 and HD4 ranged from 3.7 to 11.5 m in October 2006, levels potentially accessible to tree roots. Further upstream at HD0, the water table was less accessible at a depth of 45.0 m making it unlikely that groundwater formed a significant component of tree water uptake at the site. Given this, tree responses at HD0 are useful as a reference for comparison with the response of trees more likely to be accessing groundwater.

Downstream in the springs area at sites HD6, HDM1 and HDM2, groundwater was readily accessible within 1 m of the surface and at 2.2 m depth at HD5 in October 2006 (Figure 28). The rate of groundwater drawdown observed at different sites was a function of the distance from dewatering. Close to dewatering at HD2, levels fell at an average rate of 13.8 mm/day between October 2006 and December 2014, compared with only 0.34 mm/day at HD6, the site just upstream of discharge from the gabion.

Figure 28: Depth to groundwater at tree health monitoring sites at previously ephemeral and perennial sites upstream of the gabion at HD1.



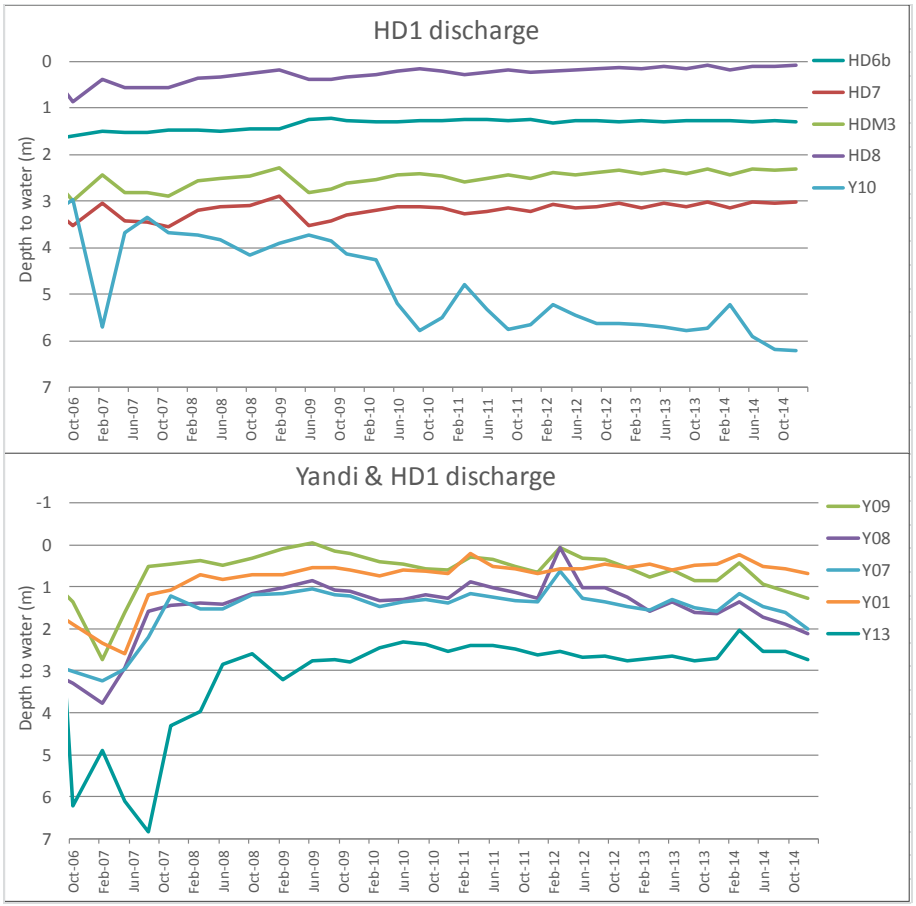
HD1 discharge sites

Figure 29 shows depth to water for sites between the gabion and Yandi, as well as for sites downstream of DO6 at Yandi. The accuracy of estimated depth to water for sites between the gabion at HD1 and Yandi are constrained by the absence of bores along this part of Weeli Wolli creek and the reliance on levels measured at only 2 locations (the Weeli Wolli Springs and Tarina stations). The accuracy of absolute values of water levels estimated for sites may be low because of the distance between monitoring locations. However trends in levels at sites between the gabion and Tarina station (HD6b, HD7, HDM3 and HD8) are likely to be relatively reliable because of good quality data available for the gauging stations. No water level data is available for a distance of 6 km downstream of Tarina. Trends in water levels are likely complex along this part of the creek, since levels are increased by discharge from the gabion at one end, and decreased by dewatering at the other. There are no data to inform how water levels are responding in between. Given that HD1 drawdown impacted on water levels of bores almost 6.5 km from dewatering (e.g. BH17d), it appears possible that JSE dewatering may influence levels at sites HD9, Y12, Y11. Hence both trends and absolute values for water levels estimated for these sites are considered too unreliable to be

useful. Levels estimated for site Y10 are included because of the site's proximity (< 400 m) to bore JSE34.

In October 2006, estimated depth to water was relatively shallow (<3.6 m) at sites HD6b, HD7, HD8, HDM3 and Y10. Following the start of discharge from the gabion, levels tended to increase at each of the sites except Y10 where levels decreased because of the site's proximity to dewatering at JSE (Figure 19). Mean rates of water levels rise were slow, with the lowest rates observed at HD6b (0.10 mm/day). The rate of rise increased progressively for sites further downstream to 0.26 mm/day at HD8. At Y10, depth to water increased from 3.0 m in October 2006 to 6.2 m in December 2014, falling at a mean rate of 1.1 mm/day.

Figure 29: Depth to water at tree health monitoring sites downstream of the gabion receiving discharge from HD1, and at sites downstream of both HD1 and Yandi discharges.



Sites downstream of discharge from both HD1 and Yandi

Interpretation of water level responses at tree health monitoring sites downstream of DO6 is complex because of potential impacts from dewatering, discharge and reinjection along this section of Weeli Wolli Creek. It is also constrained both by the limited number and distribution of bores downstream of the gabion, but also by the short timeframe of monitoring that has occurred in alluvial bores. Long-term river stage data from the Weeli Wolli springs and Tarina gauges allows us to conclude with some confidence how much water levels have

changed from the natural condition prior to discharge. However, the earliest data available for alluvial bores at Yandi is from October 2004, allowing less than 2 years of information on the natural variation in levels prior to dewatering, discharge and reinjection. Where bores were installed in 2004, subsequent data collection is erratic, with only 1 to 3 readings in 2005 and limited readings in 2006 before the time of potential impact. Data is inadequate to establish pre-impact water levels and their annual and seasonal variation. Given these constraints, we can only infer with limited confidence the nature and size of the impact of operations on water levels.

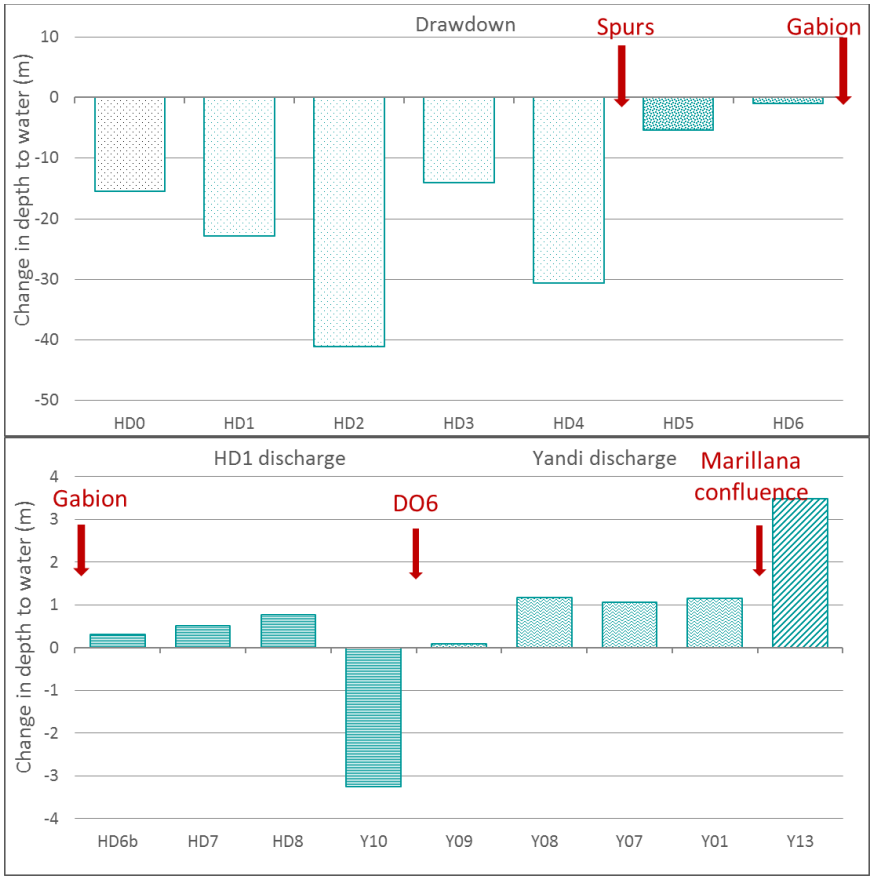
Water levels rose at all sites downstream of DO6 compared with levels measured in October 2006 (Figure 29). The most rapid increases were experienced in 2007 at all these sites, and levels at sites Y09, Y08, Y07 and Y01 had stabilised somewhat by the end of that year. Levels rose further in early 2008 at Y13, becoming more stable mid-way through that year. All sites downstream of DO6 showed a trend of decreasing levels from February 2014 as reinjection and discharge volumes were reduced. The water table was shallowest at Y09 and Y01, and remained within 1 m of the surface from early 2008 through to December 2014 in Y01 and mid-December 2014 in Y09. The water table was deeper at Y07 and YO8, generally within 1.5 m of the surface from 2008 to mid-2012. Estimated levels were deeper again downstream of the confluence with Marillana at Y13, remaining between about 2 to 3m depth from 2009 to the end of 2014.

Change in depth to water over the study period

The net change in depth to water at tree health monitoring sites between October 2006 and December 2014 was quite variable (Figure 30). Drawdown was greatest at sites closest to dewatering where levels fell by more than 30 m and 40 m at HD4 and HD2, respectively. The impact of drawdown was less pronounced further from the bore field, but was still greater than 10 m at all other sites without supplemental irrigation.

Drawdown at sites HD5 and HD6 in the springs area of Weeli Wolli Creek was 5.5 and 1.0 m respectively, and drawdown at Y10 adjacent to JSE dewatering was -3.3 m. Downstream of the gabion, water levels at all sites except Y10 rose in response to discharge from HD1 and Yandi (Figure 30). Water level rises were generally smaller for perennial sites immediately downstream of HD1 discharge than for sites receiving discharge from Yandi. The largest response to discharge from the gabion was observed at HD8 where levels rose by 0.76 m.

Figure 30: Change in estimated depth to water between October 2006 and December 2014 for drawdown and discharge sites.



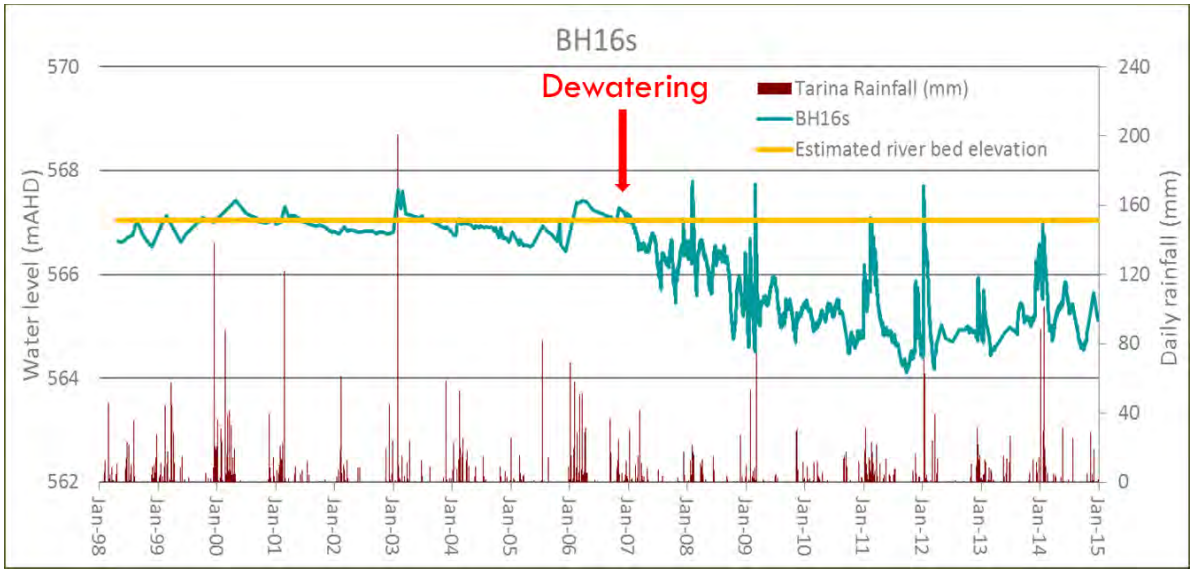
Downstream of DO6, levels rose by > 1 m at all sites except Y09 where levels increased by only 0.1 m, suggesting that dewatering could be mitigating water level rises due to discharge at this site. The greatest increase was observed at Y13 where levels rose by 3.5 m over the study period, with discharges into both Marillana and Weeli Wolli Creeks potentially contributing to this rise.

3.4. Responses in runoff and streamflow

3.4.1. Impacts of drawdown on streamflow in Weeli Wolli Creek

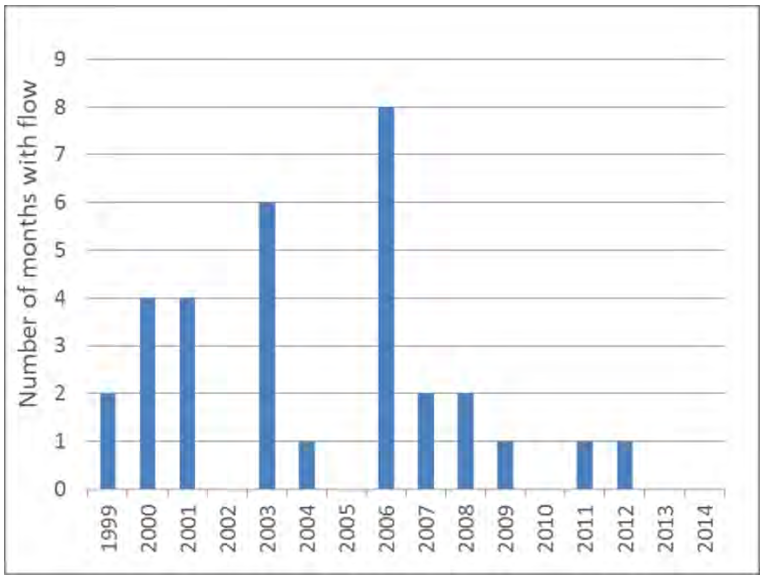
No streamflow data was available to evaluate potential impacts of drawdown at HD1 on runoff and streamflow in Weeli Wolli creek upstream of the gabion. As a surrogate analysis, the response in water levels at BH16s within the drawdown zone along Weeli Wolli creek (Figure 7) were used as an indicator of the frequency and duration of flows in the creek (Figure 31).

Figure 31:Temporal changes in water level at bore BH16s, adjacent to Weeli Wolli Creek. The estimated elevation of the river bed and daily rainfall at the Tarina station are also shown.



Flow was assumed to occur when the water level at BH16s was greater than the estimated elevation of the river bed. Prior to the start of dewatering, levels in BH16s remained within 0.6 m below the river bed. Dewatering caused water levels to fall, reaching depths close to 3 m lower than the level of the bed. As a result, the frequency and duration of intervals when the water level at BH16s was above the level of the river bed was reduced compared with conditions prior to dewatering (Figure 31). This suggests that both the frequency and duration of streamflow in Weeli Wolli Creek upstream of the gabion was reduced by dewatering. The number of months each year when water levels in BH16s were above the river bed elevation was calculated for years before and after the start of dewatering (Figure 32).

Figure 32: Number of months in each year that water levels at BH16s exceeded river bed elevation, indicative of months with flow in Weeli Wolli Creek

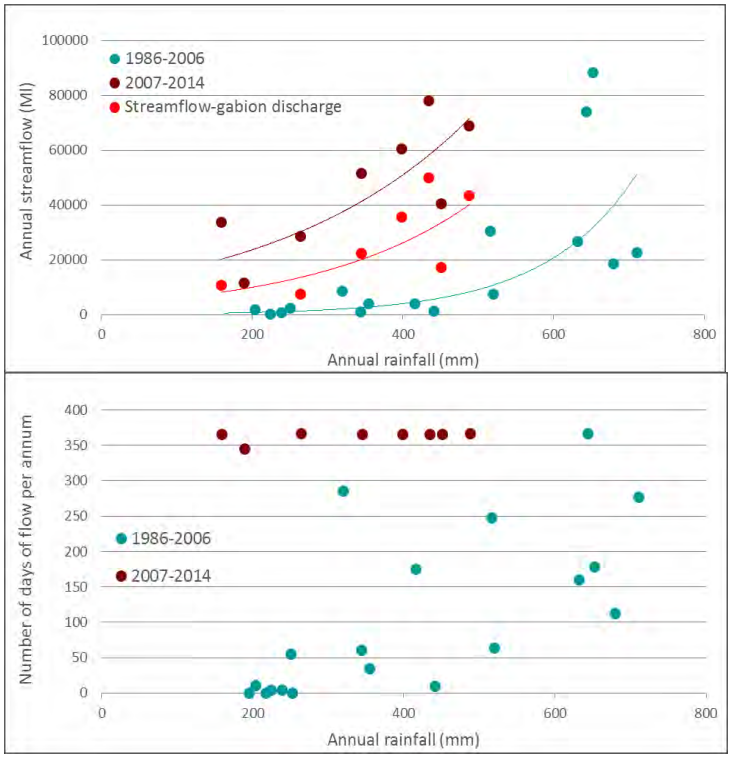


For years prior to the start of dewatering the number of months with flow is likely underestimated since bores were monitored only once or twice per month, and there were several months when no monitoring occurred (e.g. February and December 2002). From December 2006, levels in BH16s were monitored twice per day, so the number of months with flow could be reliably determined after dewatering started. Dewatering reduced the number of months per year with flow at BH16s, with up to 8 months per year prior to dewatering and a maximum of only 2 months per year afterwards. The mean number of months with flow for years 1999-2006 and 2007-2014 was 3.2 and 0.9 respectively.

3.4.2. Impacts of discharge on streamflow downstream of the gabion

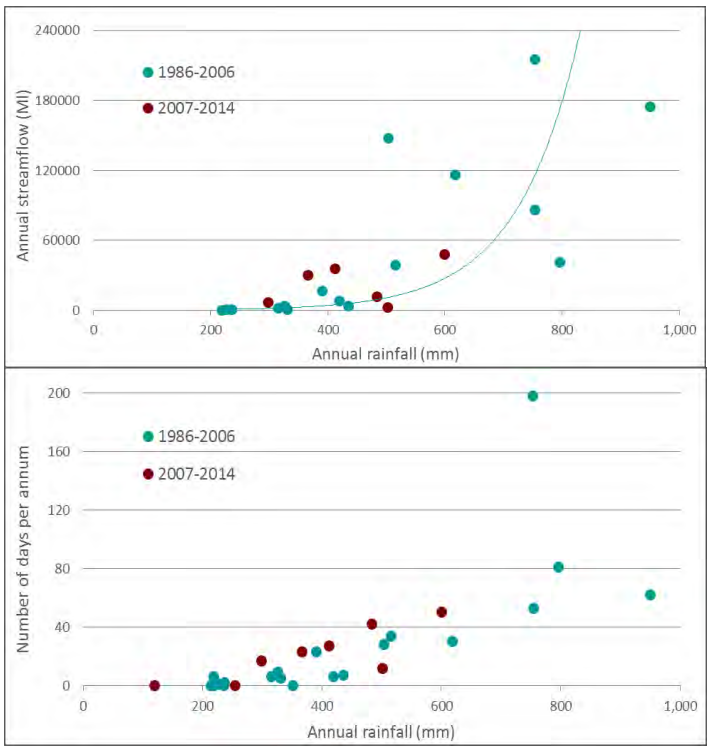
Annual rainfall and streamflow data from the Tarina station was used to assess changes to streamflow downstream of the gabion after the start of dewatering and discharge operations. As expected, streamflow at Tarina was increased by discharge into Weeli Wolli Creek (Figure 33). Both the volume of streamflow and the number of days per year of flow at Tarina were increased by discharge. Prior to 2007, the number of days of flow per year ranged from 0 to 366 in a leap year (2000), but after 2007 flow was continuous throughout the year. Increases in the volume of streamflow were greater than would be expected if the increase were simply due to the volumes discharged each year.

Figure 33: Relationship between annual rainfall and streamflow measured at the Tarina station. Separate figures are shown for response in streamflow volumes and the number of days per annum of flow as a function of rainfall. Separate relationships are shown for years 1986-2006 and 2007-2014, years before and after potential impacts. Data for annual streamflow minus gabion discharge for the period 2007-2014 are also shown.



Further downstream at Waterloo Bore (Figure 34) streamflow did not appear to be impacted by discharges from HD1 or Yandi. Neither the volume of streamflow, nor the number of days of flow each year appeared to be increased by the combined impacts of these discharges.

Figure 34: Relationships between annual rainfall and streamflow measured at the Waterloo Bore station. Data are shown separately for years 1986-2006 and 2007-2014, years before and after potential impacts. Separate figures are shown for response in streamflow volumes and the number of days per annum of flow as a function of rainfall.



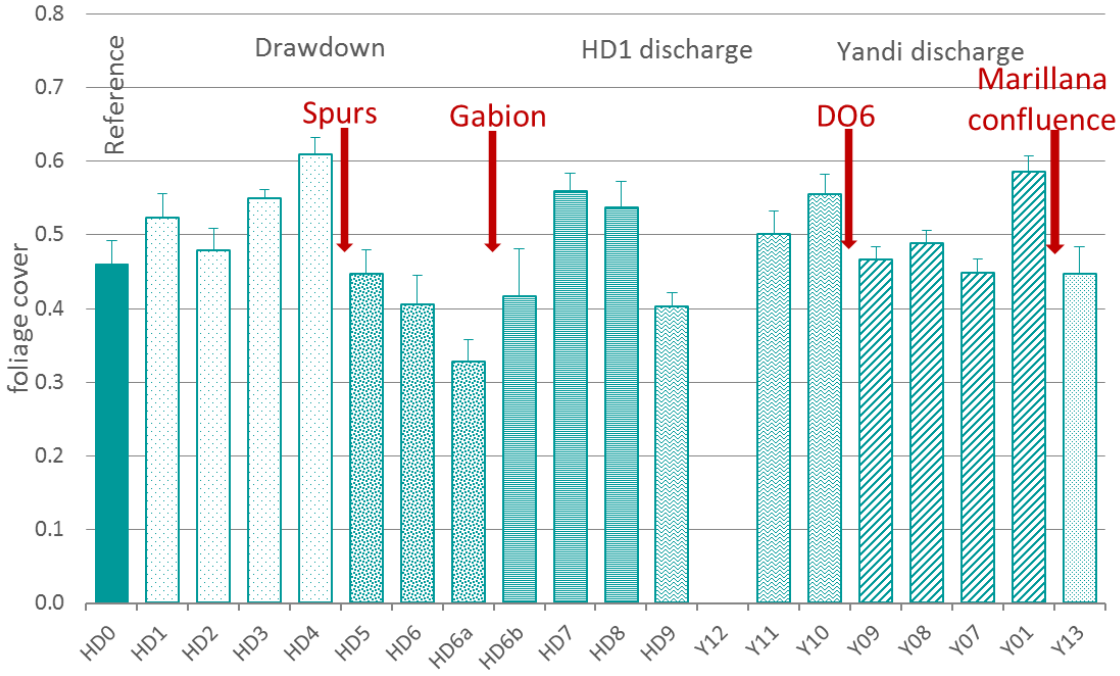
3.5. Vegetation responses

3.5.1. Temporal changes in foliage cover

2- way repeated measures ANOVA of site and temporal responses in foliage cover gave statistically significant responses for both site and time (Appendix 1), and for the interaction of these factors. Given this, further statistical analyses were applied to investigate in more detail the significance of different responses observed in the figures presented below.

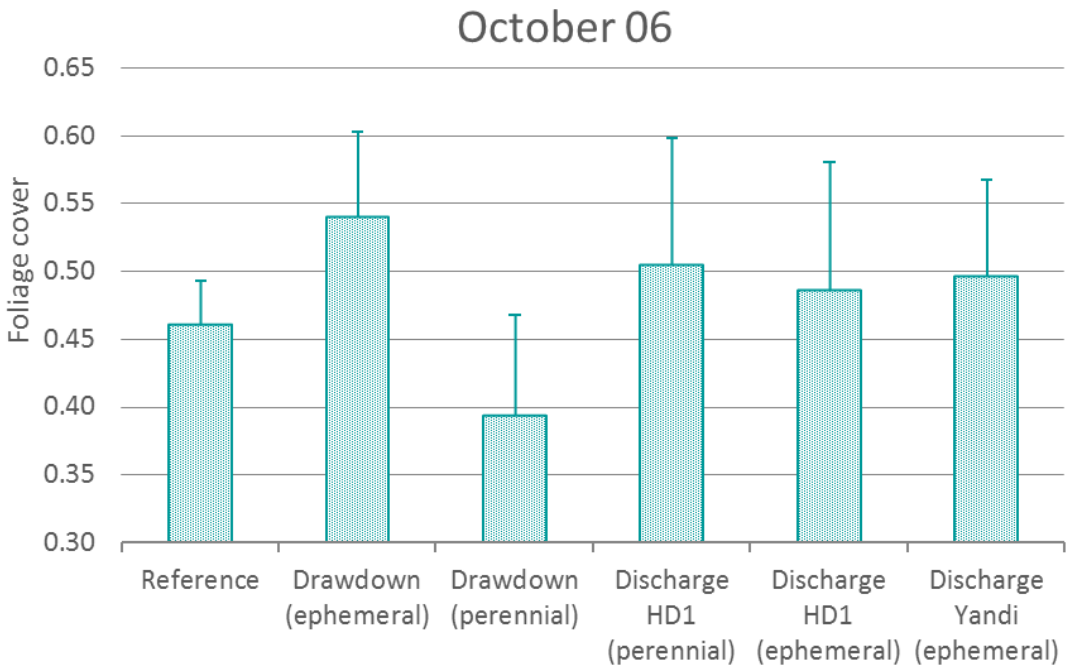
Prior to the start of dewatering at HD1 and discharge from the gabion and DO6 there was already considerable variation in eucalypt foliage cover at different sites (Figure 35). Foliage cover ranged from 0.33 at HD6a to 0.61 at HD4. Foliage cover was low in the springs/pools area of Weeli Wolli Creek (drawdown ephemeral treatment) and high in upstream areas (drawdown perennial treatment, Figure 36).

Figure 35: Foliage cover in October 2006 prior to the start of dewatering and prior to discharge from HD1 and Yandi DO6. Foliage cover at Y12, and reference sites PB1 & HD10 were unavailable for October 2006.



Foliage cover in the springs/pools area was significantly lower than all other treatments, including those further downstream that also historically received perennial flow (HD1 discharge perennial). There were no significant differences in foliage cover between any of the other treatments in October 2006.

Figure 36: Mean foliage cover of treatment groups at the start of monitoring in October 2006.

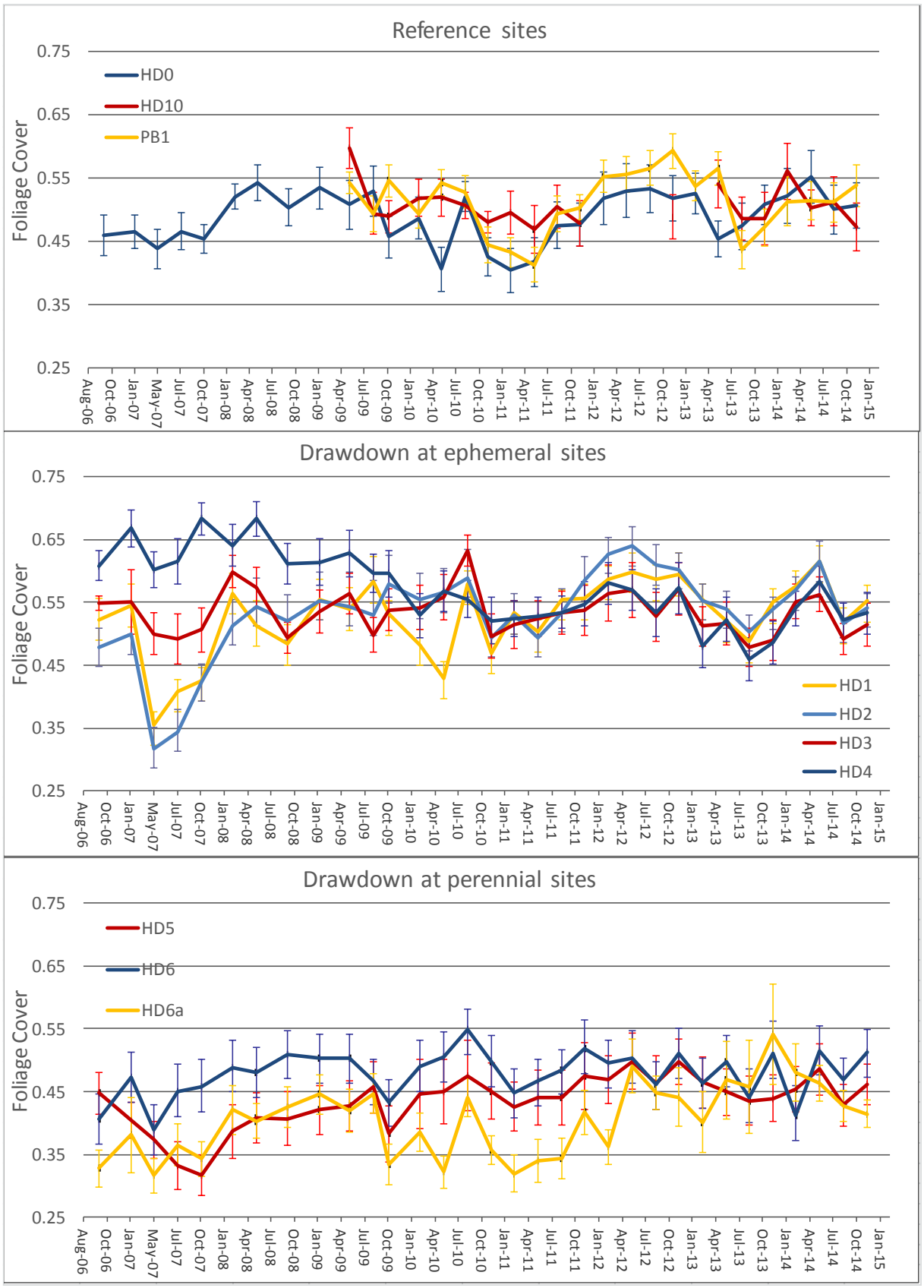


As would be expected at sites experiencing high seasonal and annual variation in rainfall, and subject to disparate water management regimes, temporal responses in foliage cover were very dynamic at all sites (Figure 37 and Figure 38). Over the time period with concurrent monitoring at the reference sites HD0, HD10 and PB1, seasonal trends were generally consistent between sites lending confidence to the selection of HD0 as a reference site (Figure 37).

When monitoring commenced, foliage cover at sites in the drawdown ephemeral treatment was initially quite variable (Figure 37). Cover decreased at all of these sites between February and May 2007, soon after the start of dewatering. Sites HD1 and HD2 showed greater foliage cover reductions than HD3 and HD4 (Figure 37). The impact of any stress was short-lived, and foliage cover recovered progressively over subsequent monitoring intervals. By March 2008 cover was similar to levels measured prior to potential impact in October 2006. From September 2010 to December 2014, trends in foliage cover were similar at all these sites.

Trees in the drawdown perennial treatment showed much smaller declines in foliage cover after dewatering commenced than those upstream subject to ephemeral flows (Figure 37). The largest decline occurred in HD5, the perennial site closest to dewatering. The response at HD5 appeared delayed compared with ephemeral sites, as foliage cover continued to decline progressively from May reaching a minimum in October 2007. The delay in response may simply reflect the greater distance from dewatering at HD5 compared with ephemeral sites upstream, and longer timeframes for groundwater to respond. Similar to the upstream trend, foliage cover at HD5 subsequently recovered. Foliage cover was quite variable between sites in the drawdown perennial treatment, possibly a response to differential applications of water from spurs due to variations in the distance from a spur and the volumes applied at each site. Foliage cover at HD6 was consistently greatest for several years from 2007 to mid-2012, and cover was lowest at HD6a from June 2009 to April 2013.

Figure 37: Temporal responses in foliage cover for reference sites and for both ephemeral and perennial sites in areas potentially impacted by groundwater drawdown.

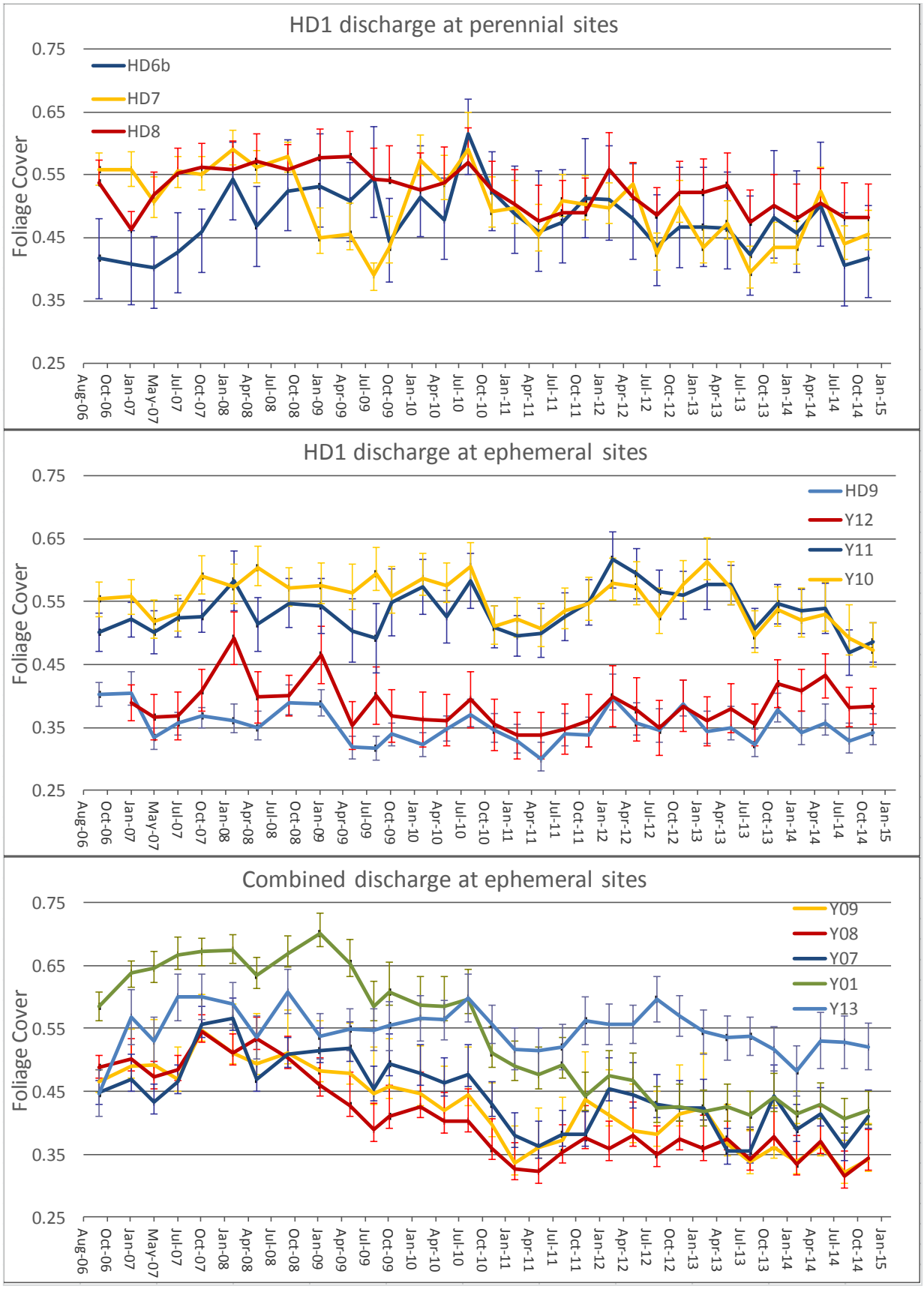


At perennial sites downstream of the gabion, sites subject to discharge from HD1 showed no evidence of early decline due to impact (Figure 38). Foliage cover was initially low in HD6b compared with other sites in this treatment, but tended to increase throughout 2007 and 2008. Foliage cover in HD7 showed a sharp decline in February 2007, the result of impacts of a bushfire at this site. These impacts persisted for some time, with foliage cover in HD7 declining further by September 2009, but subsequently recovering to levels similar to other sites by March 2010. Despite showing some seasonal responses, foliage cover in all sites in the perennial discharge treatment showed evidence of a gradual decline in foliage cover from September 2010 to 2014, a possible response to long-term or cumulative impacts of discharge.

The foliage cover of ephemeral sites subject to discharge from HD1 was initially quite variable (Figure 38) with lower foliage cover found in upstream sites closest to the springs (HD9 and Y12) compared downstream sites (Y11 and Y10). These differences persisted throughout the study period from 2007 to 2014. There was evidence for a gradual decline in foliage cover throughout the study period in the upstream ephemeral site closest to the gabion (HD9), and cover in Y11 and Y12 showed evidence of a gradual decline from 2013.

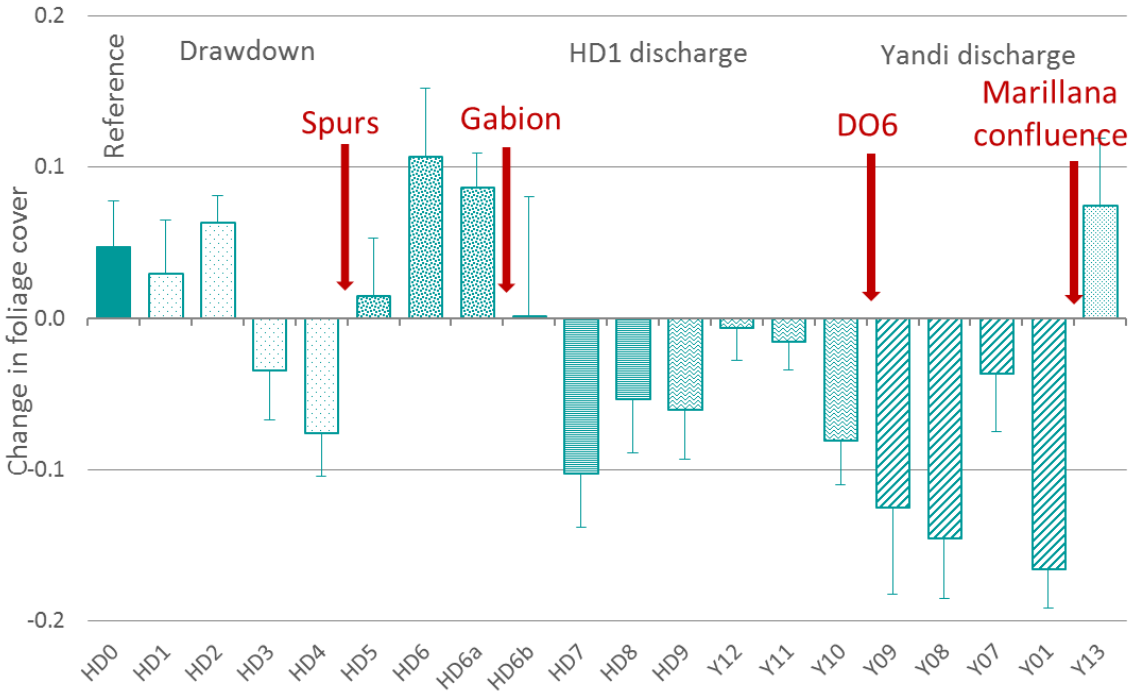
Ephemeral sites further downstream showed differing responses in foliage cover to combined discharges from HD1 and Yandi (Figure 38). Foliage cover at the site downstream of the confluence with Marillana (Y13) was initially low, but increased following the start of discharge from DO6. Trees at Y13 largely maintained this level of cover throughout subsequent years, but showed evidence of decline from September 2012. Trees at this site had potentially been subject to impacts of discharges into Marilla Creek for some years prior to the start of this study. Foliage cover at Y01, close to the confluence with Marillana, was greater at the start of monitoring than all other sites downstream of DO6 discharge. After an initial increase to February 2009 foliage cover progressively declined at this site, reaching a minimum in September 2014. It may be possible that this response reflect the impacts of Yandi discharges into both Marillana and Weeli Wolli Creeks, due to the site's proximity to the confluence. Foliage cover of trees at sites (Y07, Y08 and Y09) increased slightly from August to November 2007, each reaching maxima for the study period in either late 2007 or early 2008. Cover at all these sites subsequently showed a gradual decline for the remainder of the study, reaching minima in September 2014.

Figure 38: Temporal responses in foliage cover for sites potentially affected by discharge. Foliage cover is shown for both ephemeral and perennial sites downstream of HD1 discharge and for ephemeral sites downstream of combined discharges from HD1 and Yandi.



The impacts of the different water management regimes on eucalypt foliage cover over the entire study period are represented below in Figure 39. In this figure, positive values represent an increase in foliage cover between October 2006 and December 2014, and negative values a decrease. With the exception of ephemeral sites subject to drawdown, site responses in foliage cover were generally consistent within treatments.

Figure 39: Change in foliage cover of study sites from the start of monitoring in October 2006 to December 2014. Sites in similar treatments (drawdown ephemeral; drawdown perennial; HD1 discharge perennial, HD1 discharge ephemeral and Yandi discharge ephemeral) are represented by bars with similar fill patterns.

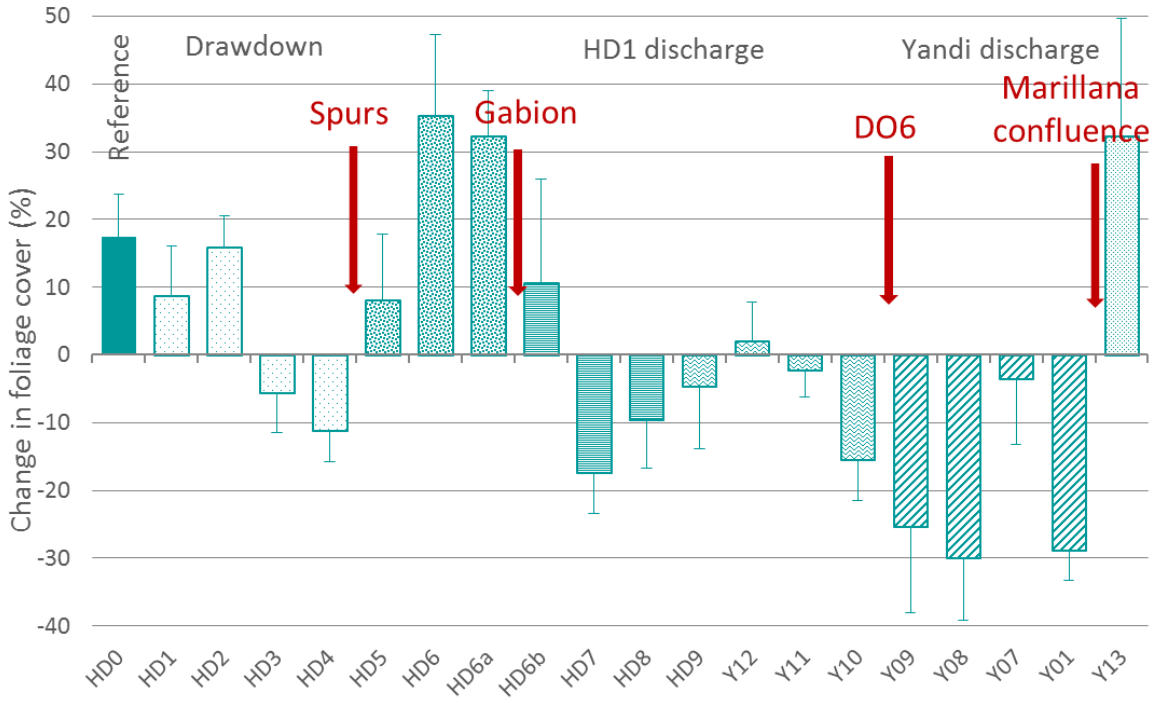


Foliage cover increased over the study period at the reference site HD0. Cover also increased in the perennial drawdown sites, most likely a response to spur discharges along this section of Weeli Wolli Creek. Site responses were variable at the ephemeral drawdown sites upstream of the spurs, as foliage cover increased at sites HD1 and HD2, but decreased at HD3 &HD4. It is possible that these contrasting responses resulted from changes in surface water management associated with the HD1 mine site, and the diversion of Pebble Mouse Creek. This may have reduced surface water availability to HD4, and increased availability to HD2. Thus any impacts of drawdown at these sites may be either masked or magnified by surface water management interventions.

Tree responses to discharge over the study period were largely consistent, with foliage cover decreasing at sites in both ephemeral and perennial areas of Weeli Wolli Creek (Figure 39). Exceptions were sites HD6b where foliage cover was similar at the start and finish of the study, and Y13 where foliage cover increased.

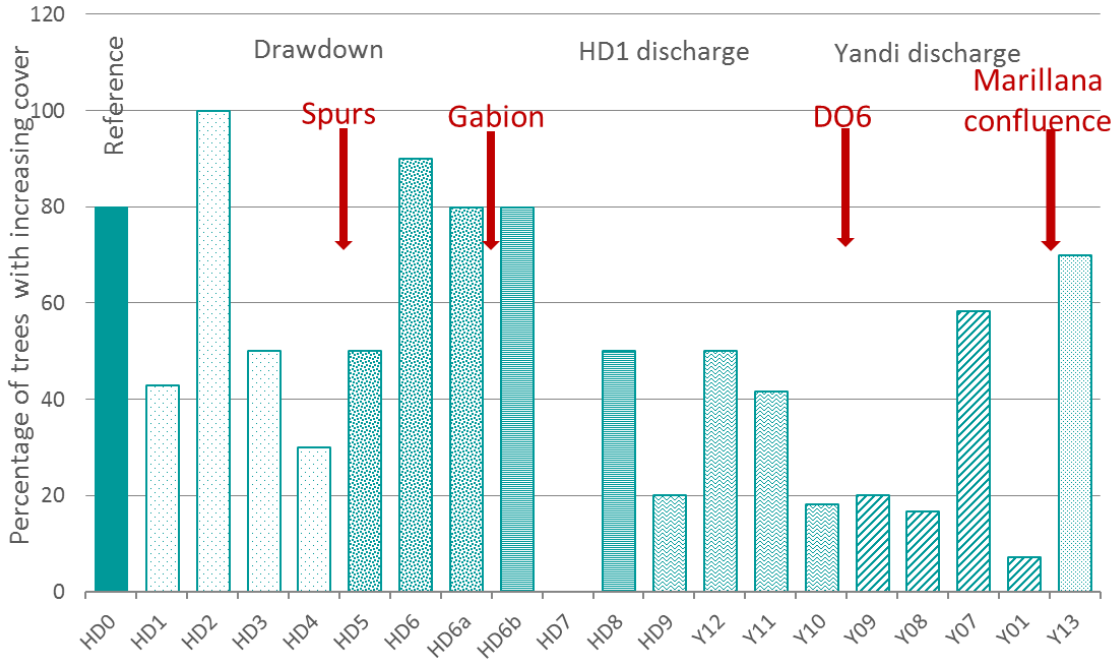
Trends in the percentage change in foliage cover over the study period (Figure 40) are generally consistent with the absolute changes in foliage cover shown above (Figure 39). Increases in foliage cover at sites in the perennial drawdown treatment ranged from 8.1% to 35.2%, and foliage cover of trees at Y13 increased by 32%. Decreases in foliage ranged from -2.3% in Y11 to -29.9% at the worst affected site, Y08. A small net decrease in foliage cover at Y12 represented a mean relative increase of 2% in cover at this site. This occurs because increases in foliage cover found for some trees at the site were larger relative to their original cover than the relative size of the decrease occurring in others. This suggests that the responses of all trees at a particular site to management impacts aren't necessarily consistent.

Figure 40: Percentage change in foliage cover of study sites from the start of monitoring in October 2006 to December 2014. Sites in similar treatments (drawdown ephemeral; drawdown perennial; HD1 discharge perennial, HD1 discharge ephemeral and Yandi discharge ephemeral) are represented by bars with similar fill patterns.



The variability in response between trees at a site is further illustrated by Figure 41, which shows the proportion of trees at each site which increased their foliage cover over the study period. HD2 was the only site where foliage cover of all trees increased, and HD7 the only site where cover declined in all trees. At sites showing the greatest decreases in foliage cover (Y01 and Y08), foliage cover increased in 7.1% (1 in 14) and 16.7% (2 in 12) of trees at the site, respectively.

Figure 41: Percentage of trees at each site showing an increase in foliage cover over the study period from October 2006 to December 2014.



3.6. Factors influencing foliage cover responses

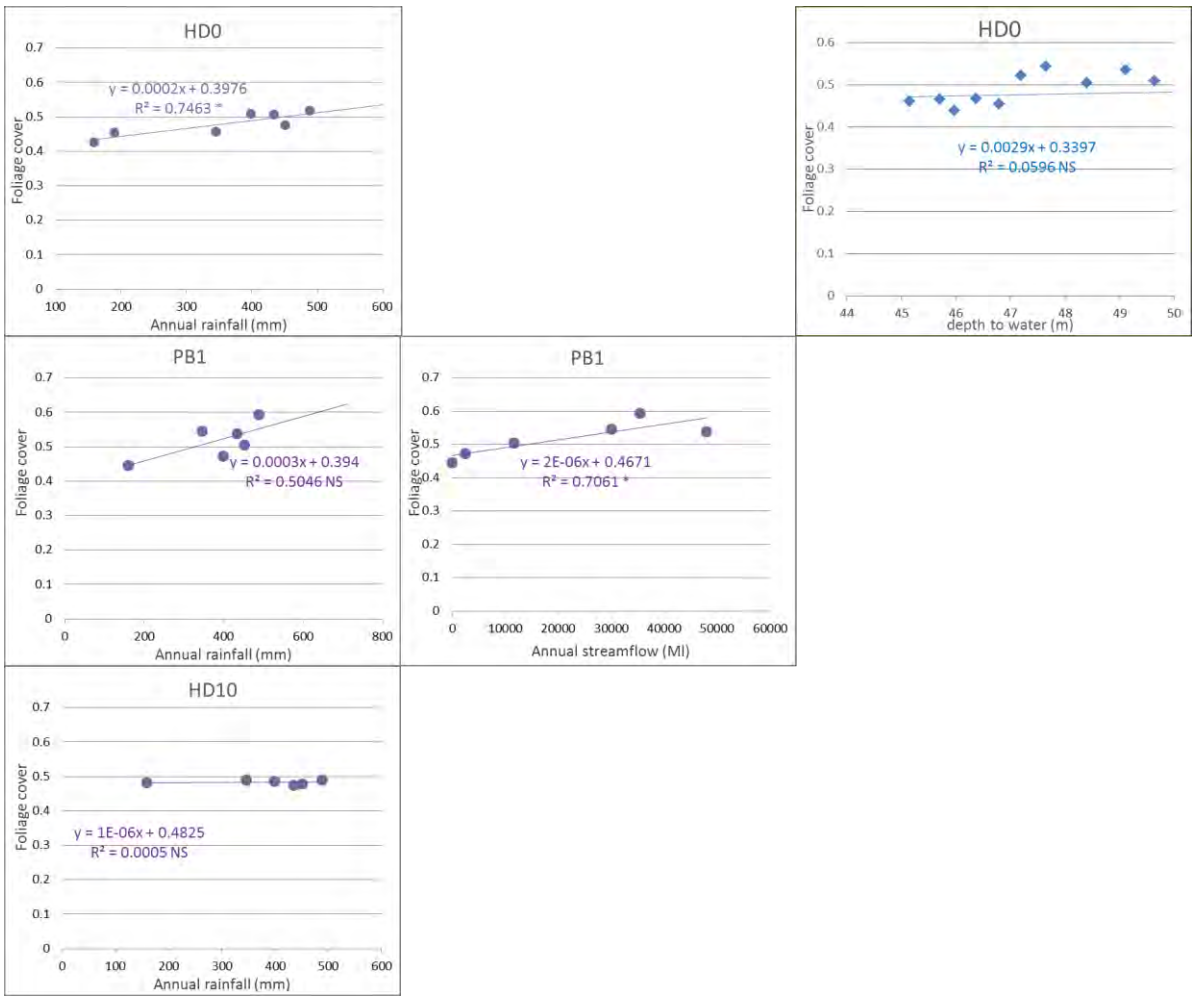
Correlations between foliage cover and hydrological variables including rainfall, streamflow, estimated depth to water and discharge reveal the key influences on vegetation responses at the different sites. To identify the most useful relationships, different rainfall statistics such as annual rainfall, wet and dry season rainfall and quarterly rainfall were used to correlate separately with foliage cover measured in Q1, Q2, Q3 and Q4 (data not shown). The rainfall statistic and quarterly foliage cover that gave the most frequent significant correlations across all sites was Q4 foliage cover regressed against annual rainfall. This result may appear counter-intuitive given that a proportion of annual rainfall may not have been received when Q4 monitoring was undertaken. Part of the explanation for this result may lie with the fact that monitoring was carried out in December for 5 out of the 7 years of monitoring. A further explanation is that vegetation growth may be particularly responsive to water availability under the warm temperature conditions of spring, and this response is best captured in the Q4 data. Correlations between annual rainfall and Q4 foliage cover was thus selected as the most reliable indicator of site response to rainfall.

3.6.1. Factors influencing foliage cover responses at reference sites

Estimates of groundwater depth were unavailable for sites HD10 and PB1, and streamflow data were unavailable for HD0 and HD10. Foliage cover at reference site HD0 did not respond significantly to changing groundwater depth due to drawdown (Figure 42), most likely because it was too deep (>45 m) to be readily accessible for uptake by tree roots.

This lack of a significant relationship with groundwater supports the use of HD0 as a reference site, given that foliage cover data is only available from June 2009 for sites HD10 and PB1.

Figure 42: Relationships between foliage cover and annual rainfall, annual streamflow and estimated depth to water for reference sites HD0, PB1 and HD10. Q4 foliage cover is used to correlate with annual rainfall and streamflow at Waterloo Bore. Foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



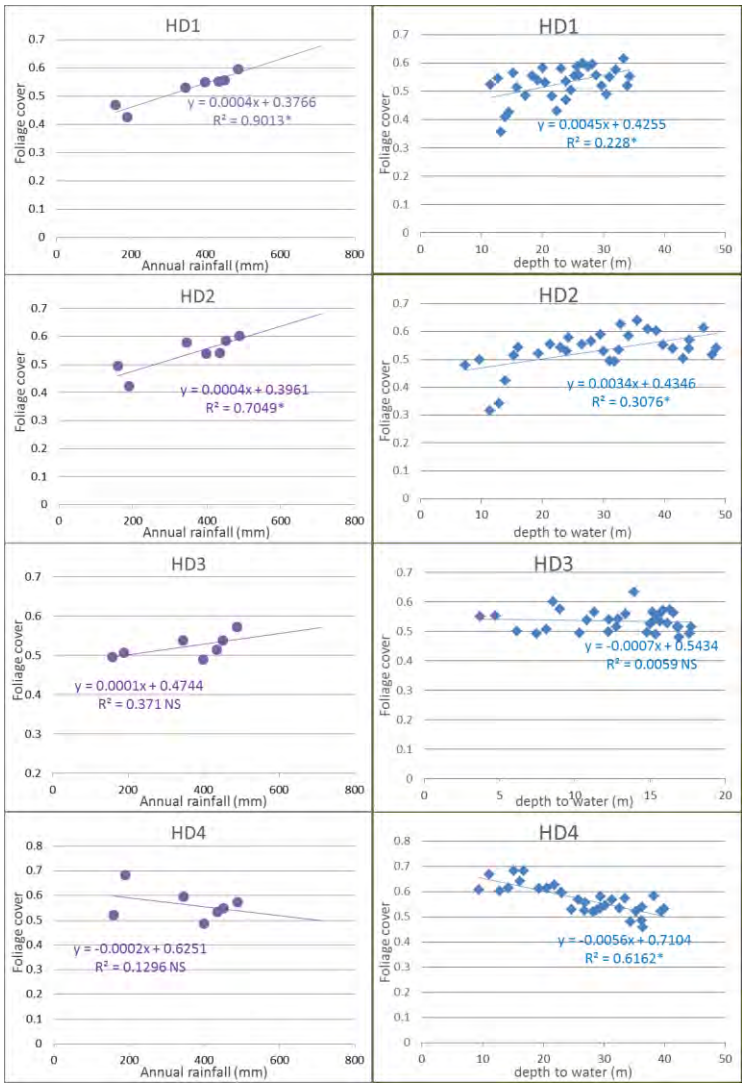
Foliage cover at HD0 was positively correlated with annual rainfall, but relationships for PB1 and HD10 were not significant. However, PB1 foliage cover was positively correlated with streamflow at Waterloo Bore. The lack of a significant relationship with rainfall at PB1 may partly result from the few data points and lower degrees of freedom to test the statistical significance of the correlation. Q4 foliage cover at HD10 showed little change with time, making it unlikely that a statistically significant relationship could result from regression analyses.

3.6.2. Factors influencing foliage cover responses at ephemeral drawdown sites

Foliage cover at HD1 and HD2 were positively correlated with annual rainfall, but relationships for HD3 and HD4 were not significant (Figure 43). The sites showed

contrasting responses to impacts of drawdown, with foliage cover at HD4 decreasing as groundwater levels fell, whilst cover at HD1 and HD2 increased with increasing depth. It is likely these contrasting responses result from changes to surface water management due to the diversion of Pebblemouse creek. This would have reduced the volume of streamflow to HD4 located downstream of the diversion on Pebblemouse Creek, and increased flow to sites along Weeli Wolli Creek.

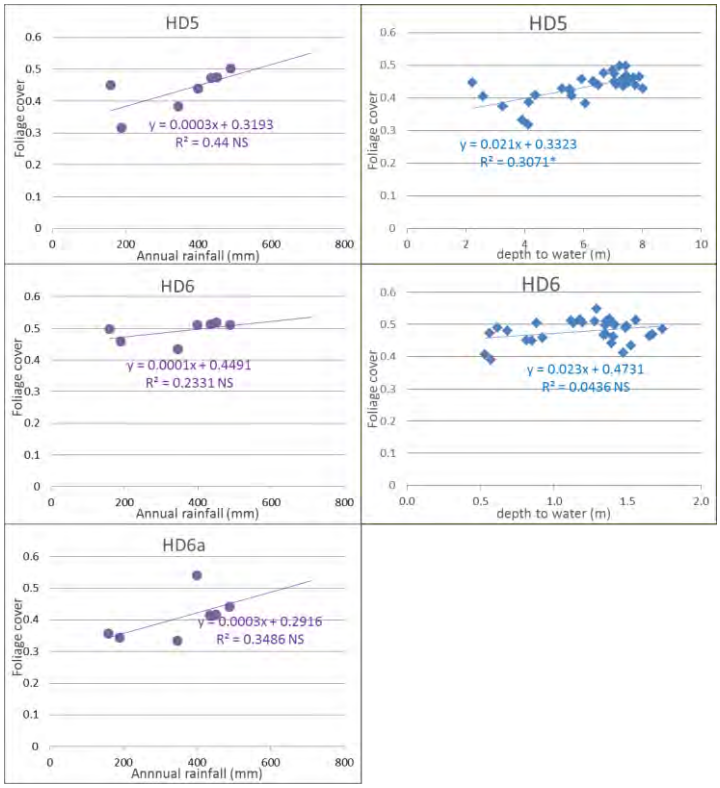
Figure 43: Relationships between foliage cover and annual rainfall and estimated depth to water for ephemeral drawdown sites HD1, HD2, HD3 and HD4. Q4 foliage cover is used to correlate with annual rainfall and foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



3.6.3. Factors influencing foliage cover responses at perennial drawdown sites

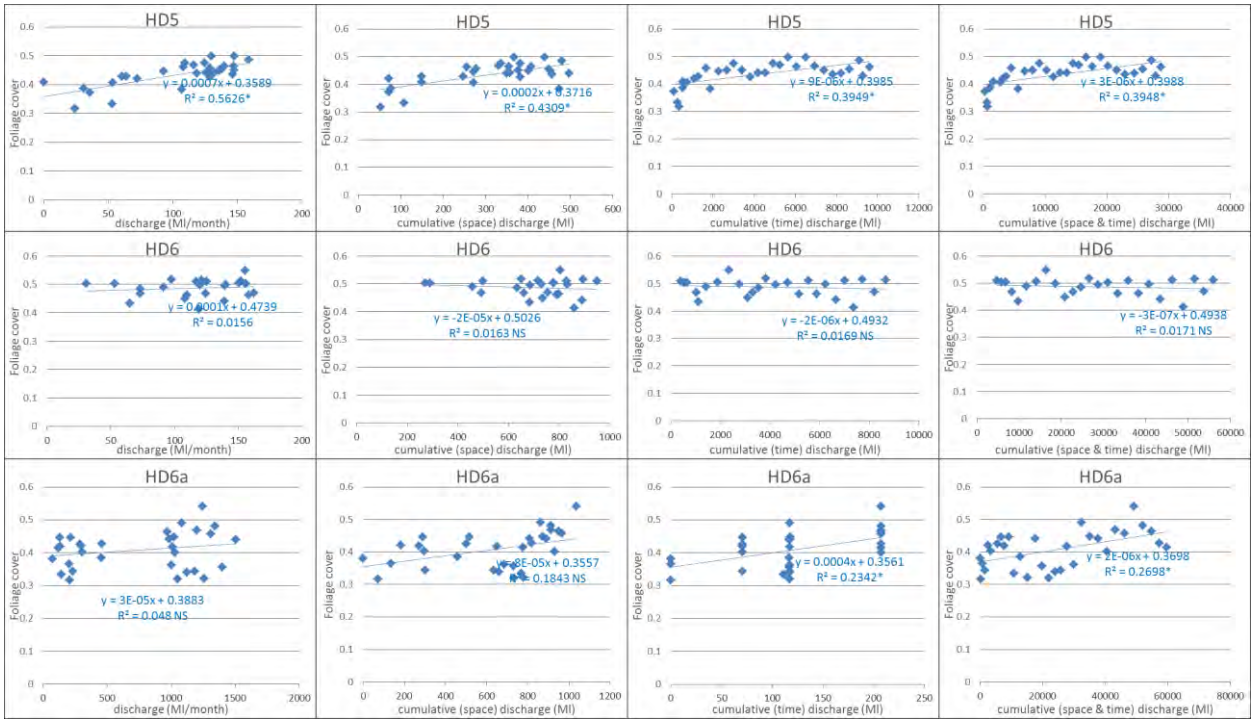
Although each of the eucalypt sites in the perennial drawdown zone HD5, HD6 and HD6a showed increasing trends with rainfall, correlation coefficients for the relationships weren't statistically significant (Figure 44).

Figure 44: Relationships between foliage cover and annual rainfall and estimated depth to water for perennial drawdown sites HD5, HD6, and HD6a. Q4 foliage cover is used to correlate with annual rainfall and foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



Foliage cover at HD5 showed a positive correlation with increasing depth to water. This most likely occurs through the co-incidence of increasing volumes of spur discharge with time as groundwater levels decreased (Figure 15). Foliage cover at HD5 was closely correlated with the rate of discharge from the nearby spur, and also correlated with discharges accumulated from upstream spurs and with time (Figure 45). At perennial sites further downstream (HD6 and HD6a) where impacts of drawdown were less pronounced, foliage cover was generally unresponsive to local spur discharge. However, the increase through time in foliage cover observed at HD6a (Figure 37) could be explained through the significant response to cumulative spur discharges (Figure 45).

Figure 45: Relationships between foliage cover and discharge from the nearest spur for perennial drawdown sites HD5, HD6, and HD6a. Separate relationships are shown for discharge rates; cumulative (space) discharge which includes discharge accumulated from all upstream spurs; cumulative (time) discharge which includes all discharge from the nearest spur accumulated with time; and cumulative (space and time) discharge which includes all discharge from upstream spurs accumulated with time.



3.6.4. Factors influencing foliage cover responses at perennial discharge sites

Downstream of the gabion, foliage cover at perennial sites HD6a, HD7 and HD8 all tended to decrease with increases in both rainfall and streamflow (Figure 46), but these relationships weren't statistically significant. None of these sites showed a statistically significant response to the rising water levels that resulted from discharge (Figure 46). However, foliage cover at both HD7 & HD8 showed evidence of a negative response to volumes of discharge from the gabion (Figure 47). Foliage cover at HD7 decreased with increasing rates of gabion discharge and with volumes of discharge accumulated both through space and time. HD8 foliage cover was negatively impacted by cumulative discharge. It is possible that some decline in foliage cover at HD7 resulted from impacts of bushfire. However, evidence of the subsequent recovery after the fire (Figure 38) and the negative response to cumulative discharge observed at HD8 further downstream together suggest that discharge is impacting negatively on tree health at these sites. The consistency in trends of decreasing foliage cover with increasing rainfall and streamflow at all 3 sites also supports a hypothesis that an excess of water is impacting on tree health.

Figure 46: Relationships between foliage cover and annual rainfall; annual streamflow and estimated depth to water for perennial discharge sites downstream of the gabion (HD6b, HD7 and HD8). Q4 foliage cover is used to correlate with annual rainfall and streamflow and foliage cover for all monitoring dates is correlated with estimated depth to water for that month.

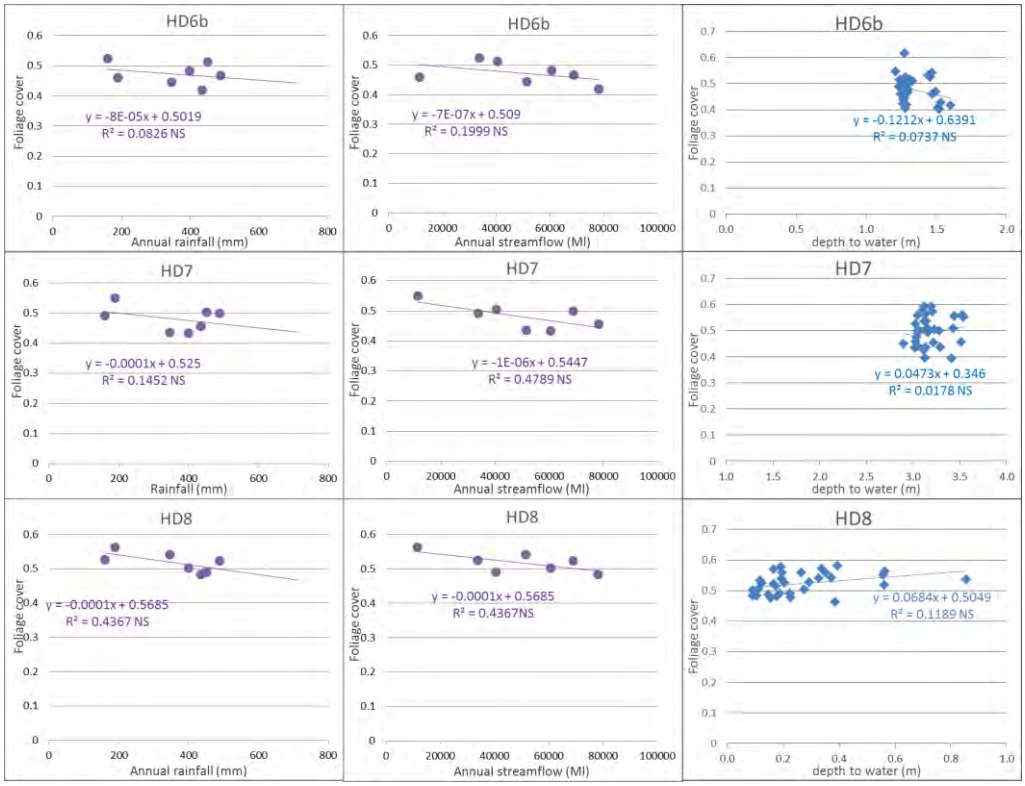
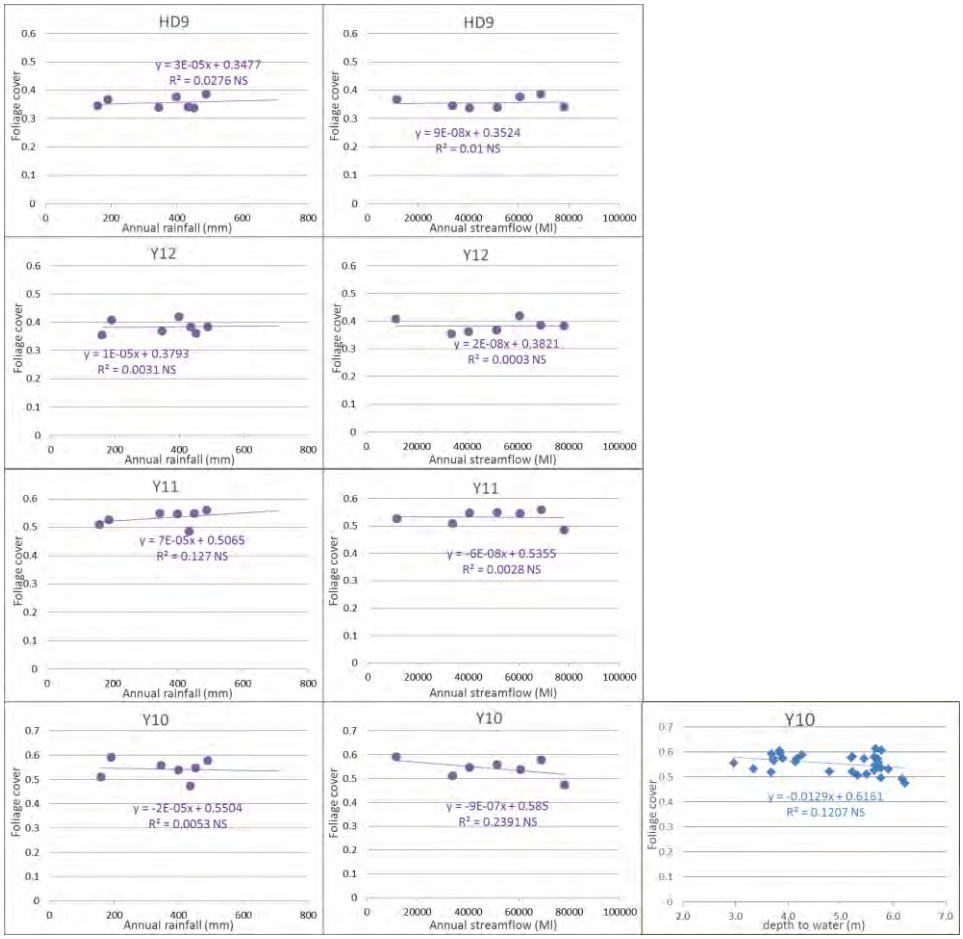


Figure 47: Relationships between foliage cover and discharge for perennial discharge sites downstream of the gabion HD6b, HD7 and HD8. Separate relationships are shown for gabion discharge rates; cumulative (space) discharge which includes discharge accumulated from the gabion and spurs; cumulative (time) discharge which includes discharge from the gabion accumulated with time; and cumulative (space and time) discharge which includes all discharge from the gabion and spurs accumulated with time.

3.6.5. Factors influencing foliage cover responses at annual discharge sites between the gabion and Yandi

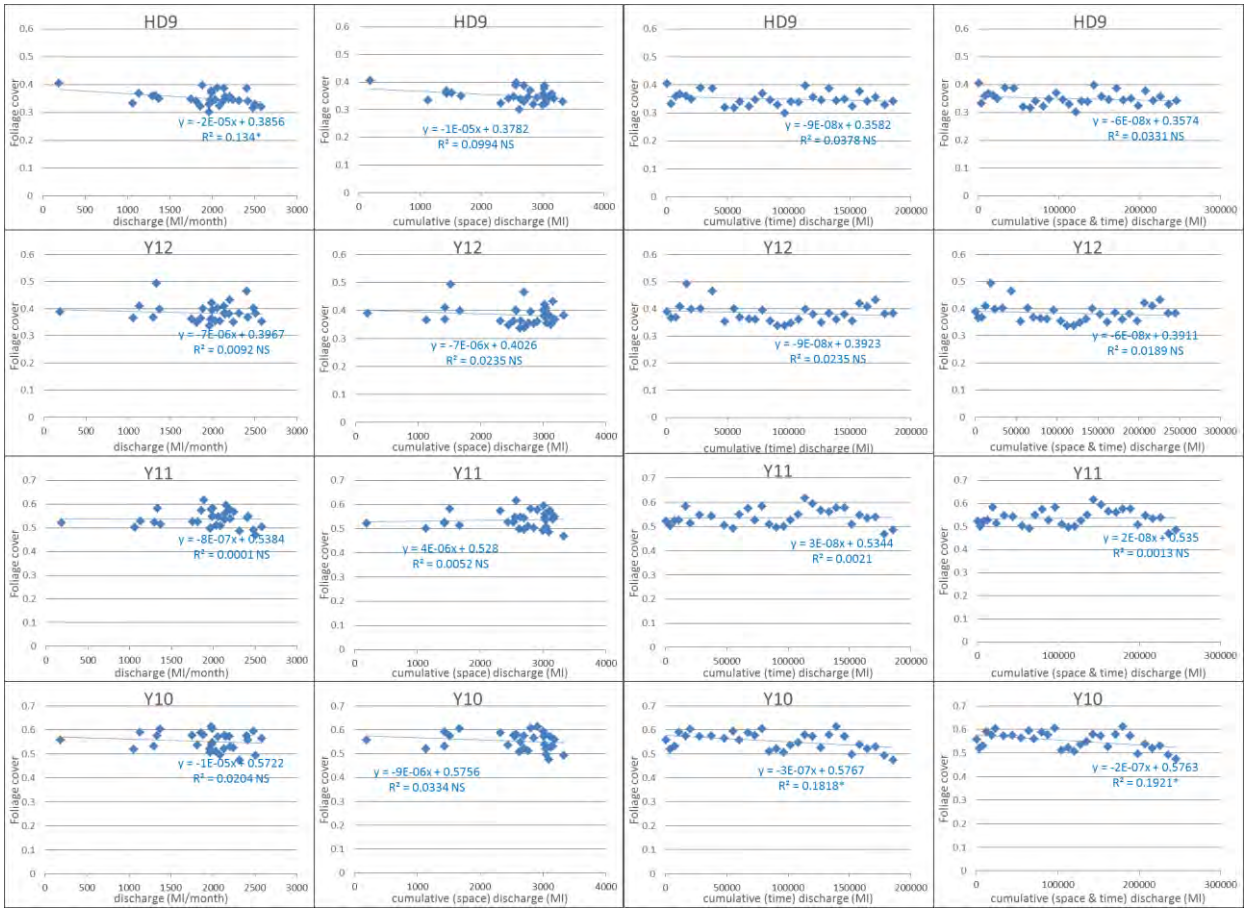
Further downstream, Q4 foliage cover at previously ephemeral sites HD9, Y12, Y11 and Y10 exposed to discharge from the gabion, didn't respond to increasing annual rainfall or streamflow (Figure 48). Declining foliage cover at Y10 also didn't appear to be related to falling water levels caused by dewatering at JSE (Figure 48). However, the decline in foliage cover observed at the ephemeral site closest to the gabion (HD9) was significantly related to the rate of discharge from the gabion (Figure 49).

Figure 48: Relationships between foliage cover and annual rainfall; annual streamflow and estimated depth to water for annual discharge sites downstream of the gabion (HD9, Y12, Y11 and Y10). Q4 foliage cover is used to correlate with annual rainfall and streamflow and foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



Further downstream, foliage cover at Y10 showed a negative response to cumulative discharge (Figure 49). However, eucalypts at sites between HD9 and Y10 (Y12 and Y11) weren't adversely affected by discharge volumes. Thus responses to discharge were somewhat variable along the ephemeral section of Weeli Wolli Creek between the gabion and Yandi.

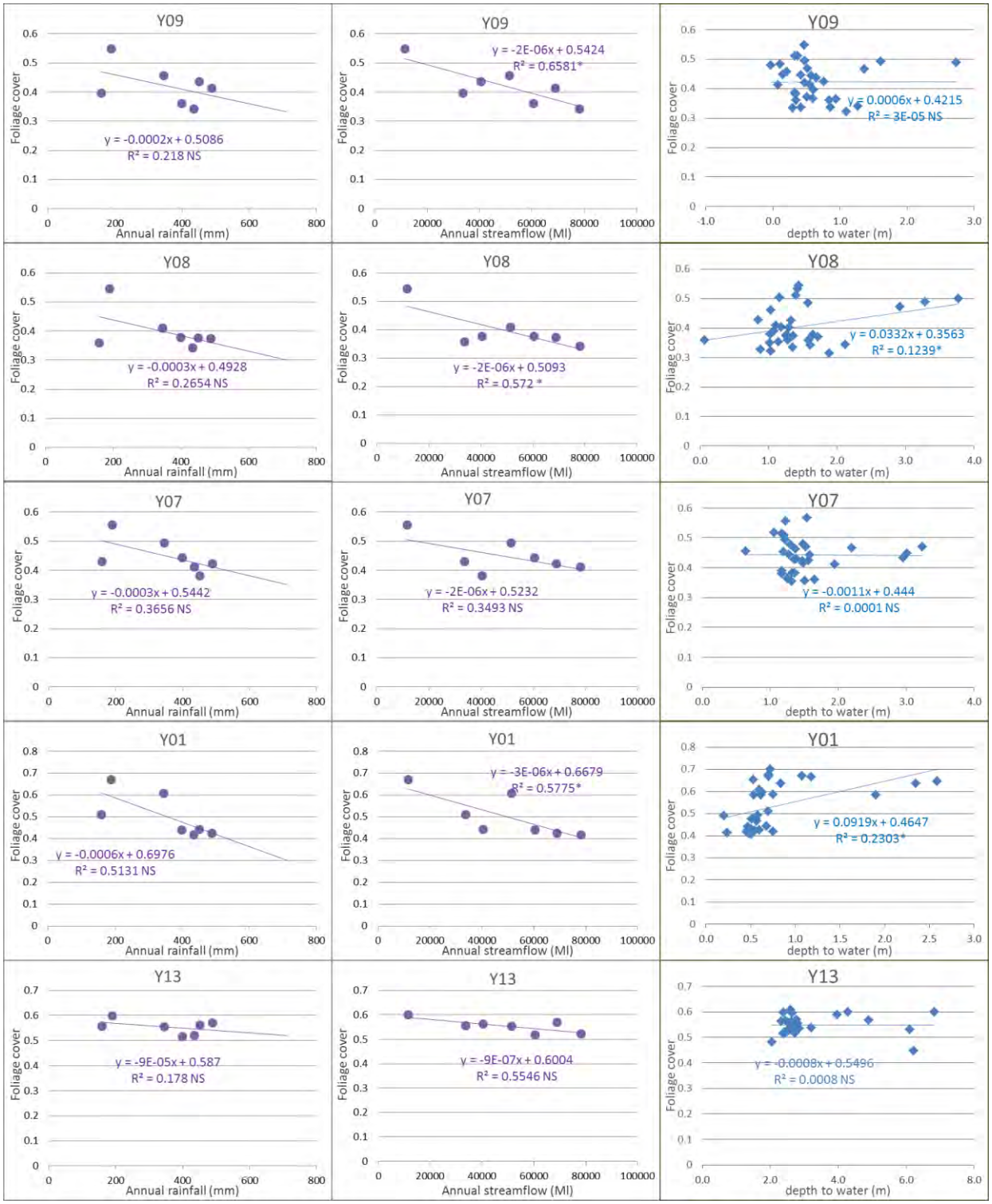
Figure 49: Relationships between foliage cover and discharge for annual discharge sites downstream of the gabion (HD9, Y12, Y11 and Y10). Separate relationships are shown for gabion discharge rates; cumulative (space) discharge which includes discharge accumulated from the gabion and spurs; cumulative (time) discharge which includes discharge from the gabion accumulated with time; and cumulative (space and time) discharge which includes all discharge from the gabion and spurs accumulated with time.



3.6.6. Factors influencing foliage cover responses at discharge sites downstream of Yandi D06

The foliage cover at sites downstream of DO6, Y09, Y08, Y07, Y01 and Y13 all responded similarly to annual rainfall and streamflow, showing a decreasing trend as these factors increased (Figure 50). Relationships between foliage cover and rainfall were not statistically significant for any of the sites, but relationships with annual streamflow were significant for sites Y09, Y08 and Y01. Foliage cover at Y08 and Y01 also showed significant responses to changing depth to water, with rising water levels associated with decreasing foliage cover (Figure 50).

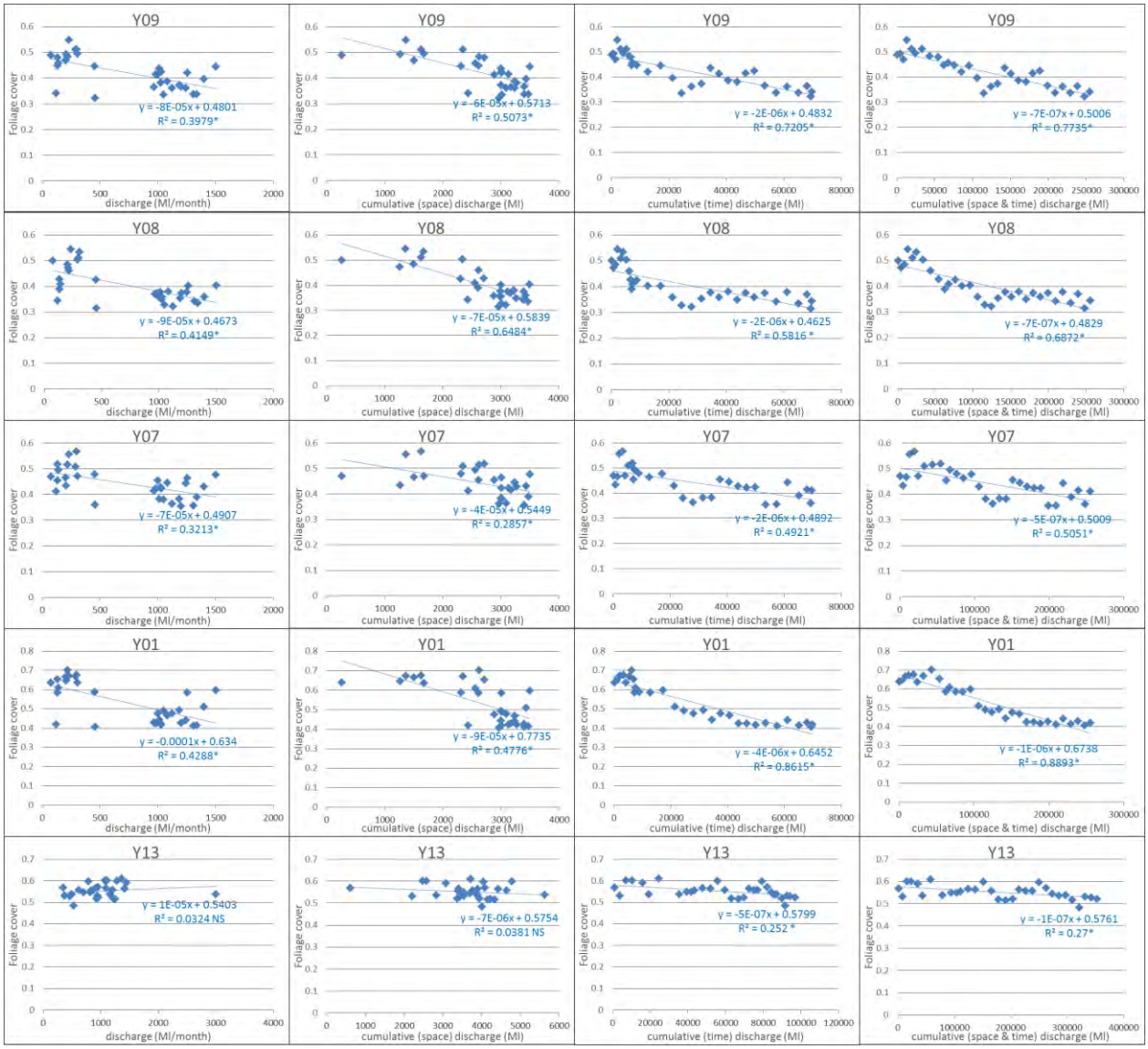
Figure 50: Relationships between foliage cover and annual rainfall; annual streamflow and estimated depth to water for annual discharge sites downstream of Yandi discharge outlet DO6 (Y09, Y08, Y07, Y01 and Y13). Q4 foliage cover is used to correlate with annual rainfall and streamflow and foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



Increasing rates of discharge from D06 reduced foliage cover for each of the sites Y09, Y08, Y07 and Y01 (Figure 51), and relationships between foliage cover and discharge rate were found to be significant for each of these sites. In addition to negative impacts of local

discharge rates, there was also evidence of cumulative impacts on vegetation health, with a trend of increasingly significant responses in foliage cover to discharge accumulated in space and in time. At sites Y09, Y08, Y07 and Y01 correlations with discharge were most significant for relationships with volumes accumulated through both space (i.e. including discharge from DO6, the gabion and spurs) and time (Figure 51). In contrast to these sites, foliage cover further downstream at Y13 wasn't responsive to combined rates of local discharge from DO6 and into Marillana Creek (Figure 51).

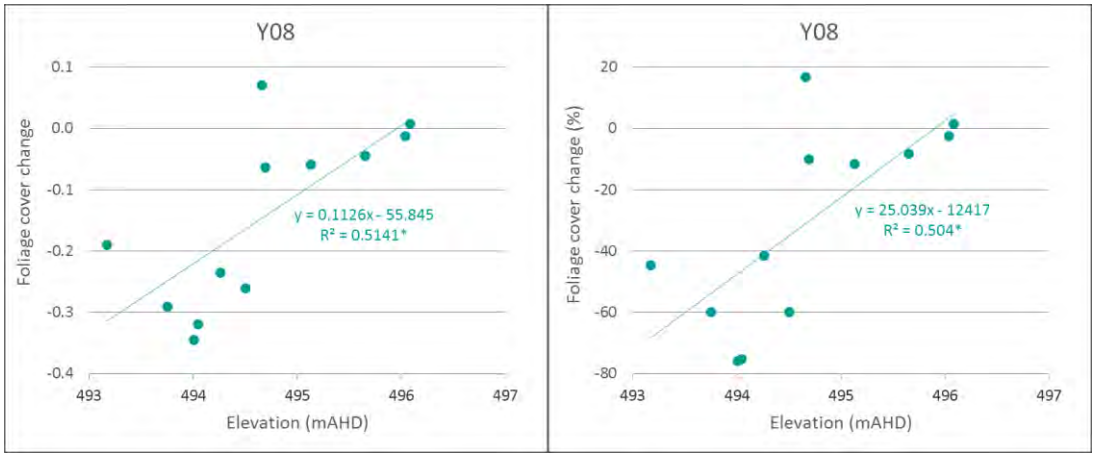
Figure 51: Relationships between foliage cover and discharge for discharge sites downstream of downstream of Yandi discharge outlet DO6 (Y09, Y08, Y07, Y01 and Y13). Separate relationships are shown for DO6 discharge rates; cumulative (space) discharge which includes all discharge accumulated from upstream; cumulative (time) discharge which includes discharge from DO6 accumulated with time; and cumulative (space and time) discharge which includes all discharge from DO6, the gabion and spurs accumulated with time.



This contrast most likely arises because of the difference in the depth to water table experienced by trees at Y13 compared with those at the other sites (Figure 29). The water table remained at a depth of greater than 2 m at Y13, but was consistently shallower throughout the study period at sites Y09, Y08, Y07 and Y01. From 2008 to early 2014, levels were less than 1 m depth at Y09 and Y01. Although foliage cover of trees at Y13 weren't influenced by local discharge rates, there was evidence that they experienced a decline due to cumulative impacts of discharge (Figure 51). The effect appeared to be principally related to volumes of local discharge from DO6 and into Marillana Creek accumulated through time, since the response in foliage cover to discharge volumes accumulated from upstream (Marillana, DO6, gabion and spurs) was not significant.

Although site mean foliage cover data indicated declining foliage cover at discharge sites, responses of individual trees at some sites were related to their elevation. Trees at low elevations tended to show larger declines in foliage cover and those at higher elevations increased their cover. For example, at site Y08 there was significant positive relationship between the change in foliage cover from October 2006 to December 2014 and elevation (Figure 52). This response most likely results from greater impacts of waterlogging on tree health for those trees in lower landscape positions. In contrast, trees at higher elevations may benefit from greater access to water from the capillary fringe.

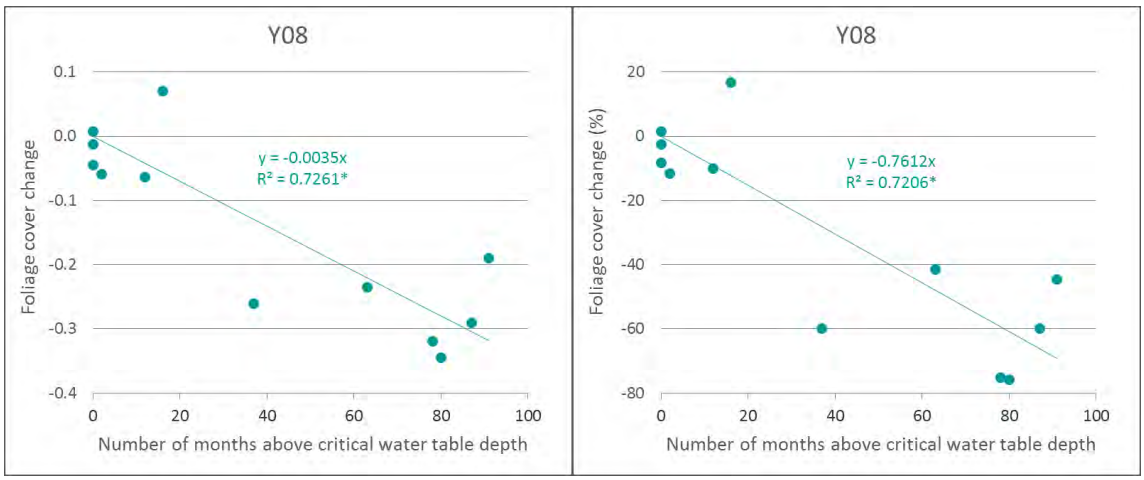
Figure 52: Relationship between elevation and change in foliage cover from October 2006 to December 2014 for individual trees at site Y08. The relationship between elevation and percentage change in foliage cover is also shown.



Given the dependence of tree foliage cover on elevation, and the significant relationship between mean foliage cover and depth to water for Y08 (Figure 50) over the study period, analyses were undertaken to identify a critical depth to water influencing foliage cover decline at Y08. The number of months over the study period that depth to water was less than this critical depth was calculated from estimated water levels (Figure 29) and elevation for each tree at Y08. Change in foliage cover over the study period was plotted as a function of the number of months levels were above the critical level, and regression analysis used to

identify the critical depth that gave the best correlation for this relationship for trees at Y08 (Figure 53). A depth to water of about 1 m (0.98 m) was found to be the critical depth that best explained the change in foliage cover over the study period for individual trees at Y08.

Figure 53: Relationship between change in foliage cover from October 2006 to December 2014 and the number of months that depth to water was less than 1.0 m for individual trees at site Y08. The relationship between the number of months and percentage change in foliage cover is also shown.

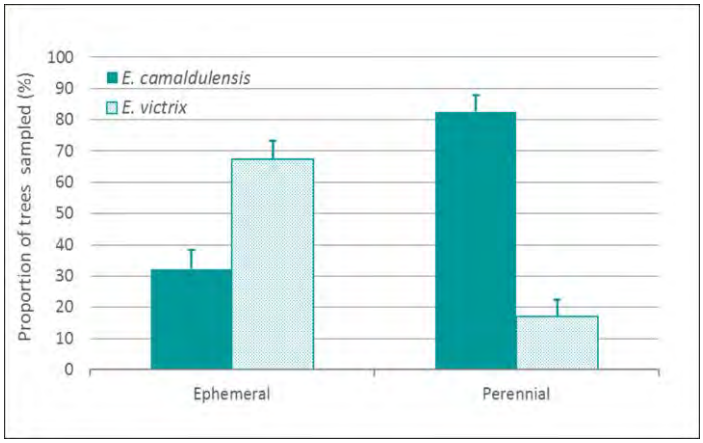


3.6.7. Responses of *Eucalyptus victrix* and *Eucalyptus camaldulensis* to drawdown and discharge

Distribution of Eucalyptus victrix and Eucalyptus camaldulensis

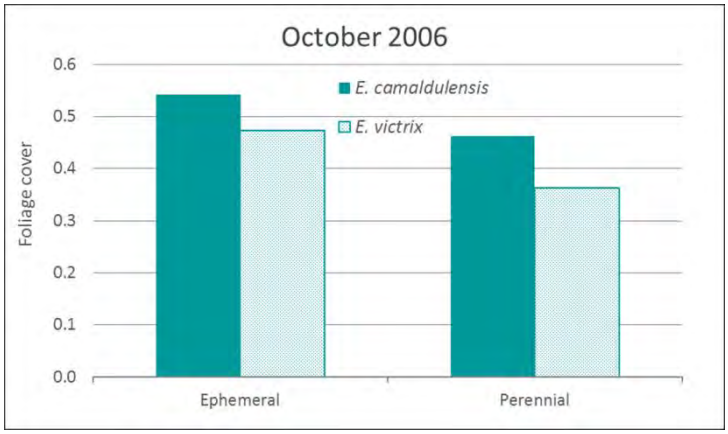
Analysis of the proportion of trees monitored at each site that were *E. camaldulensis* (Ec) or *E. victrix* (Ev) revealed statistically significant differences in their distribution between sites with previously ephemeral or perennial flow (Figure 54). Ec occurred more frequently than Ev at sites with perennial flow (Figure 54) but Ev was found to be more common at ephemeral sites. An analysis of the distribution of these species between beds and banks at perennial and ephemeral sites found no significant difference in their distribution (i.e. Ev was equally likely to be found on beds or banks at ephemeral and perennial sites as Ec).

Figure 54: The proportion of trees monitored at ephemeral and perennial sites that were *E. camaldulensis* or *E. victrix*



Two-way ANOVA was used to compare the foliage cover of Ev and Ec at ephemeral and perennial sites in October 2006 (i.e. prior to drawdown or discharge). Foliage cover of both Ev and Ec was found to be significantly greater at ephemeral compared with perennial sites (Figure 55). However, there was no significant different in the foliage cover of each species at ephemeral compared with perennial sites.

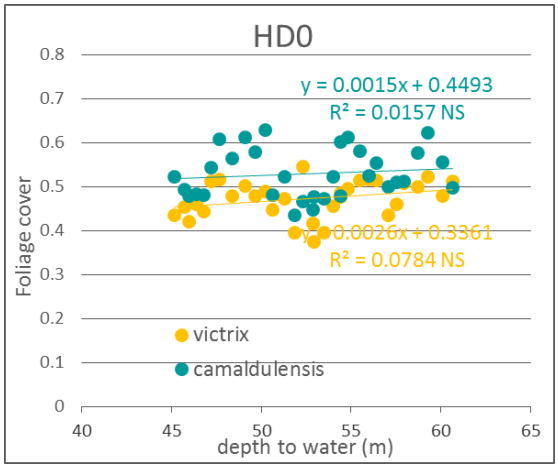
Figure 55: Mean foliage cover of *E. camaldulensis* and *E. victrix* at ephemeral and perennial sites in October 2006.



Responses to drawdown and discharge

At the reference site HD0 where the groundwater was originally greater than 45 m, the responses of *E. camaldulensis* and *E. victrix* were similar, with neither species showing a change in foliage cover with falling water levels (Figure 56).

Figure 56: Relationships between foliage cover and estimated depth to water for *Eucalyptus victrix* and *Eucalyptus camaldulensis* at reference site HD0



The responses of Ev and Ec to drawdown and changing streamflow due to the diversion of Pebblemouse Creek were not consistent between sites (Figure 57). The statistically significant relationships between mean foliage cover and groundwater depth observed at sites HD1 and HD2 (Figure 43) reflected significant relationships for Ev at HD1 and Ec at HD2 (Figure 57).

Further downstream at HD3, the foliage cover of neither species responded to changing groundwater depth. The decrease in foliage cover with increasing depth to groundwater observed at HD4 (Figure 43) was due solely to responses of Ev, since there were no Ec monitored at this site.

Figure 57: Relationships between foliage cover and estimated depth to water for *Eucalyptus victrix* and *Eucalyptus camaldulensis* at ephemeral drawdown sites HD1, HD2, HD3 and HD4.

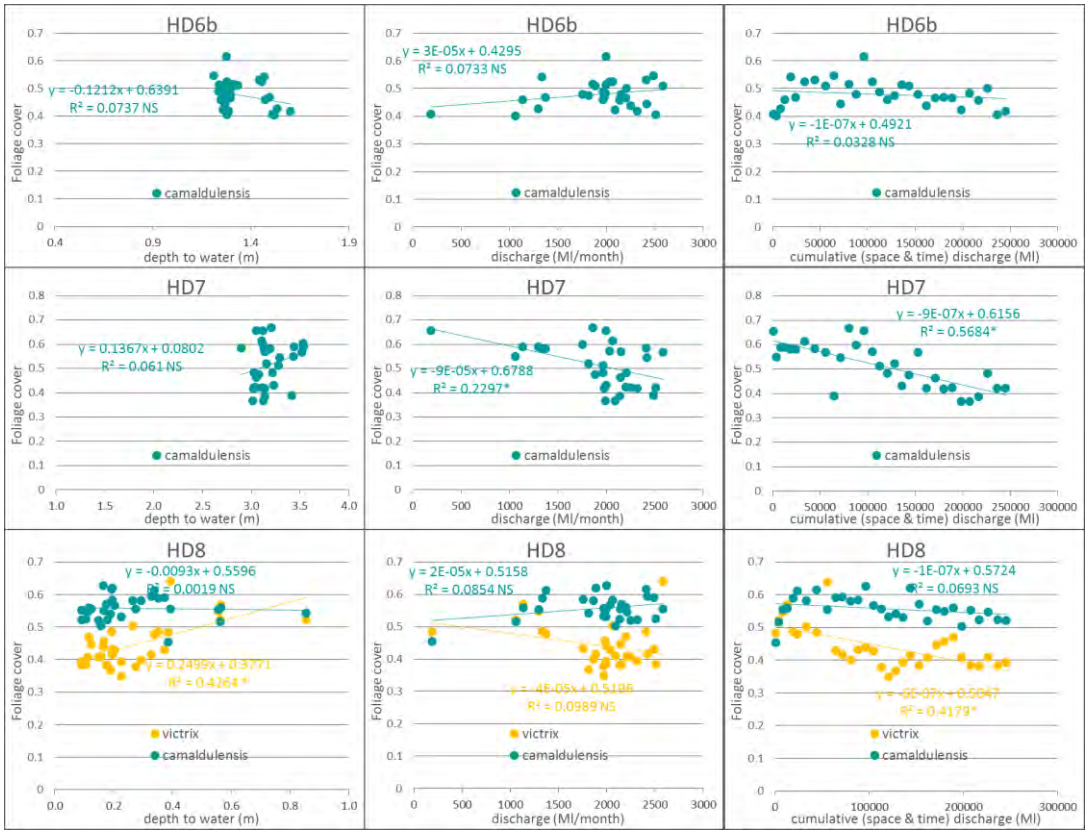
The responses of Ev and Ec to drawdown and discharge were also inconsistent between sites in the previously perennial springs area of Weeli Wolli Creek (Figure 58).

Figure 58: Relationships between foliage cover of *Eucalyptus victrix* and *Eucalyptus camaldulensis* and estimated depth to water and discharge from the nearest spur for perennial drawdown sites HD5, HD6, and HD6a. Separate relationships are also shown for cumulative (space and time) discharge which includes all discharge from upstream spurs accumulated with time.

The increases in mean foliage cover with increasing depth to groundwater observed at HD5 (Figure 44) resulted from changes in Ec foliage cover, and Ev appeared unresponsive to either parameter. In contrast, foliage cover of Ev increased as depth to water increased at HD6 (Figure 58), with Ec showing no response at this site. Ev and Ec also showed inconsistent responses to spur discharge, with foliage cover of Ec increasing as discharge increased at HD5, and Ev showing a significant response to discharge at HD6a. Neither species responded to discharge volumes at HD6.

At perennial discharge sites beyond the gabion, relationships between foliage cover of Ec and depth to water were not significant at any of the sites HD6b, HD7 and HD8 (Figure 59). Responses of Ec to discharge were inconsistent between these sites, with foliage cover declining in response to increasing discharge rates and volumes at HD7, but no significant response observed at HD6b and HD8. Ev was not present at sites HD6b and HD7 but further downstream at HD8, foliage cover of Ev appeared more sensitive to impacts of discharge than Ec. Ev foliage cover decreased with decreasing depth to water at this site, and was also significantly reduced at increasing discharge rates and cumulative volumes.

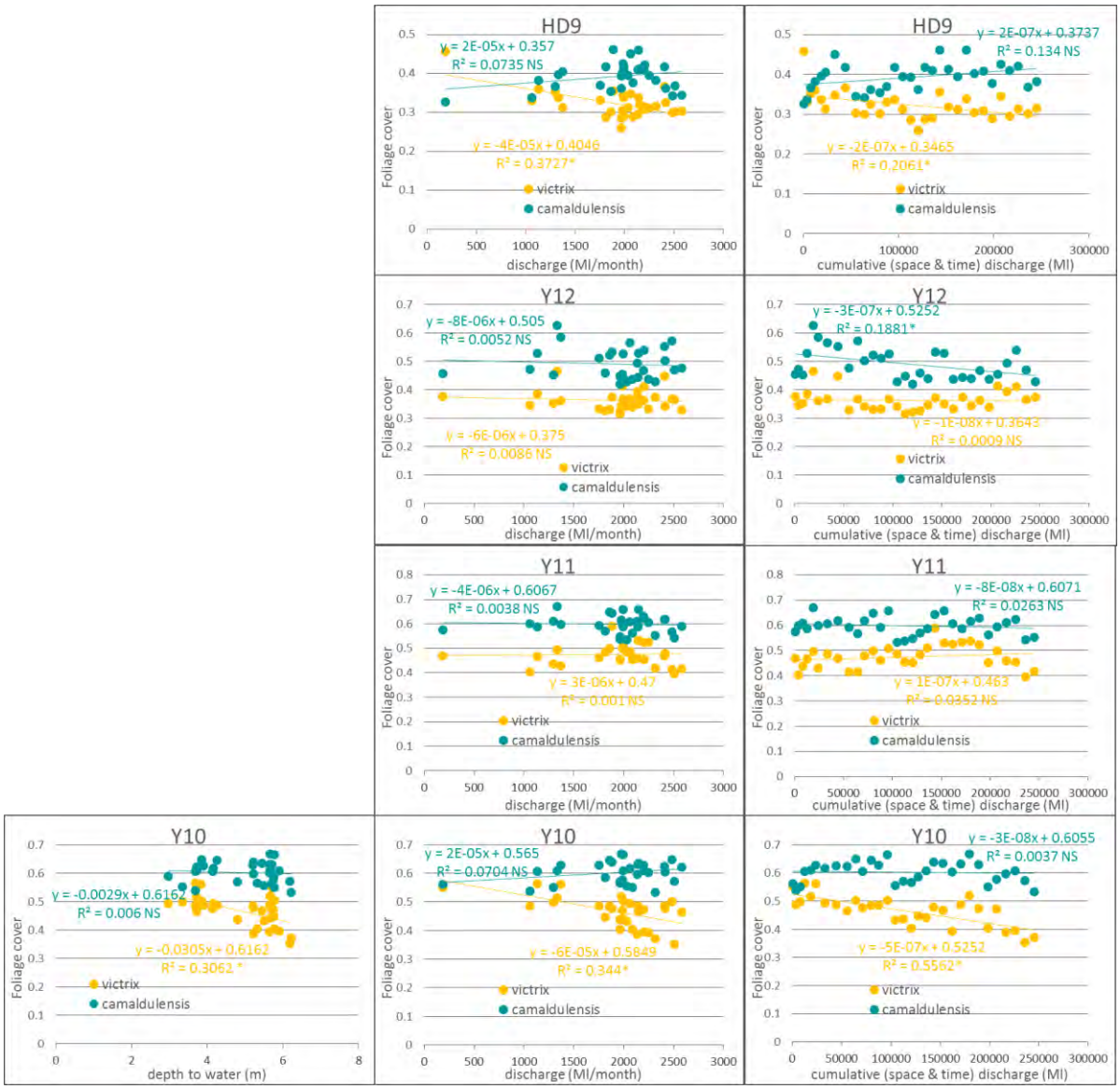
Figure 59: Relationships between foliage cover of *Eucalyptus victrix* and *Eucalyptus camaldulensis* and estimated depth to water and discharge for perennial discharge sites downstream of the gabion HD6b, HD7 and HD8.



At ephemeral sites downstream of the gabion there was also some evidence of greater sensitivity of foliage cover of Ev to discharge compared with Ec. Foliage cover of Ev declined

with increasing discharge rate and volumes at sites HD9 and Y10, but Ec showed no response to either parameter at these sites (Figure 60). At Y12 however, Ec foliage cover declined in response to cumulative discharge, but foliage cover of Ev wasn't adversely impacted, and neither species was impacted by discharge at Y11.

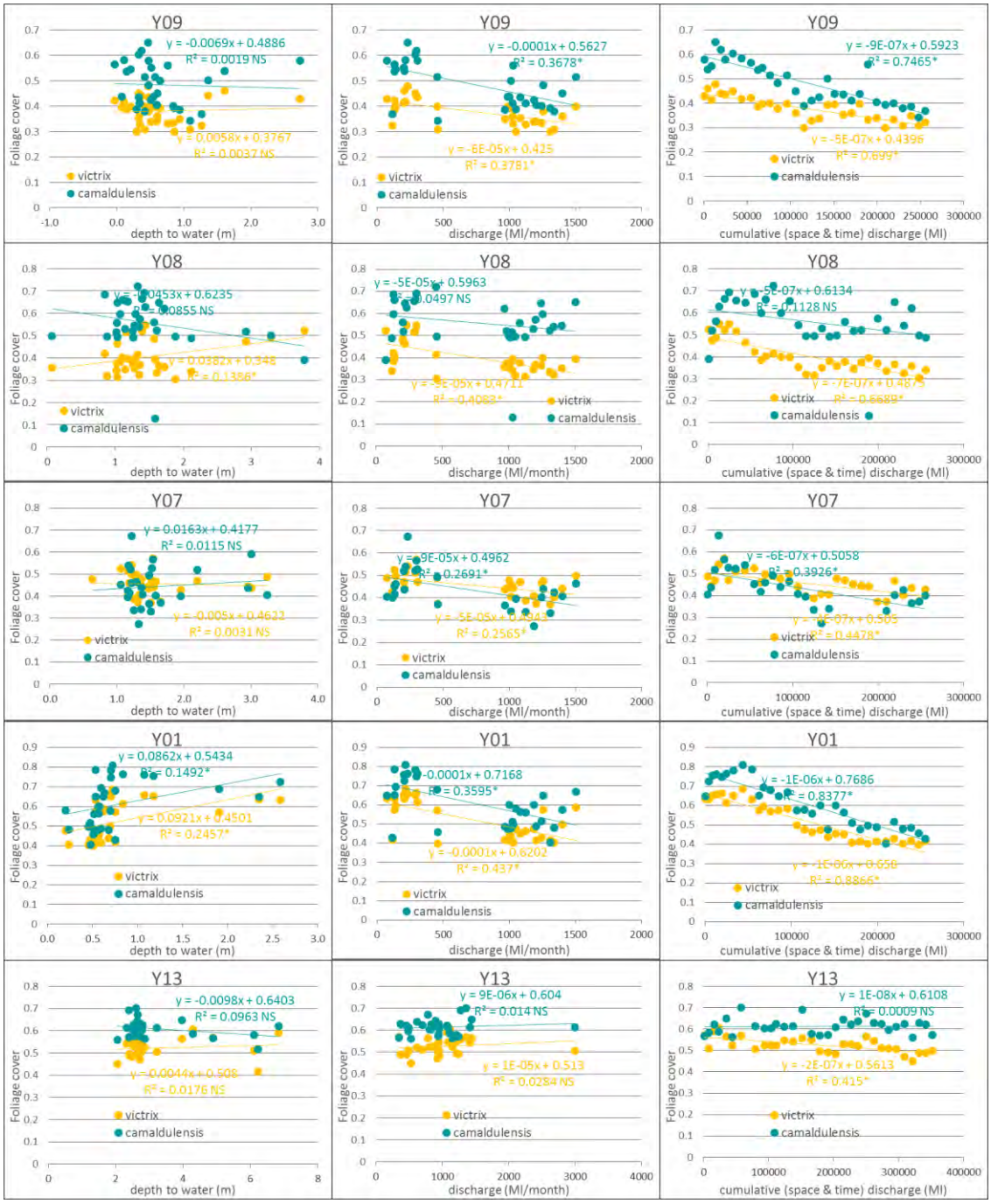
Figure 60: Relationships between foliage cover of *Eucalyptus victrix* and *Eucalyptus camaldulensis* and estimated depth to water and discharge for annual discharge sites downstream of the gabion HD9, Y12, Y11 and Y10.



Responses in foliage cover of Ev and Ec were largely similar at monitoring sites downstream of DO6, showing a decreasing trend with increasing discharge rates and cumulative volumes at Y09, Y08, Y07 and Y01 (Figure 61). These relationships were statistically significant for Ev at each of these sites, and for Ec at Y09, Y07 and Y01. The decline in foliage cover with increasing discharge was associated with significant negative responses of Ev and Ec foliage cover to decreasing water depth at Y01, and negative responses of Ev to rising levels at Y08. Further downstream past the confluence with Marillana Creek at Y13, levels were somewhat

deeper and the foliage cover of neither species responded to rising levels. However, the significant decline in mean foliage cover with cumulative discharge observed at this site (Figure 51) was related to the declining cover of Ev with no significant impact on Ec.

Figure 61: Relationships between foliage cover of *Eucalyptus victrix* and *Eucalyptus camaldulensis* and estimated depth to water and discharge for discharge sites Y09, Y08, Y07, Y01 and Y13 downstream of DO6.

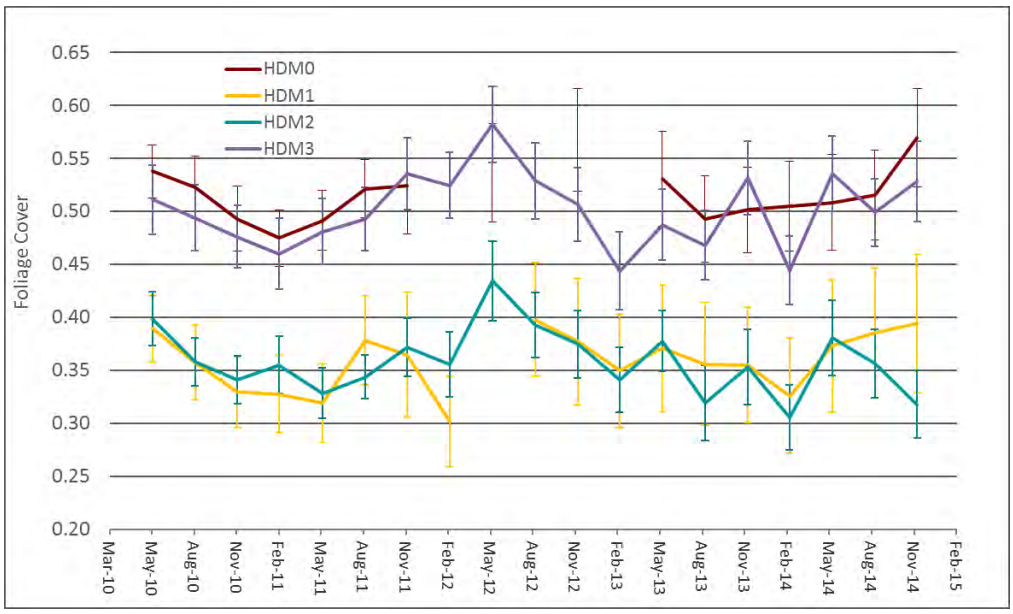


3.6.8. Responses of *Melaleuca argentea* to drawdown and discharge

Monitoring of foliage cover of *Melaleuca argentea* by digital canopy photography started in June 2010, more than 3 years after the start of drawdown and discharge operations at HD1.

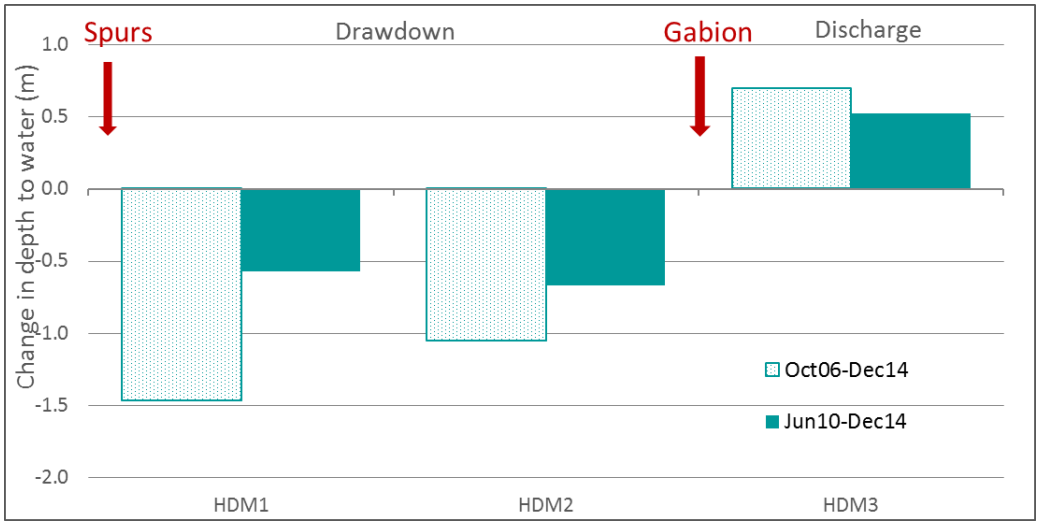
At intervals through the period of monitoring, data was missing for particular trees, sometimes for relatively extended periods. The dataset is thus incomplete making it difficult to reliably define trends and responses to drawdown or discharge. In June 2010, foliage cover of *M. argentea* at site HDM3 downstream of the gabion was similar to cover at the reference site HDM0, and their foliage cover remained largely similar throughout the study (Figure 62). In contrast, foliage cover in June 2010 was lower at HDM1 and HDM2 in the springs area of Weeli Wolli Creek than at HDM0 (Figure 62), and these differences were maintained throughout the study. Lower foliage cover of melaleucas in the springs area is consistent with response in foliage cover of eucalypts which also had lower foliage cover in this part of the creek than at other sites (Figure 35). Seasonal trends in foliage cover were generally similar at the reference and potential impact sites. However, there was some divergence in response in December 2014 when foliage cover decreased at HDM2 whilst foliage cover increased at other melaleuca sites.

Figure 62: Temporal responses in foliage cover for melaleuca monitoring sites HDM0, HDM1, HDM2 and HDM3



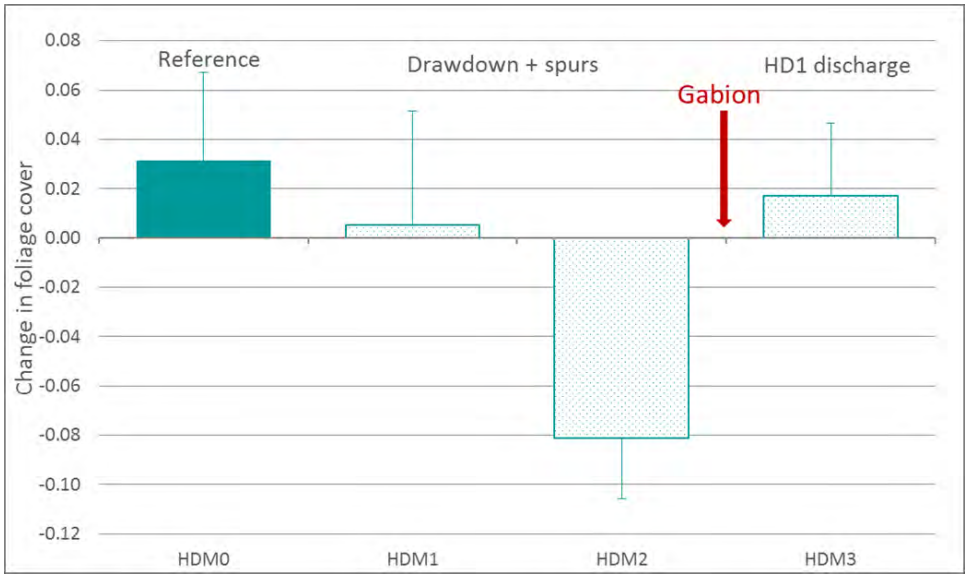
When monitoring began in June 2010, water levels for melaleuca sites HDM1 and HDM2 had already declined in response to dewatering (Figure 28). Water levels continued to decline throughout the period of monitoring. By December 2014 levels had fallen by almost 1.5 m at HDM1 and by > 1m at HDM2 from levels at the start of dewatering (Figure 63). In contrast, discharge from the gabion increased levels at HDM3 by 0.7 m over the same period.

Figure 63: Change in estimated depth to water at melaleuca monitoring sites HDM1, HDM2 and HDM3. Changes are shown from October 2006 to December 2014 and from the start of monitoring in June 2010 to December 2014.



Changes in foliage cover at melaleuca sites over the period of monitoring between were relatively small (Figure 64), but may not fully represent changes since the start of drawdown and discharge operations. Foliage cover increased at the reference site HDM0, possibly a result of contrasting rainfall conditions between the year monitoring commenced (2010) and in 2014. 2010 was a very dry year and 2014 a relatively wet one (Figure 11 and Figure 12). Despite a fall in water levels, foliage cover also increased in HDM1 and at HDM3 where levels increased. In contrast to the increase in cover at HDM1, foliage cover at HDM2 decreased over the period of monitoring, although both sites experienced a similar drawdown in levels between June 2010 and December 2014 and drawdown over the study period was greater at HDM1.

Figure 64: Change in foliage cover at melaleuca monitoring sites from the start of monitoring in June 2010 to December 2014.

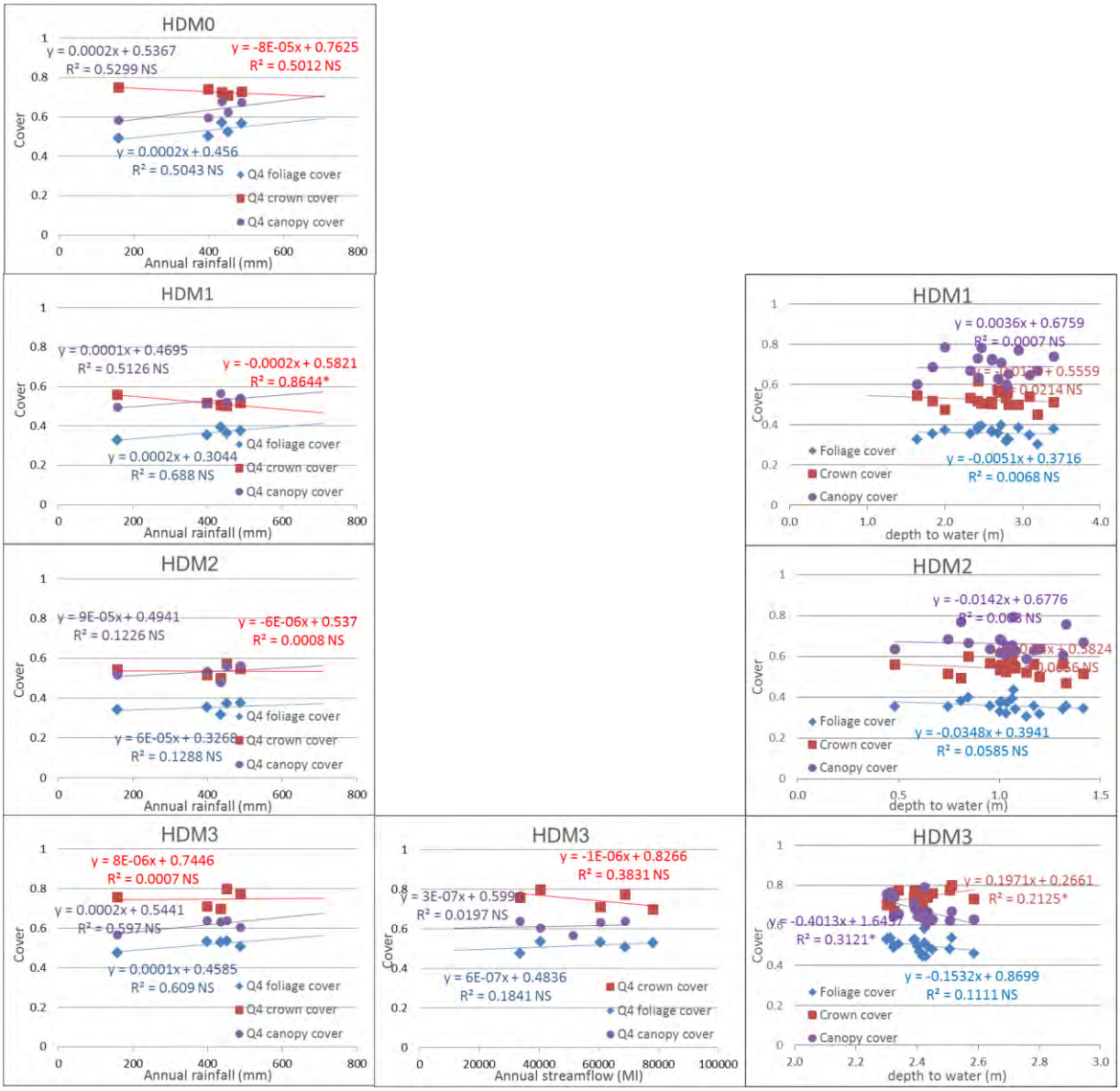


For the eucalypts under investigation in this study, the responses in Fc and crown cover (Crc) captured by digital canopy photography were generally similar at each site (data not

shown). However responses in Fc and Crc weren't always consistent for *Melaleuca argentea* sites. Because of this inconsistency, responses in all 3 tree health monitoring parameters (Fc, Crc and canopy cover, Cc) to key hydrological parameters are presented in Figure 65 and Figure 66 below.

Relationships between Q4 vegetation cover parameters and annual rainfall and streamflow were generally not statistically significant, partly because of the limited number of data points afforded by the shorter period of monitoring for melaleuca sites (Figure 65). The exception was for site HMD1 where crown cover of melaleucas decreased in response to increasing annual rainfall (Figure 65).

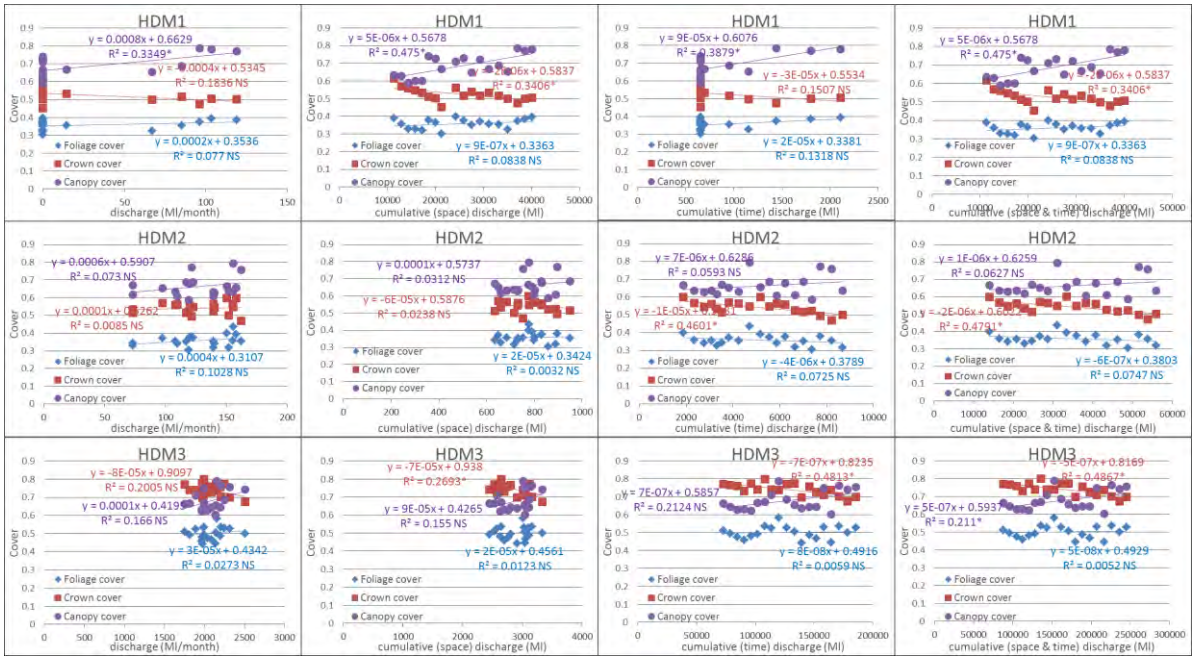
Figure 65: Relationships between foliage, crown and canopy cover and annual rainfall, annual streamflow and estimated depth to water for melaleuca sites HDM0, HDM1, HDM2 and HDM3. Q4 foliage cover is used to correlate with annual rainfall and streamflow at Tarina for HDM3. Foliage cover for all monitoring dates is correlated with estimated depth to water for that month.



None of the melaleuca sites showed a significant relationship between foliage cover and depth to water, but at HDM3 the crown cover of melaleucas increased and canopy cover decreased with increasing depth to water (Figure 65). Similarly, melaleuca foliage cover at each of the sites showed no response to discharge rates or cumulative volumes of discharge (Figure 66).

In contrast, crown cover at each of the melaleuca sites decreased as discharge accumulated from upstream sources and with time increased (Figure 66). At site HDM1, melaleuca canopy cover increased as rates and cumulative volumes of discharge increased. Canopy cover of HDM3 also increased in response to discharge accumulated with both space and time.

Figure 66: Relationships between foliage, crown and canopy cover and discharge for melaleuca sites HDM1, HDM2 and HDM3. Separate relationships are shown for local discharge rates; cumulative (space) discharge which includes discharge accumulated from all upstream sources; cumulative (time) discharge which includes all discharge from the nearest source accumulated with time; and cumulative (space and time) discharge which includes all discharge from upstream sources accumulated with time.



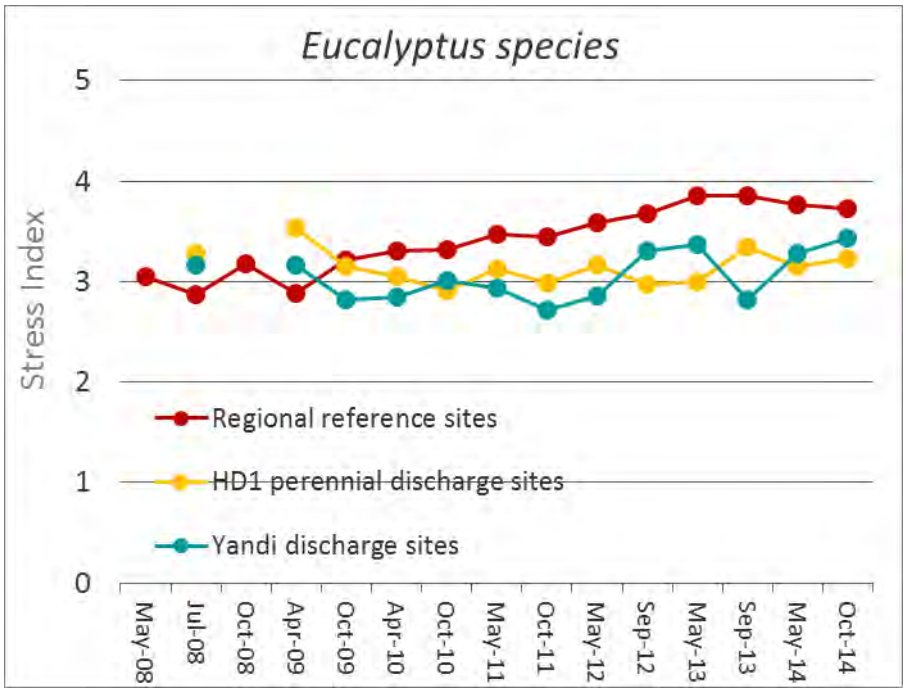
3.7. Vegetation responses from the Mattiske vegetation survey

The percentage cover of different lifeforms in each quadrat of all sample transects in the Weeli Wolli Springs area (Reach 1) are shown in Appendix 2. Percentage cover for each transect is shown on a separate graph for each sampling date from October 2008 to May 2014. Figures in Appendix 2 reveal the great spatial variation in cover of lifeforms across each transect, and variation between transects. For some quadrats and sites, foliage cover was greater than 100%. This result may seem counter-intuitive, but results from the ovelapping of canopies of overstorey and understorey vegetation. Comparison of cover on

transects monitored at different dates between 2008 and 2014 reveal that cover of different lifeforms also varied through time. The dominant trend through time for vegetation in the majority of transects in Reach 1 was for cover to increase with time. This trend is consistent with the enhancement of foliage cover measured by DCP, resulting from positive response to spur discharge in the Weeli Wolli Springs area. Thus the Mattiske data suggest that both understorey and overstorey cover were generally enhanced by spur discharge. The variation in tree foliage cover along each transect is consistent with the different response in foliage cover of trees measured by DCP at different topgraphical positions and elevation at a site. Thus data from Mattiske transects that extend across the full width of the riparian zone may better capture the overall response in tree health to discharge or drawdown than DCP data largely monitored for trees located close to or within the creek.

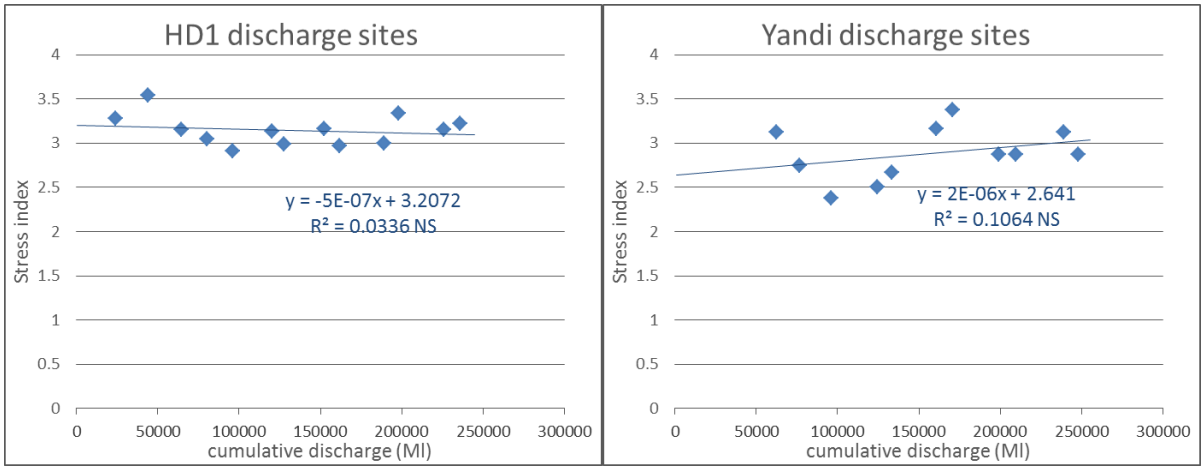
Mean stress indices for eucalypts on vegetation survey transects at sites exposed to HD1 and Yandi discharge and for regional reference sites are shown in Figure 67. The mean level of stress at regional references sites was initially close to 3 (ie. "stressed"), but stress levels tended to decrease with time towards "slightly stressed" levels. In contrast, stress levels at discharge sites varied around a value of 3 or "stressed". Stress levels at discharge sites in October 2014 were largely similar to levels when Mattiske vegetation monitoring was commenced (ie close to 3 or "stressed").

Figure 67: Mean stress index of eucalyptus species on transects exposed to HD1 and Yandi discharge. The mean stress index for eucalypts at regional reference sites on Weeli Wolli Creek, Coondiner Creek and Mindy Mindy Creek is also shown. Increasing values for the index is indicative of decreasing levels of stress, with 1 = dead; 2 = very stressed; 3 = stressed; 4 = slightly stressed and 5 = healthy trees.



Levels of the stress index for eucalypts at HD1 perennial and Yandi discharge sites showed no correlation with cumulative discharge (Figure 68). These responses contrast with the significant decline in foliage cover measured by DCP with cumulative discharge observed for these sites. An explanation for the contrasting response in DCP compared with stress index data may be that eucalypts selected for DCP monitoring aren't representative of trees across the riparian zone at each site location. Trees selected for DCP monitoring may represent the more severely-affected trees, with the Mattiske monitoring better capturing responses of eucalypts across the riparian zone.

Figure 68: Relationship between cumulative discharge and mean stress index for eucalypts on transects at HD1 perennial discharge sites and for Yandi discharge sites.



For sites where Mattiske vegetation monitoring was in close proximity to DCP monitoring sites (WW28 and HD9; WW9 and HD3; WW01 and HD5; WW02 and HD5; WW13 and Y01; WW17 and Y13) foliage cover was regressed against the mean water stress index from Mattiske vegetation data. However, no statistically significant relationships were found between foliage cover and water stress index for any site. Poor correlations between DCP and Mattiske data could arise because the trees selected for DCP sampling aren't representative of trees across the riparian zone monitored by the Mattiske survey. It could also be partly attributable to DCP and the Mattiske monitoring being carried out in different months of the year.

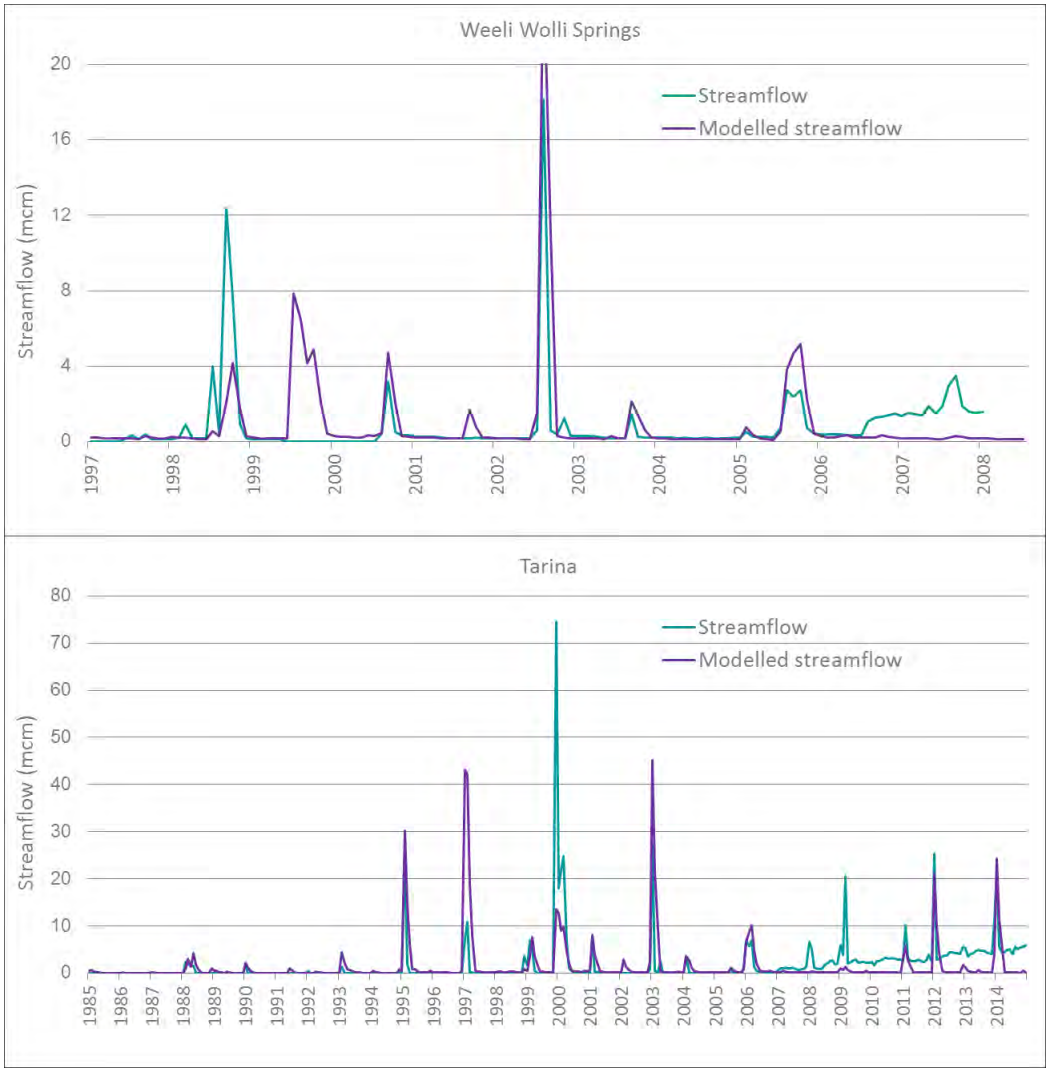
3.8. Hydrological modelling

Measured and modelled streamflow for the Weeli Wolli Springs and Tarina stations show reasonably good agreement for the period prior to discharge (Figure 69). The baseflow component is generally well represented, but the higher flows experienced during flood events are captured less reliably. Factors contributing to discrepancies between modelled and measured peak flows may include high localised spatial variability in rainfall and limitations to accurately measuring streamflow in high energy and flow environments. Thus rainfall measured at a rain gauge in a catchment may not represent average rainfall

conditions experienced across the catchment which contribute to runoff and streamflow, and streamflow at a gauging station may not be accurately measured at high flows.

The response in streamflow to discharge from the gabion can be observed from the divergence between measured and modelled flow for both gauges from 2007 (Figure 69). The impact of the transition from ephemeral to perennial flow at Tarina may be quantified by comparing the duration of modelled and measured flows from 2007. After the start of discharge, measured streamflow at Tarina persisted for 12 months of the year, but modelled flows indicate zero flow throughout 2007 and 2010. The duration of modelled flow in other years was 3 months in 2014 and 4 months in 2009, 2011, 2012 and 2013.

Figure 69:Streamflow and modelled streamflow for the Weeli Wolli Springs and Tarina stations on Weeli Wolli Creek.



4. DISCUSSION AND CONCLUSIONS

4.1. Study limitations

The responses in water levels to dewatering, reinjection and discharge at vegetation monitoring sites at HD1 and Yandi haven't been monitored because bores were not installed at these sites. This study has attempted to estimate levels for each site through interpolation between levels at bores upstream and downstream of the site. However, such estimates are likely to incur errors, particularly when bores used in interpolations are some distance apart. Alluvial bores are generally installed at some distance from the creek, so errors may also be incurred in estimating levels for vegetation adjacent to the creek if water levels vary across it, for example if mounding occurs under discharges. The significance of any error is generally likely to be greater when assessing impacts of discharge compared with drawdown. This is because changes in water levels under impacts of discharge are generally small compared with the magnitude of changes due to drawdown. Furthermore, discharge impacts are largely incurred at levels closer to the ground surface than drawdown, rendering them more likely to be significant for tree health. Interpretation of the significance of changing water levels on tree health at Yandi is also compromised by very limited baseline data for levels prior to the start of dewatering and discharge. Data to assess long-term levels and their seasonal response for comparison with post-impact levels is unavailable. The uncertainty is exacerbated by wet conditions for baseline monitoring, with rainfall being the highest on record at Tarina in 2006.

Pre-impact vegetation monitoring data is also very limited, with digital canopy photography starting in October 2006 at all eucalypt sites except Y12. Monitoring at Y12 was started in February 2007 and monitoring at melaleuca sites in June 2010. The coincidence of the timing of the start of operations with the unusually wet year in 2006 is unfortunate, and lends uncertainty over the suitability of early foliage cover measurements as an appropriate baseline. Since dewatering and reinjection at Yandi began in August 2006, it is also possible that foliage cover at nearby sites may have been impacted prior to the start of monitoring.

The original intent of this project was to interrogate in depth the Mattiske vegetation dataset. However, closer inspection of the database revealed analyses were less straightforward than anticipated because of inconsistencies and constraints in data entry. Thus there was insufficient time and resources to complete the analyses within this study. Some preliminary work on the data was carried out. Further analyses and collation of these results will be

required to identify vegetation responses to changing hydrological conditions similar to the relationships with depth to water table and discharge identified for DCP data for different sites.

4.2. Hydrological impacts of dewatering, discharge and reinjection

Operations at both HD1 and Yandi mine sites impacted on hydrological parameters significant for riparian vegetation along Weeli Wolli Creek. Drawdown associated with dewatering at both HD1 and JSE at Yandi reduced both groundwater levels and water levels in the alluvium. The disposal of water extracted by dewatering by reinjection into a borefield at Yandi and as discharges into Weeli Wolli and Marillana Creeks increased levels in the alluvium.

The potential influence of reinjection on water levels relevant for riparian vegetation has not been quantified in this study. However, gradients in levels measured in transects of bores at intervals along Weeli Wolli creek at Yandi suggest that its influence varies both spatially and temporally. Levels at sites Y10, Y09 and Y08 are the most likely to have been influenced by reinjection, with hydraulic gradients towards the creek occurring periodically between September 2006 and February 2007, October 2009 and December 2011 respectively at these sites. The potential influence of reinjection on water levels relevant to vegetation at sites further north on Weeli Wolli Creek (Y07, Y01 and Y13) are unknown, but likely to become increasingly insignificant with distance from the re-injection bore field.

It appears likely that discharge had a more significant influence than re-injection on water levels relevant to riparian vegetation over the study period. Although reinjection volumes were initially similar to or greater than discharges from DO6, discharge volumes increased from January 2010 and consistently exceeded reinjection volumes for the remainder of the study. Furthermore, volumes from D06 were supplemented by HD1 discharges, as indicated by the rapid progression of surface expression of discharge along the creek downstream of the gabion. Gabion discharge contributed to flows from DO6 from February 2007 and impacts of discharge (as indicated by the surface expression of discharge) extended beyond the most northern tree health monitoring site at Yandi (Y13) from July 2007 onwards. Thus the spatial extent of influence of discharge on water levels relevant for riparian vegetation likely exceeded those of re-injection.

Hydraulic gradients influencing the rate of water movement to riparian vegetation may also be greater for discharge compared with reinjection. Water is discharged from an outlet above the ground surface and the level of the alluvial aquifer, creating a positive head. In contrast, water is discharged from re-injection bores installed below ground and slotted at depths of 18.0 to 89.7 m. Gradients are also influenced by distance from the source of

water, and the location of reinjection bores at some distance from the creek contribute to the probability of higher gradients from discharge because of its closer proximity to trees along the creek. These factors point to discharge as a more significant influence than re-injection on water levels relevant for riparian vegetation over the study period. Given this, the discussion below on foliage cover responses at Yandi refers principally to impacts of discharge. However, it is recognised and acknowledged that both reinjection and discharge are likely to influence tree health if they contribute significantly to rising water levels in the root zone.

Impacts of dewatering on groundwater levels at HD1 extended for several kilometres from the dewatering borefield. Impacts on water levels were observed to extend about 6.5 km to the northeast of the borefield along Weeli Wolli Creek at BH17d. Impacts also extended about 6.4 km along Weeli Wolli Creek towards bore BH20d in the south. The significance and extent of influence of drawdown at Yandi on levels relevant for riparian vegetation along Weeli Wolli Creek cannot be readily assessed because impacts are confounded by discharge and reinjection. Levels at Y10 and Y09 are likely to be influenced by drawdown, as nearby alluvial bores WW1 and JSE16 became dry during the course of this study. There is little evidence for drawdown influencing levels significantly further downstream at Y08 and no bore data south of Y10 to inform whether impacts extend upstream to Y11. However, any influence at Y11 appears unlikely given the distance from dewatering and assuming that dewatering impacts propagate similar distances upstream as downstream.

Long-term gauging of streamflow at the Tarina and Waterloo Bore stations has facilitated an analysis of the impacts of below water table mining operations on streamflow in Weeli Wolli Creek downstream of the gabion. Early indications are that streamflow at Tarina has increased disproportionately in years after the start of discharge. The reasons behind this apparent increase are unknown, but could relate to the lack of opportunity for riparian storages to absorb a volume of runoff, since these have already been filled to capacity by discharge. Other factors potentially influencing the surface water hydrology (e.g. area open for mining) could also be significant. There are indications that streamflow downstream at Waterloo Bore remains unaffected by cumulative impacts of discharge from BHP Billiton and Rio Tinto Iron Ore operations at HD1 and Yandi, since neither the volume nor duration of flow have changed. This supports the thesis that mining operations in Weeli Wolli catchments haven't altered the hydrology of the Fortescue Marsh further downstream.

4.3. Foliage cover responses to drawdown

The only tree health monitoring site where water levels appeared to decline in response to dewatering at JSE at Yandi was Y10, where depth to water increased from 3.0 to 6.2 m.

Foliage cover of trees at this site didn't appear to respond to drawdown, and the relationship between foliage cover and depth to water wasn't significant for this site. Any response to drawdown was likely confounded by responses to discharge from HD1, which reached Y10 by February 2007.

Foliage cover responses to groundwater drawdown at HD1 were quite site-specific and confounded in places by changes in surface water hydrology as a result of the diversion of Pebblemouse Creek. Discharge from spurs also masked any response of eucalypts to drawdown in the springs area of Weeli Wolli Creek. The lack of response in foliage cover to groundwater drawdown at HD0 confirms that *E. victrix* and *E. camaldulensis* aren't accessing significant water from very deep (> 40 m) groundwater. The rapid decline in foliage cover close to dewatering at sites HD1 and HD2 between February and May 2007 suggest that these eucalypts may be vulnerable to dewatering if drawdown is rapid and water levels are initially shallow enough to be accessible for uptake by tree roots. However, the subsequent recovery in foliage cover at these sites suggests adaptation to the changed hydrological conditions is possible if the availability of surface water resources is maintained. In contrast, foliage cover at HD4 declined with increasing drawdown because surface water availability was also reduced by the diversion of Pebblemouse Creek. Foliage cover further downstream at HD3, a site where diversion of Pebblemouse Creek would likely have minimal impact, showed no response to significant but relatively gradual drawdown of groundwater from depths readily accessible to tree roots. The response suggests that these *Eucalyptus* species are resilient to drawdown if surface water availability remains unaffected.

The importance of surface water availability in maintaining foliage cover of eucalypts is supported by other responses observed in this study. With the exception of HD4, foliage cover at all HD1 drawdown sites (i.e. HD1, HD2, HD3, HD5, HD6 and HD6a) showed a positive response to annual rainfall which was statistically significant for HD1 and HD2. Positive responses to rainfall are also observed at reference sites HD0 and PB1. Though the response at PB1 wasn't statistically significant, foliage cover at this site showed a significant positive response to streamflow. Foliage cover of *Eucalyptus* species in the springs was also responsive to spur discharge, an alternate source of surface water. Trees at HD5 and HD6a all showed a significant positive response to volumes of spur discharge, despite a very significant fall in groundwater levels from approximately 2 to 8m at HD5. Indeed, there is a suggestion that spur discharge has over-compensated for any reduced water availability caused by drawdown. Foliage cover increased between October 2006 and December 2014 at all eucalypt sites in the springs area receiving supplemental irrigation from spurs. Increases at HD6 and HD6a were greater than at any other sites, including at the reference site HD0. These increases were positively correlated with discharge volumes at both HD5 and HD6a. It is possible that eucalypts here have been over-irrigated and the enhanced foliage cover is in disequilibrium with water available under undisturbed conditions. This has

implications for the cessation of spur discharge and the transition back to an unmanaged system. Adopting and trialling a system for scheduling supplementary water applications through the spurs to better match vegetation demand for water would facilitate this transition through improved understanding of the system and vegetation responses.

Given the significance of surface water availability for tree health, impacts of groundwater drawdown are likely to be more significant in situations where drawdown also influences the frequency and duration of streamflow. A preliminary analysis of changing levels at bore BH16s in this study suggest that both the frequency and duration of streamflow in Weeli Wolli Creek upstream of the gabion was reduced by drawdown. This response decreases the frequency with which water stored in unsaturated sediments and used by riparian vegetation is replenished. It also prolongs the length of time between flood events, and increases the risk of water deficits developing. Thus falling water levels exert a dual influence through decreasing the accessibility of water from the saturated zone, and decreasing availability from unsaturated alluvium. Given this significance, an important consideration in understanding impacts of drawdown on vegetation health is adequate monitoring of depth to water as well as streamflow responses and water availability in the unsaturated zone. Reinstating the gauging of streamflow at the Weeli Wolli Springs station would allow a quantitative analysis of streamflow responses to drawdown at HD1. Monitoring of streamflow at other locations upstream of the gabion would also be relevant, but would not have the advantage of a longer term dataset to compare pre- and post-impact responses.

4.4. Foliage cover responses to discharge

Responses in *Eucalyptus* foliage cover at sites downstream of discharges from the gabion at HD1 and D06 at Yandi indicate variable impacts of discharge on tree health. Sites HD6b, Y12 and Y11 downstream of the gabion didn't respond negatively to discharge rates or cumulative volumes. However, foliage cover at sites HD7 and HD9 showed statistically significant negative responses to gabion discharge rates, and sites HD7, HD8 and Y10 significant negative responses to cumulative discharges.

Foliage cover responses at sites downstream of DO6 at Yandi were more consistent and significant than responses to discharge from HD1. Foliage cover showed statistically significant negative responses to DO6 discharge rates and cumulative volumes at sites Y09, Y08, Y07 and Y01. Site Y13 also showed a negative response to cumulative discharge. The greater impact on foliage cover of discharges at Yandi results from generally shallower water tables in the alluvium compared with sites impacted by HD1 discharge. Relationships between foliage cover and depth to water showed statistically significant reductions in foliage cover with rising levels at sites Y08 and Y01. However, the response of individual trees at a

site wasn't uniform, and at most of the sites there were some trees that increased their foliage cover. This finding has significance since it suggests that a proportion of trees at each site occupy an ecological niche which has allowed them to maintain or increase their leaf area. It also has significance for the regeneration of the ecosystem in the longer term.

The negative impacts of discharge on foliage cover of *Eucalyptus* species at some sites is supported by other responses observed in this study. In contrast with the generally positive responses in foliage cover to annual rainfall and streamflow observed for reference and drawdown sites, foliage cover at discharge sites was not enhanced in years with greater annual rainfall or streamflow. At discharge sites HD9, Y12, Y11 and Y10, foliage cover was unresponsive to annual rainfall and streamflow. However, trends of declining foliage cover with increasing annual rainfall and streamflow were found for all perennial discharge sites downstream of the gabion and for all sites at Yandi downstream of DO6. Trends of decreasing foliage cover with increasing annual streamflow were statistically significant at sites Y09, Y08 and Y01. Lower foliage cover found in *Eucalyptus* species at perennial compared with annual sites at the start of this study is also indicative of negative responses to shallow water tables. However, it is possible that differences in foliage cover between perennial and annual sites, and responses to cumulative discharge, may result from anomalies associated with the DCP technique. Consistent differences between response to different factors (e.g. tree height, maturity, canopy form and distribution, or size of branches and stem etc.) at a site may contribute to apparent differences in their foliage cover measured by the technique. To my knowledge, the application of the DCP technique to capture long- term changes in foliage cover of individual trees hasn't been investigated to ascertain whether anomalies/inaccuracies may occur. Given the widespread application of the technique for compliance monitoring within Rio Tinto Iron Ore, it would be appropriate to investigate this for a long-term dataset.

The decrease in foliage cover with rising water levels observed for some of the sites in this study is not unexpected, and consistent with reports of negative impacts of waterlogging on health of some eucalypts. That foliage cover changes relate to the elevation of individual trees at site Y08 also suggests that depth to water is a key factor. The preliminary analysis of foliage cover decline for individual trees at Y08 suggests a critical depth to water for foliage cover decline of about 1 m. The relationship between percentage change in foliage cover and the duration of water levels above the critical level derived for Y08 suggests a 9.1% decline in foliage cover for each year that levels are within 1m of the surface (Figure 53).

The depth of 1 m identified as the critical depth to water explaining foliage cover decline for trees at Y08 should be taken as indicative only, since it was determined only for a single site and using estimated rather than measured water levels. The identification of a critical depth

to water for explaining foliage cover decline is useful for predicting impacts of discharge on riparian vegetation where depth to water can be estimated or measured. It also informs better management of discharge to maintain levels below this critical depth. Confirmation of actual water levels at tree health monitoring sites will enable critical levels for foliage cover decline to be determined with greater confidence.

In this study, the trend in decreasing foliage cover with cumulative discharge observed for several discharge sites cannot be consistently attributed to rising water levels. Further investigation to establish with greater certainty the water levels at each site may confirm whether or not this is the key factor causing decline. Foliage cover responses to cumulative discharge may not be simply due to waterlogging, but could also relate to indirect effects of discharge e.g. through increasing disease, unknown impacts of precipitate or changing soil chemistry and plant nutrition. Further studies are warranted to understand the underlying mechanisms behind the decrease in foliage cover with cumulative discharge.

A comparison of the two different tree health parameters monitored on Weeli Wolli Creek (foliage cover and stress index calculated from the Mattiske qualitative assessments of tree condition) reveals contrasting responses to discharge. Where monitoring sites were in close proximity, there was no correlation between these parameters. These findings suggest that eucalypts selected for foliage cover monitoring aren't representative of trees across the riparian zone at each site location. Trees monitored for foliage cover may represent the more severely-affected trees, with the Mattiske monitoring transects better capturing responses of eucalypts across the riparian zone. Alternatively, the qualitative assessment method may not adequately capture a decline in tree health at discharge sites. This alternative explanation appears unlikely, since the stress index is effective in revealing differences in response between reference and discharge sites.

4.5. Responses of *E. victrix*, *E. camaldulensis* and *M. argentea* to drawdown and discharge

The capacity to undertake a systematic comparison of the responses of *E. victrix* or *E. camaldulensis* in this study was limited by the small number of trees of a species sampled at some sites (ie unequal replication). However, there is little evidence to support differential responses of these species to drawdown, as their responses are somewhat inconsistent at the different sites. There is also little evidence that *E. victrix* or *E. camaldulensis* are responding differently to discharge or to rising water levels. Both species show either no response or negative relationships between foliage cover and discharge rates or cumulative volumes, and their responses are often very similar at discharge sites. More detailed and fine-scaled investigations of individual tree response at a site, or using more sophisticated

physiological monitoring techniques may reveal differences between them. Alternatively, the lack of differentiation between their responses may also reflect incorrect species identification, given observations that their form may vary somewhat depending on site conditions.

Understanding responses of *Melaleuca argentea* to drawdown is limited in this study by the short timeframe of monitoring and the confounding responses to spur discharge. However, none of the components of tree health monitored by digital canopy photography (foliage cover, crown cover and canopy cover) were responsive to changing depth to water. This is perhaps unsurprising given the relatively small changes in depth to water experienced at melaleuca drawdown sites. Depth at HDM1 varied between 1.6 and 3.4 m, and between 0.5 and 1.4 m at HDM2. These depths are well within the range in depth to water reported by Loomes (2010) for *Melaleuca argentea* at sites in the Pilbara.

The significance of discharge for the health of *Melaleuca argentea* is unclear from this study, principally because the significance of contrasting responses in foliage cover, crown cover or canopy cover cannot be determined without a separate, independent measure of tree health. Foliage cover at sites HDM1, HDM2 and HDM3 were not responsive to rates or cumulative volumes of discharge from spurs or the gabion. However crown cover of melaleucas at all these sites gave a significant decline in response to increasing cumulative discharge volumes, whilst canopy cover increased significantly with increasing cumulative discharges at sites HDM1 and HDM3. Except for a statistically significant decrease in crown cover with increasing annual rainfall at HDM1, none of the parameters of tree health responded to annual rainfall at melaleuca sites including the reference site HDM0. Tree health parameters were also unresponsive to annual streamflow at HDM3. The lack of response to rainfall and streamflow may simply reflect the low degrees of freedom (df) for determining the statistical significance, given the short timeframe for monitoring. However, it may also indicate that the health of melaleucas at all sites isn't limited by water deficits.

Further studies are warranted to understand the responses in foliage cover, crown cover and canopy cover of Melaleucas and to identify which parameter best represents their condition. This will allow determination of whether or not cumulative discharge is impacting negatively on tree health. If negative impacts are identified, further studies are warranted to understand the underlying mechanism for this response.

4.6. Conceptual models developed in this study and steps required to facilitate prediction of impacts at other sites

Conceptual models developed in this study relevant to predicting potential impacts of drawdown and discharge on vegetation health at other sites include:

i) Identification of a critical depth above which the duration of waterlogging impacts negatively on foliage cover of eucalypt species. Verification of estimated water levels is required, followed by deriving a critical depth that explains foliage decline across more than one of the sites studied. These steps will allow Rio Tinto Iron Ore to more confidently apply the criteria to predict impacts at other sites in conjunction with streamflow modelling to predict water levels in the alluvium.

ii) The response in foliage cover of eucalypts exposed to discharge is related to cumulative discharge volume. Further investigation to investigate mechanisms causing this decline is warranted to facilitate the application of the model to other sites.

iii) Riparian eucalypts growing at ephemeral sites are resilient to drawdown provided surface water availability and flows remain unaffected. Given the limited replication of sites available at HD1 to test this conclusion, similar analyses for vegetation at other sites with drawdown should be carried out to confirm the wider application of this result.

4.7. Significance of study findings for Pockets and Billiards South

The finding from this study that foliage cover of *E. victrix* and *E. camaldulensis* are resilient to impacts of drawdown if streamflow and hence surface water availability remain undisturbed is of significance for dewatering of Pockets and Billiards South. Since Weeli Wolli Creek was ephemeral at Yandi prior to discharge from HD1 and DO6, the cessation of perennial flow in the creek may simply represent a return to the original, undisturbed condition. However, if drawdown or other operations reduce the frequency, duration or extent of flood events, the health of riparian vegetation may be compromised.

Irrespective of the longer term impacts of drawdown on vegetation, the transition from existing to a new equilibrium condition should be managed to minimise adverse impacts. Given evidence from this study that foliage cover of *Eucalyptus* species at Yandi has largely declined under impacts of discharge, it is possible that an adjustment to new equilibrium conditions without perennial discharge will involve an increase in foliage cover from existing levels. This suggests an easier transition to a new equilibrium than would be expected if foliage cover had been enhanced by discharge. However, it is also likely that prolonged waterlogging as a result of shallow water tables in the alluvium has caused the senescence of deeper roots and promoted the development of shallow roots. A rapid reduction in water

levels in the alluvium could be detrimental to tree health if water availability in the shallow root zone becomes limiting. If drawdown occurs during months of high evaporative demand, water stress could develop relatively rapidly, reducing the capacity of trees to develop a deeper root system to access the water they require. Under these circumstances, supplemental irrigation may be required to reduce the risk of significant tree deaths. If drawdown occurs during cooler winter months, the risk of tree deaths is likely to be reduced. However, application of supplemental irrigation may still be required to prevent tree deaths.

Part of demonstrating the sustainability of discharge into Pilbara river systems as a means of managing excess water is the successful management of a transition to the cessation of discharge. Careful monitoring of vegetation responses to changing water availability in both the saturated and unsaturated profile will facilitate a successful transition. The timing and duration of any supplemental water applications should be based on monitoring and analyses to avoid enhancing foliage cover to unsustainable levels requiring ongoing irrigation.

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6. APPENDICES

6.1. Appendix 1

2-way (site x time) repeated measures ANOVA of responses in foliage cover

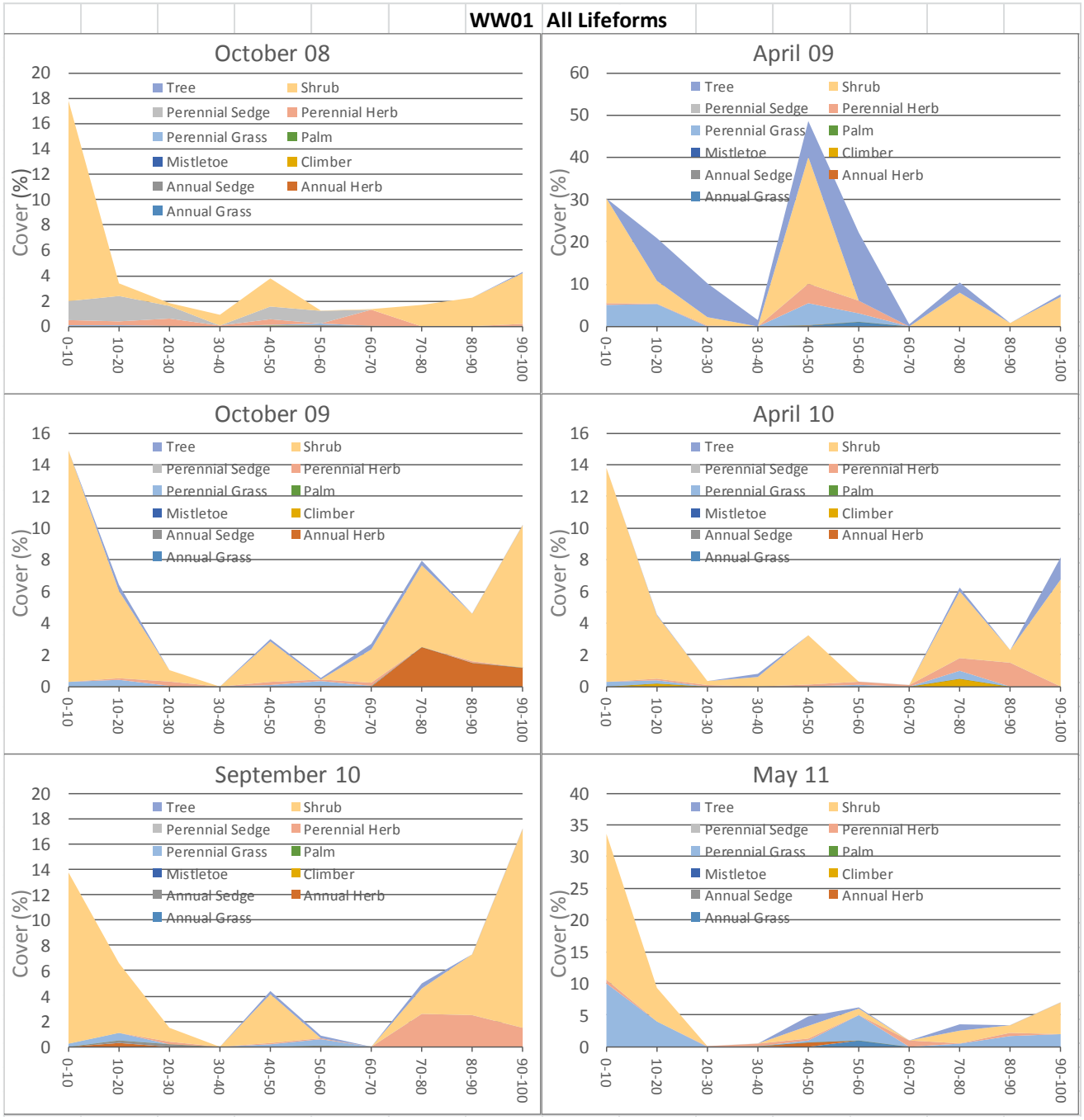
ANOVA					Alpha	0.05
	SS	*df*	*MS*	*F*	*P value*	*F crit*
Between Subjects	56.71255	189				
- Sites	18.49591	18	1.155994	3.085342	0.000289688	246.4639
- Error	38.21664	171	0.374673			
Within Subjects	24.61814	5700				
- Time	2.592874	30	0.086429	18.37105	1.68901E-88	1.462858
- Interaction	7.629072	540	0.015894	3.378347	1.62915E-90	1.117992
- Error	14.39619	5130	0.004705			
Total	81.33068	5889	0.022053			

Greenhouse and Geisser					Alpha	0.05
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Time	2.592874	6.294728	0.411912	18.37105	9.42937E-20	2.112684
Interaction	7.629072	100.7156	0.075749	3.378347	1.43926E-20	1.268401
Error	14.39619	642.0622	0.022422			

Huyhn and Feldt					Alpha	0.05
Sources	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Time	2.592874	6.753619	0.383924	18.37105	7.42958E-20	2.11174
Interaction	7.629072	108.0579	0.070602	3.378347	5.18973E-22	1.257773
Error	14.39619	688.8691	0.020898			

6.2. Appendix 2

The percentage cover of different lifeforms in each quadrat of all sample transects in the Weeli Wolli Springs area (Reach 1). Percentage cover for transects is shown on separate graphs for each sampling date from October 08 to May 2014.



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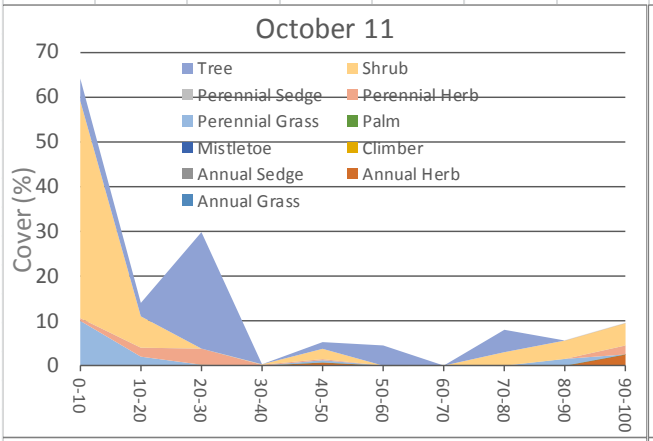
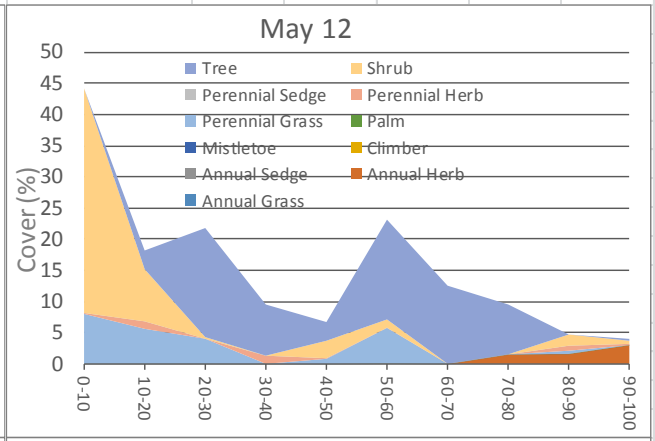
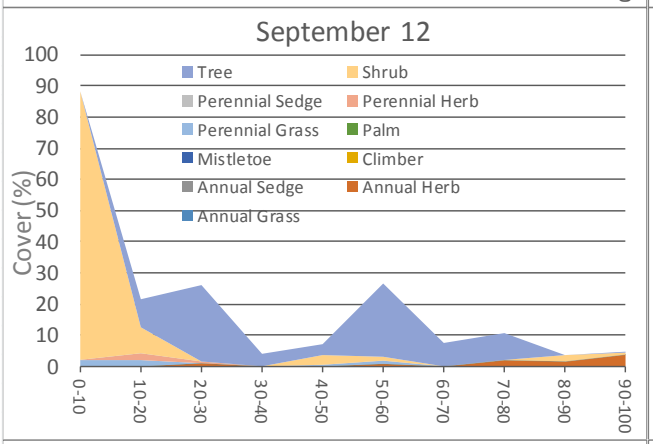
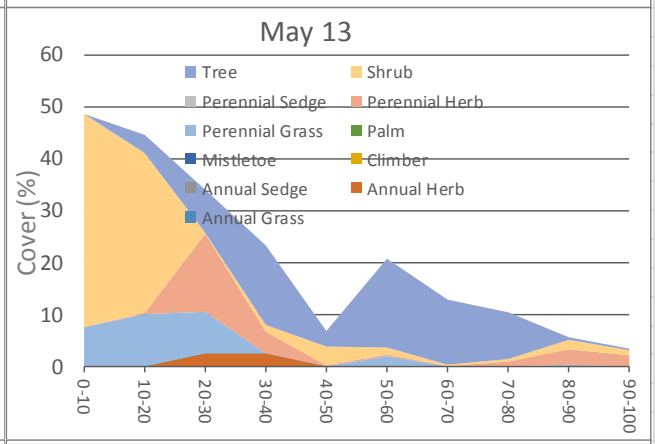
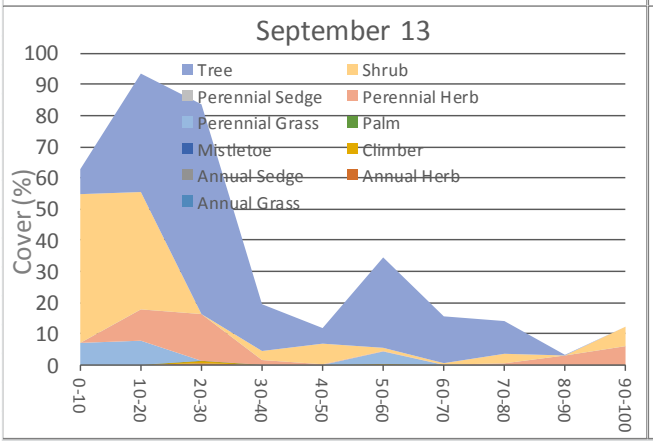
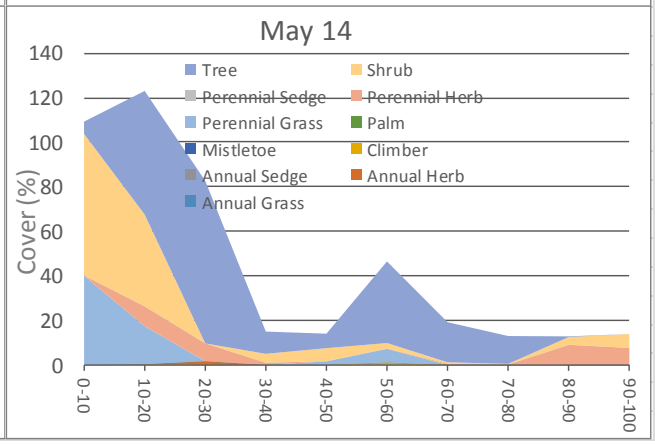




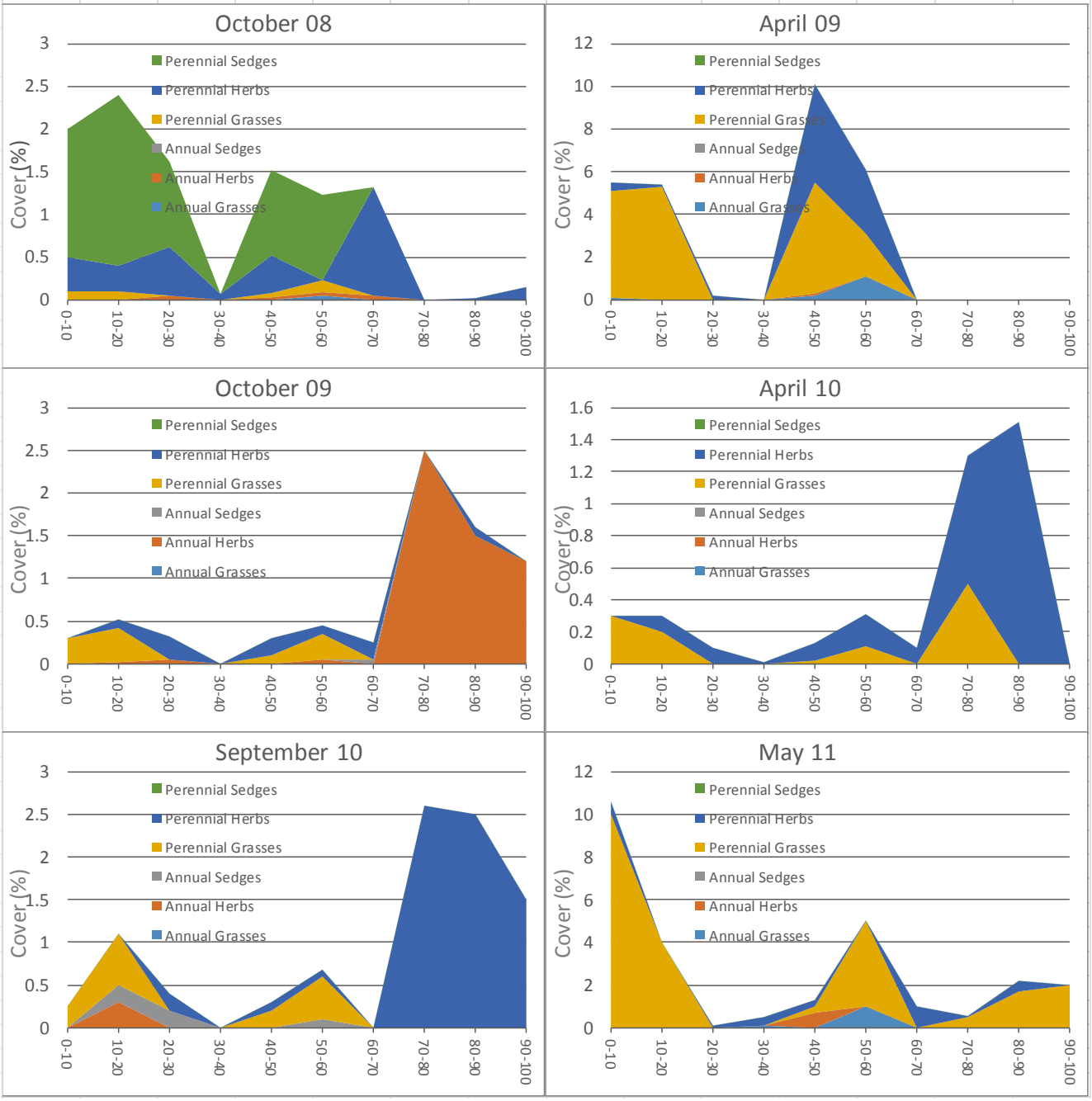








WW01 Groundcovers



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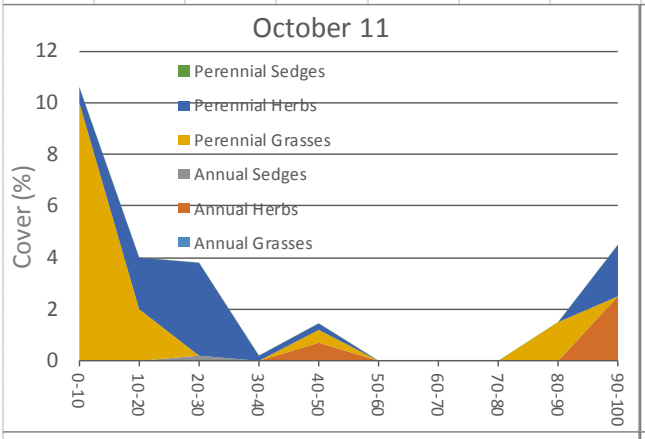
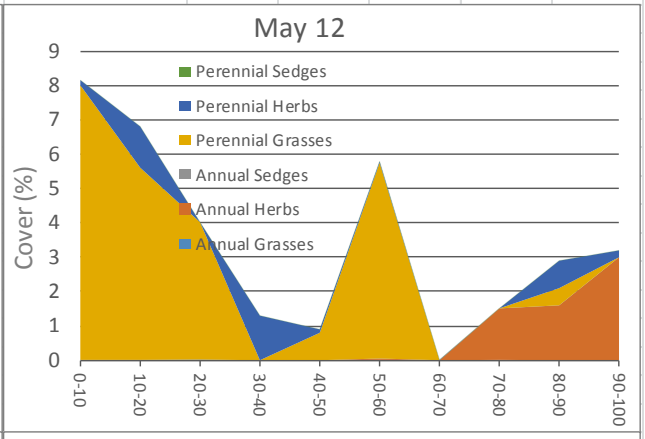
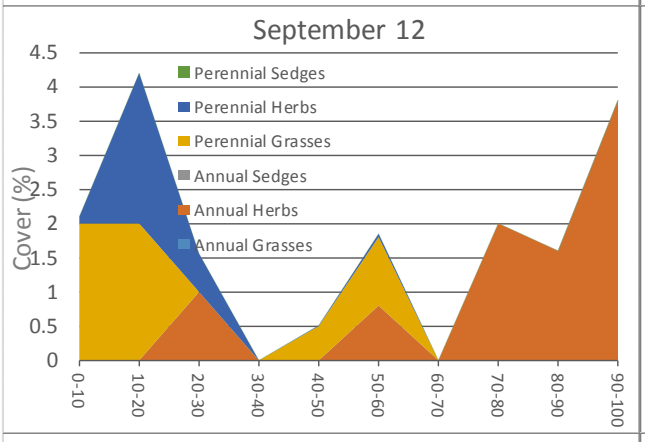
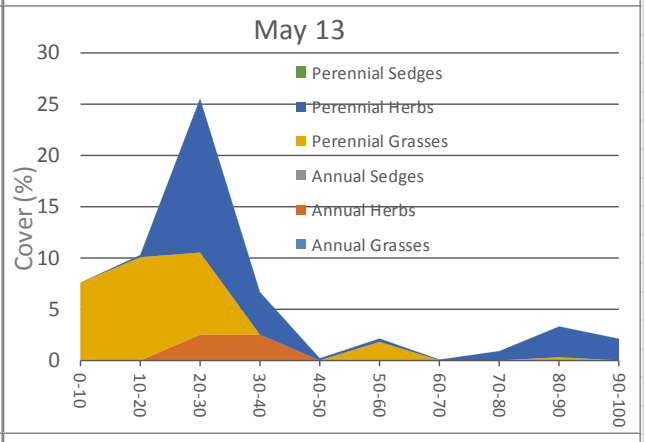
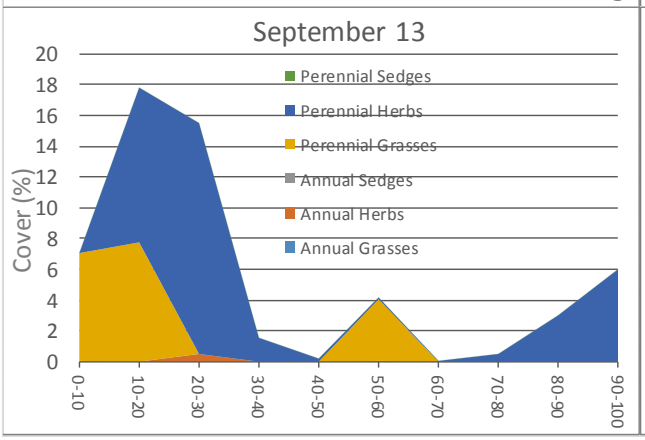
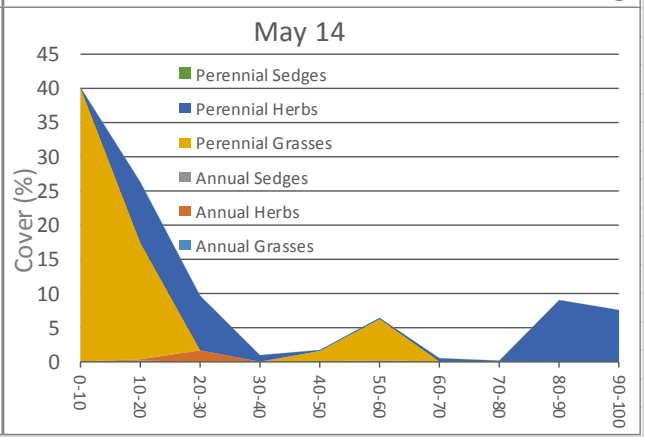




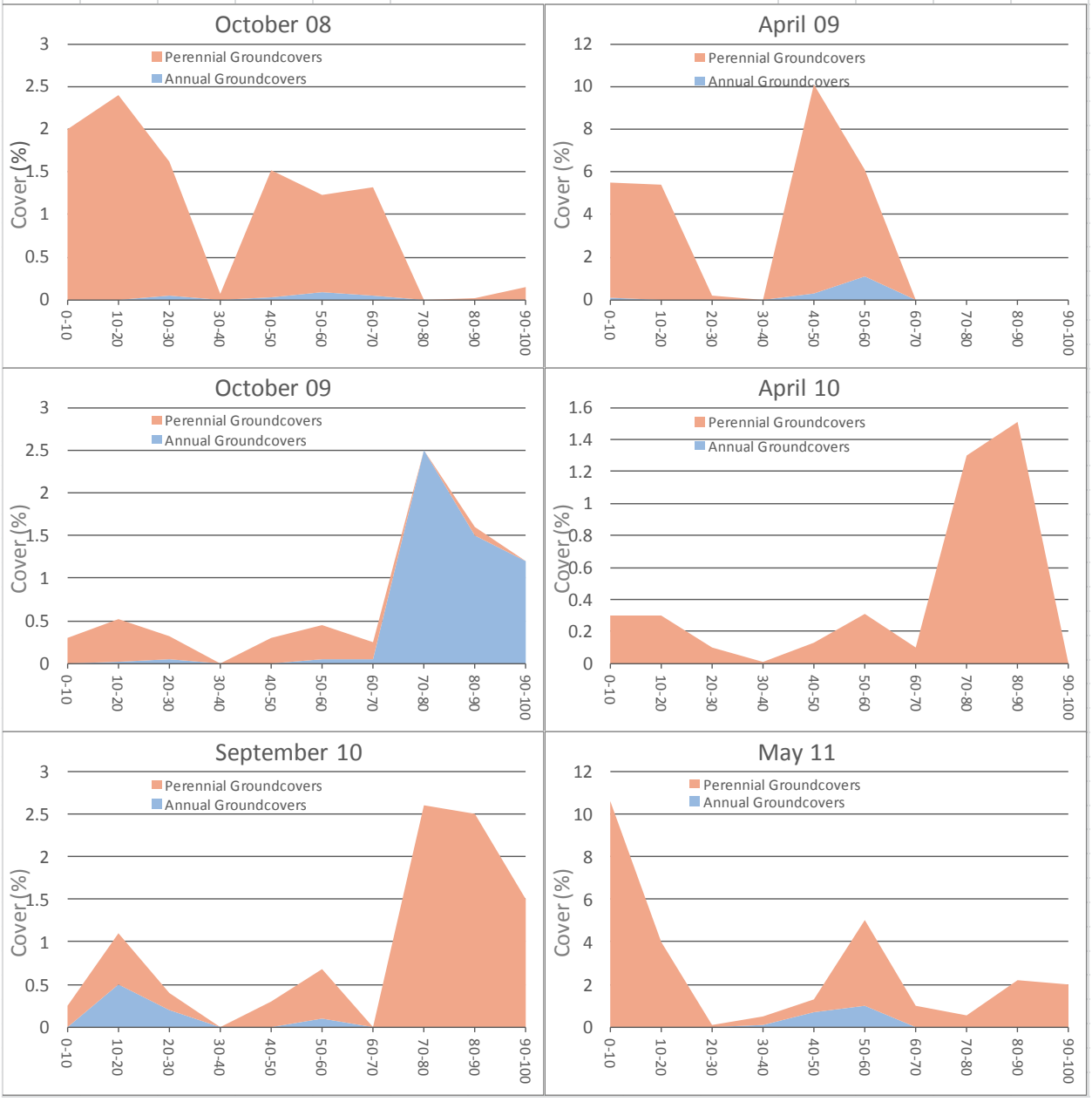


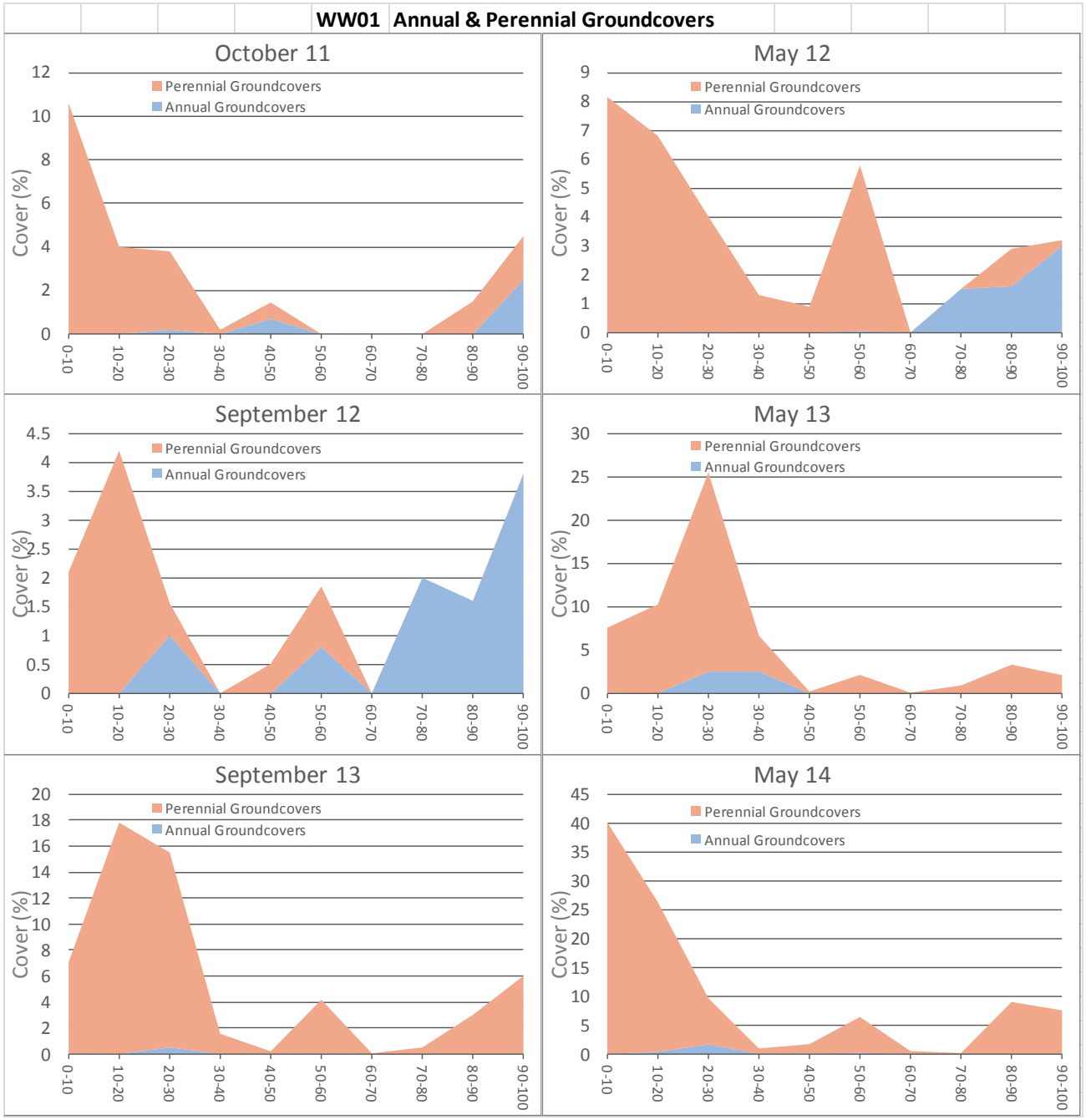




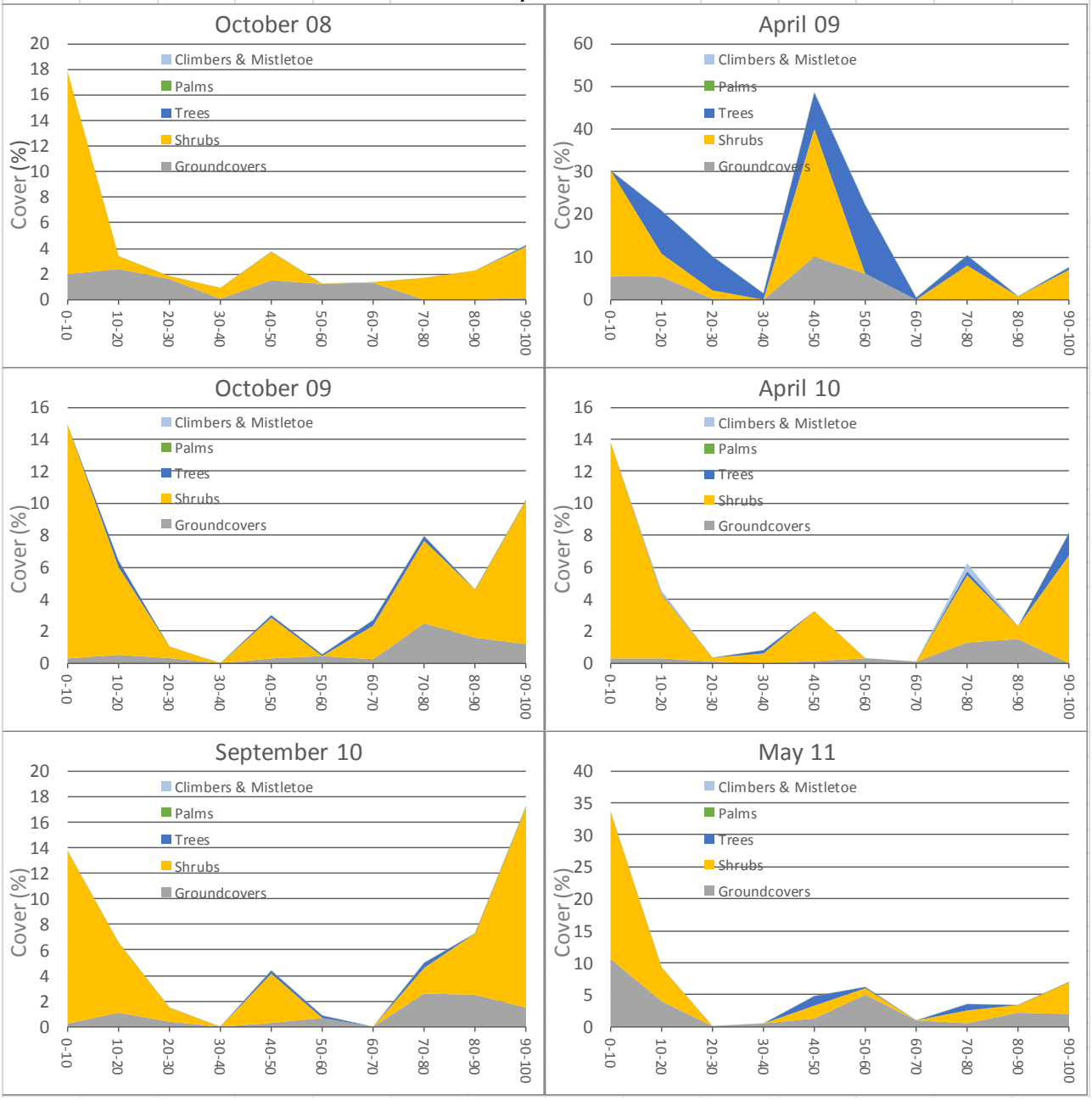


WW01 Annual & Perennial Groundcovers




WW01 Annual & Perennial Groundcovers
October 11
May 12
September 12
May 13
September 13
May 14
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

WW01 Grouped Lifeforms



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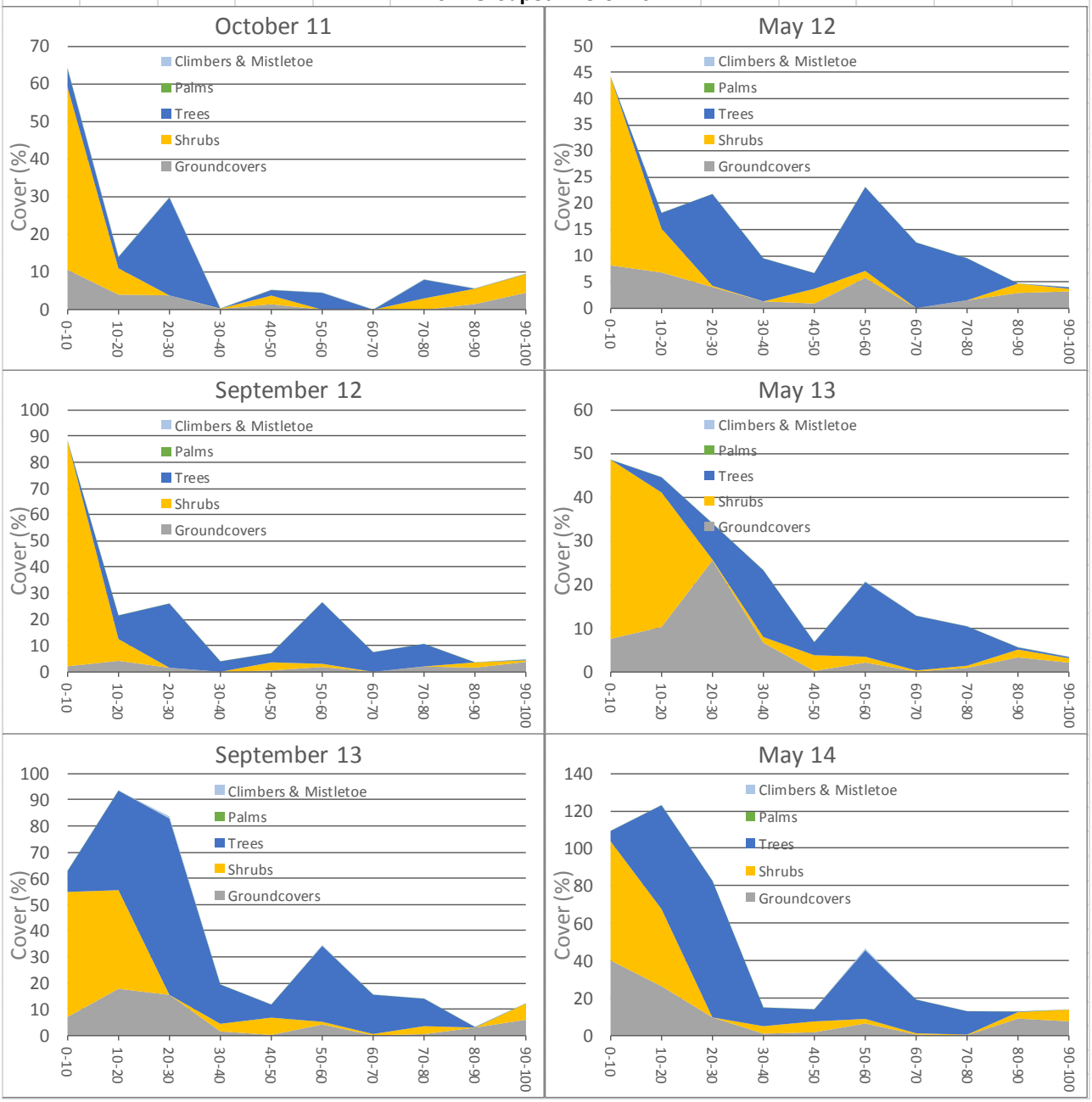
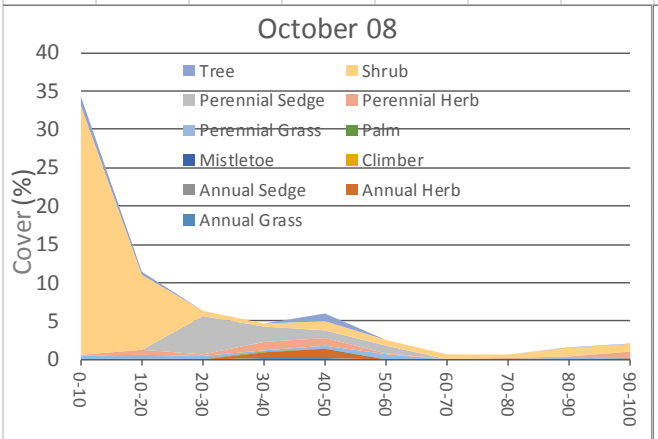
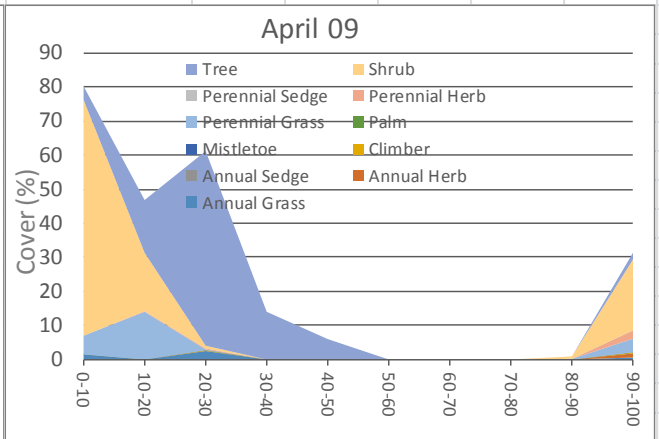
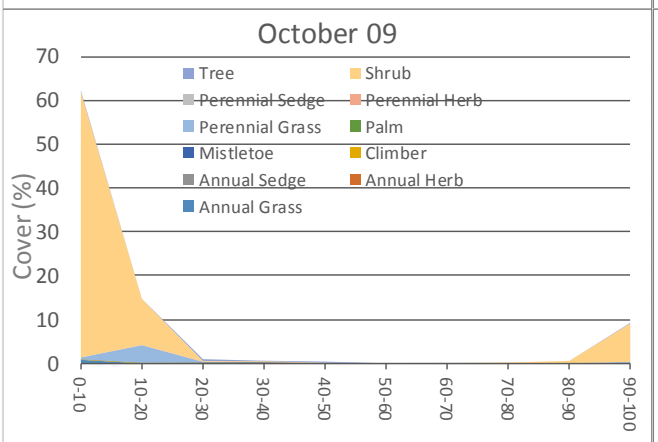
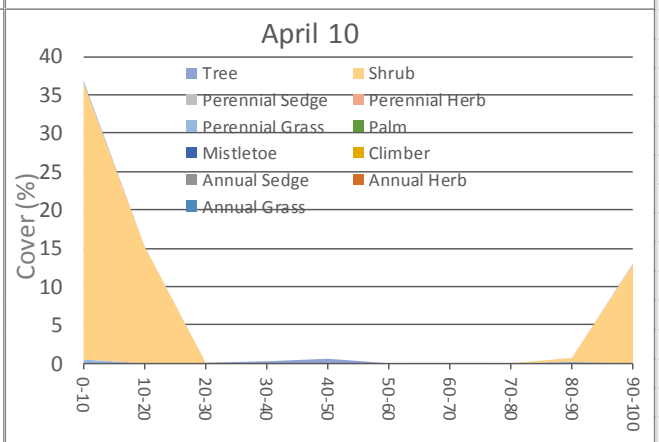


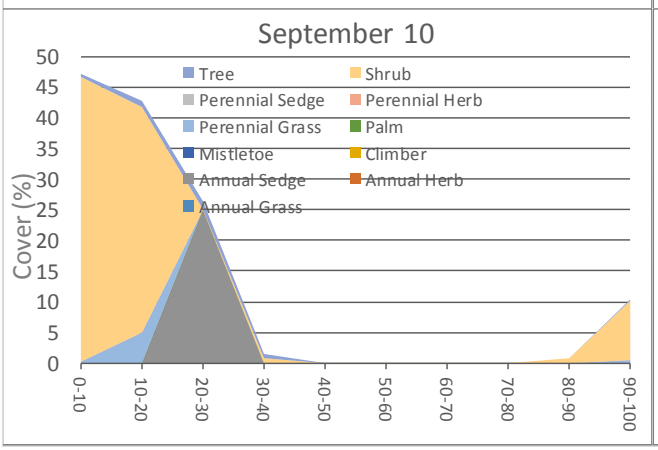
WW02 All Lifeforms

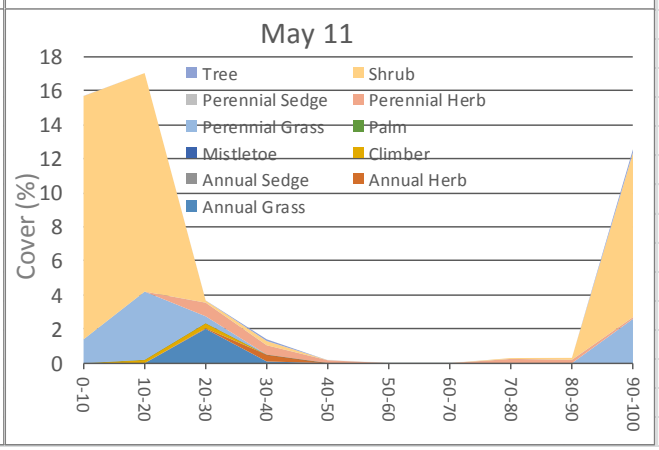




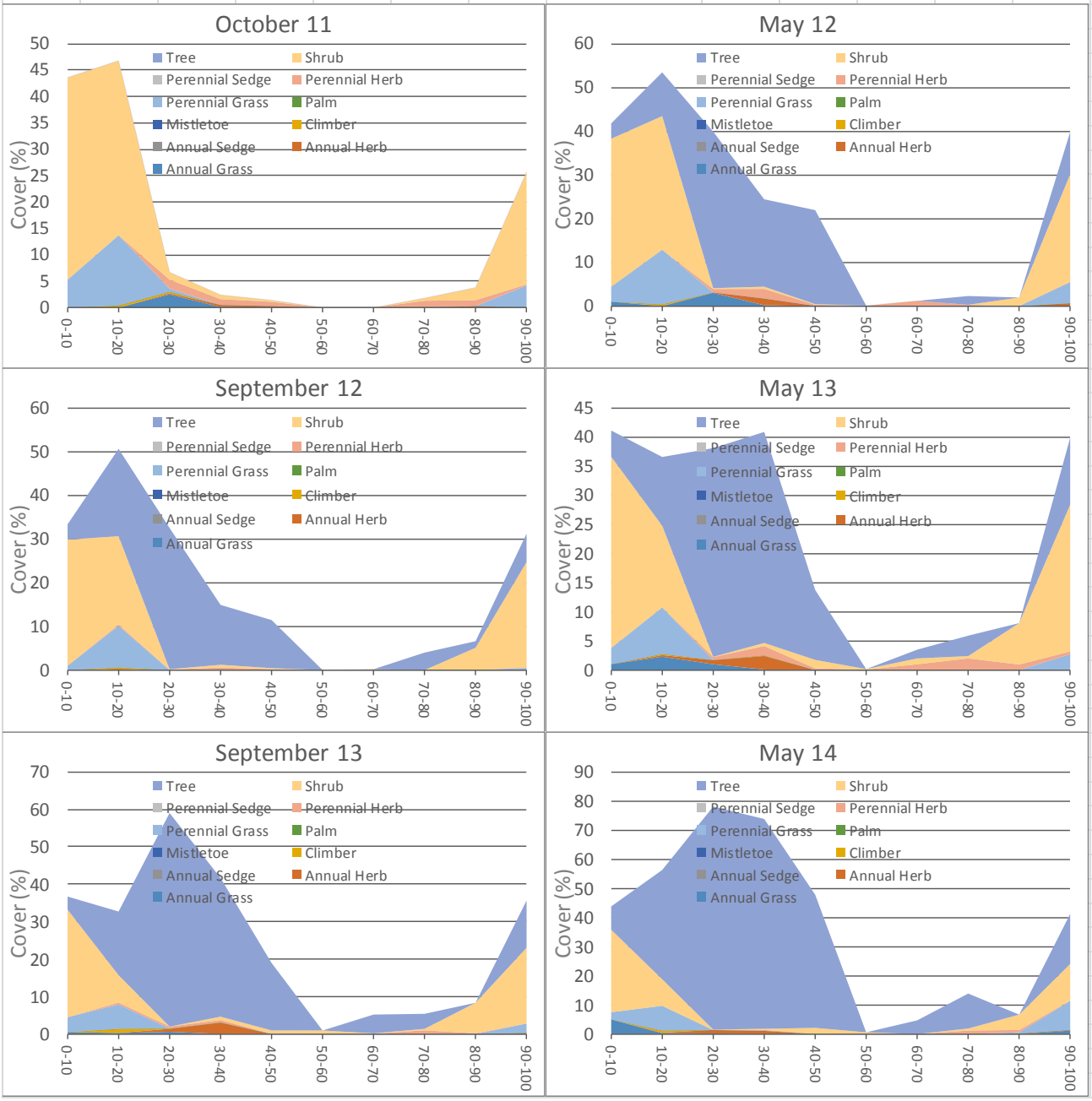




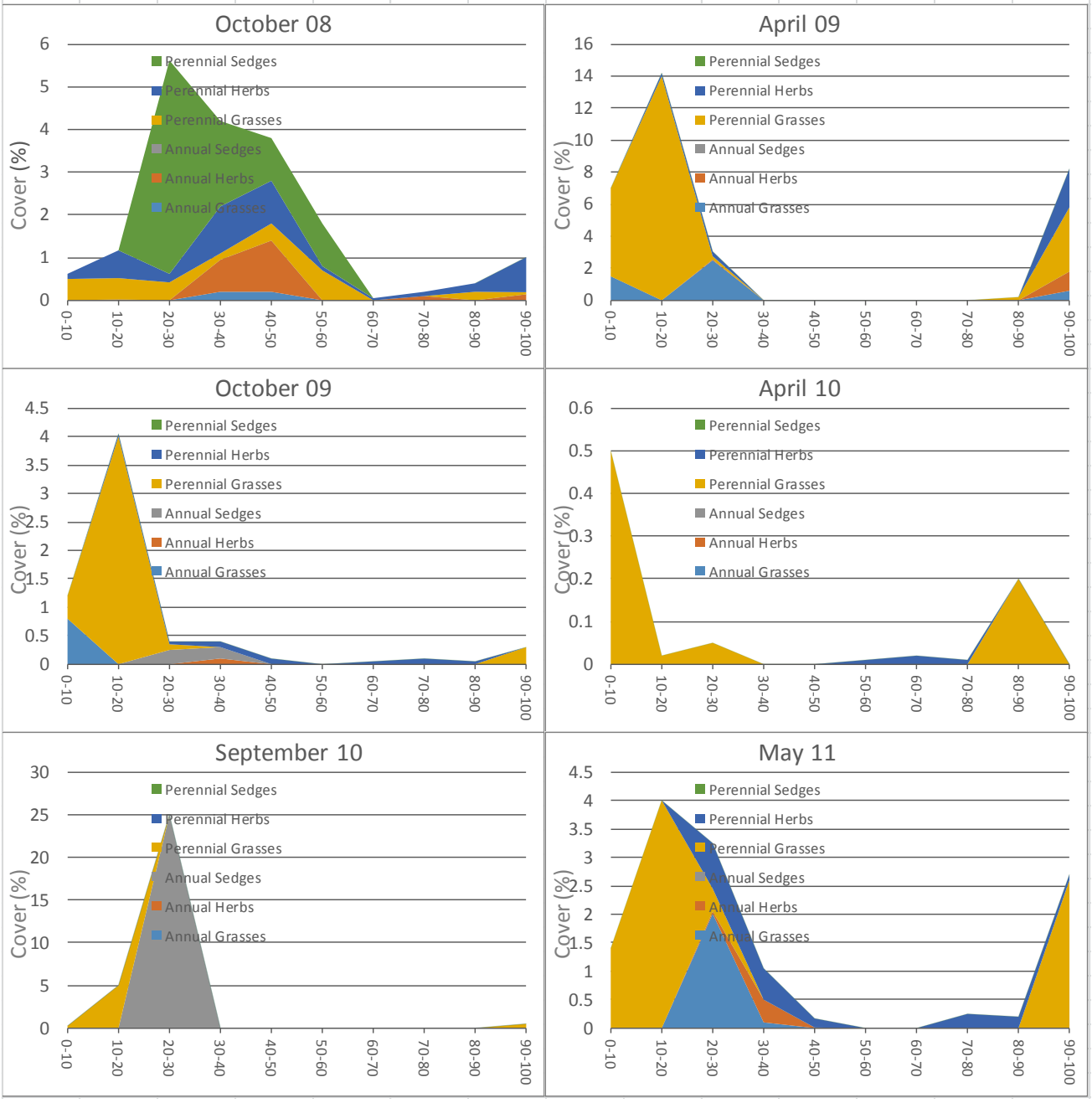




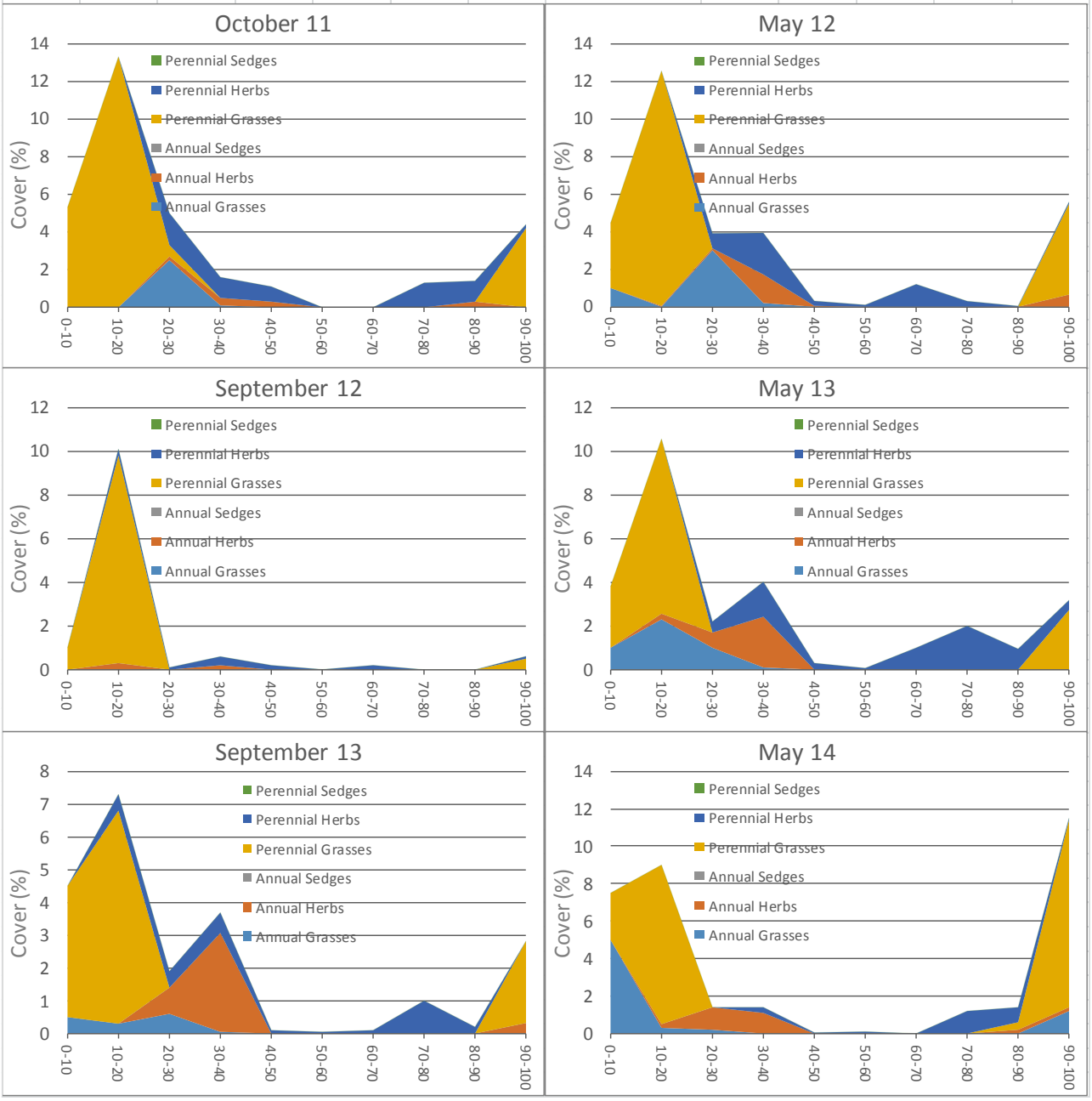
WW02 All Lifeforms

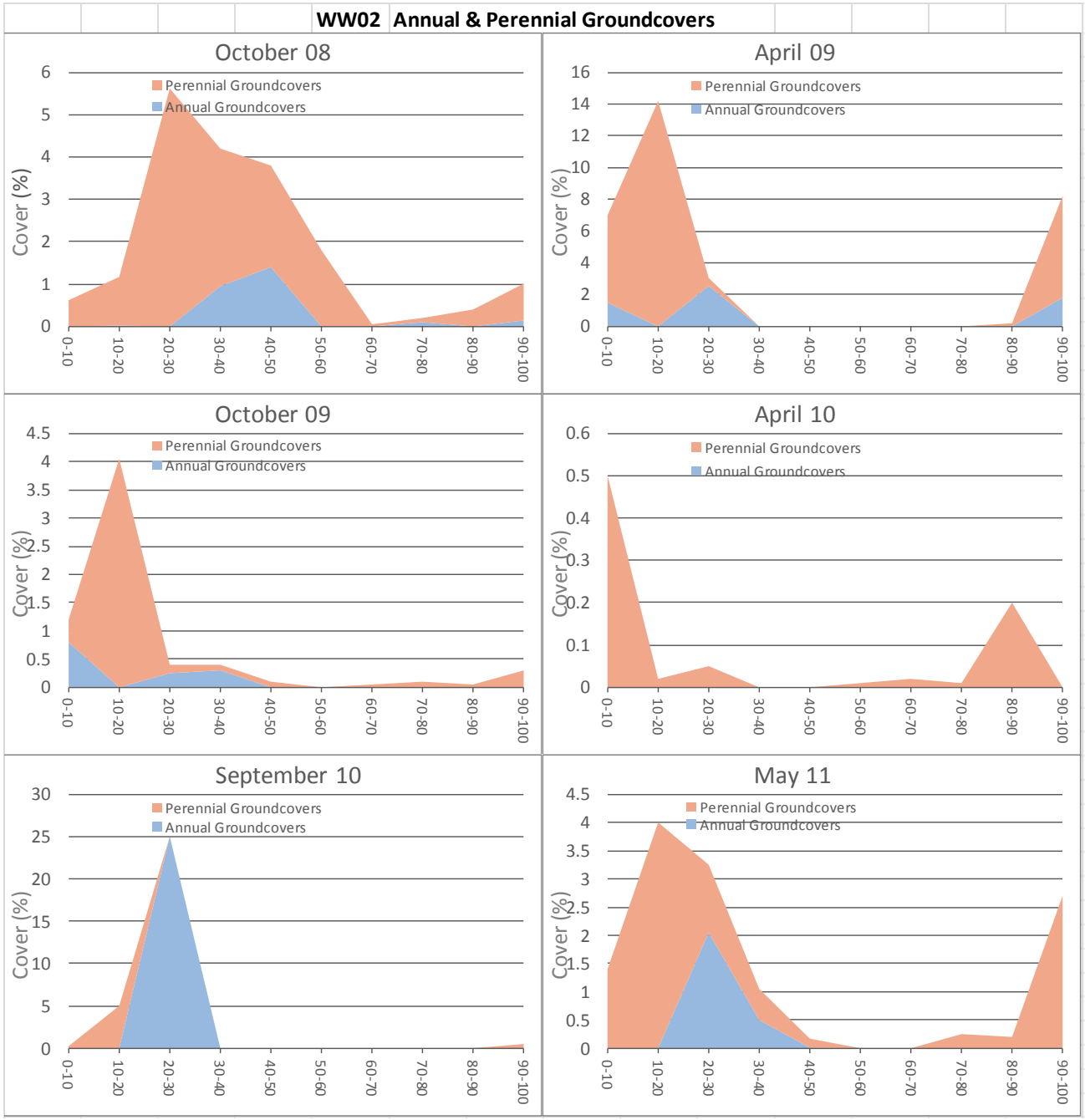


WW02 Groundcovers

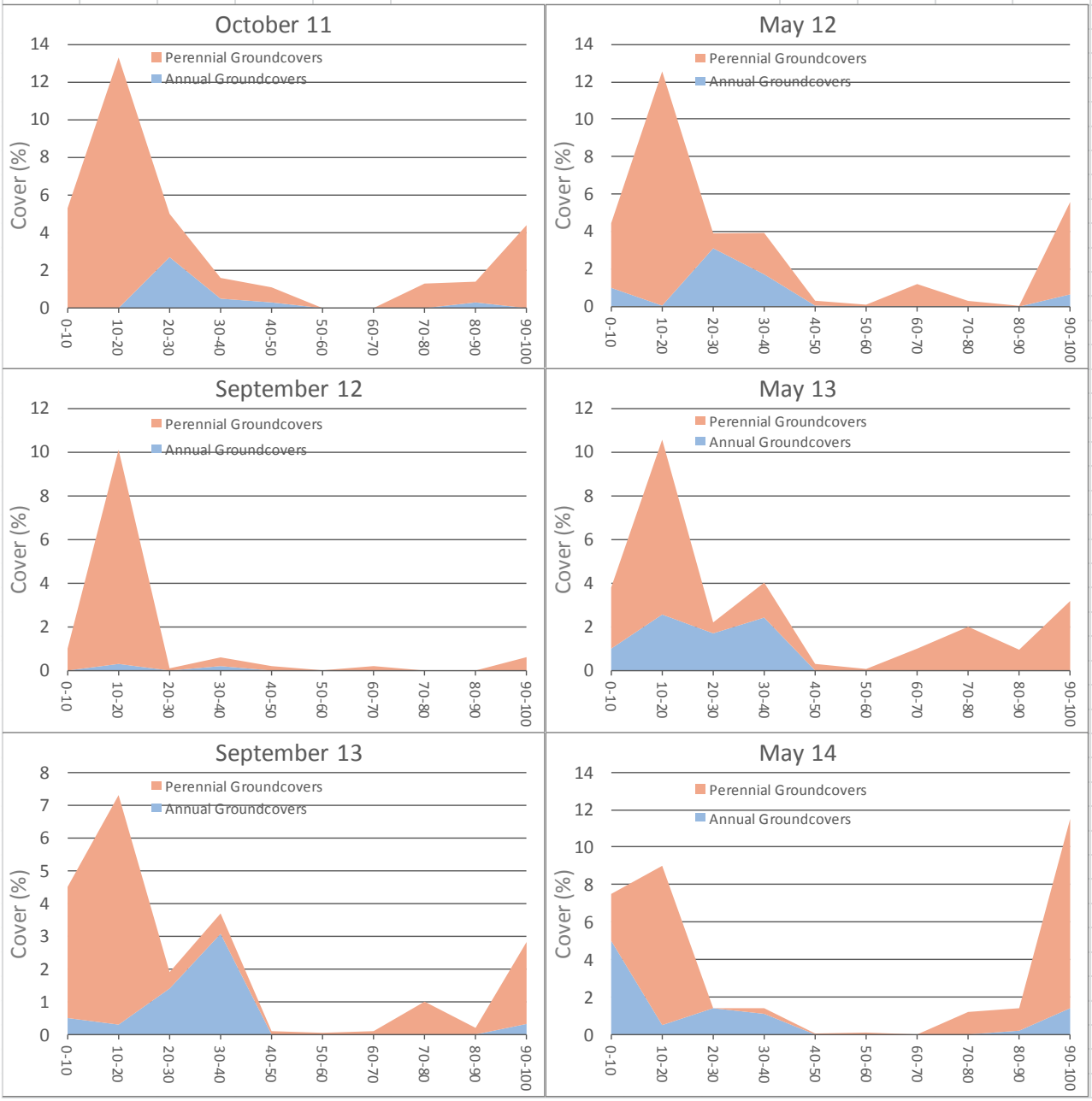


WW02 Groundcovers

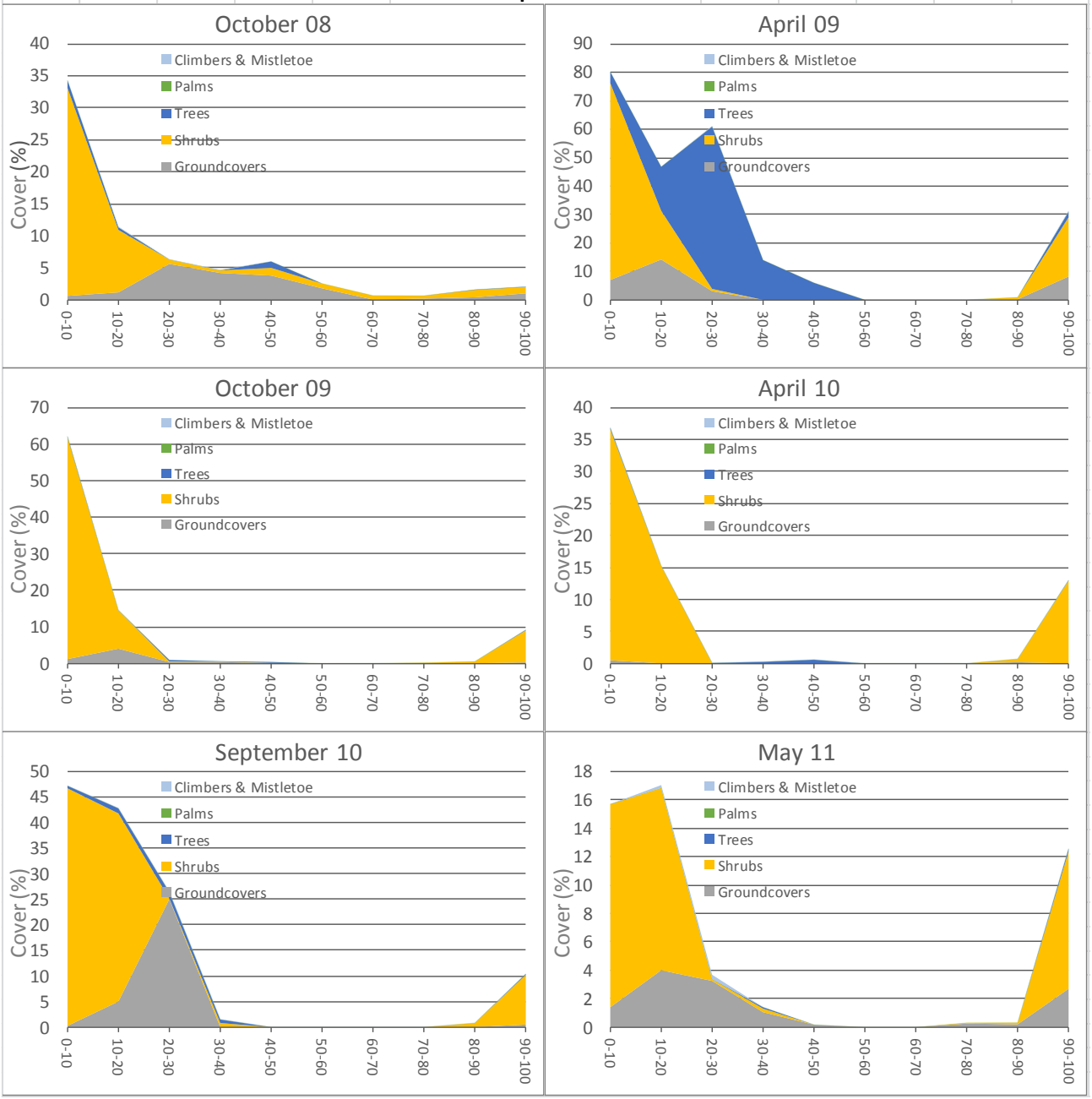



WW02 Annual & Perennial Groundcovers
October 08
April 09
October 09
April 10
September 10
May 11
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

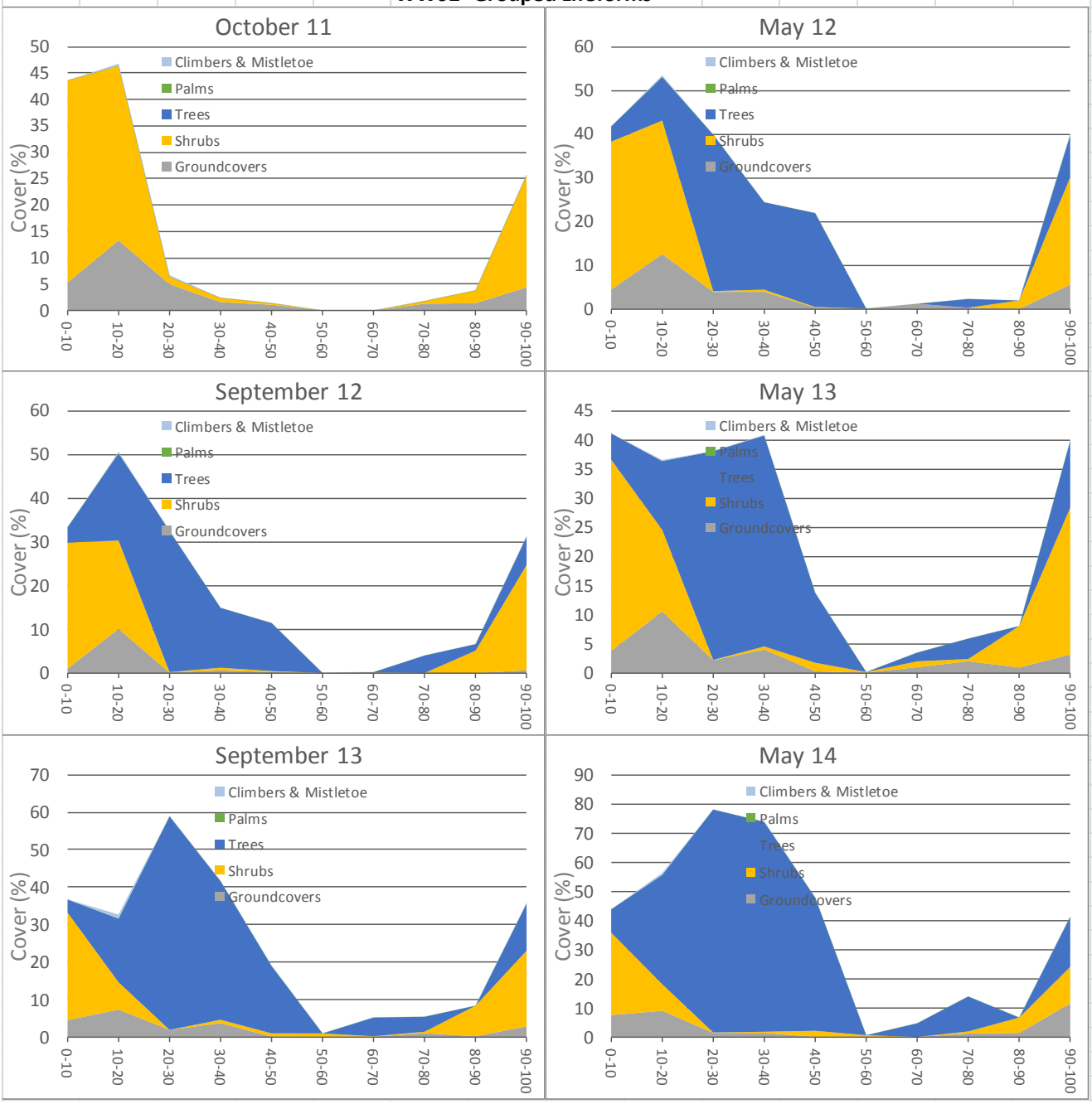
WW02 Annual & Perennial Groundcovers



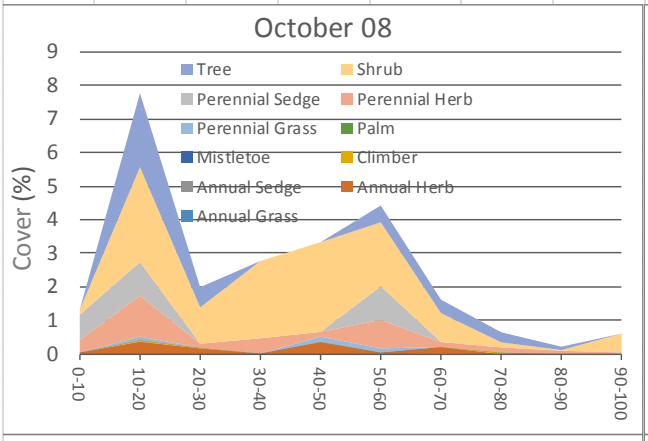
WW02 Grouped Lifeforms

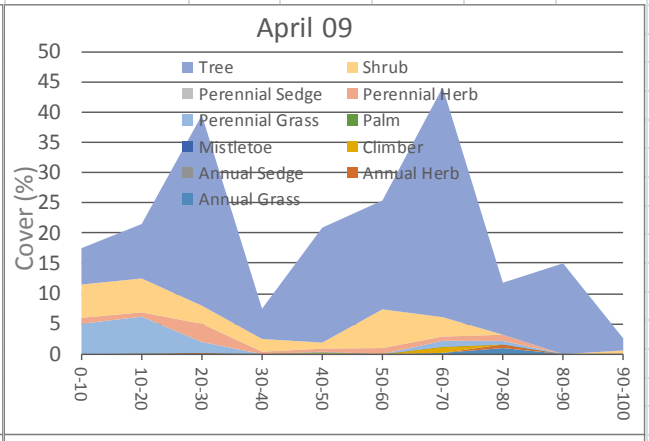


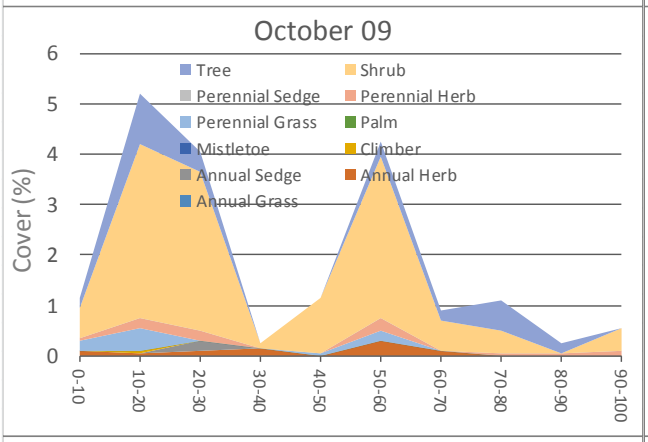
WW02 Grouped Lifeforms

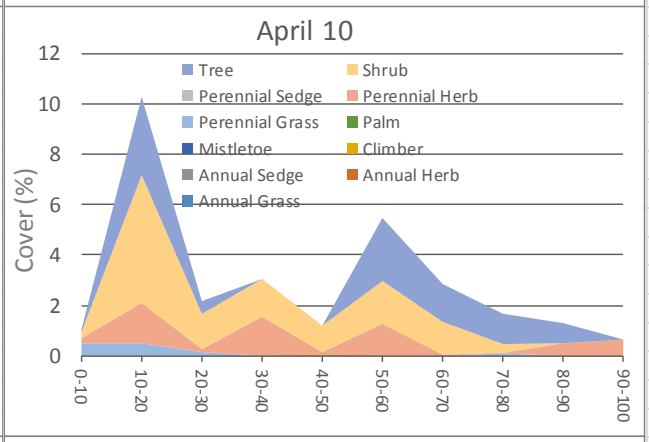


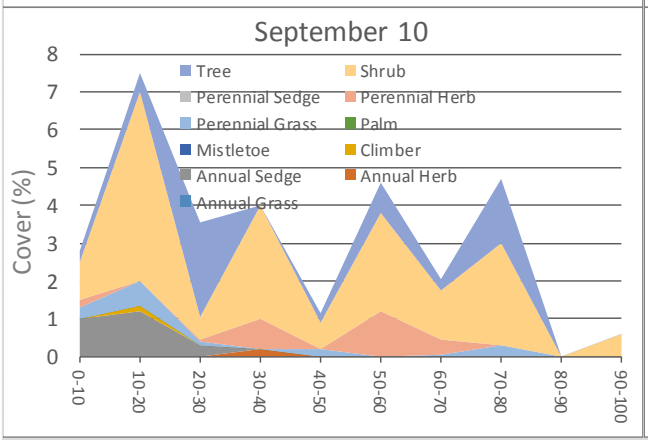
WW03 All Lifeforms

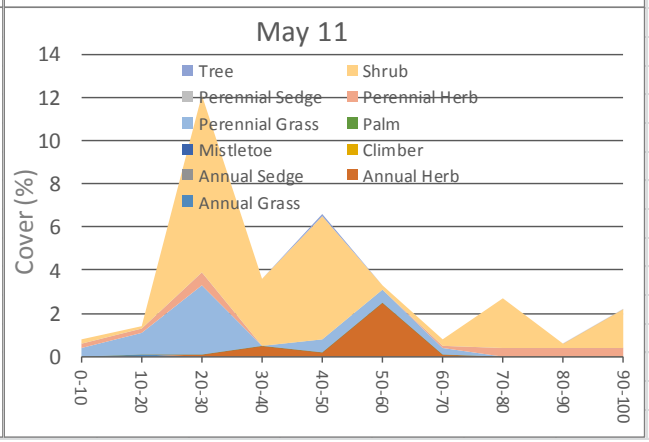




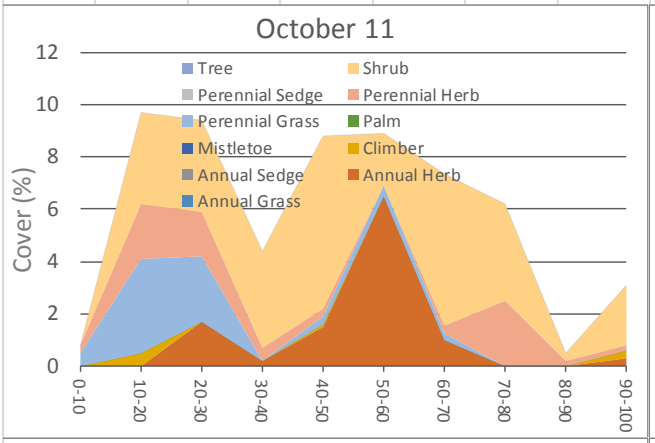


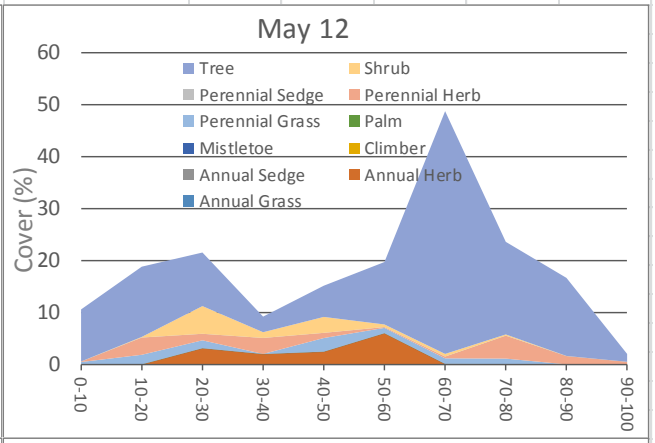


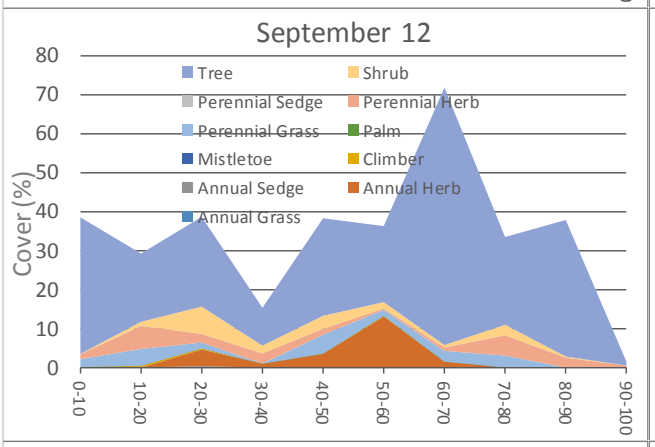


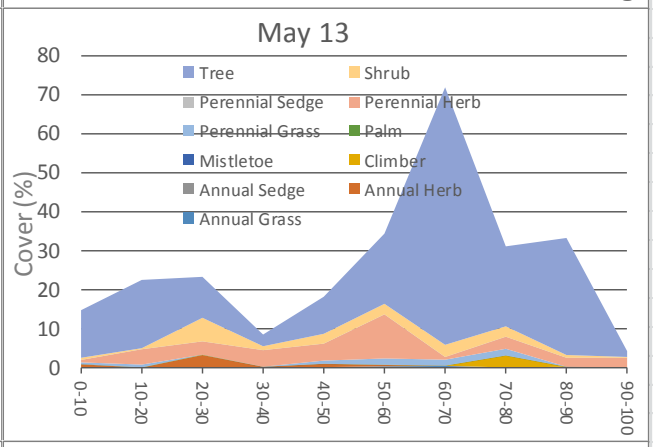


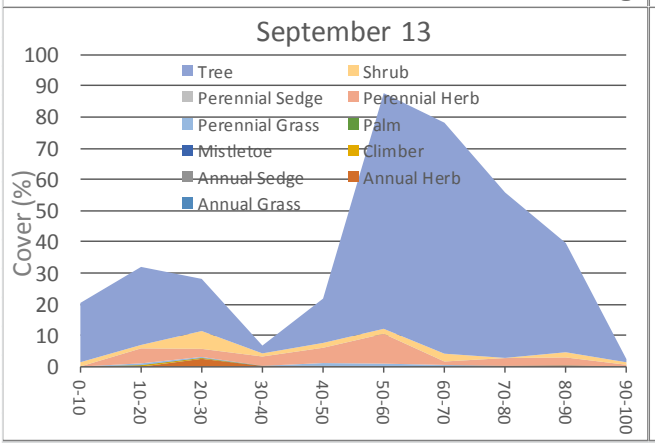
WW03 All Lifeforms

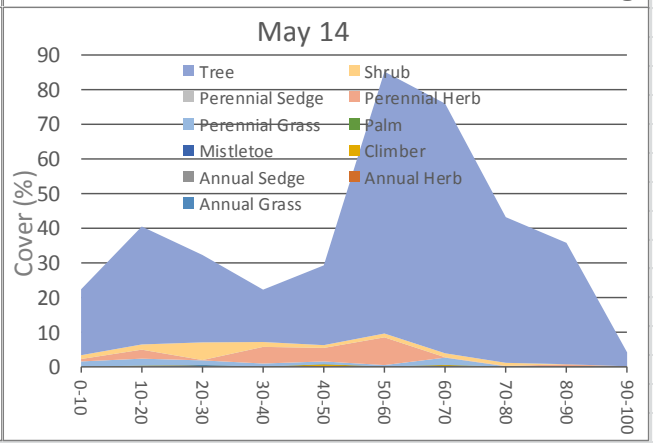




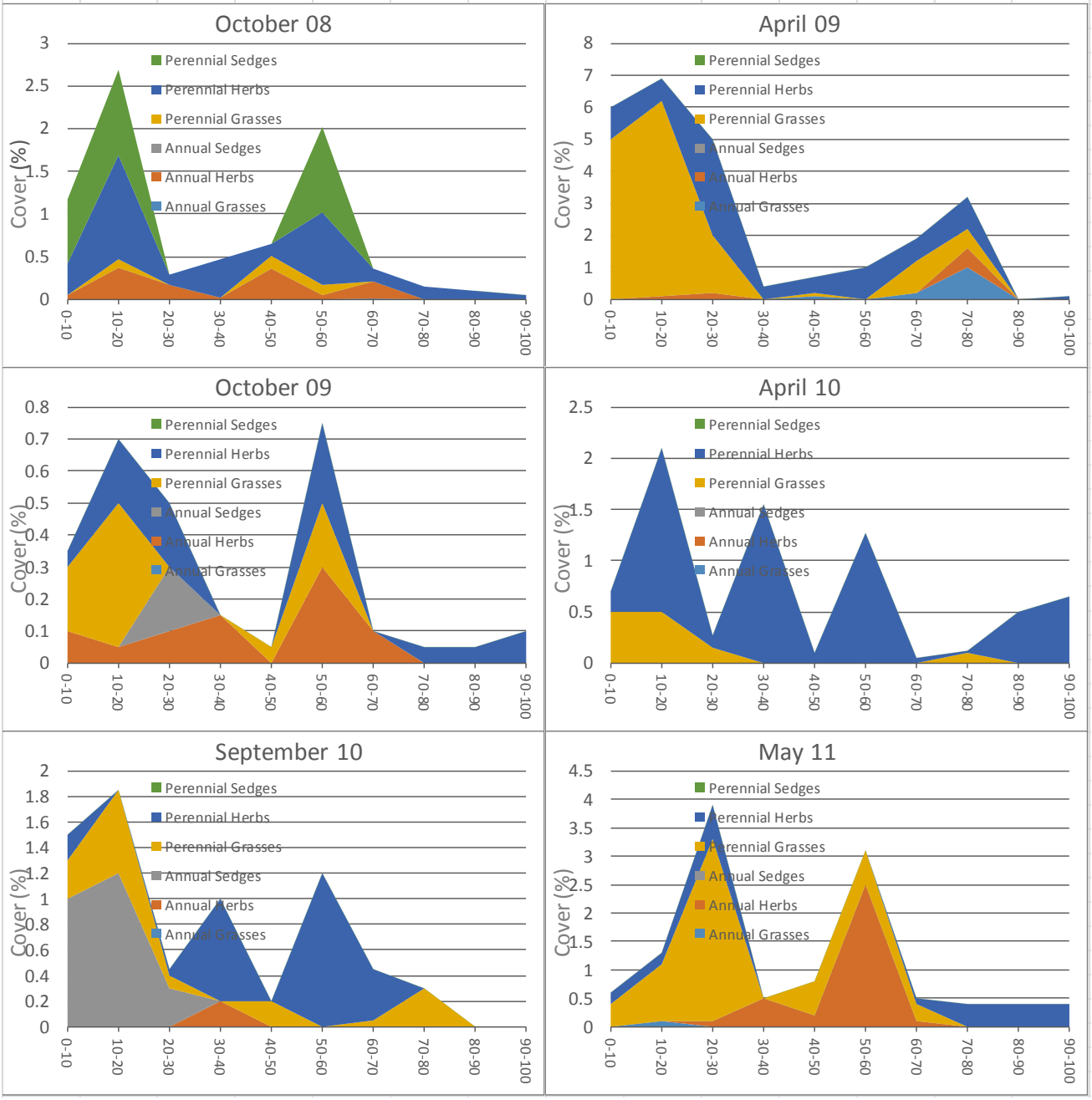




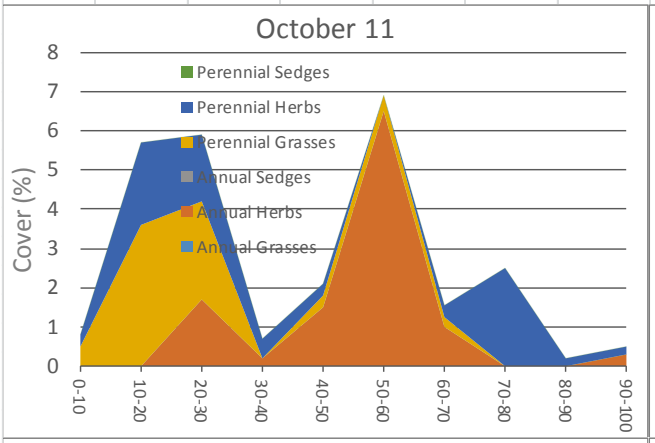


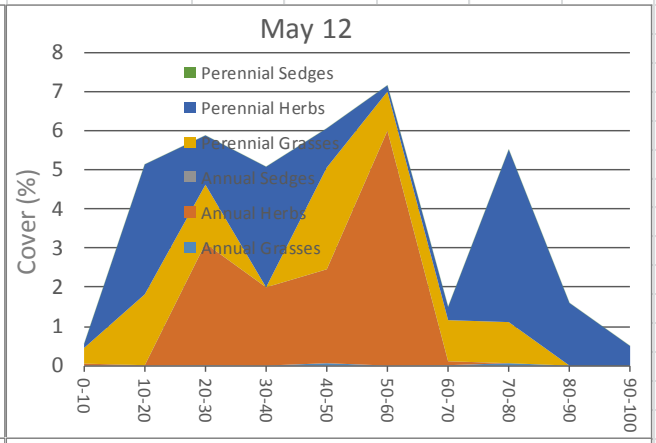


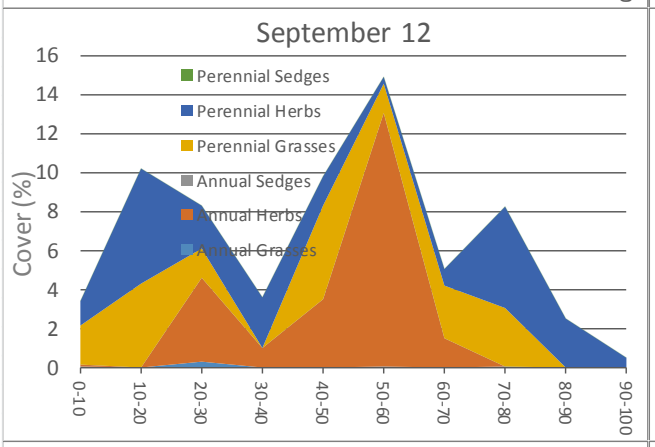
WW03 Groundcovers

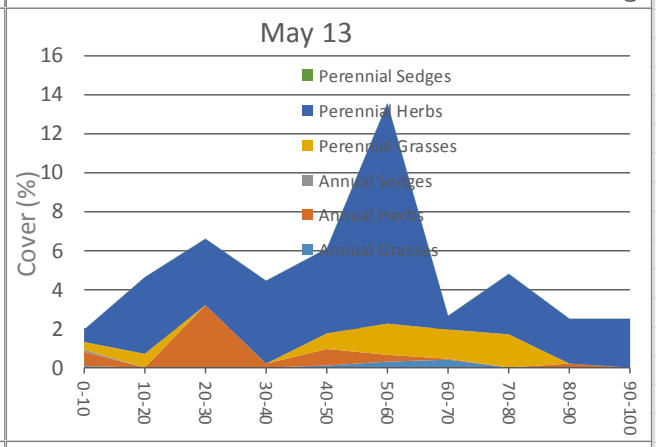


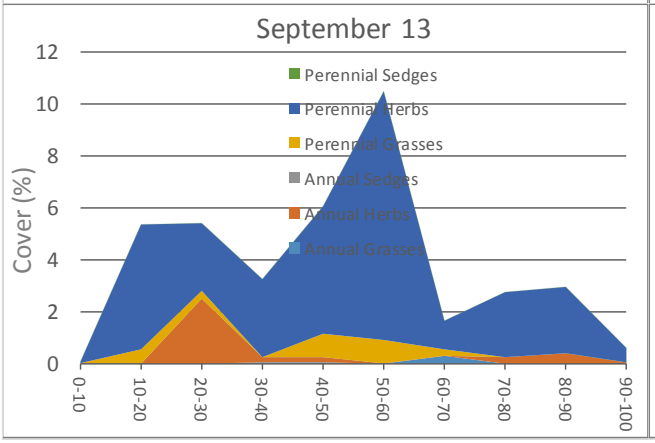
WW03 Groundcovers

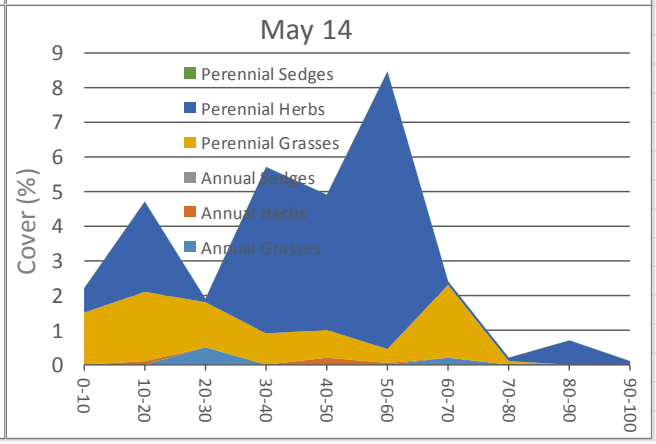


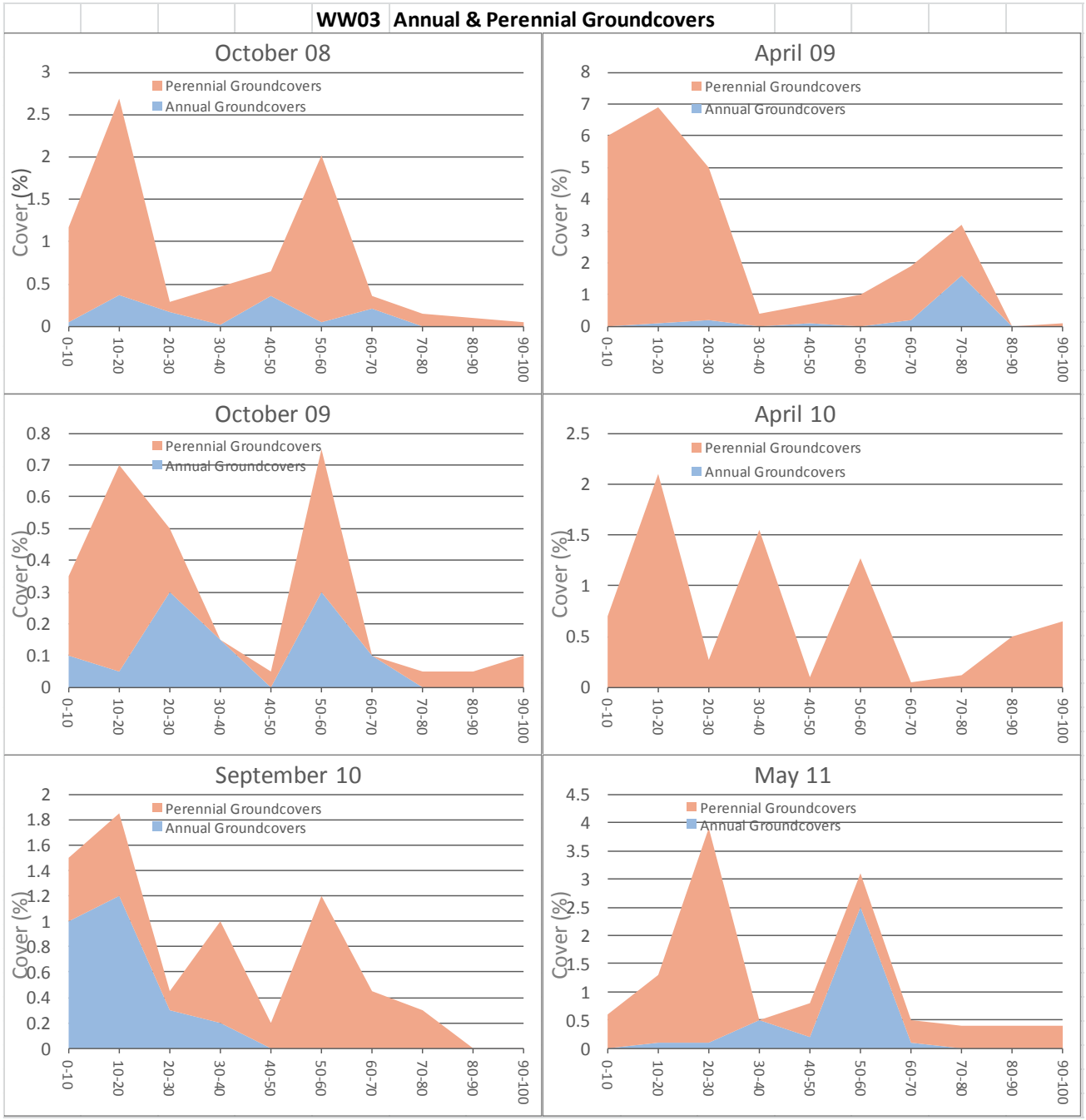


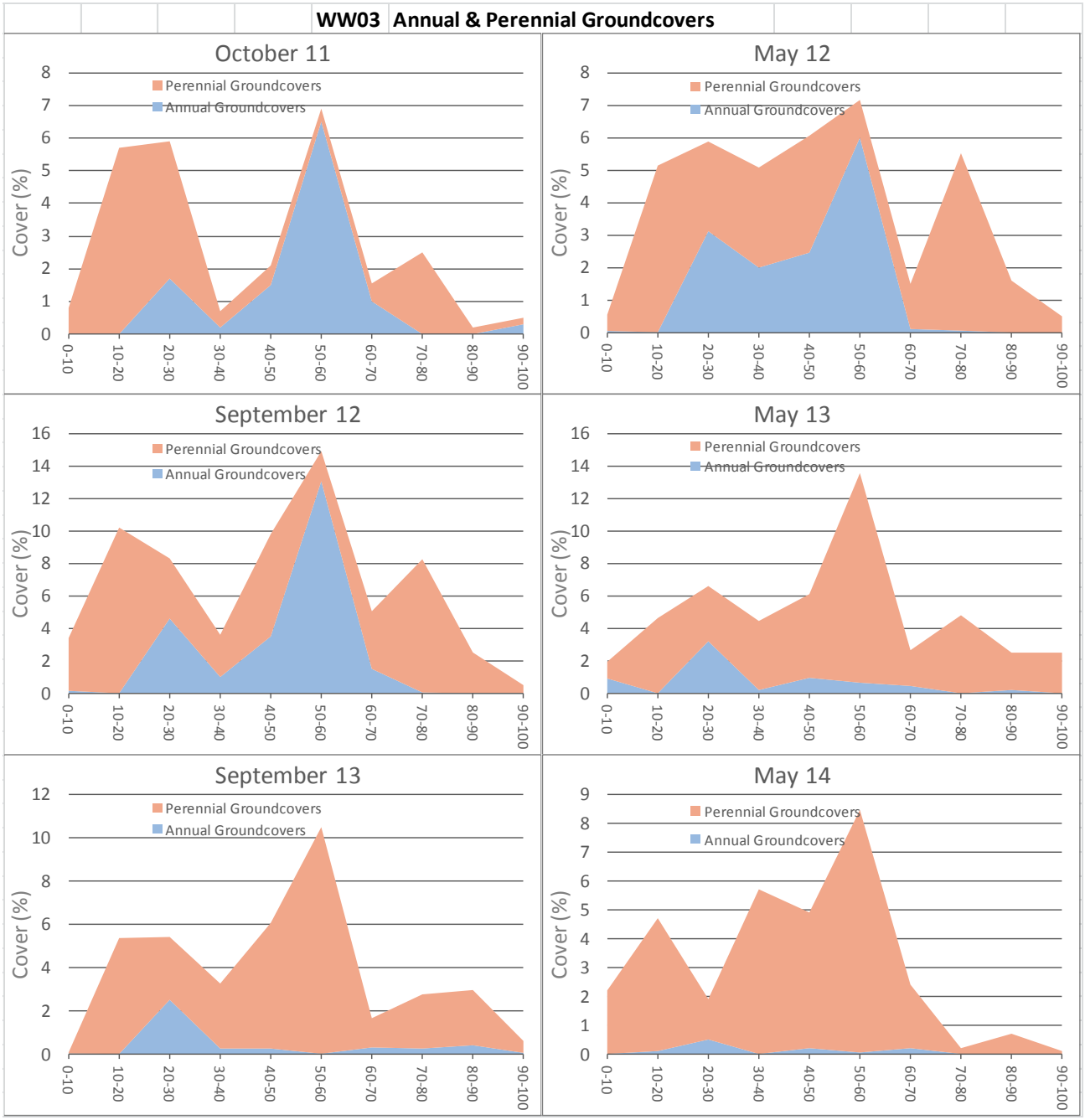




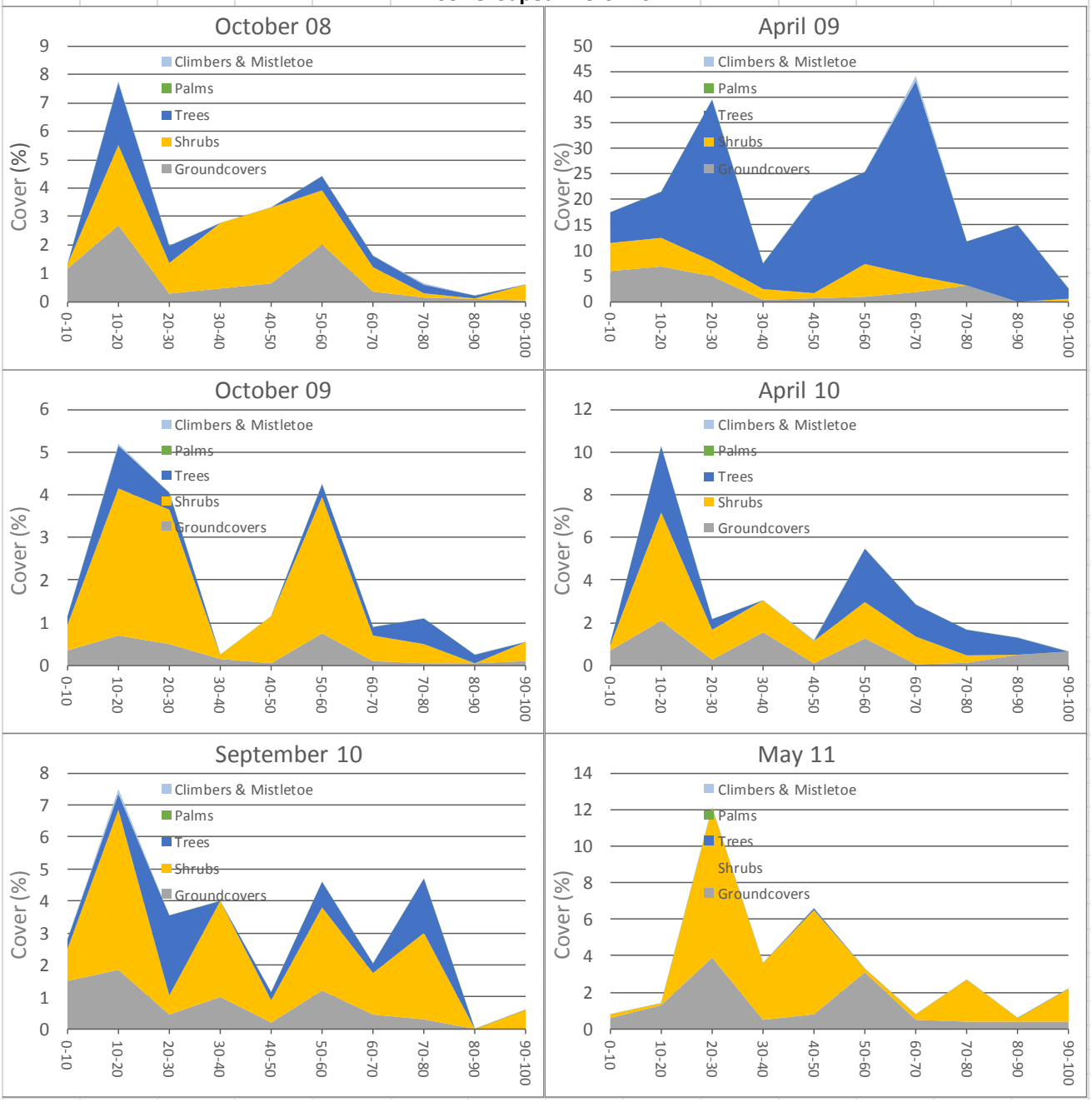




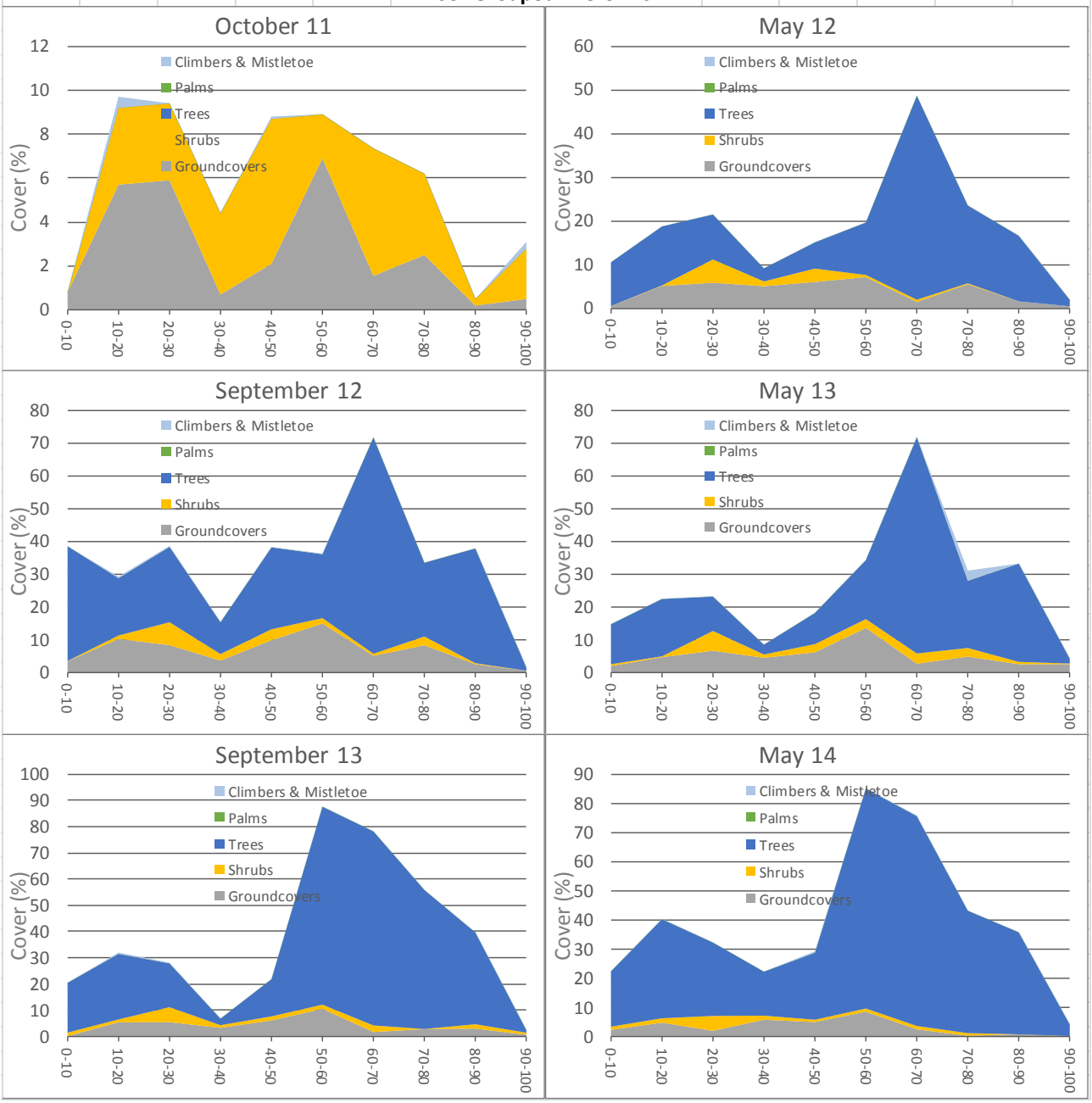

WW03 Annual & Perennial Groundcovers
October 08
April 09
October 09
April 10
September 10
May 11
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100


WW03 Annual & Perennial Groundcovers
October 11
May 12
September 12
May 13
September 13
May 14
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

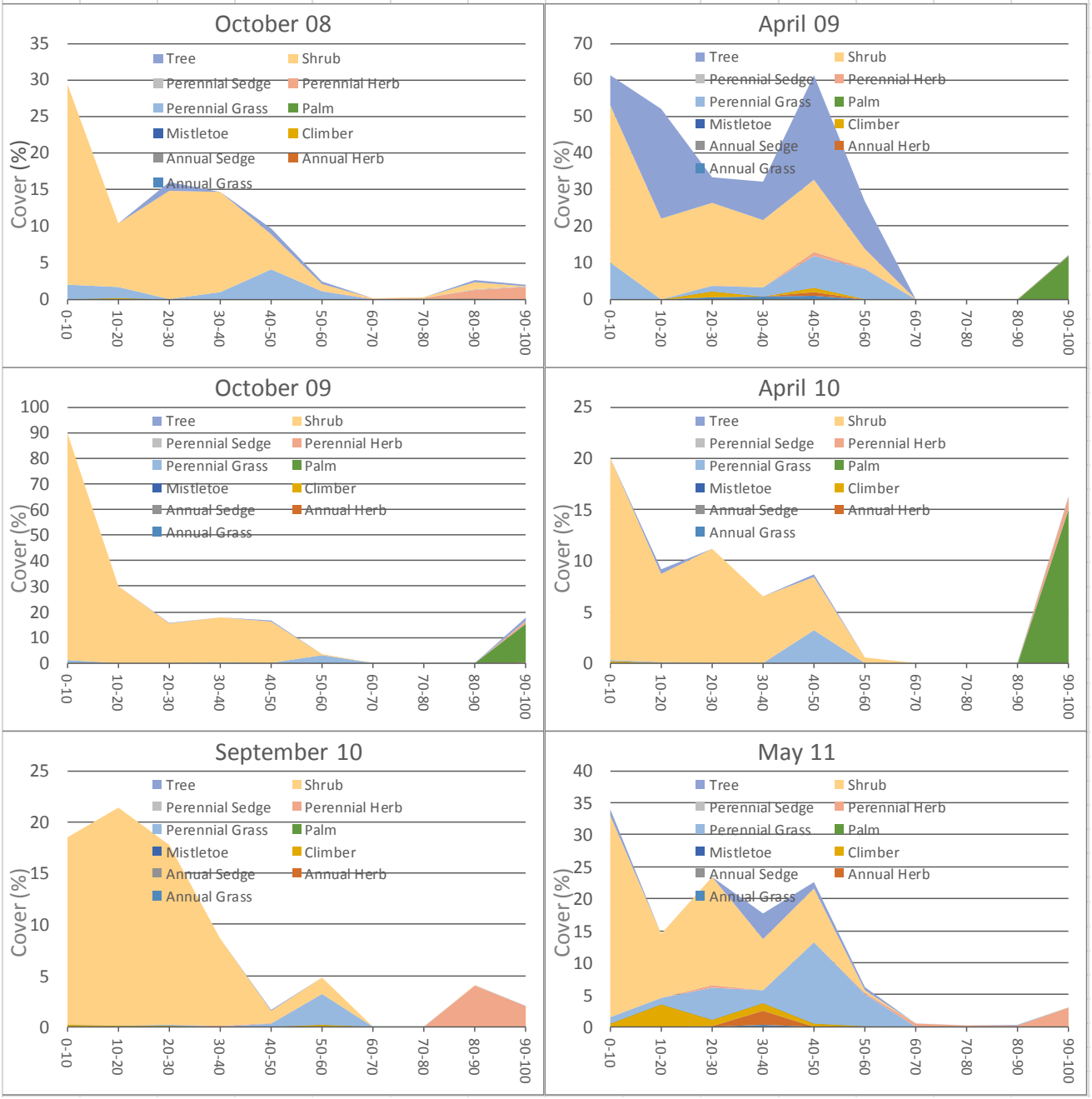
WW03 Grouped Lifeforms

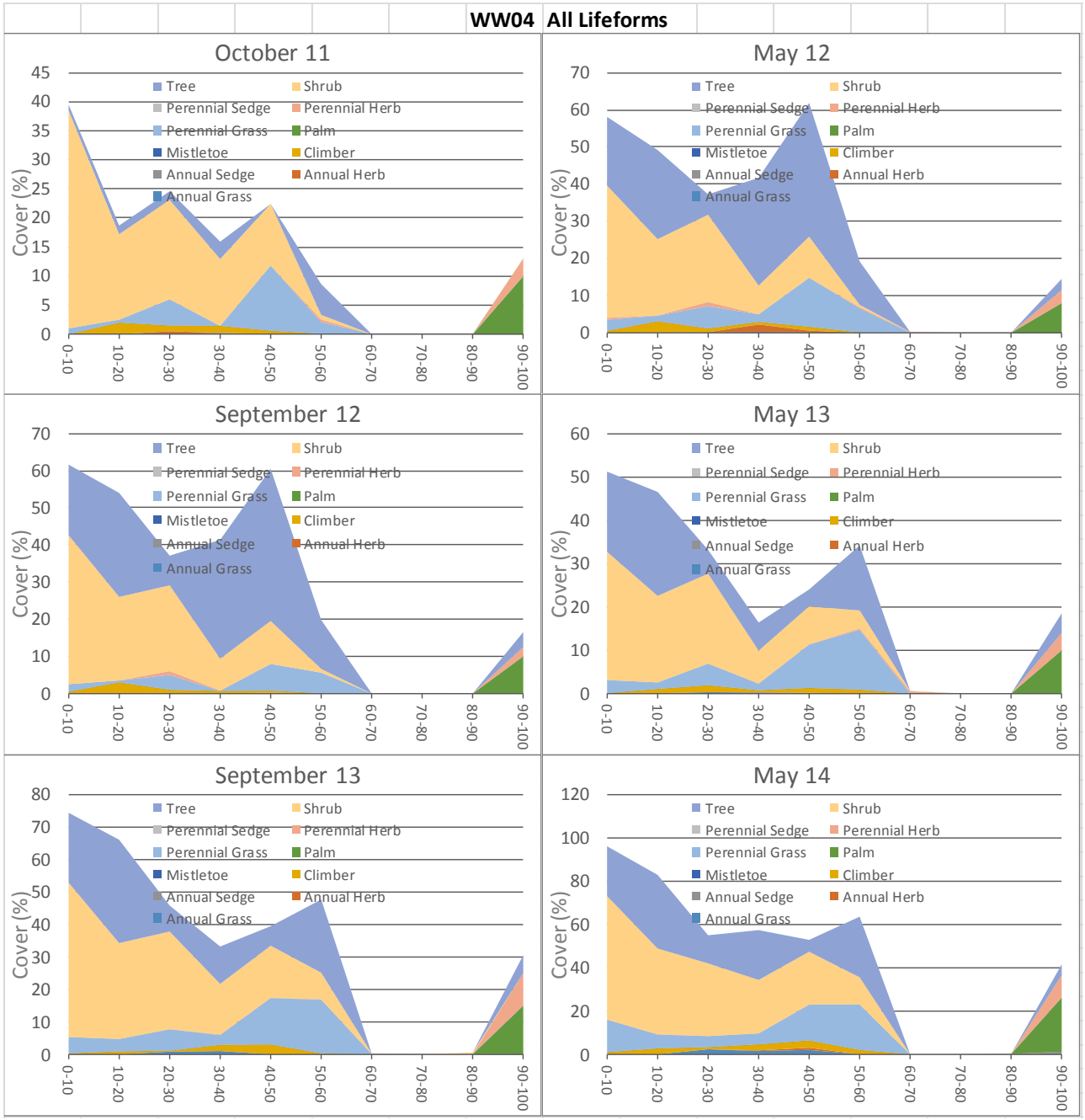


WW03 Grouped Lifeforms

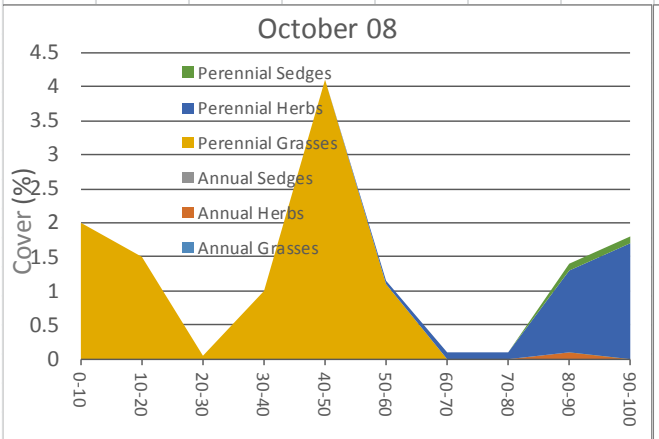


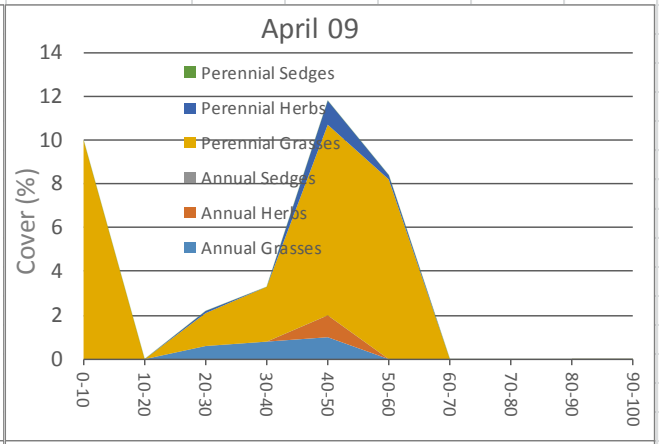
WW04 All Lifeforms

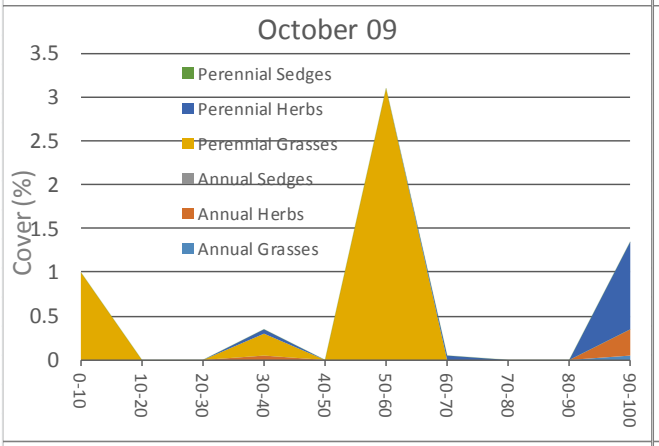


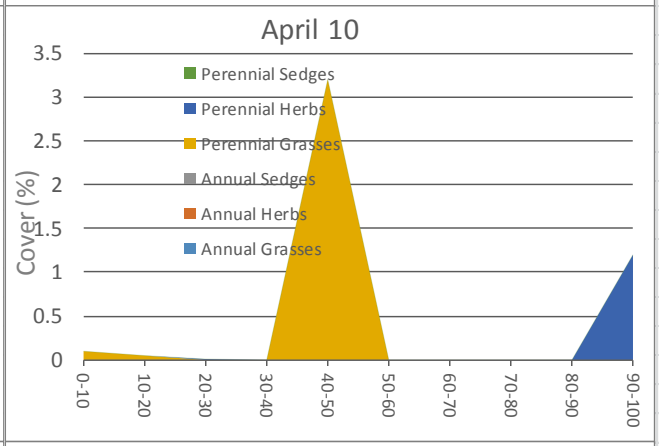

WW04 All Lifeforms
October 11
May 12
September 12
May 13
September 13
May 14
Cover (%)
Tree
Shrub
Perennial Sedge
Perennial Herb
Perennial Grass
Palm
Mistletoe
Climber
Annual Sedge
Annual Herb
Annual Grass
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

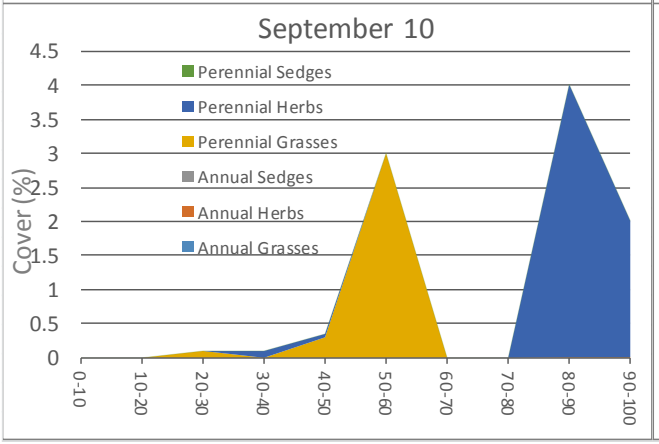
WW04 Groundcovers

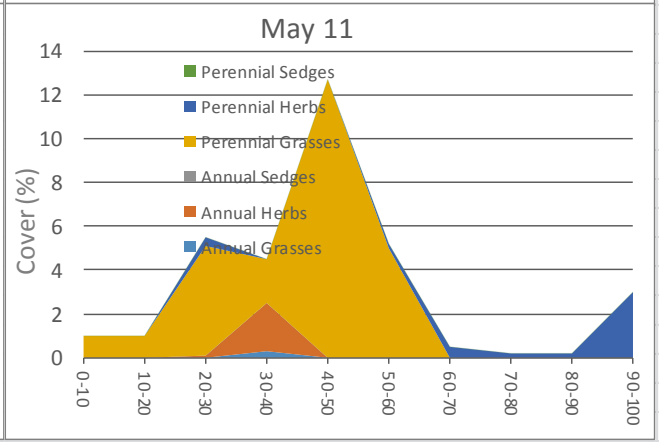




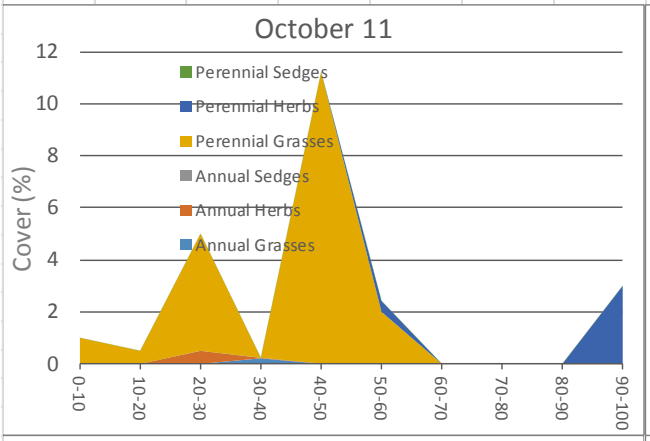


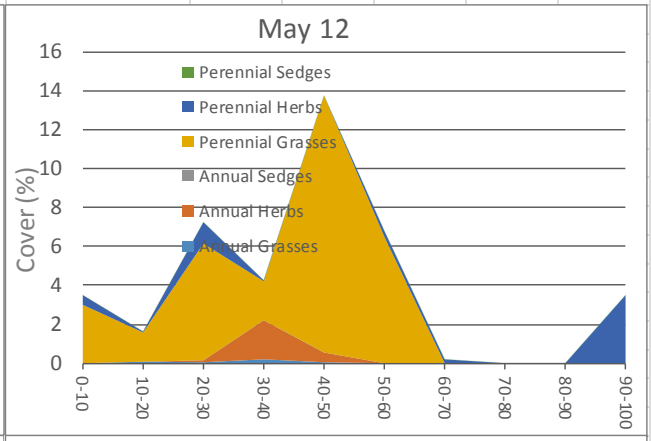


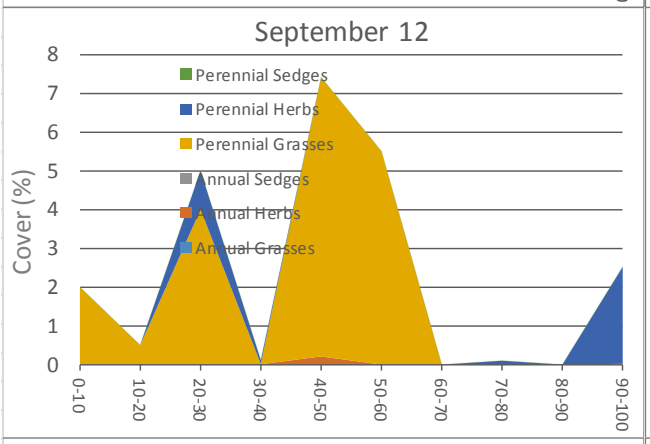


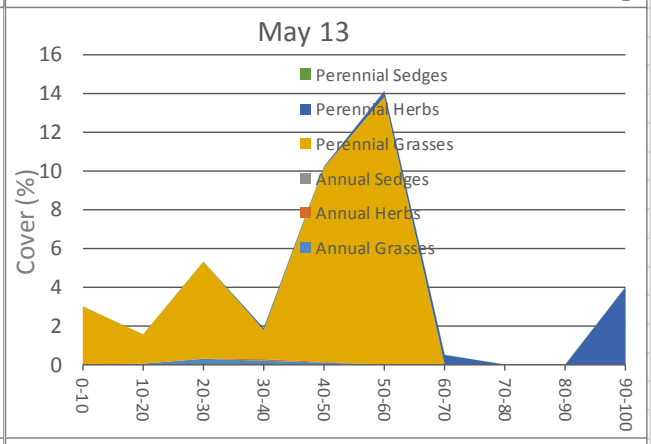


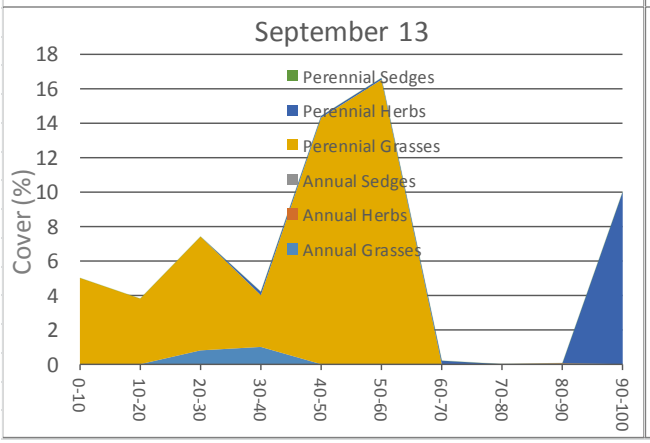
WW04 Groundcovers

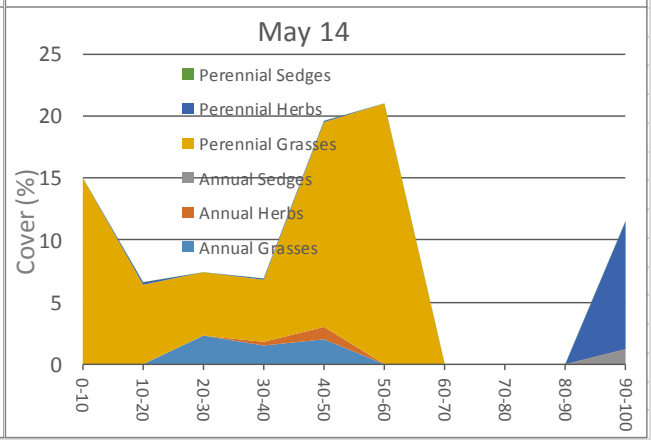




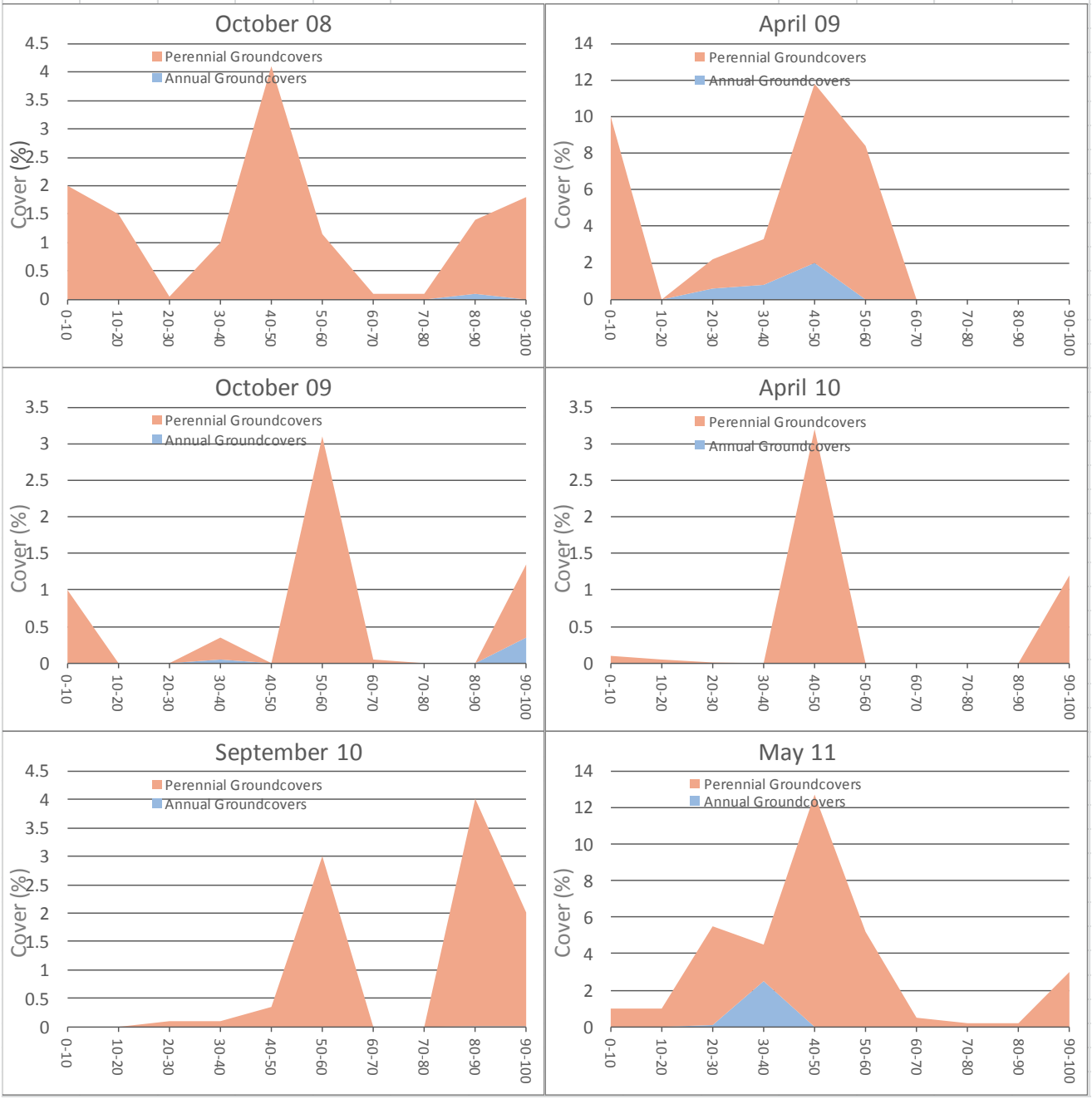


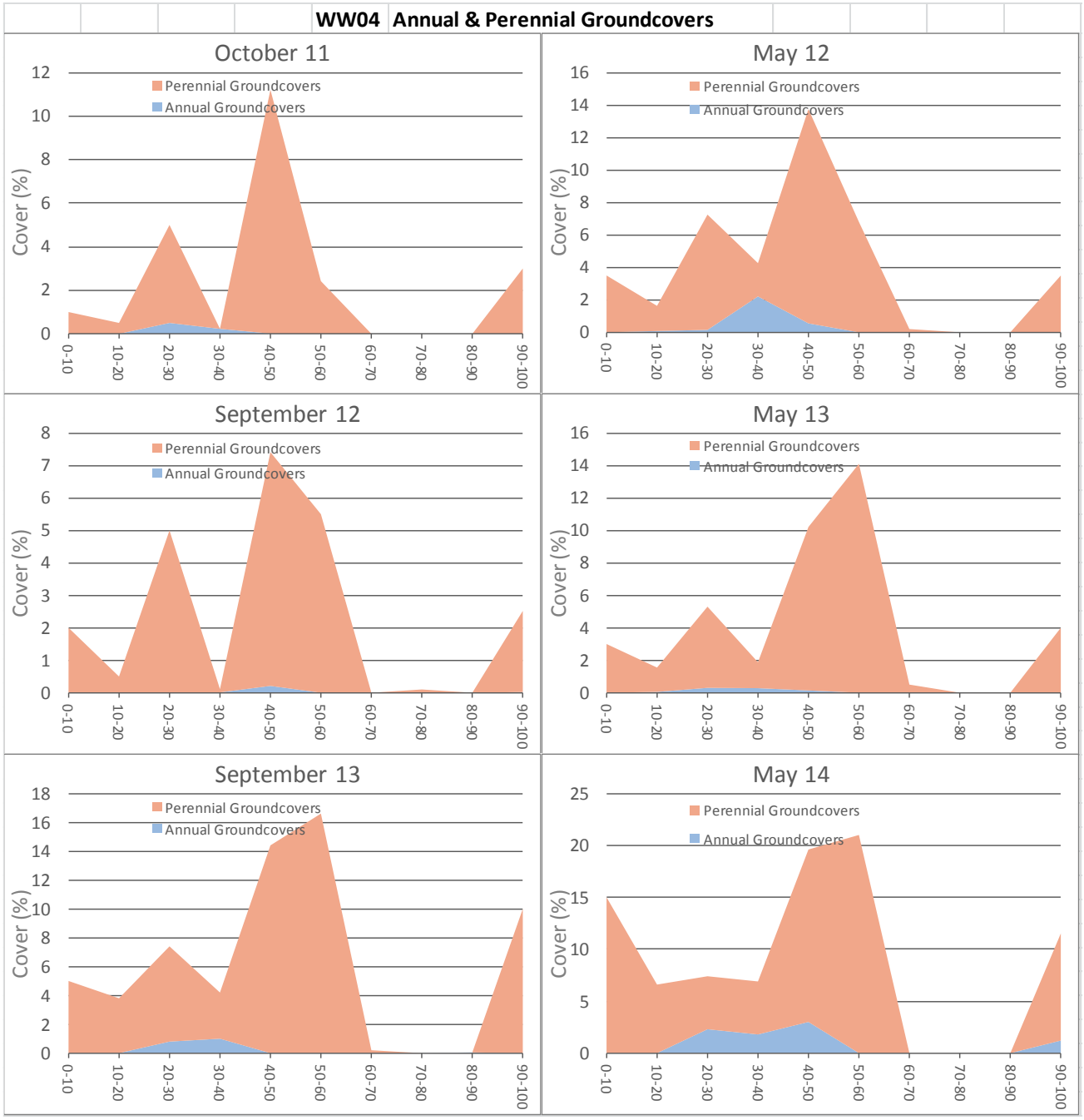


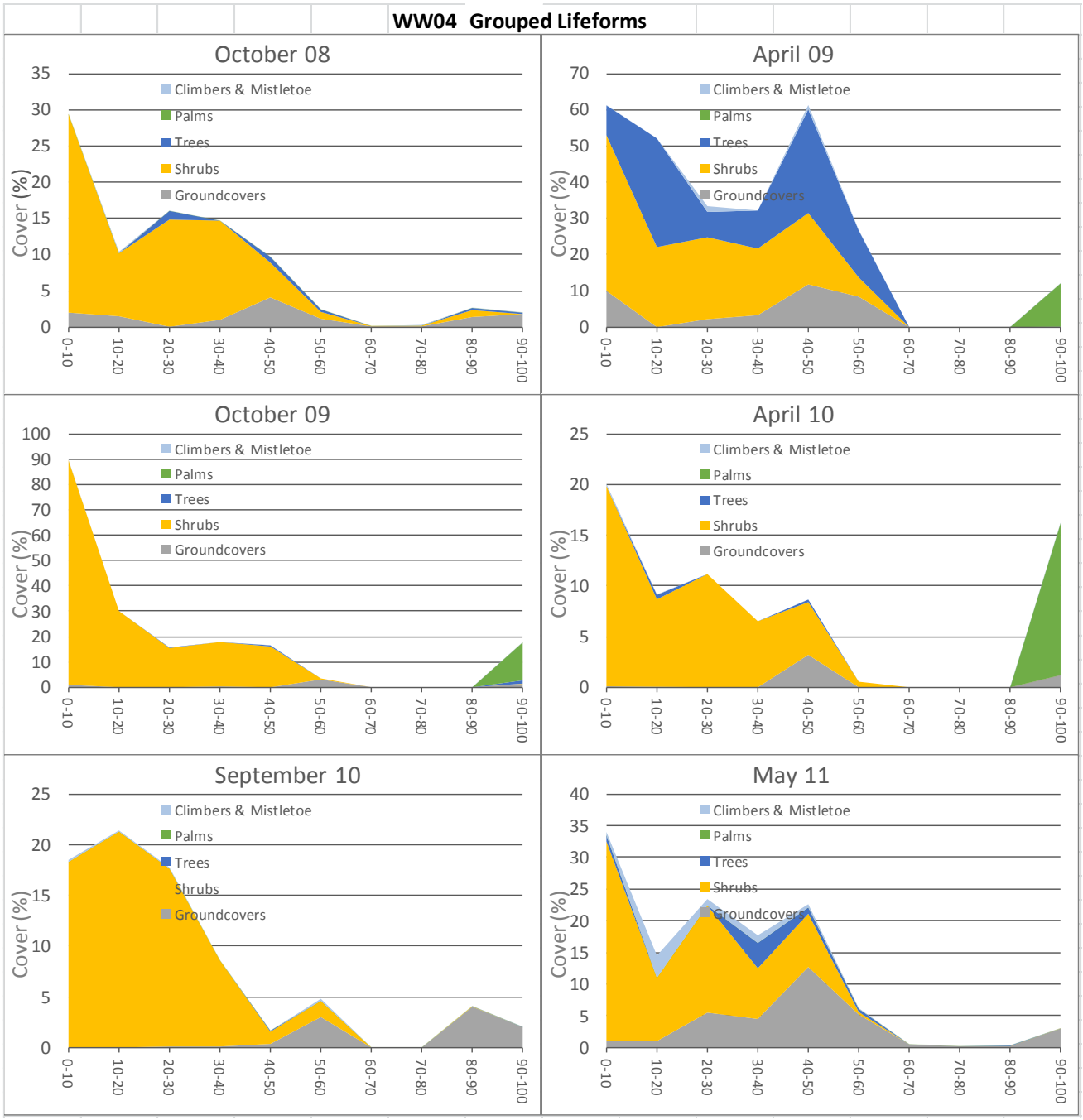




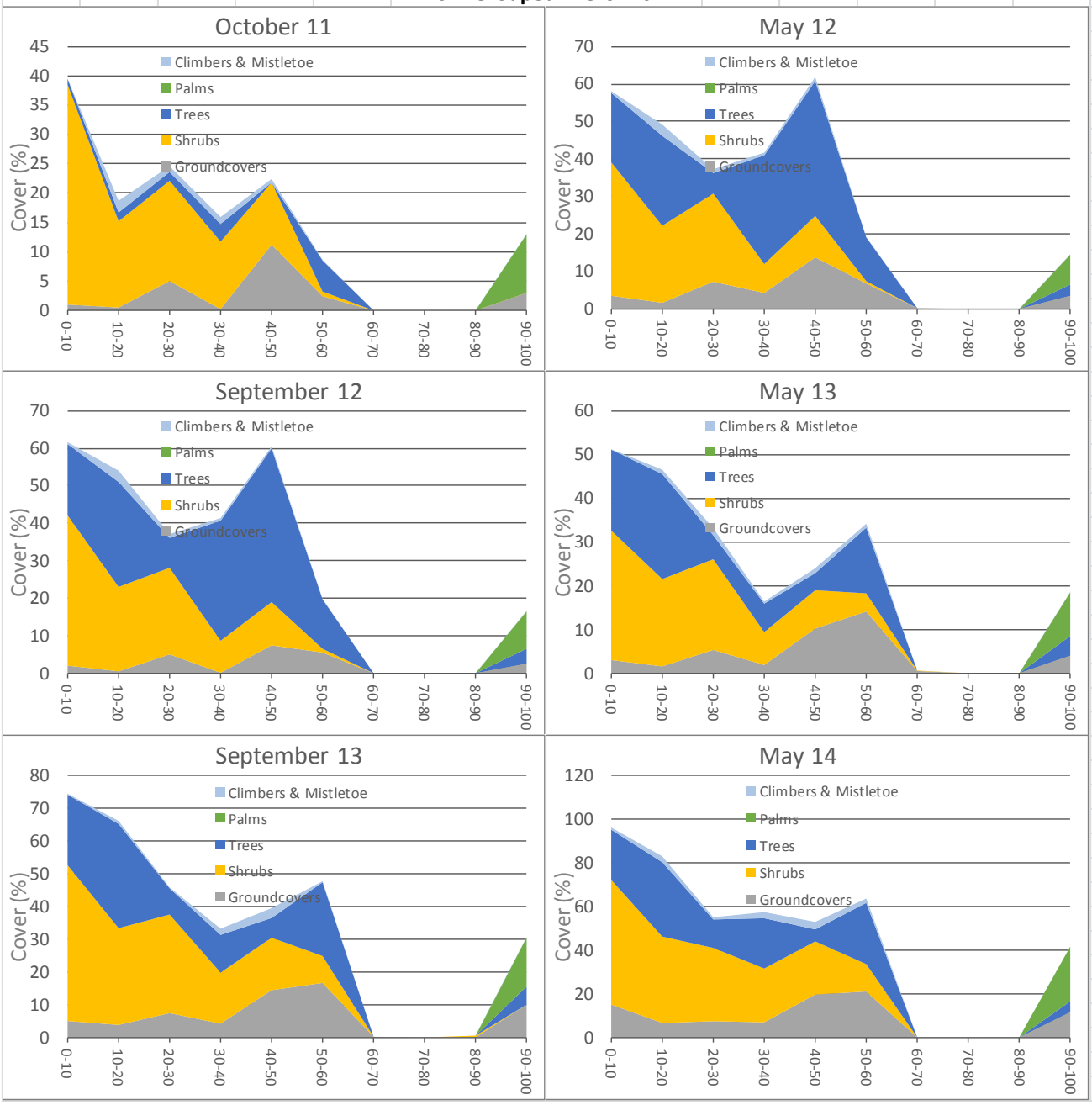
WW04 Annual & Perennial Groundcovers



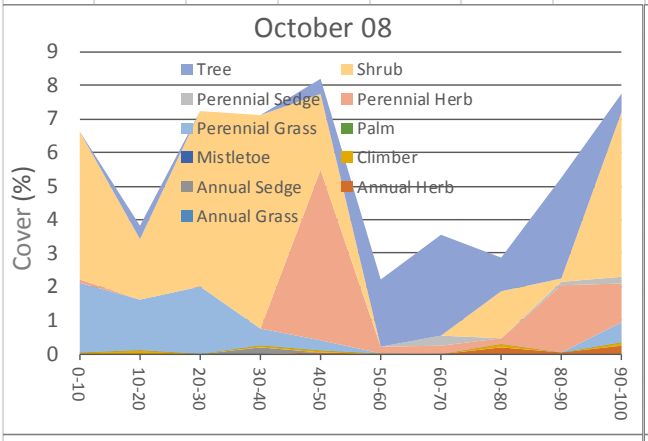

WW04 Annual & Perennial Groundcovers
October 11
May 12
September 12
May 13
September 13
May 14
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

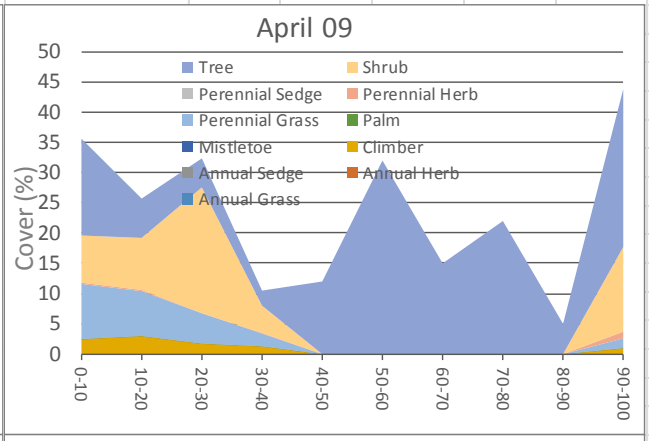

WW04 Grouped Lifeforms
October 08
April 09
October 09
April 10
September 10
May 11
Climbers & Mistletoe
Palms
Trees
Shrubs
Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

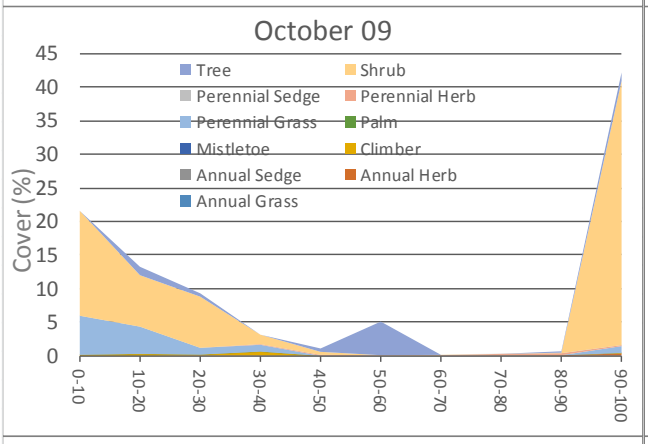
WW04 Grouped Lifeforms

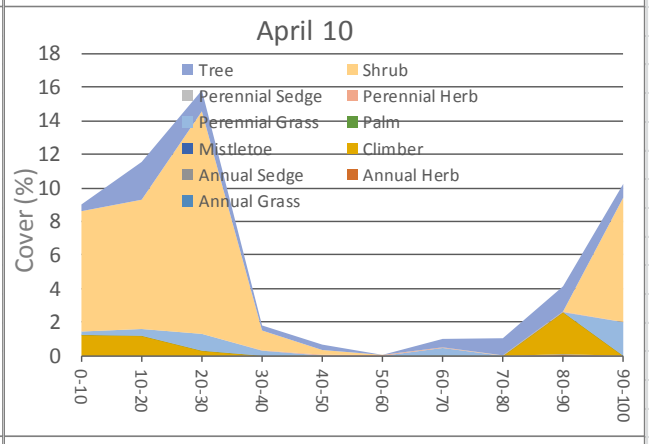


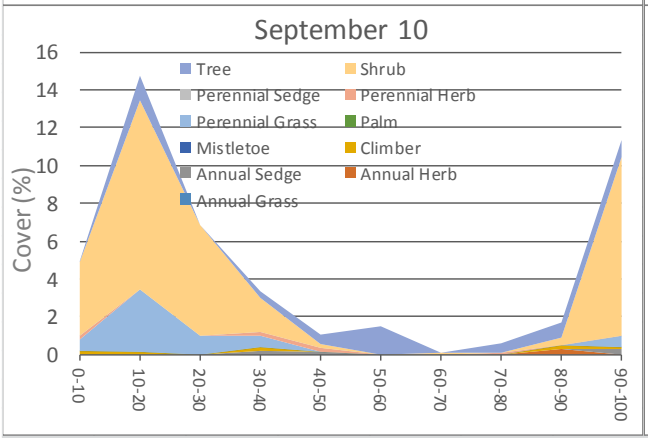
WW05 All Lifeforms

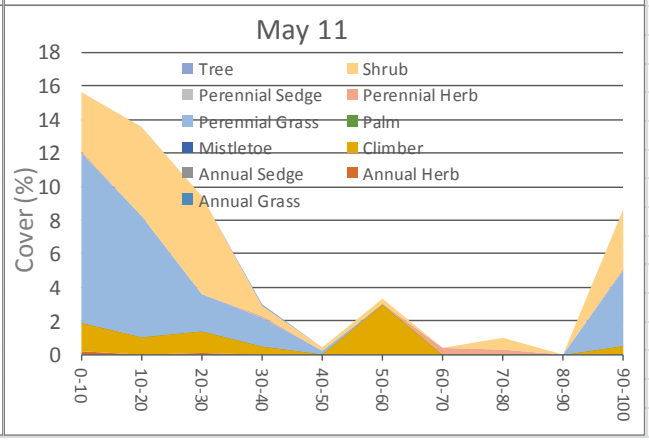




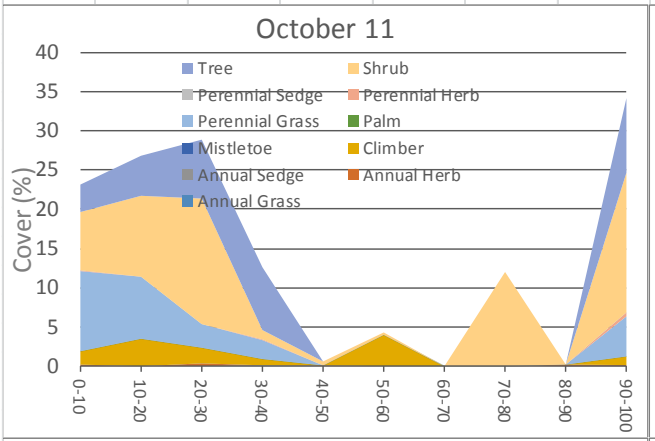


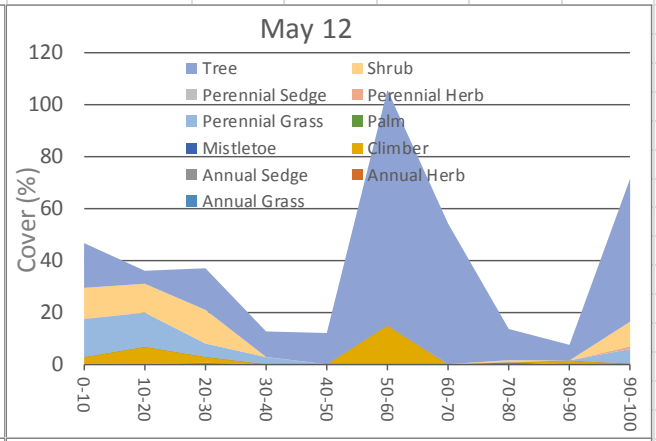


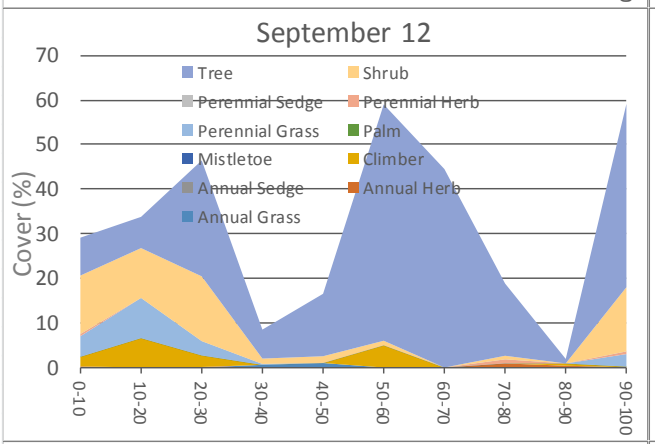


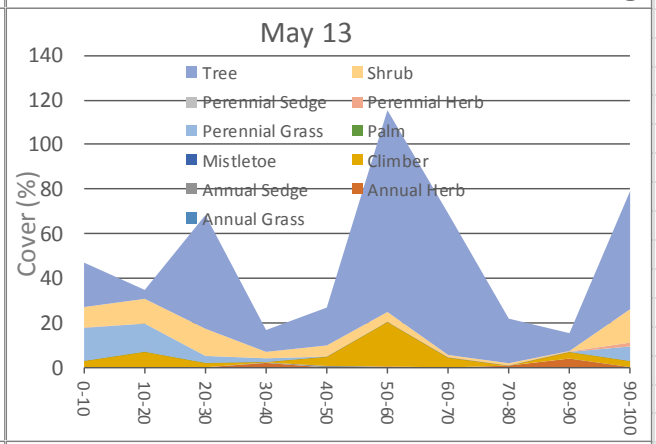


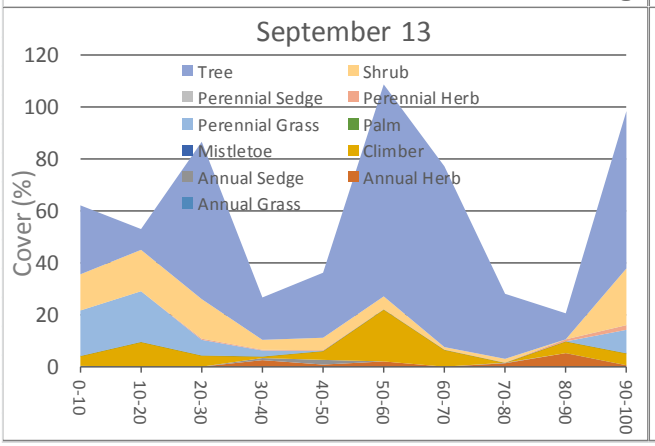
WW05 All Lifeforms

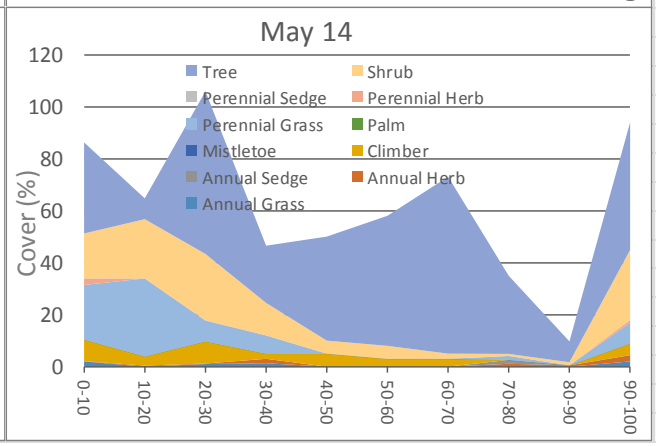




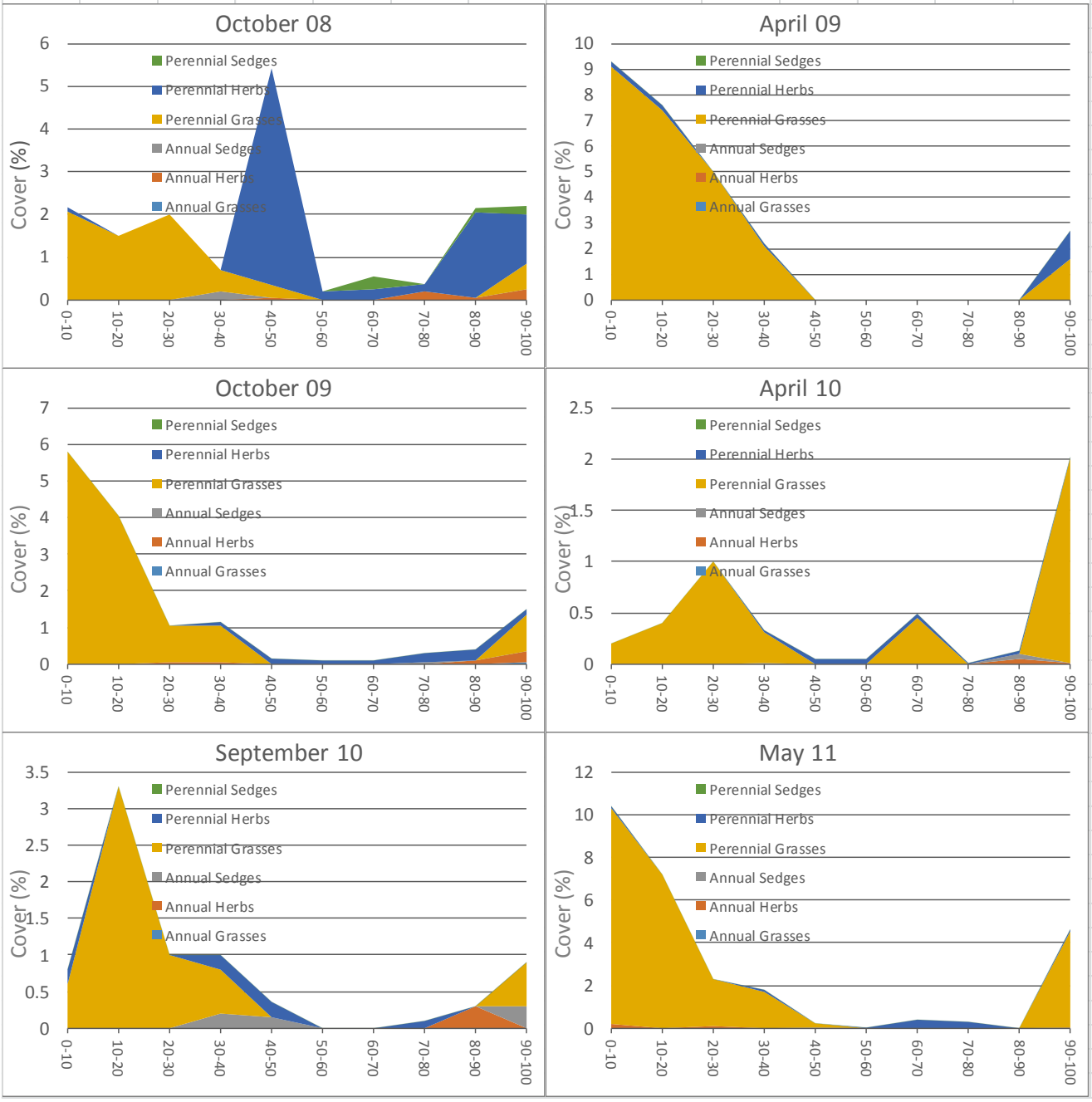




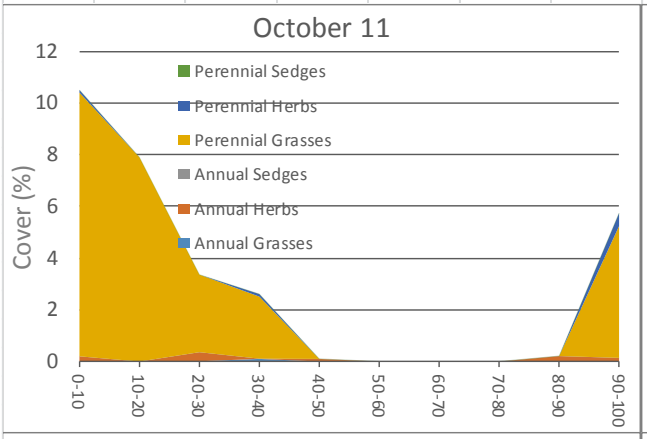


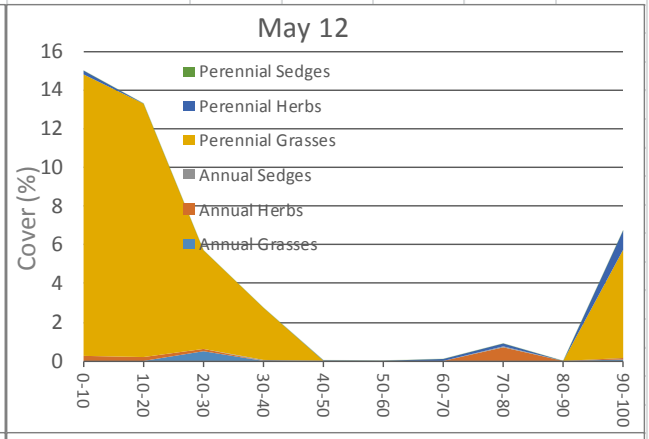


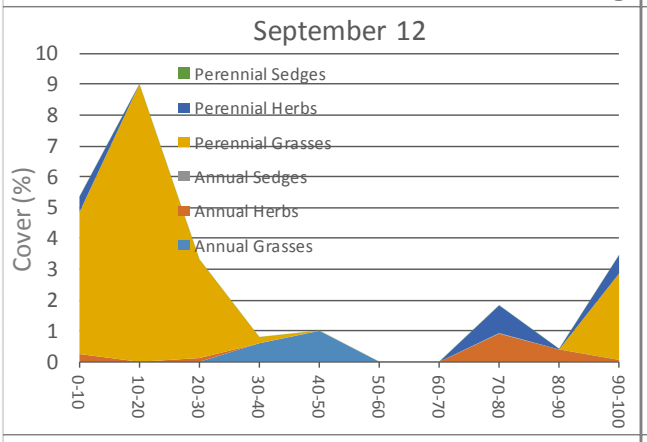
WW05 Groundcovers

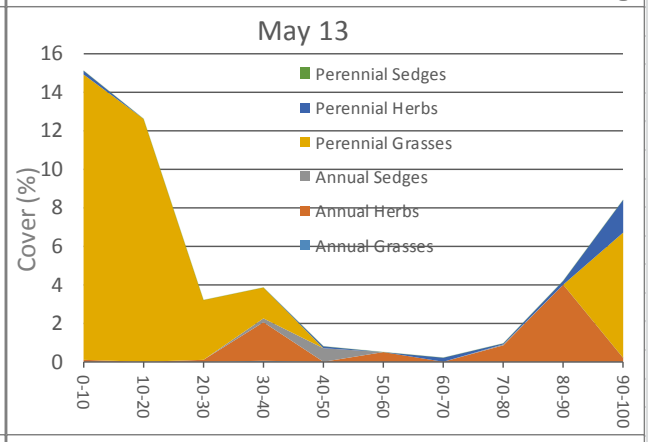


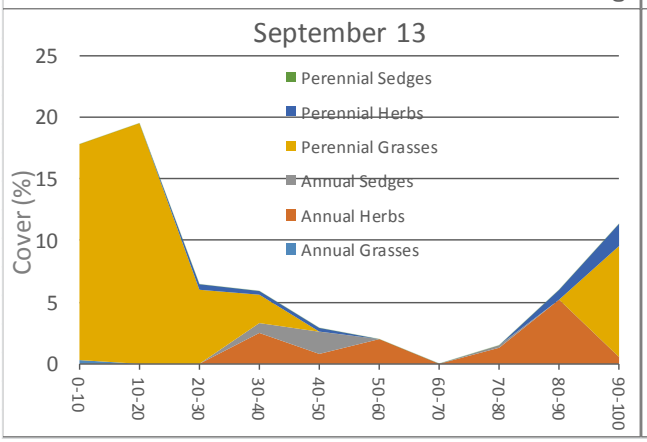
WW05 Groundcovers

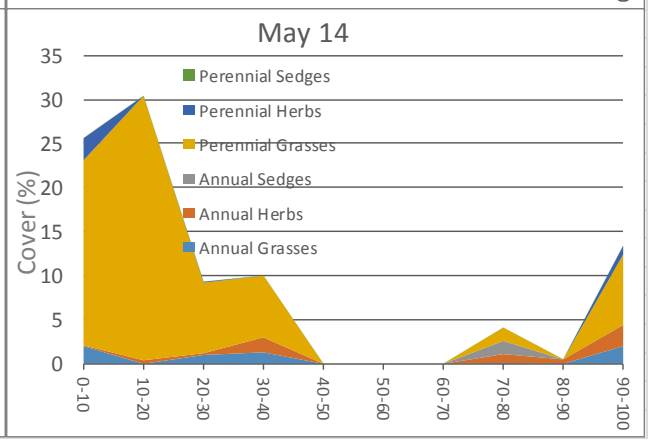




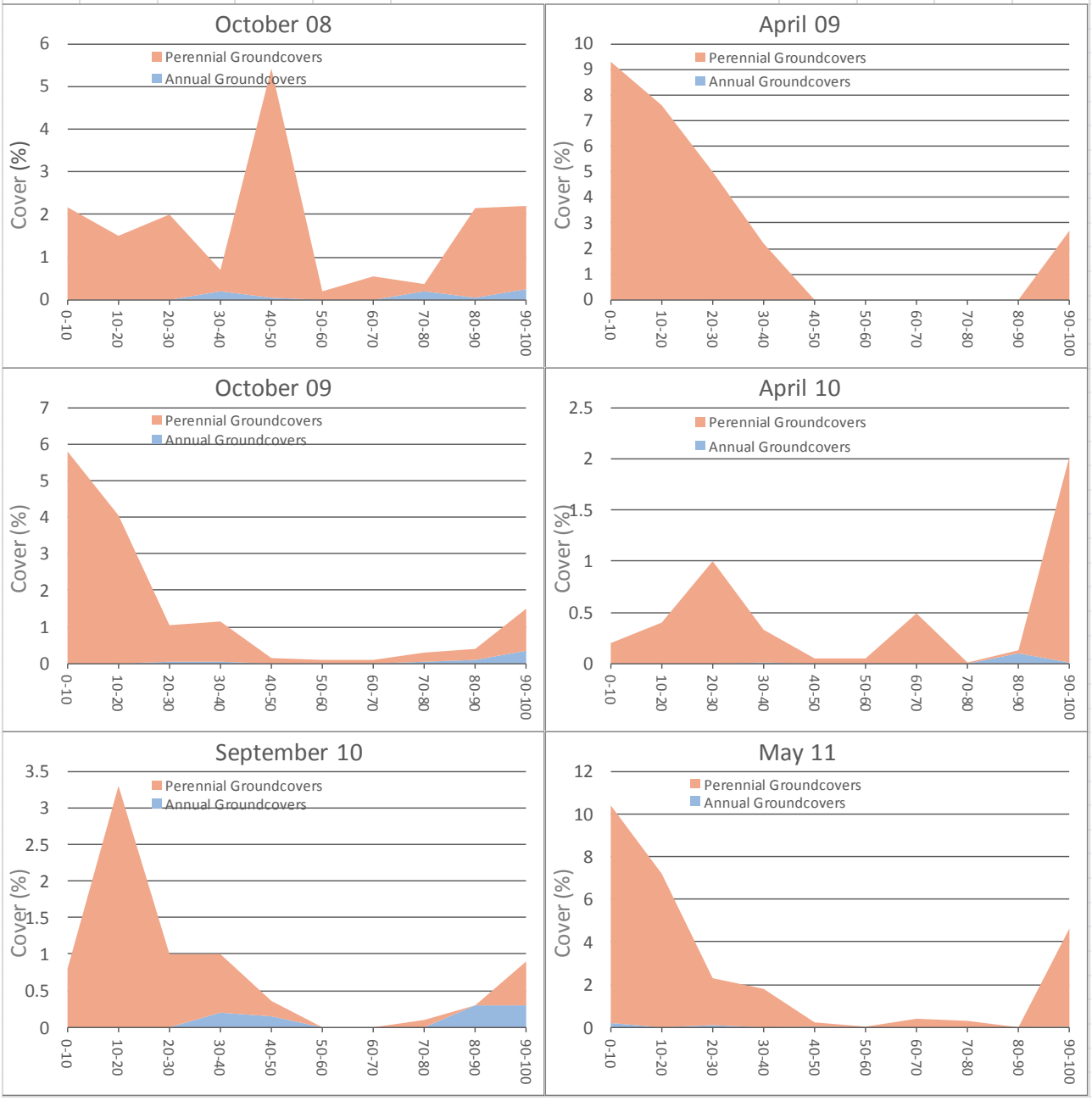




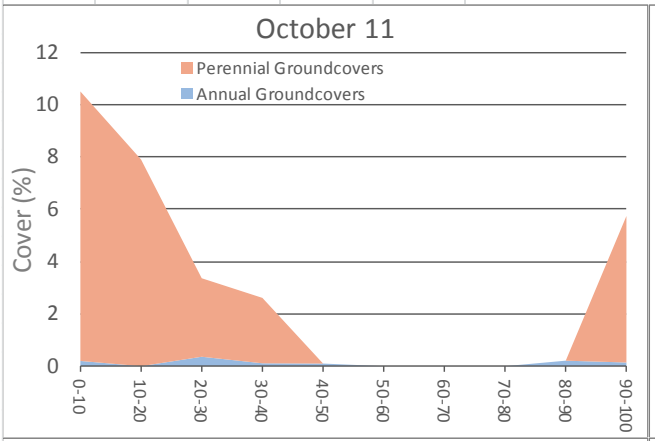


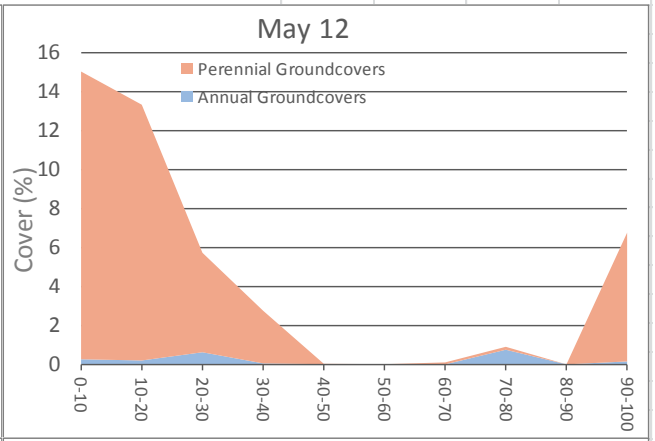


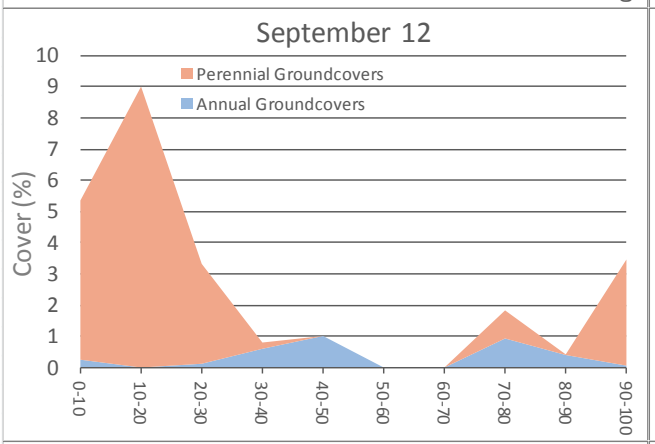
WW05 Annual & Perennial Groundcovers

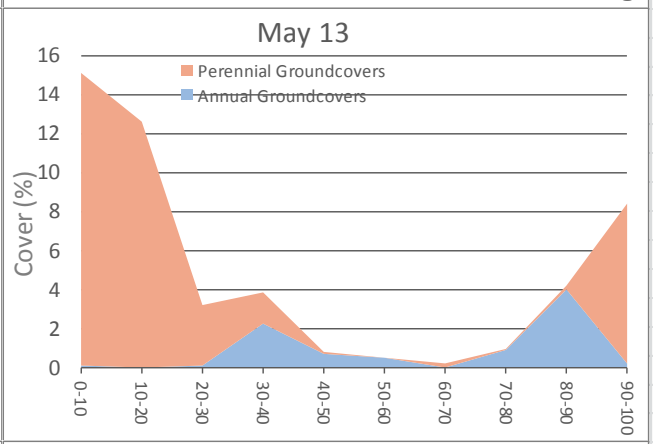


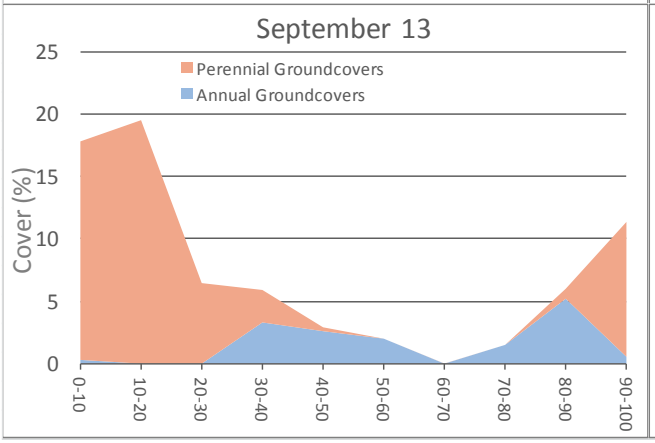
WW05 Annual & Perennial Groundcovers

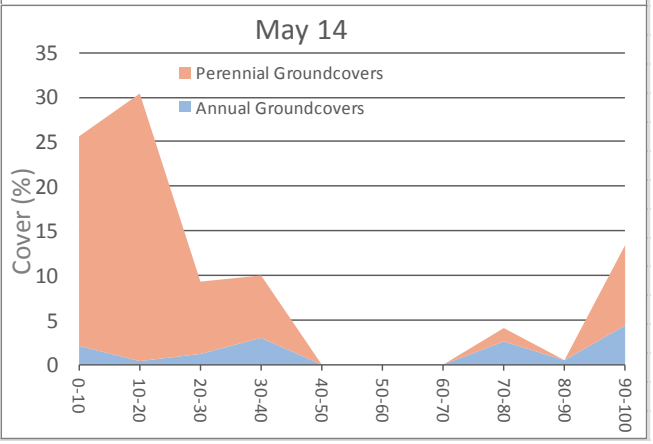




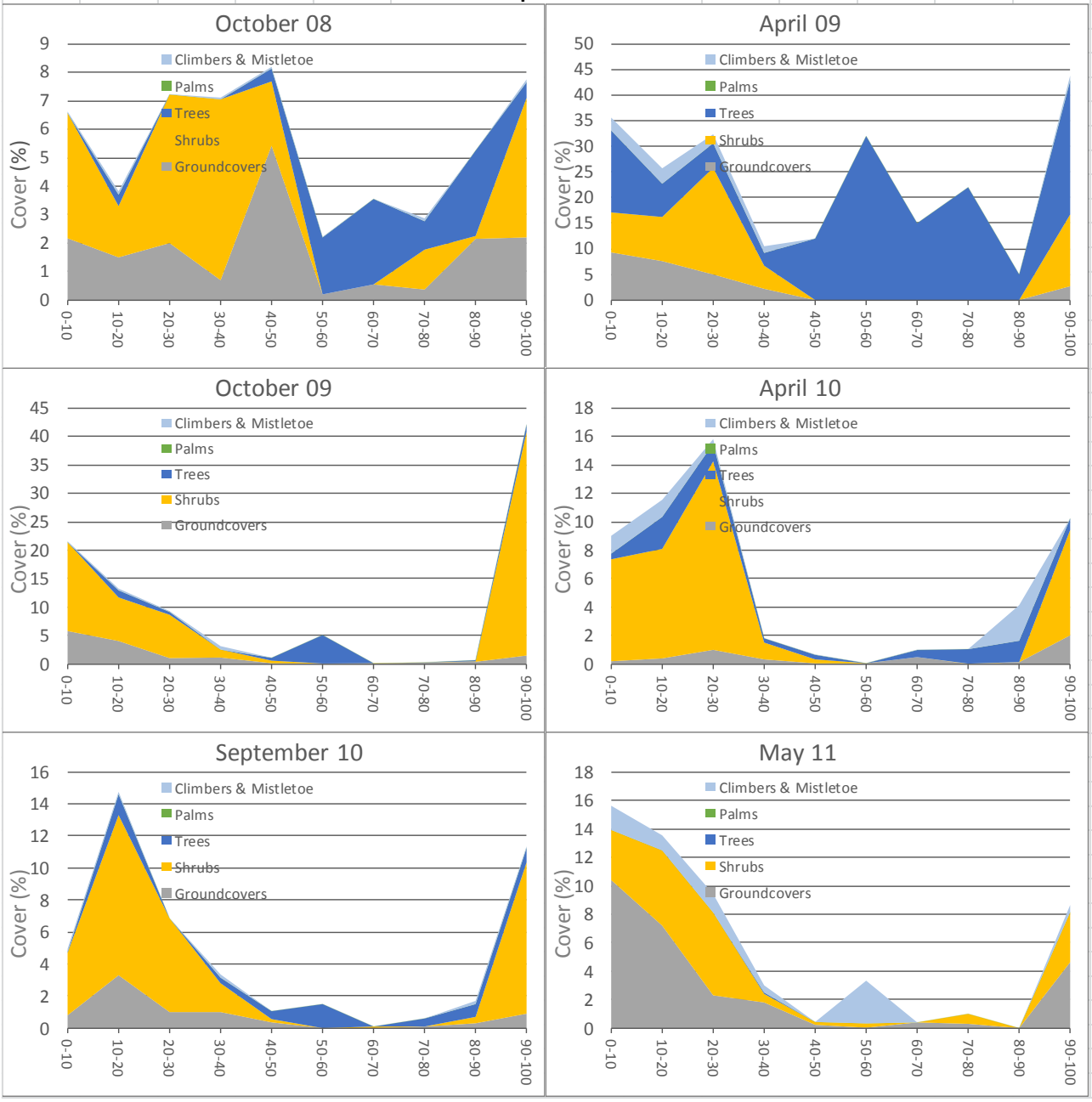


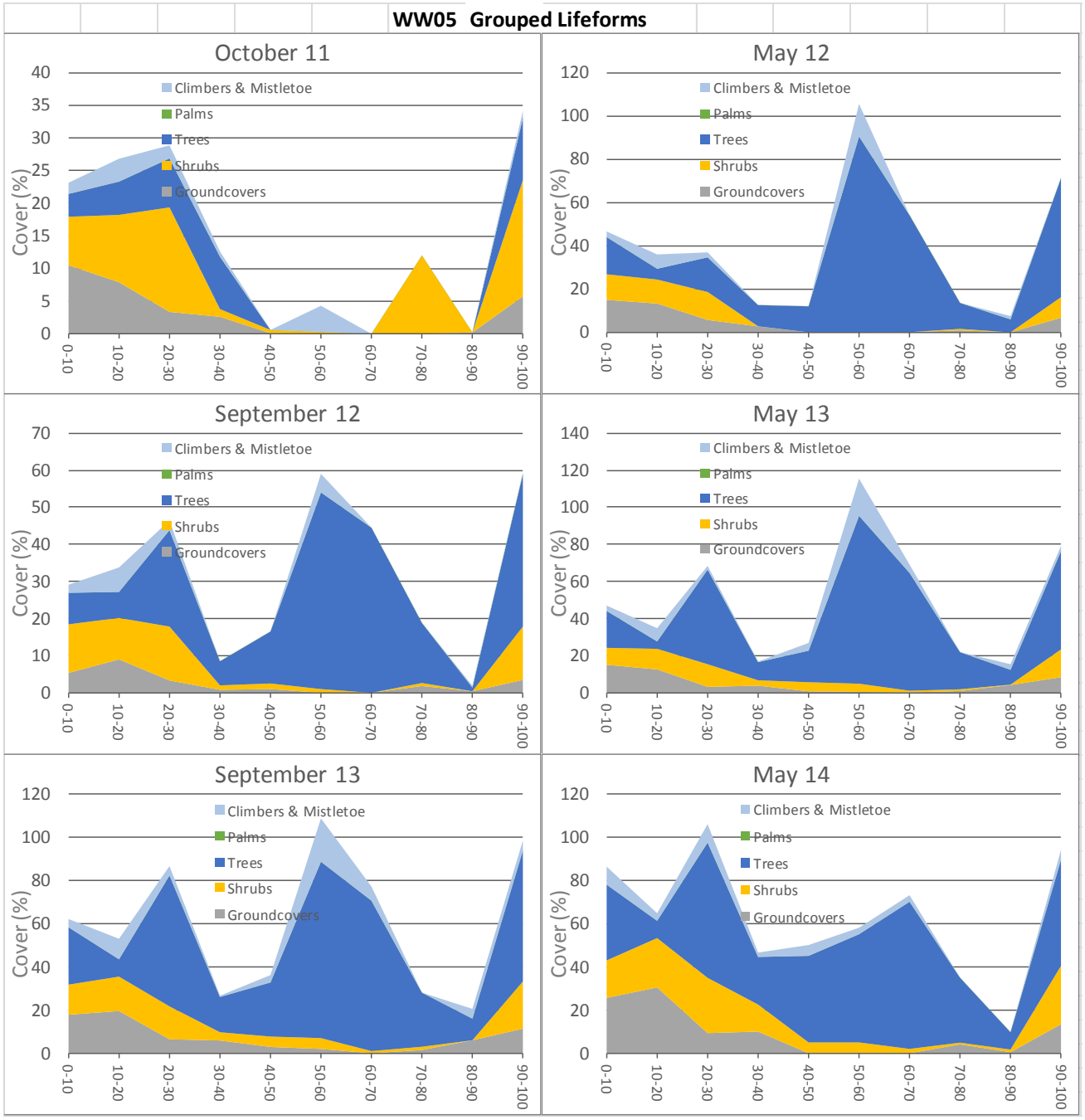




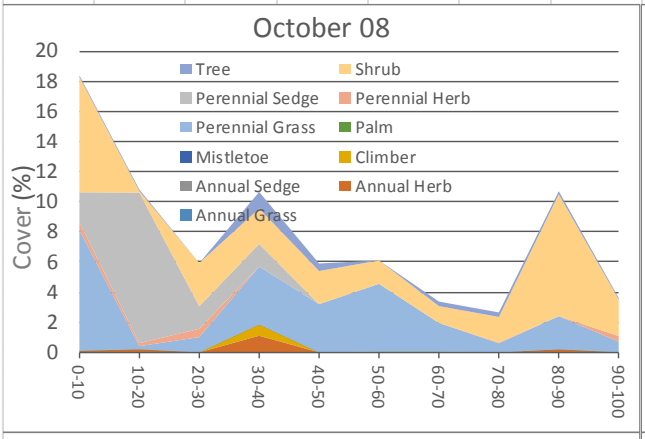


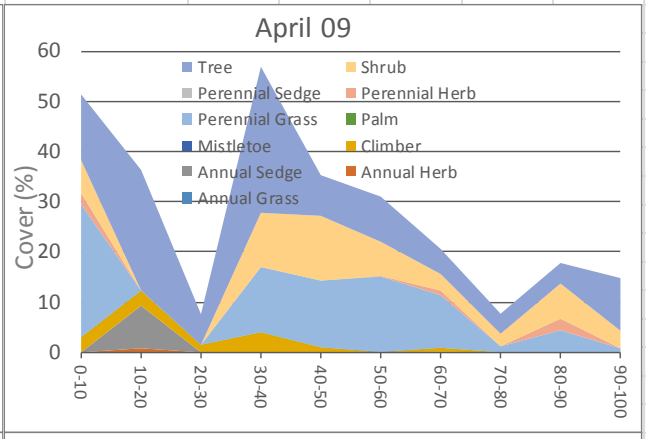
WW05 Grouped Lifeforms

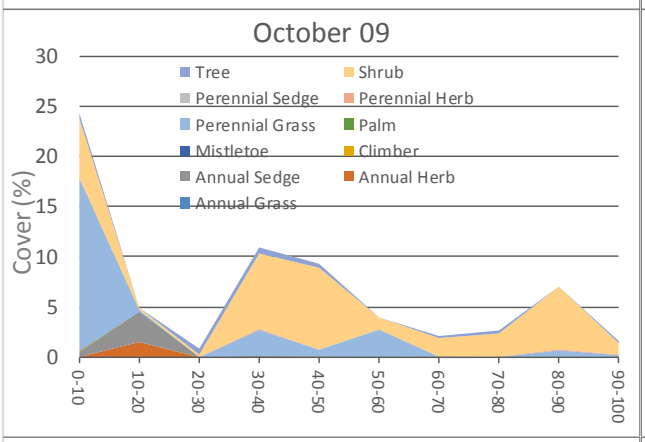


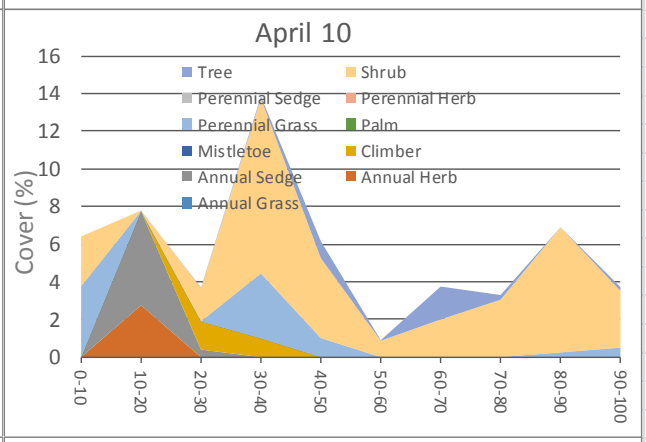

WW05 Grouped Lifeforms
October 11
May 12
September 12
May 13
September 13
May 14
Climbers & Mistletoe
Palms
Trees
Shrubs
Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

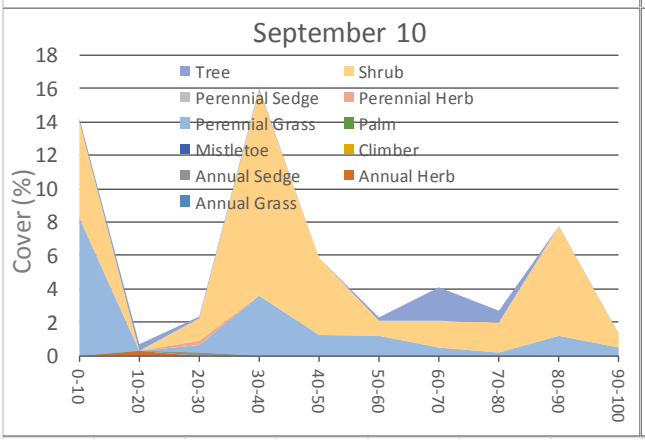
WW06 All Lifeforms

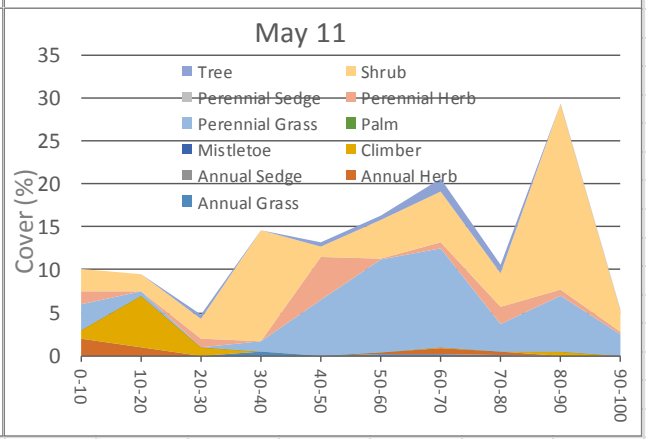


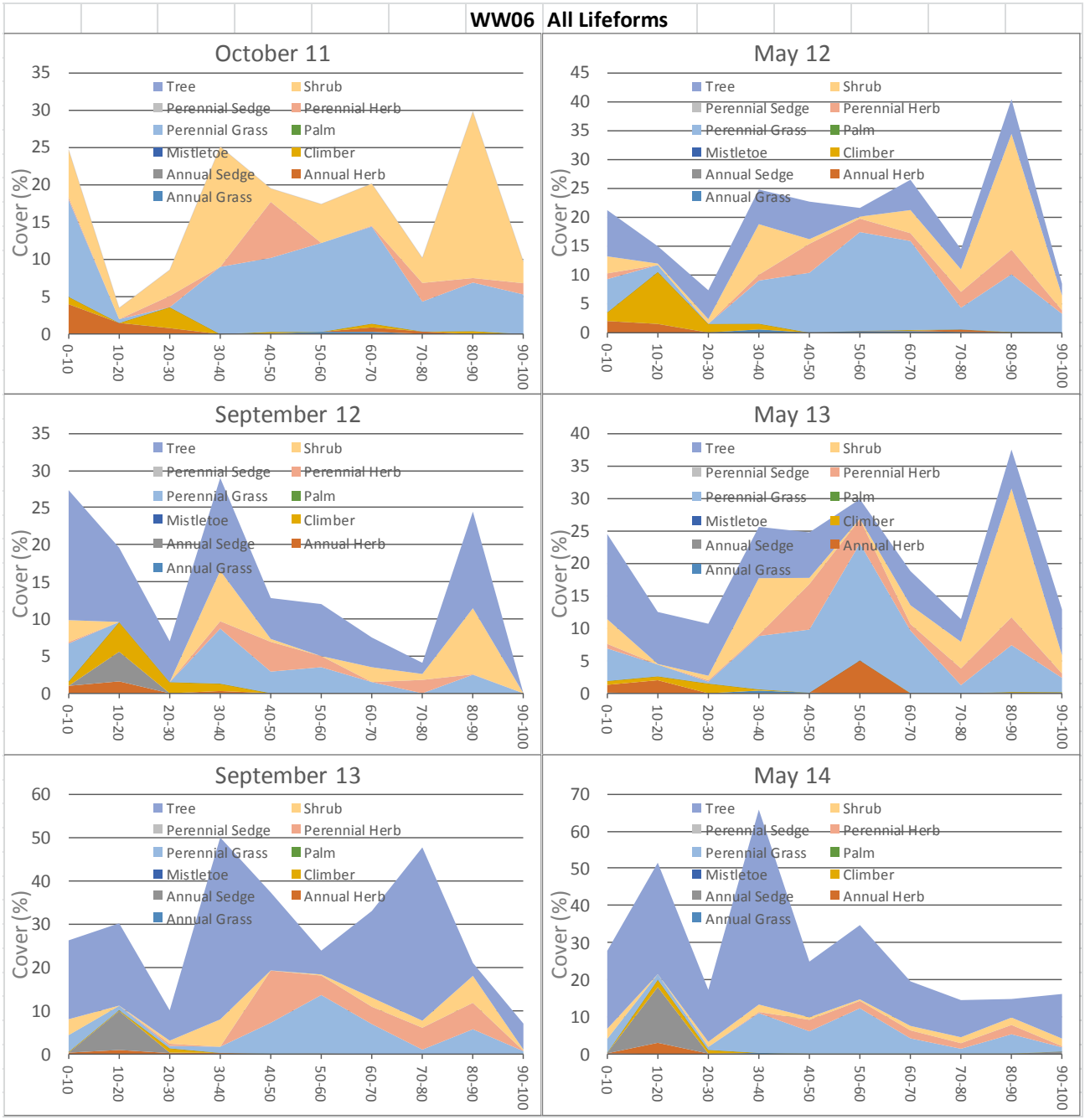




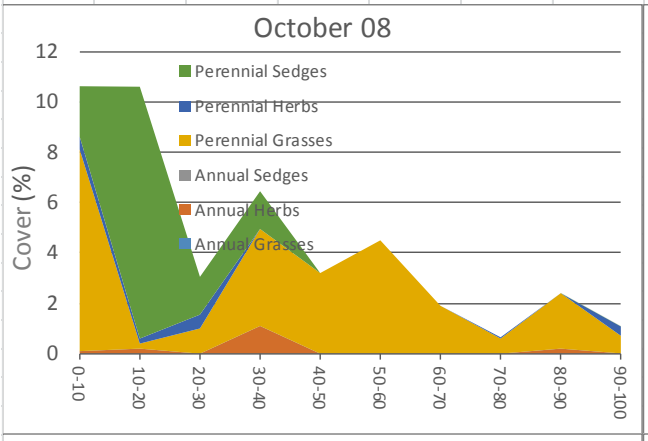


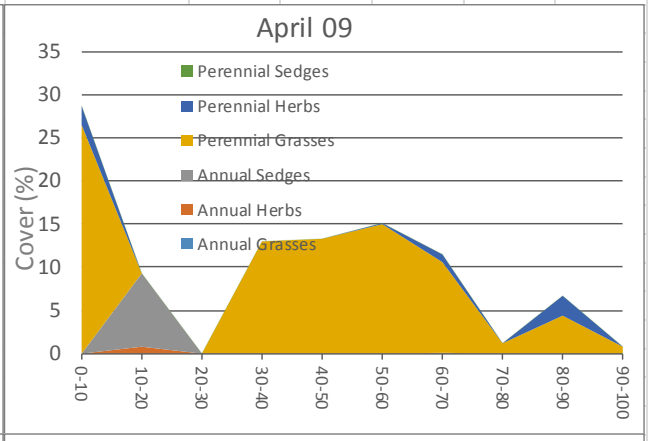


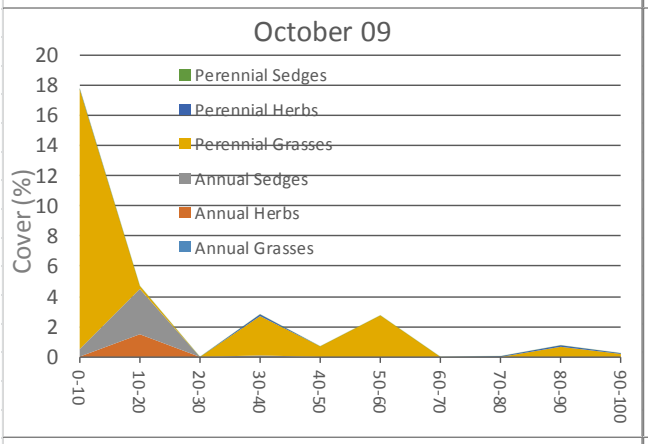


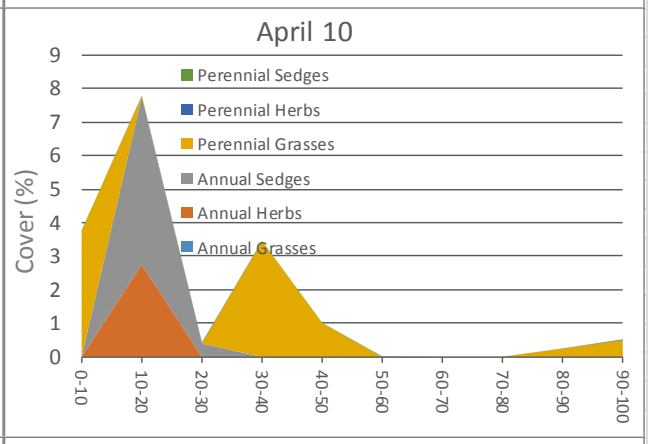

WW06 All Lifeforms
October 11
May 12
September 12
May 13
September 13
May 14
Cover (%)
Tree
Shrub
Perennial Sedge
Perennial Herb
Perennial Grass
Palm
Mistletoe
Climber
Annual Sedge
Annual Herb
Annual Grass
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

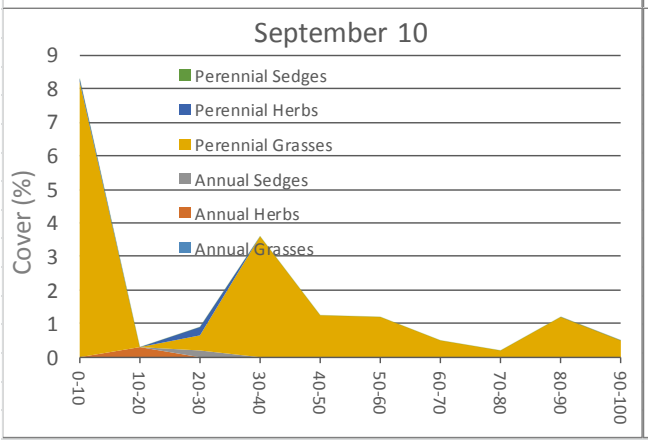
WW06 Groundcovers

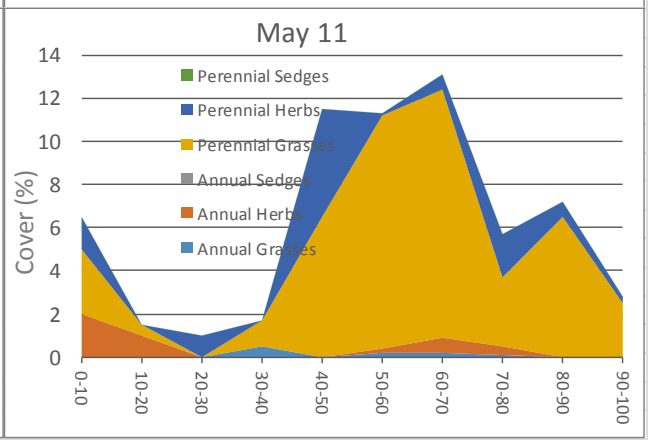




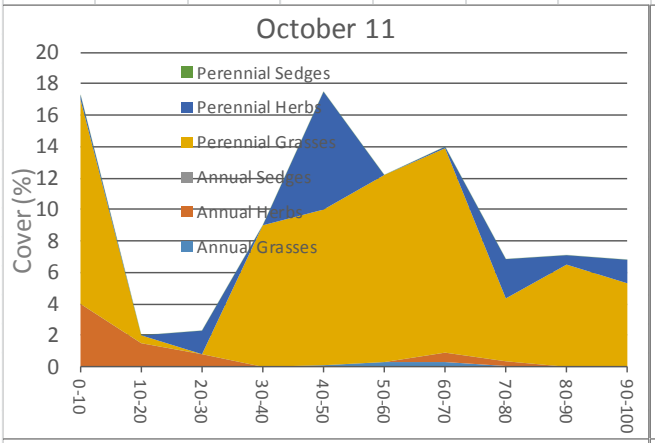


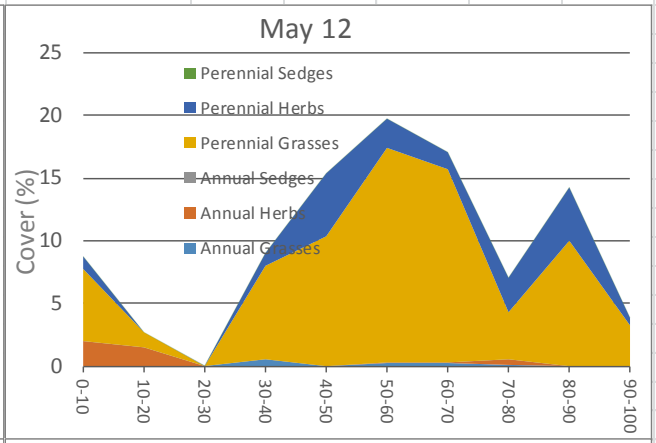


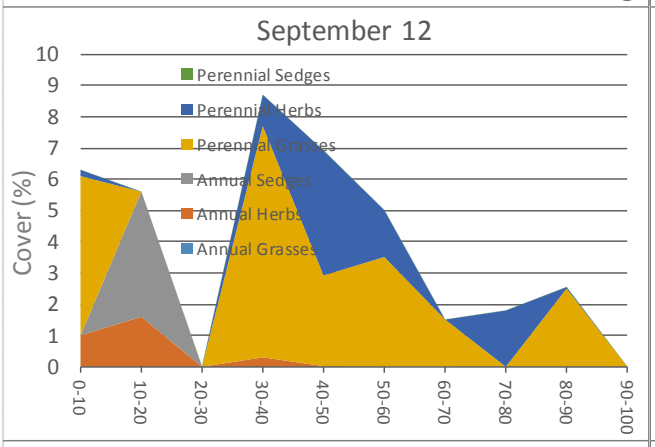


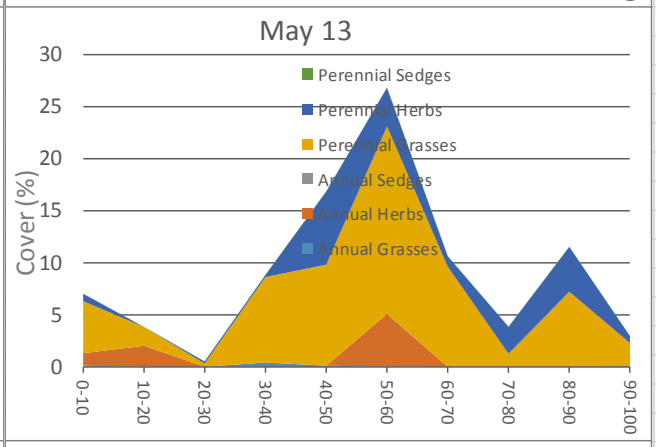


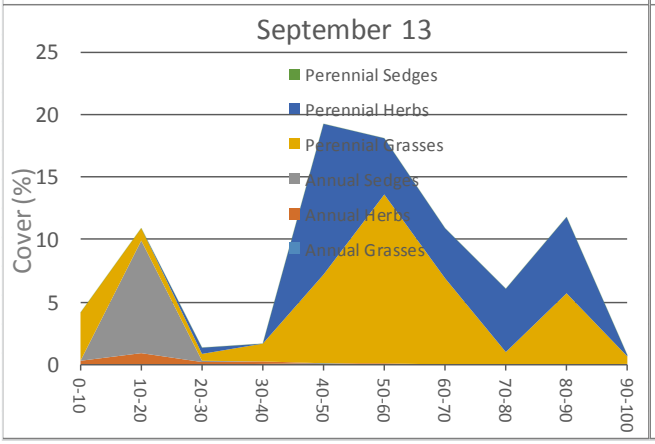
WW06 Groundcovers

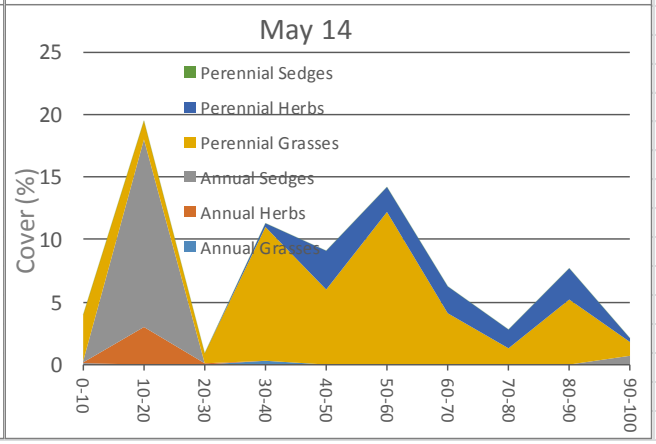




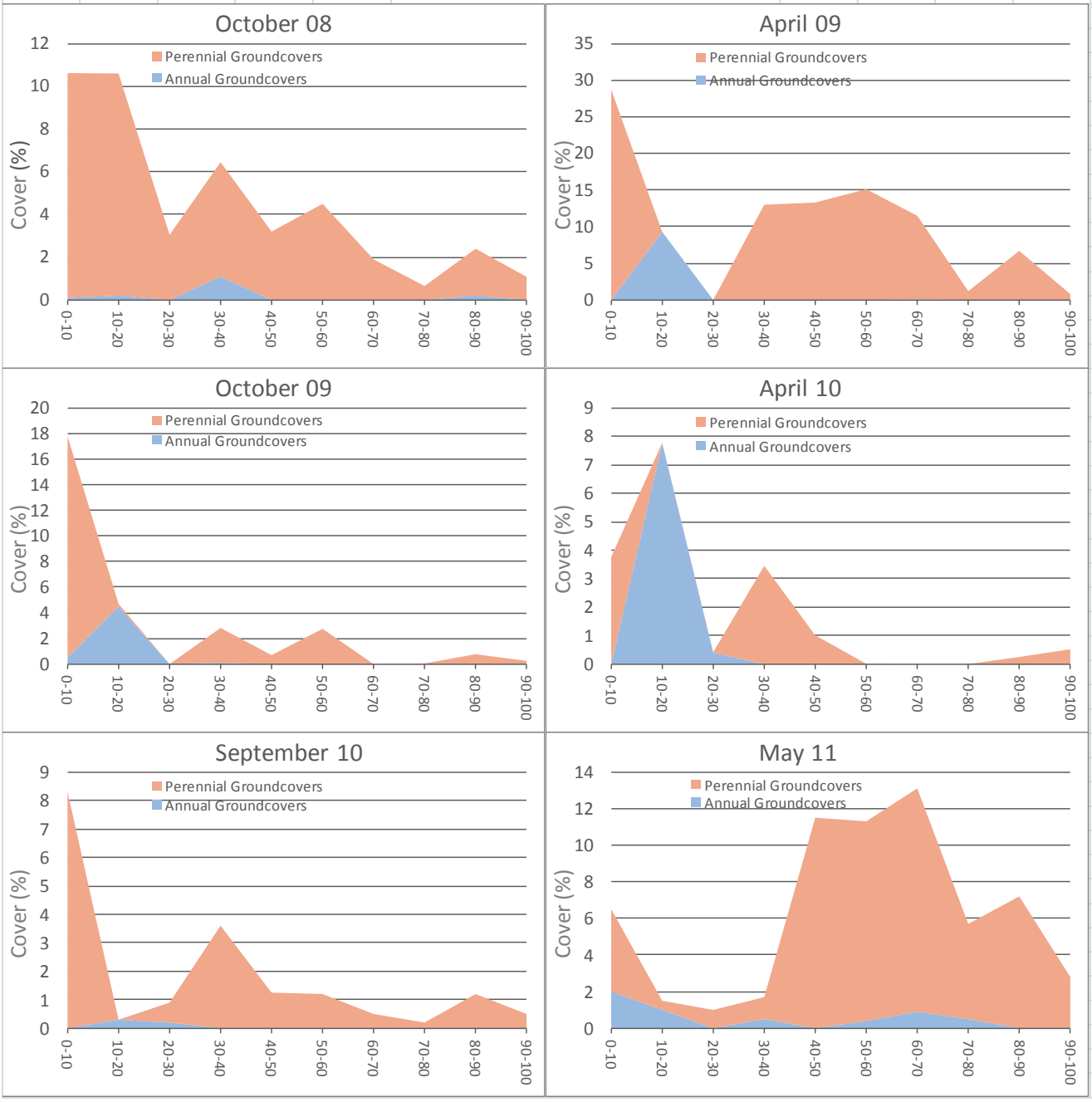




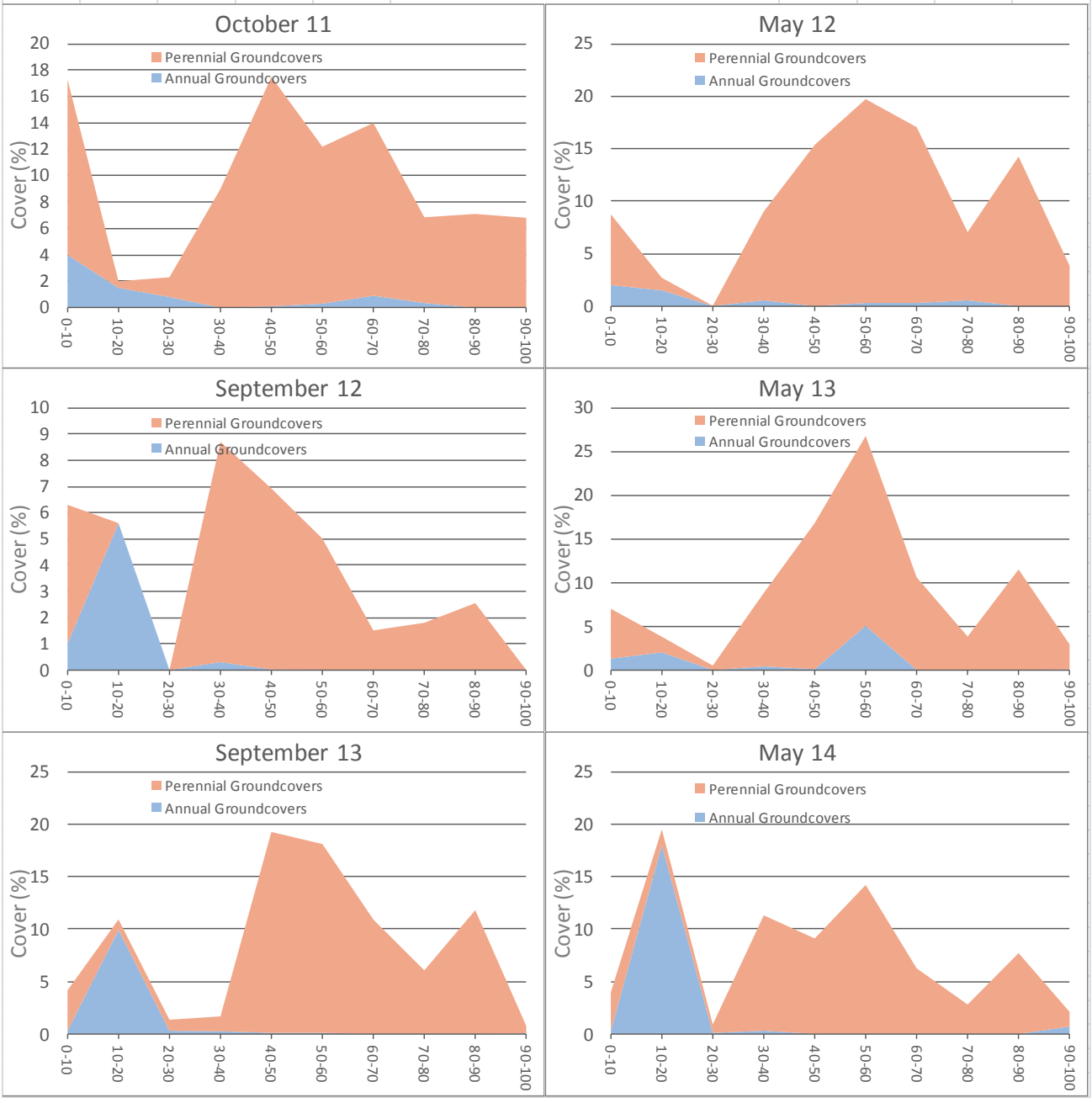




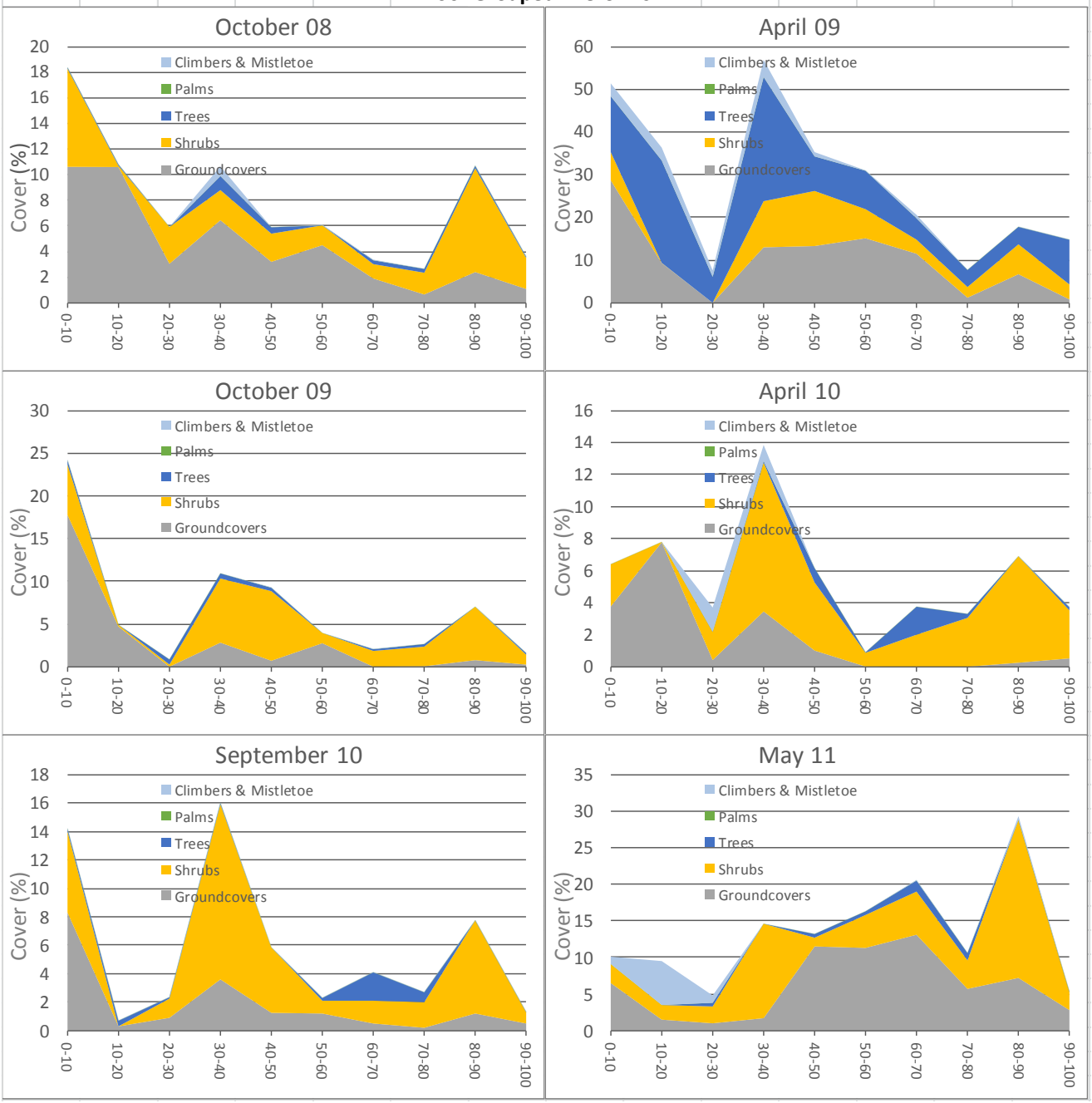
WW06 Annual & Perennial Groundcovers



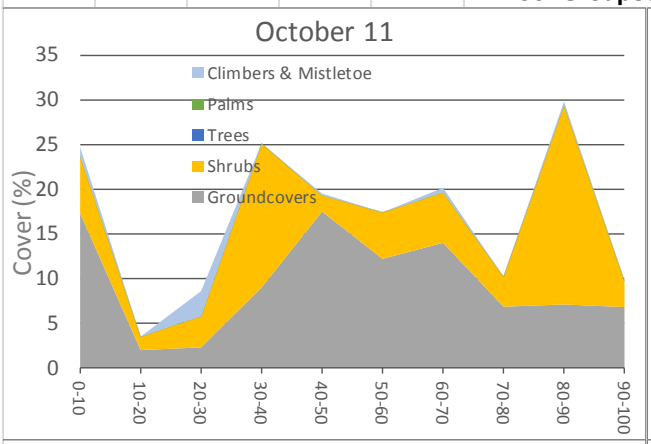
WW06 Annual & Perennial Groundcovers

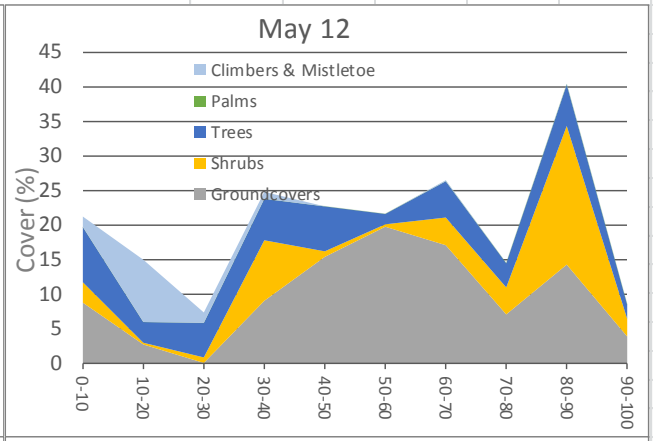


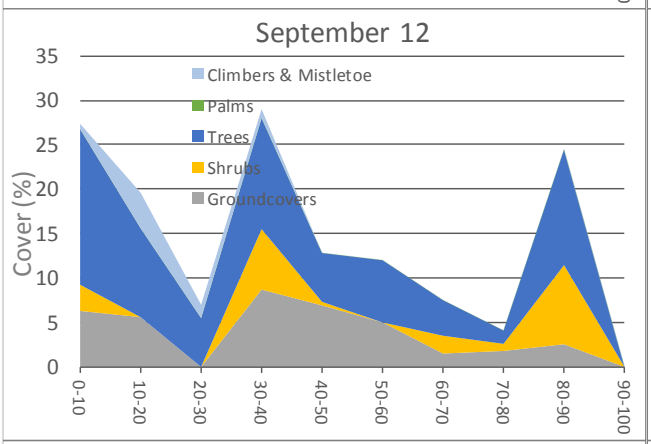
WW06 Grouped Lifeforms

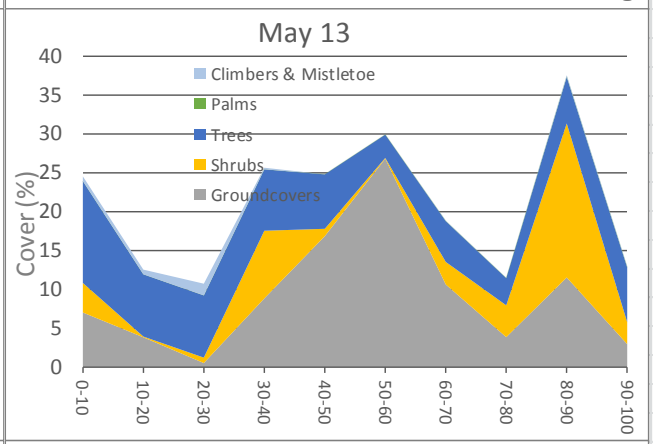


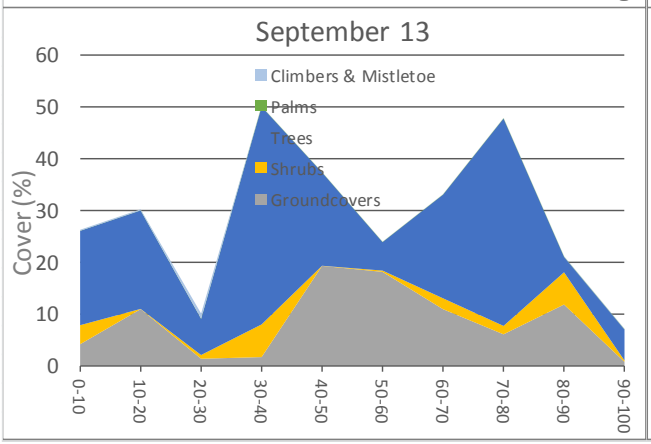
WW06 Grouped Lifeforms

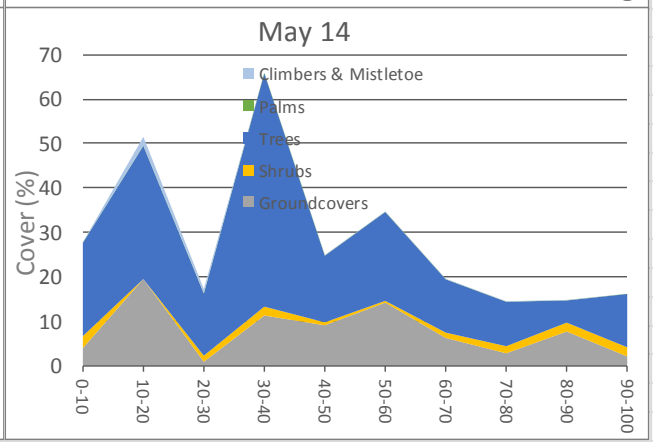












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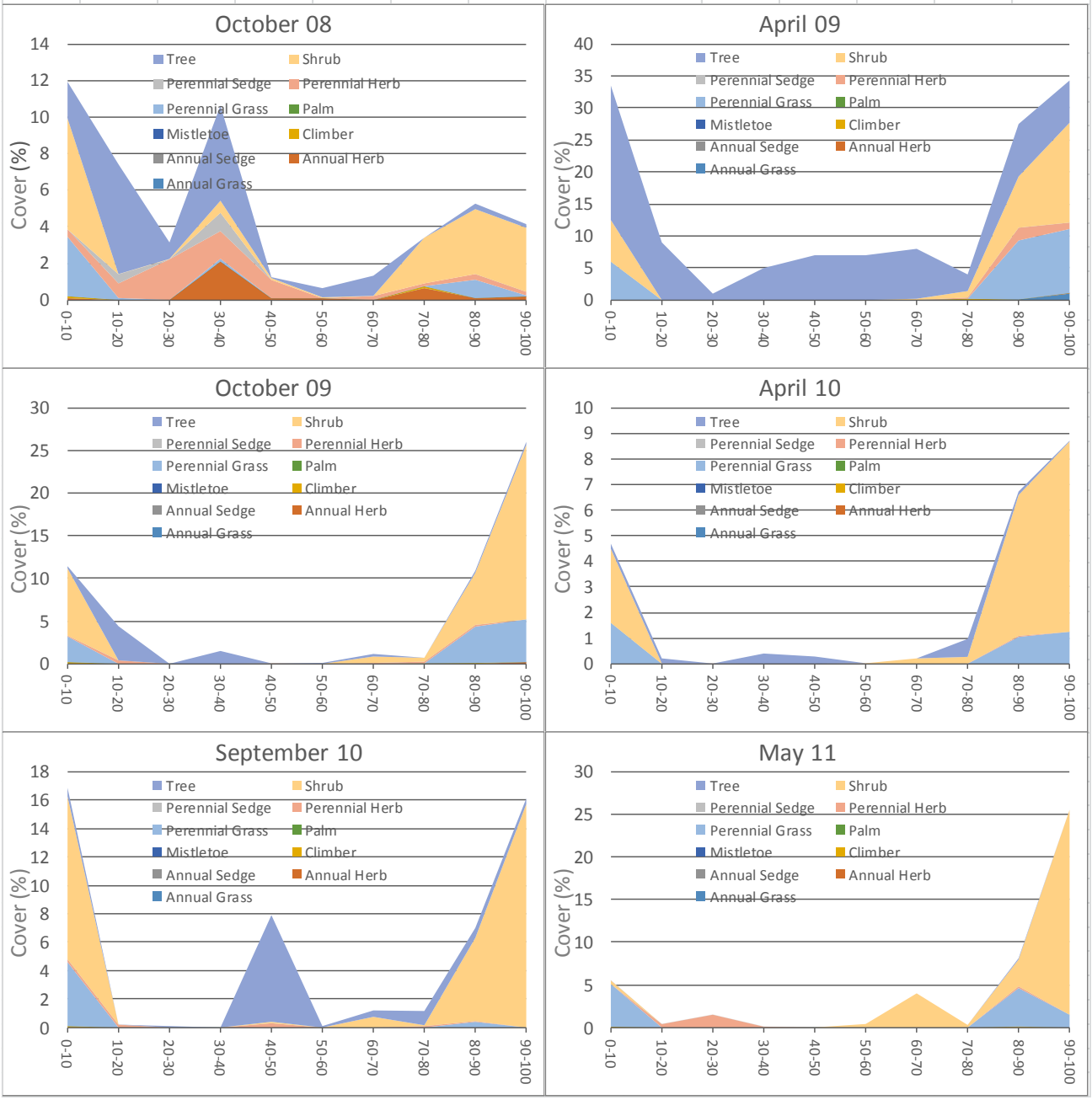

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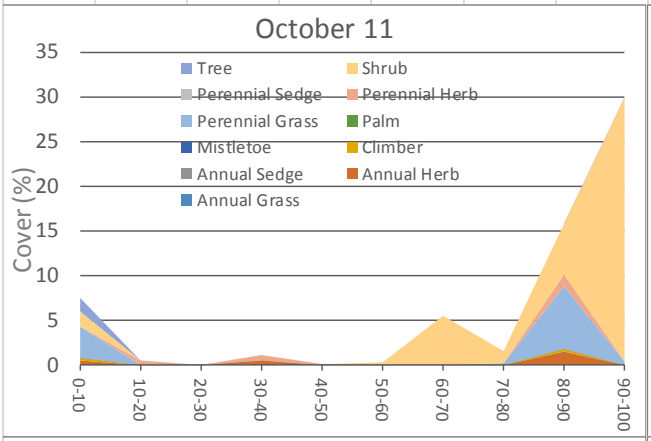

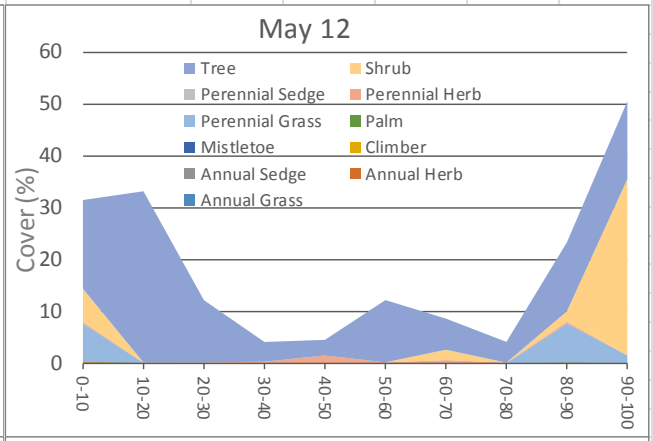

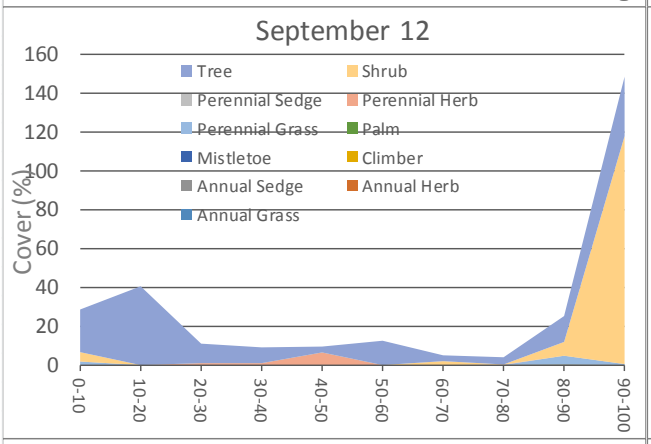

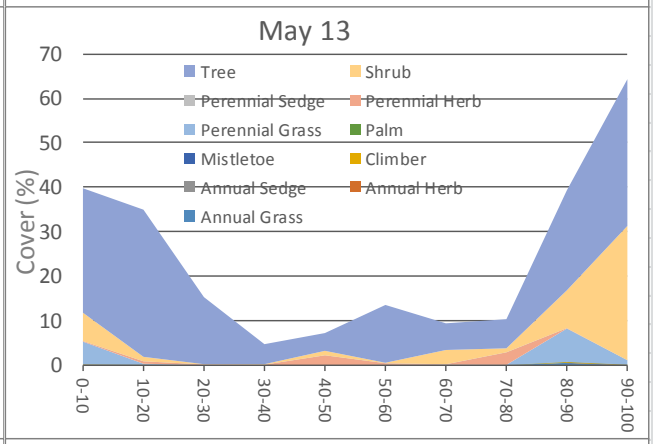

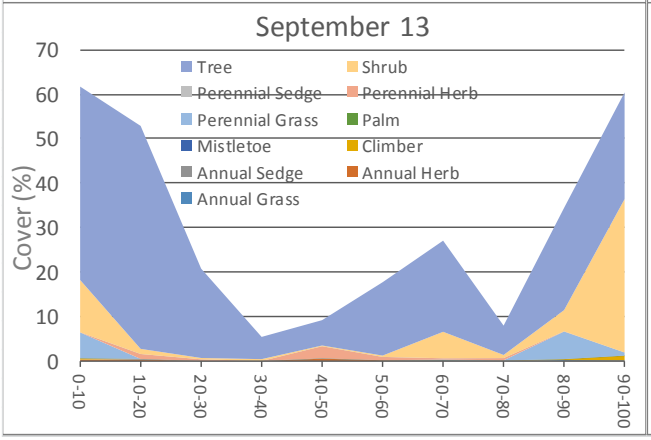

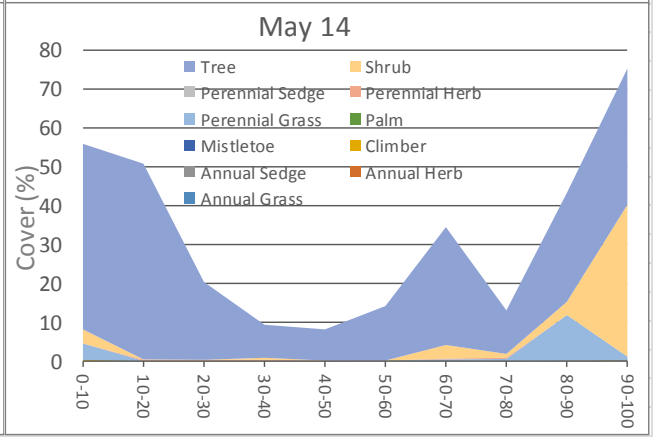

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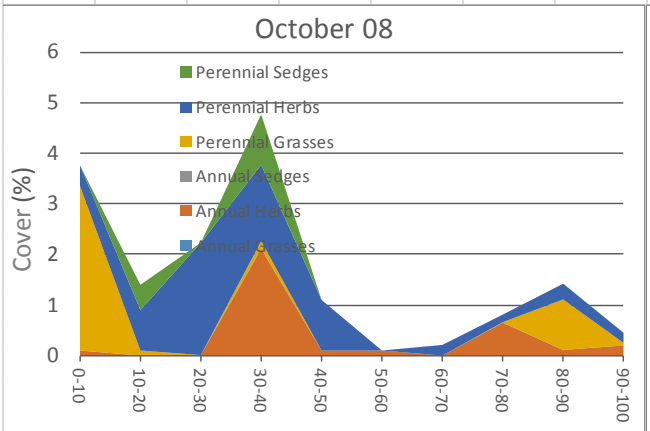

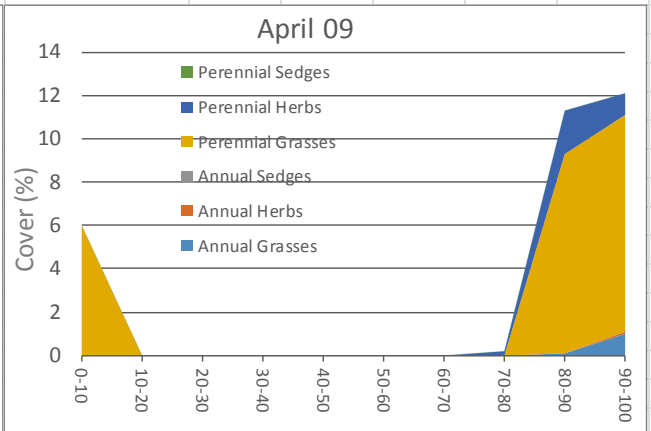

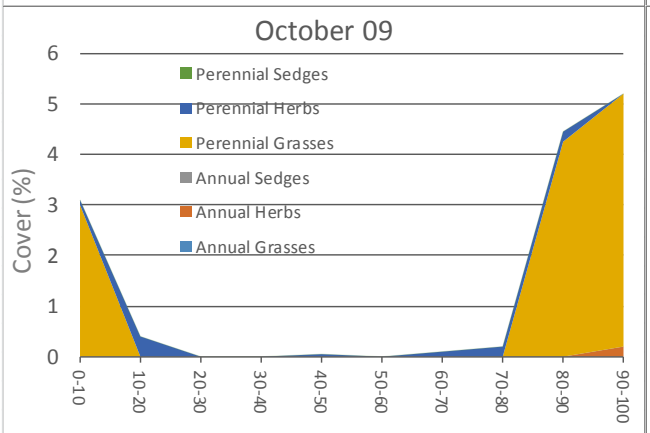

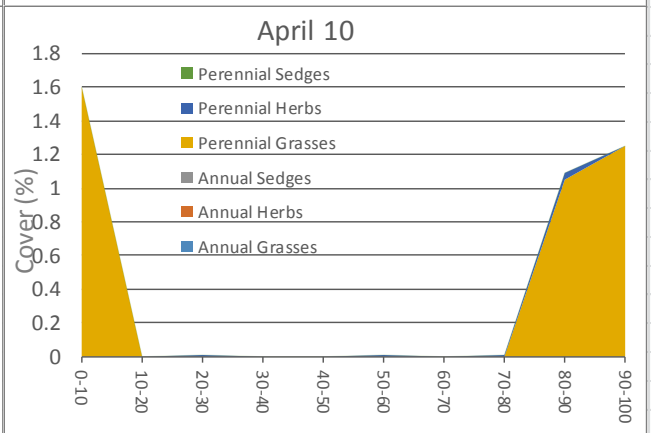

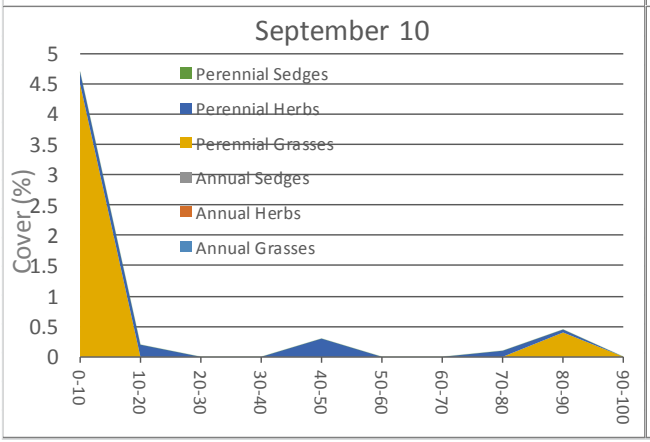

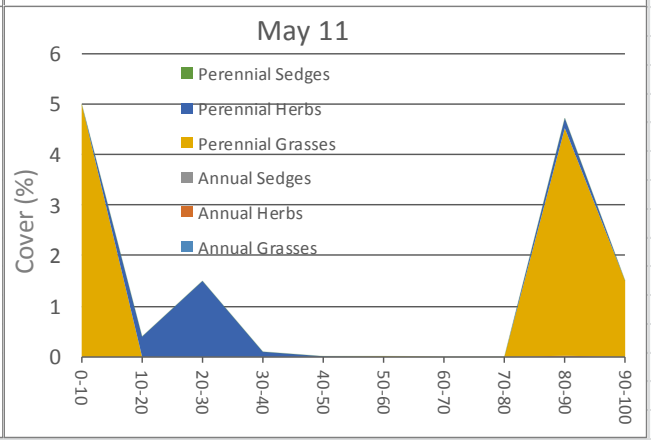

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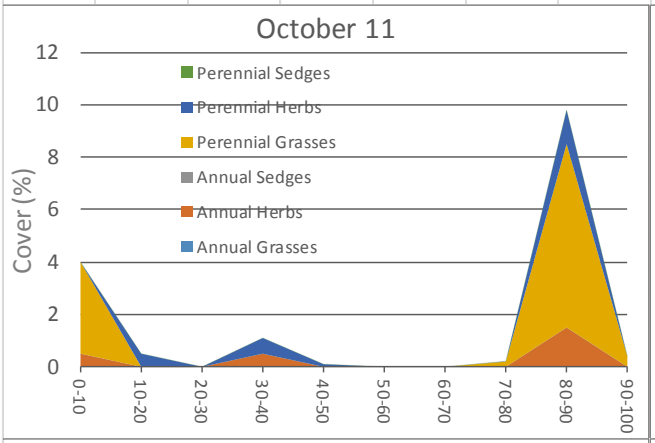

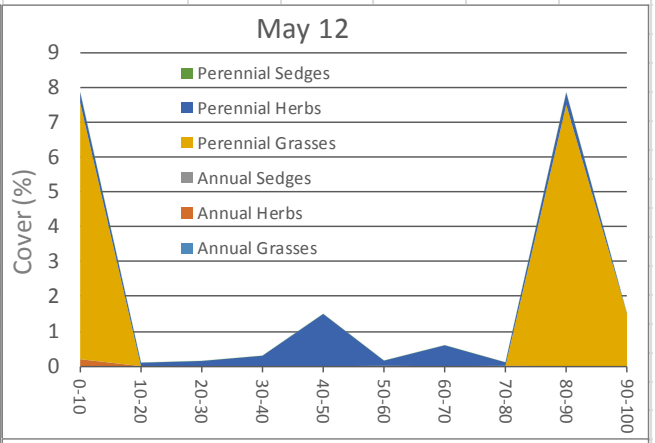

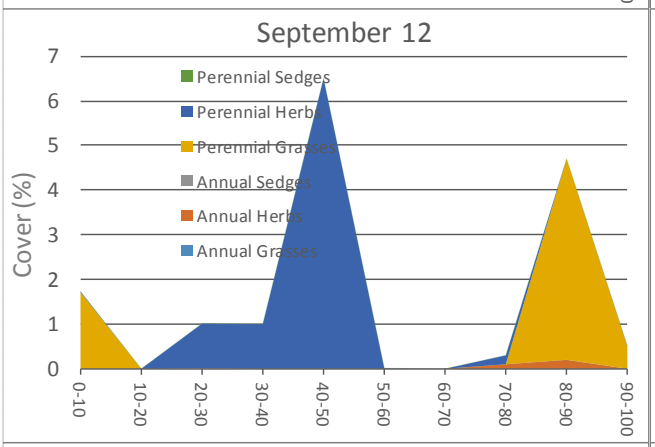

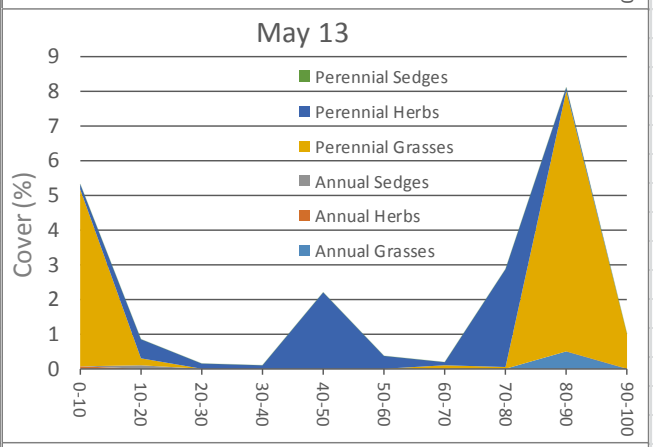

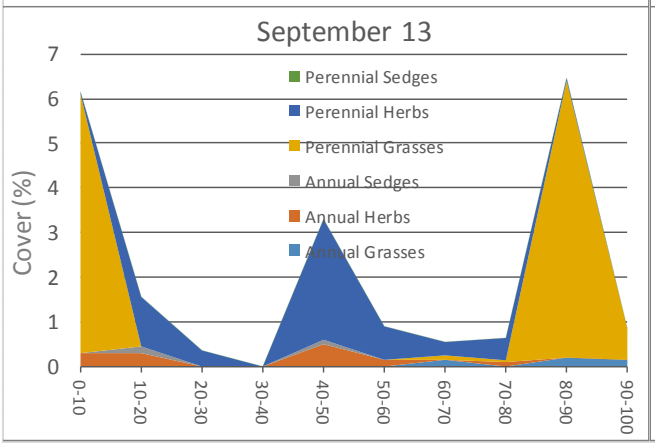

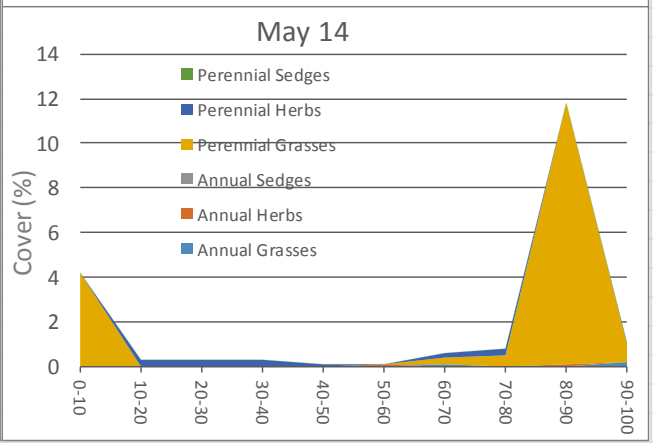

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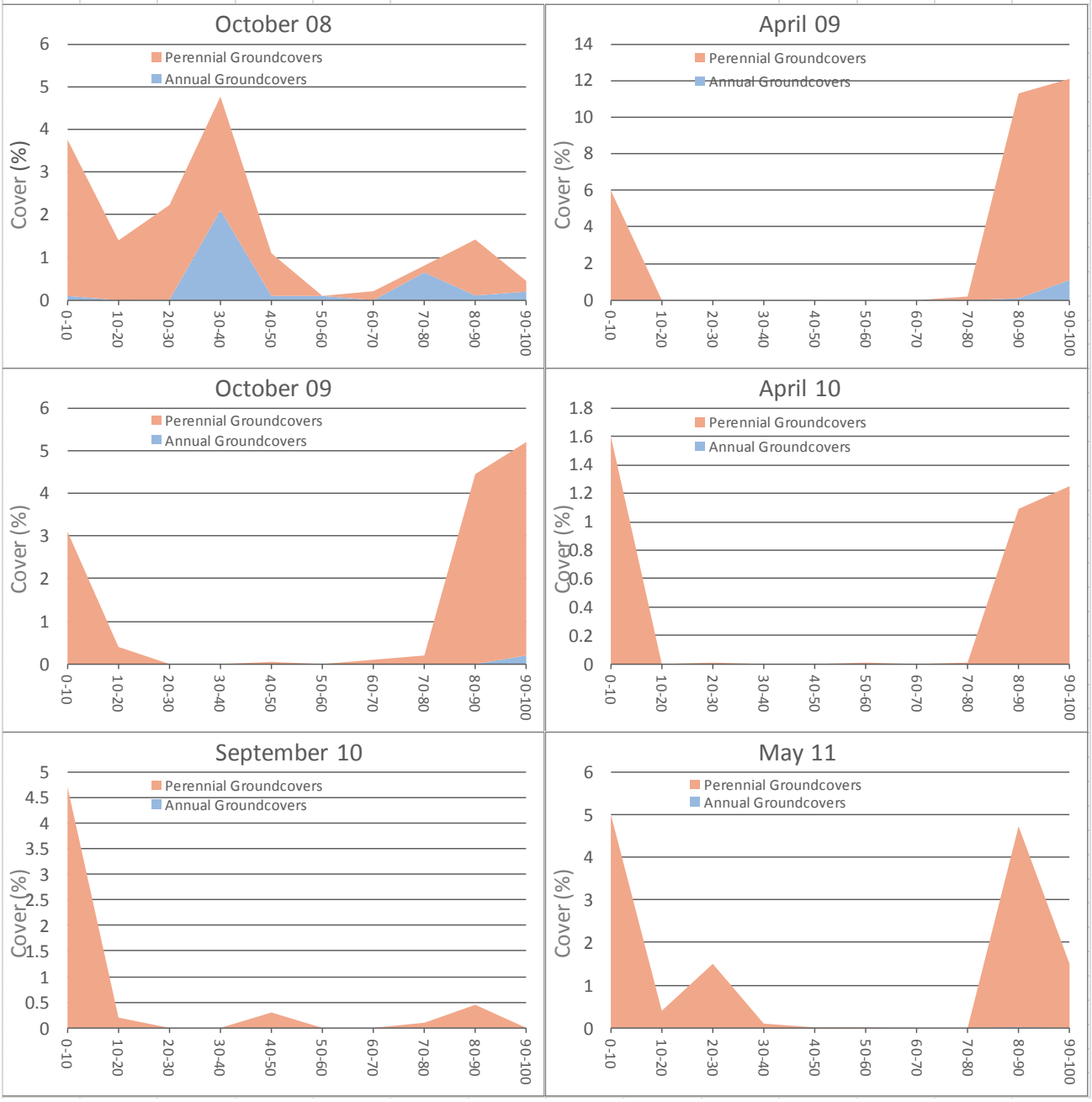

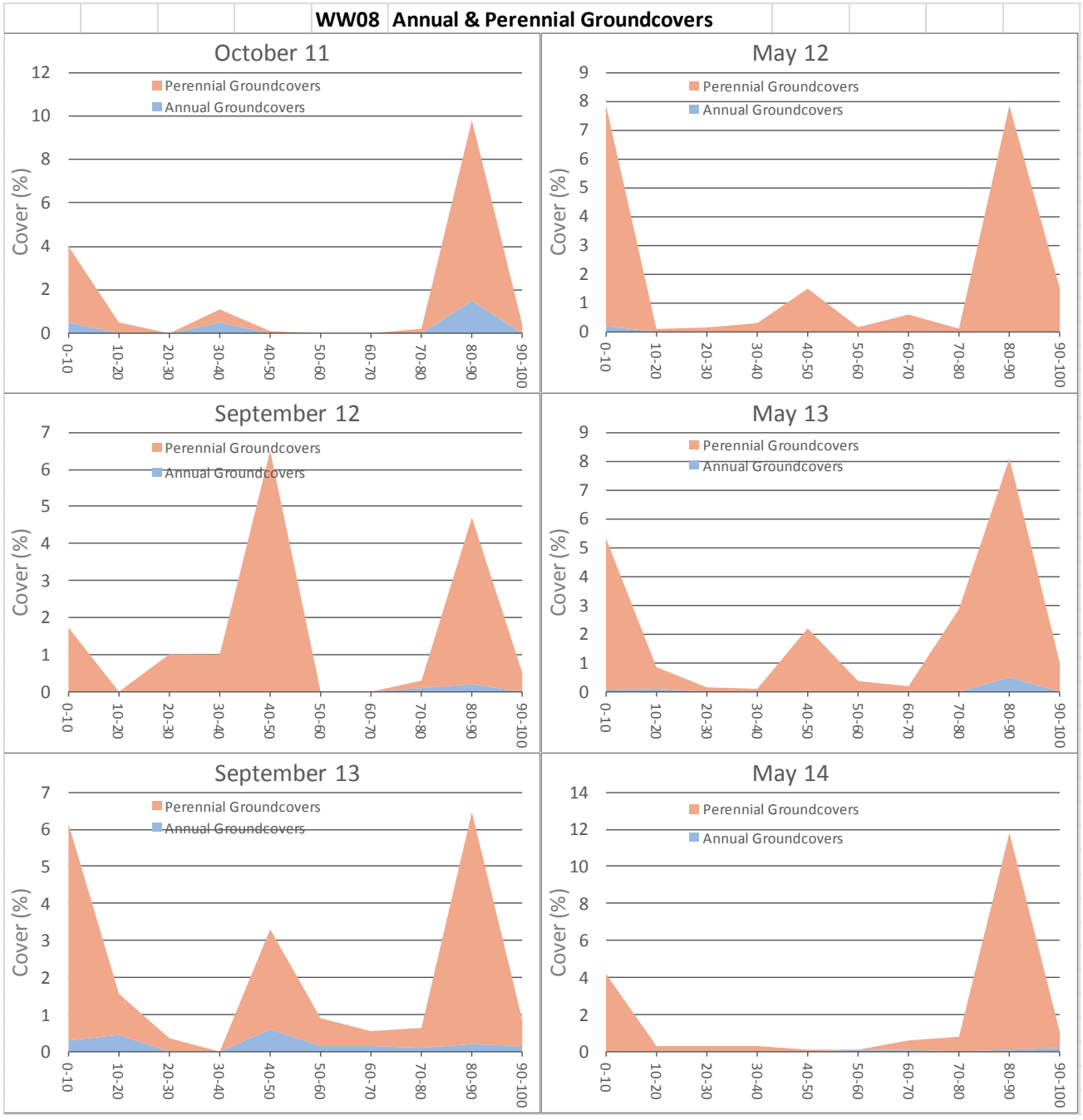
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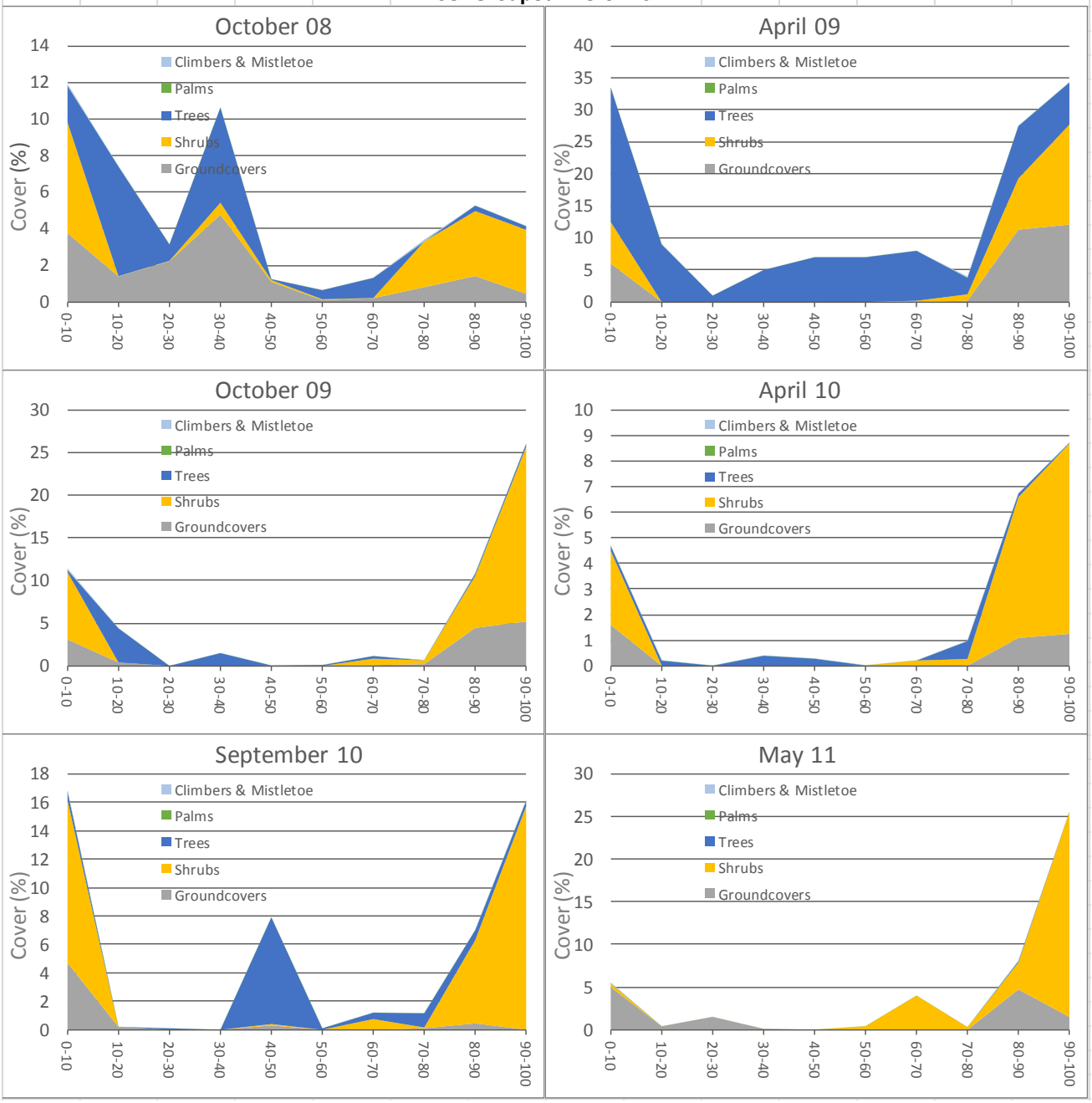
October 11
May 12
September 12
May 13
September 13
May 14
Perennial Groundcovers
Annual Groundcovers
Cover (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

WW08 Grouped Lifeforms



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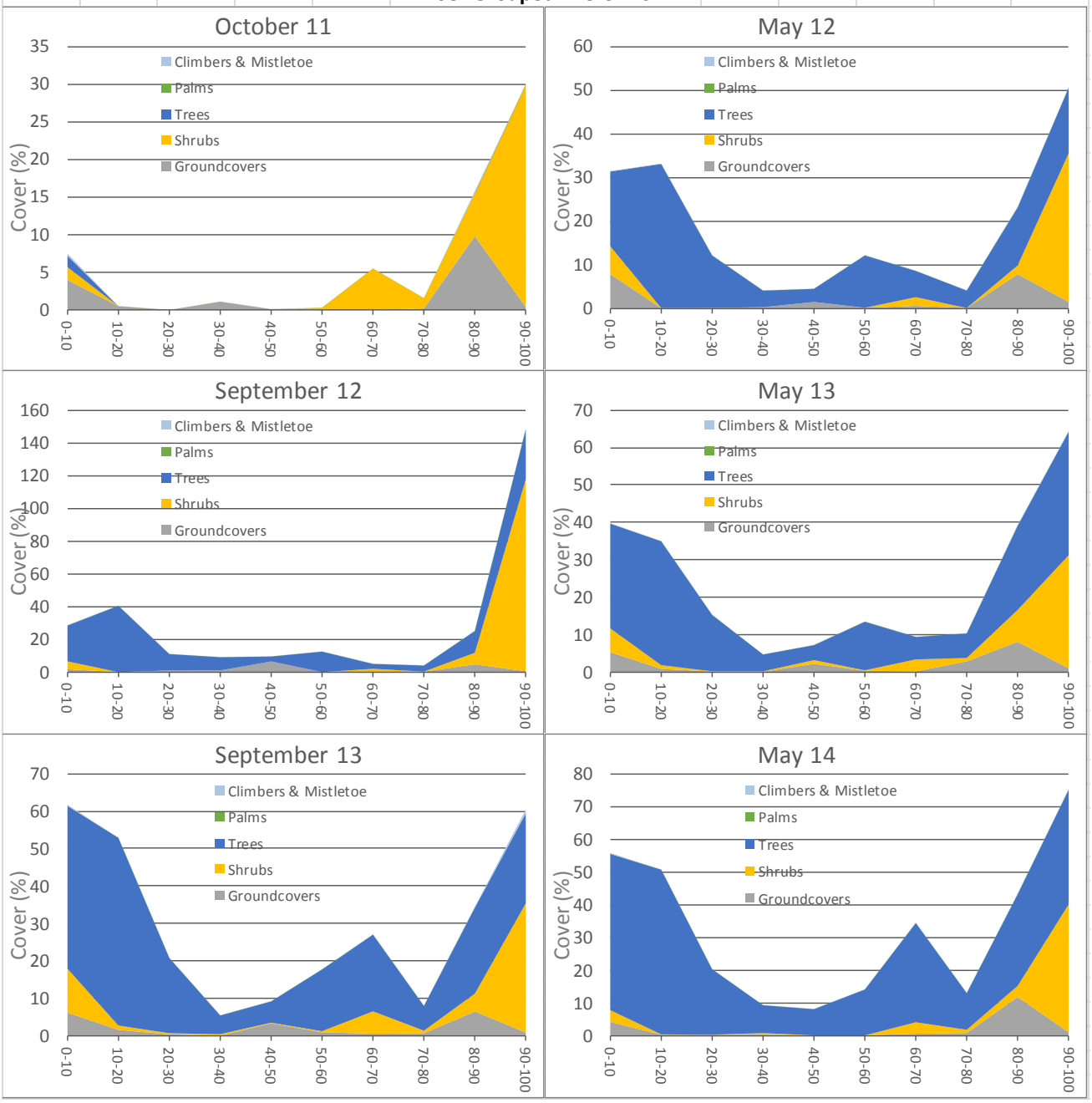

Biota Environmental Sciences

Yandi Operations Stygofauna Data Consolidation 2003 - 2014

Prepared for Rio Tinto

April 2015

Biota Environmental Sciences

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Yandi Stygofauna Data Consolidation

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1.0 Executive Summary

Rio Tinto currently operates the Yandi iron ore mine, located approximately 90 km northwest of Newman in the Pilbara region of Western Australia. The original Yandi deposit, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999. An expansion to existing mining developments was later proposed in 2005 in the form of the Junction South East (JSE) deposit. A number of other expansions have subsequently occurred, including at the Junction South West (JSW) and Oxbow deposits.

All the deposits at Yandi are Channel Iron Deposits (CID) adjoining, or in close proximity to the Marillana and Weeli Wolli Creek systems. Advance dewatering and groundwater management is required to access the ore as the deposits are mostly situated below the water table. Marillana, Yandicoogina and Weeli Wolli creeks generally only flow naturally and recharge superficial aquifer systems after heavy rainfall events. However, the discharge of dewatered water from neighboring mines since 1992, coupled with discharge from Rio Tinto's operations, has resulted in virtually continuous surface flow through some sections of Weeli Wolli and Marillana Creeks in recent times.

The geology and hydrology of the superficial alluvial aquifers at Yandi are well suited for stygobitic fauna utilisation. Dewatering and groundwater management therefore have the potential to impact stygofauna communities and, as part of related environmental assessments, extensive sampling for stygofauna has been undertaken in the area since 2003.

This report is designed to provide:

- summaries of sampling effort and methodologies for each survey phase from 2003 – 2014;
- an amalgamation of stygofauna data collected from the Yandi operations;
- a summary of conservation significant stygofauna species; and
- an update to taxonomic groups using either genetic or morphological techniques.

Stygofauna sampling at Yandi has been undertaken by Biota since 2003, with 13 phases completed in total, representing a significant and sustained sampling effort. A total of 139 boreholes have been sampled to date, encompassing Junction Central, Junction South-East, Junction South-West, Oxbow and Pocket and Billiards South deposits, together with the adjacent creeklines and also the Billiards North deposit.

Stygobitic fauna sampling was undertaken during all past phases using modified plankton haul nets. Stygofauna sampling nets were lowered to the bottom of the drillholes and bore holes before being slowly hauled to the surface where the contents of the catch jar were collected. Specimens from all taxonomic groups were preserved in 100% ethanol, which allows for both morphological and molecular analysis. Most groups were identified from morphology, with representative amphipod specimens sequenced for variation at the mitochondrial COI gene. These specimens were compared to reference sequences of other Paramelitidae amphipods from the Pilbara, to determine the number of species collected and to assess the relationships of the Yandi specimens to taxa previously collected.

A total of 9,654 specimens of stygobitic fauna have been collected from surveys between 2003 and 2014. The collected specimens represented eight phyla and 12 orders as summarised by taxonomic group below.

- Six specimens of Protozoa were recorded from site DO7YJ138. These specimens were unable to be identified further due to a lack of taxonomic framework for this group in the Pilbara region.
- A total of 832 platyheminth worm specimens were collected from the Yandi area. The specimens were identified to the class Turbellaria, however this group is difficult to identify based on morphology.
- Thirteen specimens belonging to the phylum Nematoda were recorded from the Yandi area, from both Marillana and Weeli Wolli Creeks, but cannot be resolved below phylum.
- A total of 388 specimens of Oligochaeta were recorded during all phases of sampling, representing five families and 13 species.

- A single damaged gastropod shell was recorded from site 99YJWB02 during sampling in 2010. It is currently unclear if this shell represents a surface aquatic form or a stygobitic taxon.
- A total of 3,195 copepod specimens were recorded during all phases of sampling. The order Cyclopoida was the most abundantly collected and the specimens represented 17 distinct species, four of which still remain undescribed.
- A total of 2,775 specimens belonging to the order Ostracoda were recorded from the Yandi area over all phases of sampling. Sixteen distinct species were recorded representing two families (Candonidae and Limnocytheridae). Nine of these species have been formally described.
- A total of 72 specimens of Bathynellacea were recorded from the Yandi area. Seven distinct morphological species were collected, all belonging to the family Parabathynellidae.
- A total of 1,454 specimens belonging to the order Amphipoda were recorded from Yandi over the 13 phases of sampling. Amphipods were mostly identified morphologically, however 146 specimens were identified either genetically or by both methods. A total of eight species have been identified based on morphological characteristics, and genetic analysis also indicates the presence of eight genetic lineages from the 146 specimens successfully sequenced. Lineage WWA2 comprised specimens from the morphologically identified species Paramelitidae sp. B02 and sp. B03, whereas Lineage YB6 included specimens morphologically identified as Paramelitidae sp. B02 and *Pilbarus millsi*. These results suggest that some of the amphipod species represented at Yandi may be morphologically cryptic, as documented elsewhere.
- A total of 686 isopod specimens were collected, with 382 specimens belonging to the species *Pygolabis weeliwolli*, which was recorded from 29 sites from both Marillana and Weeli Wolli Creeks. The species *Pygolabis* sp. B06 was also widely collected.
- A total of 227 specimens of water mite were recorded from Yandi over the 13 phases of sampling. The specimens represented 12 distinct species from eight families.
- Three specimens of Coleoptera were recorded in 2011. These specimens belonged to the species *Boongurrus occidentalis* and were collected from site MNEW1upstream adjacent to Marillana Creek.

The documented fauna now comprises at least 88 stygal taxa, with the greatest abundance of species and specimens recorded from within alluvial and calcrete formations or associated with either Marillana or Weeli Wolli Creek. Sites Marillana07 and MNEW1upstream both yielded the highest abundance and species numbers (1,280 specimens and 1,032 specimens respectively; 23.95% of total records). Six other sites yielded over 31 species, while 53 sites yielded four species or less. These site richness findings should be interpreted with caution, as sampling effort varied by site amongst phases, with any given site sampled between one and 11 times during the study.

With the taxonomic resolution of some groups of stygobitic fauna, it is difficult to definitively assign conservation significance to some of the taxa recorded at Yandi. Thirteen of the taxa collected are undescribed, singleton records, which have been recorded only from within the Yandi study area. A precautionary position then would be to consider these as potentially restricted in distribution, and therefore of higher conservation significance, until otherwise demonstrated. However, given the abundance of other wider ranging Pilbara taxa collected (for example; *Meridiescandona facies, Enchytraeus* Pilbara sp. 2 (PSS) and *Boongurrus occidentalis*), it is unlikely that the recorded singleton species are confined to the Yandi study area. This may suggest that singleton records are more an artefact of sampling rather than reflecting true distributions.

The alluvial geology and superficial, highly transmissive aquifer that extends beyond the Yandi study area is also likely to allow stygobitic fauna dispersal to at least local catchment scale. This alluvial unit is associated with the Weeli Wolli Creek system and extends beyond the Yandi study area to the north and south, with the northern extent meeting the confluence with Marillana Creek and further northwards, opening up into a wide alluvial outwash fan which drains into the Fortescue Marsh. In addition, seasonally variable flooding from cyclonic events are also likely to aid in fauna dispersal. These habitat attributes suggest very small geographic scale restrictions to the Billiards project area, for example, may be unlikely in the stygofauna of the Yandi locality.

2.0 Introduction

Rio Tinto Pty Ltd (Rio Tinto) currently operates the Yandicoogina (Yandi) iron ore mine located approximately 90 km northwest of Newman in the Pilbara region of Western Australia (Figure 2.1). The original Yandi deposit, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999. An expansion to the existing mining developments was later proposed in 2005 in the form of the Junction South East (JSE) deposit. A number of further expansions have subsequently occurred, including at the Junction South West (JSW) and Oxbow deposits (Figure 2.1).

Rio Tinto plans to sustain the operations at the existing Yandi mine. The proposed sustaining operations include the development of the Pocket and Billiard South (PBS) deposits within the existing Yandi Operations development envelope (MS914; Figure 2.1). All the deposits at Yandi are Channel Iron Deposits (CID) located adjacent to, or in close proximity to the Marillana and Weeli Wolli Creek systems. In order to access the ore within the deposits, advance dewatering and groundwater management will be required, as the deposits are almost entirely below the water table. Such activity has the potential to impact stygofauna communities and as part of environmental assessments, extensive sampling of stygofauna communities has been undertaken in the area since 2003. Historical phases of stygofauna sampling at Billiards and the surrounding tenements have also collected several specimens of troglobitic fauna (or troglofauna) (Biota 2010), though these are not considered in this report.

Environmental Protection Authority (EPA) policy requires Rio Tinto to determine the potential impacts of proposed mining operations on subterranean fauna prior to formal approval and operations commencing (EPA 2013).

2.1 Report Aims

This report is designed to provide:

- summaries of sampling effort and methodologies for each survey phase from 2003 – 2014;
- an amalgamation of stygofauna data collected from the Yandi operations;
- a summary of conservation significant stygofauna species; and
- an update to taxonomic groups using either genetic or morphological techniques.

2.2 Stygofauna Overview

Subterranean fauna in north Western Australia have been recorded for some time from karstic or limestone cave systems on Cape Range and Barrow Island. In the Pilbara, surveys have collected subterranean fauna from other formations such as pisolitic iron formations, channel iron deposits, unconsolidated alluvium and sedimentary basalt (Marmonier et al. 1993, Biota 2004, 2006, 2010, 2011, 2013), indicating that the suitability of a given geology as habitat for subterranean fauna lies more with the availability of habitable space (Marmonier et al. 1993, Humphreys 1999, Biota 2006), than with a specific rock type.

Subterranean fauna habitats are characterised by a suite of physical parameters that include: a lack of light, stable temperatures and humidity, and limited nutrient infiltration from surface environments (Juberthie 2001, Romero 2009). These habitat characteristics have led to the evolution of common body morphology amongst subterranean fauna. Morphological characteristics common to most subterranean fauna include (Culver and Pipan 2009, Romero 2009):

- reduced or lack of pigmentation;
- reduced or lack of eyes; and
- elongate body morphology and appendages adapted for sensory movement.

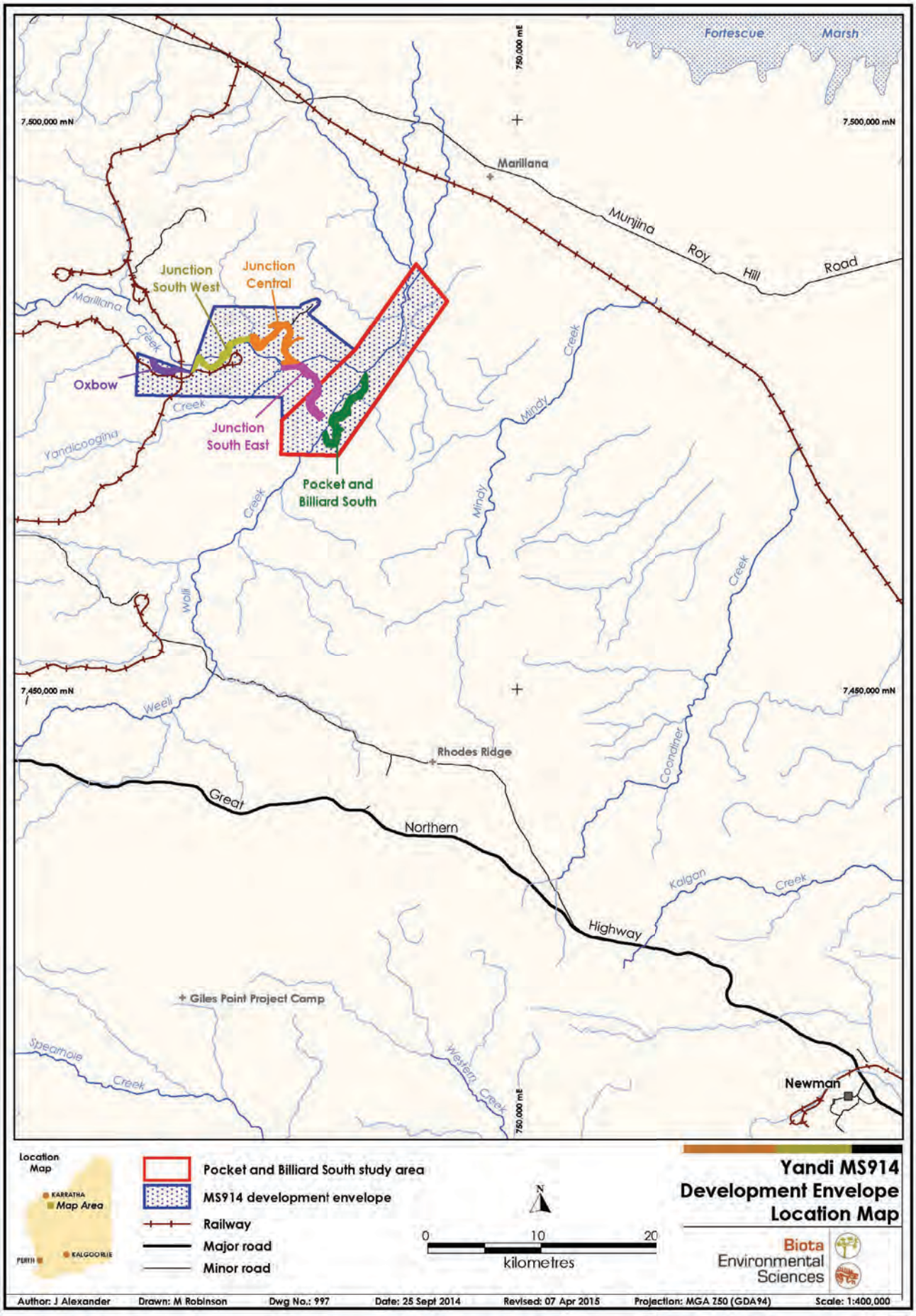

Figure 2.1: Location of the Yandi MS914 development envelope and ore bodies in relation to Newman.

Subterranean fauna can be categorised into two distinct groups based on habitat: troglobitic fauna (troglofauna) and stygobitic fauna (stygofauna). Troglofauna are a suite of fauna that survive only in cavities and interstices between the ground surface and the water table. Stygofauna occupy a similar niche, however are adapted to aquatic conditions and exist in groundwater aquifers and subterranean water bodies. True stygobites are obligatory subterranean habitat dwellers, and while they may occur close to surface environments, are evolved specifically for a subterranean environment, which make it unable, or highly unlikely to survive surface conditions.

Stygal communities in Western Australia are predominantly crustacean (Amphipoda, Isopoda, Decapoda, Syncarida, Ostracoda, Copepoda), however the Annelida (Oligochaeta), Arachnida (Hydracarina) and Platyhelminthes are also commonly collected. Three species of stygal vertebrates have been recorded from Australia, from Barrow Island, Cape Range and the Pilbara. This includes two species of blind gudgeon (*Milyeringa veritas, M. justitia*) as well as a blind cave eel, *Ophisternon candidum*. (Humphreys 2001, DSEWPaC 2008, Foster and Humphreys 2011, Humphreys et al. 2013, Larson et al. 2013).

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3.0 Stygofauna Habitat Characterisation

3.1 Climatic Conditions

The climate at Yandi is typified by arid conditions with hot, wet summers and mild, dry winters. Average temperatures for the locality range from 39.0 ºC in January to 8.1 ºC in July (BOM, 2014). The majority of rainfall occurs in the summer months and is driven mostly by cyclonic activity. The average annual rainfall for the area is 310.2 mm, with approximately half of this falling between December and February (Biota 2010).

Marillana and Weeli Wolli creek are ephemeral and generally only flow naturally after heavy rainfall events, however the discharge from neighboring upstream mines since 1992, coupled with discharge from Rio Tinto's operations, has resulted in a virtually continuous flow through sections of Weeli Wolli Creek in recent times.

3.2 Hydrology, Geology and Subterranean Fauna Habitat

The suitability of any geological formation as habitat for subterranean fauna is predominantly determined by the availability of space and potential for nutrient infiltration. In the case of stygofauna, this is further refined to where such rock formations occur below the water table. Several geological units are recognised as being core habitat for subterranean fauna as they characteristically form fractures, caverns and vugs, which allows for a greater rate of fauna dispersal and nutrient penetration. These geologies include limestone karstic systems, calcrete, alluvium, gravels, limonite and dolomite (Marmonier et al. 1993, Humphreys 1999).

The surface geology of the Yandi area (Figure 3.1) includes several units that represent suitable habitat for stygofauna. These comprise alluvium (Qa), colluvium (Qw) and calcrete units (Czk) (Table 3.1), all of which occur as valley fill formations broadly associated with contemporary drainages in the area and have been well sampled during past surveys (Figure 3.1).

Table 3.1: Geological units occurring in the Yandi study area.

Geological Time Scale	Code	Description
Quaternary Period	Qw	Alluvium and Colluvium - red-brown sandy and clayey soil; on low slopes and sheetwash areas.
	Qa	Alluvium - unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains.
	Qc	Alluvium-partly consolidated silt, sand, and gravel; old alluvium dissected by present-day drainage
	Qs	Eolian deposit - sand; in sheets and longitudinal dunes.
Cenozoic Era	Czp	Robe Pisolite: pisolitic limonite deposits developed along river channels.
	Cza	Hematite-goethite deposits on banded iron-formation and adjacent scree deposits
	Czc	Colluvium - partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits.
	Czr	Hematite-goethite deposits on banded iron-formation and adjacent scree deposits
	Czk	Calcrete - sheet carbonate; found along major drainage lines
Proterozoic Eon	PLHb	Brockman Iron Formation: banded iron-formation, chert, and pelite.
	PLHt	Medium to coarse-grained metadolerite sills intruded into Hamersley Group
	PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills.

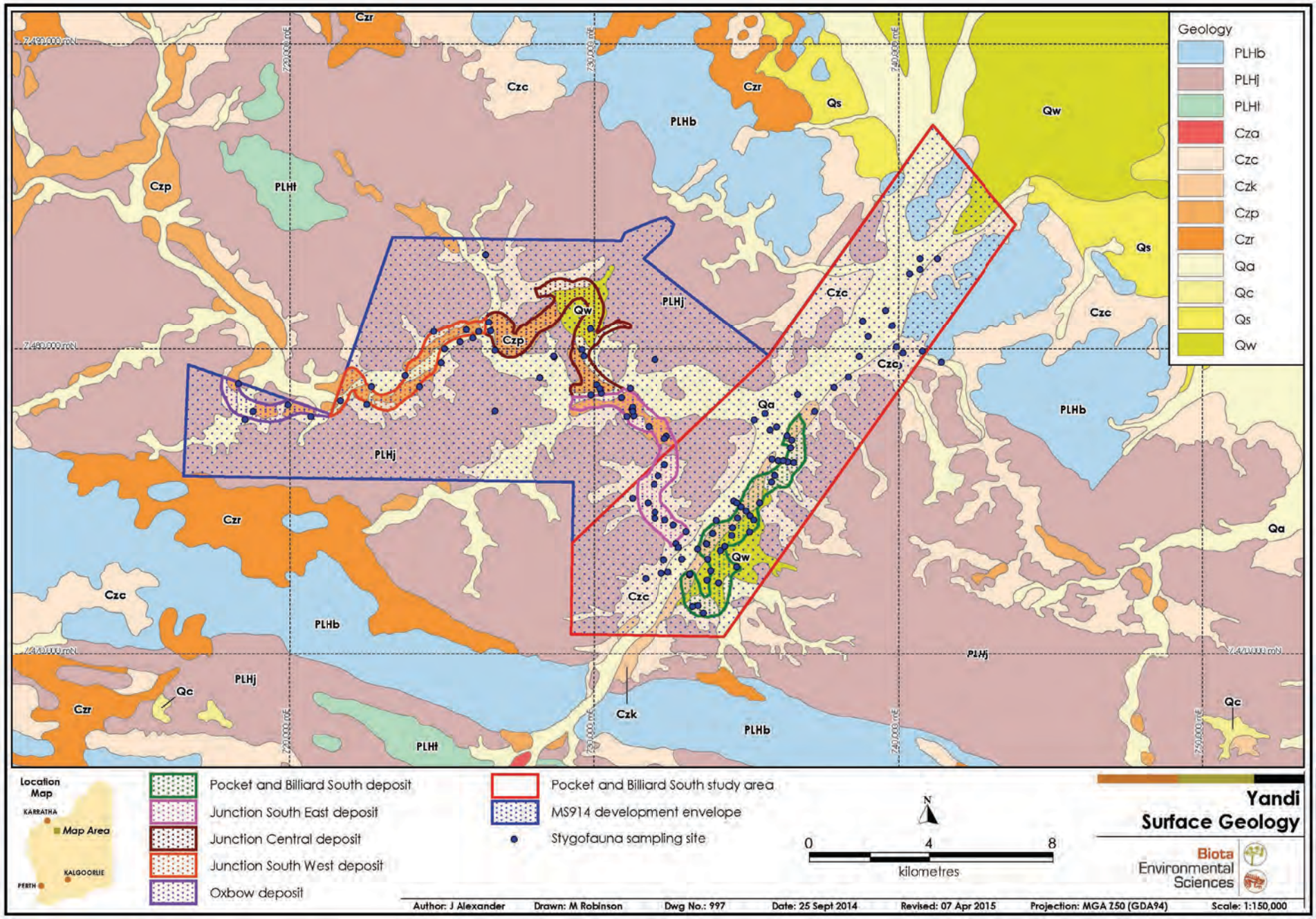

Figure 3.1: Geological units of the study area with stygofauna sampling sites from 2003 – 2014 (see Table 3.1 for geology unit codes and descriptions).

The CID in the Yandi area was eroded into bedrock of shale, dolerite and banded iron formation (BIF) of the Weeli Wolli formation, which overlies the Brockman Iron Formation. The CID is mostly below the water table and is overlain with varying depths of unconsolidated alluvium and colluvium (Rio Tinto 2010). Other units include chert, shale, minor dolerite and occasional CID clasts (Figure 3.2).

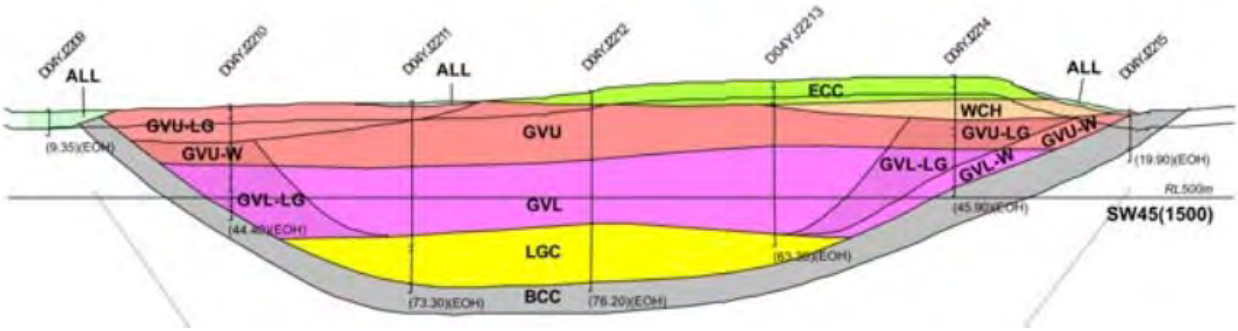

Figure 3.2: Cross-section of the CID at JSW shows relative geological layering (figure supplied by Rio Tinto).

Key	
Basal Conglomerate (BCC)	Pebble conglomerate with varying amounts of cobbles and larger fragments. The BCC is invariably present as the basal channel facies overlying basement
Limonitic Goethite Channel (LGC)	This material forms the footwall of the ore body. Typically hydrated/ altered material with well preserved to weakly preserved relict pisolitic textures and parent mineralogy. Lenses of unaltered to weakly hydrated/ altered material similar to the overlying GVL
Goethite Vitreous Upper (GVU)	Comprises the bulk of the above water table high grade CID. The GVU ranges from hard dense siliceous material that breaks with a conchoidal fracture to an earthy brown porous rock.
Goethite Vitreous Lower (GVL)	Comprises the bulk of the below water table high grade CID.

Alluvial processes have shaped the surface topography of the Yandi locality with the contemporary drainages winding between low-lying mesas and hills. The three major landforms that can be distinguished within the area are the low stony hills, valleys and drainage lines, the latter of which represent prospective habitat for stygofauna when saturated.

The overlying geology of both Marillana and Weeli Wolli Creeks are very similar and schematic cross-sections illustrating the system are shown in Figure 3.3 and Figure 3.4. The CID occurs in two broad configurations: adjacent to the contemporary drainage (Figure 3.3) or underlying it (Figure 3.4). Major rainfall events and subsequent surface creek flows result in recharge of the alluvium (Figure 3.3) and/or directly into the CID (Figure 3.4). Prolonged discharge of dewatering output into the Marillana Creek has, however, caused sections of both Marillana and Weeli Wolli Creek downstream from existing Rio Tinto and BHP Billiton Iron Ore operations to retain water for much a longer duration than normally occurs with seasonal variation. This has resulted in superficial formations remaining saturated for extended periods compared to past conditions.

The geology and hydrology of the superficial aquifer at Yandi is therefore well suited for stygobitic fauna utilisation with a high percentage of the shallow stratigraphy is comprised of saturated alluvium (Figure 3.1,). This shallow alluvial aquifer overlays a deeper aquifer where the CID is situated. These systems are recharged both directly and indirectly by rainfall, groundwater and surface water flow. The CID is primarily recharged by seepage in areas where the creek overlays the CID (Figure 3.4, Figure 3.3 and Figure 3.4) (Rio Tinto 2010). The shallow water table and seasonally variable influx of water from storm events are also likely to aid in fauna dispersal and general hydraulic connectivity of subterranean habitats within the area.

Figure 3.3: Schematic cross-section from Oxbow, illustrating contemporary drainage adjacent to the CID (figure supplied by Rio Tinto).

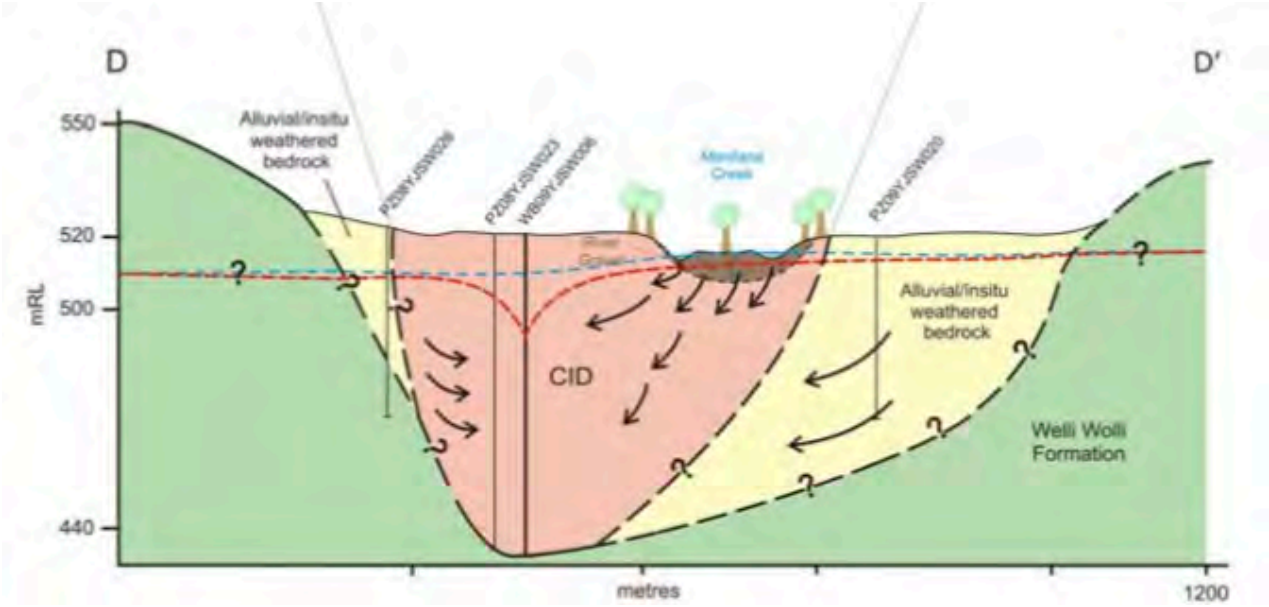

Figure 3.4: Schematic cross-section from JSW, illustrating CID underlying contemporary drainage (figure supplied by Rio Tinto).

4.0 Methodology

The methodology and approach employed during the surveys consolidated in this report were consistent with those outlined in relevant government policy; including:

- Guidance for the assessment of environmental factors; Sampling of Subterranean Fauna in Groundwater and Caves (EPA 2003);
- Guidance for the assessment of environmental factors: Sampling methods and survey considerations for subterranean fauna in Western Australia (EPA 2007); and
- Environmental Assessment Guideline for Consideration of subterranean fauna in environmental impact assessment in Western Australia (EPA 2013).

4.1 Stygofauna Sampling Methodology

Stygofauna sampling during all phases was undertaken using modified plankton haul nets. These sampling nets were constructed from 50 – 70 μm plankton mesh, with 45 – 150 mm apertures, dependent on the site being sampled, attached to a weighted catch jar. Stygofauna sampling nets were lowered to the bottom of the drillholes and boreholes before being slowly hauled to the surface where the contents of the catch jar were flushed into a uniquely labelled container. Each site was sampled in this way five times unless the water sample was very turbid, in which case the site was only sampled two or three times. On the final haul the net was agitated gently, which acts to stir the benthos layer and mobilises any fauna present for more effective specimen collecting. Specimens were stored in a shaded esky in order to preserve the sample prior to sorting and identification.

Following sampling of each drillhole, the nets were thoroughly rinsed with water, inspected and where possible, left to dry before using on another drillhole. This prevented cross-contamination of specimens between sample sites.

Collected stygofauna specimens underwent preliminary identification using dissecting microscopes (Olympus SZ40 and SZ61, magnification up to 40x) to identify specimens as far as possible, most commonly to order level. Fauna specimens were then assigned a unique number based on drillhole name and location and tracked on customised data sheets. Specimens were preserved in 100% ethanol, which allows for both morphological and molecular analysis.

4.2 Molecular Analysis

Select amphipods were sequenced for variation at the mitochondrial COI gene by Helix Molecular Solutions (Helix). The amphipod specimens were compared to reference sequences of members of the same family (Paramelitidae) from the Pilbara, to clarify the number of species collected and to determine the relationships of the Yandi samples to specimens previously collected in the Pilbara. A complete account of the molecular analysis methodology is provided in Appendix 1.

4.3 Survey Design

4.3.1 Personnel and Survey Timing

Stygofauna sampling at Yandi has been undertaken by Biota since 2003, with 13 phases completed in total (Table 4.1). Jason Alexander, Dan Kamien and Phil Runham (all of Biota, managed the projects with Garth Humphreys providing overall direction for the duration of the 13 phases.

Table 4.1: Summary of all field surveys completed by Biota (all personnel were employed directly by Biota unless otherwise indicated).

Year / Phase	Date	Personnel	Trip Focus
2003 Phase 1	3rd – 5th November	Kyle Armstrong, Phil Runham	Baseline stygofauna survey
2005 Phase 2	3rd – 7th April	Phil Runham, Lee Mould	Baseline stygofauna survey
2008 Phase 3	4th – 7th August	Jason Alexander, Jess Delaney (WRM)	Compliance stygofauna monitoring
2009 Phase 4	14th – 17th April	Jason Alexander, Tim Sachse	Compliance stygofauna monitoring
Phase 5	5th – 12th October	Jason Alexander, Jess Cairnes, Jess Delaney, David Keirle	Compliance stygofauna monitoring and targeted Northern Quoll Search
2010 Phase 6	20th – 25th September	Jason Alexander, Jess Cairnes	Compliance stygofauna monitoring
Phase 7	11th – 14th November	Jason Alexander, Jack Tatler	Compliance stygofauna monitoring
2011 Phase 8	20th – 24th June	Jason Alexander, Sylvie Schmidt	Compliance stygofauna monitoring
Phase 9	19th – 15th August	Jason Alexander, Jess Delaney (WRM)	Compliance stygofauna monitoring and Weeli Wolli Amphipod project
2012 Phase 10	3rd – 6th July	Jason Alexander, Andrew Sheppard	Compliance stygofauna monitoring
Phase11	29th October – 2nd November	Jess Cairnes, Jacinta King	Compliance stygofauna monitoring
2013 Phase 12	5th – 9th August	Dan Kamien, Chris Cole	Baseline stygofauna survey for Billiards deposit mine approval
2014 Phase 13	17th – 23rd May	Dan Kamien, Chris Cole	Baseline stygofauna survey for Billiards deposit mine approval

Morphological species level identification was completed by taxonomic specialists, including:

- Jane McRae, Stuart Halse and Mike Scanlon – Bennelongia Environmental Consultants;
- Mark Harvey and Ivana Karonovic – Western Australian Museum (WAM);
- Adrian Pinder - Department of Parks and Wildlife; and
- Russell Shiel – University of Adelaide

Yvette Hitchen of Helix completed molecular sequencing of the Amphipoda (Section 4.2), with Terrie Finston and Oliver Berry (Helix), providing analysis and interpretation of molecular data (Appendix 1).

4.3.2 Sampling Effort

A total of 139 boreholes have been sampled to date, encompassing Junction Central (JC), Junction South-East (JSE), Junction South-West (JSW), Oxbow and Billiards deposits (Table 4.2 and Figure 4.1). Sites were selected in conjunction with Rio Tinto personnel based on bore availability, viability for subterranean fauna and study focus. Many sites were sampled over multiple phases with the two best-sampled sites (99YJWB02 and Marillana06) being sampled during 11 of the 13 phases.

Table 4.2: Summary of sites sampled during all phases completed in the Yandi MS914 development envelope.

Site Name	Easting	Nothing	Phase												Total
	(m E)	(m N)	1	2	3	4	5	6	7	8	9	10	11	12	13	
99YJWB01	740705	7482617		✓	✓										✓	3
99YJWB02	732433	7472677		✓	✓	✓	✓	✓	✓	✓	✓				✓	9
99YJWB03	734711	7474442		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		11
99YJWB04	735790	7477323		✓		✓	✓	✓	✓	✓	✓	✓	✓			9
Airport EA	729874	7480651	✓	✓												2
B1	731070	7477776				✓	✓									2
BH14a	719445	7460851									✓					1
BH14b	719445	7460851									✓					1
BH15s	722005	7461150									✓					1
BH16d	723914	7462225									✓					1
BH16s	723917	7462226									✓					1
BH17d	725600	7463550									✓					1
BH17s	725600	7463550									✓					1
BH18s	725168	7463015									✓					1
BH30	719130	7457167									✓					1
BH32d	726089	7463757									✓					1
BH32s	726089	7463757									✓					1
Camp YMCC	726744	7477949	✓													1
D03YJ1636	731792	7477445		✓												1
D03YJ1647	731231	7478013		✓	✓											2
D03YJ1667	731298	7477800		✓	✓	✓	✓									4
D06YJ135	735437	7474938												✓		1
D06YJ386	736680	7478500												✓		1
D07YJ079	733416	7471574													✓	1
D07YJ131	736461	7476738												✓		1
D07YJ138	740142	7479848												✓		1
D07YJ159	741267	7482962												✓		1
D07YJ162	740704	7482968												✓		1
D07YJ180	739569	7481266												✓		1
D07YJ197	731688	7472459												✓		1
D08YJ005	732291	7473066												✓		1
D08YJ050	732887	7473094				✓	✓	✓	✓	✓						5
D08YJ126	737876	7478718													✓	1
D08YJ151	735613	7477871												✓		1
D08YJ155	735264	7477654												✓		1

Site Name	Easting	Nothing	Phase												Total
	(m E)	(m N)	1	2	3	4	5	6	7	8	9	10	11	12	13	
D08YJ186	740352	7482471												✓		1
D08YJ188	739792	7480757													✓	1
D08YJ198	739923	7480053													✓	1
D08YJ216	739004	7480406													✓	1
D08YJ225	740780	7479923												✓		1
D08YJ230	738814	7480909												✓		1
DD09YJ017	732220	7472638												✓		1
DD10YJ014	734692	7472844												✓		1
Discharge YMCD	730236	7478532	✓	✓												2
DR08YJ032	739999	7479430												✓		1
Fauna	726431	7483093		✓	✓	✓	✓	✓	✓	✓	✓					8
HD27	721776	7456990									✓					1
HGA0011M	709242	7463074									✓					1
JSE1	731262	7477960		✓												1
JSE10	731993	7474430		✓												1
JSE11	732326	7474375		✓												1
JSE12	732608	7474217		✓												1
JSE14	733707	7473602		✓		✓	✓	✓	✓	✓	✓	✓	✓			9
JSE15	733701	7473597		✓												1
JSE16	733899	7473935		✓												1
JSE2A	731262	7478074		✓												1
JSE3	732386	7477126		✓	✓											2
JSE31	732694	7473600			✓	✓	✓									3
JSE34	733141	7472578													✓	1
JSE36	735937	7475846				✓	✓	✓	✓	✓	✓	✓	✓			8
JSE37	736346	7477140				✓	✓								✓	3
JSE38	734525	7473866													✓	1
JSE39	733145	7472585			✓	✓	✓	✓		✓	✓	✓	✓		✓	9
JSE4	732318	7477053		✓												1
JSE49	733717	7472407													✓	1
JSE6	732322	7476191		✓	✓											2
JSE61	731264	7475091				✓										1
JSE62	735839	7475628													✓	1
JSE7	732102	7475828		✓												1
JSE8	731975	7475552		✓												1
JSE9	731769	7474933		✓												1

Site Name	Easting	Nothing	Phase												Total
	(m E)	(m N)	1	2	3	4	5	6	7	8	9	10	11	12	13	
Marillana01	723792	7479113	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			10
Marillana02	725082	7479990	✓		✓	✓	✓	✓	✓	✓	✓					8
Marillana03	728209	7479045	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			10
Marillana05	729890	7478482	✓	✓												2
Marillana06	731182	7478693	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			11
Marillana07	725592	7480218	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			10
MB08YJPC021	726201	7480572				✓	✓									2
MB09YJSB004	732776	7473478													✓	1
MB13YB001	735850	7476371													✓	1
MB13YB002	736047	7476325													✓	1
MB13YB004	736363	7476281													✓	1
MB13YB005	736211	7476323													✓	1
MB13YB006	735256	7474379													✓	1
MB13YB007	734992	7474665													✓	1
MB13YB008	734588	7475007													✓	1
MB13YB009	734693	7474937													✓	1
MB13YB010	734833	7474814													✓	1
MB13YJSE001	733023	7473992													✓	1
MC10	730082	7478812			✓	✓	✓									3
MC4	730180	7478691				✓	✓	✓	✓							4
MM031	741404	7479549												✓		1
MNEW1upstream	726009	7480355	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			10
Old BHP Airstrip	727185	7465385									✓					1
Old BHP Camp	726660	7464250									✓					1
Plant	728677	7479732	✓	✓	✓					✓	✓	✓				6
PZ08YJSE003	730892	7478388				✓	✓	✓	✓	✓						5
PZ08YJSW002	721670	7478287							✓							1
PZ08YJSW003	721670	7478287				✓	✓	✓	✓	✓		✓	✓			7
PZ08YJSW004	722689	7478744				✓	✓	✓	✓	✓	✓	✓	✓			8
PZ08YJSW009	722534	7478167				✓	✓	✓		✓	✓	✓	✓			7
PZ08YJSW017	724263	7478750				✓	✓	✓	✓	✓	✓	✓	✓			8
PZ08YJSW020	724976	7479538				✓	✓	✓	✓	✓	✓	✓	✓			8
PZ08YJSW026	724728	7480567				✓	✓									2
PZ08YOXB003	718308	7478847				✓	✓	✓	✓	✓	✓	✓	✓			8
PZ08YOXB004	718788	7477937				✓	✓	✓	✓		✓	✓	✓			7
PZ08YOXB005	718514	7477670				✓	✓	✓	✓	✓	✓					6

Site Name	Easting	Nothing	Phase												Total
	(m E)	(m N)	1	2	3	4	5	6	7	8	9	10	11	12	13	
PZ08YOXB006	719936	7478158				✓	✓	✓	✓	✓	✓	✓	✓			8
PZ08YOXB007	720681	7477777				✓	✓	✓	✓	✓	✓	✓	✓			8
RC04YJ2349	736500	7476992												✓		1
RC06YJ006	737239	7477941												✓		1
RD09YJ114	733738	7473098												✓		1
RD09YJ142	733843	7472709												✓		1
RD09YJ258	733600	7471329												✓		1
RD09YJ330	733245	7471543												✓		1
RD10YJ006	734303	7473519												✓		1
RD10YJ028	734160	7473381												✓		1
RD10YJ129	734552	7474128												✓		1
RS10YJ004	735117	7473986												✓		1
SA	729664	7479749	✓	✓												2
SB	731263	7477933	✓	✓												2
SC	731995	7474638	✓	✓												2
TS3DC	738706	7479737												✓		1
W01YJ15D	726605	7480589	✓	✓	✓											3
W02YJ001	726535	7480876	✓	✓	✓											3
WB/YJ99	725805	7480628	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			10
WB13YB001	736555	7476263													✓	1
WB13YB002	735125	7474523													✓	1
WB13YB003	735996	7477431													✓	1
WB13YB005	734094	7472322													✓	1
WSO04obs	729595	7479968			✓											1
WW1	732427	7472676		✓												1
WW2	733149	7472618		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			10
WW3	733405	7473428		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			10
WW4	734018	7474365		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			10
YASC	731995	7479638	✓	✓												2
YM119	738345	7479063				✓	✓	✓	✓	✓	✓	✓	✓		✓	9
YMCCA	726742	7479946									✓	✓	✓			3
YPP07	728673	7479755											✓			1
		Total	18	40	25	39	38	31	28	30	44	25	26	30	29	

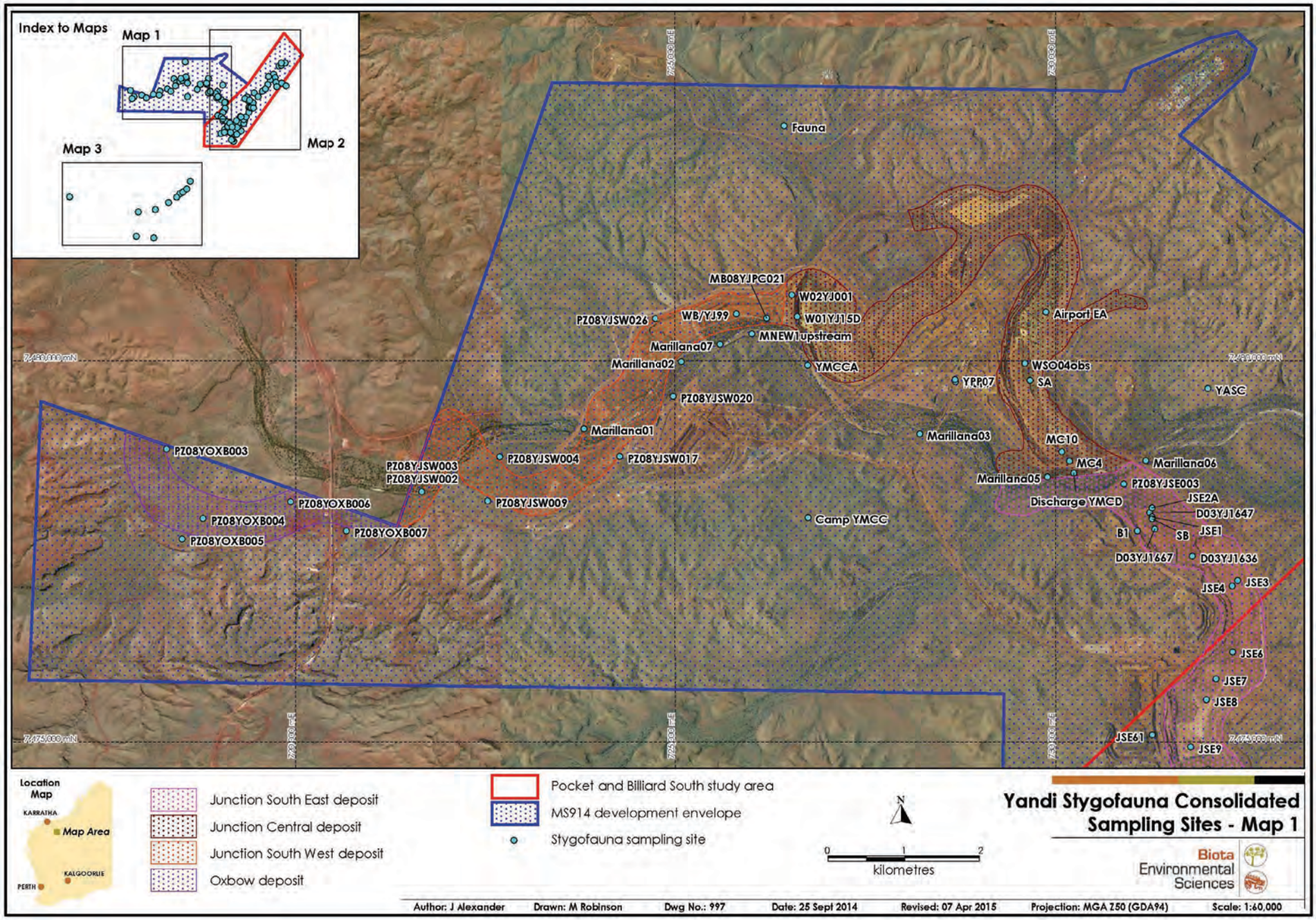

Figure 4.1: Location of all sites sampled for stygofauna in the Yandi MS914 development envelope – Map 1.

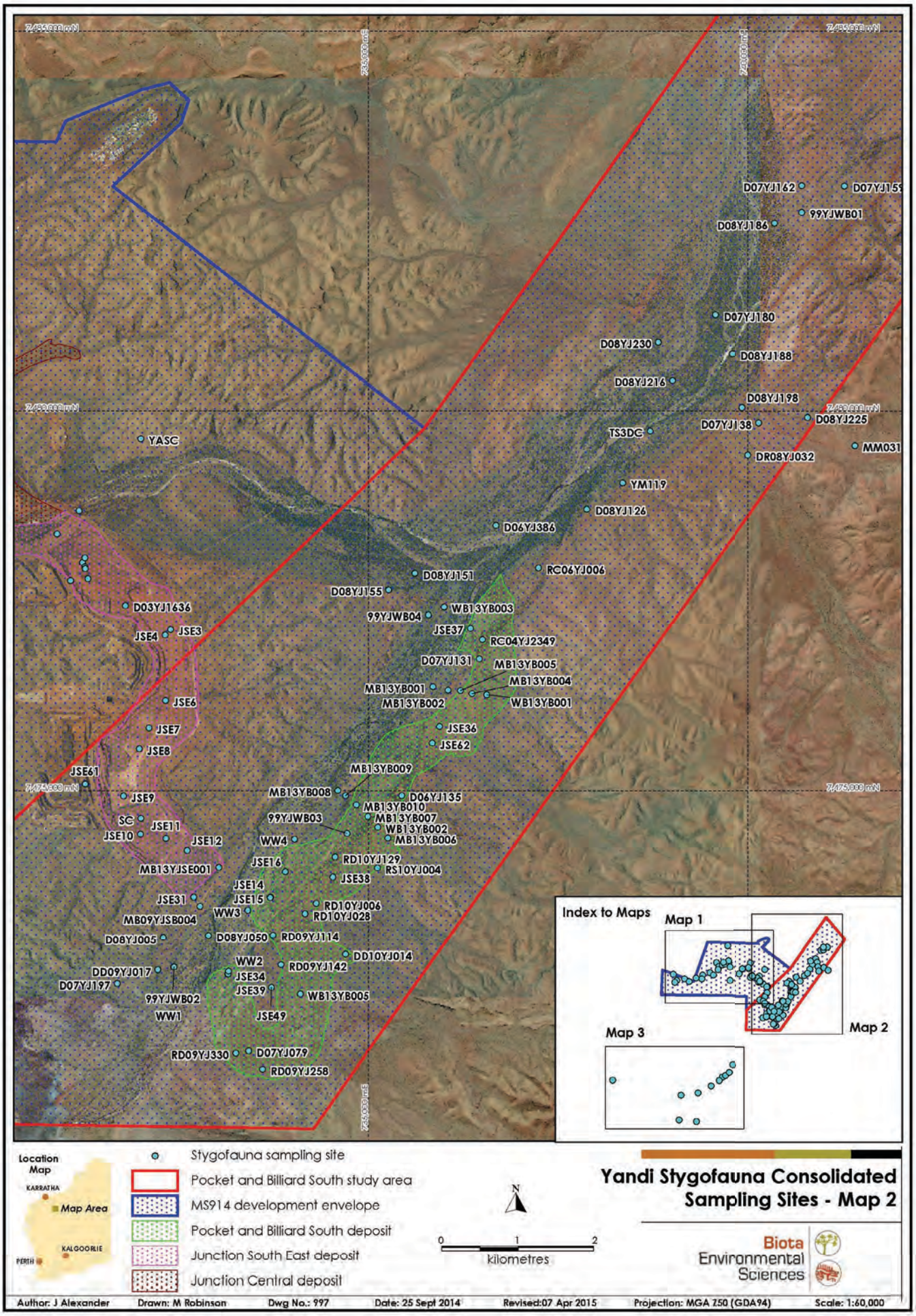

Figure 4.2: Location of all sites sampled for stygofauna in the Yandi MS914 development envelope – Map 2.

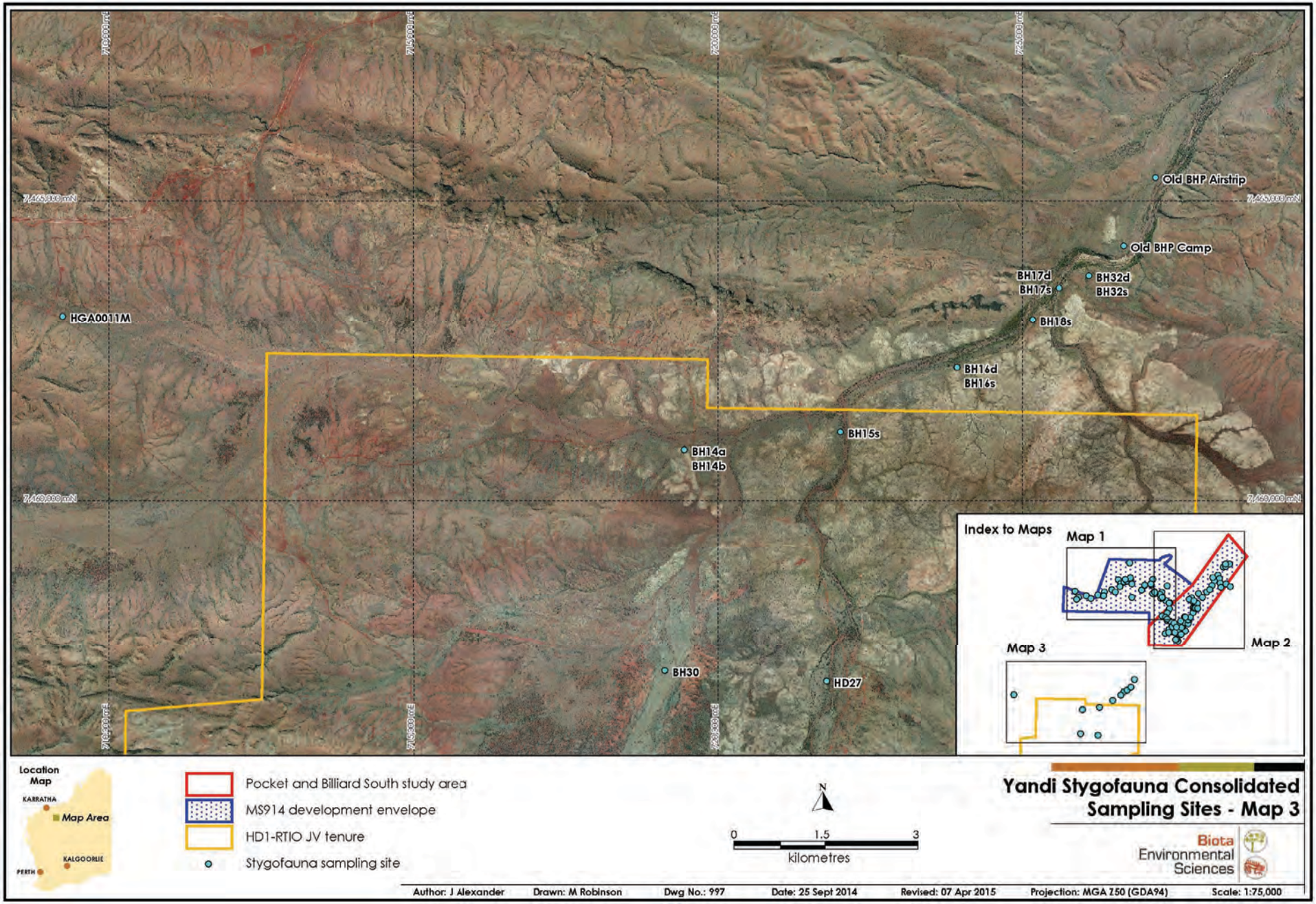

Figure 4.3: Location of all sites sampled for stygofauna in the Yandi MS914 development envelope – Map 3.

4.3.3 Limitations

A common limitation with stygofauna sampling is the limited taxonomic frameworks available for the identification of some groups. The groups collected during this study with limited taxonomic framework include Gastropoda, Nematoda, Platyhelminthes and Protozoa. Without such frameworks it is difficult to infer species distributions and consequently, impacts in relation to mining developments.

Additionally, juvenile and damaged specimens belonging to groups where taxonomy is better resolved are often generally unable to be identified to species level. Indeterminate identifications, or specimens not identified to species level due to specimen damage or age, were excluded from species counts as standard practice, as they potentially belong to already recorded species. Genetic analysis of all historically collected indeterminate, juvenile and damaged specimens would be required to provide additional identifications and confirm this.

The taxonomy of many groups has however been substantially improved since studies began at Yandi in 2003. As a result, not all specimens that were unidentifiable in early phases were able to be assigned to the species recognised in later phases. Recent work has reconciled this for some groups where this has occurred, but there are historical collections of ostracods and copepods that are currently not assigned to current names. In order to apply current taxonomic classification to all groups, all past specimens would need to be re-identified morphologically or genetically. This has not been undertaken as part of the current study as the majority of existing material has been determined to species level.

5.0 Results

5.1 Overview

A total of 9,654 specimens of stygofauna have been collected from surveys between 2003 and 2014 (Table 5.1, Appendix 2). The collected specimens represent eight phyla and 12 orders. Three of the higher taxa, Gastropoda, Nematoda and Protozoa, were unable to be identified below phylum due to a lack of taxonomic framework for these groups in the Pilbara. The flatworms (phylum Platyhelminthes) were similarly unable to be identified beyond class (Turbellaria).

The phylum Crustacea was the most commonly recorded, comprising 85% of the total records. The Copepoda, Ostracoda and Amphipoda were the most abundant, comprising 33% (n= 3,195), 29% (n= 2,775) and 15% (n= 1,454) respectively (Table 5.1). The phylum Gastropoda was least commonly recorded, with only a singleton specimen (Figure 5.1).

A complete breakdown of collected specimens, including distribution, abundance and final identifications from the Yandi area is provided in Section 5.2.

Table 5.1: Summary of higher order taxa collected at Yandi from 2003 – 2013.

Phylum	Class	Order (Common name)	Number Collected
Protozoa	Indeterminate	Indeterminate (Protozoa)	6
Nematoda	Indeterminate	Indeterminate (Nematode)	13
Platyhelminthes	Turbellaria	Indeterminate (Flatworm)	832
Annelida	Clitellata	Oligochaeta (Earthworm)	390
Crustacea	Maxillipoda	Copepoda (Copepod)	3,195
	Malacostraca	Ostracoda (Seed Shrimp)	2,775
		Bathynellacea (Bathynellid)	72
		Amphipoda (Landhopper)	1,454
		Isopoda (Slater)	686
Gastropoda	Indeterminate	Indeterminate (Snail)	1
Chelicerata	Arachnida	Hydracarina (Water Mite)	227
Uniramia	Insecta	Coleoptera (Beetle)	3
		Total	9,654

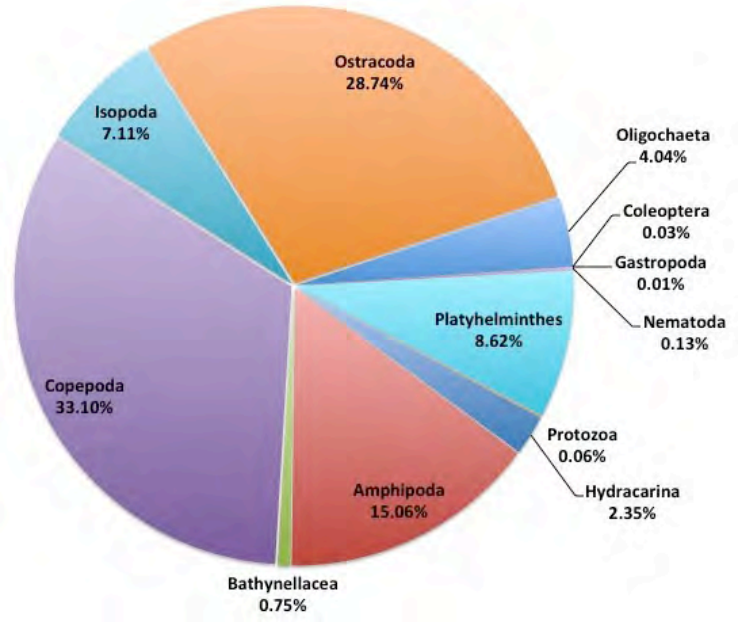

Figure 5.1: Proportional representation of taxa amongst specimens recorded during stygofauna surveys between 2003 and 2014.

5.2 Annotated List of Stygobitic Taxa

5.2.1 Kingdom Protozoa

Six specimens of Protozoa were recorded from site DO7YJ138. These specimens were unable to be identified further due to a lack of taxonomic framework for this group in the Pilbara region. Further genetic studies would be required from contextual specimens from around the Pilbara to determine the species-level distribution of taxa amongst the collected specimens. As little genetic work has been conducted on Protozoa in the Pilbara, this would require many specimens to be analysed.

5.2.2 Phylum Platyhelminthes

Overall, 832 specimens of the phylum platyheminth worms were recorded from the Yandi area (Table 5.2). All recorded specimens belonged the class Turbellaria but specimens from this class are difficult to identify based on morphology as there are few distinguishing features and all specimens possess a similar vermiform body shape. Further genetic studies would be required from contextual specimens from around the Pilbara to determine the species-level distribution of taxa amongst the collected specimens. As little genetic work has been conducted on Platyhelminthes in the Pilbara, this would again require many specimens to be analysed.

Table 5.2: Summary of Platyhelminthes collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level Identification	Recorded	Recorded	
-	Turbellaria sp. indet.	832	D08YJ050, Discharge, JSE14, Marillana01, Marillana02, Marillana06, Marillana07, MB13YB006, MC10, MNEW1upstream, PZ08YJSW003, PZ08YJSW009, W01YJ15D, YMCCA	Only able to identify to class.
	Total	832		

5.2.3 Phylum Nematoda

Thirteen specimens belonging to the phylum Nematoda were recorded from the Yandi area (Table 5.3). Specimens were recorded from both Marillana and Weeli Wolli Creeks. Specimens were unable to be identified further due to a lack of morphological taxonomic framework for the group. It is technically very difficult to morphologically identify nematodes (this is best done with live animals), and the group is typically not considered in environmental impact assessments (EPA 2007).

Table 5.3: Summary of Nematoda collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level Identification	Recorded	Recorded	
-	Nematoda sp. indet.	13	D08YJ186, DD09YJ017, Marillana07, MNEW1upstream, RC04YJ2349, RD09YJ114, WW3	Unable to identify further
	Total	13		

5.2.4 Order Oligochaeta

A total of 388 specimens of Oligochaeta were recorded across 13 phases of sampling (Table 5.4). Specimens collected represented five families (Aeolosomatidae, Enchytraeidae, Naididae, Phreodrilidae and Tubificidae) and 13 distinct species. A total of 21 specimens from four families (Enchytraeidae sp. indet., Naididae sp. indet., Phreodrilidae sp. indet. and Tubificidae sp. indet.) were unable to be identified due to specimen damage (Table 5.4).

Three of the collected species (*Pristina longiseta, Pristina aequiseta* and *Dero furcata*) are formally described. The described species *Pristina longiseta* was the most abundant oligochaete species recorded from six sites along Marillana Creek and the confluence of Marillana and Weeli Wolli

Creeks. *Pristina aequiseta* was the only singleton oligochaete record, collected from Weeli Wolli creek in the south of the study area, however is known from elsewhere in Australia and globally.

Two singleton species (*Pristina aequiseta*, and Phreodrilidae sp. indet.) of Oligochaeta were recorded over the 13 phases of sampling (Figure 5.2).

Table 5.4: Summary of Oligochaeta collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level identification	Recorded	Recorded	
Aeolosomatidae	*Aeolosoma* sp. 1 (PSS)	3	Marillana06, Marillana07	First collected during DEC Pilbara Stygofauna Survey
Enchytraeidae	Enchytraeidae sp. indet.	10	Marillana06, Plant, YM119	Immature specimens
	Enchytraeidae pilbara sp. 1 (pss)	49	Marillana02, WW2	First collected during DEC Pilbara Stygofauna Survey
	Enchytraeus Pilbara sp. 2 (PSS)	50	Fauna, JSE14, Marillana02, MNEW1upstream, WW2, WW3, YMCCA	Also known as "Enchytraeidae Pilbara sp 2 (DEC code)". First collected during DEC Pilbara Stygofauna Survey
Naididae	Naididae sp. indet.	7	Marillana06, WB13YB003	Immature and damaged specimens
	Dero furcata	2	D08YJ188	-
	Pristina aequiseta	1	D08YJ050	
	Pristina longiseta	140	99YJWB03, Marillana03, Marillana06, Marillana07, MNEW1upstream, YMCCA	
Phreodrilidae	*Insulodrilus* sp. indet.	21	Marillana06	
	Phreodrilidae sp. indet.	1	D08YJ216	Immature
	Phreodrilidae with similar ventral chaetae (pss)	14	D08YJ050, Marillana07, Plant, PZ08YJSW009, WW3	First collected during DEC Pilbara Stygofauna Survey
	Phreodrilidae with dissimilar ventral chaetae	2	YMCCA	-
Tubificidae	*Ainudrilus* sp.	43	Marillana05, Marillana07, Plant, W02YJ001	
	Ainudrilus sp. WA26	30	Marillana06	
	Tubificidae sp. indet.	3	Plant	Damaged specimens
	Tubificidae morphospecies 1/1a (pss)	4	JSE14, Marillana06, MNEW1upstream	First collected during DEC Pilbara Stygofauna Survey
	Tubificidae stygo type 5	8	99YJWB02, YMCCA	
	Total	388		

5.2.5 Class Gastropoda

A single damaged gastropod shell was recorded from site 99YJWB02 during sampling in 2010. It is currently unknown if this shell represents a surface aquatic form or a stygobitic taxon. In order to determine the stygobitic status of the gastropod, the specimen would need to be morphologically identified by Winston Ponder of the Australian museum. Stygobitic gastropods are uncommonly collected in the Pilbara and have the potential to display short range endemism (Biota 2013).

5.2.6 Class Copepoda

A total of 3,195 specimens of copepods were recorded across all phases of sampling (Table 5.5). The order Cyclopoida was the most abundantly collected taxon and records comprised 17 distinct species and three indistinct groups (Cyclopidae sp. indet., *Diacyclops* sp. indet., and *Mesocyclops* sp. indet. (juvenile and damaged specimens)) (Table 5.5). Thirteen of the 17 species identified have been recorded previously from the wider Pilbara area. The remaining four species, *Australocamptus* sp. nov., Canthocamptidae sp. B1, *Goniocyclops* sp. and *Parastenocaris* sp. B9, are not yet formally described and are only known from the study area. Two of these (*Australocamptus* sp. nov. and *Parastenocaris* sp. B9) are known from single specimens in Marillana Creek. It is possible these specimens represent existing species but genetic examination would be required to assess this.

The species *Diacyclops humphreysi humphreysi* was the most commonly recorded copepod species, with 2,021 specimens collected from 49 sites over all phases of sampling. Three singleton species (*Australocamptus* sp. nov., *Mesocyclops* sp. indet., and *Parastenocaris* sp. B9) of Copepoda were recorded over the 13 phases of sampling (Figure 5.2).

Table 5.5: Summary of Copepoda collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level identification	Recorded	Recorded	
Ameiridae	*Gordonitocrella trajani*	308	99YJWB01, 99YJWB02, 99YJWB03, 99YJWB04, JSE14, JSE39, MB13YB002, Plant, PZ08YJSW002, WW2, WW3, WW4, YM119	Previously called "*Inermipes* sp. B2"
Canthocamptidae	*Australocamptus* sp. nov.	1	Marillana02	-
	Canthocamptidae sp. B1	68	JSE14, Marillana06, Marillana07, Plant, PZ08YOXB006, RC06YJ006 WSO04obs, WW2, WW3, WW4, YPP07	Some previously called *Australocamptus* sp. B06
Cyclopidae	*Australocyclops similis*	3	MNEW1upstream, YMCCA	-
	Australoeucyclops karaytugi	4	MNEW1Upstream, PZ08YJSW003	-
	Cyclopidae sp. indet.	29	BH14b, BH16s, BH32s, D08YJ188, HD27, JSE37, Old BHP Airstrip, Marillana07, WW2	Juvenile (naupuli) or not identified past order level
	Diacyclops cockingi	175	99YJWB03, 99YJWB04, JSE14, JSE39, Marillana01, Marillana06, Marillana07, MNEW1upstream, Plant, PZ08YJSW003, PZ08YJSW009, PZ08YJSW020, SB, WW3, YM119	-
	Diacyclops humphreysi humphreysi	2021	99YJWB01, 99YJWB02, 99YJWB03, 99YJWB04, D03YJ1667, D06YJ386, D07YJ079, D08YJ186, D08YJ188, D08YJ216, D08YJ230, D08YJ050,	-

Taxonomy		Number	Sites	Notes
Family	Lowest level identification	Recorded	Recorded	
			JSE14, JSE36, JSE37, JSE38, JSE39, Marillana01, Marillana02, Marillana03, Marillana06, Marillana07, MB13YB001, MB13YB002, MB13YB005, MB13YB006, MB13YB007, MB13YB008, MB13YB009, MB13YB010, MB13YJSE001, MNEW1upstream, Plant, PZ08YJSW002, PZ08YJSW003, PZ08YJSW009, PZ08YJSW020, PZ08YOXB006, PZ08YJSW020, RC06YJ006, WB/YJ99, WB13YB001, WB13YB002, WSO04obs, WW2, WW3, WW4, YM119, YMCCA.	
	Diacyclops humphreysi unispinosus	62	99YJWB02, WW2	-
	Diacyclops sobeprolatus	219	99YJWB02, B1, JSE14, Marillana03, Marillana06, Marillana07, MB08YJPC021, Plant, PZ08YJSW002, PZ08YJSW003, WW2, WW3	-
	Diacyclops sp. indet.	69	Marillana02, MNEW1upstream, SB, YPP07	Juvenile specimens
	Goniocyclops sp.	2	PZ08YOXB004	-
	Mesocyclops darwini	97	Marillana06, MNEW1upstream	-
	Mesocyclops notius	10	Marillana06	-
	Mesocyclops sp. indet.	1	Marillana03	-
	Metacyclops pilbaricus	56	PZ08YOXB004, PZ08YOXB006, W01YJ15D	-
	Microcyclops varicans	56	Marillana03, Marillana06, Marillana07, MNEW1upstream, YMCCA	-
	Paracyclops chiltoni	3	D08YJ188	-
	Thermocyclops decipiens	10	Marillana06	-
Parastenocarididae	*Parastenocaris* sp. B9	1	Marillana06	-
	Total	3,195		

5.2.7 Order Ostracoda

A total of 2,775 specimens belonging to the order Ostracoda were recorded from the Yandi area over all phases of sampling (Table 5.6). Overall, 69 juvenile specimens were unable to be identified to species level (Ostracoda sp. indet and *Gomphodella* sp. indet).

At least 16 morphologically distinct species were recorded from the remaining 2,706 specimens, representing two families (Candonidae and Limnocytheridae) (Table 5.6). Nine of these species (*Areacandona mulgae, Candonopsis tenuis, Meridiescandona facies, Meridiescandona lucerne, Meridiescandona marillanae, Notacandona boultoni, Notocandona modesta, Gomphodella alexanderi, Gomphodella hirsuta*) have been formally described based on morphological information (Table 5.6).

Table 5.6: Summary of Ostracoda collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level identification	Recorded	Recorded	
-	Ostracoda sp. indet.	55	BH32s, HD27, Old BHP Airstrip, Old BHP camp, PZ08YJSW003	Not identified past order
Candonidae	*Areacandona mulgae*	1	99YJWB03	
	Candonopsis ? n. sp. indet.	1	MNEW1upstream	
	Candonopsis tenuis	158	Marillana03, Marillana07, MNEW1upstream, WB/YJ99, YMCCA	
	Meridiescandona sp. BOS399	6	MB13YB009, WB13YB003	
	Meridiescandona facies	1270	99YJWB02, B1, D08YJ188, Discharge, Fauna, JSE14, JSE8, Marillana01, Marillana02, Marillana03, Marillana05, Marillana06, Marillana07, MB13YB002, MB13YB005, MB13YB006, MNEW1upstream, Plant, PZ08YJSW003, PZ08YJSW020, W02YJ001, WB13YB002, WW2, WW3, WW4, YM119, YMCCA	
	Meridiescandona lucerna	65	Marillana07, MNEW1upstream, Plant, WW3, WW4, YM119, YMCCA	
	Meridiescandona marillanae	124	B1, JSE14, SB, WW3, WW4	
	Meridiescandona sp.	134	Discharge, Marillana01, Marillana02, Marillana05, Marillana06, Marillana07, MNEW1upstream, Plant, W02YJ001	Specimens undescribed at time of first collection (2003). Likely to be *M. facies*.
	Notacandona boultoni	789	99YJWB02, B1, D08YJ188, Discharge, JSE14, JSE39, Marillana01, Marillana02, Marillana03. Marillana06. Marillana07, MB13YB001, MB13YB007, MNEW1upstream, Plant, PZ08YJSW003, WW2, WW3, WW4, YM119, YMCCA	Plate 5.1
	Notocandona modesta	1	B1	
	Pilbaracandona sp. indet.	11	Discharge, Marillana07, MNEW1upstream	Species being described at time of first collection (2003). Needs to be revisited for updated identification.
Limnocytheridae	*Gomphodella alexanderi*	123	Marillana01, Marillana06, Marillana07, MNEW1upstream, WW2, WW3, YMCCA	Historically *Gomphodella* sp. "yandi". Plate 5.1
	Gomphodella hirsuta	8	Marillana06, Marillana07, WW2, WW3	
	Gomphodella sp BOS200	7	Marillana06, WW2	
	Gomphodella sp. indet.	14	Marillana05, Marillana07, YMCCA	Some juvenile specimens
	Gomphodella sp. BOS334	7	MNEW1upstream	
	New genus sp. BOS333	1	MNEW1upstream	
	Total	2,775		

Ostracod taxonomy has developed significantly since 2003 with many new species described. In accordance with the superseded Ministerial Statement (Condition 695:M11), *Gomphodella* sp. "yandi" was formally described and renamed *Gomphodella alexanderi* (Plate 5.1) (Karanovic and Humphrey 2014). It is likely that many specimens recorded in early surveys, which were unable to be identified to species (such as *Meridiescandona* sp.), may belong to groups described since (such as *Notocandona boultoni*; Plate 5.1). These specimens would need to be revisited to confirm their taxonomic status.

A number of singleton species were recorded from both families. Singleton records include the taxon *Areacandona mulgae* recorded adjacent to Weeli Wolli Creek, and *Candonopsis* ? n. sp. indet., *Notocandona modesta* and New genus sp. BOS333, adjacent to Marillana Creek (Figure 5.2).

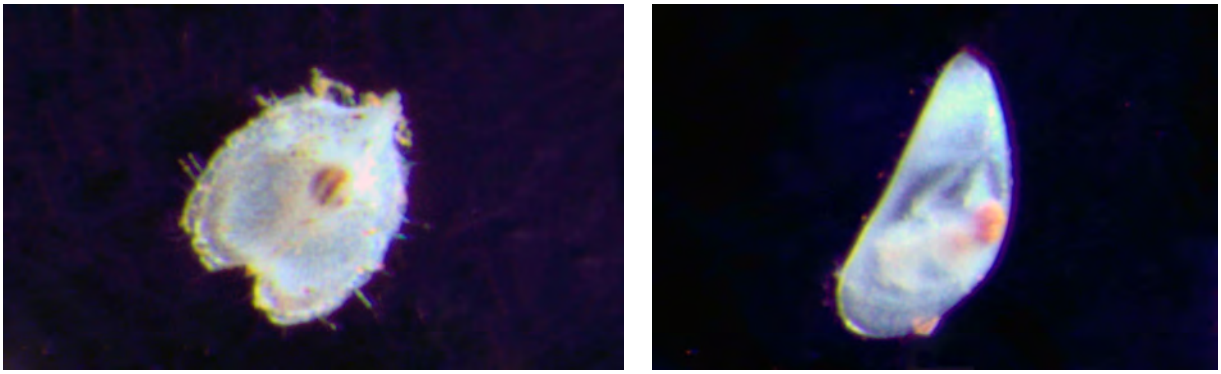

Plate 5.1: *Gomphodella alexanderi* (left) and *Notocandona boultoni* (right) collected from Marillana06.

5.2.8 Order Bathynellacea

A total of 72 specimens of Bathynellacea were recorded from the Yandi area between 2003 and 2014 (Table 5.7). Sixty-two of these specimens belong to the family Parabathynellidae. It is likely that the remaining 10 specimens also belong to the family Parabathynellidae, however they could not be identified to family level as they were either juveniles or damaged specimens. Twenty of the bathynellids collected were identified to eight distinct morphological species. The remaining 52 specimens (Bathynellacea sp. indet. and *Atopobathynella* sp. indet.) were unable to be identified to species level due to either being juvenile specimens or because the specimens were damaged (Table 5.7).

Five singleton species (*Atopobathynella* sp. B07, *Billibathynella* sp. B02, *Billibathynella* sp. B03, *Chilibathynella*? sp. B06, and *Notobathynella* sp.) of Bathynellacea were recorded over the 13 phases of sampling at Yandi (Figure 5.2).

Table 5.7: Summary of Bathynellacea collections and morphological identifications from 2003 – 2014.

Taxonomy		Number Recorded	Sites Recorded	Notes
Family	Lowest level identification			
Indet.	Bathynellacea sp. indet.	10	HD27, Marillana01, Marillana07, MNEW1upstream	Juvenile and damaged
Parabathynellidae	*Atopobathynella* sp. indet.	42	PZ08YOXB006, SA, WW3	Juvenile and damaged
	Atopobathynella sp. B04	7	Marillana01, Marillana03, Marillana07, MNEW1upstream	Some juveniles
	Atopobathynella sp. B07	1	MNEW1upstream	-
	Billibathynella sp. B01	6	MM031, MNEW1upstream, YMCCA	-

Taxonomy		Number Recorded	Sites Recorded	Notes
Family	Lowest level identification			
	Billibathynella sp. B02	1	WB13YB002	-
	Billibathynella sp. B03	1	WW4	-
	Brevisomabathynella cf. *pilbaraensis*	2	MB13YB004	Two described species of this genus from the Pilbara (Ethel Creek and Millstream) have only small differences between them also.
	Chilibathynella? sp. B06	1	WW4	-
	Notobathynella sp.	1	JSE14	-
	Total	72		

5.2.9 Order Amphipoda

A total of 1,454 specimens belonging to the order Amphipoda were recorded from Yandi during 13 phases of sampling (Table 5.8). Of the 1,454 specimens collected, 1,311 were identified based on morphology only. One hundred and forty-three specimens collected from Phases 12 and 13 were subsequently successfully analysed using molecular techniques, 55 of which were also morphologically identified (Table 5.8). The 88 specimens that were successfully analysed using molecular techniques only comprised the majority of amphipods collected from Phases 12 and 13, however three specimens from these two phases were identified morphologically, and three specimens failed to amplify and yield a genetic sequence (Biota 2014).

On further consideration, and in liaison with Rio Tinto personnel, a selection of 89 historically collected, morphologically-identified specimens were subject to molecular analysis. This genetic analysis was completed in an attempt to rationalise inconsistencies in morphological identifications due to historical limitations in the amphipod taxonomic framework. These specimens were selected to represent different described species and working morphotypes. Fifty-five specimens were successfully sequenced however 34 failed to amplify and yield a genetic sequence due to the age of the specimens and related DNA degradation (Appendix 1; Helix 2014).

A total of eight distinct species were identified based on morphological characteristics, excluding indeterminate specimen classifications (Amphipoda sp. indet., Paramelitidae sp. indet., and *Chydaekata* sp. indet.) (Table 5.8). Genetic analysis then indicated the presence of eight genetic lineages from the 143 amphipod specimens successfully sequenced (Table 5.8 and Table 5.9). Of these specimens, 55 had also been identified morphologically. It should be noted Lineage WWA2 and Lineage YB6 contained specimens that were identified as two different morphological species. Lineage WWA2 comprised specimens from the morphologically identified species Paramelitidae sp. B02 and B03, whereas Lineage YB6 included specimens that had been morphologically identified as Paramelitidae sp. B02 and *Pilbarus millsi* (Table 5.8).

Genetic differentiation between lineages within the study area ranged from 11.89 % between Lineages YB3 and YB4, to 25.68 % between WWA2 and YB4 (Table 5.9). Within lineage variation ranged up to just 3.8 % differentiation, considerably less than the between lineage variation, supporting the view that they represent separate species. WWA3 and YB3 contained insufficient specimens to allow for assessment of intra-lineage variation.

Table 5.8: Genetic and morphological analysis and site location for Amphipoda specimens collected during surveys from 2003 – 2014.

Taxonomy			Number	Sites	Notes
Taxon	Genetic Lineage	Lowest Morphological ID	Collected	Collected	
-	(Not sequenced or failed to yield a sequence)	Amphipoda sp. indet.	21	BH17s, BH32s, D08YJ216, MB13YB007, WB13YB001, Marillana07, Old BHP Airstrip, Old BHP camp	3 specimens failed to yield a sequence. Specimens damaged or not identified past order.
-	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. indet.	156	99YJWB02, D08YJ050, JSE14, Marillana01, Marillana07, MB08YJPC021, MNEW1upstream, Plant, PZ08YJSW003, PZ08YOXB004, W02YJ001, WB/YJ99, YM119	1 specimen failed to yield a sequence. Juvenile or damaged specimens
-	(Not sequenced or failed to yield a sequence)	*Chydaekata* sp. indet.	383	99YJWB02, 99YJWB03, D08YJ050, JSE12, JSE14, JSE2a, JSE39, Marillana01, Marillana02, Marillana03, Marillana06, Marillana07, MNEW1upstream, Plant, PZ08YJSW003, PZ08YJSW009, PZ08YJSW020, PZ08YOXB003, PZ08YOXB005, WSO04obs, WW2, WW3, WW4, YM119, YMCCA	Unable to be identified further due to lack in taxonomic framework.
Chydaekata sp. B01	(Not sequenced or failed to yield a sequence)	*Chydaekata* sp. B01	7	PZ08YJSW003, JSE14	-
Maarrka weeliwollii	(Not sequenced or failed to yield a sequence)	*Maarrka weeliwolli*	50	JSE14, Marillana03, Marillana06, Marillana07, MNEW1upstream, Plant, PZ08YJSW003, PZ08YJSW009, WW2, WW3, WW4, YM119, YMCCA	-
Paramelitidae sp. B02	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. B02	653	99YJWB02, B1, D08YJ050, JSE14, JSE2a, JSE36, JSE39, Marillana01, Marillana03, Marillana06, Marillana07, MC4, MNEW1upstream, Plant, PZ08YJSW002, PZ08YJSW003, PZ08YJSW009, PZ08YJSW020, PZ08YOXB004, WB/YJ99, WW2, WW3, WW4, YM119, YMCCA	29 specimens failed to yield a sequence
Paramelitidae sp. B03	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. B03	32	MB13YB004, Marillana07	-
Paramelitidae sp. B06	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. B06	2	PZ08YOXB003, WB/YJ99	-
Paramelitidae sp. B16	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. B16	2	MB13YB004, YMCCA	1 specimen failed to yield a sequence
Paramelitidae sp. B25	(Not sequenced or failed to yield a sequence)	Paramelitidae sp. B25	4	MNEW1upstream, PZ08YOXB006	3 specimens failed to yield a sequence.
Pilbarus millsi	(Not sequenced or failed to yield a sequence)	*Pilbarus millsi*	1	99YJWB02	-

Taxonomy			Number	Sites	Notes
Taxon	Genetic Lineage	Lowest Morphological ID	Collected	Collected	
Lineage WWA2	Lineage WWA2	Paramelitidae sp. B02	19	D08YJ050, Marillana01, Marillana03, MB08YJPC021, PZ08YJSW003, WB/YJ99, WW2	-
		Paramelitidae sp. B03	5	Marillana07	-
Lineage WWA3	Lineage WWA3	Paramelitidae sp. B25	1	MNEW1upstream	-
Lineage YB1	Lineage YB1	Paramelitidae sp. B02	24	D08YJ050, JSE14, Marillana01, Marillana02, Plant, WW2, WW3, WW4	Helix reference WWA1 (Appendix 1)
		(Not identified morphologically)	17	MB13YB001, MB13YB005, MB13YB007, RC06YJ006, TS3DC, WB13YB001, WB13YB003, WB13YB005, YM119	
Lineage YB2	Lineage YB2	(Not identified morphologically)	16	D08YJ188	-
Lineage YB3	Lineage YB3	(Not identified morphologically)	7	MB13YB002, MB13YB006, MB13YB007	-
Lineage YB4	Lineage YB4	(Not identified morphologically)	2	MB13YB001, TS3DC	-
Lineage YB5	Lineage YB5	(Not identified morphologically)	3	99YJWB03, JSE39, MB13YB010	-
Lineage YB6	Lineage YB6	Paramelitidae sp. B02	2	Marillana01	Helix reference WWA4 (Appendix 1)
		Pilbarus millsi	4	Marillana06, WW3	
		(Not identified morphologically)	43	99YJWB02, D07YJ079, D08YJ188, MB13YB001, MB13YB002, MB13YB005, MB13YB007, MB13YB010, RC06YJ006, RD09YJ258, RD10YJ129, RS10YJ004, TS3DC, WB13YB001, WB13YB002, WB13YB005, YM119	
		Total	1,454		

Table 5.9: Genetic differentiation within and between lineages from within the Yandi area.

		Inter-lineage genetic differentiation (%)							
Lineage	Intra-lineage variation (%)	WWA2	WWA3	YB1	YB2	YB3	YB4	YB5	YB6
WWA2	1.1	-							
WWA3	-	21.08	-						
YB1	0 – 3.8	21.35	20.54	-					
YB2	0.8	18.92	21.62	21.35	-				
YB3	-	21.35	20.27	18.11	21.35	-			
YB4	0.3	25.68	21.08	17.30	20.27	11.89	-		
YB5	1.6	25.14	22.97	18.11	21.08	17.84	14.59	-	
YB6	0.3 – 0.8	23.51	22.70	13.51	23.78	18.92	20.27	20.00	-

Considering both morphological and molecular data, eight distinct species of Amphipoda have been identified morphologically, and eight species using molecular techniques. However, four of the specimens identified using molecular techniques (Lineages WWA2, WWA3, YB1 and YB6) were also identified morphologically, and they corresponded to four of the same species that had already been identified by morphology only. Therefore, the most conservative assessment is that 12 species of Amphipoda have now been identified at Yandi.

5.2.10 Order Isopoda

A total of 686 isopod specimens were collected across all 13 phases of sampling, representing at least six species based on morphological identifications (Table 5.10). This included 32 specimens unable to be identified to species level (Isopoda sp. indet., and *Pygolabis* sp. indet.) due to being either juveniles or damaged specimens. Of the remaining 654 specimens, the majority (382) belonged to the locally widespread species *Pygolabis weeliwolli* (Plate 5.2), which was recorded at 29 sites from both Marillana and Weeli Wolli Creeks. The species *Pygolabis* sp. B06 was also extensively collected (n = 247) however it was only recorded from seven sites from Marillana Creek.

Table 5.10: Summary of Isopoda collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level identification	Recorded	Recorded	
-	Isopoda sp. indet.	7	BH15, BH17s, BH32s	Not identified past order level
Tainisopidae	*Pygolabis* sp. "Wilson Sp. 3"	17	Marillana05, SB	-
	Pygolabis sp. B06	247	Discharge, Marillana01, Marillana02, Marillana03, Marillana06, Marillana07, MNEW1upstream	-
	Pygolabis sp. indet.	25	JSE14, Marillana01, Marillana02, Marillana03, Marillana06, Marillana07, MNEW1upstream, Plant, WW3, WW4	Juvenile specimens
	Pygolabis sp. humphreysi?	8	Marillana07	-
	Pygolabis weeliwolli	382	99YJWB02, 99YJWB04, Airport, D08YJ050, D08YJ188, Discharge, Fauna, JSE14, JSE2a, JSE34, JSE39, Marillana01, Marillana05, Marillana06, MB13YB001, MB13YB002, MB13YB010, MNEW1upstream, Plant, PZ08YJSW003, PZ08YJSW004, PZ08YOXB006, SB, WB13YB002, WSO04obs, WW2, WW3, WW4, YM119	Plate 5.2
	Total	686		

Plate 5.2: *Pygolabis weeliwolli* collected from sites MNEW1upstream in 2012.

5.2.11 Order Hydracarina

A total of 227 specimens of water mites (e.g. *Arrenurus* sp. 01 (Yandi); Plate 5.3) were recorded across 13 phases of sampling (Table 5.11). The specimens represented 12 distinct species from eight families (Table 5.11). Additionally, three groups (Hydracarina indet., *Arrenurus* sp. indet. and Trombidioidea sp. indet.), were unable to be identified further due to damaged and juvenile specimens (Table 5.11).

The taxon *Recifella* sp. "Yandi" was the most abundantly recorded water mite, being collected from both Weeli Wolli and Marillana Creek. This taxon is yet to be formally described. Three singleton species (*Albia* sp. B1, *Limnesia* sp. B03 and *Mideopsinae penemidopsis*) of Hydracarina were recorded over the 13 phases (Figure 5.2).

Table 5.11: Summary of Hydracarina collections and morphological identifications from 2003 – 2014.

Taxonomy		Number	Sites	Notes
Family	Lowest level identificiation	Recorded	Recorded	
-	Hydracarina indet.	5	Marillana01, Marillana03, Marillana07, Plant	Damaged specimens
Arrenuridae	*Arrenurus* sp. 01 (Yandi)	23	MNEW1upstream, Marillana07, Marillana01, YMCCA	Plate 5.3
	Arrenurus sp. indet.	14	D08YJ188, Marillana03, Marillana07, MNEW1upstream, WW3	Juvenile and damaged specimens
	Arrenurus sp. 02	27	Marillana07, MNEW1upstream, WW3	-
	Arrenurus sp. 03	10	Marillana01, WW3, YMCCA	-
Axonopidae	*Albia* sp. B1	1	MNEW1upstream	-
	Axonopsella sp. B1	14	Marillana06, Marillana07, MNEW1upstream, YM119	-
Halacaridae	Halacaridae sp.	2	Marillana06	-
Limnesiidae	*Limnesia* sp. B03	1	MNEW1upstream	-
	Limnesia sp. B01	10	Marillana07, MNEW1upstream	-
Mideopsidae	*Guineaxonopsis* sp. S1 (PSS)	7	99YJWB04, JSE14, WW3	-
	Mideopsinae penemidopsis	1	Marillana06	-
Piersigiidae	*Stygolimnochares* sp. B1	13	Marillana06, Marillana07	-
Trombidioidea	Trombidioidea sp. Indet	16	Fauna	Juvenile
Unionicolidae	*Recifella* sp. "Yandi"	83	Discharge, JSE3, JSE37, Marillana01, Marillana05, Marillana06, Marillana07, MNEW1upstream, Plant, WB13YB002, WW4, YMCCA	-
	Total	227		

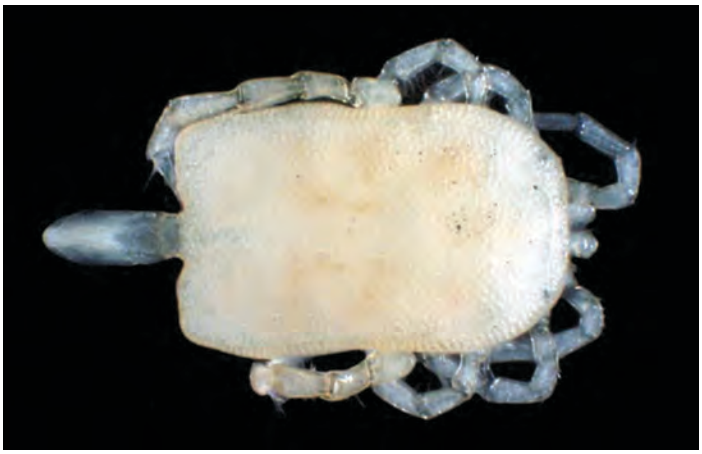

Plate 5.3: *Arrenurus* sp. 01 (Yandi) specimen collected from site MNEW1upstream.

5.2.12 Order Coleoptera

Three beetle specimens were recorded from sampling in 2011. These specimens belonged to the species *Boongurrus occidentalis* (Family Dytiscidae: Watts and Humphrey 2004) and were collected from site MNEW1upstream adjacent to Marillana Creek. This species has been recorded previously and described from outside the Yandi area at Wittenoom Gorge, Killara Station, Moorarie Station and Wagga Wagga Station. The specimens collected at other sites have been collected at the edge of pools in sandy riverbeds and from boreholes. The specimen collected from a borehole at Killara Station was in a calcrete area containing other short-range endemics (Watts and Humphrey 2004).

5.3 Singleton Species

Seventeen singleton species were recorded from five of the orders collected (Table 5.12, Figure 5.2). Singleton species were those recorded from one individual only and in most cases are also currently only known from the Yandi locality. Four of the 17 singletons have previously been described from elsewhere in the region (Table 5.12). It is therefore precautionary to attach higher conservation significance to the remaining 13 species until their wider distribution is demonstrated. The greatest number of singleton species was recorded from Site MNEW1upstream, which is adjacent to Marillana Creek, with five singleton taxa. Sites Marillana06 and WW4 both yielded two singleton species.

Table 5.12: Summary of singleton species collected from the Yandi MS914 development envelope from 2003 – 2014.

Taxonomy			Site Recorded	Notes
Order	Family	Species		
Hydracarina	Axonopidae	*Albia* sp. B1	MNEW1upstream	
	Limnesiidae	*Limnesia* sp. B03	MNEW1upstream	
	Mideopdidae	*Mideopsinae penemidopsis*	Marillana06	Previously described
Copepoda	Canthocamptidae	*Australocamptus* sp. nov.	Marillana02	
	Cyclopidae	*Mesocyclops* sp. indet.	Marillana03	
	Parastenocarididae	*Parastenocaris* sp. B9	Marillana06	
Bathynellacea	Parabathynellidae	*Atopobathynella* sp. B07	MNEW1upstream	
		Billibathynella sp. B02	WB13YB002	
		Billibathynella sp. B03	WW4	
		Chilibathynella? sp. B06	WW4	
		Notobathynella sp.	JSE14	
Oligochaeta	Naididae	*Pristina aequiseta*	D08YJ050	Previously described
	Phreodrilidae	Phreodrilidae sp. indet.	D08YJ216	Immature
Ostracoda	Candonidae	*Areacandona mulgae*	99YJWB03	Previously described
		Candonopsis ? n. sp. indet.	MNEW1upstream	
		Notocandona modesta	B1	Previously described
	Limnocytheridae	New genus sp. BOS333	MNEW1upstream	

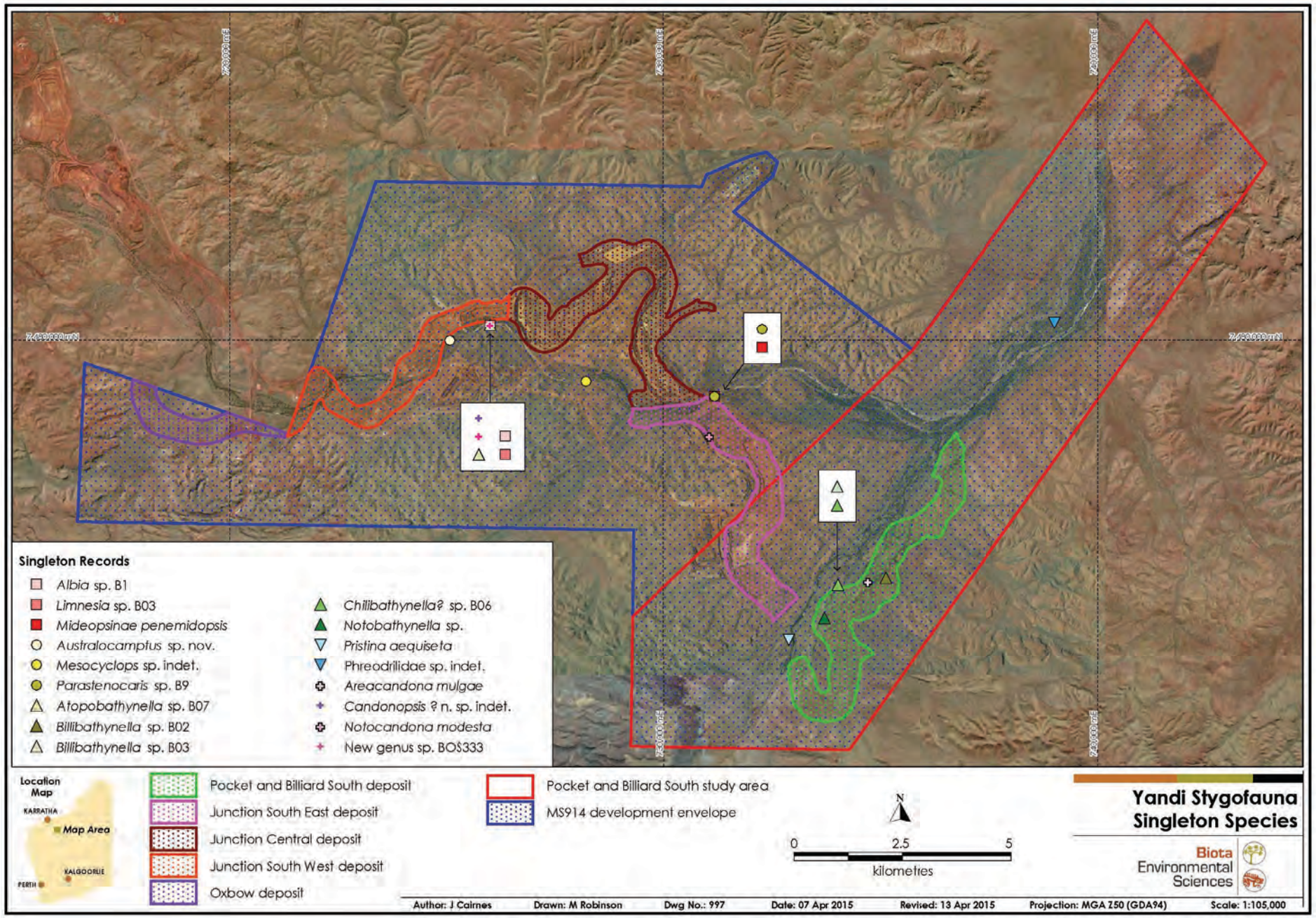

Figure 5.2: Singleton species collected from the Yandi MS914 development envelope from 2003 – 2014.

6.0 Discussion

Extensive sampling for stygofauna has been completed in the Yandi study area over more than a decade, and the fauna of the locality is now one of the best documented in the Pilbara region. As many as 31 new taxa have now been discovered from the area, and Yandi specimens have also been used as holotypes in formal identifications, such as *G. alexanderi*, and in unfinished descriptions, such as *Recifella* sp. "Yandi". Additionally, eight previously undetected Amphipoda genetic lineages have now been identified in an attempt to resolve this morphologically cryptic group and to provide context to genetic and morphological analysis from the surrounding area.

A total of at least 88 taxa were recorded over the 13 phases of sampling, with the greatest abundance of species and specimens having been recorded from saturated alluvium and calcrete habitats within or immediately adjacent to either Marillana or Weeli Wolli Creek (Figure 6.1 - Figure 6.3). Six sites yielded over 31 species while 53 sites yielded four species or less (Figure 6.1), all of which were associated with calcrete or alluvial units. However this result is likely to have been strongly affected by sampling effort amongst phases, as these richer sites were sampled multiple times during the various surveys. Sites Marillana07 and MNEW1upstream both yielded the highest abundance and species numbers (1,280 specimens and 1,032 specimens respectively; 23.95 % of total records) (Figure 6.1 - Figure 6.3), both of which were situated in calcrete geology.

Thirty-nine of the morphologically-identified species (accounting for 6,183 specimens; or 64.04 % of total records) collected from the Yandi study area have been recorded from elsewhere in Australia or globally. Thirteen of the remaining species documented for the area are singleton taxa that are currently only known from the Yandi locality (Section 5.3). Given the state of taxonomy for some of these stygal groups, it is difficult to definitively assign conservation significance to most of these singleton taxa. A precautionary assessment would treat them as potentially restricted to the area until their wider status can be demonstrated. However, the abundance of other wider ranging Pilbara taxa collected from Yandi (for example; *Meridiescandona facies, Enchytraeus* Pilbara sp. 2 (PSS) and *Boongurrus occidentalis*); and that almost half of the overall assemblage is known from the wider region, may suggest a lower risk of very localised restrictions in species distributions. This may indicate that the recorded singleton species are more an artefact of sampling, rather than reflecting true distributions.

Theses observations are consistent with the nature of the alluvial and calcrete geological units that comprise core stygofauna habitat in the area. The connected nature of these units and the highly transmissive superficial aquifer that extends beyond the Yandi study area, are also likely to promote stygobitic fauna dispersal to at least local catchment scale (Finston and Johnson 2004). These alluvial units are associated with the Marillana - Weeli Wolli Creek system and extend beyond the Yandi study area to the north and south, with the northern extent meeting the confluence with Marillana Creek and extending northwards, opening up into a wide alluvial outwash fan which drains into the Fortescue Marsh. In addition, seasonally variable flooding from cyclonic events are also likely to aid in fauna dispersal. These habitat attributes also suggest very small geographic scale restrictions to the Billiards project area, for example, may be unlikely in the stygofauna of the Yandi locality.

Some of the potentially restricted stygal taxa are predisposed to short range endemism and may truly have small-scale distributions. Subterranean gastropods in particular are infrequently collected in the Pilbara and have been shown to have potential to display such short range endemism (Ponder and Colgan 2002). It would be beneficial to obtain an undamaged specimen of the stygal snail collected from the project area for further analysis. Given the sampling effort to date and infrequency of collection, it is, however, unlikely that additional specimens will be readily forthcoming.

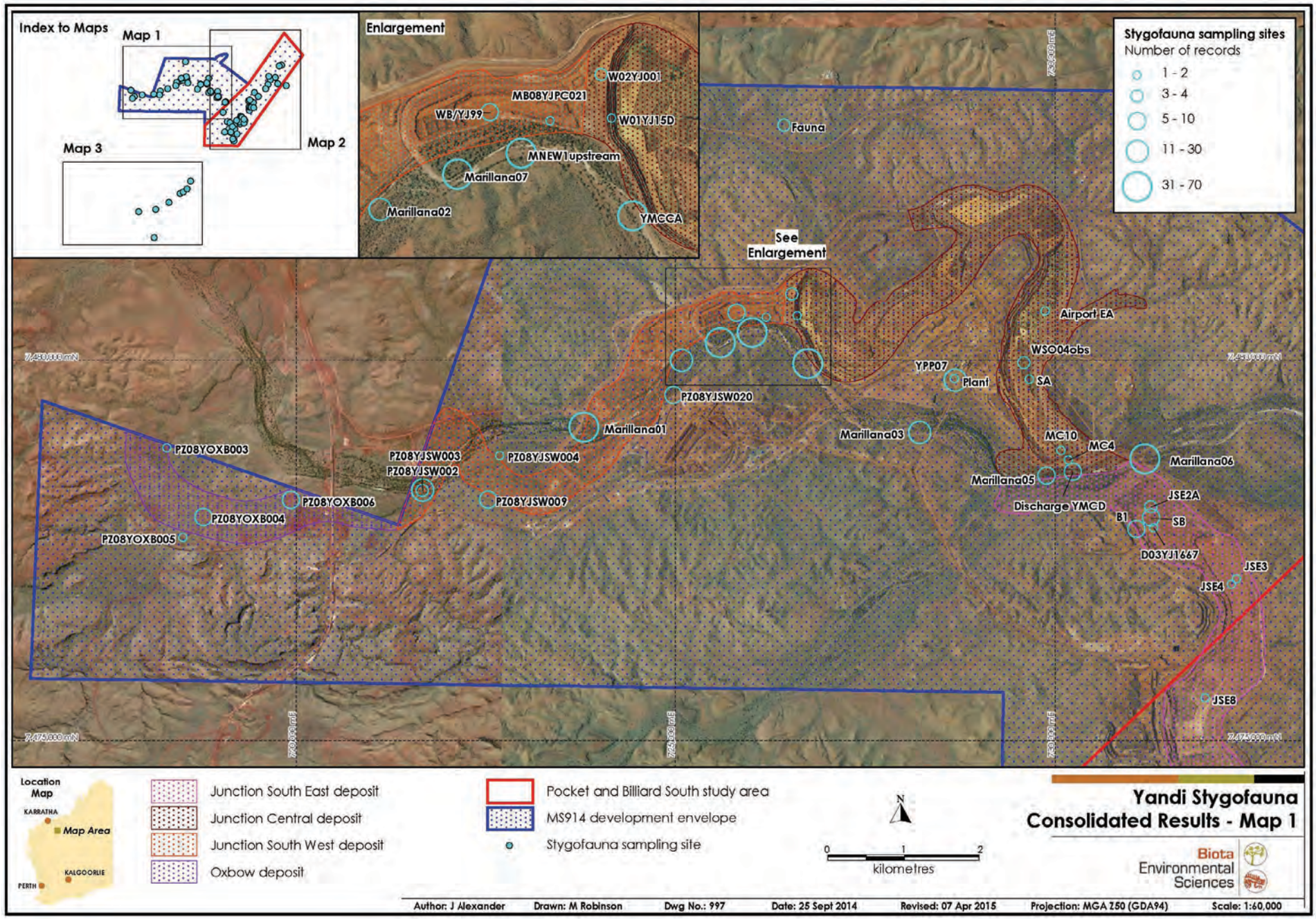

Figure 6.1: Number of species collected from each site during all phases of sampling – Map 1.

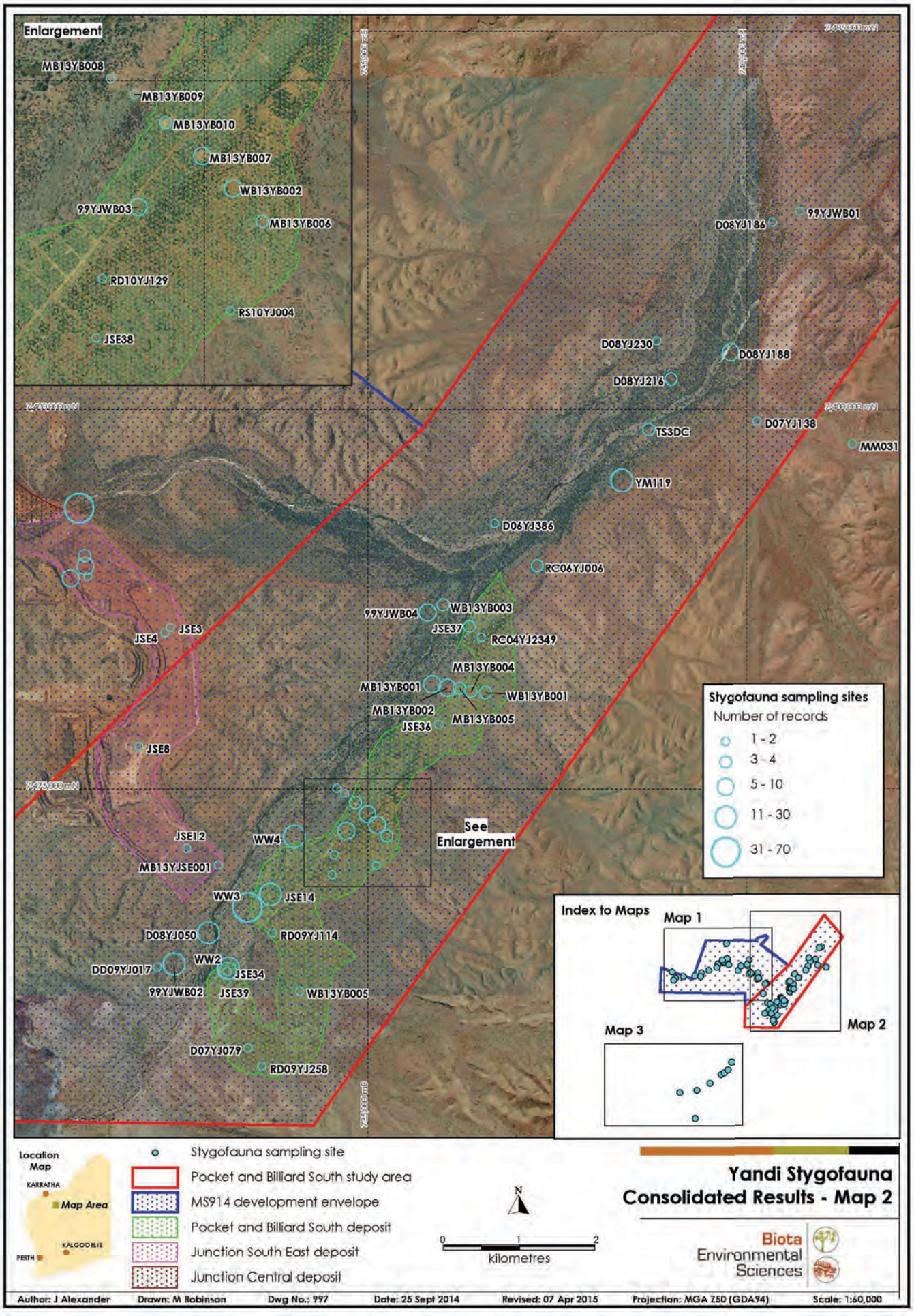

Figure 6.2: Number of species collected from each site during all phases of sampling – Map 2.

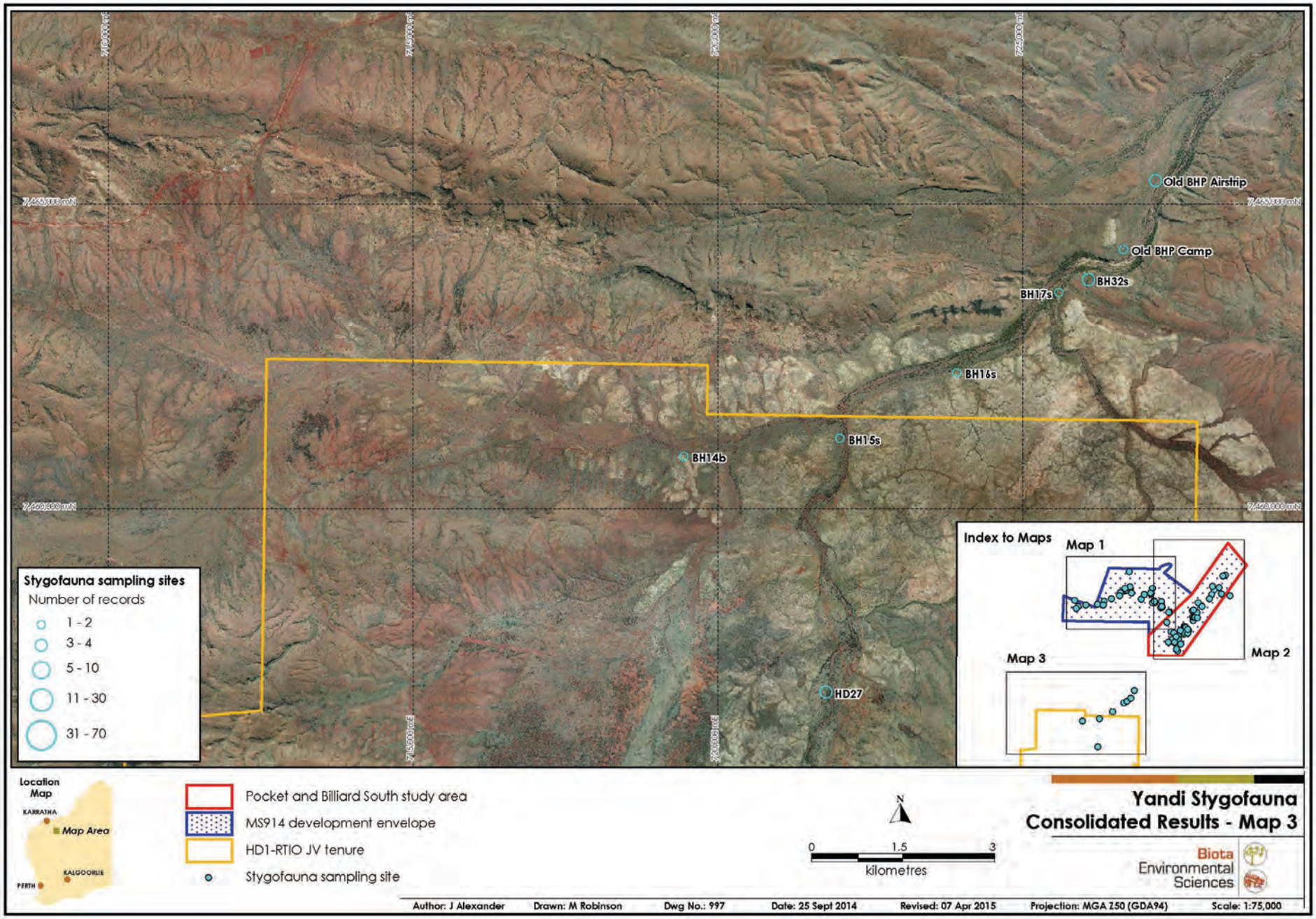

Figure 6.3: Number of species collected from each site during all phases of sampling – Map 3.

7.0 Glossary

cf.	For Latin *confer*, means "compare with". Identification is not confirmed, but is similar to a particular species.
CID	Channel Iron Deposit.
COI	Mitochondrial cytochrome oxidase subunit I gene.
Cryptic	Two or more species hidden under one species name.
EPA	Environmental Protection Authority of Western Australia.
Epigean	Living or occurring on or near the surface of the ground.
Haplotype	A set of genetic determinants located on a single chromosome.
Lineage	Direct descent from a particular ancestor; ancestry. The descendants of a common ancestor considered to be the founder of the line.
Phylogenetic	Relating to or based on evolutionary development or history.
Stygofauna	Obligate groundwater fauna.
Taxon (plural: taxa)	A taxonomic entity; typically at species level or below.
Taxonomy	Theory and practice of biological classification.
Vermiform	Resembling or having the shape of a worm

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Appendix 1

Helix Genetic Analysis Reports

Helix
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Solutions

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29 July, 2014

Via email

Re. Report on the molecular systematics of Amphipoda from the Yandi Billiards region

Dear Dan,

Following is a summary of the results of the Amphipoda study we have completed. Owing to the observed level of sequence divergence between lineages and comparison to reference sequences, it is likely that there are six species of Paramelitidae in your collections. Five of those species have been detected or described previously at Mindy-Coondiner and Marillana and Weeli Wolli Creeks, whereas one appears to be new, based on the material available for comparison.

Sincerely,

Dr. Terrie Finston and Dr. Oliver Berry
Helix Molecular Solutions

Background

The groundwater amphipod fauna of Western Australia is diverse. Since 1995, 27 species of amphipods have been described from north-western Western Australia, including the Pilbara and nearby Barrow Island and Cape Range Peninsula (Barnard and Williams 1995; Bradbury and Williams 1996, 1997a; Bradbury 2000; Finston *et al*., 2008). The majority of these species (19) belong to the family Paramelitidae. Extensive molecular work has been conducted on the amphipod fauna of Western Australia (Helix, 2011). The resulting dataset provides a molecular framework that can be used to provide a regional context for localised sampling. The present study concerns 91 specimens of Amphipoda belonging to the Paramelitidae from the Yandi Billiards site in the Pilbara.

Objective

Ninety-one specimens of Paramelitidae from the Yandi Billiards site in the Pilbara were sequenced for variation at the mitochondrial gene COI. The specimens were compared to reference sequences of Paramelitidae from the Pilbara to estimate the number of species in the collection and determine the relationships of the new samples to specimens previously collected in the Pilbara.

Executive summary

- Ninety-one specimens of Paramelitidae from the Yandi Billiards site in the Pilbara were sequenced for variation at the mitochondrial gene COI.
- Eighty-eight of the 91 specimens yielded a COI sequence.
- A neighbour-joining analysis, which included the 88 specimens analysed here, revealed the presence of six distinct genetic lineages, which represent six species.
- A representative of each species was included in a second phylogenetic analysis, which included 43 reference specimens of Paramelitidae from sites in the Pilbara and voucher sequences of Paramelitidae from the international DNA sequence database GenBank.
- Five of the six species have been detected or described previously at Mindy-Coondiner and Marillana and Weeli Wolli Creeks, whereas one appears to be new, based on the material available for comparison.

Methods

Ninety-one specimens of Paramelitidae from Yandi Billiards in the Pilbara were sequenced for variation at the mitochondrial gene cytochrome oxidase subunit I (COI; Table 1). Primers LCO1490 and HCO2198 (Folmer et al., 1994) were used to amplify a ~700 bp fragment of COI.

Sequences were edited using SEQUENCHER software (Gene Codes Corporation, Ann Arbor, MI, USA). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. To test that the amplified sequences were the target mtDNA, sequences were translated into proteins and checked for the presence of stop codons. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotides different between sequences). To account for polymorphism within lineages, the net genetic diversity of Nei (1987) was calculated to give a 'corrected' distance between lineages.

To reduce analysis time, a preliminary neighbour-joining analysis was run to identify the number of distinct genetic lineages among the 91 specimens. One specimen from each of the lineages was included in a second model-based phylogenetic analysis, which included 43 reference specimens of Paramelitidae from sites in the Pilbara outside the study area and voucher sequences of Paramelitidae from the international DNA sequence database Genbank.

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data. Bayesian analysis was used to construct the phylogenetic tree, incorporating the General Time Reversible (GTR+G) model as identified in MODELTEST. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after

discarding the first 5000 ("burn-in") trees. The burn-in value was assessed by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded. Forty-three specimens of Paramelitidae from the PIlbara were included in the phylogenetic analysis as references, eight of which are lodged with the international DNA sequence database Genbank as follows: *Maarrka etheli* (Genbank accession # DQ838031), *Maarrka weeliwollii* (Genbank accession # DQ838032), *Yilgarus* sp. BES9348 (Genbank accession #EF118228), *Kruptus linnaei* (Genbank accession # GU111906), *Molina pleobranchos* (Genbank accession #DQ255962), *Chydaekata* sp. Marillana (Genbank accession # DQ255989), *Pilbarus millsi* (Genbank accession # DQ490126), *Chydaekata acuminata* (Genbank accession # DQ838024). The remaining 35 specimens were detected in previous surveys of the Pilbara (Helix, 2011). Two species from the Isopoda family Tainisopidae, *Pygolabis paraburdoo* (Genbank accession # EU107628) and *Pygolabis weeliwolli* (Genbank accession # EU107618) were used as outgroups.

Results

Eighty-eight of the 91 specimens yielded a 630 to 716 bp fragment of COI (Table 1). The neighbour-joining analysis revealed the presence of six distinct genetic lineages (YB1 – YB6; Figure 1). The six lineages contained between two and 46 specimens (Table 1; Figure 1).Variation within the six lineages was low, averaging between 0.1 and 0.4% sequence divergence (Table 2). The six lineages differed by between 9.3 and 21.7% mean sequence divergence (Table 3).

A representative from each of the six lineages detected at Yandi Billiards was included in a model-based phylogenetic analysis with the 43 reference specimens. Five of the six representatives from Yandi Billiards were placed in lineages containing reference sequences from Mindy-Coondiner, Marillana and Weeli Wolli Creeks (Figure 2). Specifically, specimen GK56 (representing lineage YB1) was placed in a lineage containing specimen AM9 (Paramelitidae sp. 2C-WW), collected during a previous survey at Weeli Wolli Creek and specimen H28 from Marillana Creek (Figure 2). Specimen GK62 (representing lineage YB2) was placed in a lineage with reference specimen H8 (Paramelitidae sp. H8) from Marillana Creek (Figure 2). Specimen GK91 (representing lineage YB4) was placed in a lineage containing the reference specimen of *Maarrka weeliwolliii* from Weeli Wolli Creek (Figure 2). This species is also known from Marillana Creek (Finston et al., 2011). Specimen GK24 (representing lineage YB5) was placed in a lineage containing specimen G267 (Paramelitidae sp. MC1) from Mindy-Coondiner and specimen G265 (*Maarka* sp MA1) from Marillana Creek (Figure 2). Specimen GK48 (representing lineage YB6) was placed in a lineage with the reference specimen of *Chydaekata sp.* E from Marillana Creek (Figure 2). This species is also known from Weeli Wolli Creek (Finston et al., 2007).

The five specimens that matched reference sequences differed from their nearest reference sequence by between 0.3 and 1.6% sequence divergence (Figure 2; Table 4). The sixth specimen, which showed no close relationship to any of the reference sequences, differed from the reference sequences by between 14.1 and 25.4% sequence divergence (Table 4).

Conclusions

COI is considered by some authors to be a suitable gene for species delineation (Hebert *et al*., 2003a). Based on comparisons between over 1700 crustacean species, Hebert *et al* (2003b) found an average of 15.4 % sequence divergence between species pairs, with nearly 82% of pair-wise comparisons showing greater than 8% sequence divergence. Similar to the Hebert *et al*. (2003b) results, Bradford *et al* (2010) found 11-13% sequence divergence among three lineages of the Amphipoda family Chiltonidae in a single calcrete in the Yilgarn. Reproductive isolation between lineages was confirmed with nuclear (allozyme) markers, indicating that each lineage represented a distinct species.

Owing to the high level of sequence divergence between the six observed lineages in the Yandi Billiards collection (9.3 to 21.7%), it is likely that there are at six species present. Five of the six lineages showed close genetic relationships to reference specimens (0.3 to 1.6% sequence divergence), indicating that they belong to those species. The five were detected previously at Mindy-Coondiner, Marillana and Weeli Wolli Creeks. The sixth species showed no close

relationship to any of the reference sequences and is likely to represent a new species. The six species present at Yandi Billiards are as follows:

1. lineage YB1 =Paramelitidae sp. WW-2C; previously detected at Marillana and Weeli Wolli Creeks
2. lineage YB2 =Paramelitidae sp. H8; previously detected at Marillana Creek
3. lineage YB3 =new
4. lineage YB4 =*Maarka weeliwollii*; previously detected at Marillana and Weeli Wolli Creeks
5. lineage YB5 =Paramelitidae sp. MC1/*Maarka* sp. MA1; previously detected at Mindy-Coondiner and Marillana Creek.
6. lineage YB6 =*Chydaekata sp. E*; previously detected at Marillana and Weeli Wolli Creeks

Further explanation is required for the identification of lineage YB5. The reference specimens to which YB5 was most closely matched (reference specimen G265 from Marillana Creek and G267 from Mindy-Coondiner) were identified on the basis of morphology as Paramelitidae sp. and *Maarka* sp, respectively. As these three specimens cluster with other reference specimens of *Maarka*, they are likely to belong to this genus.

In summary, six species of Paramelitidae were detected at Yandi Billiards. Five of the species (lineages YB1, YB2, YB4 – YB6) have been described or recorded previously, whereas one (lineage YB3) appears to be unrecorded based on the material available for comparison.

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Table 1. Specimens of Amphipoda used in the present study and the genetic lineage in which they were placed based on a neighbour-joining phylogenetic analysis. ND=no data.

Tracking_number	Cap Number	Helix ID	Lineage/species
MB13YB002-180514-03	Cap 7	GK1	YB6/Chydaekata sp. E
MB13YB002-180514-03	Cap 7	GK2	YB6/Chydaekata sp. E
MB13YB002-180514-03	Cap 7	GK3	YB3/new species
MB13YB002-180514-03	Cap 7	GK4	YB3/new species
MB13YB002-180514-03	Cap 7	GK5	YB3/new species
MB13YB002-180514-03	Cap 7	GK6	YB3/new species
MB13YB002-180514-03	Cap 7	GK7	YB3/new species
MB13YB002-180514-03	Cap 7	GK8	YB6/Chydaekata sp. E
MB13YB005-180514-01	Cap 14	GK9	YB6/Chydaekata sp. E
MB13YB005-180514-01	Cap 14	GK10	YB6/Chydaekata sp. E
MB13YB005-180514-01	Cap 14	GK11	YB1/Paramelitidae sp. WW-2C
MB13YB005-180514-01	Cap 14	GK12	YB6/Chydaekata sp. E
WB13YB001-180514-02	Cap 18	GK13	YB6/Chydaekata sp. E
WB13YB001-180514-02	Cap 18	GK14	YB6/Chydaekata sp. E
WB13YB001-180514-02	Cap 18	GK15	ND
WB13YB001-180514-02	Cap 18	GK16	YB1/Paramelitidae sp. WW-2C
MB13YB001-180514-01	Cap 1	GK17	YB4/Maarka weeliwollii
MB13YB001-180514-01	Cap 1	GK18	YB6/Chydaekata sp. E
MB13YB001-180514-01	Cap 1	GK19	YB6/Chydaekata sp. E
MB13YB001-180514-01	Cap 1	GK20	YB1/Paramelitidae sp. WW-2C
MB13YB001-180514-01	Cap 1	GK21	YB1/Paramelitidae sp. WW-2C
MB13YB010-180514-02	Cap 12	GK22	YB6/Chydaekata sp. E
MB13YB010-180514-02	Cap 12	GK23	YB6/Chydaekata sp. E
MB13YB010-180514-02	Cap 12	GK24	YB5/Paramelitidae MC1/Maarka sp. MA1
WB13YB003-190514-03	Cap 21	GK25	YB1/Paramelitidae sp. WW-2C
MB13YB007-200514-02	Cap 63	GK26	YB1/Paramelitidae sp. WW-2C
MB13YB007-200514-02	Cap 63	GK27	ND
MB13YB007-200514-02	Cap 63	GK28	YB3/new species
MB13YB007-200514-02	Cap 63	GK29	YB6/Chydaekata sp. E
WB13YB002-190514-02	Cap 41	GK30	YB6/Chydaekata sp. E
WB13YB002-190514-02	Cap 41	GK31	YB6/Chydaekata sp. E
WB13YB002-190514-02	Cap 41	GK32	YB6/Chydaekata sp. E
WB13YB002-190514-02	Cap 41	GK33	YB6/Chydaekata sp. E
WB13YB005-190514-01	Cap 37	GK34	YB1/Paramelitidae sp. WW-2C
WB13YB005-190514-01	Cap 37	GK35	YB1/Paramelitidae sp. WW-2C
WB13YB005-190514-01	Cap 37	GK36	YB1/Paramelitidae sp. WW-2C
WB13YB005-190514-01	Cap 37	GK37	YB6/Chydaekata sp. E
JSE39-190514-03	Cap 32	GK38	YB5/Paramelitidae MC1/Maarka sp. MA1
D07YJ079-190514-02	Cap 39	GK39	YB6/Chydaekata sp. E

MB13YB006-190514-03	Cap 35	GK40	YB3/new species
99YJWB02-200514-01	Cap 48	GK41	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK42	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK43	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK44	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK45	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK46	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK47	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK48	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK49	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK50	YB6/Chydaekata sp. E
99YJWB02-200514-01	Cap 48	GK51	YB6/Chydaekata sp. E
YM119-200514-02	Cap 60	GK52	YB6/Chydaekata sp. E
YM119-200514-02	Cap 60	GK53	YB6/Chydaekata sp. E
YM119-200514-02	Cap 60	GK54	YB6/Chydaekata sp. E
YM119-200514-02	Cap 60	GK55	YB1/Paramelitidae sp. WW-2C
YM119-200514-02	Cap 60	GK56	YB1/Paramelitidae sp. WW-2C
YM119-200514-02	Cap 60	GK57	YB1/Paramelitidae sp. WW-2C
D08YJ216-200514-03	Cap 68	GK58	ND
D08YJ188-200514-01	Cap 52	GK59	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK60	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK61	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK62	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK63	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK64	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK65	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK66	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK67	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK68	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK69	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK70	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK71	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK72	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK73	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK74	YB2/Paramelitidae sp. H8
D08YJ188-200514-01	Cap 52	GK75	YB6/Chydaekata sp. E
RC06YJ006P1-3	12	GK76	YB1/Paramelitidae sp. WW-2C
RD10YJ129P1-1	8	GK77	YB6/Chydaekata sp. E
RD10YJ129P1-1	8	GK78	YB6/Chydaekata sp. E
RS10YJ004P1-1	7	GK79	YB6/Chydaekata sp. E
TS3DCP1-1	3	GK80	YB1/Paramelitidae sp. WW-2C
TS3DCP1-1	3	GK81	YB6/Chydaekata sp. E
TS3DCP1-1	3	GK82	YB1/Paramelitidae sp. WW-2C
TS3DCP1-1	3	GK83	YB1/Paramelitidae sp. WW-2C
TS3DCP1-1	3	GK84	YB1/Paramelitidae sp. WW-2C

RD09YJ258P1-1	2	GK85	YB6/Chydaekata sp. E
RC06YJ006P1-4	13	GK86	YB6/Chydaekata sp. E
TS3DCP1-2	4	GK87	YB6/Chydaekata sp. E
TS3DCP1-2	4	GK88	YB6/Chydaekata sp. E
99YJWB03P1-1	6	GK89	YB5/Paramelitidae MC1/Maarka sp. MA1
RC06YJ006P1-5	14	GK90	YB6/Chydaekata sp. E
TS3DCP1-3	5	GK91	YB4/Maarka weeliwollii

Table 2. Mean sequence divergence and standard error (s.e.) between individuals within the six lineages detected in the Yandi Billiards specimens.

Lineage	Distance	s.e.
YB1	0.004	0.002
YB2	0.004	0.001
YB3	0.001	0.001
YB4	0.002	0.002
YB5	0.002	0.001
YB6	0.002	0.001

Table 3. Mean sequence divergence (below diagonal) and standard error (above diagonal) between the six lineages detected in the Yandi Billiards specimens.

Lineage	YB1	YB2	YB3	YB4	YB5	YB6
YB1		0.011	0.011	0.015	0.015	0.017
YB2	0.093		0.012	0.015	0.013	0.016
YB3	0.157	0.137		0.014	0.013	0.015
YB4	0.191	0.202	0.196		0.012	0.015
YB5	0.195	0.191	0.201	0.122		0.015
YB6	0.210	0.205	0.205	0.217	0.199	

Table 4 (attached). Pair-wise sequence divergence (below diagonal) and standard error (above diagonal) between all specimens used in the model-based phylogenetic analysis shown in Figure 2. Distances between the six lineages detected at Yandi Billiards and the reference specimens are highlighted in yellow.

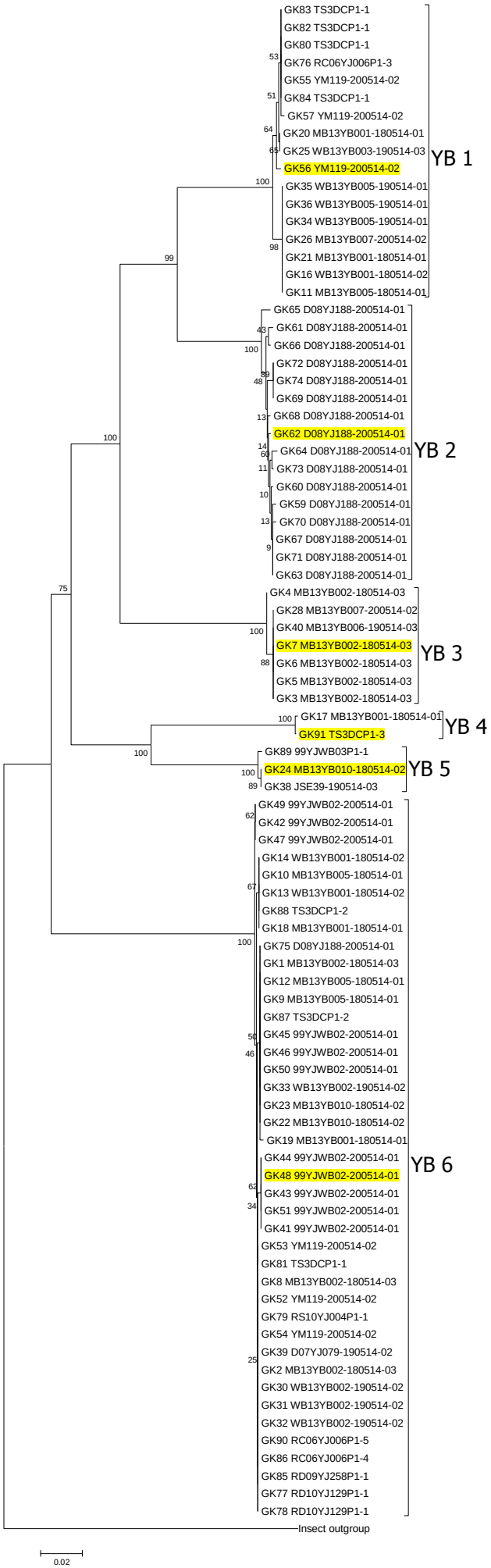
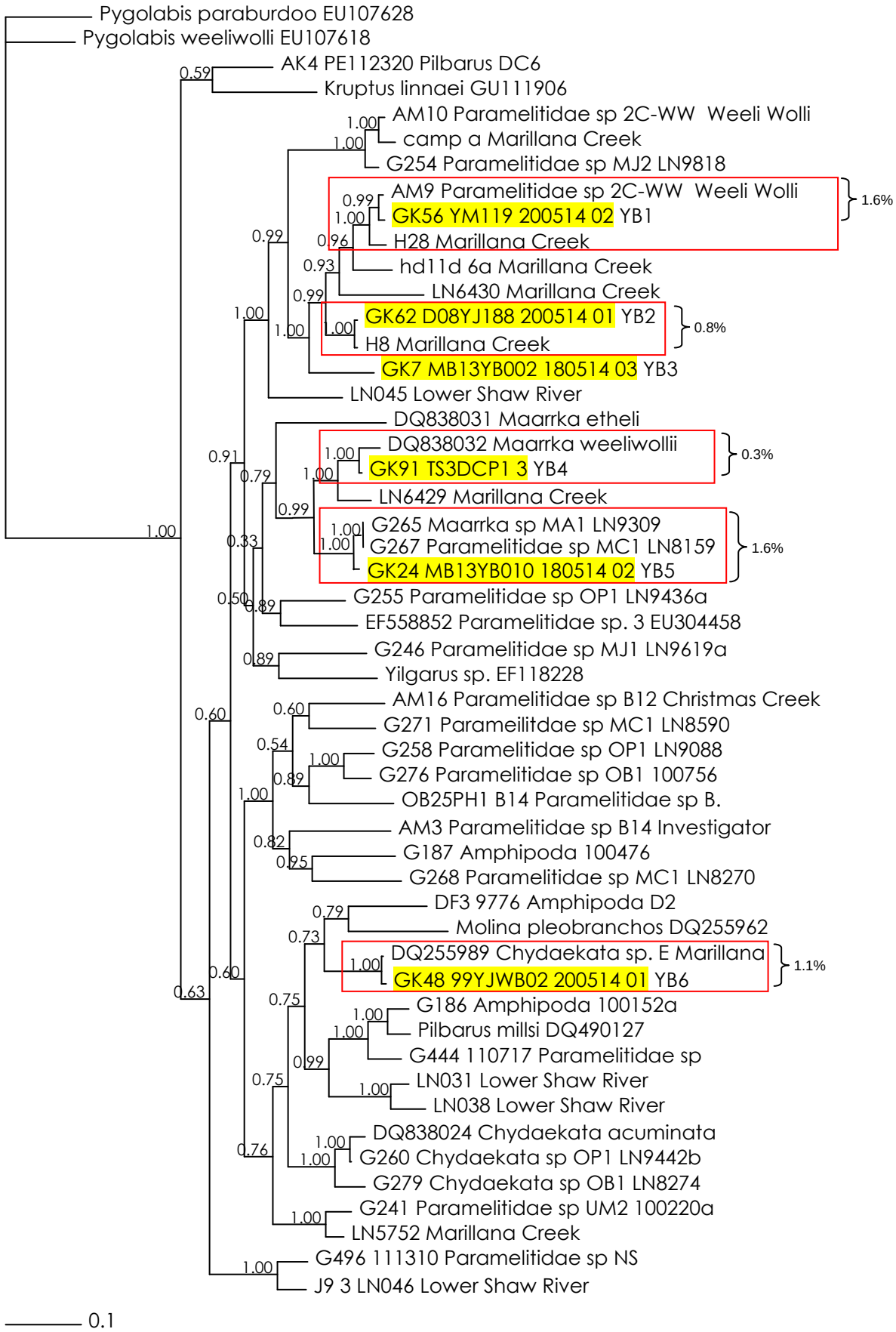


Figure 1. Neighbour-joining analysis of 91 specimens of Amphipoda from Yandi Billiards. Numbers on nodes represent bootstrap support over 100 iterations. The six lineages are labelled YB1 – YB6. Specimens selected to represent each lineage is highlighted in yellow.

Figure 2. Bayesian analysis of COXI haplotypes of Paramelitidae. Numbers on major nodes correspond to posterior probabilities. Specimens from the present study are highlighted in yellow; Scale bar= number of substitutions per site. Red boxes enclose the species detected in the present study. Distances between the Yandi Billiards specimens and the nearest reference sequences are shown next to each pair.



Appendix 2

Collection data 2003 - 2014

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
1	Discharge	730236	7478532	Isopoda	*35*	*Pygolabis weeli wolli*	-	
1	Discharge	730236	7478532	Ostracoda	*2*	*Meridiescandona* sp.	-	
1	Discharge	730236	7478532	Ostracoda	*2*	*Pilbaracandona* sp.	-	
1	Discharge	730236	7478532	Platyhelminthes	5	Turbellaria	-	
1	Marillana01	723792	7479113	Ostracoda	*38*	*Meridiescandona* sp.	-	
1	Marillana01	723792	7479113	Platyhelminthes	5	Turbellaria	-	
1	Marillana02	725082	7479990	Amphipoda	*16*	*Chydaekata* sp.	-	Many juveniles amongst the specimens.
1	Marillana02	725082	7479990	Ostracoda	*47*	*Meridiescandona* sp.	-	
1	Marillana02	725082	7479990	Platyhelminthes	3	Turbellaria	-	
1	Marillana03	728209	7479045	Isopoda	*27*	*Pygolabis weeli wolli*	-	
1	Marillana05	729890	7478482	Isopoda	*11*	*Pygolabis* sp "Wilson Sp. 3"	-	
1	Marillana05	729890	7478482	Oligochaeta	12	*Ainudrilus* sp.	-	
1	Marillana05	729890	7478482	Ostracoda	*12*	*Gomphodella* sp.	-	
1	Marillana05	729890	7478482	Ostracoda	*4*	*Meridiescandona* sp.	-	
1	Marillana06	731182	7478693	Copepoda	*1*	*Mesocyclops darwini*	-	
1	Marillana06	731182	7478693	Hydracarina	*3*	*Recifella* sp. "Yandi"	-	Species level identifications yet to be completed
1	Marillana06	731182	7478693	Ostracoda	*2*	*Meridiescandona* sp.	-	
1	Marillana06	731182	7478693	Platyhelminthes	17	Turbellaria	-	
1	Marillana07	725592	7480218	Amphipoda	24	Paramelitidae sp. B02	-	
1	Marillana07	725592	7480218	Copepoda	*4*	*Diacyclops cockingi*	-	
1	Marillana07	725592	7480218	Hydracarina	1	Hydracarina indet.	-	
1	Marillana07	725592	7480218	Isopoda	*86*	*Pygolabis weeli wolli*	-	
1	Marillana07	725592	7480218	Oligochaeta	8	*Ainudrilus* sp.	-	
1	Marillana07	725592	7480218	Ostracoda	*2*	*Meridiescandona* sp.	-	
1	Marillana07	725592	7480218	Ostracoda	*7*	*Pilbaracandona* sp.	-	
1	Marillana07	725592	7480218	Platyhelminthes	71	Turbellaria	-	
1	MNEW1upstream	726009	7480355	Amphipoda	*1*	*Chydaekata* sp.	-	
1	MNEW1upstream	726009	7480355	Amphipoda	31	Paramelitidae sp. B02	-	
1	MNEW1upstream	726009	7480355	Copepoda	*2*	*Diacyclops* sp. indet.	-	Juveniles
1	MNEW1upstream	726009	7480355	Hydracarina	*1*	*Arrenurus* sp. nov. yandi (sp 1)	-	
1	MNEW1upstream	726009	7480355	Isopoda	*18*	*Pygolabis weeli wolli*	-	
1	MNEW1upstream	726009	7480355	Ostracoda	*33*	*Meridiescandona* sp.	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
1	MNEW1upstream	726009	7480355	Ostracoda	*2*	*Pilbaracandona* sp.	-	
1	MNEW1upstream	726009	7480355	Platyhelminthes	24	Turbellaria	-	
1	Plant	728677	7479732	Amphipoda	*1*	*Chydaekata* sp.	-	
1	Plant	728677	7479732	Hydracarina	1	Hydracarina indet.	-	
1	Plant	728677	7479732	Isopoda	*4*	*Pygolabis* sp. indet.	-	female and immature specimens only
1	Plant	728677	7479732	Oligochaeta	13	*Ainudrilus* sp.	-	
1	Plant	728677	7479732	Ostracoda	*1*	*Meridiescandona* sp.	-	
1	SB	731263	7477933	Copepoda	*19*	*Diacyclops* sp. indet.	-	
1	SB	731263	7477933	Isopoda	*6*	*Pygolabis* sp "Wilson Sp. 3"	-	
1	W01YJ15D	726605	7480589	Platyhelminthes	1	Turbellaria	-	
1	W02YJ001	726535	7480876	Amphipoda	1	Paramelitidae sp. indet.	-	damaged
1	W02YJ001	726535	7480876	Oligochaeta	10	*Ainudrilus* sp.	-	
1	W02YJ001	726535	7480876	Ostracoda	*5*	*Meridiescandona* sp.	-	
1	WB/YJ99	725805	7480628	Amphipoda	4	Paramelitidae sp. B02	-	
2	99YJWB02	732433	7472677	Isopoda	1	*Pygolabis weeli wolli*	-	female
2	99YJWB04	735790	7477323	Isopoda	1	*Pygolabis weeli wolli*	-	subadult male
2	Airport	729874	7480651	Isopoda	1	*Pygolabis weeli wolli*	-	female
2	D03YJ1667	731298	7477800	Isopoda	1	Armadillidae	-	fragments, not troglobitic
2	Discharge	730236	7478532	Hydracarina	1	*Recifella* sp. "Yandi"	-	male
2	Discharge	730236	7478532	Isopoda	5	*Pygolabis weeli wolli*	-	subadult male, female and juvs
2	Discharge	730236	7478532	Ostracoda	6	*Meridiescandona facies*	-	
2	Discharge	730236	7478532	Ostracoda	35	*Notacandona boultoni*	-	
2	Discharge	730236	7478532	Platyhelminthes	26	Indeterminate	-	
2	Fauna	726431	7483093	Ostracoda	1	*Meridiescandona facies*	-	
2	JSE12	732608	7474217	Amphipoda	1	*Chydaekata* sp.	-	
2	JSE14	733707	7473602	Ostracoda	1	*Meridiescandona facies*	-	
2	JSE2A	731262	7478074	Amphipoda	1	*Chydaekata* sp.	-	
2	JSE2A	731262	7478074	Amphipoda	7	Paramelitidae sp. B02	-	
2	JSE2A	731262	7478074	Isopoda	2	*Pygolabis weeli wolli*	-	male and female
2	JSE3	732386	7477126	Hydracarina	2	*Recifella* sp. "Yandi"	-	male and female
2	JSE4	732318	7477053	Ostracoda	42	*Meridiescandona marillanae*	-	
2	JSE8	731975	7475552	Ostracoda	1	*Meridiescandona facies*	-	
2	Marillana03	728209	7479045	Isopoda	9	*Pygolabis weeli wolli*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
2	Marillana05	729890	7478482	Hydracarina	1	*Recifella* sp. "Yandi"	-	female
2	Marillana05	729890	7478482	Isopoda	1	*Pygolabis weeli wolli*	-	male
2	Marillana05	729890	7478482	Ostracoda	1	*Gomphodella alexanderi*	-	
2	Marillana05	729890	7478482	Ostracoda	24	*Meridiescandona facies*	-	
2	Marillana06	731182	7478693	Copepoda	2	*Diacyclops cockingi*	-	
2	Marillana06	731182	7478693	Copepoda	1	*Mesocyclops darwini*	-	
2	Marillana06	731182	7478693	Hydracarina	7	*Recifella* sp. "Yandi"	-	
2	Marillana06	731182	7478693	Hydracarina	10	*Stygolimnochares* sp. B1	-	
2	Marillana06	731182	7478693	Ostracoda	1	coleoptera	-	no head or legs
2	Marillana06	731182	7478693	Ostracoda	3	*Gomphodella alexanderi*	-	Calling it sp. BOS200 - undescribed featureless species
2	Marillana06	731182	7478693	Ostracoda	1	*Meridiescandona facies*	-	
2	Marillana06	731182	7478693	Ostracoda	1	*Meridiescandona facies*	-	valve
2	Marillana06	731182	7478693	Ostracoda	2	*Notacandona boultoni*	-	valve
2	Marillana06	731182	7478693	Ostracoda	28	*Notacandona boultoni*	-	
2	Marillana06	731182	7478693	Platyhelminthes	14	Indeterminate	-	
2	Marillana07	725592	7480218	Hydracarina	1	*Arrenurus* sp. nov. yandi (sp 1)	-	
2	MNEW1upstream	726009	7480355	Copepoda	3	*Diacyclops cockingi*	-	
2	MNEW1upstream	726009	7480355	Hydracarina	1	*Arrenurus* sp. nov. yandi (sp 1)	-	female
2	Plant	728677	7479732	Isopoda	2	*Pygolabis weeli wolli*	-	male and female
2	SA	729664	7479749	Bathynellacea	40	*Atopobathynella* sp.	-	
2	SB	731263	7477933	Copepoda	1	*Diacyclops cockingi*	-	
2	SB	731263	7477933	Isopoda	2	*Pygolabis weeli wolli*	-	males
2	SB	731263	7477933	Ostracoda	1	*Meridiescandona marillanae*	-	
2	W01YJ15D	726605	7480589	Copepoda	1	*Metacyclops pilbaricus*	-	
2	W02YJ001	726535	7480876	Ostracoda	35	*Meridiescandona facies*	-	
3	Fauna	726431	7483093	Isopoda	1	*Pygolabis weeli wolli*	-	female
3	Marillana01	723792	7479113	Amphipoda	7	*Chydaekata* sp.	-	(1 gravid female)
3	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
3	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	Lineage YB6	
3	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	Lineage YB6	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
3	Marillana01	723792	7479113	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
3	Marillana01	723792	7479113	Hydracarina	2	Hydracarina sp	-	juveniles with eyes
3	Marillana01	723792	7479113	Hydracarina	3	*Recifella* sp. "Yandi"	-	
3	Marillana01	723792	7479113	Isopoda	1	Pygolabis sp.	-	juvenile
3	Marillana01	723792	7479113	Ostracoda	8	*Gomphodella alexanderi*	-	
3	Marillana01	723792	7479113	Ostracoda	30	*Meridiescandona facies*	-	
3	Marillana01	723792	7479113	Ostracoda	6	*Notacandona boultoni*	-	
3	Marillana01	723792	7479113	Platyhelminthes	16	Indeterminate	-	Specimens at Biota
3	Marillana02	725082	7479990	Amphipoda	1	*Chydaekata* sp.	-	
3	Marillana02	725082	7479990	Copepoda	1	*Australocamptus* sp.	-	female not like any formally described WA sp
3	Marillana02	725082	7479990	Copepoda	1	Diacyclops sp	-	juv
3	Marillana02	725082	7479990	Oligochaeta	3	Enchytraeidae Pilbara sp 2 (DEC code)	-	
3	Marillana02	725082	7479990	Ostracoda	23	*Meridiescandona facies*	-	
3	Marillana06	731182	7478693	Amphipoda	3	Paramelitidae sp. B02	-	
3	Marillana06	731182	7478693	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
3	Marillana06	731182	7478693	Hydracarina	1	Mideopsinae sp. (nr Penemidopsis)	-	whole animal on slide with palps
3	Marillana06	731182	7478693	Isopoda	1	Pygolabis sp.	-	juvenile
3	Marillana06	731182	7478693	Oligochaeta	2	*Bezzia* sp.	-	not oligochaete, ceratopogonidae. Not stygal
3	Marillana06	731182	7478693	Ostracoda	1	*Gomphodella hirsuta*	-	
3	Marillana06	731182	7478693	Ostracoda	1	*Notacandona boultoni*	-	
3	Marillana06	731182	7478693	Platyhelminthes	7	Indeterminate	-	
3	Marillana07	725592	7480218	Amphipoda	4	*Chydaekata* sp.	-	
3	Marillana07	725592	7480218	Amphipoda	1	*Maarrka weeliwolli*	-	Damaged
3	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
3	Marillana07	725592	7480218	Copepoda	2	cyclopoida	-	juveniles
3	Marillana07	725592	7480218	Hydracarina	1	*Recifella* sp. "Yandi"	-	
3	Marillana07	725592	7480218	Isopoda	1	Pygolabis sp.	-	juvenile
3	Marillana07	725592	7480218	Ostracoda	2	*Gomphodella hirsuta*	-	valves, warts at base of hairs obvious
3	Marillana07	725592	7480218	Ostracoda	14	*Meridiescandona facies*	-	
3	Marillana07	725592	7480218	Ostracoda	34	*Notacandona boultoni*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
3	Marillana07	725592	7480218	Platyhelminthes	3	Indeterminate	-	
3	MNEW1upstream	726009	7480355	Amphipoda	4	*Chydaekata* sp.	-	
3	MNEW1upstream	726009	7480355	Amphipoda	2	*Maarrka weeliwolli*	-	
3	MNEW1upstream	726009	7480355	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
3	MNEW1upstream	726009	7480355	Hydracarina	1	*Recifella* sp. "Yandi"	-	
3	MNEW1upstream	726009	7480355	Isopoda	4	Pygolabis sp.	-	juvenile
3	MNEW1upstream	726009	7480355	Ostracoda	3	*Gomphodella alexanderi*	-	some valves present that may be G hirsuta or juv G yandi
3	MNEW1upstream	726009	7480355	Ostracoda	56	*Notacandona boultoni*	-	
3	MNEW1upstream	726009	7480355	Platyhelminthes	12	Indeterminate	-	
3	Plant	728677	7479732	Amphipoda	7	*Chydaekata* sp.	-	
3	Plant	728677	7479732	Amphipoda	1	*Maarrka weeliwolli*	-	
3	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
3	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
3	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
3	Plant	728677	7479732	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
3	Plant	728677	7479732	Isopoda	1	*Pygolabis weeli wolli*	-	female
3	Plant	728677	7479732	Ostracoda	4	*Meridiescandona facies*	-	
3	Plant	728677	7479732	Ostracoda	8	*Notacandona boultoni*	-	
3	WSO04obs	729595	7479968	Amphipoda	2	*Chydaekata* sp.	-	
3	WSO04obs	729595	7479968	Copepoda	1	Canthocamptidae sp	-	juvenile
3	WSO04obs	729595	7479968	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
3	WSO04obs	729595	7479968	Isopoda	20	*Pygolabis weeli wolli*	-	males and females
3	WW2	733149	7472618	Amphipoda	3	*Chydaekata* sp.	-	
3	WW3	733405	7473428	Amphipoda	4	Paramelitidae sp. B02	-	
3	WW3	733405	7473428	Copepoda	1	Canthoacmptidae (nr australocamptus sp.)	-	female
3	WW3	733405	7473428	Copepoda	43	*Diacyclops humphreysi humphreysi*	-	
3	WW3	733405	7473428	Isopoda	9	*Pygolabis weeli wolli*	-	males and females
3	WW3	733405	7473428	Nematoda	1	Indeterminate	-	Specimens at Biota
3	WW3	733405	7473428	Ostracoda	1	*Gomphodella hirsuta*	-	
3	WW3	733405	7473428	Ostracoda	4	*Mediescandona marillana*	-	no males and may be within

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
								the variation of M facies
3	WW3	733405	7473428	Ostracoda	12	*Meridiescandona facies*	-	
3	WW4	734018	7474365	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
3	WW4	734018	7474365	Ostracoda	5	*Meridiescandona facies*	-	
4	99YJWB02	732433	7472677	Amphipoda	6	*Chydaekata* sp.	-	
4	99YJWB02	732433	7472677	Amphipoda	2	Paramelitidae sp.	-	
4	99YJWB02	732433	7472677	Amphipoda	1	Paramelitidae sp. B02	-	
4	99YJWB03	734711	7474442	Amphipoda	1	*Chydaekata* sp.	-	
4	99YJWB03	734711	7474442	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
4	99YJWB03	734711	7474442	Ostracoda	1	*Areacandona mulgae*	-	female
4	99YJWB04	735790	7477323	Copepoda	7	*Diacyclops humphreysi humphreysi*	-	
4	99YJWB04	735790	7477323	Copepoda	5	*Gordonitocrella trajani*	-	
4	D03YJ1667	731298	7477800	Copepoda	50	*Diacyclops humphreysi humphreysi*	-	
4	JSE14	733707	7473602	Amphipoda	1	*Chydaekata* sp.	-	
4	JSE14	733707	7473602	Amphipoda	1	Paramelitidae sp.	-	juvenile
4	JSE14	733707	7473602	Amphipoda	3	Paramelitidae sp. B02	-	
4	JSE14	733707	7473602	Bathynellacea	1	*Notacandona boultoni*	-	small, mature dissected on slide
4	JSE14	733707	7473602	Copepoda	1	Canthocamptidae sp. B01	-	
4	JSE14	733707	7473602	Copepoda	17	*Diacyclops humphreysi humphreysi*	-	
4	JSE14	733707	7473602	Copepoda	8	*Gordonitocrella trajani*	-	
4	JSE14	733707	7473602	Isopoda	1	Pygolabis sp.	-	female
4	JSE14	733707	7473602	Ostracoda	2	*Meridiescandona facies*	-	
4	JSE14	733707	7473602	Ostracoda	26	*Notacandona boultoni*	-	
4	JSE36	735937	7475846	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
4	JSE37	736346	7477140	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
4	JSE39	733145	7472585	Amphipoda	1	*Chydaekata* sp.	-	
4	JSE39	733145	7472585	Amphipoda	2	Paramelitidae sp. B02	-	
4	JSE39	733145	7472585	Copepoda	23	*Diacyclops humphreysi humphreysi*	-	
4	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	-	
4	Marillana01	723792	7479113	Copepoda	21	*Diacyclops humphreysi humphreysi*	-	
4	Marillana01	723792	7479113	Ostracoda	1	*Gomphodella alexanderi*	-	
4	Marillana01	723792	7479113	Ostracoda	90	*Meridiescandona facies*	-	all female, shell correct
4	Marillana01	723792	7479113	Platyhelminthes	2	Turbellaria	-	
4	Marillana03	728209	7479045	Amphipoda	1	Paramelitidae sp. B02	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
4	Marillana03	728209	7479045	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
4	Marillana03	728209	7479045	Hydracarina	1	Hydracarina	-	1 deuteronymph with eyes not stygal
4	Marillana03	728209	7479045	Ostracoda	2	*Meridiescandona facies*	-	in mite vial, males, dissected, soft part match, shell reticulated as well as spotted
4	Marillana06	731182	7478693	Amphipoda	2	Paramelitidae sp. B02	-	
4	Marillana06	731182	7478693	Amphipoda	2	Paramelitidae sp. B02	-	
4	Marillana06	731182	7478693	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
4	Marillana06	731182	7478693	Copepoda	1	*Mesocyclops darwini*	-	
4	Marillana06	731182	7478693	Hydracarina	1	*Axonopsella* sp B1	-	
4	Marillana06	731182	7478693	Isopoda	2	Paramelitidae sp. B02	-	labled as isopod
4	Marillana06	731182	7478693	Ostracoda	5	*Meridiescandona facies*	-	male dissected
4	Marillana06	731182	7478693	Ostracoda	3	*Notacandona boultoni*	-	
4	Marillana06	731182	7478693	Platyhelminthes	2	Turbellaria	-	
4	Marillana07	725592	7480218	Amphipoda	10	*Chydaekata* sp.	-	
4	Marillana07	725592	7480218	Copepoda	1	Canthocamptidae sp. B01	-	male
4	Marillana07	725592	7480218	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
4	Marillana07	725592	7480218	Hydracarina	2	*Axonopsella* sp B1	-	
4	Marillana07	725592	7480218	Ostracoda	60	*Meridiescandona facies*	-	facies shell and CB2 absent, marillana hemipenis
4	Marillana07	725592	7480218	Ostracoda	40	*Notacandona boultoni*	-	
4	Marillana07	725592	7480218	Platyhelminthes	6	Turbellaria	-	
4	MNEW1upstream	726009	7480355	Amphipoda	4	*Chydaekata* sp.	-	
4	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp.	-	juvenile
4	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp. B02	-	
4	MNEW1upstream	726009	7480355	Copepoda	70	*Diacyclops humphreysi humphreysi*	-	
4	MNEW1upstream	726009	7480355	Copepoda	5	*Microcyclops varicans*	-	
4	MNEW1upstream	726009	7480355	Hydracarina	1	*Albia* sp. B1	-	Male with highly modified legIV
4	MNEW1upstream	726009	7480355	Hydracarina	10	*Axonopsella* sp B1	-	male leg IV not modified.
4	MNEW1upstream	726009	7480355	Hydracarina	1	*Limnesia* sp B01	-	male in poor condition
4	MNEW1upstream	726009	7480355	Oligochaeta	1	Enchytraeidae Pilbara sp. 2	-	
4	MNEW1upstream	726009	7480355	Ostracoda	9	*Gomphodella alexanderi*	-	
4	MNEW1upstream	726009	7480355	Ostracoda	42	*Meridiescandona facies*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
4	MNEW1upstream	726009	7480355	Ostracoda	25	*Notacandona boultoni*	-	
4	MNEW1upstream	726009	7480355	Platyhelminthes	43	Turbellaria	-	
4	Plant	728677	7479732	Amphipoda	5	*Chydaekata* sp.	-	
4	Plant	728677	7479732	Amphipoda	1	*Maarrka weeliwolli*	-	
4	Plant	728677	7479732	Amphipoda	24	Paramelitidae sp.	-	
4	Plant	728677	7479732	Amphipoda	12	Paramelitidae sp. B02	-	
4	Plant	728677	7479732	Copepoda	20	Canthocamptidae sp. B01	-	
4	Plant	728677	7479732	Copepoda	110	*Diacyclops humphreysi humphreysi*	-	Harp. & Cyclo.
4	Plant	728677	7479732	Copepoda	1	*Gordonitocrella trajani*	-	
4	Plant	728677	7479732	Oligochaeta	3	Enchytraeidae	-	immature x 2
4	Plant	728677	7479732	Oligochaeta	3	Tubificidae	-	mangled posterior only x 1
4	Plant	728677	7479732	Ostracoda	50	*Meridiescandona facies*	-	dissected male, hemipenis match
4	Plant	728677	7479732	Ostracoda	40	*Notacandona boultoni*	-	
4	PZ08YJSW003	721670	7478287	Amphipoda	11	*Chydaekata* sp.	-	
4	PZ08YJSW003	721670	7478287	Amphipoda	5	Paramelitidae sp.	-	
4	PZ08YJSW003	721670	7478287	Amphipoda	5	Paramelitidae sp. B02	-	
4	PZ08YJSW003	721670	7478287	Copepoda	35	*Diacyclops humphreysi humphreysi*	-	
4	PZ08YJSW003	721670	7478287	Isopoda	19	*Pygolabis weeli wolli*	-	
4	PZ08YJSW003	721670	7478287	Ostracoda	1	*Notacandona boultoni*	-	male, dissected
4	PZ08YJSW003	721670	7478287	Platyhelminthes	1	Turbellaria	-	
4	PZ08YOXB004	718788	7477937	Amphipoda	1	Paramelitidae sp.	-	
4	PZ08YOXB004	718788	7477937	Amphipoda	1	Paramelitidae sp. B02	-	
4	PZ08YOXB004	718788	7477937	Copepoda	2	*Metacyclops pilbaricus*	-	
4	PZ08YOXB006	719936	7478158	Bathynellacea	1	*Atopobathynella* sp.	-	
4	PZ08YOXB006	719936	7478158	Copepoda	60	*Diacyclops humphreysi humphreysi*	-	
4	PZ08YOXB006	719936	7478158	Copepoda	1	*Metacyclops pilbaricus*	-	
4	WB/YJ99	725805	7480628	Amphipoda	3	Paramelitidae sp.	-	juvenile and damaged
4	WB/YJ99	725805	7480628	Amphipoda	4	Paramelitidae sp. B02	-	
4	WB/YJ99	725805	7480628	Copepoda	7	*Diacyclops humphreysi humphreysi*	-	
4	WW2	733149	7472618	Amphipoda	5	*Chydaekata* sp.	-	
4	WW2	733149	7472618	Amphipoda	1	*Maarrka weeliwolli*	-	
4	WW2	733149	7472618	Copepoda	20	*Diacyclops humphreysi humphreysi*	-	
4	WW2	733149	7472618	Copepoda	6	*Gordonitocrella trajani*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
4	WW2	733149	7472618	Ostracoda	4	*Meridiescandona facies*	-	female, shell match
4	WW2	733149	7472618	Ostracoda	7	*Notacandona boultoni*	-	
4	WW3	733405	7473428	Amphipoda	5	*Chydaekata* sp.	-	
4	WW3	733405	7473428	Bathynellacea	1	*Atopobathynella* sp.	-	juvenile only 6 legs
4	WW3	733405	7473428	Copepoda	2	Canthocamptidae sp. B01	-	male and female
4	WW3	733405	7473428	Copepoda	28	*Diacyclops humphreysi humphreysi*	-	
4	WW3	733405	7473428	Isopoda	3	Pygolabis sp.	-	juveniles and female
4	WW3	733405	7473428	Ostracoda	2	*Meridiescandona facies*	-	in syncarid vial
4	WW3	733405	7473428	Ostracoda	70	*Meridiescandona marillanae*	-	male dissected, clearly marillana on shell and hemipenis
4	WW4	734018	7474365	Amphipoda	1	*Chydaekata* sp.	-	
4	WW4	734018	7474365	Copepoda	30	*Diacyclops humphreysi humphreysi*	-	
4	WW4	734018	7474365	Ostracoda	7	*Meridiescandona lucerna*	-	dissected male, hemipenis and shell match
4	YM119	738345	7479063	Amphipoda	2	Paramelitidae sp.	-	juvenile and damaged
4	YM119	738345	7479063	Amphipoda	1	Paramelitidae sp. B02	-	
4	YM119	738345	7479063	Copepoda	7	*Diacyclops humphreysi humphreysi*	-	
4	YM119	738345	7479063	Copepoda	1	*Gordonitocrella trajani*	-	male
4	YM119	738345	7479063	Hydracarina	1	*Axonopsella* sp B1	-	
4	YM119	738345	7479063	Isopoda	2	*Pygolabis weeli wolli*	-	male and juvenile
4	YM119	738345	7479063	Ostracoda	19	*Meridiescandona lucerna*	-	
4	YM119	738345	7479063	Ostracoda	36	*Notacandona boultoni*	-	
5	99YJWB02	732433	7472677	Amphipoda	2	*Chydaekata* sp.	-	2 harpacticoid copepod contaminants
5	99YJWB02	732433	7472677	Amphipoda	2	Paramelitidae sp. B02	-	
5	99YJWB02	732433	7472677	Amphipoda	1	*Pilbarus millsi*	-	
5	99YJWB02	732433	7472677	Copepoda	2	*Diacyclops humphreysi unispinosus*	-	
5	99YJWB02	732433	7472677	Copepoda	3	*Diacyclops sobeprolatus*	-	has short dorsal caudal setae like humphreysi
5	99YJWB02	732433	7472677	Copepoda	1	*Gordonitocrella trajani*	-	
5	99YJWB02	732433	7472677	Ostracoda	10	*Notacandona boultoni*	-	
5	99YJWB04	735790	7477323	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
5	99YJWB04	735790	7477323	Copepoda	5	*Gordonitocrella trajani*	-	
5	B1	731070	7477776	Amphipoda	2	Paramelitidae sp. B02	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
5	B1	731070	7477776	Copepoda	8	*Diacyclops sobeprolatus*	-	has short dorsal caudal setae like humphreysi
5	B1	731070	7477776	Ostracoda	2	*Meridiescandona facies*	-	
5	B1	731070	7477776	Ostracoda	1	*Meridiescandona marillanae*	-	
5	B1	731070	7477776	Ostracoda	1	*Notacandona boultoni*	-	
5	B1	731070	7477776	Ostracoda	1	*Notocandona modesta*	-	
5	D03YJ1667	731298	7477800	Copepoda	22	*Diacyclops humphreysi humphreysi*	-	
5	D08YJ050	732887	7473094	Amphipoda	5	*Chydaekata* sp.	-	
5	D08YJ050	732887	7473094	Amphipoda	6	Paramelitidae sp.	-	juvenile
5	D08YJ050	732887	7473094	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	D08YJ050	732887	7473094	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	D08YJ050	732887	7473094	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	D08YJ050	732887	7473094	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
5	D08YJ050	732887	7473094	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
5	D08YJ050	732887	7473094	Oligochaeta	1	Phreodrilidae with similar ventral chaetae (pss)	-	immature
5	D08YJ050	732887	7473094	Oligochaeta	1	*Pristina aequiseta*	-	
5	D08YJ050	732887	7473094	Platyhelminthes	2	Turbellaria sp.	-	
5	Marillana01	723792	7479113	Amphipoda	1	*Chydaekata* sp.	-	
5	Marillana01	723792	7479113	Amphipoda	9	*Chydaekata* sp.	-	
5	Marillana01	723792	7479113	Amphipoda	4	Paramelitidae sp	-	3 juveniles + 1 with U3 missing
5	Marillana01	723792	7479113	Amphipoda	4	Paramelitidae sp. B02	-	
5	Marillana01	723792	7479113	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
5	Marillana01	723792	7479113	Isopoda	1	*Chydaekata* sp.	-	
5	Marillana01	723792	7479113	Isopoda	1	Pygolabis sp.	-	juvenile
5	Marillana01	723792	7479113	Ostracoda	11	*Meridiescandona facies*	-	
5	Marillana01	723792	7479113	Ostracoda	1	*Notacandona boultoni*	-	
5	Marillana01	723792	7479113	Platyhelminthes	15	Turbellaria sp.	-	
5	Marillana02	725082	7479990	Amphipoda	1	*Chydaekata* sp.	-	
5	Marillana02	725082	7479990	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	1 Collembola contaminant

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
5	Marillana02	725082	7479990	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
5	Marillana02	725082	7479990	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
5	Marillana02	725082	7479990	Copepoda	35	*Diacyclops humphreysi humphreysi*	-	
5	Marillana02	725082	7479990	Isopoda	1	*Chydaekata* sp.	-	
5	Marillana02	725082	7479990	Isopoda	2	Pygolabis sp.	-	juvenile
5	Marillana02	725082	7479990	Oligochaeta	2	Enchytraeidae pilbara sp. 1 (pss)	-	
5	Marillana02	725082	7479990	Ostracoda	50	*Meridiescandona facies*	-	
5	Marillana02	725082	7479990	Platyhelminthes	2	Turbellaria sp.	-	
5	Marillana03	728209	7479045	Amphipoda	4	*Chydaekata* sp.	-	
5	Marillana03	728209	7479045	Amphipoda	9	Paramelitidae sp. B02	-	
5	Marillana03	728209	7479045	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
5	Marillana03	728209	7479045	Ostracoda	1	*Notacandona boultoni*	-	
5	Marillana06	731182	7478693	Amphipoda	8	Paramelitidae sp. B02	-	
5	Marillana06	731182	7478693	Amphipoda	1	*Pilbarus millsi*	Lineage YB6	
5	Marillana06	731182	7478693	Amphipoda	1	*Pilbarus millsi*	Lineage YB6	
5	Marillana06	731182	7478693	Amphipoda	1	*Pilbarus millsi*	Lineage YB6	
5	Marillana06	731182	7478693	Ostracoda	3	*Meridiescandona facies*	-	
5	Marillana06	731182	7478693	Ostracoda	5	*Notacandona boultoni*	-	
5	Marillana06	731182	7478693	Platyhelminthes	6	Turbellaria sp.	-	
5	Marillana07	725592	7480218	Amphipoda	1	Amphipoda sp.	-	missing posterior end from L6
5	Marillana07	725592	7480218	Amphipoda	2	*Chydaekata* sp.	-	
5	Marillana07	725592	7480218	Amphipoda	79	Paramelitidae sp.	-	juvenile
5	Marillana07	725592	7480218	Copepoda	21	*Diacyclops humphreysi humphreysi*	-	
5	Marillana07	725592	7480218	Isopoda	8	*Pygolabis* sp. humphreysi?	-	inc males
5	Marillana07	725592	7480218	Ostracoda	1	Gomphodella sp.	-	Juvenile animal, think it is probably a Gomphodella (and therefore G. yandi) but not sure
5	Marillana07	725592	7480218	Ostracoda	25	*Meridiescandona facies*	-	
5	Marillana07	725592	7480218	Ostracoda	1	*Meridiescandona lucerna*	-	
5	Marillana07	725592	7480218	Ostracoda	70	*Notacandona boultoni*	-	Supposedly 66 animals in vial -

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
								think there were more
5	Marillana07	725592	7480218	Platyhelminthes	29	Turbellaria sp.	-	
5	MB08YJPC021	726201	7480572	Amphipoda	1	Paramelitidae sp.	-	Failed to Amplify
5	MB08YJPC021	726201	7480572	Amphipoda	1	Paramelitidae sp.	Lineage WWA2	
5	MB08YJPC021	726201	7480572	Copepoda	5	*Diacyclops sobeprolatus*	-	has short dorsal caudal setae like humphreysi
5	MC10	730082	7478812	Platyhelminthes	1	Turbellaria sp.	-	
5	MNEW1upstream	726009	7480355	Amphipoda	4	*Chydaekata* sp.	-	
5	MNEW1upstream	726009	7480355	Amphipoda	17	Paramelitidae sp.	-	juvenile
5	MNEW1upstream	726009	7480355	Amphipoda	4	Paramelitidae sp. B02	-	
5	MNEW1upstream	726009	7480355	Copepoda	51	*Diacyclops humphreysi humphreysi*	-	
5	MNEW1upstream	726009	7480355	Hydracarina	3	*Arrenurus* sp. 02	-	3 females, do not think they are same species as male as much smaller
5	MNEW1upstream	726009	7480355	Hydracarina	1	*Arrenurus* sp. nov. yandi (sp 1)	-	1 male
5	MNEW1upstream	726009	7480355	Hydracarina	1	*Limnesia* sp B01	-	female in poor condition (assume same sp as collected before do not have specimen to compare)
5	MNEW1upstream	726009	7480355	Hydracarina	3	*Recifella* sp. “Yandi”	-	2 females, 1 male
5	MNEW1upstream	726009	7480355	Isopoda	1	*Pygolabis weeli wolli*	-	male, much shorter telson and shorter teeth on the appendix masculina, subadult?
5	MNEW1upstream	726009	7480355	Oligochaeta	1	Tubificidae morphospecies 1/1a (pss)	-	
5	MNEW1upstream	726009	7480355	Ostracoda	1	*Candonopsis* ? n. sp. Indet	-	F. reticulate valves. Arch more ant than C tenuis. No medial seta on T3, basal sets present on T2
5	MNEW1upstream	726009	7480355	Ostracoda	6	*Gomphodella alexanderi*	-	
5	MNEW1upstream	726009	7480355	Ostracoda	9	*Meridiescandona facies*	-	
5	MNEW1upstream	726009	7480355	Ostracoda	40	*Notacandona boultoni*	-	
5	MNEW1upstream	726009	7480355	Platyhelminthes	16	Turbellaria sp.	-	
5	PZ08YJSW003	721670	7478287	Amphipoda	1	*Chydaekata* sp.	-	
5	PZ08YJSW003	721670	7478287	Amphipoda	2	Paramelitidae sp.	-	No U3

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
5	PZ08YJSW003	721670	7478287	Amphipoda	8	Paramelitidae sp. B02	-	
5	PZ08YJSW003	721670	7478287	Copepoda	21	*Diacyclops sobeprolatus*	-	has short dorsal caudal setae like humphreysi
5	PZ08YJSW003	721670	7478287	Isopoda	54	*Pygolabis weeli wolli*	-	
5	PZ08YJSW003	721670	7478287	Ostracoda	14	*Notacandona boultoni*	-	
5	PZ08YJSW003	721670	7478287	Platyhelminthes	7	Turbellaria sp.	-	
5	PZ08YOXB004	718788	7477937	Amphipoda	7	Paramelitidae sp.	-	juvenile
5	PZ08YOXB004	718788	7477937	Amphipoda	3	Paramelitidae sp. B02	-	
5	PZ08YOXB004	718788	7477937	Copepoda	2	*Goniocyclops* sp.	-	
5	PZ08YOXB004	718788	7477937	Copepoda	1	*Metacyclops pilbaricus*	-	
5	PZ09YJSW020	724976	7479538	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
5	WB/YJ99	725805	7480628	Amphipoda	9	Paramelitidae sp. B02	-	
5	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
5	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WB/YJ99	725805	7480628	Copepoda	13	*Diacyclops humphreysi humphreysi*	-	
5	WW2	733149	7472618	Amphipoda	7	*Chydaekata* sp.	-	
5	WW2	733149	7472618	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
5	WW2	733149	7472618	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
5	WW2	733149	7472618	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WW2	733149	7472618	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WW2	733149	7472618	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
5	WW2	733149	7472618	Copepoda	2	Canthocamptidae sp. B01	-	female
5	WW2	733149	7472618	Copepoda	60	*Diacyclops humphreysi unispinosus*	-	
5	WW2	733149	7472618	Oligochaeta	35	Enchytraeidae Pilbara sp. 1 (pss)	-	
5	WW2	733149	7472618	Ostracoda	1	*Gomphodella alexanderi*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
5	WW2	733149	7472618	Ostracoda	7	*Meridiescandona facies*	-	
5	WW2	733149	7472618	Ostracoda	4	*Notacandona boultoni*	-	
5	WW2	733149	7472618	Unknown 1	2	copepod naupuli	-	
5	WW3	733405	7473428	Amphipoda	4	Paramelitidae sp. B02	-	
5	WW3	733405	7473428	Amphipoda	1	*Pilbarus millsi*	Lineage YB6	
5	WW3	733405	7473428	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
5	WW3	733405	7473428	Isopoda	9	*Pygolabis weeli wolli*	-	
5	WW3	733405	7473428	Oligochaeta	1	Enchytraeidae pilbara sp. 2 (pss)	-	
5	WW3	733405	7473428	Ostracoda	13	*Meridiescandona lucerna*	-	
5	WW4	734018	7474365	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
5	YM119	738345	7479063	Amphipoda	1	*Maarrka weeliwolli*	-	
5	YM119	738345	7479063	Ostracoda	7	*Meridiescandona lucerna*	-	
5	YM119	738345	7479063	Ostracoda	8	*Notacandona boultoni*	-	
6	99YJWB02	732433	7472677	Copepoda	8	*Diacyclops humphreysi humphreysi*	-	
6	99YJWB02	732433	7472677	Copepoda	2	*Gordonitocrella trajani*	-	
6	99YJWB04	735931	7477480	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
6	99YJWB04	735931	7477480	Copepoda	17	*Gordonitocrella trajani*	-	
6	D08YJ050	732887	7473094	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
6	D08YJ050	732887	7473094	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
6	FAUNA	726433	7483097	Oligochaeta	5	Enchytraeidae pilbara sp. 2	-	
6	JSE14	733707	7473602	Amphipoda	3	*Chydaekata* sp.	-	
6	JSE14	733707	7473602	Amphipoda	7	Paramelitidae sp. B02	-	
6	JSE14	733707	7473602	Copepoda	1	Canthocamptidae sp. B01	-	male
6	JSE14	733707	7473602	Copepoda	29	*Diacyclops humphreysi humphreysi*	-	
6	JSE14	733707	7473602	Copepoda	3	*Gordonitocrella trajani*	-	
6	JSE14	733707	7473602	Ostracoda	13	*Notacandona boultoni*	-	
6	JSE39	733145	7472585	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
6	JSE39	733145	7472585	Isopoda	4	*Pygolabis weeli wolli*	-	
6	Marillana01	723792	7479113	Amphipoda	2	*Chydaekata* sp.	-	
6	Marillana01	723792	7479113	Copepoda	12	*Diacyclops humphreysi humphreysi*	-	
6	Marillana01	723792	7479113	Hydracarina	4	*Arrenurus* sp. nov. yandi (sp 1)	-	
6	Marillana01	723792	7479113	Isopoda	1	*Atopobathynella* sp. B04	-	
6	Marillana01	723792	7479113	Isopoda	8	*Pygolabis weeli wolli*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
6	Marillana01	723792	7479113	Ostracoda	3	*Meridiescandona facies*	-	1 in sample, CB2 seta absent
6	Marillana01	723792	7479113	Platyhelminthes	3	Turbellaria sp.	-	
6	Marillana01	723792	7479113	Platyhelminthes	50	Turbellaria sp.	-	2 males 2 females
6	Marillana02	725082	7479990	Copepoda	27	*Diacyclops humphreysi humphreysi*	-	
6	Marillana02	725082	7479990	Isopoda	1	*Pygolabis weeli wolli*	-	
6	Marillana02	725082	7479990	Ostracoda	50	*Meridiescandona facies*	-	
6	Marillana02	725082	7479990	Platyhelminthes	1	Turbellaria sp.	-	
6	Marillana03	728209	7479045	Bathynellacea	1	*Atopobathynella* sp. B04	-	
6	Marillana03	728209	7479045	Copepoda	35	*Diacyclops sobeprolatus*	-	
6	Marillana03	728209	7479045	Ostracoda	1	*Meridiescandona facies*	-	
6	Marillana06	731182	7478693	Amphipoda	5	*Chydaekata* sp.	-	
6	Marillana06	731182	7478693	Amphipoda	2	*Maarrka weeliwolli*	-	
6	Marillana06	731182	7478693	Amphipoda	10	Paramelitidae sp. B02	-	
6	Marillana06	731182	7478693	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
6	Marillana06	731182	7478693	Copepoda	1	*Mesocyclops darwini*	-	
6	Marillana06	731182	7478693	Copepoda	1	Parastenocaris sp. B09	-	male
6	Marillana06	731182	7478693	Isopoda	1	*Pygolabis weeli wolli*	-	
6	Marillana06	731182	7478693	Oligochaeta	1	*Aeolosoma* sp. 1 (PSS)	-	
6	Marillana06	731182	7478693	Ostracoda	2	*Gomphodella* sp BOS200	-	small, featureless
6	Marillana06	731182	7478693	Platyhelminthes	20	Turbellaria sp.	-	
6	Marillana07	725592	7480218	Amphipoda	1	*Chydaekata* sp.	-	
6	Marillana07	725592	7480218	Amphipoda	6	Paramelitidae sp. B02	-	
6	Marillana07	725592	7480218	Bathynellacea	4	Bathynella sp.	-	
6	Marillana07	725592	7480218	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
6	Marillana07	725592	7480218	Copepoda	5	*Diacyclops sobeprolatus*	-	
6	Marillana07	725592	7480218	Copepoda	5	*Microcyclops varicans*	-	
6	Marillana07	725592	7480218	Hydracarina	6	*Arrenurus* sp. 02	-	
6	Marillana07	725592	7480218	Hydracarina	1	*Limnesia* sp B01	-	
6	Marillana07	725592	7480218	Hydracarina	14	*Recifella* sp. “Yandi”	-	
6	Marillana07	725592	7480218	Hydracarina	1	*Stygolimnochares* sp. B1	-	Elongate body
6	Marillana07	725592	7480218	Isopoda	27	*Pygolabis weeli wolli*	-	
6	Marillana07	725592	7480218	Oligochaeta	2	*Aeolosoma* sp. 1 (PSS)	-	
6	Marillana07	725592	7480218	Oligochaeta	1	Phreodrilidae with similar ventral chaetae	-	(probably immature Insulodrilus)

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
6	Marillana07	725592	7480218	Ostracoda	12	*Meridiescandona facies*	-	
6	Marillana07	725592	7480218	Platyhelminthes	50	Turbellaria sp.	-	
6	MC4	730180	7478691	Amphipoda	1	Paramelitidae sp. B02	-	
6	MNEW1upstream	726009	7480355	Bathynellacea	2	*Atopobathynella* sp. B04	-	juv
6	MNEW1upstream	726009	7480355	Bathynellacea	1	Bathynella sp.	-	
6	MNEW1upstream	726009	7480355	Copepoda	50	*Diacyclops humphreysi humphreysi*	-	
6	MNEW1upstream	726009	7480355	Copepoda	4	*Microcyclops varicans*	-	
6	MNEW1upstream	726009	7480355	Hydracarina	5	*Arrenurus* sp. 02	-	1 male 3 females 1 juv
6	MNEW1upstream	726009	7480355	Hydracarina	2	*Limnesia* sp B01	-	
6	MNEW1upstream	726009	7480355	Hydracarina	1	*Recifella* sp. “Yandi”	-	male
6	MNEW1upstream	726009	7480355	Nematoda	1		-	
6	MNEW1upstream	726009	7480355	Ostracoda	4	*Meridiescandona facies*	-	4 animals, CB2 seta absent
6	MNEW1upstream	726009	7480355	Ostracoda	6	*Meridiescandona lucerna*	-	6 animals, CB2 seta present
6	PZ08YJSW003	730892	7478388	Amphipoda	1	*Maarrka weeliwolli*	-	
6	PZ08YJSW003	730892	7478388	Amphipoda	12	Paramelitidae sp. B02	-	
6	PZ08YJSW003	730892	7478388	Copepoda	12	*Diacyclops humphreysi humphreysi*	-	
6	PZ08YJSW003	730892	7478388	Copepoda	4	*Diacyclops sobeprolatus*	-	
6	PZ08YJSW003	730892	7478388	Isopoda	12	*Pygolabis weeli wolli*	-	
6	PZ08YJSW003	730892	7478388	Ostracoda	9	*Meridiescandona facies*	-	
6	PZ08YJSW004	722689	7478744	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
6	PZ08YJSW004	722689	7478744	Isopoda	1	*Pygolabis weeli wolli*	-	
6	PZ08YJSW020	724976	7479538	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
6	PZ08YJSW020	724976	7479538	Ostracoda	2	*Meridiescandona facies*	-	
6	PZ08YOXB004	718788	7477937	Amphipoda	11	Paramelitidae sp. B02	-	
6	PZ08YOXB006	719936	7478158	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
6	PZ08YOXB006	719936	7478158	Copepoda	50	*Metacyclops pilbaricus*	-	
6	WW2	733200	7472664	Amphipoda	1	*Chydaekata* sp.	-	
6	WW2	733200	7472664	Amphipoda	1	*Maarrka weeliwolli*	-	
6	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	-	
6	WW2	733200	7472664	Copepoda	29	*Diacyclops humphreysi humphreysi*	-	
6	WW2	733200	7472664	Copepoda	5	*Gordonitocrella trajani*	-	
6	WW2	733200	7472664	Isopoda	6	*Pygolabis weeli wolli*	-	
6	WW2	733200	7472664	Ostracoda	2	*Gomphodella hirsuta*	-	2 animals
6	WW2	733200	7472664	Ostracoda	2	*Gomphodella* sp BOS200	-	2 animals

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
6	WW2	733200	7472664	Ostracoda	2	*Meridiescandona facies*	-	2 animals
6	WW2	733200	7472664	Ostracoda	2	*Notacandona boultoni*	-	2 animals
6	WW3	733370	7473592	Amphipoda	11	*Chydaekata* sp.	-	
6	WW3	733370	7473592	Amphipoda	1	*Maarrka weeliwolli*	-	
6	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
6	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
6	WW3	733370	7473592	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
6	WW3	733370	7473592	Copepoda	10	*Diacyclops sobeprolatus*	-	
6	WW3	733370	7473592	Isopoda	9	*Pygolabis weeli wolli*	-	
6	WW3	733370	7473592	Ostracoda	1	*Gomphodella hirsuta*	-	1 plus 1 valve
6	WW4	734448	7474705	Copepoda	1	Canthocamptidae sp. B01	-	male
6	WW4	734448	7474705	Copepoda	21	*Diacyclops humphreysi humphreysi*	-	
6	WW4	734448	7474705	Isopoda	1	*Pygolabis weeli wolli*	-	
6	WW4	734448	7474705	Ostracoda	6	*Meridiescandona facies*	-	
6	YM119	738345	7479063	Amphipoda	4	*Maarrka weeliwolli*	-	very juv
6	YM119	738345	7479063	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
6	YM119	738345	7479063	Ostracoda	35	*Notacandona boultoni*	-	35 animals
7	99YJWB02	732433	7472677	Copepoda	1	*Diacyclops sobeprolatus*	-	
7	99YJWB02	732433	7472677	Gastropoda	1	Hydrobiidae? sp.	-	shell only dead when collected
7	99YJWB02	732433	7472677	Isopoda	1	*Pygolabis weeli wolli*	-	male
7	99YJWB02	732433	7472677	Ostracoda	1	*Meridiescandona facies*	-	1 juv
7	99YJWB03	734850	7474599	Copepoda	39	*Diacyclops humphreysi humphreysi*	-	
7	99YJWB03	734850	7474599	Copepoda	1	*Gordonitocrella trajani*	-	
7	99YJWB04	735931	7477480	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
7	99YJWB04	735931	7477480	Copepoda	6	*Gordonitocrella trajani*	-	
7	D08YJ050	732887	7473094	Isopoda	1	*Pygolabis weeli wolli*	-	female
7	Fauna	726433	7483097	Oligochaeta	2	Enchytraeidae pilbara sp. 2	-	
7	JSE14	733707	7473602	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	JSE14	733707	7473602	Copepoda	1	Canthocamptidae sp. B01	-	female has cephalic window on cehalothorax
7	JSE14	733707	7473602	Copepoda	45	*Diacyclops sobeprolatus*	-	plus 1 harpacticoid
7	JSE14	733707	7473602	Copepoda	6	*Gordonitocrella trajani*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
7	JSE14	733707	7473602	Ostracoda	4	*Notacandona boultoni*	-	
7	JSE36	735937	7475846	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	Marillana01	723792	7479113	Amphipoda	1	*Chydaekata* sp.	-	
7	Marillana01	723792	7479113	Amphipoda	3	Paramelitidae sp. B02	-	plus 1 cyclopoid
7	Marillana01	723792	7479113	Bathynellacea	1	*Atopobathynella* sp. B04	-	
7	Marillana01	723792	7479113	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	juv
7	Marillana01	723792	7479113	Hydracarina	4	*Arrenurus* sp. nov. yandi (sp 1)	-	1 male 3 females
7	Marillana01	723792	7479113	Hydracarina	5	*Recifella* sp. "Yandi"	-	
7	Marillana01	723792	7479113	Ostracoda	11	*Gomphodella alexanderi*	-	11 animals
7	Marillana01	723792	7479113	Ostracoda	21	*Meridiescandona facies*	-	21 animals
7	Marillana01	723792	7479113	Ostracoda	1	*Notacandona boultoni*	-	1 animal
7	Marillana01	723792	7479113	Platyhelminthes	2	Turbellaria sp.	-	
7	Marillana02	725082	7479990	Copepoda	30	*Diacyclops humphreysi humphreysi*	-	
7	Marillana02	725082	7479990	Ostracoda	50	*Meridiescandona facies*	-	
7	Marillana06	731182	7478693	Amphipoda	6	Paramelitidae sp. B02	-	
7	Marillana06	731182	7478693	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
7	Marillana06	731182	7478693	Hydracarina	1	Halicaridae	-	Desiccated. On slide in poor condition
7	Marillana06	731182	7478693	Isopoda	5	*Pygolabis weeli wolli*	-	
7	Marillana06	731182	7478693	Oligochaeta	30	*Ainudrilus* sp. WA26	-	
7	Marillana06	731182	7478693	Ostracoda	8	*Meridiescandona facies*	-	
7	Marillana06	731182	7478693	Platyhelminthes	18	Turbellaria sp.	-	
7	Marillana07	725592	7480218	Amphipoda	1	*Chydaekata* sp.	-	
7	Marillana07	725592	7480218	Copepoda	11	*Diacyclops sobeprolatus*	-	
7	Marillana07	725592	7480218	Copepoda	1	*Microcyclops varicans*	-	
7	Marillana07	725592	7480218	Hydracarina	9	*Recifella* sp. "Yandi"	-	
7	Marillana07	725592	7480218	Hydracarina	1	*Stygolimnochares* sp. B1	-	
7	Marillana07	725592	7480218	Isopoda	10	*Pygolabis weeli wolli*	-	
7	Marillana07	725592	7480218	Ostracoda	5	*Meridiescandona facies*	-	
7	Marillana07	725592	7480218	Platyhelminthes	20	Turbellaria sp.	-	
7	PZ08YJSW002	730892	7478388	Amphipoda	4	Paramelitidae sp. B02	-	8 dead/partial
7	PZ08YJSW002	730892	7478388	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	PZ08YJSW002	730892	7478388	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	PZ08YJSW002	730892	7478388	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
7	PZ08YJSW002	730892	7478388	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	PZ08YJSW002	730892	7478388	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
7	PZ08YJSW002	730892	7478388	Copepoda	10	*Diacyclops sobeprolatus*	-	
7	PZ08YJSW002	730892	7478388	Copepoda	5	*Gordonitocrella trajani*	-	
7	PZ08YJSW003	730892	7478388	Amphipoda	3	Paramelitidae sp. B02	-	
7	PZ08YJSW003	730892	7478388	Copepoda	4	*Diacyclops sobeprolatus*	-	
7	PZ08YJSW003	730892	7478388	Isopoda	10	*Pygolabis weeli wolli*	-	
7	PZ08YJSW003	730892	7478388	Ostracoda	4	*Meridiescandona facies*	-	4 animals
7	PZ08YJSW003	730892	7478388	Ostracoda	6	*Notacandona boultoni*	-	6 animals
7	PZ08YJSW004	722689	7478744	Copepoda	9	*Diacyclops humphreysi humphreysi*	-	
7	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	WW2	733200	7472664	Copepoda	26	*Diacyclops humphreysi humphreysi*	-	
7	WW2	733200	7472664	Isopoda	4	*Pygolabis weeli wolli*	-	
7	WW2	733200	7472664	Ostracoda	1	*Meridiescandona facies*	-	1 animal, 2 valves
7	WW2	733200	7472664	Ostracoda	4	*Notacandona boultoni*	-	4 animals
7	WW3	733370	7473592	Amphipoda	7	*Chydaekata* sp.	-	
7	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
7	WW3	733370	7473592	Copepoda	15	*Diacyclops humphreysi humphreysi*	-	
7	WW3	733370	7473592	Copepoda	15	*Diacyclops sobeprolatus*	-	
7	WW3	733370	7473592	Hydracarina	4	*Arrenurus* sp. B03	-	2 male 2 females
7	WW3	733370	7473592	Isopoda	1	*Pygolabis weeli wolli*	-	One partial specimen
7	WW3	733370	7473592	Ostracoda	1	*Gomphodella hirsuta*	-	1 animal
7	WW3	733370	7473592	Ostracoda	1	*Meridiescandona facies*	-	1 animal
7	WW3	733370	7473592	Ostracoda	1	*Notacandona boultoni*	-	1 animal
7	WW4	734448	7474705	Amphipoda	1	*Chydaekata* sp.	-	gravid female
7	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
7	WW4	734448	7474705	Bathynellacea	1	*Chilibathynella*? sp. B06	-	female
7	WW4	734448	7474705	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
7	WW4	734448	7474705	Copepoda	3	*Gordonitocrella trajani*	-	
7	WW4	734448	7474705	Hydracarina	1	*Recifella* sp. “Yandi”	-	male
7	WW4	734448	7474705	Isopoda	1	*Pygolabis weeli wolli*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
7	WW4	734448	7474705	Ostracoda	7	*Meridiescandona facies*	-	7 animals
7	WW4	734448	7474705	Ostracoda	1	*Notacandona boultoni*	-	1 animal
7	YM119	738345	7479063	Amphipoda	4	*Maarrka weeliwolli*	-	Dead
7	YM119	738345	7479063	Ostracoda	1	*Notacandona boultoni*	-	Dead
8	99YJWB02	732433	7472677	Amphipoda	3	*Chydaekata* sp.	-	
8	99YJWB02	732433	7472677	Copepoda	50	*Diacyclops humphreysi humphreysi*	-	
8	99YJWB02	732433	7472677	Copepoda	50	*Gordonitocrella trajani*	-	
8	99YJWB02	732433	7472677	Oligochaeta	1	Tubificidae stygo type 5	-	
8	99YJWB02	732433	7472677	Ostracoda	1	*Meridiescandona facies*	-	
8	99YJWB02	732433	7472677	Ostracoda	1	*Notacandona boultoni*	-	
8	99YJWB03	734850	7474599	Amphipoda	1	*Chydaekata* sp.	-	
8	99YJWB03	734850	7474599	Copepoda	40	*Diacyclops humphreysi humphreysi*	-	
8	99YJWB03	734850	7474599	Oligochaeta	2	*Pristina longiseta*	-	
8	99YJWB04	735931	7477480	Copepoda	26	*Diacyclops humphreysi humphreysi*	-	
8	99YJWB04	735931	7477480	Copepoda	19	*Gordonitocrella trajani*	-	
8	99YJWB04	735931	7477480	Hydracarina	1	*Guineaxonopsis* sp. S1 (PSS)	-	
8	D08YJ050	735931	7477480	Amphipoda	12	*Chydaekata* sp.	-	
8	D08YJ050	735931	7477480	Amphipoda	7	Paramelitidae sp. B02	-	
8	D08YJ050	735931	7477480	Oligochaeta	1	Phreodrilid with similar ventral chaetae	-	
8	JSE14	733707	7473602	Amphipoda	1	*Chydaekata* sp.	-	
8	JSE14	733707	7473602	Amphipoda	1	Paramelitidae sp. B02	-	
8	JSE14	733707	7473602	Isopoda	1	*Pygolabis weeli wolli*	-	
8	JSE14	733707	7473602	Ostracoda	1	*Meridiescandona marillanae*	-	
8	JSE14	733707	7473602	Ostracoda	2	*Notacandona boultoni*	-	
8	JSE39	733145	7472585	Isopoda	1	*Pygolabis weeli wolli*	-	
8	Marillana01	723792	7479113	Amphipoda	24	*Chydaekata* sp.	-	
8	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	-	
8	Marillana01	723792	7479113	Bathynellacea	1	*Atopobathynella* sp. B04	-	
8	Marillana01	723792	7479113	Bathynellacea	3	Bathynella sp.	-	
8	Marillana01	723792	7479113	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
8	Marillana01	723792	7479113	Hydracarina	4	*Arrenurus* sp. nov. yandi (sp 1)	-	
8	Marillana01	723792	7479113	Hydracarina	12	*Recifella* sp. “Yandi”	-	
8	Marillana01	723792	7479113	Isopoda	2	*Pygolabis* sp. B06	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
8	Marillana01	723792	7479113	Ostracoda	15	*Gomphodella alexanderi*	-	
8	Marillana01	723792	7479113	Ostracoda	31	*Meridiescandona facies*	-	
8	Marillana01	723792	7479113	Platyhelminthes	1		-	
8	Marillana02	725082	7479990	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
8	Marillana02	725082	7479990	Oligochaeta	7	Enchytraeidae pilbara sp. 1 (pss)	-	
8	Marillana02	725082	7479990	Ostracoda	150	*Meridiescandona facies*	-	
8	Marillana02	725082	7479990	Ostracoda	1	*Notacandona boultoni*	-	
8	Marillana03	728209	7479045	Amphipoda	3	*Chydaekata* sp.	-	
8	Marillana03	728209	7479045	Amphipoda	4	Paramelitidae sp. B02	-	
8	Marillana03	728209	7479045	Copepoda	3	*Microcyclops varicans*	-	
8	Marillana03	728209	7479045	Oligochaeta	50	*Pristina longiseta*	-	
8	Marillana06	731182	7478693	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Marillana06	731182	7478693	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Marillana06	731182	7478693	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Marillana06	731182	7478693	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
8	Marillana06	731182	7478693	Copepoda	10	*Diacyclops sobeprolatus*	-	
8	Marillana06	731182	7478693	Copepoda	3	*Mesocyclops darwini*	-	
8	Marillana06	731182	7478693	Hydracarina	1	*Recifella* sp. “Yandi”	-	
8	Marillana06	731182	7478693	Isopoda	1	*Pygolabis* sp. B06	-	
8	Marillana06	731182	7478693	Oligochaeta	6	Enchytraeidae	-	
8	Marillana06	731182	7478693	Ostracoda	1	*Notacandona boultoni*	-	
8	Marillana07	725592	7480218	Amphipoda	7	*Maarrka weeliwolli*	-	
8	Marillana07	725592	7480218	Amphipoda	47	Paramelitidae sp. B02	-	
8	Marillana07	725592	7480218	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
8	Marillana07	725592	7480218	Copepoda	1	*Microcyclops varicans*	-	
8	Marillana07	725592	7480218	Hydracarina	4	Arrenurus sp.	-	
8	Marillana07	725592	7480218	Hydracarina	1	*Recifella* sp. “Yandi”	-	
8	Marillana07	725592	7480218	Hydracarina	1	*Stygolimnochares* sp. B1	-	
8	Marillana07	725592	7480218	Isopoda	11	*Pygolabis* sp. B06	-	
8	Marillana07	725592	7480218	Oligochaeta	7	Phreodrilid with similar ventral chaetae	-	
8	Marillana07	725592	7480218	Ostracoda	13	*Meridiescandona facies*	-	
8	Marillana07	725592	7480218	Ostracoda	6	*Notacandona boultoni*	-	
8	MNEW1upstream	726009	7480355	Amphipoda	1	*Maarrka weeliwolli*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
8	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp. B25	-	Failed to Amplify
8	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp. B25	-	Failed to Amplify
8	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp. B25	-	Failed to Amplify
8	MNEW1upstream	726009	7480355	Amphipoda	1	Paramelitidae sp. B25	Lineage WWA3	
8	MNEW1upstream	726009	7480355	Copepoda	1	*Australocyclops similis*	-	
8	MNEW1upstream	726009	7480355	Copepoda	18	*Diacyclops humphreysi humphreysi*	-	
8	MNEW1upstream	726009	7480355	Copepoda	5	*Microcyclops varicans*	-	
8	MNEW1upstream	726009	7480355	Hydracarina	3	Arrenurus sp.	-	
8	MNEW1upstream	726009	7480355	Hydracarina	5	*Limnesia* sp B01	-	
8	MNEW1upstream	726009	7480355	Hydracarina	3	*Recifella* sp. “Yandi”	-	
8	MNEW1upstream	726009	7480355	Nematoda	5		-	
8	MNEW1upstream	726009	7480355	Oligochaeta	16	*Pristina longiseta*	-	
8	MNEW1upstream	726009	7480355	Ostracoda	1	*Candonopsis tenuis*	-	
8	MNEW1upstream	726009	7480355	Ostracoda	3	*Meridiescandona facies*	-	
8	MNEW1upstream	726009	7480355	Ostracoda	6	*Notacandona boultoni*	-	
8	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Plant	728677	7479732	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	Plant	728677	7479732	Copepoda	10	Canthocamptidae sp. B01	-	
8	Plant	728677	7479732	Copepoda	2	*Diacyclops sobeprolatus*	-	
8	Plant	728677	7479732	Hydracarina	1	*Recifella* sp. “Yandi”	-	
8	Plant	728677	7479732	Oligochaeta	1	Phreodrilid with similar ventral chaetae	-	
8	PZ08YJSW003	721670	7478287	Amphipoda	2	*Chydaekata* sp.	-	
8	PZ08YJSW003	721670	7478287	Amphipoda	29	Paramelitidae sp. B02	-	
8	PZ08YJSW003	721670	7478287	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
8	PZ08YJSW003	721670	7478287	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
8	PZ08YJSW003	721670	7478287	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
8	PZ08YJSW003	721670	7478287	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
8	PZ08YJSW003	721670	7478287	Isopoda	20	*Pygolabis weeli wolli*	-	
8	PZ08YJSW003	721670	7478287	Ostracoda	6	*Meridiescandona facies*	-	
8	PZ08YJSW003	721670	7478287	Ostracoda	4	*Notacandona boultoni*	-	
8	PZ08YJSW009	722534	7478167	Amphipoda	1	*Chydaekata* sp.	-	
8	PZ08YJSW009	722534	7478167	Amphipoda	1	*Maarrka weeliwolli*	-	
8	PZ08YJSW009	722534	7478167	Amphipoda	3	Paramelitidae sp. B02	-	
8	PZ08YJSW009	722534	7478167	Copepoda	70	*Diacyclops humphreysi humphreysi*	-	
8	PZ08YJSW020	724976	7479538	Copepoda	21	*Diacyclops humphreysi humphreysi*	-	
8	PZ08YOXB003	718308	7478847	Amphipoda	6	*Chydaekata* sp.	-	
8	PZ08YOXB003	718308	7478847	Amphipoda	1	Paramelitidae sp. B06	-	
8	PZ08YOXB005	718514	7477670	Amphipoda	2	*Chydaekata* sp.	-	
8	PZ08YOXB006	719936	7478158	Amphipoda	1	Paramelitidae sp. B25	-	
8	PZ08YOXB006	719936	7478158	Copepoda	1	Canthocamptidae sp. B01	-	
8	PZ08YOXB006	719936	7478158	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
8	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B06	-	
8	WW2	733200	7472664	Amphipoda	6	*Chydaekata* sp.	-	
8	WW2	733200	7472664	Amphipoda	2	*Maarrka weeliwolli*	-	
8	WW2	733200	7472664	Amphipoda	4	Paramelitidae sp. B02	-	
8	WW2	733200	7472664	Copepoda	1	Canthocamptidae sp. B01	-	
8	WW2	733200	7472664	Copepoda	10	*Diacyclops sobeprolatus*	-	
8	WW2	733200	7472664	Copepoda	10	*Gordonitocrella trajani*	-	
8	WW2	733200	7472664	Oligochaeta	1	Enchytraeidae pilbara sp. 1 (pss)	-	
8	WW2	733200	7472664	Ostracoda	2	*Gomphodella alexanderi*	-	
8	WW2	733200	7472664	Ostracoda	3	*Meridiescandona facies*	-	
8	WW2	733200	7472664	Ostracoda	4	*Notacandona boultoni*	-	
8	WW3	733370	7473592	Amphipoda	19	*Chydaekata* sp.	-	
8	WW3	733370	7473592	Amphipoda	25	Paramelitidae sp. B02	-	
8	WW3	733370	7473592	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
8	WW3	733370	7473592	Copepoda	20	*Diacyclops sobeprolatus*	-	
8	WW3	733370	7473592	Copepoda	3	*Gordonitocrella trajani*	-	
8	WW3	733370	7473592	Hydracarina	8	*Arrenurus* sp. 02	-	
8	WW3	733370	7473592	Hydracarina	1	*Guineaxonopsis* sp. S1 (PSS)	-	
8	WW3	733370	7473592	Isopoda	4	*Pygolabis weeli wolli*	-	
8	WW3	733370	7473592	Oligochaeta	1	Phreodrilid with similar ventral	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
						chaetae		
8	WW3	733370	7473592	Ostracoda	3	*Gomphodella alexanderi*	-	
8	WW3	733370	7473592	Ostracoda	4	*Notacandona boultoni*	-	
8	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
8	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
8	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
8	WW4	734448	7474705	Bathynellacea	1	*Billibathynella* sp. B3	-	
8	WW4	734448	7474705	Copepoda	16	*Diacyclops humphreysi humphreysi*	-	
8	WW4	734448	7474705	Isopoda	1	*Pygolabis weeli wolli*	-	
8	WW4	734448	7474705	Ostracoda	5	*Meridiescandona marillanae*	-	
8	WW4	734448	7474705	Ostracoda	1	*Notacandona boultoni*	-	
8	YM119	738345	7479063	Amphipoda	2	*Chydaekata* sp.	-	
8	YM119	738345	7479063	Amphipoda	3	*Maarrka weeliwolli*	-	
8	YM119	738345	7479063	Amphipoda	4	Paramelitidae sp. B02	-	
8	YM119	738345	7479063	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
8	YM119	738345	7479063	Copepoda	2	*Gordonitocrella trajani*	-	
8	YM119	738345	7479063	Ostracoda	9	*Meridiescandona facies*	-	
8	YM119	738345	7479063	Ostracoda	43	*Notacandona boultoni*	-	
9	99YJWB02	732433	7472677	Amphipoda	1	Paramelitidae sp. B02	-	
9	99YJWB03	734850	7474599	Copepoda	21	*Diacyclops cockingi*	-	
9	99YJWB04	735931	7477480	Copepoda	22	*Diacyclops cockingi*	-	
9	99YJWB04	735931	7477480	Copepoda	43	*Gordonitocrella trajani*	-	
9	BH14b	719445	7460851	Copepoda	5		-	Not identified past order
9	BH15	722005	7461150	Isopoda	1		-	Not identified past order
9	BH16s	723917	7462226	Copepoda	5		-	Not identified past order
9	BH17s	725600	7463550	Amphipoda	2		-	Not identified past order
9	BH17s	725600	7463550	Isopoda	1		-	Not identified past order
9	BH32s	726089	7463757	Amphipoda	3		-	Not identified past order
9	BH32s	726089	7463757	Copepoda	1		-	Not identified past order
9	BH32s	726089	7463757	Isopoda	5		-	Not identified past order
9	BH32s	726089	7463757	Ostracoda	3		-	Not identified past order

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
9	Fauna	726433	7483097	Hydracarina	16	Trombidioidea	-	
9	HD27	721776	7456990	Bathynellacea	2		-	Not identified past order
9	HD27	721776	7456990	Copepoda	6		-	Not identified past order
9	HD27	721776	7456990	Ostracoda	1		-	Not identified past order
9	JSE14	733707	7473602	Amphipoda	2	*Chydaekata* sp.	-	
9	JSE14	733707	7473602	Amphipoda	4	Paramelitidae sp. B02	-	
9	JSE14	733707	7473602	Amphipoda	1	Paramelitidae sp. B03	Lineage YB1	
9	JSE14	733707	7473602	Copepoda	1	*Australocamptus* sp. B6	-	
9	JSE14	733707	7473602	Copepoda	11	*Diacyclops cockingi*	-	
9	JSE14	733707	7473602	Copepoda	2	*Gordonitocrella trajani*	-	
9	JSE14	733707	7473602	Isopoda	1	*Pygolabis weeli wolli*	-	
9	JSE14	733707	7473602	Oligochaeta	3	*Enchytraeus* Pilbara sp. 2 (PSS)	-	
9	JSE39	733145	7472585	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
9	JSE39	733145	7472585	Copepoda	1	*Diacyclops cockingi*	-	
9	JSE39	733145	7472585	Isopoda	2	*Pygolabis weeli wolli*	-	
9	JSE39	733145	7472585	Ostracoda	1	*Notacandona boultoni*	-	
9	Marillana01	723792	7479113	Amphipoda	9	*Chydaekata* sp.	-	
9	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
9	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	Marillana01	723792	7479113	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	Marillana01	723792	7479113	Copepoda	5	*Diacyclops cockingi*	-	
9	Marillana01	723792	7479113	Hydracarina	5	*Arrenurus* sp. nov. yandi (sp 1)	-	
9	Marillana01	723792	7479113	Hydracarina	4	*Recifella* sp. “Yandi”	-	
9	Marillana01	723792	7479113	Ostracoda	14	*Gomphodella alexanderi*	-	
9	Marillana01	723792	7479113	Ostracoda	8	*Meridiescandona facies*	-	
9	Marillana01	723792	7479113	Ostracoda	2	*Notacandona boultoni*	-	
9	Marillana01	723792	7479113	Platyhelminthes	22		-	
9	Marillana02	725082	7479990	Amphipoda	2	*Chydaekata* sp.	-	
9	Marillana02	725082	7479990	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
9	Marillana02	725082	7479990	Isopoda	1	*Pygolabis* sp. B06	-	
9	Marillana02	725082	7479990	Oligochaeta	4	Enchytraeidae pilbara sp. 1 (pss)	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
9	Marillana02	725082	7479990	Ostracoda	75	*Meridiescandona facies*	-	
9	Marillana03	728209	7479045	Amphipoda	7	*Chydaekata* sp.	-	
9	Marillana03	728209	7479045	Amphipoda	1	*Maarrka weeliwolli*	-	
9	Marillana03	728209	7479045	Amphipoda	4	Paramelitidae sp. B02	-	
9	Marillana03	728209	7479045	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
9	Marillana03	728209	7479045	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
9	Marillana03	728209	7479045	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
9	Marillana03	728209	7479045	Oligochaeta	2	*Pristina longiseta*	-	
9	Marillana03	728209	7479045	Ostracoda	3	*Candonopsis tenuis*	-	
9	Marillana06	731182	7478693	Amphipoda	45	Paramelitidae sp. B02	-	
9	Marillana06	731182	7478693	Copepoda	10	*Diacyclops cockingi*	-	
9	Marillana06	731182	7478693	Copepoda	1	*Microcyclops varicans*	-	
9	Marillana06	731182	7478693	Hydracarina	1	Halacaridae	-	
9	Marillana06	731182	7478693	Oligochaeta	21	*Insulodrilus* sp.	-	
9	Marillana06	731182	7478693	Platyhelminthes	24		-	
9	Marillana07	725592	7480218	Amphipoda	2	*Maarrka weeliwolli*	-	
9	Marillana07	725592	7480218	Amphipoda	30	Paramelitidae sp. B03	-	
9	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B03	Lineage WWA2	
9	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B03	Lineage WWA2	
9	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B03	Lineage WWA2	
9	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B03	Lineage WWA2	
9	Marillana07	725592	7480218	Amphipoda	1	Paramelitidae sp. B03	Lineage WWA2	
9	Marillana07	725592	7480218	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
9	Marillana07	725592	7480218	Hydracarina	1	*Recifella* sp. “Yandi”	-	
9	Marillana07	725592	7480218	Isopoda	4	*Pygolabis* sp. B06	-	
9	Marillana07	725592	7480218	Ostracoda	2	*Candonopsis tenuis*	-	
9	Marillana07	725592	7480218	Ostracoda	12	*Meridiescandona facies*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
9	Marillana07	725592	7480218	Ostracoda	3	*Notacandona boultoni*	-	
9	Marillana07	725592	7480218	Platyhelminthes	8		-	
9	MNEW1upstream	726009	7480355	Amphipoda	1	*Maarrka weeliwolli*	-	
9	MNEW1upstream	726009	7480355	Amphipoda	10	Paramelitidae sp. B02	-	
9	MNEW1upstream	726009	7480355	Bathynellacea	1	*Atopobathynella* sp. B07	-	
9	MNEW1upstream	726009	7480355	Bathynellacea	1	*Billibathynella* sp. B1	-	
9	MNEW1upstream	726009	7480355	Coleoptera	3	*Boongurrus occidentalis*	-	
9	MNEW1upstream	726009	7480355	Copepoda	1	*Australocyclops similis*	-	
9	MNEW1upstream	726009	7480355	Copepoda	5	*Diacyclops cockingi*	-	
9	MNEW1upstream	726009	7480355	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
9	MNEW1upstream	726009	7480355	Copepoda	1	*Microcyclops varicans*	-	
9	MNEW1upstream	726009	7480355	Hydracarina	1	*Recifella* sp. “Yandi”	-	
9	MNEW1upstream	726009	7480355	Isopoda	1	*Pygolabis* sp. B06	-	
9	MNEW1upstream	726009	7480355	Oligochaeta	2	*Enchytraeus* Pilbara sp. 2 (PSS)	-	
9	MNEW1upstream	726009	7480355	Oligochaeta	13	*Pristina longiseta*	-	
9	MNEW1upstream	726009	7480355	Ostracoda	30	*Candonopsis tenuis*	-	
9	MNEW1upstream	726009	7480355	Ostracoda	2	*Gomphodella alexanderi*	-	
9	MNEW1upstream	726009	7480355	Ostracoda	6	*Meridiescandona facies*	-	
9	MNEW1upstream	726009	7480355	Ostracoda	4	*Notacandona boultoni*	-	
9	MNEW1upstream	726009	7480355	Platyhelminthes	14		-	
9	Old BHP Airstrip	727185	7465385	Amphipoda	11		-	Not identified past order
9	Old BHP Airstrip	727185	7465385	Copepoda	7		-	Not identified past order
9	Old BHP Airstrip	727185	7465385	Ostracoda	11		-	Not identified past order
9	Old BHP camp	726660	7464250	Amphipoda	1		-	Not identified past order
9	Old BHP camp	726660	7464250	Ostracoda	39		-	Not identified past order
9	Plant	728677	7479732	Copepoda	12	*Australocamptus* sp. B6	-	
9	Plant	728677	7479732	Copepoda	9	*Diacyclops cockingi*	-	
9	PZ08YJSW009	722534	7478167	Copepoda	16	*Diacyclops cockingi*	-	
9	PZ08YJSW009	722534	7478167	Platyhelminthes	1		-	
9	PZ08YJSW020	724976	7479538	Copepoda	3	*Diacyclops cockingi*	-	
9	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	
9	WB/YJ99	725805	7480628	Amphipoda	1	Paramelitidae sp. B02	Lineage WWA2	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
9	WW2	733200	7472664	Amphipoda	4	*Chydaekata* sp.	-	
9	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
9	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW2	733200	7472664	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW2	733200	7472664	Isopoda	1	*Pygolabis weeli wolli*	-	
9	WW2	733200	7472664	Ostracoda	3	*Notacandona boultoni*	-	
9	WW3	733370	7473592	Amphipoda	1	*Chydaekata* sp.	-	
9	WW3	733370	7473592	Amphipoda	5	Paramelitidae sp. B02	-	
9	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW3	733370	7473592	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	WW3	733370	7473592	Copepoda	41	*Diacyclops cockingi*	-	
9	WW3	733370	7473592	Hydracarina	5	*Arrenurus* sp. 02	-	
9	WW3	733370	7473592	Hydracarina	2	*Guineaxonopsis* sp. S1 (PSS)	-	
9	WW3	733370	7473592	Isopoda	11	*Pygolabis weeli wolli*	-	
9	WW3	733370	7473592	Oligochaeta	25	*Enchytraeus* Pilbara sp. 2 (PSS)	-	
9	WW3	733370	7473592	Ostracoda	1	*Gomphodella alexanderi*	-	
9	WW3	733370	7473592	Ostracoda	3	*Meridiescandona facies*	-	
9	WW3	733370	7473592	Ostracoda	1	*Notacandona boultoni*	-	
9	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
9	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	-	Failed to Amplify
9	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	Lineage YB1	
9	YM119	738345	7479063	Amphipoda	5	*Chydaekata* sp.	-	
9	YM119	738345	7479063	Copepoda	2	*Diacyclops cockingi*	-	
9	YM119	738345	7479063	Copepoda	5	*Gordonitocrella trajani*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
9	YM119	738345	7479063	Oligochaeta	1	Enchytraeidae	-	
9	YM119	738345	7479063	Ostracoda	7	*Meridiescandona lucerna*	-	
9	YM119	738345	7479063	Ostracoda	24	*Notacandona boultoni*	-	
9	YMCCA	726742	7479946	Amphipoda	6	Paramelitidae sp. B02	-	
9	YMCCA	726742	7479946	Amphipoda	1	Paramelitidae sp. B16	-	Failed to Amplify
9	YMCCA	726742	7479946	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
9	YMCCA	726742	7479946	Copepoda	8	*Microcyclops varicans*	-	
9	YMCCA	726742	7479946	Hydracarina	4	*Arrenurus* sp. B03	-	
9	YMCCA	726742	7479946	Hydracarina	1	*Arrenurus* sp. nov. yandi (sp 1)	-	
9	YMCCA	726742	7479946	Oligochaeta	2	Phreodrilid with dissimilar ventral chaetae	-	
9	YMCCA	726742	7479946	Oligochaeta	7	Tubificidae stygo type 5	-	
9	YMCCA	726742	7479946	Ostracoda	12	*Candonopsis tenuis*	-	
9	YMCCA	726742	7479946	Ostracoda	3	*Gomphodella alexanderi*	-	
9	YMCCA	726742	7479946	Ostracoda	1	*Meridiescandona facies*	-	
9	YMCCA	726742	7479946	Platyhelminthes	11		-	
10	99YJWB03	734850	7474599	Amphipoda	10	*Chydaekata* sp.	-	
10	99YJWB03	734850	7474599	Copepoda	25	*Diacyclops humphreysi humphreysi*	-	
10	99YJWB04	735931	7477480	Copepoda	7	*Diacyclops humphreysi humphreysi*	-	
10	99YJWB04	735931	7477480	Copepoda	4	*Gordonitocrella trajani*	-	
10	JSE14	733707	7473602	Amphipoda	1	*Chydaekata* sp.	-	
10	JSE14	733707	7473602	Amphipoda	1	*Maarrka weeliwolli*	-	
10	JSE14	733707	7473602	Ostracoda	1	*Meridiescandona facies*	-	
10	JSE39	733145	7472585	Isopoda	6	*Pygolabis weeli wolli*	-	
10	Marillana03	728209	7479045	Amphipoda	1	*Chydaekata* sp.	-	
10	Marillana03	728209	7479045	Amphipoda	1	*Maarrka weeliwolli*	-	
10	Marillana03	728209	7479045	Amphipoda	2	Paramelitidae sp. B02	-	
10	Marillana03	728209	7479045	Copepoda	1	*Mesocyclops* sp.	-	juvenile
10	Marillana03	728209	7479045	Hydracarina	1	Arrenurus sp.	-	juvenille
10	Marillana03	728209	7479045	Ostracoda	1	*Notacandona boultoni*	-	
10	Marillana06	731182	7478693	Amphipoda	5	Paramelitidae sp. B02	-	
10	Marillana06	731182	7478693	Copepoda	1	Canthocamptidae sp. B01	-	
10	Marillana06	731182	7478693	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
10	Marillana06	731182	7478693	Copepoda	9	*Mesocyclops darwini*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
10	Marillana06	731182	7478693	Copepoda	1	*Microcyclops varicans*	-	
10	Marillana06	731182	7478693	Oligochaeta	8	*Pristina longiseta*	-	
10	Marillana06	731182	7478693	Oligochaeta	2	Tubificidae stygo type 1A	-	Immature 1/1a
10	Marillana06	731182	7478693	Ostracoda	3	*Gomphodella alexanderi*	-	
10	Marillana06	731182	7478693	Ostracoda	5	*Notacandona boultoni*	-	
10	Marillana06	731182	7478693	Platyhelminthes	19	Platyhelminthes sp.	-	
10	Marillana07	725592	7480218	Amphipoda	13	*Chydaekata* sp.	-	
10	Marillana07	725592	7480218	Amphipoda	7	Paramelitidae sp. B02	-	
10	Marillana07	725592	7480218	Copepoda	3	*Diacyclops humphreysi humphreysi*	-	
10	Marillana07	725592	7480218	Hydracarina	1	Arrenurus sp.	-	female
10	Marillana07	725592	7480218	Hydracarina	3	*Recifella* sp. “Yandi”	-	
10	Marillana07	725592	7480218	Ostracoda	2	*Candonopsis tenuis*	-	
10	Marillana07	725592	7480218	Ostracoda	30	*Gomphodella alexanderi*	-	
10	Marillana07	725592	7480218	Ostracoda	7	*Meridiescandona facies*	-	
10	Marillana07	725592	7480218	Platyhelminthes	34	Platyhelminthes sp.	-	
10	MNEW1upstream	726009	7480355	Amphipoda	2	*Chydaekata* sp.	-	
10	MNEW1upstream	726009	7480355	Amphipoda	2	*Maarrka weeliwolli*	-	
10	MNEW1upstream	726009	7480355	Amphipoda	20	Paramelitidae sp. B02	-	
10	MNEW1upstream	726009	7480355	Copepoda	13	*Diacyclops humphreysi humphreysi*	-	
10	MNEW1upstream	726009	7480355	Copepoda	1	*Mesocyclops darwini*	-	
10	MNEW1upstream	726009	7480355	Hydracarina	2	Arrenurus sp.	-	female
10	MNEW1upstream	726009	7480355	Hydracarina	1	*Limnesia* sp. B03	-	male, this is not the same species as B01 collected here from a previous sampling event. i have compared the males and there are many differences.
10	MNEW1upstream	726009	7480355	Hydracarina	1	*Recifella* sp. “Yandi”	-	
10	MNEW1upstream	726009	7480355	Isopoda	6	*Pygolabis weeli wolli*	-	
10	MNEW1upstream	726009	7480355	Ostracoda	28	*Candonopsis tenuis*	-	
10	MNEW1upstream	726009	7480355	Ostracoda	2	*Gomphodella alexanderi*	-	
10	MNEW1upstream	726009	7480355	Ostracoda	1	*Meridiescandona facies*	-	
10	MNEW1upstream	726009	7480355	Ostracoda	20	*Notacandona boultoni*	-	
10	MNEW1Upstream	726009	7480355	Platyhelminthes	5	Platyhelminthes sp.	-	
10	Plant	728677	7479732	Amphipoda	3	Paramelitidae sp. B02	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
10	Plant	728677	7479732	Copepoda	2	Canthocamptidae sp. B01	-	
10	Plant	728677	7479732	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
10	Plant	728677	7479732	Ostracoda	4	*Meridiescandona lucerna*	-	cb2 seta present
10	PZ08YJSW003	721670	7478287	Amphipoda	1	*Chydaekata* sp. B01	-	
10	PZ08YJSW003	721670	7478287	Amphipoda	10	Paramelitidae sp. B02	-	
10	PZ08YJSW003	721670	7478287	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
10	PZ08YJSW003	721670	7478287	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
10	PZ08YJSW003	721670	7478287	Isopoda	50	*Pygolabis weeli wolli*	-	
10	PZ08YJSW003	721670	7478287	Ostracoda	1	*Meridiescandona facies*	-	
10	PZ08YJSW003	721670	7478287	Ostracoda	7	*Notacandona boultoni*	-	
10	PZ08YJSW003	721670	7478287	Platyhelminthes	2	Platyhelminthes sp.	-	
10	PZ08YOXB006	719936	7478158	Isopoda	3	*Pygolabis weeli wolli*	-	
10	WB/YJ99	725805	7480628	Amphipoda	5	Paramelitidae sp. B02	-	has a gravid female
10	WB/YJ99	725805	7480628	Ostracoda	1	*Candonopsis tenuis*	-	
10	WW2	733200	7472664	Amphipoda	5	*Chydaekata* sp.	-	
10	WW2	733200	7472664	Amphipoda	3	Paramelitidae sp. B02	-	
10	WW2	733200	7472664	Copepoda	15	*Diacyclops humphreysi humphreysi*	-	
10	WW3	733370	7473592	Amphipoda	20	*Chydaekata* sp.	-	
10	WW3	733370	7473592	Amphipoda	3	*Maarrka weeliwolli*	-	
10	WW3	733370	7473592	Hydracarina	2	Arrenurus sp.	-	female and juv
10	WW3	733370	7473592	Isopoda	4	*Pygolabis weeli wolli*	-	
10	WW3	733370	7473592	Ostracoda	1	*Meridiescandona facies*	-	
10	WW4	734448	7474705	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
10	YM119	738345	7479063	Amphipoda	17	*Chydaekata* sp.	-	
10	YM119	738345	7479063	Amphipoda	1	*Maarrka weeliwolli*	-	
10	YM119	738345	7479063	Amphipoda	2	Paramelitidae sp. B02	-	
10	YM119	738345	7479063	Copepoda	15	*Diacyclops humphreysi humphreysi*	-	
10	YM119	738345	7479063	Copepoda	1	*Gordonitocrella trajani*	-	
10	YM119	738345	7479063	Ostracoda	1	*Notacandona boultoni*	-	
10	YMCCA	726742.35	7479946.3	Amphipoda	2	Paramelitidae sp. B02	-	
10	YMCCA	726742	7479946	Bathynellacea	4	*Billibathynella* sp. B01	-	
10	YMCCA	726742	7479946	Copepoda	1	*Australocyclops similis*	-	
10	YMCCA	726742	7479946	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
10	YMCCA	726742	7479946	Copepoda	1	*Microcyclops varicans*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
10	YMCCA	726742	7479946	Hydracarina	1	*Recifella* sp. “Yandi”	-	male
10	YMCCA	726742	7479946	Oligochaeta	3	*Enchytraeus* Pilbara sp. 2 (PSS)	-	
10	YMCCA	726742	7479946	Ostracoda	39	*Candonopsis tenuis*	-	
10	YMCCA	726742	7479946	Ostracoda	1	Gomphodella sp.	-	juv
10	YMCCA	726742	7479946	Ostracoda	10	*Meridiescandona facies*	-	no cb2 seta, valve pattern more facies like
10	YMCCA	726742	7479946	Ostracoda	1	*Notacandona boultoni*	-	
10	YMCCA	726742	7479946	Platyhelminthes	2	Platyhelminthes sp.	-	
11	99YJWB03	734850	7474599	Amphipoda	3	*Chydaekata* sp.	-	
11	99YJWB03	734850	7474599	Copepoda	36	*Diacyclops humphreysi humphreysi*	-	
11	99YJWB03	734850	7474599	Copepoda	1	*Gordonitocrella trajani*	-	
11	99YJWB04	735931	7477480	Copepoda	53	*Diacyclops humphreysi humphreysi*	-	
11	99YJWB04	735931	7477480	Copepoda	68	*Gordonitocrella trajani*	-	
11	JSE14	733707	7473602	Amphipoda	6	*Chydaekata* sp. B01	-	
11	JSE14	733707	7473602	Amphipoda	9	Paramelitidae sp. B02	-	
11	JSE14	733707	7473602	Copepoda	17	*Diacyclops humphreysi humphreysi*	-	
11	JSE14	733707	7473602	Hydracarina	3	*Guineaxonopsis* sp. S1 (PSS)	-	
11	JSE14	733707	7473602	Oligochaeta	1	Tubificidae stygo type 1A	-	
11	JSE14	733707	7473602	Ostracoda	24	*Notacandona boultoni*	-	dissected vmale, checked hemipenis etc
11	JSE14	733707	7473602	Platyhelminthes	1	Platyhelminthes sp.	-	
11	Marillana01	723792	7479113	Amphipoda	3	*Chydaekata* sp.	-	
11	Marillana01	723792	7479113	Amphipoda	44	Paramelitidae sp. B02	-	
11	Marillana01	723792	7479113	Hydracarina	1	*Arrenurus* sp. B03	-	female
11	Marillana01	723792	7479113	Hydracarina	1	*Arrenurus* sp. nov. yandi (sp 1)	-	female
11	Marillana01	723792	7479113	Isopoda	1	Pygolabis sp.	-	juv
11	Marillana01	723792	7479113	Ostracoda	4	*Gomphodella alexanderi*	-	
11	Marillana01	723792	7479113	Ostracoda	130	*Meridiescandona facies*	-	
11	Marillana01	723792	7479113	Platyhelminthes	5	Platyhelminthes sp.	-	
11	Marillana03	728209	7479045	Amphipoda	5	Paramelitidae sp. B02	-	
11	Marillana03	728209	7479045	Isopoda	1	Pygolabis sp.	-	juvenile
11	Marillana03	728209	7479045	Ostracoda	2	*Meridiescandona facies*	-	
11	Marillana06	731182	7478693	Copepoda	80	*Mesocyclops darwini*	-	
11	Marillana06	731182	7478693	Copepoda	10	*Mesocyclops notius*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
11	Marillana06	731182	7478693	Copepoda	4	Naididae sp.	-	immature & semimature specimens only
11	Marillana06	731182	7478693	Copepoda	10	*Thermocyclops decipiens*	-	
11	Marillana06	731182	7478693	Isopoda	3	Pygolabis sp.	-	
11	Marillana06	731182	7478693	Ostracoda	2	*Notacandona boultoni*	-	
11	Marillana06	731182	7478693	Platyhelminthes	133	Platyhelminthes sp.	-	
11	Marillana07	725592	7480218	Amphipoda	6	Paramelitidae sp. B02	-	
11	Marillana07	725592	7480218	Bathynellacea	1	*Atopobathynella* sp. B04	-	male, 7 pairs of legs id from drawings
11	Marillana07	725592	7480218	Copepoda	100	*Diacyclops humphreysi humphreysi*	-	
11	Marillana07	725592	7480218	Isopoda	1	*Pygolabis* sp. B06	-	damaged male
11	Marillana07	725592	7480218	Nematoda	2	Nematoda sp	-	
11	Marillana07	725592	7480218	Oligochaeta	39	*Pristina longiseta*	-	
11	Marillana07	725592	7480218	Ostracoda	28	*Meridiescandona facies*	-	
11	Marillana07	725592	7480218	Ostracoda	7	*Notacandona boultoni*	-	
11	Marillana07	725592	7480218	Platyhelminthes	3	Platyhelminthes sp.	-	
11	MNEW1upstream	726009	7480355	Amphipoda	9	*Chydaekata* sp.	-	
11	MNEW1upstream	726009	7480355	Amphipoda	1	*Maarrka weeliwolli*	-	
11	MNEW1upstream	726009	7480355	Amphipoda	5	Paramelitidae sp. B02	-	
11	MNEW1Upstream	726009	7480355	Copepoda	2	*Australoeucyclops karaytugi*	-	
11	MNEW1upstream	726009	7480355	Copepoda	8	*Diacyclops humphreysi humphreysi*	-	
11	MNEW1upstream	726009	7480355	Isopoda	8	*Pygolabis* sp. B06	-	
11	MNEW1upstream	726009	7480355	Ostracoda	18	*Candonopsis tenuis*	-	
11	MNEW1upstream	726009	7480355	Ostracoda	3	*Gomphodella alexanderi*	-	valves
11	MNEW1upstream	726009	7480355	Ostracoda	7	*Gomphodella* sp. BOS334	-	
11	MNEW1upstream	726009	7480355	Ostracoda	17	*Meridiescandona facies*	-	
11	MNEW1upstream	726009	7480355	Ostracoda	1	New genus sp. BOS333	-	T2 with 2 long and 1 short setae, ant claw of furca with v long spine, valves elongataed trapezoid with lucerna like markings. Lost furca in dissection (BOS333)
11	MNEW1upstream	726009	7480355	Ostracoda	26	*Notacandona boultoni*	-	
11	PZ08YJSW003	721670	7478287	Amphipoda	1	Paramelitidae sp. B02	-	
11	PZ08YJSW003	721670	7478287	Copepoda	2	*Australoeucyclops karaytugi*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
11	PZ08YJSW003	721670	7478287	Copepoda	19	*Diacyclops cockingi*	-	
11	PZ08YJSW003	721670	7478287	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
11	PZ08YJSW003	721670	7478287	Isopoda	62	*Pygolabis weeli wolli*	-	
11	PZ08YJSW003	721670	7478287	Ostracoda	1	*Notacandona boultoni*	-	
11	PZ08YJSW003	721670	7478287	Ostracoda	1	Ostracoda (unident) sp.	-	
11	PZ08YJSW009	722534	7478167	Copepoda	74	*Diacyclops humphreysi humphreysi*	-	
11	PZ08YJSW009	722534	7478167	Oligochaeta	2	Phreodrilid with similar ventral chaetae	-	
11	PZ08YJSW020	724976	7479538	Amphipoda	1	*Chydaekata* sp.	-	fragment only (prob chydakata)
11	PZ08YJSW020	724976	7479538	Amphipoda	1	Paramelitidae sp. B02	-	
11	PZ08YOXB004	718788	7477937	Amphipoda	5	Paramelitidae sp. B02	-	
11	PZ08YOXB004	718788	7477937	Copepoda	1	*Metacyclops pilbaricus*	-	female
11	WW2	733200	7472664	Amphipoda	6	*Chydaekata* sp.	-	
11	WW2	733200	7472664	Amphipoda	3	*Chydaekata* sp.	-	
11	WW2	733200	7472664	Amphipoda	37	Paramelitidae sp. B02	-	
11	WW2	733200	7472664	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
11	WW2	733200	7472664	Isopoda	3	*Pygolabis weeli wolli*	-	males
11	WW2	733200	7472664	Isopoda	2	*Pygolabis weeli wolli*	-	
11	WW2	733200	7472664	Oligochaeta	5	*Enchytraeus* Pilbara sp. 2 (PSS)	-	
11	WW2	733200	7472664	Ostracoda	2	*Gomphodella alexanderi*	-	
11	WW2	733200	7472664	Ostracoda	6	*Meridiescandona facies*	-	
11	WW3	733370	7473592	Amphipoda	3	Paramelitidae sp. B02	-	
11	WW4	734448	7474705	Amphipoda	8	*Chydaekata* sp.	-	
11	WW4	734448	7474705	Amphipoda	1	*Maarrka weeliwolli*	-	
11	WW4	734448	7474705	Amphipoda	1	Paramelitidae sp. B02	-	
11	WW4	734448	7474705	Copepoda	20	*Diacyclops humphreysi humphreysi*	-	
11	WW4	734448	7474705	Isopoda	2	Pygolabis sp.	-	female and juv (prob welliwolli but need male)
11	YM119	738345	7479063	Amphipoda	1	Paramelitidae sp. B02	-	male vial says harpacticoida
11	YM119	738345	7479063	Copepoda	19	*Diacyclops humphreysi humphreysi*	-	
11	YM119	738345	7479063	Copepoda	1	*Gordonitocrella trajani*	-	male vial says isopoda
11	YMCCA	726742.35	7479946.3	Amphipoda	2	*Chydaekata* sp.	-	
11	YMCCA	726742.35	7479946.3	Amphipoda	2	*Maarrka weeliwolli*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
11	YMCCA	726742.35	7479946.3	Amphipoda	15	Paramelitidae sp. B02	-	
11	YMCCA	726742.35	7479946.3	Amphipoda	6	Paramelitidae sp. B02	-	
11	YMCCA	726742	7479946	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
11	YMCCA	726742	7479946	Copepoda	20	*Microcyclops varicans*	-	
11	YMCCA	726742	7479946	Hydracarina	1	*Arrenurus* sp. B03	-	female
11	YMCCA	726742	7479946	Oligochaeta	10	*Pristina longiseta*	-	
11	YMCCA	726742	7479946	Ostracoda	22	*Candonopsis tenuis*	-	
11	YMCCA	726742	7479946	Ostracoda	10	*Meridiescandona facies*	-	mostly juv
11	YMCCA	726742	7479946	Ostracoda	1	*Meridiescandona lucerna*	-	juv
11	YMCCA	726742	7479946	Ostracoda	2	*Notacandona boultoni*	-	juv
11	YMCCA	726742	7479946	Platyhelminthes	46	Platyhelminthes sp.	-	
11	YPP07	728673	7479755	Copepoda	7	*Australocamptus* sp. B06	-	
11	YPP07	728673	7479755	Copepoda	47	Diacyclops sp.	-	all juvs
12	99YJWB03	734850	7474599	Amphipoda	1	-	Lineage YB5	YB5/*Paramelitidae* sp. MC1/*Maarka* sp. MA1
12	D06YJ386	736680	7478500	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
12	D07YJ138	740142	7479848	Protozoa	6	–	-	
12	D08YJ186	740352	7482471	Copepoda	10	*Diacyclops humphreysi humphreysi*	-	
12	D08YJ186	740352	7482471	Nematoda	1	–	-	
12	D08YJ230	738814	7480909	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
12	DD09YJ017	732220	7472638	Nematoda	1	–	-	
12	MM031	741404	7479549	Bathynellacea	1	*Billibathynella* sp. B01	-	
12	RC04YJ2349	736500	7476992	Nematoda	1	–	-	
12	RC06YJ006	737239	7477941	Amphipoda	1	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
12	RC06YJ006	737239	7477941	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	RC06YJ006	737239	7477941	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	RC06YJ006	737239	7477941	Copepoda	2	Canthocamptidae sp. B01	-	Note: previous records of *Australocamptus* sp. B06 are now = Canthocamptidae sp. B01.
12	RC06YJ006	737239	7477941	Copepoda	13	*Diacyclops humphreysi humphreysi*	-	
12	RD09YJ114	733738	7473098	Nematoda	1	-	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
12	RD09YJ258	733600	7471329	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	RD10YJ129	734552	7474128	Amphipoda	2	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	RS10YJ004	735117	7473986	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	TS3DC	738706	7479737	Amphipoda	4	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
12	TS3DC	738706	7479737	Amphipoda	1	-	Lineage YB4	YB4/*Maarka weeliwollii*
12	TS3DC	738706	7479737	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
12	TS3DC	738706	7479737	Amphipoda	2	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	99YJWB01	740705	7482617	Copepoda	3	*Diacyclops humphreysi humphreysi*	-	
13	99YJWB01	740705	7482617	Copepoda	5	*Gordonitocrella trajani*	-	
13	99YJWB02	732433	7472677	Amphipoda	11	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	99YJWB02	732433	7472677	Copepoda	29	*Diacyclops humphreysi humphreysi*	-	
13	99YJWB02	732433	7472677	Copepoda	1	*Gordonitocrella trajani*	-	
13	99YJWB02	732433	7472677	Isopoda	1	*Pygolabis weeli wolli*	-	
13	99YJWB02	732433	7472677	Ostracoda	1	*Meridiescandona facies*	-	
13	D07YJ079	733416	7471574	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	D07YJ079	733416	7471574	Copepoda	15	*Diacyclops humphreysi humphreysi*	-	
13	D08YJ188	739792	7480757	Amphipoda	16	-	Lineage YB2	YB2/Paramelitidae sp. H8
13	D08YJ188	739792	7480757	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	D08YJ188	739792	7480757	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
13	D08YJ188	739792	7480757	Copepoda	3	*Paracyclops chiltoni*	-	This has longer furca and shorter spines on P4 than typical *chiltoni*.
13	D08YJ188	739792	7480757	Hydracarina	1	*Arrenurus* sp.	-	Small; either *Arrenurus* sp 2 or 3, but would need to see specimens collected from previous rounds to confirm.

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
13	D08YJ188	739792	7480757	Isopoda	1	*Pygolabis weeli wolli*	-	
13	D08YJ188	739792	7480757	Oligochaeta	2	*Dero furcata*	-	Cosmopolitan species, with 4 pairs of gills and two caudal filaments.
13	D08YJ188	739792	7480757	Ostracoda	1	*Meridiescandona facies*	-	
13	D08YJ188	739792	7480757	Ostracoda	2	*Notacandona boultoni*	-	
13	D08YJ216	739004	7480406	Amphipoda	1	Indet.	-	Failed to Amplify
13	D08YJ216	739004	7480406	Copepoda	9	*Diacyclops humphreysi humphreysi*	-	
13	D08YJ216	739004	7480406	Oligochaeta	1		-	Immature Phreodrilidae with paired bifid ventral chaetae and 1-2 hairs per dorsal bundle. N=1.
13	JSE34	732386	7477126	Isopoda	3	*Pygolabis weeli wolli*	-	
13	JSE37	736346	7477140	Copepoda	1	Cyclopoida sp.	-	Very juvenile; cannot identify further.
13	JSE37	736346	7477140	Hydracarina	1	*Recifella* sp. “Yandi”	-	
13	JSE38	734525	7473866	Copepoda	1	*Diacyclops humphreysi humphreysi*	-	
13	JSE39	733145	7472585	Amphipoda	1	-	Lineage YB5	YB5/Paramelitidae sp. MC1/*Maarka* sp. MA1
13	JSE39	733145	7472585	Copepoda	7	*Diacyclops humphreysi humphreysi*	-	
13	JSE39	733145	7472585	Copepoda	6	*Gordonitocrella trajani*	-	
13	MB13YB001	735850	7476371	Amphipoda	2	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	MB13YB001	735850	7476371	Amphipoda	1	-	Lineage YB4	YB4/*Maarka weeliwollii*
13	MB13YB001	735850	7476371	Amphipoda	2	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	MB13YB001	735850	7476371	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB001	735850	7476371	Isopoda	2	*Pygolabis weeli wolli*	-	
13	MB13YB001	735850	7476371	Ostracoda	6	*Notacandona boultoni*	-	
13	MB13YB002	736047	7476325	Amphipoda	5	-	Lineage YB3	YB3/new species
13	MB13YB002	736047	7476325	Amphipoda	3	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	MB13YB002	736047	7476325	Copepoda	9	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB002	736047	7476325	Copepoda	10	*Gordonitocrella trajani*	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
13	MB13YB002	736047	7476325	Isopoda	1	*Pygolabis weeli wolli*	-	
13	MB13YB002	736047	7476325	Ostracoda	1	*Meridiescandona facies*	-	Juvenile.
13	MB13YB004	736363	7476281	Amphipoda	2	Paramelitidae sp. B03	-	
13	MB13YB004	736363	7476281	Amphipoda	1	Paramelitidae sp. B16	-	
13	MB13YB004	736363	7476281	Bathynellacea	2	*Brevisomabathynella* cf. *pilbaraensis*	-	Differences to *pilbaraensis* (type locality is 85 km away) are minor, having longer spines on the furca and uropodal endopodite. Two described species of this genus from the Pilbara (Ethel Creek and Millstream) have only small differences between them also.
13	MB13YB005	736211	7476323	Amphipoda	1	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	MB13YB005	736211	7476323	Amphipoda	3	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	MB13YB005	736211	7476323	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB005	736211	7476323	Ostracoda	3	*Meridiescandona facies*	-	Juveniles.
13	MB13YB006	735256	7474379	Amphipoda	1	-	Lineage YB3	YB3/new species
13	MB13YB006	735256	7474379	Copepoda	12	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB006	735256	7474379	Ostracoda	2	*Meridiescandona facies*	-	
13	MB13YB006	735256	7474379	Platyhelminthes	1	-	-	Unsure of identification.
13	MB13YB007	734992	7474665	Amphipoda	1	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	MB13YB007	734992	7474665	Amphipoda	1	-	Lineage YB3	YB3/new species
13	MB13YB007	734992	7474665	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	MB13YB007	734992	7474665	Amphipoda	1	Indet.	-	Failed to Amplify
13	MB13YB007	734992	7474665	Copepoda	4	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB007	734992	7474665	Ostracoda	1	*Notacandona boultoni*	-	
13	MB13YB008	734588	7475007	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB009	734693	7474937	Copepoda	6	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB009	734693	7474937	Ostracoda	4	*Meridiescandona* sp. BOS399	-	

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
13	MB13YB010	734833	7474814	Amphipoda	1	-	Lineage YB5	YB5/Paramelitidae sp. MC1/*Maarka* sp. MA1
13	MB13YB010	734833	7474814	Amphipoda	2	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	MB13YB010	734833	7474814	Copepoda	3	*Diacyclops humphreysi humphreysi*	-	
13	MB13YB010	734833	7474814	Isopoda	3	*Pygolabis weeli wolli*	-	
13	MB13YJSE001	733023	7473992	Copepoda	19	*Diacyclops humphreysi humphreysi*	-	
13	WB13YB001	736555	7476263	Amphipoda	1	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	WB13YB001	736555	7476263	Amphipoda	2	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	WB13YB001	736555	7476263	Amphipoda	1	Indet.	-	Failed to Amplify
13	WB13YB001	736555	7476263	Copepoda	5	*Diacyclops humphreysi humphreysi*	-	
13	WB13YB002	735125	7474523	Amphipoda	4	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	WB13YB002	735125	7474523	Bathynellacea	1	*Billibathynella* sp. B02 (=Parabathynellidae sp. S03)	-	
13	WB13YB002	735125	7474523	Copepoda	2	*Diacyclops humphreysi humphreysi*	-	
13	WB13YB002	735125	7474523	Hydracarina	1	*Recifella* sp. “Yandi”	-	
13	WB13YB002	735125	7474523	Isopoda	1	*Pygolabis weeli wolli*	-	
13	WB13YB002	735125	7474523	Ostracoda	18	*Meridiescandona facies*	-	
13	WB13YB003	735996	7477431	Amphipoda	1	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	WB13YB003	735996	7477431	Oligochaeta	3		-	Immature Naididae with 3-4 bifid chaetae per bundle dorsally and ventrally and dorsal chaetal bundles also with a single hair. Bifid chaetae with thin teeth; lower thicker and longer than upper. N=3 + fragments (fragments may include extra animals with heads missing).
13	WB13YB003	735996	7477431	Ostracoda	2	*Meridiescandona* sp. BOS399	-	This species is similar to *M. marillanae* but dorsal arch of shell is flat, no CB1 seta, male max. palps narrower.

Phase	Bore Name	Easting (m E)	Northing (m N)	Field Specimen ID	Number	Morphological Identification	Genetic Lineage	Notes
13	WB13YB005	734094	7472322	Amphipoda	3	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	WB13YB005	734094	7472322	Amphipoda	1	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	YM119	738345	7479063	Amphipoda	3	-	Lineage YB1	YB1/Paramelitidae sp. WW-2C
13	YM119	738345	7479063	Amphipoda	3	-	Lineage YB6	YB6/*Chydaekata* sp. E
13	YM119	738345	7479063	Copepoda	11	*Diacyclops humphreysi humphreysi*	-	
13	YM119	738345	7479063	Isopoda	1	*Pygolabis weeli wolli*	-	Immature male.

Biota Environmental Sciences

Yandi Billiards – Interim Report on Conservation Significant Terrestrial Fauna

Prepared for Rio Tinto Iron Ore

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Yandi Billiards Interim Report on Conservation Significant Terrestrial Fauna

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1.0 Introduction

1.1 Project Background

Rio Tinto currently operates the Yandi iron ore mine as part of its Pilbara Iron operations. Yandi is located approximately 75 km northwest of Newman in the Pilbara region of Western Australia. The original Yandi mine, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999. The Yandi operations are approved under *Environmental Protection Act 1986* Ministerial Statement 914 (MS914; see Figure 1.1).

Rio Tinto is currently undertaking a 'Pre-feasibility Study' for development of two channel-iron deposits at Yandi Billiards, Pocket and Billiards South, located approximately 7 km east of the existing Yandi mine.

It is anticipated that the future development of Yandi Billiards will be formally assessed under the State *Environmental Protection Act 1986* and potentially the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Any potential impacts on fauna species listed as Threatened under the *EPBC Act 1999* constitutes a Matter of National Environmental Significance (MNES) and requires referral under the Commonwealth act.

Numerous biological surveys have been completed in the Yandi locality, and although some of these overlap Yandi Billiards, they do not provide full coverage of the anticipated development area. A desktop review and gap analysis of the surveys completed in the Yandi Billiards area was recently conducted (Biota 2013a), in order to determine further work required to bring the information for the area to a level suitable to support environmental impact assessment under both State and Commonwealth legislation.

Biota Environmental Sciences (Biota) was commissioned to undertake a Level 2, seasonal fauna survey and a targeted survey in the Yandi Billiards area to address the recommendations of the desktop review and gap analysis report (Biota 2014a, 2014b). Currently, only Phase 1 of the Level 2 survey has been conducted, with Phase 2 fieldwork scheduled for September 2014. A targeted survey for the Threatened Northern Quoll (*Dasyurus hallucatus*) was also completed in July 2014. The Yandi Billiards survey area is approximately 8,640 ha in size and is hereafter referred to as the 'study area' (see Figure 1.1).

1.2 Scope and Objectives of this Study

The objective of this report is to provide up to date information on conservation significant fauna at Yandi Billiards that are relevant to the terms of the *EPBC Act 1999*. To this end, this report will act as a supporting document for referral of the Yandi Billiards development to the Department of the Environment (DotE). The fauna relevant to the referral comprise MNES species listed as Critically Endangered, Endangered or Vulnerable under the *EPBC Act 1999.*

Investigation of records from previous studies in the vicinity of Yandi billiards has been conducted, including fauna recorded at Yandi Billiards from the first phase of the Level 2 study (Biota 2014a) and recent Northern Quoll (*Dasyurus hallucatus*) targeted surveys (Biota 2009a, 2014b).

1.3 Relevant MNES Fauna Species

Reviews of previous surveys (Biota 2013a), database and literature searches have identified that five MNES fauna species may potentially occur in the study area (Table 1.1).

Table 1.1: MNES fauna species potentially occurring in the study area based on database searches.

Scientific name	Common name	Conservation Status	
		State	Federal
Pezoporus occidentalis	Night Parrot	S1	Critically Endangered
Dasyurus hallucatus	Northern Quoll	S1	Endangered
Liasis olivaceus barroni	Pilbara Olive Python	S1	Vulnerable
Macrotis lagotis	Bilby	S1	Vulnerable
Rhinonicteris aurantia	Pilbara Leaf-nosed Bat	S1	Vulnerable

A current account of survey effort expended to detect these species in the study area and results to date are presented in Section 2.0 and 3.0 respectively. Additional reviews of relevant databases were also conducted to supplement the existing knowledge base in regards to MNES species in the study area (see Section 2.4).

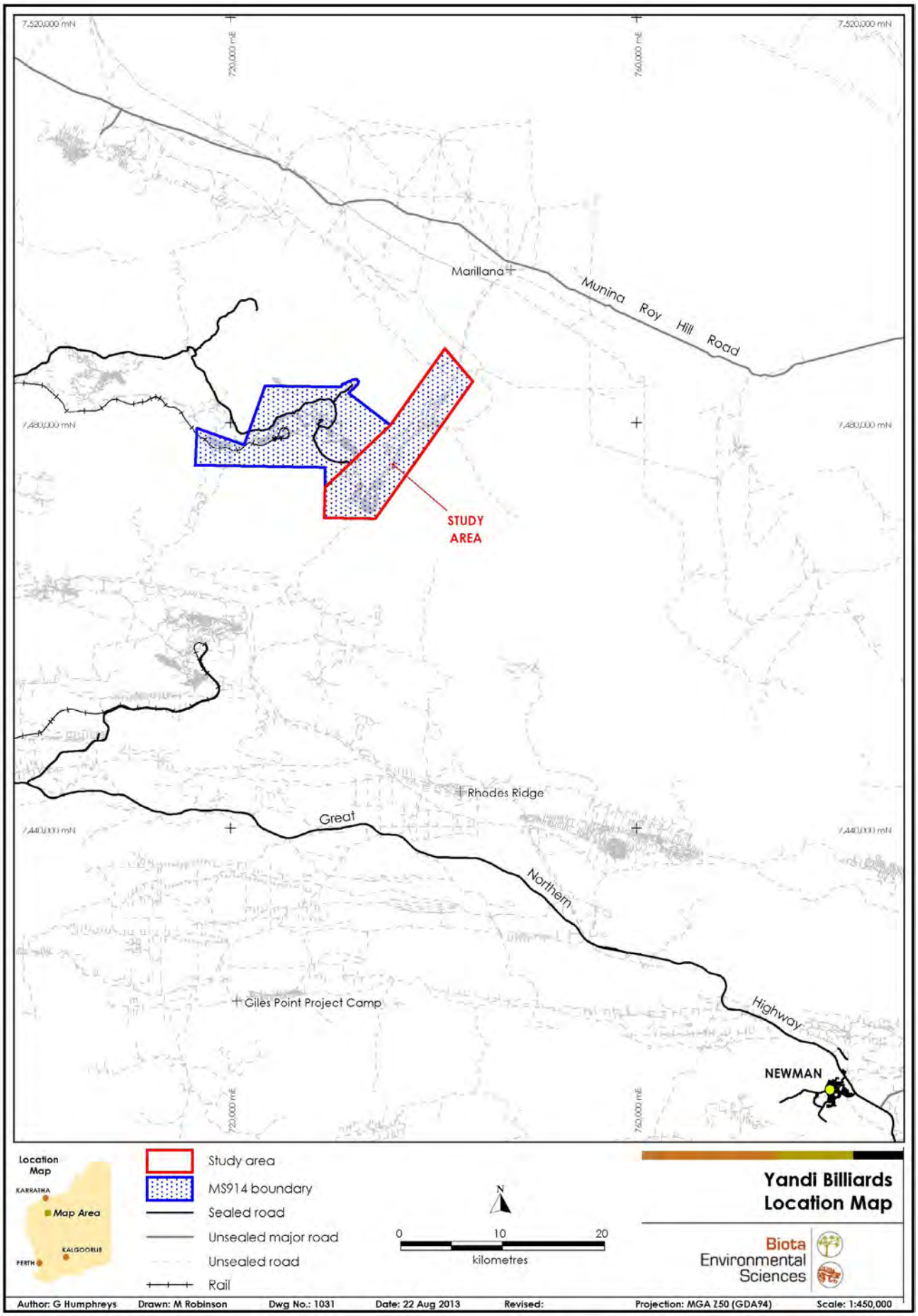

Figure 1.1: Location of the study area and the MS914 boundary.

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2.0 Summary of Survey Effort and Methodology

2.1 Overview of Fauna Sampling

Phase 1 of the Level 2 fauna survey consisted of systematic baseline trapping combined with opportunistic and targeted searching for conservation significant vertebrates. The survey was completed over a 10-day period, from March 8th to 18th, 2014 (Biota 2014a) (Section 2.2). In addition, a targeted Northern Quoll survey was also conducted within the study area in August 2014 (Biota 2014b) (Section 2.3).

2.2 Level 2 Fauna Survey (Phase 1)

The fauna survey consisted of baseline trapping combined with opportunistic and targeted searching for conservation significant vertebrates (Biota 2014a). Systematic terrestrial fauna sampling was carried out at 11 sites located in land systems that were not sampled, or sampled at lower intensity, during previous surveys in the study area (based on findings of Biota 2013).

Systematic trapping sites comprised:

- Five pitfall trapping grids, consisting of a single row of ten pit-fall traps (alternating 20 litre buckets and PVC tubes), spaced at approximately 10 m intervals and connected with a 100 m single length of 30 cm high flywire fence.
- Four funnel trapping grids, consisting of 8-10 pairs of funnel traps (i.e. 16-20 traps) placed adjacent to a 100 m single length of 30 cm high flywire fence.
- Two Elliott trap transects, consisting of ten large Elliott box traps, four cage traps and 25 medium Elliott traps (sampling for Northern Quoll (*Dasyurus hallucatus*)).

Sampling of avifauna was conducted using a combination of techniques including:

- unbounded, habitat-specific area searches (30 minute duration) conducted at each of the systematic trapping sites; and
- opportunistic observations of birds while traversing the study area.

A minimum of two systematic avifauna surveys was conducted at each of the systematic sites. These surveys provided a total of 11.5 person hours of systematic avifauna survey for the study area.

Bats were sampled at five sites from echolocation call recordings using SongMeter SM2BAT bat detector units, which detect and record ultrasonic echolocation calls emitted by bats during flight. This methodology is appropriate to detect the Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*) if present.

Non-systematic sampling targeting vertebrate conservation significant species and other cryptic or additional species that are not likely to be trapped systematically was conducted at 11 locations. Non-systematic sampling techniques were included:

- motion camera trapping (suitable for Northern Quoll (*Dasyurus hallucatus*) and Pilbara Olive Python (*Liasis olivaceus barroni*) if present);
- nocturnal searches (suitable for Pilbara Olive Python (*Liasis olivaceus barroni*) and Night Parrot (*Pezoporus occidentalis*) if present);
- searches for evidence and secondary signs in habitat potentially containing fauna of conservation significance (all potential MNES fauna species); and,
- audio recording for night birds and amphibian calls using SM2 SongMeter bat detector units configured to record audible noise (suitable for Night Parrot (*Pezoporus occidentalis*) if present).

2.3 Targeted Northern Quoll Survey

Targeted trapping for the Northern Quoll (*Dasyurus hallucatus*) was carried out by two Biota zoologists in accordance with the federal referral guidelines (DSEWPaC 2011). Sites were chosen within the study area to represent a range of habitats with the best potential to be utilised by Northern Quolls including drainage lines and breakaways. Transects comprising of 20 large Elliott traps and four cage traps were deployed at each of five trapping locations for a minimum of seven nights (Biota 2014b).

In addition, timed track and scat searches were conducted and baited remote cameras were deployed for a minimum of three days at each systematic trapping site. The survey was undertaken from 5th to 13th August 2014, consistent with the timing identified in DSEWPaC (2011).

While this survey primarily targeted the Northern Quoll, the opportunity was also taken to deploy four SM2 SongMeter bat detection units over the course of the survey and to include searches for evidence of Pilbara Olive Pythons during traverses for the Northern Quoll.

2.4 Database Searches and Likelihood Assessment

In addition to the survey effort outlined in Sections 2.1 to 2.3, the following databases were searched to further inform the likelihood of MNES species occurring in the study area:

1. The Commonwealth *EPBC Act 1999* Protected Matters Database was searched to identify MNES fauna species that may occur in the locality.
2. NatureMap[1] was then used to review records of the MNES fauna species identified from the *EPBC Act 1999* Protected Matters Database. NatureMap is the most comprehensive source of information on the distribution of the State's fauna, and comprises records from the Fauna Survey Returns Database(maintained by the Department of Parks and Wildlife (DPaW)), the WA Museum Specimen Database, and BirdLife Australia's Atlas of Australian Birds.

The MNES species identified as potentially occurring in the study area were then assigned a likelihood ranking based on the criteria detailed in Table 2.1.

Table 2.1: Ranking system used to assign the likelihood that a species would occur in the study area.

Rank	Criteria
Recorded	1. The species has been previously recorded in the study area.
Likely	1. There are existing records of the species in close proximity to the study area, or from the locality; and • the species is strongly linked to a specific habitat, which is present in the study area; or • the species has more general habitat preferences, and suitable habitat is present.
May potentially occur	1. There are existing records of the species from the locality, however • the species is strongly linked to a specific habitat, of which only a small amount is present in the study area; or • the species has more general habitat preferences, but only some suitable habitat is present. 2. There is suitable habitat in the study area, but the species is recorded infrequently in the region.
Unlikely	1. The species is linked to a specific habitat, which is absent from the study area; or 2. Suitable habitat is present, however there are no existing records of the species from the locality despite reasonable previous search effort in suitable habitat; or 3. There is some suitable habitat in the study area, however the species is very infrequently recorded in the region.
Would not occur	1. The species is strongly linked to a specific habitat, which is absent from the study area; and/or 2. The species' range is very restricted and would not include the study area.

[1] http://naturemap.dec.wa.gov.au

3.0 MNES Fauna in the Study Area

3.1 Recorded MNES Fauna

To date, the Pilbara Olive Python (*Liasis olivaceus barroni*) (Plate 3.1) is the only MNES threatened fauna species recorded within the study area (Figure 3.1). Two avifauna species listed as Migratory under the *EPBC Act 1999* have also been recorded, but neither is of conservation concern in regards to the proposed development of the Yandi Billiards project.

Pilbara Olive Python *Liasis olivaceus barroni* (State: Schedule 1, Federal: Vulnerable)

A single Pilbara Olive Python was observed in Weeli Wolli Creek during a nocturnal search YBLNoct04 (22º50'39"S, 119º15'56"E; Figure 1.1). The species has also been previously recorded in the immediate vicinity of the study area, with several sightings made at the existing Yandi operations at Marillana Creek.

The Pilbara Olive Python appears to be relatively common in the wider locality with additional nearby records from Koodaideri (38 km northwest; Biota 2012), and Flat Rocks (37 km west; Biota 2013b) and Hope Downs (21 km southwest; Biota 2009a), which lie within the same catchment.

Plate 3.1: Pilbara Olive Python *Liasis olivaceus barroni*.

Regarded as a Pilbara endemic, the Pilbara Olive Python has a known distribution that coincides roughly with the Pilbara bioregion (Environment Australia 2000). Core habitat for the species includes gorges, escarpments, rocky outcrops and water holes where it may find suitable prey that utilise these environments (DotE 2014). It seeks shelter in caves, beneath boulders, in pools of water and occasionally in trees overhanging water (Bush and Maryan 2011).

Within the study area, its core habitat is likely to be consistent with that described above; comprising the major riverine systems of Marillana and Weeli Wolli Creeks and the limited rocky breakaway landforms present (see Figure 1.1). The great majority of this habitat, and the current record, occur outside of areas that may be affected by the planned mine pit and waste dump locations for the development (Figure 1.1), but within the zone of potential hydrological impact.

Fork-tailed Swift, *Apus pacificus* (State: Schedule 3, Federal: Migratory)

An opportunistic observation of nine Fork-tailed Swift individuals flying over the study area was made during the Biota (2014a) survey. This species is expected to be a transient visitor to the study area and is unlikely to rely on any terrestrial habitats present, as it is entirely aerial in Australia, occurring only as a non-breeding visitor (Johnstone and Storr 1998).

Rainbow Bee-eater, *Merops ornatus* (State: Schedule 3, Federal: Migratory)

This species has been recorded on numerous occasions opportunistically and whilst conducting systematic avifauna surveys in the study area (Biota 2014a). This species, which is very common and widespread in the Pilbara bioregion (Biota 2013c), is likely to be a breeding resident or non-breeding visitor to the region, with Weeli Wolli Creek providing attractive wetter habitat with ample tall trees from which to forage (Johnstone and Storr 1998).

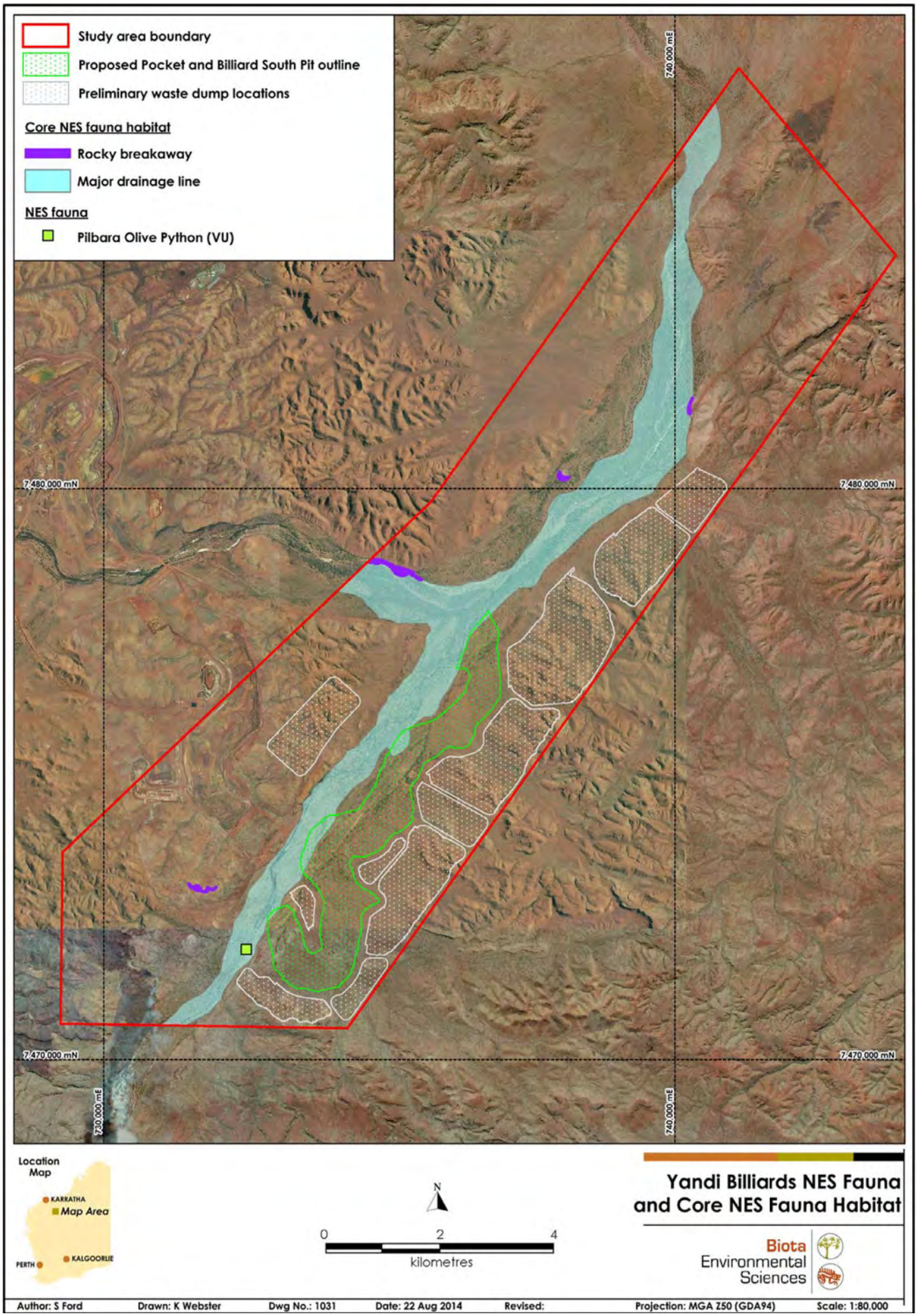

Figure 3.1: Locations of recorded MNES fauna and MNES core habitat, showing conceptual mine pit and waste dump design.

3.2 MNES Fauna that May Potentially Occur in the Study Area

Five of the remaining MNES species yielded by database searches (Table 1.1; Appendix 1) may potentially occur in the study area but have yet to be confirmed.

Northern Quoll *Dasyurus hallucatus* (State: Schedule 1, Federal: Endangered)

The Northern Quoll is considered to primarily occur along rocky gorges, rocky free faces and hills, usually of high relief; and secondarily along drainage lines, which are used for denning purposes (DEWHA 2010, DSEWPaC 2011). Adjacent plains and vegetated areas provide habitats suitable for foraging and dispersal of young (Van Dyck and Strahan 2008), but are considered to be of less importance for the purpose of the species' conservation.

There has been anecdotal sighting of Northern Quoll individuals at the existing Yandi warehouse (Biota 2009a, 2010) and camp (M. Brand, Rio Tinto, pers. comm. 2014). However, these represents the only evidence from the Yandi vicinity in the past 19 years and come from a higher relief area containing landforms more suitable for the species than the current study area. With a total trap effort of over 10,000 Elliott trap nights spread over a number of years and seasons in the Yandi operational mine area, it is considered extremely unlikely that a significant population of this species occurs within the study area (Biota 2010). The species may potentially occur in the study area, but the recent targeted Northern Quoll survey at Billiards detected no evidence of its presence (Biota 2014b) and suitable core habitat is limited to a few rocky breakaways, all of which are outside conceptual mine pit and waste dump locations (Figure 3.1).

Pilbara Leaf-nosed Bat *Rhinonicteris aurantia* (State: Schedule 1, Federal: Vulnerable)

The occurrence of this species is influenced by the availability and proximity of suitable roost caves (Churchill 1998); that is, deep caves offering suitable humidity and a stable temperature.

In the Pilbara, they are thought to be restricted to caves where at least semi-permanent water is nearby (Bob Bullen, Bat Call WA, pers. comm. 2013). The habitats of the study area may provide foraging opportunities for this species, but no suitable roost caves are currently known to occur in the vicinity. The closest known roost is situated at Koodaideri, some 43 km to the northwest, which is outside of the maximum documented foraging range of individual Pilbara Leaf-nosed Bats (approximately 30 km from the roost; Biota 2013c). It is possible another currently unknown *Rhinonicteris aurantia* roost occurs in the locality but the probability of this is relatively low and no echolocation calls of the species have been recorded to date during any of the field surveys.

Other Migratory Species.

The *EPBC Act 1999* search results list three other migratory species that may occur in the study area, comprising the Great Egret *Ardea alba*, Cattle Egret *Ardea ibis* and Oriental Plover *Charadrius veredus* (Appendix 1). None of these avifauna have been recorded during recent systematic surveys of the study area (Biota 2014a).

All of these species may potentially occur in the study area on a periodic basis, with recent records for all three from within 40 km of the study area on NatureMap. However, these migratory taxa are likely to utilise the habitats of the study area on a transitory or intermittent basis only, if they do occur. There are no records of breeding activity or other data that suggest these migratory species are reliant on the habitats of the study area.

3.3 MNES Fauna Unlikely to Occur in the Study Area

Three of the MNES fauna species identified by database searches are considered unlikely to occur and no evidence of their presence has been detected during recent surveys.

Night Parrot *Pezoporus occidentalis* (State: Schedule 1, Federal: Critically Endangered)

There is a confirmed Night parrot record from Minga Well, north of the Fortescue Marsh (Davis and

Metcalf 2008), and an unconfirmed sighting from the southern edge of the Fortescue Marsh (Roy Teale, Biota, pers. obs.). However, no evidence of this species has been observed within the study area and the majority of the habitat is not suitable.

The study area lies in the vicinity of the Fortescue Marsh (approximately 26 km at its closest point), where the most recent Night Parrot observations in Western Australia have been made. Although the Night Parrot has potential to occur in the study area, the likelihood is low due to the rare nature of this species and lack of suitable habitat.

Bilby *Macrotis lagotis* (State: Schedule 1, Federal: Endangered)

This species has been documented as holding temporary home ranges and showing relatively rapid changes in distribution in response to variation in habitat resources (Johnson 1995).

Two individuals were recorded approximately 50 km northeast of the study area in 1997 (NatureMap database). While these records came from the opposite side of the Fortescue Marsh to the study area, there is a small potential for this species to occur within the study area, particularly on the plains in the most northwestern section. However, to date no evidence of this species has been noted despite ground searches for burrows. The species is considered unlikely to be present.

Australian Painted Snipe *Rostratula australis* (State: Schedule 1, Federal: Vulnerable)

The Australia Painted Snipe is a very rarely recorded species that utilises shallow inland wetlands and swamps (Johnstone and Storr 1998). There is a single record of the species on NatureMap from the Fortescue Marsh, some 40 km east of the study area. This is consistent with Johnstone and Storr (1998) who consider the species a rare summer visitor with only three individuals recorded from the Pilbara bioregion in the last century. Given its scarcity, and the lack of recent evidence it occurs in the study area, it is considered unlikely to occur.

3.4 MNES Fauna not Occurring in the Study Area

The remaining species yielded from the *EPBC Act 1999* database search (Appendix 1), would not occur in the study area.

Northern Marsupial Mole *Notoryctes caurinus* (State: Schedule 1, Federal: Endangered)

The Northern Marsupial Mole occurs in soft red sand dunes and other suitable sandy habitats in the Great Sandy Desert and Little Sandy Desert (Benmesh and Aplin 2008). It is apparently absent from even dune swales, as these are too compacted, and does not occur in harder substrate topography. Given that no dune landforms occur in the study area, and as NatureMap indicates the nearest reliable record is from 230 km east within the Little Sandy Desert, it is reasonable to conclude the species would not occur in the study area.

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Appendix 1

EPBC Act 1999 Search Tool Results

Australian Government

Department of the Environment

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 15/09/14 15:58:53

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements

No Image Available

This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates
Buffer: 1.0Km

No Image Available

Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Areas:	None
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	8
Listed Migratory Species:	6

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place and the heritage values of a place on the Register of the National Estate.

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	6
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

Place on the RNE:	None
State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	8
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat likely to occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Mammals		
Dasyurus hallucatus Northern Quoll [331]	Endangered	Species or species habitat likely to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Notoryctes caurinus Kakarratul, Northern Marsupial Mole [295]	Endangered	Species or species habitat likely to occur within area
Rhinonicteris aurantia (Pilbara form) Pilbara Leaf-nosed Bat [82790]	Vulnerable	Species or species habitat likely to occur within area
Plants		
Lepidium catapycnon Hamersley Lepidium, Hamersley Catapycnon [9397]	Vulnerable	Species or species habitat likely to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies) [66699]	Vulnerable	Species or species habitat likely to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Migratory Wetlands Species		
Ardea alba Great Egret, White Egret [59541]		Species or species habitat likely to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Species or species habitat likely to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Extra Information

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Mammals		
Camelus dromedarius Dromedary, Camel [7]		Species or species habitat likely to occur within area
Equus asinus Donkey, Ass [4]		Species or species habitat likely to occur within area
Equus caballus Horse [5]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Cenchrus ciliaris Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area

Coordinates

-22.6382 119.107,-22.6344 119.374,-22.8556 119.378,-22.8594 119.11,-22.6382 119.107

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World Heritage and Register of National Estate properties, Wetlands of International Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Department of Environment, Climate Change and Water, New South Wales
-Department of Sustainability and Environment, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment and Natural Resources, South Australia
-Parks and Wildlife Service NT, NT Dept of Natural Resources, Environment and the Arts
-Environmental and Resource Management, Queensland
-Department of Environment and Conservation, Western Australia
-Department of the Environment, Climate Change, Energy and Water
-Birds Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-SA Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
-State Forests of NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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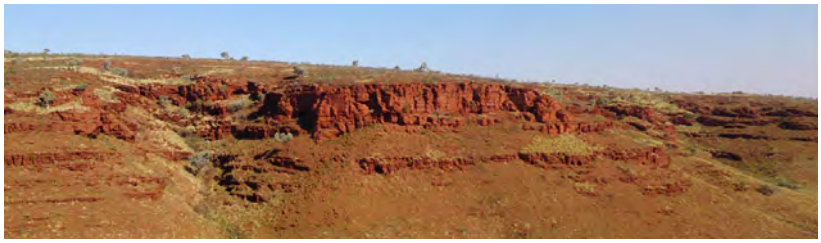
Yandi Billiards Troglobitic Fauna Assessment



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Yandi Billiards Troglobitic Fauna Assessment

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1.0 Executive Summary

Rio Tinto plans to sustain the operations at the existing Yandicoogina (Yandi) mine, located approximately 90 km northwest of Newman, Western Australia. The proposed sustaining operations include the development of the Channel Iron Deposits (CID) at Pocket and Billiard South (PBS) within the existing Yandi Operations development envelope (MS914).

Following earlier survey work, Biota was commissioned to undertake a second phase of troglobitic fauna sampling within the study area. Troglobitic fauna, or troglofauna, are considered to be of conservation significance, given species often display extreme short-range endemism and may be affected by relatively small-scale developments such as mining and construction.

Phase 2 of troglofauna sampling was completed under "Licence to Take Fauna for Scientific Purposes" No. SF009624. Methodology and approach were consistent with those outlined in Environmental Protection Agency (EPA) Guidance Statement No. 54a and EPA Environmental Assessment Guideline (EAG) No. 12.

Two phases of troglofauna sampling have now been completed in the wider Yandi tenure to date. A total of 52 sites were sampled in 2009, Phase 1, incorporating 58 traps installed. Thirty-four of these sites, 46 traps, were located within the current Yandi Billiards study area, and were considered in this report. Phase 2 was completed in 2014, with a total of 32 sites sampled with 58 troglofauna traps. Additionally, troglofauna were collected as by-catch from four sites during past stygofauna sampling within the wider Yandi tenure. All troglobitic fauna records from the broader Yandi tenure are included in the results of this report, however this assessment focused on those collected within the Billiards study area.

Several geological units within the study area are recognised as being suitable for troglobitic fauna as they characteristically incorporate interstitial spaces, vugs or fractures that provide habitat space when above water table. The relevant units present in the study area included alluvium, colluvium, calcrete and banded iron formation. These habitats combined comprise 86.1% of the surface geology units of the Billiards study area.

Six troglobitic fauna specimens have been recorded in the wider Yandi tenure. Taxa collected comprise:

- the spider *Myrmopopaea* sp. nov – collected from Billiards study area site WW2;
- the beetle Pselaphinae sp. indet – collected from Billiards study area site RC13YBR0037;
- a pauropod, Pauropoda sp. indet. - collected from Billiards study area site D07YJ218;
- the schizomids *Draculoides* sp. 'Lineage WWS1' (site RC13YBR0038) and *Draculoides* sp. indet. (site WW3) – both collected from Billiards study area; and
- the pseudoscorpion *Lagynochthonius* sp. nov. - collected from JSW deposit, site MNEW1upstream (outside of the Billiards study area).

Four of the five specimens recorded from within the Billiards study area were collected from sites outside the PBS deposit itself. The taxon *Myrmopopaea* sp. nov. was the only specimen recorded from within the PBS deposit. Given the geology where this specimen was recorded, continuous and interconnected calcrete and alluvium, it is unlikely that this species is restricted to this site, and it is more probable that the single record is a sampling artefact. These geological units run in a generally connected extent adjacent to the course of Weeli Wolli Creek and contain sufficient interstitial spaces and cavities to allow movement of troglobitic fauna. This habitat continuity suggests that *Myrmopopaea* sp. nov. is likely to occur more widely than the current record and its distribution probably extends beyond the study area.

Given the limited returns from sampling completed to-date, both via troglofauna habitat traps and via stygofauna haul nets, it is unlikely that troglobitic fauna inhabit the PBS Deposit in high density. Additional sampling targeting surrounding geologies would be required to better

determine potential core troglofauna habitats within the Billiards study area as the primary habitat for the fauna in the area is currently poorly defined. The long-term persistence of the fauna in this riverine habitat setting also suggests these habitats are well connected with other older geological units that do provide core habitat over longer timeframes.

2.0 Introduction

Rio Tinto Pty Ltd (Rio Tinto) currently operates the Yandi iron ore mine located approximately 90 km northwest of Newman in the Pilbara region of Western Australia (Figure 2.1). The original Yandi deposit, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999. An expansion to existing mining developments was later proposed in 2005 in the form of the Junction South East (JSE) deposit. A number of other expansions have subsequently occurred, including at the Junction South West (JSW) and Oxbow deposits (Figure 2.1).

Rio Tinto plans to sustain the operations at the existing Yandicoogina (Yandi) mine, located approximately 90 km northwest of Newman, Western Australia. The proposed sustaining operations include the development of the Channel Iron Deposits at Pocket and Billiard South (PBS) within the existing Yandi Operations development envelope (MS914; Figure 2.1). Approximately 99% of the PBS deposit lies below the water table. Historical phases of stygobitic fauna (or stygofauna) sampling at Billiards and the surrounding tenements collected several specimens of troglobitic fauna (troglofauna) (Biota 2010a). Mining operations have the potential to impact on troglobitic fauna communities and as such, Environmental Protection Authority (EPA) policy requires Rio Tinto to determine potential impacts on subterranean fauna prior to operations commencing (EPA 2013).

2.1 Troglobitic Fauna Background

Australia was historically thought to lack habitat suitable for subterranean fauna. Studies in recent decades however, mostly with an emphasis on environmental impact assessment, have revealed Australia to be highly diverse in subterranean fauna with numerous areas of interest throughout the continent (Guzik et al. 2010). In Western Australia these zones of subterranean biodiversity can be found at the Nullarbor, Yilgarn, Cape Range, Barrow Island and the Pilbara bioregion (Humphreys 2001, Page et al. 2008, Guzik et al. 2010).

Subterranean fauna can be categorised into two distinct ecological groups based on habitat, troglobitic fauna (troglofauna) and stygobitic fauna (stygofauna). Troglofauna are a suite of fauna that survive only in air-filled cavities and interstices between the surface and the water table. Troglobites are obligatory subterranean habitat dwellers, and while they may occur close to surface environments, are strongly adapted to subterranean environments. This makes such fauna unable or highly unlikely to survive surface conditions. A range of similarly adapted fauna occur that opportunistically use subterranean habitats but are able to survive outside these stable environments. Studies from the Pilbara bioregion have demonstrated that these latter suites of fauna; troglophiles, trogloxenes and edaphobites, are not similarly restricted in range and therefore unlikely to be impacted at taxon level by small scale developments (Biota and Helix 2011, Helix 2012).

Troglofauna in northern Western Australia have been known for some time from karstic limestone systems on Cape Range and Barrow Island. Surveys in the Pilbara over the past decade or more have collected subterranean fauna from other geological units such as banded iron formations, channel iron deposits, unconsolidated alluvium and sedimentary basalt (Marmonier et al. 1993, Biota 2004, 2006a, 2010a, 2011a, 2013a), indicating that the suitability of a formation as habitat for troglobitic fauna is mostly a function of the availability of habitable space (Marmonier et al. 1993, Humphreys 1999, Biota 2006a), rather than a specific rock type.

Subterranean habitats are characterised by shared physical parameters that include a lack of light, stable temperature, limited nutrient infiltration from surface environments and a constant humidity (Juberthie 2001, Romero 2009). These habitat characteristics have resulted in convergence in body morphology evolution amongst many subterranean fauna.

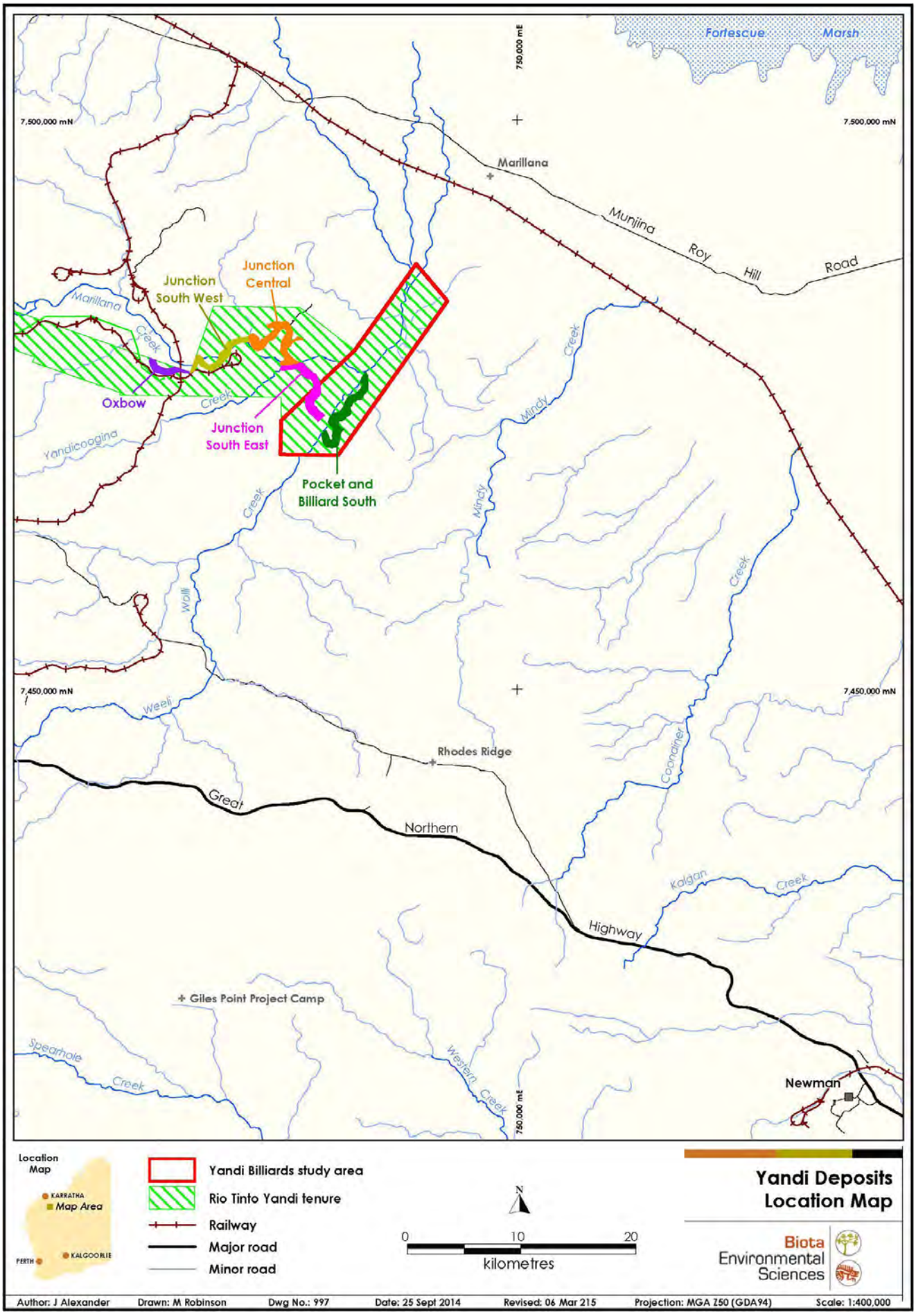

Figure 2.1: Location of Yandi mine areas in relation nearby Newman townsite.

Morphological characteristics common to most subterranean fauna include reduced or lack of pigmentation, reduced or lack of eyes, and elongate body morphology and appendages adapted for sensory movement (Culver and Pipan 2009, Romero 2009).

Troglofauna in semi-arid Australia are thought to be relictual rainforest fauna. Fauna adapted to humid environments, which retreated underground to subterranean environments during the aridification of Australia (in the late Miocene; Humphreys 1993). This is inferred from affinities of the taxonomic groups represented amongst the troglofauna with other extant taxa in tropical climates. Some invertebrate groups with troglobitic representatives include the Arachnida (e.g. Schizomida, Pseudoscorpiones and Araneae), Chilopoda (e.g. Scolopendrida), Diplopoda (e.g. Polydesmida and Haplodesmida), and Insecta (e.g. Diplura, Thysanura, Coleoptera and Blattodea). A single troglobitic vertebrate species of blind snake (*Ramphotyphlops longissimus*) is known from Australia, collected from Barrow Island (Aplin 1998, Humphreys et al. 2013)

Due to their dependence on constant humidity, dispersal and distribution of troglobitic fauna species tends to remain limited to individual blocks of inter-connected habitat, leading to long periods of population isolation and localised speciation. As a result, troglobitic fauna are considered to be of conservation significance, given species often display extreme short-range endemism and species may therefore be affected by relatively small-scale developments such as mining and construction.

2.2 Study Scope and Objectives

Biota Environmental Sciences (Biota) was commissioned to undertake a single-phase troglobitic fauna survey targeting the proposed PBS deposit expansion and wider Yandi tenure, which encompasses 8,639 ha (Table 4.1). The scope of this study was to sample for additional troglobitic fauna specimens from within the Billiards study area to support the environmental assessment of the project.

The objectives of this study included:

- the implementation of a second, single-phase troglobitic fauna survey focussing on the Billiards study area;
- morphological identification of groups thought to display short range endemism or troglomorphism;
- potential genetic analysis of specimens of interest, such as Schizomida; and
- the production of a single report outlining the results of the current phase of sampling.

The aim of this report is to provide a summary of the recent phase of sampling and amalgamate historical and current data within the wider Yandi tenure, with emphasis on the Billiards study area.

2.3 Historical Sampling

Extensive sampling for stygobitic fauna has been completed in the Rio Tinto Yandi tenements. Biota has completed 13 stygofauna surveys in the Yandi locality, encompassing all operations and deposits including the PBS study area. These surveys were completed between 2003 and 2014, and have included nine monitoring surveys for the purposes of regulatory compliance (Biota 2010a, 2011b, 2011c, 2013b). While these studies do not specifically target troglobitic fauna, four specimens have been collected as by-catch from the following sites (all coordinates in zone 50, GDA94):

- D07YJ218 (732924 mE, 7471648 mN);
- MNEW1upstream (726009 mE, 7480355 mN);
- WW2 (733149 mE, 7472618 mN); and
- WW3 (733405 mE, 7473428 mN).

As a result of troglobitic fauna collections during stygofauna surveys, Biota was commissioned to completed a targeted troglobitic fauna survey, Phase 1, in 2009 (Biota 2010a). A total of 52 sites were sampled incorporating 58 traps installed. Thirty-four of these sites, comprising 46 traps, were located within the current Yandi Billiards study area, and will be focussed on in this report.

The results of this sampling are summarised in Section 5.0.

3.0 Methodology

Troglobitic fauna sampling was completed under "Licence to Take Fauna for Scientific Purposes" No. SF009624 issued to Dan Kamien (Appendix 1). Methodology and approach were consistent with those outlined in the EPA Guidance Statement No. 54a (EPA 2007) and EPA Environmental Assessment Guideline (EAG) No. 12 (EPA 2013).

3.1 Troglobitic Fauna Sampling Methodology

Troglobitic fauna were sampled by means of custom-built litter colonisation traps suspended within drillholes located within the study area. Traps were constructed from 60 mm internal diameter PVC irrigation pipe cut to a length of 180 mm. Each trap had a series of 20 mm holes drilled into the side, and traps remained open at the upper end. Up to three traps were installed to provide greater vertical coverage of the stratigraphy.

Leaf litter was gathered locally from the ground surface in the study area, particularly from the bases of *Acacia* shrubs. The collected litter was soaked in water and irradiated in a microwave oven for two minutes on maximum power setting. This killed any surface invertebrates present and assisted in the breaking down of organic matter. Wet litter was added to the traps, which were kept in sealed containers until immediately prior to insertion into the drillholes to avoid desiccation of leaf litter. After the installation of traps, the opening of each drillhole was sealed to maintain humidity and to avoid entry of surface fauna.

Traps were recovered from each drillhole after seven weeks and stored in labelled zip lock bags in order to maintain humidity and prevent desiccation of potential troglofauna specimens during transportation to Perth.

Fauna specimens were recovered from the traps using specially designed Tullgren funnel units. Leaf litter from each trap was placed in a sieve under an aluminium lamp containing a 25-watt globe. This created a temperature of approximately 30°C at the surface of the leaf litter. A funnel situated below the leaf litter collected the fauna as they fell, directing them into an attached vial of 100% ethanol. Leaf litter was left in the Tullgren funnels for a period of 24 hours, or until dry, after which time the bulked invertebrate sample was removed.

Fauna specimens collected via Tullgren funnels were identified to order level using dissecting microscopes (Olympus SZ40 and SZ61, magnification up to 40x). Fauna specimens were assigned a unique number based on drillhole name and location and tracked on customised data sheets. Specimens were preserved in 100% ethanol, which allows for both morphological and molecular analysis.

3.2 Survey Design

3.2.1 Timing and Personnel

The Yandi Billiards troglobitic fauna assessment project was managed by Jason Alexander, with directional input from Garth Humphreys of Biota. Dan Kamien, Jason Alexander, Chris Cole and Andrew Sheppard, all of Biota, completed troglofauna sampling. Sampling was completed between 17th of May and 10th of July 2014 (Table 3.1).

Table 3.1: Summary of Yandi Billiards troglofauna field survey.

Dates	Purpose	Personnel
21/05/14 – 22/05/14	Troglobitic fauna habitat trap installation	Dan Kamien, Chris Cole
9/07/14 – 10/07/14	Troglobitic fauna habitat trap recovery	Jason Alexander, Andrew Sheppard

Preliminary and final morphological identification of troglofauna specimens to order level was completed by Dr Mieke Strong of Biota. Collected schizomid specimens were handed onto Helix Molecular Solutions for genetic analysis (Appendix 2). Melissa Robinson and Kylie Webster of Biota prepared maps for field surveys and reporting purposes.

3.2.2 Sampling Effort

3.2.2.1 Phase 2 Sampling Effort

A total of 32 sites, incorporating 58 traps, were sampled during the single-phase survey in 2014 (Table 3.2, Figure 3.1). These sites were selected in liaison with Rio Tinto personnel based on accessibility and drillhole viability.

Table 3.2: Summary of location and sampling effort for troglofauna survey within the Billiards study area in 2014.

Site Name	Easting (m E)	Northing (m N)	Traps Installed	Traps Recovered	Trap depths (m)
2014 Sampling					
D06YJ237	736885	7476597	2	2	2, 7
D07YJ128	736390	7476243	1	1	5
D07YJ132	736533	7476667	1	1	5
D07YJ169	740703	7479849	3	3	10, 20, 30
D07YJ218	732924	7471648	2	2	5, 15
D08YJ010	732359	7472992	2	2	10, 20
D08YJ050	732886	7473094	2	2	2, 7
D08YJ124	738227	7478932	1	1	5
D08YJ152	735611	7477872	1	1	3
D08YJ156	735399	7477520	1	1	4
D08YJ199	739362	7480065	1	1	4
DD09YJ046	733028	7472319	2	2	10, 20
DO6YJ258	736071	7475714	1	1	5
DR08YH008	736886	7477445	1	1	4
RC04YJ2343	735224	7473733	2	2	5, 10
RC13YBR0032	742409	7485562	2	2	10, 20
RC13YBR0033	739547	7485062	2	2	10, 20
RC13YBR0035	736481	7480434	2	2	10, 20
RC13YBR0037	737952	7482681	2	2	10, 20
RC13YBR0038	738296	7482166	2	2	5, 10
RC13YBR0048	741557	7483010	3	3	15, 30, 45
RD09YJ096	733602	7473374	1	1	10
RD09YJ103	734089	7472886	2	2	5, 15
RD09YJ163	734231	7472178	3	3	10, 20, 30
RD09YJ279	734023	7471330	1	1	10
RD09YJ315	733457	7471614	3	3	10, 20, 30
RD09YJ362	733244	7471967	3	3	10, 20, 35
RD10YJ069	734513	7472744	2	2	8, 18
RD10YJ104	734445	7473662	1	1	10
RD10YJ166	735012	7474089	2	2	5, 10
RD10YJ169	734622	7474474	1	1	5
SC07YJ020	739853	7479566	3	3	15, 25, 35
		Total	58	58	

(Coordinates in GDA94, Zone 50)

Three of the sites were sampled in both Phases of sampling in 2009 and 2014. These sites include D07YJ218, D08YJ050 and RD09YJ163.

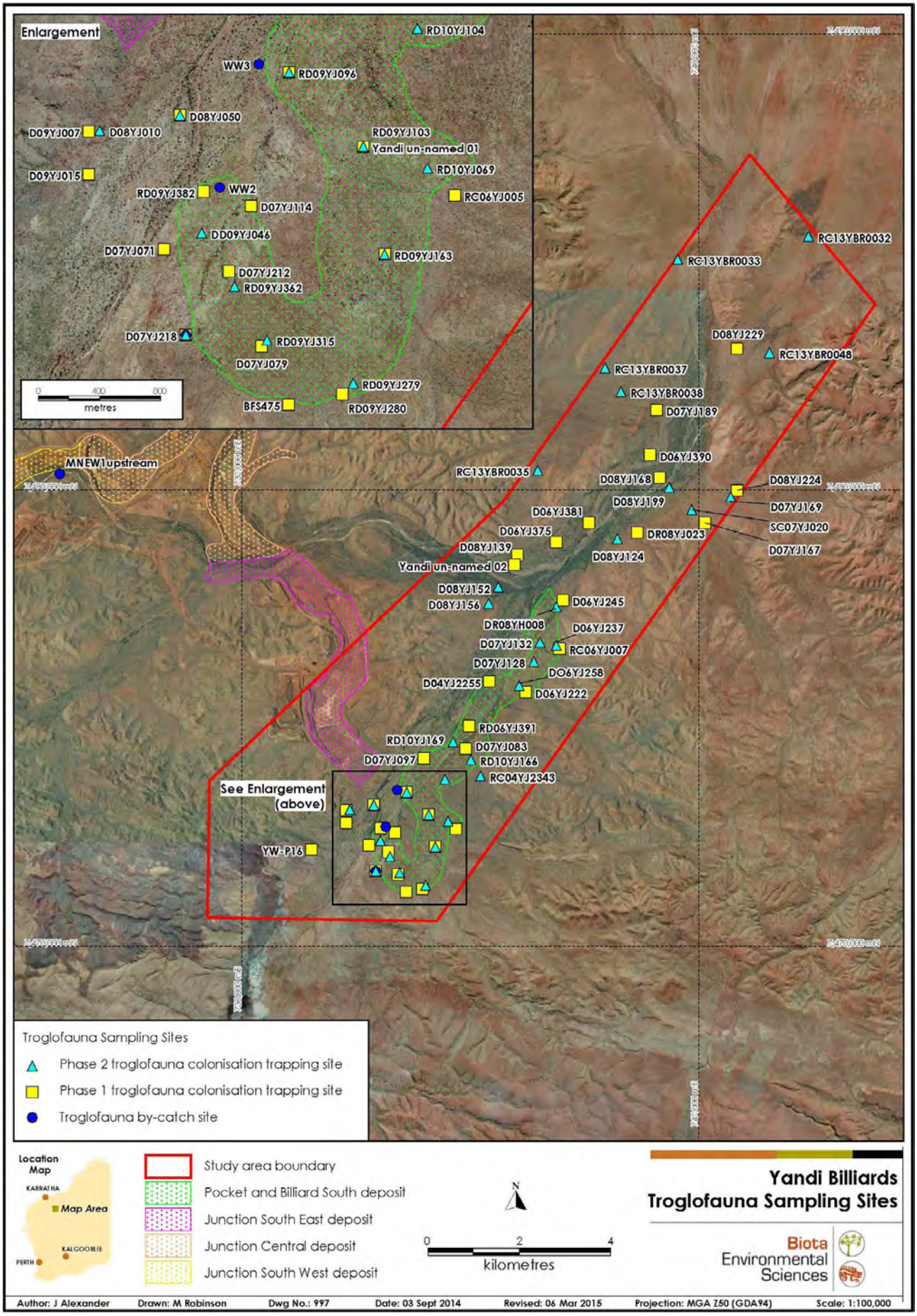

Figure 3.1: Location of sites sampled using habitat colonisation traps within the Billiards study area as well as locations of opportunistic collections.

3.3 Limitations

A number of limitations apply to the troglobitic fauna surveys completed within the Yandi Billiards study area. A specimen of Schizomida unable to be identified due to DNA degradation and as a result no further information can be provided on this specimen (distribution or conservation status).

Two of the taxa, Pauropoda and Coleoptera, were unable to be identified due to poor resolution of their wider taxonomic framework. This limited the conclusiveness of some of the findings on some taxa in regards to both taxonomic placement and ecological status. Further studies would be required to determine the conservation status of these groups.

Troglobitic fauna sampling at Yandi has been limited to existing drill holes, which are focused on the CID and the surrounding alluvium. As the alluvium is subject to seasonal inundation it is unlikely to constitute core habitat for troglobitic communities. Surveys targeting surrounding geologies above inundation level (such as surrounding hills) would be beneficial to determine core troglofauna habitat for conservation.

4.0 Geological Habitat Characterisation

The suitability of potential subterranean fauna habitat is predominantly a function of availability of space, potential for nutrient filtration from surface sources and the ability of the substrate to maintain a stable humidity. Several geological units are recognised as being suitable for troglobitic fauna as they characteristically incorporate interstitial spaces, which provide these attributes and allow for fauna dispersal. These geologies include limestone karstic systems, calcrete, alluvium (particularly when associated with paleochannel aquifers), gravels, limonite and dolomite (Marmonier et al. 1993, Humphreys 1999, Biota 2006b).

The CID in the Yandi locality forms part of the palaeodrainage of the Marillana Formation CID (Ramanaidou et al. 2004) and was formed by the erosion of shale bedrock, dolerite and Banded Iron Formation of the Weeli Wolli Formation, which overlies the older Brockman Iron Formation. The CID is mostly below the water table and is overlain with varying depths of unconsolidated alluvium and colluvium, with areas of calcrete development associated with the contemporary drainage lines.

The study area encompasses eight major surface geology units, as outlined in Geological Survey of Western Australia (2002) (Table 4.1 and Figure 4.1). These predominantly comprise Qa "Alluvium", Czc "Colluvium" and PLHj "Weeli Wolli Formation", each representing approximately 27% of the study area (Table 4.1). Most of the sites sampled during this study were located in the Qa "Alluvium", Qw "Alluvium and Colluvium" and Czk "Calcrete" geological units.

The Weeli Wolli Creek system within the study area consists of a superficial layer of alluvial aquifer overlaying CID deposit. A cross-section schematic of the PBS deposit provided in Figure 4.2.

Table 4.1: Geological units occurring in the Yandi Billiards study area.

Geological Period	Code	Description	Area (ha)	% of Study Area	Potential for Troglofauna Habitat
Quaternary Period	Qw	Alluvium and colluvium - red-brown sandy and clayey soil; on low slopes and sheetwash areas.	557	6.5	Low
	Qa	Alluvium - unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains.	2,413	27.9	Medium
	Qs	Eolian deposit - sand; in sheets and longitudinal dunes.	1	<0.1	Low
Cenozoic Era	Czp	Robe Pisolite: pisolitic limonite deposits developed along river channels.	5	0.1	High
	Czc	Colluvium - partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits.	2,337	27.1	Medium
	Czk	Calcrete - sheet carbonate; found along major drainage lines	341	3.9	High
Proterozoic Eon	PLHb	Brockman Iron Formation: banded iron-formation, chert, and pelite.	638	7.4	High
	PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills.	2,349	27.2	Medium
		Total	8,641		

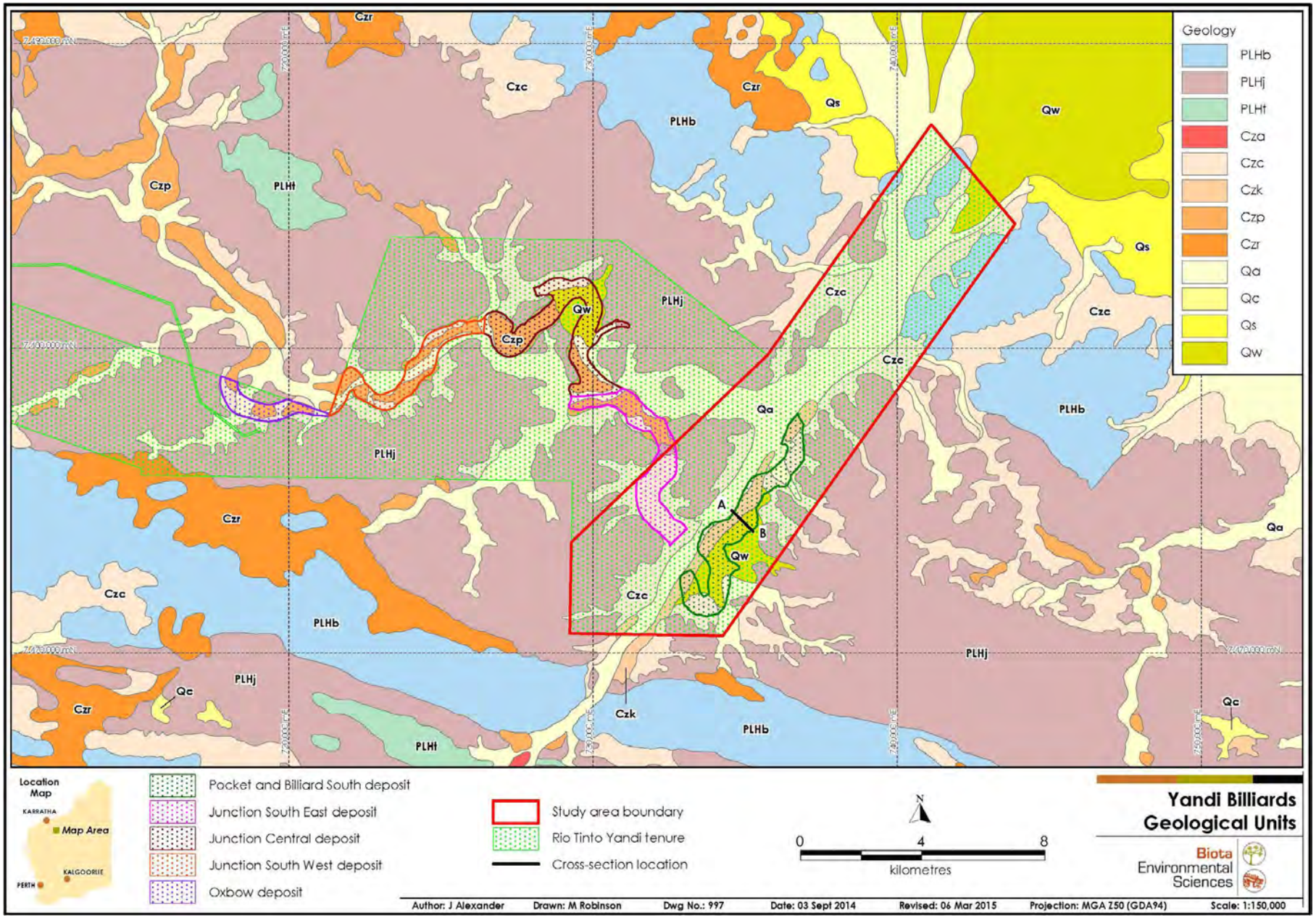

Figure 4.1: Geological units of the study area (see Table 4.1 for unit codes and descriptions).

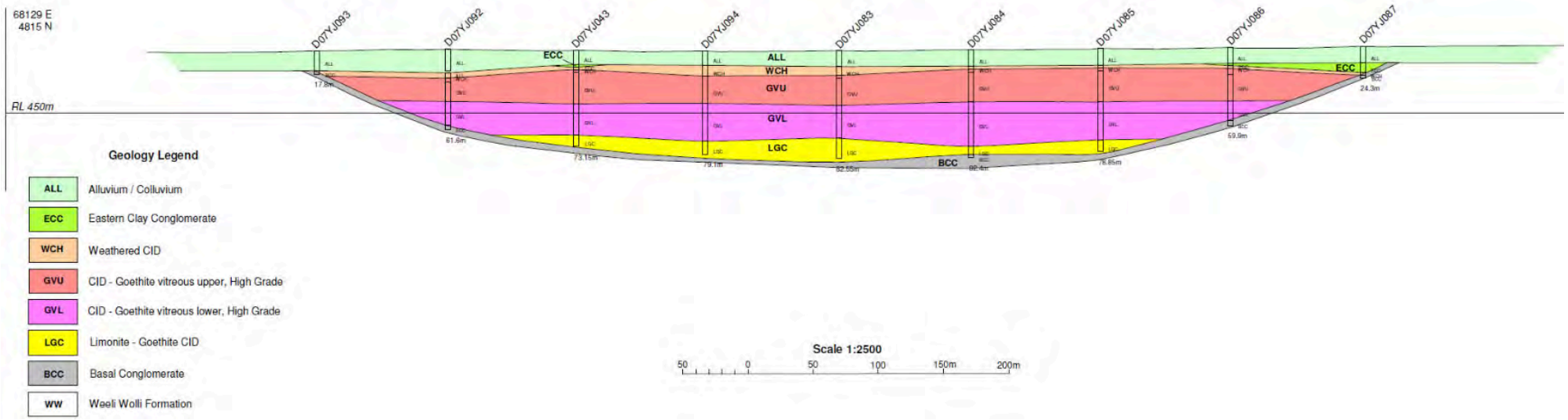

Figure 4.2: Cross-section of the PBS deposit (figure supplied by Rio Tinto).

The prospectivity of the various geological units present for troglobitic fauna is outlined in Table 4.1 based on findings of past surveys in the region. Troglobitic fauna have previously been recorded in low-lying alluvium and colluvium formations, including during extensive subterranean fauna sampling at the Bungaroo Valley (Biota 2013a). Previously completed studies have determined that troglobitic fauna potentially occur in areas where superficial alluvium and colluvium are common (Robe Headwaters, Western Hill, Mt Ella and Arrowhead; Biota 2013c). Calcrete also represents a known habitat for troglofauna as, like karst systems, provides large cavities required for movement and dispersal (Biota 2009a, 2011d, 2013c).

The geological units on the higher elevation margins of the study area include Brockman Iron formation and Weeli Wolli formation (Figure 4.1), both of which contain Banded Iron Formation (BIF) and have the potential to contain habitat for troglofauna. Brockman Iron formation, in particular, has yielded troglobitic fauna records, including in settings where adjacent to or overlain by alluvium or colluvium during various studies throughout the Pilbara, including Koodaideri, Hope Downs 4 and West Turner Syncline (Biota 2009b, 2014a, 2014b). Troglofauna habitat within these formations predominantly appears to be associated with hydrated zones, where the interaction of downward percolating groundwater and a fluctuating water table leads to cavities habitable by subterranean fauna. Hydrated zones in BIF have been identified as potential troglofauna habitat in at Koodaideri, Hope Downs 1 (Biota 2006c) and 4 (Biota 2009b) and Marandoo (Biota 2008). Hydrated zones also occur in contact with more superficial colluvial deposits (Biota 2014a), which may facilitate movement between geological units.

5.0 Survey Results

5.1 Phase 1 / Stygofauna By-Catch - Results Overview

Four specimens of troglofauna were collected using stygofauna haul nets in 2008 and 2009 (Section 2.3) throughout the wider Yandi tenure. No troglofauna were recorded from Phase 1 of troglofauna colonisation trap sampling in 2009.

Table 5.1: Summary of potential troglobitic fauna recorded as by-catch from stygofauna haul nets from the wider Yandi study tenure

Taxon			Total Individuals	Notes
Subphylum	Class	Order (Common Name)		
Chelicerata	Arachnida	Aranea (Spider)	1	Collected during stygofauna sampling in 2009.
		Pseudoscorpiones (Pseudoscorpion)	1	Collected from site MNEW1upstream, in the JSW tenement. Collected in 2009.
		Schizomida (Schizomid)	1	Collected during stygofauna sampling in 2008. Specimen partially decayed.
Uniramia	Pauropoda	Pauropod (Pauropods)	1	Collected from habitat trap in 2009
		Total	4	

Note that while polyxenid millipedes were historically collected from the area and thought to display short-range endemism, recent evidence has indicated that members of this order in the Pilbara are not SREs and are therefore not likely to be troglobites (Biota and Helix 2011). Therefore, past records of Polyxenida have not been considered as troglobitic for the purposes of this report.

5.2 Phase 2 - Results Overview

A total of 1,850 specimens were collected from troglofauna colonisation traps in 2014 (Appendix 3). As is common in troglobitic fauna sampling, many of the specimens collected were not troglobitic, but were surface (epigean) or soil (edaphobitic) fauna. This included Acarina (mites), Collembola (springtails), Diptera (flies) and Psocoptera (Booklice) (Berry 2005, Biota 2006a, 2010b). These groups are not considered at high risk of limited species distributions and are therefore at a reduced risk of impact to their conservation status from developments. For the purposes of this report no further consideration is given to these groups.

Two specimens of troglobitic fauna were collected from the Billiards Study area in 2014. These specimens represent two classes, Arachnida (order Schizomida) and Insecta (order Coleoptera). Both specimens were recorded from the north of the study area (Figure 5.2).

Table 5.2: Summary of collections from recent sampling at the Billiards study area.

Taxon			Total Individuals	Site
Subphylum	Class	Order (Common Name)		
Chelicerata	Arachnida	Schizomida (Schizomid)	1	RC13YBR0038
Uniramia	Insecta	Coleoptera (Beetle)	1	RC13YBR0037
		Total	2	

5.3 Account of Troglobitic Fauna

5.3.1 Order: Araneae (Spiders)

A single mature, female spider specimen was collected from sample site WW2 while sampling for stygofauna in April 2009 (Figure 5.2). This specimen was identified as a previously undescribed taxon (M. Harvey, W.A. Museum, pers. comm. 2009) belonging to the genus *Myrmopopaea* (*Myrmopopaea* sp. nov.).

5.3.2 Order: Coleoptera (Beetles)

A single specimen of troglobitic beetle was collected in 2014 (Plate 5.1). This specimen was recorded from site RC13YBR0037 (Figure 5.2). The specimen, belonging to the subfamily Pselaphinae (Family: Staphylinidae), was unable to be identified morphologically to species level due to a lack in taxonomic framework on the group. Pselaphinae specimens have been recorded from caves, leaf litter and ant nests and the group is very diverse in the tropics (Brian Hanich, W.A. Museum, pers. comm. 2014).

It is currently unclear if this specimen represents a troglobitic or SRE species, or is troglophilic and likely not to display restricted distribution at species level. This specimen has residual eyes which may indicate a recent adaptation to subterranean environment, or that this species inhabits both subterranean and surface environments (i.e. a trogloxene).

Prior studies completed on Coleoptera specimens from the Kimberley region in Western Australia indicates that these specimens have the potential to display short range endemism (Helix 2011).

Plate 5.1: Pselaphinae sp. indet. collected from site RC13YBR0037 at Billiards study area, dorsal (above) and lateral (below) view.

5.3.3 Order: Pauropoda (Pauropods)

These arthropods are rarely collected and the Western Australian Museum collection has only a handful of specimens from widely scattered locations (Framenau and Harvey 2009). A single pauropod specimen was collected from sample site D07YJ218, within the PBS deposit (Figure 5.2).

The status of specimen from Yandi is uncertain. It is possible that some pauropod species in Western Australian represent SRE species, but other pauropod species are widely distributed around the world, suggesting that short- range endemism is not prevalent in this group (Scheller 1960). A full taxonomic treatment of the Western Australian specimens is necessary by a specialist before their status can be properly assessed.

5.3.4 Order: Pseudoscorpiones (Pseudoscorpions)

A single troglobitic pseudoscorpion specimen belonging to the genus *Lagynochthonius* was collected from alluvial substrate at site MNEW1upstream. This mature, male specimen (*Lagynochthonius* sp. nov) is a new species collected from the JSW tenement (Figure 5.2), and is thought to represent an SRE taxon (M. Harvey, W.A. Museum, pers. comm. 2009). Further specimens would be beneficial prior to the formal description of this species.

5.3.5 Order: Schizomida (Schizomids)

Two specimens of the order Schizomida have been collected from the Billiards study area (Table 5.3, Figure 5.2). The first specimen, collected in 2008 via stygofauna haul net, was unable to be identified morphologically past genus level due to specimen degradation. Given the level of degradation, genetic analysis was also not feasible. The specimen, recorded from site WW3 within the PBS deposit, was identified as belonging to the genus *Draculoides*.

The second, juvenile schizomid specimen, collected via habitat trap in 2014, was identified to *Draculoides* sp. however again was unable to be identified further morphologically (Plate 5.2). This specimen was forwarded onto Helix for molecular analysis. This analysis placed the collected specimen in genetic lineage WWS1 (Table 5.3), distinct from reference specimens, indicating that this lineage represents a species currently unrecorded (genetically) from the Pilbara (Figure 5.1). This specimen was recorded from a reference site, RC13YBR0038, outside the PBS deposit (Figure 5.2).

Table 5.3: Summary of Schizomida collections and identification at Billiards study area.

Taxonomy			Number Collected	Site
Order	Family	Identification / Genetic Lineage		
Schizomida	Hubbardiidae	*Draculoides* sp. 'Lineage WWS1'	1	RC13YBR0038
		Draculoides sp. indet	1	WW3
		Total	2	

Plate 5.2: *Draculoides* sp. 'Lineage WWS1' collected from site RC13YBR0038 at Billiards study area, dorsal (above) and lateral (below) view.

Lineage WWS1 differed from other specimens included in the genetic analysis by between 10.2 % and 15.3 % genetic divergence (Appendix 2). Lowest sequence divergence occurred between the Yandi specimen and nearby Koodaideri specimens (between 10.2 – 10.7 % divergence) (Figure 5.1), indicating that these species share a common ancestor.

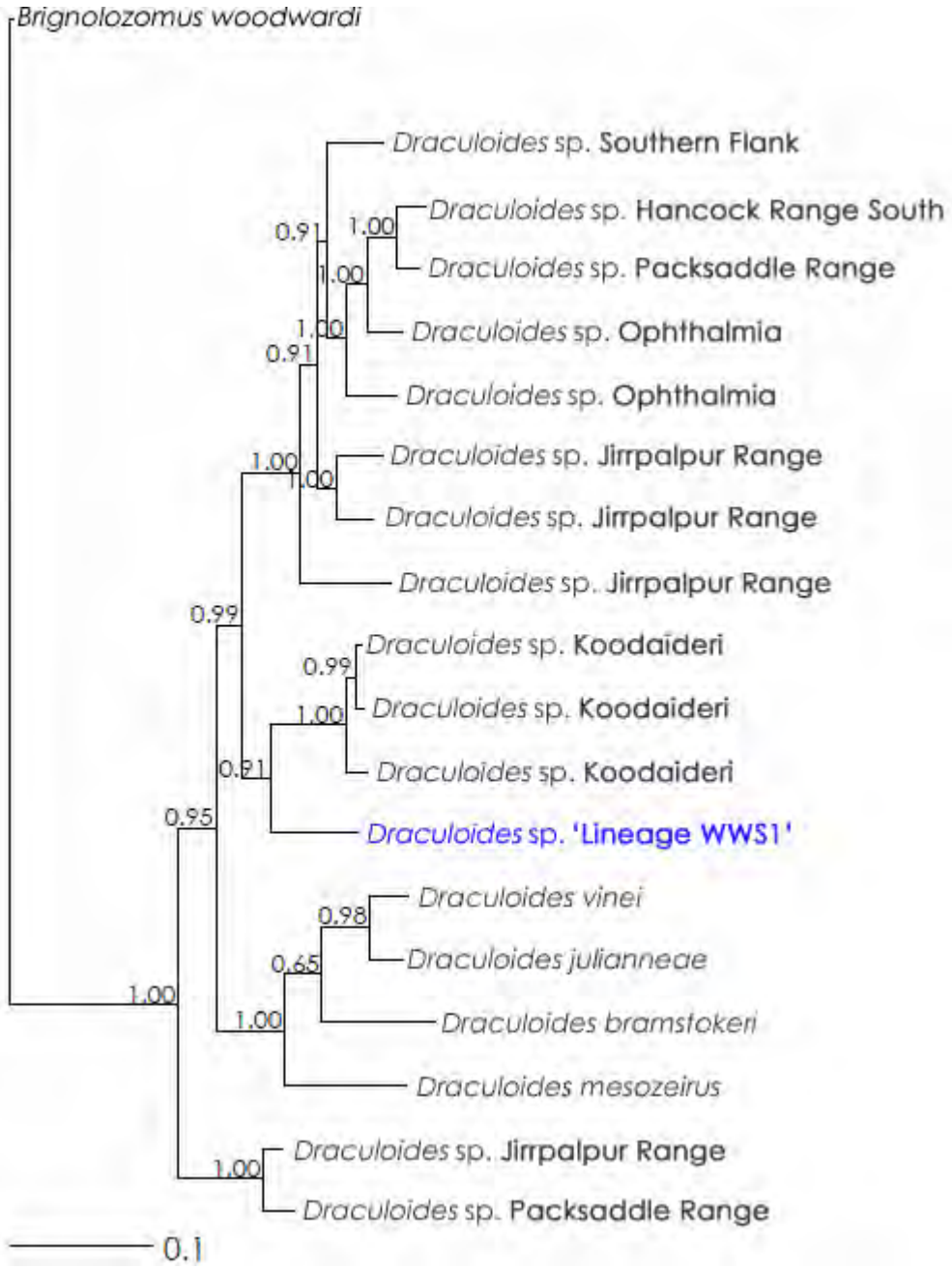

Figure 5.1: Phylogenetic tree based on Bayesian analysis of CO1 haplotypes of recorded Yandi Schizomida, and reference data from the Pilbara region.
(Yandi specimen labelled blue, specimens from other localities labelled black)

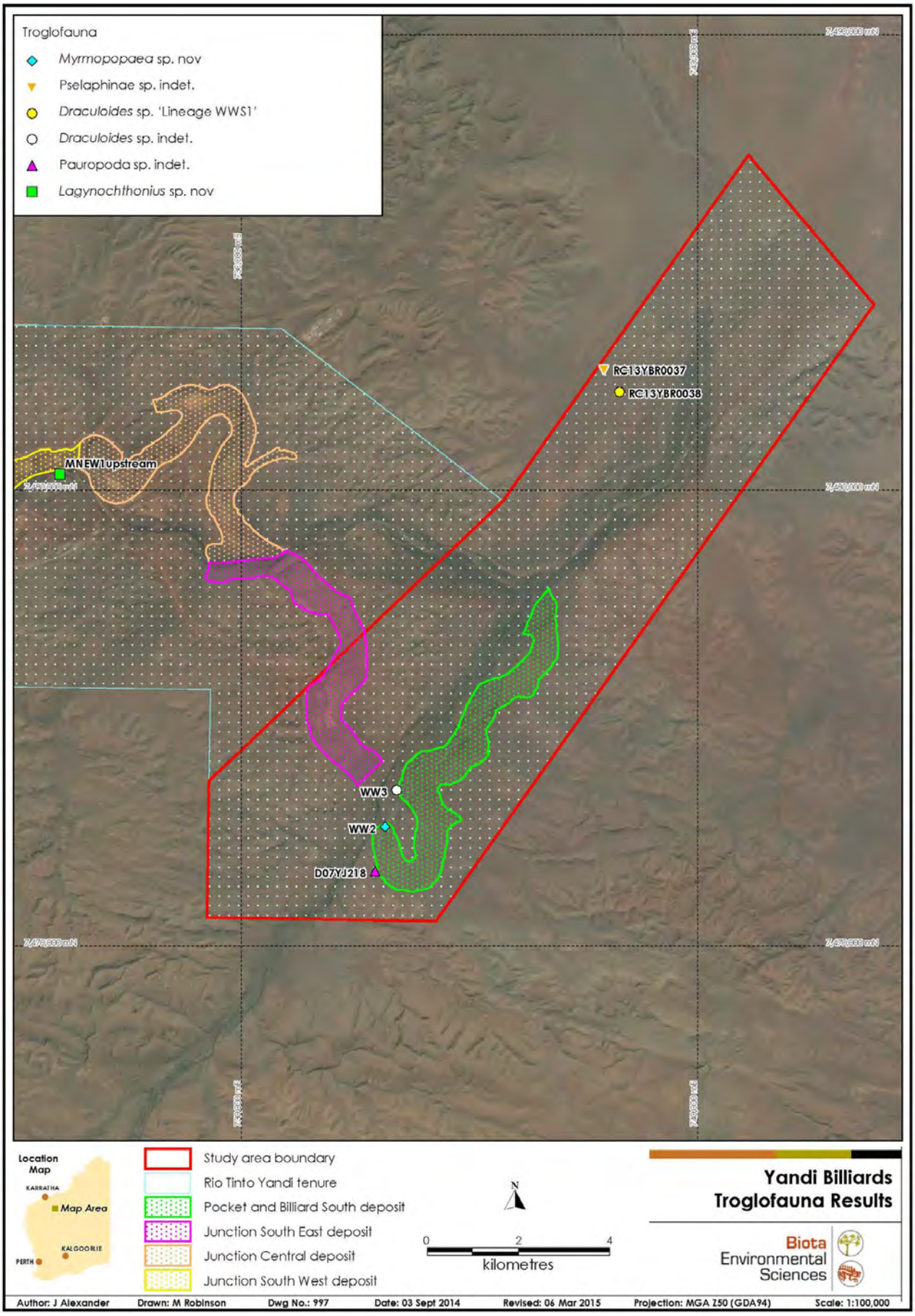

Figure 5.2: Location of all troglobitic specimens collected from the Yandi area, current and historic sampling.

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6.0 Discussion

6.1 Conservation Significance

Six potential troglobites have been recorded from the wider Yandi tenure over two phases of troglofauna sampling and 13 stygofauna surveys, all represented by single specimens. Five of these were recorded within the current Billiards study area (Table 6.1). Four are confirmed troglobites with the ecological status of the remaining two specimens unconfirmed. Additional specimens and wider spatial scale molecular analysis would be necessary to better determine species-level distribution and thereby further infer dispersal characteristics. Table 6.1 provides a summary of the taxa recorded, their likely conservation significance and notes on the geological units from which they were collected.

Table 6.1: Conservation significance of specimens from the Yandi area.

Specimen	Conservation Significance	Notes
Myrmopopaea sp. nov.	Confirmed troglobitic / SRE species	Recorded from calcrete, site WW2, within the boundary of the PBS deposit. Limited distribution but may not be restricted to this geological unit.
Pselaphinae sp. indet.	Troglobitic status unconfirmed.	Recorded from colluvium, site RC13YBR0037 outside the PBS deposit within the study area. Distribution unknown.
Pauropoda sp. indet.	Troglobitic status unconfirmed.	Recorded from calcrete, site D07YJ218, outside of the PBS deposit within the study area. Distribution unknown.
Lagynochthonius sp. nov.	Confirmed troglobitic / SRE species	Recorded from alluvium at MNEW1upstream at the JSW tenement (Figure 5.2). Likely to be of limited distribution.
Draculoides sp. 'Lineage WWS1'	Confirmed troglobitic / SRE species	Recorded from colluvium, site RC13YBR0038, outside the PBS deposit within the study area. Likely to be of limited distribution.
Draculoides sp. indet.	Confirmed troglobitic / SRE species	Recorded from calcrete, site WW3, outside the boundary of the PBS deposit. Likely to be of limited distribution but molecular and morphological analysis not possible. Specimen potentially belongs to *Draculoides* sp. 'Lineage WWS1'.

Lagynochthonius sp. nov. was recorded from JSW area adjacent to Marillana Creek and is not directly relevant to the current Billiards troglofauna environmental assessment. Of the five specimens recorded from the Billiards study area, four were recorded from sites outside the PBS deposit (*Draculoides* sp. 'Lineage WWS1', *Draculoides* sp. indet., Coleoptera sp. indet. and Pauropoda sp. indet; Table 6.1). It should be noted however that *Draculoides* sp. indet and Pauropoda sp. indet. were recorded from sites less than 50 m from the deposit boundary and may therefore still be affected by the proposed mining operations. These impacts, while not resulting in direct loss of habitat, could include secondary tier ecological changes due to clearing and mining infrastructure (water, nutrient and sediment infiltration) and alterations to the aquifer due to dewatering, which may alter the frequency and level of habitat inundation.

The remaining taxon, *Myrmopopaea* sp. nov., has been recorded only from within the PBS deposit and was collected from calcrete habitat (see Section 6.2).

6.2 Troglofauna Habitat in the Study Area

The majority of the troglofauna specimens recorded at Yandi have been collected from shallow alluvium, colluvium and calcrete drill holes with less than 10 m to water table. The surface geology units therefore generally characterise the habitats that the fauna were using at that time, given that other geological formations at depth were below water table.

All troglofauna specimens were recorded from three surface geological units, Alluvium (Qa), Colluvium (Czc) and Calcrete (Czk) (Section 4.0, Figure 6.1) and these represent habitats that the

fauna currently utilise within the Billiards study area. It should be noted, however, that the unconsolidated alluvium, colluvium and calcrete geological units, which lie adjacent Weeli Wolli Creek, are subject to seasonal inundation. This process of seasonal flooding may periodically render areas of habitat unsuitable for use by troglofauna. Brockman Iron and Weeli Wolli formations, which adjoin the alluvium, colluvium and calcrete, form part of higher elevation landforms and may act as refuge from inundation, potentially representing core troglofauna habitat over longer timeframes. Brockman Iron formation, in particular, has recorded troglobitic fauna in hydrated zones at Koodaideri and other locations in the bioregion (Biota 2014a).

At present it is therefore unclear what constitutes the longer-term core habitat for troglobitic animals in the study area, but the fauna does occur at apparently low density in relatively recent and lower elevation valley-fill and alluvial units.

The species, *Myrmopopaea* sp. nov., while recorded only from within the impact area of the deposit, was recorded from a surface geology unit which is effectively continuous throughout the Billiards study area and adjacent areas (Figure 6.1). This calcrete habitat contains sufficient inter-connected interstitial spaces and cavities to allow movement of troglobitic fauna and this suggests the risk of the species being restricted at small spatial scale would be relatively low.

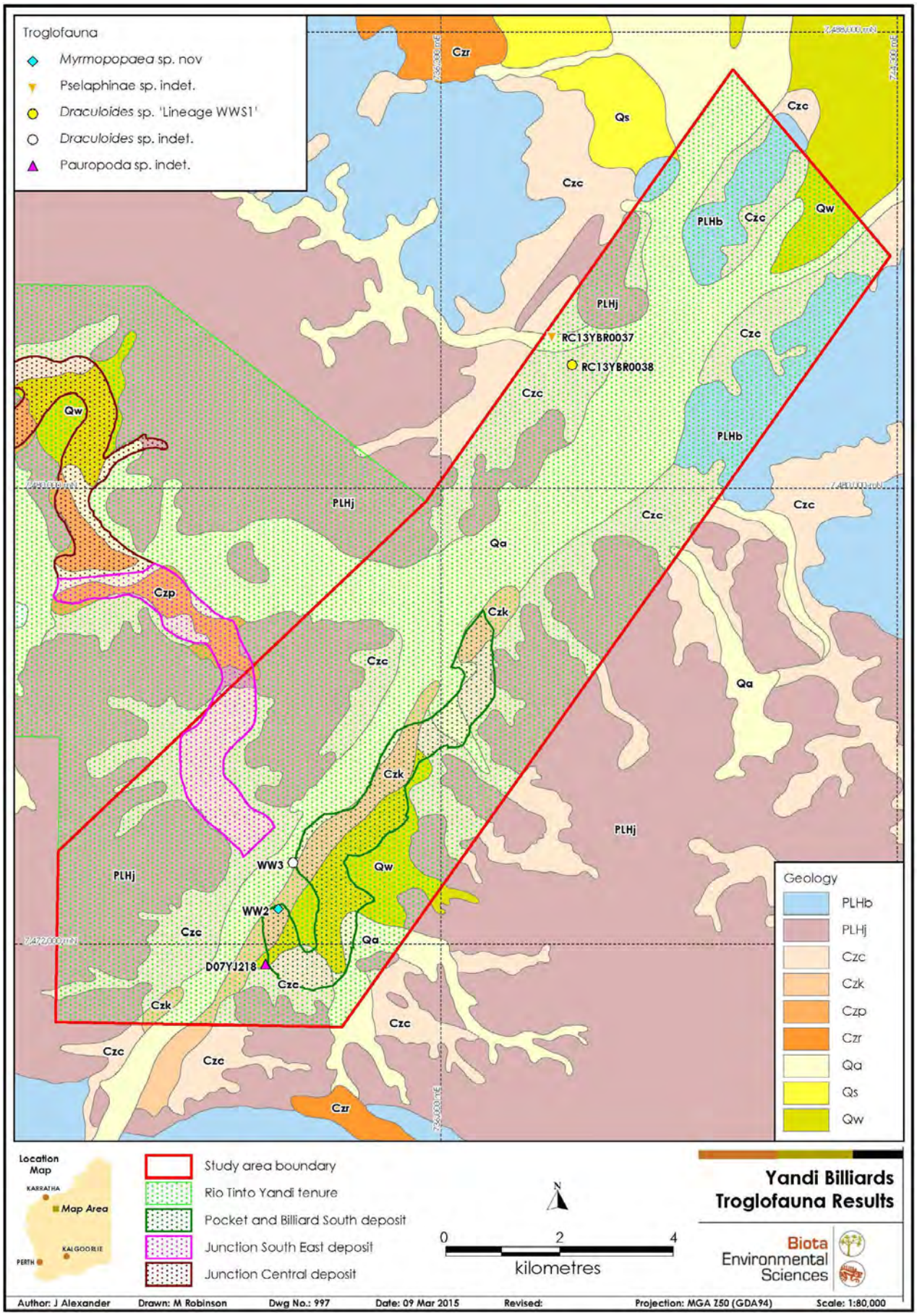

Figure 6.1: Troglofauna records from the Billiards study area in relation to surface geology.

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7.0 Glossary

Edaphobitic / Edaphobite	Soil dwelling fauna that can often display troglomorphic characteristics. Edaphobites are unlikely to have limited distributions and therefore unlikely to be classified as short-range endemics.
EPA	Environmental Protection Authority.
Haplotype	A group of alleles of different genes on a single chromosome that are closely enough linked to be inherited, usually as a unit.
Interstices	An opening or space, especially a small or narrow one between mineral grains in a rock or within sediments or soil.
Karst	Soluble-rock landscape; terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well-developed secondary porosity (Goodall et al. 2000).
Short-Range Endemic (SRE)	A species that has a naturally small distribution and is often characterised by having poor dispersal capabilities, confinement to disjunct habitats and low fecundity.
Taxonomy	Theory and practice of biological classification.
Troglomorphic	Pertaining to morphological, behavioural and physiological characters that are convergent in subterranean populations (Christiansen 1962).
Troglophilic / Troglophile	Species able to live and reproduce underground as well as in the epigean environment (Goodall et al. 2000).
Troglobite / Troglofauna	Species living obligatory in caves; also blind, depigmented and often having an elongate body morphology.
Trogloxene	Organisms that can come and go from a cave environment but use it during certain periods of their life cycles, such as nesting and hibernation.
Stygobite / Stygofauna	Obligate groundwater fauna.

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Appendix 1

Licence to take fauna for scientific purposes (Licence number SF009624)

DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
Telephone: 08 9334 0333
Facsimile: 08 9334 0242

Correspondence: **Locked Bag 30**
Bentley Delivery Centre WA 6983

AUTHORISED PERSONS

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VICKIE CARTLEDGE
CHRIS COLE
SYLVIE SCHMIDT
STEWART FORD
JACINTA KING
MICHAEL DELANEY
ANDREW SHEPPARD

AMENDED
29.4.2014 Date
DS Initial

DATE OF ISSUE 13/12/2013
VALID FROM 01/01/2014
DATE OF EXPIRY 31/12/2014

LICENSING OFFICER

RESIDENTIAL ADDRESS:
6A WONGAN AVE
WHITEGUM VALLEY WA 6162

LICENSEE: MR D KAMIEN (DANIEL)
ADDRESS
C/- BIOTA ENVIRONMENTAL
PO BOX 155
LEEDERVILLE WA 6903

DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
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Correspondence: **Locked Bag 30**
Bentley Delivery Centre WA 6983

PAGE NO. 1
SF009624
PERSON NO. 70754

RECEIPT NO. **AMOUNT** $0.00

WILDLIFE CONSERVATION ACT 1950
REGULATION 17

LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

DIRECTOR GENERAL

CONDITIONS

1 THE LICENSEE SHALL COMPLY WITH THE PROVISIONS OF THE WILDLIFE CONSERVATION ACT AND REGULATIONS AND ANY NOTICES IN FORCE UNDER THIS ACT AND REGULATIONS.

2 UNLESS SPECIFICALLY AUTHORISED IN THE CONDITIONS OF THIS LICENCE OR OTHERWISE IN WRITING BY THE DIRECTOR GENERAL, SPECIES OF FAUNA DECLARED AS LIKELY TO BECOME EXTINCT, RARE OR OTHERWISE IN NEED OF SPECIAL PROTECTION SHALL NOT BE CAPTURED OR OTHERWISE TAKEN.

3 NO FAUNA SHALL BE TAKEN FROM ANY NATURE RESERVE, WILDLIFE SANCTUARY, NATIONAL PARK, MARINE PARK, TIMBER RESERVE OR STATE FOREST WITHOUT PRIOR WRITTEN APPROVAL OF THE DIRECTOR GENERAL. NO FAUNA SHALL BE TAKEN FROM ANY OTHER PUBLIC LAND WITHOUT THE WRITTEN APPROVAL OF THE GOVERNMENT AUTHORITY MANAGING THAT LAND.

4 NO ENTRY OR COLLECTION OF FAUNA TO BE UNDERTAKEN ON ANY PRIVATE PROPERTY OR PASTORAL LEASE WITHOUT THE CONSENT IN WRITING OF THE OWNER OR OCCUPIER, OR FROM ANY ABORIGINAL RESERVE WITHOUT THE WRITTEN APPROVAL OF THE DEPARTMENT OF INDIGENOUS AFFAIRS.

5 NO FAUNA OR THEIR PROGENY SHALL BE RELEASED IN ANY AREA WHERE IT DOES NOT NATURALLY OCCUR, NOR BE HANDED OVER TO ANY OTHER PERSON OR AUTHORITY UNLESS APPROVED BY THE DIRECTOR GENERAL, NOR SHALL THE REMAINS OF SUCH FAUNA BE DISPOSED OF IN SUCH MANNER AS TO CONFUSE THE NATURAL OR PRESENT DAY DISTRIBUTION OF THE SPECIES.

6 THIS LICENCE AND THE WRITTEN PERMISSION REFERRED TO AT CONDITIONS 3 & 4 MUST BE CARRIED BY THE LICENSEE OR AUTHORISED AGENT AT ALL TIMES FOR THE PURPOSE OF PROVING THEIR AUTHORITY TO TAKE FAUNA WHEN QUESTIONED AS TO THEIR RIGHT TO DO SO BY A WILDLIFE OFFICER, ANY OTHER STATE OR LOCAL GOVERNMENT EMPLOYEE OR ANY MEMBER OF THE PUBLIC.

7 **********ANY INTERACTION INVOLVING GAZETTED THREATENED FAUNA THAT MAY BE HARMFUL AND/OR INVASIVE MAY REQUIRE APPROVAL FROM THE DEPT OF SUSTAINABILITY, ENVIRONMENT, WATER, POPULATION & COMMUNITIES PH 02 6274 1111. INTERACTION WITH SUCH SPECIES IS CONTROLLED BY THE COMMONWEALTH GOVERNMENT'S "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999" & "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION REGULATIONS 2000" AS WELL AS DPaW'S WILDLIFE CONSERVATION ACT & REGULATIONS.**********

8 NO BIOPROSPECTING INVOLVING THE REMOVAL OF SAMPLE AQUATIC AND TERRESTRIAL ORGANISMS (BOTH FLORA AND FAUNA) FOR CHEMICAL EXTRACTION AND BIOACTIVITY SCREENING IS PERMITTED TO BE CONDUCTED WITHOUT SPECIFIC WRITTEN APPROVAL BY THE DIRECTOR GENERAL OF DPaW.

9 FURTHER CONDITIONS (NUMBERED 1 TO 9) ARE ATTACHED.

PURPOSE SUBTERRANEAN FAUNA SURVEY TARGETING STYGOFAUNA AND TROGLOFAUNA, USING MODIFIED PLANKTON HAUL NETS IN 30 EXISTING DRILL HOLES AND HABITAT TRAPS FILLED WITH LEAF LITTER AT THE YANDI BILLIARDS PROJECT AREA, 90KM NORTHWEST OF NEWMAN, FOR RIO TINTO. SPECIMENS TO BE LODGED WITH THE WA MUSEUM.

WILDLIFE CONSERVATION REGULATIONS 1970

Regulation 17:- Licence to Take Fauna for Scientific Purposes

FURTHER CONDITIONS (OF LICENCE NUMBER SF00 9624)

1. The licensee shall take fauna only in the manner stated on the endorsed Regulation 17 licence application form and endorsed related correspondence.

2. Except in the case of approved lethal traps, the licensee shall ensure that measures are taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be deployed so as to prevent exposure of trapped animals to ants and debilitating weather conditions and inspected at regular intervals throughout each day of their use. At the conclusion of research all markers etc and signs erected by the licensee and all traps shall be removed, all pitfalls shall be refilled or capped and the study area returned to the condition it was in prior to the research/capture program. During any break in research, cage traps should be removed and pitfalls either removed, capped or filled with sand.

3. No collecting is to be undertaken in areas where it would impinge on pre-existing scientific research programs.

4. Any form of colour marking of birds or bats shall only be undertaken in accordance with the requirements of the Australian Bird and Bat Banding Scheme.

5. Any inadvertently captured specimen of fauna which is declared as likely to become extinct, rare or otherwise in need of special protection is to be released immediately at the point of capture. Where such a specimen is injured or deceased, the licensee shall contact Department of Parks and Wildlife licensing staff at Kensington (08 9219 9831) for advice on disposal. Records are to be kept of any fauna so captured and details included in the report required under further condition 6 below.

6. Within one month of the expiration of this licence, the holder shall submit an electronic return detailing the locality, site, geocode, date and number of each species captured, sighted or vouchered during the currency of the licence, into the Department of Parks and Wildlife Fauna Survey Database (FSD). A copy of any paper, report or thesis resulting from the research shall on completion be lodged with the Director General. If a renewal of this licence is required, the licensee shall submit a written progress report for activities undertaken during this licence period prior to the expiry of this licence.

7. Not more than ten specimens of any one protected species shall be taken and removed from any location less than 20km apart. Where exceptional circumstances make it necessary to take large series in order to obtain adequate statistical data the collector will proceed with circumspection and justify their actions to the Director General in advance.

8. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected which represents a significant extension of geographic range shall be donated on request to the Western Australian Museum.

9. To prevent any unnecessary collecting in this State, all specimens and material collected under the authority of this license shall, on request, be loaned to the Western Australian Museum. Also, the unused portion or portions of any specimen collected under the authority of this license shall be offered for donation to the Western Australian Museum or made available to other scientific workers if so required.

Appendix 2

Helix Molecular Solutions genetic analysis report

Helix
Molecular
Solutions

School of Animal Biology The University of Western Australia
Hackett Entrance No. 4 Hackett Drive Crawley WA 6009
PO Box 155
Leederville WA 6903

t: (08) 6488 4509 | f: (08) 6488 1029 | abn: 32 133 230 243 | w: www.helixsolutions.com.au

2 September, 2014

Via email

Re. Report on the molecular systematics of Amphipoda and Schizomida from the Weeli Wolli region

Dear Jason,

Following is a summary of the results of the Paramelitidae and Schizomida study we have completed. Owing to the observed level of sequence divergence between lineages and comparison to reference sequences, it is likely that there are four species of Paramelitidae in your collections. Three of those species have been detected or described previously at Munjina and Marillana and Weeli Wolli Creeks, whereas one appears to be new, based on the material available for comparison. The one specimen of Schizomida you provided appears to be a new species that has not yet been detected in the Pilbara, based on the material available for comparison.

Sincerely,

Dr. Terrie Finston and Dr. Oliver Berry
Helix Molecular Solutions

Paramelitidae

Background

The groundwater amphipod fauna of Western Australia is diverse. Since 1995, 27 species of amphipods have been described from north-western Western Australia, including the Pilbara and nearby Barrow Island and Cape Range Peninsula (Barnard and Williams 1995; Bradbury and Williams 1996, 1997a; Bradbury 2000; Finston *et al*., 2008). The majority of these species (19) belong to the family Paramelitidae. Extensive molecular work has been conducted on the amphipod fauna of Western Australia (Helix, 2011). The resulting dataset provides a molecular framework that can be used to provide a regional context for localised sampling. The present study concerns 89 specimens of Amphipoda belonging to the family Paramelitidae from the Weeli Wolli catchment in the Pilbara.

Objective

Eighty-nine specimens of Paramelitidae from the Weeli Wolli catchment in the Pilbara were sequenced for variation at the mitochondrial gene COI. The specimens were compared to reference sequences of Paramelitidae from the Pilbara to estimate the number of species in the collection and determine the relationships of the new samples to specimens previously collected in the Pilbara.

Executive summary

- Eighty-nine specimens of Paramelitidae from the Weeli Wolli catchment in the Pilbara were sequenced for variation at the mitochondrial gene COI.
- Fifty-four of the 89 specimens yielded a COI sequence; many of the specimens were old and did not yield high-quality DNA.
- A neighbour-joining analysis, which included the 54 specimens analysed here, revealed the presence of four distinct genetic lineages, which represent four species.
- Representatives of each of the four species detected at Weeli Wolli were included in a second phylogenetic analysis, which included 49 reference specimens of Paramelitidae from sites in the Pilbara and voucher sequences of Paramelitidae from the international DNA sequence database GenBank.
- Three of the four species have been detected or described previously at Munjina and Marillana and Weeli Wolli Creeks, whereas one appears to be new, based on the material available for comparison.

Methods

Eighty-nine specimens of Paramelitidae from the Weeli Wolli area in the Pilbara were sequenced for variation at the mitochondrial gene cytochrome oxidase subunit I (COI; Table 1). Primers LCO1490 and HCO2198 (Folmer et al., 1994) were used to amplify a ~700 bp fragment of COI. The specimens were collected between 2008 and 2011 and were examined morphologically and assigned to the lowest taxonomic level possible (J. Alexander, pers. comm.).

Sequences were edited using SEQUENCHER software (Gene Codes Corporation, Ann Arbor, MI, USA). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. To test that the amplified sequences were the target mtDNA, sequences were translated into proteins and checked for the presence of stop codons. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotides different between sequences).

To reduce analysis time, a preliminary neighbour-joining analysis was run to identify the number of distinct genetic lineages among the 54 specimens. Specimens from each of the lineages were included in a second model-based phylogenetic analysis, which included 49 reference specimens of Paramelitidae from sites in the Pilbara within and outside the study area and voucher sequences of Paramelitidae from the international DNA sequence database Genbank.

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data. Bayesian analysis was used to construct the phylogenetic tree, incorporating the General Time Reversible (GTR+G) model as identified in MODELTEST. The phylogeny, branch lengths and posterior probabilities were obtained by

running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the first 5000 ("burn-in") trees. The burn-in value was assessed by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded. Forty-nine specimens of Paramelitidae from the Pilbara were included in the phylogenetic analysis as references, eight of which are lodged with the international DNA sequence database Genbank as follows: *Maarrka etheli* (Genbank accession # DQ838031), *Maarrka weeliwollii* (Genbank accession # DQ838032), *Yilgarus* sp. BES9348 (Genbank accession #EF118228), *Kruptus linnaei* (Genbank accession # GU111906), *Molina pleobranchos* (Genbank accession #DQ255962), *Chydaekata* sp. Marillana (Genbank accession # DQ255989), *Pilbarus millsi* (Genbank accession # DQ490126), *Chydaekata acuminata* (Genbank accession # DQ838024). The remaining 41 specimens were detected in previous surveys of the Pilbara (Helix, 2011). Two species from the Isopoda family Tainisopidae, *Pygolabis paraburdoo* (Genbank accession # EU107628) and *Pygolabis weeliwolli* (Genbank accession # EU107618) were used as outgroups.

Results

Fifty-four of the 89 specimens yielded a 533 to 727 bp fragment of COI (Table 1). The neighbour-joining analysis revealed the presence of four distinct genetic lineages (WWA1 – WWA4; Figure 1). The four lineages contained between one and 21 specimens (Table 1; Figure 1).Variation within the four lineages was low, averaging between 0.4 and 1.4% sequence divergence (Table 2). The four lineages differed from one another by between 18.0 and 20.5% mean sequence divergence (Table 3).

Representatives from each of the four lineages detected at Weeli Wolli were included in a model-based phylogenetic analysis with the 49 reference specimens. Two representatives were included from lineage WWA1 (WWA1a, WWA1b), to reflect the variation detected within the lineage (Figure 1). The representatives from WWA1, WWA2 and WWA4 were placed in lineages containing reference sequences from Munjina and Marillana and Weeli Wolli Creeks (Figure 2). Specifically, specimens GO29 and GO45 (representing lineage WWA1) were placed in a lineage containing specimen AM9 (Paramelitidae sp. 2C-WW), collected during a previous survey at Weeli Wolli Creek and specimen H28 from Marillana Creek (Figure 2). Specimen GO21 (representing lineage WWA2) was placed in a lineage with reference specimen 'camp a' (Paramelitidae sp. 'camp') from Marillana Creek as well as specimens from Munjina and Weeli Wolli Creek (Figure 2). Specimen GO42 (representing lineage WWA4) was placed in a lineage containing the reference specimen of *Chydaekata sp.* E from Marillana Creek (Figure 2). This species is also known from Weeli Wolli Creek (Finston et al., 2007).

The Weeli Wolli specimens that matched reference sequences (lineages WWA1, WWA2, WWA4) differed from their nearest reference sequence by between 0.0 and 3.8% sequence divergence (Figure 2; Table 4). The final specimen, lineage WWA3, which showed no close relationship to any of the reference sequences, differed from the reference sequences by between 19.7 and 25.9% sequence divergence (Table 4).

Conclusions

COI is considered by some authors to be a suitable gene for species delineation (Hebert *et al*., 2003a). Based on comparisons between over 1700 crustacean species, Hebert *et al* (2003b) found an average of 15.4 % sequence divergence between species pairs, with nearly 82% of pair-wise comparisons showing greater than 8% sequence divergence. Similar to the Hebert *et al*. (2003b) results, Bradford *et al* (2010) found 11-13% sequence divergence among three lineages of the Amphipoda family Chiltonidae in a single calcrete in the Yilgarn. Reproductive isolation between lineages was confirmed with nuclear (allozyme) markers, indicating that each lineage represented a distinct species.

Owing to the high level of sequence divergence between the four observed lineages in the Weeli Wolli collection (18.0 to 20.5%), it is likely that there are four species present. Three of the

four lineages showed close genetic relationships to reference specimens (0.0 to 3.8% sequence divergence), indicating that they belong to those species. The three were detected previously at Munjina and Marillana and Weeli Wolli Creeks. The fourth species showed no close relationship to any of the reference sequences and is likely to represent a new species. The four species present at Weeli Wolli are as follows:

1. lineage WWA1 =Paramelitidae sp. WW-2C; previously detected at Marillana and Weeli Wolli Creeks
2. lineage WWA2 =Paramelitidae sp. 'camp'; previously detected at Marillana Creek, Weeli Wolli, and Munjina
3. lineage WWA3 =new
4. lineage WWA4 =*Chydaekata sp. E*; previously detected at Marillana and Weeli Wolli Creeks

In summary, four species of Paramelitidae were detected at Weeli Wolli. Three of the species (lineages WWA1, WWA2, WWA4) have been described or recorded previously, whereas one (lineage WWA3) appears to be unrecorded based on the material available for comparison. High quality DNA could not be obtained from many of the specimens, likely due to their age and exposure to heat and light during morphological examination.

Schizomida

Executive summary

- A single specimen of *Draculoides* from Weeli Wolli was sequenced for the COI gene.
- The specimen was analysed with a reference data set of Schizomida from the Pilbara.
- In a phylogenetic analysis, the specimen was placed in a distinct genetic lineage that did not contain any other reference specimens.
- The Weeli Wolli specimen differed from the reference specimen by between 10.2 and 15.3% sequence divergence.
- Owing to the high level of sequence divergence between the Weeli Wolli specimen and the reference specimens, the Weeli Wolli specimen is likely to represent a new species of *Draculoides* that has not so far been detected in the Pilbara, based on the material available for comparison.

Methods

A single specimen of Schizomida from Weeli Wolli, identified on the basis of morphology as belonging to the genus *Draculoides* (Table 1) was sequenced for COI and compared to a reference collection of schizomids from the Pilbara in a similar manner to the Paramelitidae, with the following exceptions: the specimen from Weeli Wolli was included in a model-based phylogenetic analysis along with a sub-set of reference specimens of schizomids that were selected based on the criteria that they showed ≤ 15% sequence divergence from the new specimen. One hundred seventy-eight reference sequences were tested (including the four described species of *Draculoides*), and of those, 13 were detected that differed by ≤ 15% sequence divergence from the new Weeli Wolli specimen. The 13 individuals represented 11 distinct lineages (haplotypes of groups of closely related haplotypes that differ from other such groups by >3% sequence divergence) that are likely to represent 11 presumptive species. The four described species of *Draculoides* were also included in the phylogenetic analysis.

Results

The specimen of *Draculoides* from Weeli Wolli was placed in a distinct genetic lineage (WWS1) that did not contain any of the reference specimens (Figure 3). It formed a relatively well-supported clade with three specimens of *Draculoides* from Koodaideri (Figure 3).

The specimen of *Draculoides* from Weeli Wolli differed from the reference specimens by between 10.2 and 15.3% sequence divergence (Table 5). It differed from the closest reference specimens (three specimens from Koodaideri) by between 10.2 and 10.7% (Table 5).

Conclusions

Owing to the high level of sequence divergence between the new specimen from Weeli Wolli and the reference specimens (>10%), it is likely that the Weeli Wolli specimen belongs to a new species that has not yet been detected in the Pilbara, based on the material available for comparison. It does however appear to share a common ancestor with a species of *Draculoides* detected at Koodaideri.

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Table 1. Specimens of Amphipoda and Schizomida used in the present study and the genetic lineage in which they were placed based on a model-based phylogenetic analysis.

Sample ID	Morpho Species	Helix ID	Cap ID	Lineage/Species
MAR06a	Paramelitidae Genus 2 sp. B2	GO1	-	No data
MAR06a	Paramelitidae Genus 2 sp. B2	GO2	-	No data
MAR06a	Paramelitidae Genus 2 sp. B2	GO3	-	No data
Plant	Paramelitidae Genus 2 sp. B2	GO4	-	No data
Plant	Paramelitidae Genus 2 sp. B2	GO5	-	No data
Plant	Paramelitidae Genus 2 sp. B2	GO6	-	No data
Plant	Paramelitidae Genus 2 sp. B2	GO7	-	No data
Plant	Paramelitidae Genus 2 sp. B2	GO8	-	No data
PZ08YJSW003	Paramelitidae Genus 2 sp. B2	GO9	-	WWA2/Paramelitidae sp. 'camp'
PZ08YJSW003	Paramelitidae Genus 2 sp. B2	GO10	-	WWA2/Paramelitidae sp. 'camp'
PZ08YJSW003	Paramelitidae Genus 2 sp. B2	GO11	-	No data
WWA4	Paramelitidae Genus 2 sp. B2	GO12	21	WWA1/Paramelitidae sp. WW-2C
WWA4	Paramelitidae Genus 2 sp. B2	GO13	21	WWA1/Paramelitidae sp. WW-2C
WWA4	Paramelitidae Genus 2 sp. B2	GO14	21	WWA1/Paramelitidae sp. WW-2C
Yandi JSE39	Paramelitidae Genus 2 sp. B2	GO15	34	No data
Yandi MAR01	Paramelitidae Genus 2 sp. B2	GO16	38	WWA1/Paramelitidae sp. WW-2C
Yandi MAR01	Paramelitidae Genus 2 sp. B2	GO17	38	No data
Yandi MAR01	Paramelitidae Genus 2 sp. B2	GO18	38	WWA1/Paramelitidae sp. WW-2C
Yandi MAR03	Paramelitidae Genus 2 sp. B2	GO19	46	WWA2/Paramelitidae sp. 'camp'
Yandi MAR03	Paramelitidae Genus 2 sp. B2	GO20	46	WWA2/Paramelitidae sp. 'camp'
Yandi MAR03	Paramelitidae Genus 2 sp. B2	GO21	46	WWA2/Paramelitidae sp. 'camp'
Yandi WB/YJ99	Paramelitidae Genus 2 sp. B2	GO22	2	WWA2/Paramelitidae sp. 'camp'
Yandi WB/YJ99	Paramelitidae Genus 2 sp. B2	GO23	2	WWA2/Paramelitidae sp. 'camp'
Yandi WWA2	Paramelitidae Genus 2 sp. B2	GO24	15	WWA1/Paramelitidae sp. WW-2C
Yandi WWA2	Paramelitidae Genus 2 sp. B2	GO25	15	No data
Yandi WWA2	Paramelitidae Genus 2 sp. B2	GO26	15	WWA1/Paramelitidae sp. WW-2C
Yandi WWA3	Paramelitidae Genus 2 sp. B2	GO27	13	WWA1/Paramelitidae sp. WW-2C
Yandi WWA3	Paramelitidae Genus 2 sp. B2	GO28	13	WWA1/Paramelitidae sp. WW-2C
Yandi WWA3	Paramelitidae Genus 2 sp. B2	GO29	13	WWA1/Paramelitidae sp. WW-2C
Yandi WWA3	Paramelitidae Genus 2 sp. B2	GO30	13	WWA1/Paramelitidae sp. WW-2C
Yandi WWA3	Paramelitidae Genus 2 sp. B2	GO31	13	WWA1/Paramelitidae sp. WW-2C
Yandi WWA4	Paramelitidae Genus 2 sp. B2	GO32	-	WWA1/Paramelitidae sp. WW-2C
Yandi WWA4	Paramelitidae Genus 2 sp. B2	GO33	-	No data
Yandi WWA4	Paramelitidae Genus 2 sp. B2	GO34	-	No data
Yandi JSE14	Paramelitidae Genus 2 sp. B3	GO35	25	WWA1/Paramelitidae sp. WW-2C

Yandi MAR07	Paramelitidae Genus 2 sp. B3	GO36	71	WWA2/Paramelitidae sp. 'camp'
Yandi MAR07	Paramelitidae Genus 2 sp. B3	GO37	71	WWA2/Paramelitidae sp. 'camp'
Yandi MAR07	Paramelitidae Genus 2 sp. B3	GO38	71	WWA2/Paramelitidae sp. 'camp'
Yandi MAR07	Paramelitidae Genus 2 sp. B3	GO39	71	No data
Yandi MAR07	Paramelitidae Genus 2 sp. B3	GO40	71	WWA2/Paramelitidae sp. 'camp'
Marillana01	Paramelitidae sp. 2 (DEC code)	GO41	19	WWA4/Chydaekata sp. E
Marillana01	Paramelitidae sp. 2 (DEC code)	GO42	19	WWA4/Chydaekata sp. E
Marillana01	Paramelitidae sp. 2 (DEC code)	GO43	19	WWA2/Paramelitidae sp. 'camp'
Marillana7	Paramelitidae sp. 2 (DEC code)	GO44	5	No data
Plant	Paramelitidae sp. 2 (DEC code)	GO45	24	WWA1/Paramelitidae sp. WW-2C
Plant	Paramelitidae sp. 2 (DEC code)	GO46	24	WWA1/Paramelitidae sp. WW-2C
Plant	Paramelitidae sp. 2 (DEC code)	GO47	24	WWA1/Paramelitidae sp. WW-2C
D08YJ050-40	Paramelitidae sp.2 (DEC)	GO48	68	WWA1/Paramelitidae sp. WW-2C
D08YJ050-40	Paramelitidae sp.2 (DEC)	GO49	68	WWA2/Paramelitidae sp. 'camp'
D08YJ050-40	Paramelitidae sp.2 (DEC)	GO50	68	WWA2/Paramelitidae sp. 'camp'
D08YJ050-40	Paramelitidae sp.2 (DEC)	GO51	68	WWA2/Paramelitidae sp. 'camp'
Marillana02-42	Paramelitidae sp.2 (DEC)	GO52	46	WWA1/Paramelitidae sp. WW-2C
Marillana02-42	Paramelitidae sp.2 (DEC)	GO53	46	WWA1/Paramelitidae sp. WW-2C
Marillana02-42	Paramelitidae sp.2 (DEC)	GO54	46	WWA1/Paramelitidae sp. WW-2C
MB08YJPC021-41	Paramelitidae sp.	GO55	65	WWA2/Paramelitidae sp. 'camp'
MB08YJPC021-41	Paramelitidae sp.	GO56	65	No data
WB/YJ99-41	Paramelitidae sp.2 (DEC)	GO57	2	WWA2/Paramelitidae sp. 'camp'
WB/YJ99-41	Paramelitidae sp.2 (DEC)	GO58	2	WWA2/Paramelitidae sp. 'camp'
WB/YJ99-41	Paramelitidae sp.2 (DEC)	GO59	2	WWA2/Paramelitidae sp. 'camp'
WB/YJ99-41	Paramelitidae sp.2 (DEC)	GO60	2	WWA2/Paramelitidae sp. 'camp'
WB/YJ99-41	Paramelitidae sp.2 (DEC)	GO61	2	No data
WWA2-44	Paramelitidae sp.2 (DEC)	GO62	24	WWA1/Paramelitidae sp. WW-2C
WWA2-44	Paramelitidae sp.2 (DEC)	GO63	24	WWA1/Paramelitidae sp. WW-2C
WWA2-44	Paramelitidae sp.2 (DEC)	GO64	24	WWA1/Paramelitidae sp. WW-2C
WWA2-44	Paramelitidae sp.2 (DEC)	GO65	24	No data
WWA2-44	Paramelitidae sp.2 (DEC)	GO66	24	No data
D08YJ050p6-1	Paramelitidae sp. 2 (PSS)	GO67	76	No data
WWA3p6-2	Paramelitidae sp. 2 (PSS)	GO68	26	WWA1/Paramelitidae sp. WW-2C
WWA3p6-2	Paramelitidae sp. 2 (PSS)	GO69	26	WWA1/Paramelitidae sp. WW-2C
JSE14	Paramelitidae sp. 2 (PSS)	GO70	15	No data
JSE36	Paramelitidae sp. 2 (PSS)	GO71	-	No data
PZ08YJSW002	Paramelitidae sp. 2 (PSS)	GO72	52	No data
PZ08YJSW002	Paramelitidae sp. 2 (PSS)	GO73	52	No data
PZ08YJSW002	Paramelitidae sp. 2 (PSS)	GO74	52	No data

PZ08YJSW002	Paramelitidae sp. 2 (PSS)	GO75	52	No data
WWA2	Paramelitidae sp. 2 (PSS)	GO76	51	No data
WWA2	Paramelitidae sp. 2 (PSS)	GO77	51	No data
WWA3	Paramelitidae sp. 2 (PSS)	GO78	37	No data
WWA3	Paramelitidae sp. 2 (PSS)	GO79	37	No data
WWA4	Paramelitidae sp. 2 (PSS)	GO80	28	WWA1/Paramelitidae sp. WW-2C
Yandi YMCCA	Paramelitidae sp. B16	GO81	76	No data
MNEW1upstream	Paramelitidae sp. B25 (nr. B16)	GO82	-	WWA3/ Paramelitidae new sp. WWA3
MNEW1upstream	Paramelitidae sp. B25 (nr. B16)	GO83	-	No data
MNEW1upstream	Paramelitidae sp. B25 (nr. B16)	GO84	-	No data
MNEW1upstream	Paramelitidae sp. B25 (nr. B16)	GO85	-	No data
WWA3-41	Pilbarus millsi - Chydaekata sp.	GO86	4	WWA4/Chydaekata sp. E
Mar06a-41	Pilbarus millsi - Chydaekata sp.	GO87	12	WWA4/Chydaekata sp. E
Mar06a-41	Pilbarus millsi - Chydaekata sp.	GO88	12	WWA4/Chydaekata sp. E
Mar06a-41	Pilbarus millsi - Chydaekata sp.	GO89	12	WWA4/Chydaekata sp. E
RC13YBR0038	Schizomida (Draculoides sp. (juv.))	GO90	-	WWS1/Draculoides new sp. WWS1

Table 2. Mean sequence divergence and standard error (s.e.) between individuals within the four lineages of Paramelitidae detected in the Weeli Wolli specimens. n/c= not calculated because n=1 for the group.

lineage	D	S.E.
WWA1	0.014	0.003
WWA2	0.007	0.002
WWA3	n/c	n/c
WWA4	0.004	0.002

Table 3. Mean sequence divergence (below diagonal) and standard error (above diagonal) between the four lineages of Paramelitidae detected in the Weeli Wolli specimens.

Lineage	WWA1	WWA3	WWA4	WW5
WWA1		0.015	0.016	0.018
WWA2	0.186		0.015	0.018
WWA3	0.180	0.189		0.017
WWA4	0.205	0.205	0.202	

Table 4 (attached). Pair-wise sequence divergence (below diagonal) and standard error (above diagonal) between all Paramelitidae specimens used in the model-based phylogenetic analysis shown in Figure 2. Distances between the four lineages detected at Weeli Wolli and the reference specimens are highlighted in yellow.

Table 5. (attached). Pair-wise sequence divergence (below diagonal) and standard error (above diagonal) between all Schizomida specimens used in the model-based phylogenetic analysis shown in Figure 3. Distances between the species detected at Weeli Wolli and the reference specimens are highlighted in yellow.

Figure 1. Neighbour-joining analysis of 54 specimens of Amphipoda from Weeli Wolli. Numbers on nodes represent bootstrap support over 100 iterations. The four lineages are labelled WWA1 – WWA4. Specimens selected to represent each lineage are highlighted in yellow.

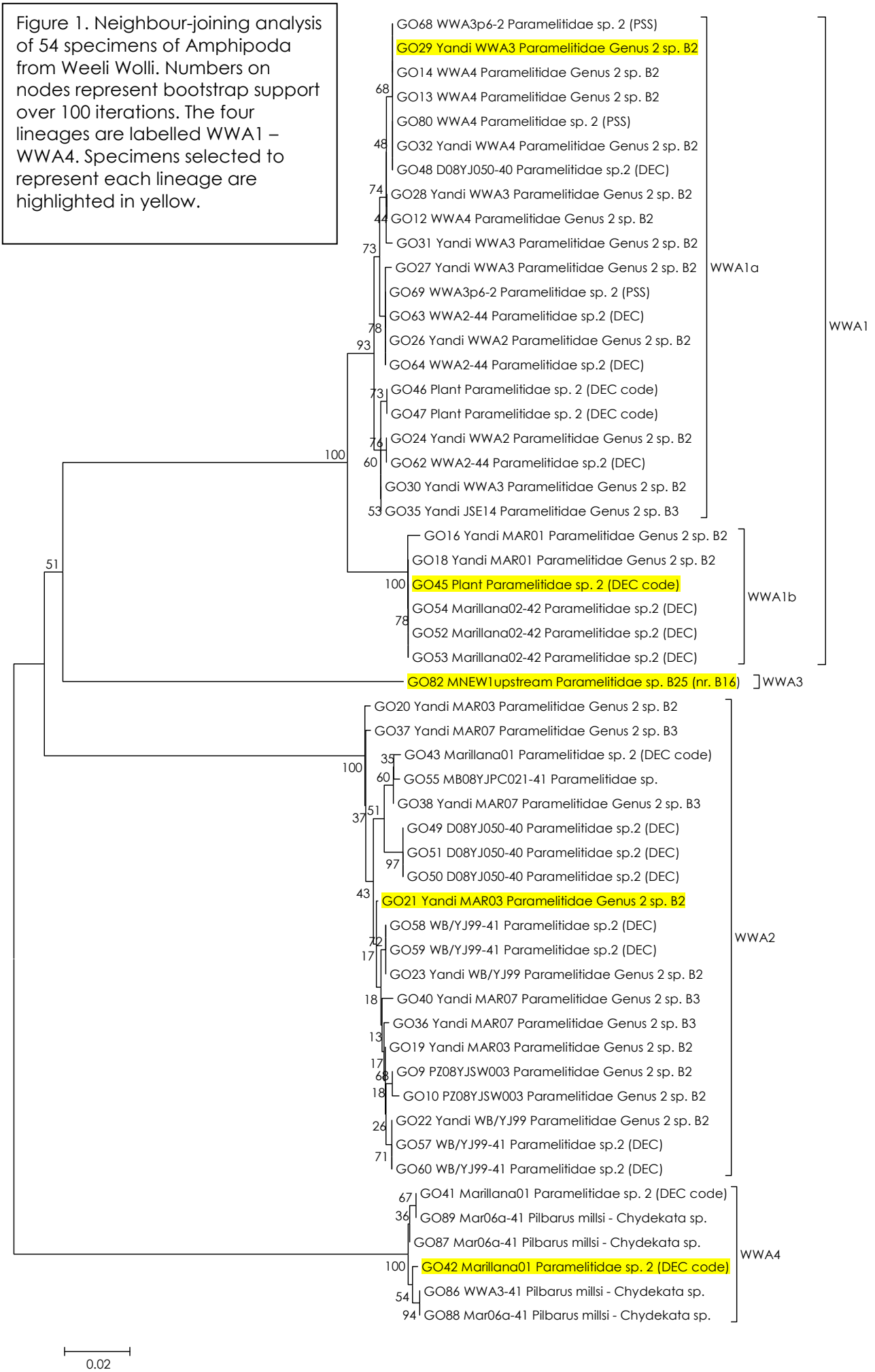


Figure 2. Bayesian analysis of COXI haplotypes of Paramelitidae. Numbers on major nodes correspond to posterior probabilities. Specimens from the present study are highlighted in yellow; Scale bar= number of substitutions per site. Red boxes enclose the species detected in the present study. Distances between the Weeli Wolli specimens and the nearest reference sequences are shown next to each pair.

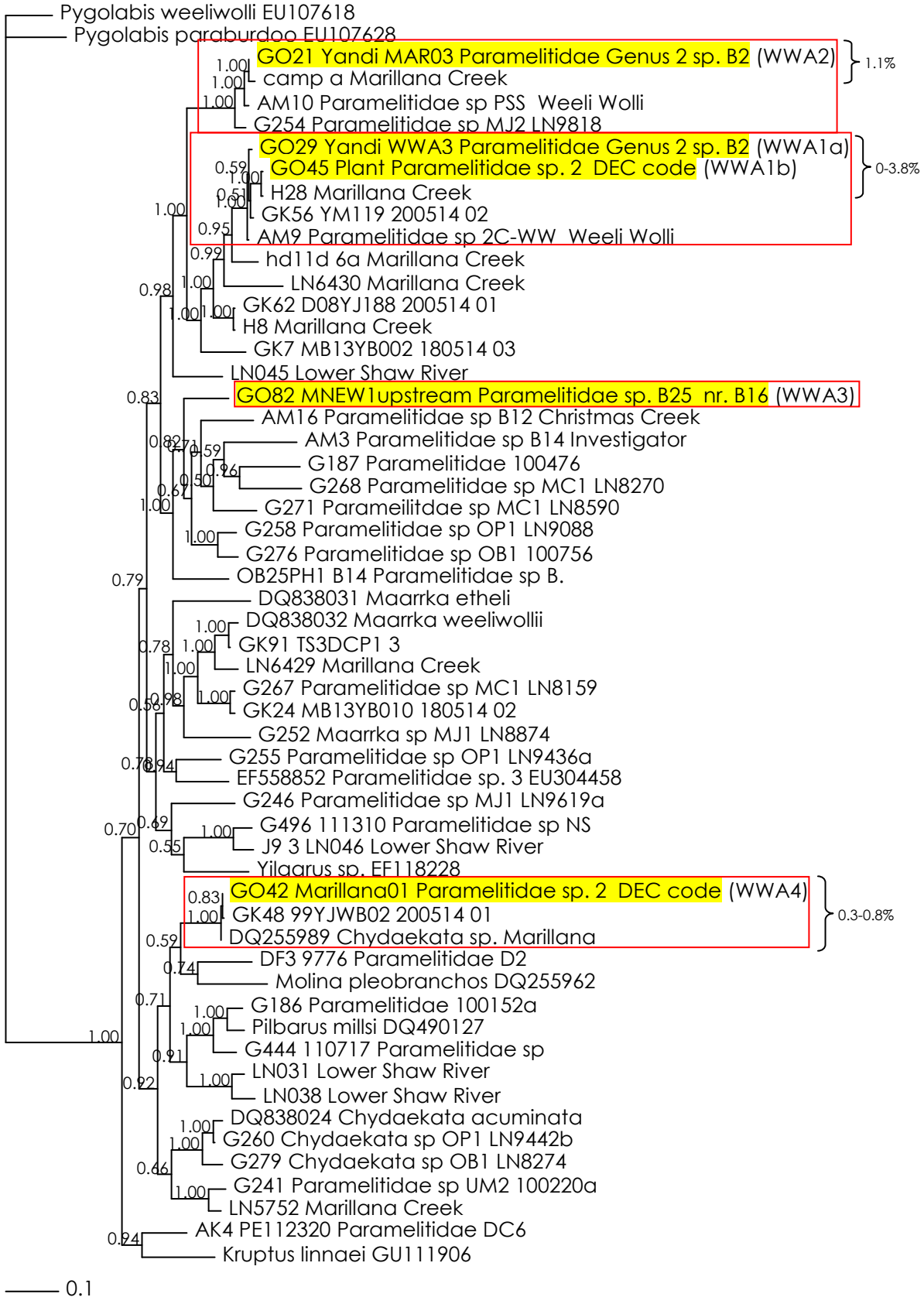
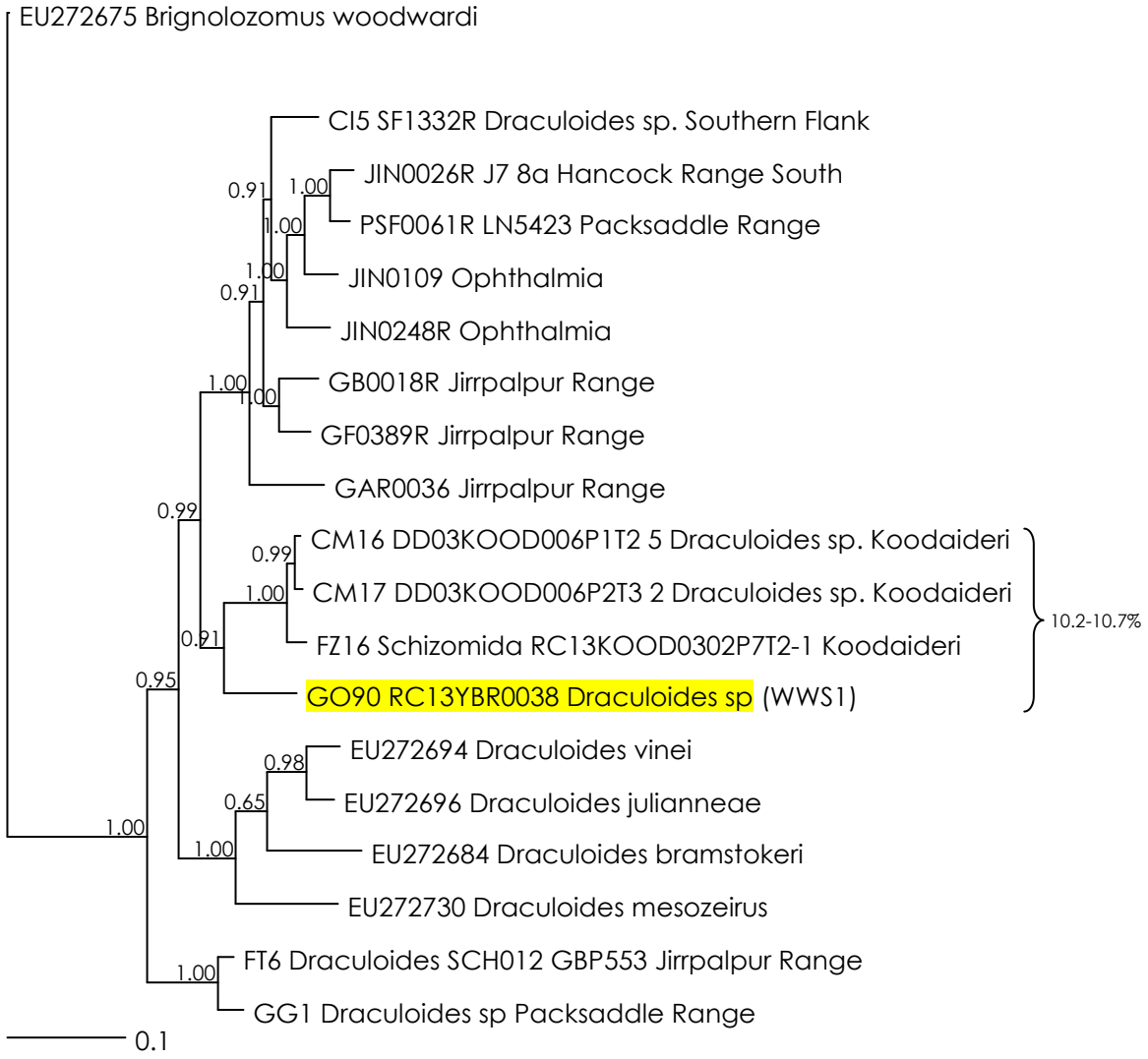


Figure 3. Bayesian analysis of COI haplotypes of Schizomida. Numbers on major nodes correspond to posterior probabilities. The specimen from the present study is highlighted in yellow; Scale bar= number of substitutions per site. Distances between the Weeli Wolli specimen and the nearest reference sequences are shown next to the clade.



Appendix 3

Collection data

Date Collected	Drillhole	Phylum	Class	Taxon	Number of Specimens	Troglobitic	Notes
10/07/2014	RD09YJ103	Chelicerata	Arachnida	Acarina	11	No	
10/07/2014	RD09YJ163	Chelicerata	Arachnida	Acarina	1	No	
10/07/2014	RD09YJ362	Chelicerata	Arachnida	Acarina	7	No	
10/07/2014	RD09YJ362	Chelicerata	Arachnida	Acarina	1	No	
10/07/2014	RD10YJ169	Chelicerata	Arachnida	Acarina	12	No	
10/07/2014	D08YJ009	Chelicerata	Arachnida	Acarina	30	No	
10/07/2014	D08YJ009	Chelicerata	Arachnida	Acarina	4	No	
10/07/2014	RD10YJ166	Chelicerata	Arachnida	Acarina	1	No	
10/07/2014	DD09YJ046	Chelicerata	Arachnida	Acarina	1	No	
10/07/2014	D07YJ128	Chelicerata	Arachnida	Acarina	1	No	
10/07/2014	D06YJ258	Chelicerata	Arachnida	Acarina	7	No	
10/07/2014	RC04YJ2343	Chelicerata	Arachnida	Acarina	50	No	
10/07/2014	RD10YJ069	Chelicerata	Arachnida	Acarina	80	No	
10/07/2014	RD10YJ069	Chelicerata	Arachnida	Acarina	3	No	
10/07/2014	RD10YJ104	Chelicerata	Arachnida	Acarina	20	No	
10/07/2014	D08YJ199	Chelicerata	Arachnida	Acarina	100	No	
09/07/2014	DR08YH008	Chelicerata	Arachnida	Acarina	4	No	
09/07/2014	D08YJ152	Chelicerata	Arachnida	Acarina	50	No	
09/07/2014	D08YJ124	Chelicerata	Arachnida	Acarina	2	No	
09/07/2014	D07YJ132	Chelicerata	Arachnida	Acarina	14	No	
10/07/2014	D07YJ218	Chelicerata	Arachnida	Acarina	70	No	
10/07/2014	D07YJ218	Chelicerata	Arachnida	Acarina	100	No	
10/07/2014	RD09YJ315	Chelicerata	Arachnida	Acarina	26	No	
10/07/2014	RD09YJ315	Chelicerata	Arachnida	Acarina	7	No	
10/07/2014	RD09YJ315	Chelicerata	Arachnida	Acarina	40	No	
09/07/2014	RC13YBR0035	Chelicerata	Arachnida	Acarina	38	No	
09/07/2014	RC13YBR0035	Chelicerata	Arachnida	Acarina	50	No	
09/07/2014	RC13YBR0038	Chelicerata	Arachnida	Acarina	24	No	
09/07/2014	RC13YBR0038	Chelicerata	Arachnida	Acarina	9	No	
09/07/2014	RC13YBR0032	Chelicerata	Arachnida	Acarina	33	No	
09/07/2014	RC13YBR0048	Chelicerata	Arachnida	Acarina	90	No	
09/07/2014	RC13YBR0048	Chelicerata	Arachnida	Acarina	100	No	
09/07/2014	RC13YBR0048	Chelicerata	Arachnida	Acarina	6	No	
09/07/2014	D06YJ237	Chelicerata	Arachnida	Acarina	1	No	

Date Collected	Drillhole	Phylum	Class	Taxon	Number of Specimens	Troglobitic	Notes
09/07/2014	D06YJ237	Chelicerata	Arachnida	Acarina	18	No	
09/07/2014	RC13YBR0033	Chelicerata	Arachnida	Acarina	4	No	
09/07/2014	D07YJ169	Chelicerata	Arachnida	Acarina	48	No	
09/07/2014	D07YJ169	Chelicerata	Arachnida	Acarina	80	No	
09/07/2014	D07YJ169	Chelicerata	Arachnida	Acarina	37	No	
09/07/2014	SC07YJ020	Chelicerata	Arachnida	Acarina	14	No	
09/07/2014	D08YJ152	Chelicerata	Arachnida	Araneae	1	No	
09/07/2014	D08YJ156	Chelicerata	Arachnida	Araneae	1	No	
09/07/2014	RC13YBR0032	Chelicerata	Arachnida	Pseudoscorpiones (Olpiidae)	1	No	Juvenile
09/07/2014	RC13YBR0038	Chelicerata	Arachnida	Schizomida (Draculoides sp.)	1	Yes	Juvenile
10/07/2014	RD09YJ362	Crustacea	Malacostraca	Amphipoda	1	No	
10/07/2014	RD09YJ362	Crustacea	Malacostraca	Amphipoda	1	No	
10/07/2014	D07YJ218	Crustacea	Malacostraca	Isopoda	1	No	
10/07/2014	RD09YJ362	Uniramia	Collembola	Collembola	50	No	
10/07/2014	RD09YJ362	Uniramia	Collembola	Collembola	40	No	
10/07/2014	RD09YJ362	Uniramia	Collembola	Collembola	50	No	
10/07/2014	RD10YJ169	Uniramia	Collembola	Collembola	34	No	
10/07/2014	D08YJ009	Uniramia	Collembola	Collembola	12	No	
10/07/2014	DD09YJ046	Uniramia	Collembola	Collembola	5	No	
10/07/2014	DD09YJ046	Uniramia	Collembola	Collembola	1	No	
10/07/2014	D06YJ258	Uniramia	Collembola	Collembola	2	No	
10/07/2014	RC04YJ2343	Uniramia	Collembola	Collembola	1	No	
10/07/2014	RD10YJ069	Uniramia	Collembola	Collembola	14	No	
09/07/2014	DR08YH008	Uniramia	Collembola	Collembola	50	No	
09/07/2014	D08YJ152	Uniramia	Collembola	Collembola	4	No	
10/07/2014	D07YJ218	Uniramia	Collembola	Collembola	1	No	
10/07/2014	RD09YJ315	Uniramia	Collembola	Collembola	3	No	
10/07/2014	RD09YJ315	Uniramia	Collembola	Collembola	23	No	
09/07/2014	RC13YBR0037	Uniramia	Collembola	Collembola	2	No	
09/07/2014	D06YJ237	Uniramia	Collembola	Collembola	3	No	
09/07/2014	D06YJ237	Uniramia	Collembola	Collembola	80	No	
09/07/2014	D07YJ169	Uniramia	Collembola	Collembola	31	No	
09/07/2014	D07YJ169	Uniramia	Collembola	Collembola	22	No	
09/07/2014	D07YJ169	Uniramia	Collembola	Collembola	90	No	

Date Collected	Drillhole	Phylum	Class	Taxon	Number of Specimens	Troglobitic	Notes
09/07/2014	SC07YJ020	Uniramia	Collembola	Collembola	20	No	
09/07/2014	SC07YJ020	Uniramia	Collembola	Collembola	5	No	
09/07/2014	SC07YJ020	Uniramia	Collembola	Collembola	6	No	
10/07/2014	D07YJ128	Uniramia	Insecta	Blattodea	2	No	
10/07/2014	D08YJ199	Uniramia	Insecta	Blattodea	1	No	
09/07/2014	D07YJ169	Uniramia	Insecta	Blattodea	2	No	
09/07/2014	RC13YBR0037	Uniramia	Insecta	Coleoptera	1	Unsure	
10/07/2014	D08YJ050	Uniramia	Insecta	Diptera	1	No	
10/07/2014	D08YJ050	Uniramia	Insecta	Diptera	1	No	
10/07/2014	RD09YJ163	Uniramia	Insecta	Diptera	1	No	
10/07/2014	RD09YJ297	Uniramia	Insecta	Diptera	1	No	
10/07/2014	RD10YJ104	Uniramia	Insecta	Diptera	1	No	
10/07/2014	RD09YJ315	Uniramia	Insecta	Diptera	1	No	
10/07/2014	RD09YJ315	Uniramia	Insecta	Diptera	1	No	
09/07/2014	RC13YBR0035	Uniramia	Insecta	Diptera	1	No	
09/07/2014	D08YJ124	Uniramia	Insecta	Hymenoptera	9	No	
09/07/2014	D08YJ156	Uniramia	Insecta	Hymenoptera	1	No	
09/07/2014	D07YJ169	Uniramia	Insecta	Orthoptera	1	No	
10/07/2014	RD09YJ103	Uniramia	Insecta	Psocoptera	4	No	
10/07/2014	RD09YJ163	Uniramia	Insecta	Psocoptera	1	No	
10/07/2014	RD09YJ163	Uniramia	Insecta	Psocoptera	3	No	
10/07/2014	DD09YJ046	Uniramia	Insecta	Psocoptera	14	No	
10/07/2014	D07YJ128	Uniramia	Insecta	Psocoptera	1	No	
10/07/2014	RC04YJ2343	Uniramia	Insecta	Psocoptera	2	No	
09/07/2014	D08YJ124	Uniramia	Insecta	Psocoptera	3	No	
09/07/2014	D08YJ156	Uniramia	Insecta	Psocoptera	1	No	
10/07/2014	D07YJ218	Uniramia	Insecta	Psocoptera	1	No	
10/07/2014	RD09YJ315	Uniramia	Insecta	Psocoptera	1	No	
10/07/2014	RD09YJ315	Uniramia	Insecta	Psocoptera	19	No	
09/07/2014	RC13YBR0032	Uniramia	Insecta	Psocoptera	14	No	
09/07/2014	D06YJ237	Uniramia	Insecta	Psocoptera	11	No	
10/07/2014	RD09YJ096	-	-	No records	-	-	
10/07/2014	RC04YJ2343	-	-	No records	-	-	
09/07/2014	RC13YBR0037	-	-	No records	-	-	

Date Collected	Drillhole	Phylum	Class	Taxon	Number of Specimens	Troglobitic	Notes
09/07/2014	RC13YBR0033	-	-	No records	-	-	
10/07/2014	RD09YJ103	-	-	No records	-	-	
Historically Collected Specimens							
2008	WW3	Chelicerata	Arachnida	Schizomida (Draculoides sp. indet.)	1	Yes	Damaged
2009	WW2	Chelicerata	Arachnida	Araneae (Myrmopopaea sp. nov)	1	Yes	
2009	MNEW1upstream	Chelicerata	Arachnida	Pseudoscorpiones (Lagynochthonius sp. nov.)	1	Yes	
2009	D07YJ218	Uniramia	Insecta	Pauropoda (Pauropoda sp. indet)	1	Unsure	

Rio Tinto

Riparian Vegetation of Marillana and Weeli Wolli Creeks

Mapping Refinement and Assessment of Values and Significance

October 2015

Disclaimer and Limitation

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1 INTRODUCTION

In the East Pilbara of Western Australia, two relatively large creek systems (Marillana Creek and Weeli Wollli Creek) form part of a broader catchment which ultimately drains into Fortescue Marsh. The historic paleo-channel of these two creek systems has created Channel Iron Deposits of significant economic value. In the process of recovering these resources, the ecological values of these creek systems have been altered, but overall (in the vicinity of the Rio Tinto Yandicoogina Project area), they appear to have been maintained. As development continues in this area a complex interaction of potential impact sources, particularly with respect to hydrological changes, and resultant spatial distribution and scale of potential ecological impacts is occurring. In addition to current impacts, the respective spatial distribution and significance of the ecological values present are of key interest to support environmental impact assessments. In many cases; the finer details on the local scale and timing of ecological impacts are enormously difficult to determine. By comparison, the ability to gain increased clarity and spatial resolution about the location and significance of the values under threat is much more achievable. In light of this fact; work is being undertaken to identify the knowledge gaps, associated spatial resolution issues, scales of significance and historical context surrounding the key ecological values of the study area.

Vegetation mapping is one of the primary tools for identifying key ecological values; their spatial location within a creek system; and their inherent sensitivity to perturbations. Current riparian monitoring/management is limited to the scale of previous vegetation mapping within the riparian zone. However when considering in detail the potential for complex hydrological impacts, a more detailed scale of mapping is required for accurate, measured and more meaningful management and mitigation. Furthermore recent monitoring has determined that some of the most significant and sensitive communities mapped within the study area have been augmented by development impacts (namely surplus-dewater discharge), and in some cases may not have existed in the pre-impact environment.

Two key focuses of this study are to increase the spatial, structural, and compositional resolution of the vegetation mapping within the riparian zone, while gaining greater understanding of the significance of communities in the riparian zone and their distribution pre-impact.

The following study outlines the work undertaken within the stretches of Marillana and Weeli Wolli Creeks surrounding the Rio Tinto Project area to:

- Refine the vegetation mapping within the riparian zone of Marillana and Weeli Wolli Creeks (within the vicinity of their confluence - the study area), with the aim of increasing the scale, accuracy and detail of vegetation mapping and associated community descriptions.

- Classify and map the age structure of Melaleuca argentea co-dominated riparian communities (“obligate phreatophytic vegetation”) within the study area.

- Provide an interpretation of the presence and distribution of present day communities in the Pre-discharge (pre-mining) environment.

- Incorporate the determined community age structure, or maturity of phreatophytic vegetation and use this information to develop inferences about their presence in the pre-discharge environment: provide interpretations of the significance of riparian communities in

the study area, based on their distribution, composition, structure, sensitivity (to hydrological changes), and associated biological values.

1.1 STUDY AREA

The study area determined to be the focus of this work incorporates a stretch of Marillana Creek from its confluence with Weeli Wolli Creek to approximately 19 km upstream. The zone along Weeli Wolli Creek includes a stretch 6 km downstream and 13 km upstream from its point of confluence with Marillana creek. Lying within the Marillana Pastoral station these stretches of both creek systems are herein to be known as the "study area" and the boundaries of this study area are presented in Figure 1-1.

1.2 COMPLEXITY OF OVERLAPPING IMPACTS TO BOTH CREEKS

Key potential impact sources active on riparian communities and ecosystems of Weeli Wolli and Marillana creeks area:

- direct impact from infrastructure clearing and transport; and
- drawdown effects on groundwater and surface water availability:
  - In some areas communities and select species experiencing drought stress and fatality due to reduced sub-surface access to groundwater sources
- effects of increased surface water (perennial flow regimes) from mining discharge:
  - in some areas communities and select species experiencing stress and fatality due to excess water presence (waterlogging);
  - in some areas communities and select species undergoing artificial augmentation due to additional water presence (increased recruitment and cover/abundance); and
  - in some areas augmented vegetation experiencing stress and fatality as discharge regimes are altered.

Throughout the Yandicoogina development area there is variability in the distribution, magnitude, spatial extent and degree of overlap of each of these potential impact factors. As a consequence, determining the resulting potential impact profile is considerably complicated, especially once coupled with the underlying environmental variability (in areas such as geology, slope, sediment characters, creek profile etc.) of the area. In some cases impacts are multiplied due to spatial overlap of impact factors, and in cases impacts are somewhat ameliorated or neutralised due overlap of offsetting impact factors. Whatever the case may be, it is clear that the potential to accurately predict impacts is heavily reduced by the spatial complexity of their interaction. Therefore, beyond broad spatial impact predictions, the key course of action for management and mitigation is to become clear on the exact location and significance of key values, to be aware of which ones are most susceptible to change, and in light of potential sensitivities determine where the most relevant impacts might occur.

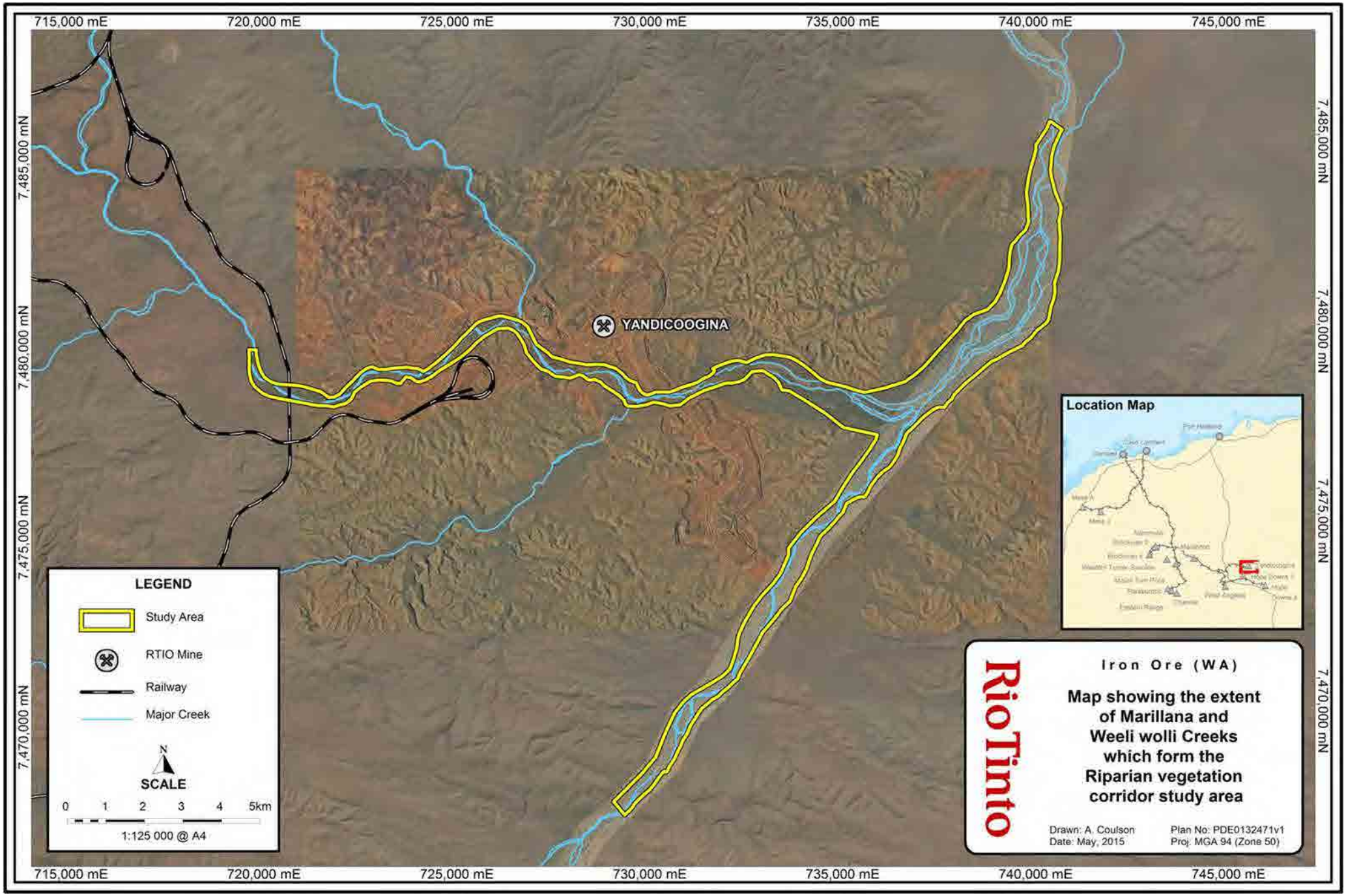


Figure 1-1: **Extent of Marillana and Weeli Wolli Creeks which form the Riparian Vegetation Corridor Study Area**

2 BACKGROUND

2.1 LARGE CREEK SYSTEMS OF THE HAMERSLEY SUB-REGION

The Hamersley subregion of the Pilbara bioregion is essentially represented by those areas occurring on and adjacent to the ranges, valleys, and plateau formations of the Hamersley Ranges. These ranges are unique in the Pilbara due to their size, relatively vast expanses of upland area, and associated large and extremely rugged and rocky habitats.

Rainfall patterns in the Hamersley Ranges, when compared to the reminder of the Pilbara region, are also different with higher annual rainfall over the Hamersley Range (up to 500 mm). This higher average rainfall is known to be a product of advection and convergence of moist sea breezes together with uplift from orography and heating associated with the steep and rocky features of the Hamersley Range (Charles *et al* 2013)).

Within the Hamersley subregion these factors combine to produce a significant number of large and relatively unique creek systems. The number and spread of these large creek systems, along with the spatial boundaries of their respective catchments, are depicted in

Figure 2-1. To provide a comparative look at the size of each of these creek systems the areal extent of the catchment of each is provided below in Table 2-1.

Table 2-1: Major Creeks of the Hamersley Range

Creek	Approximate Catchment Size (Km^2)
Mindy Mindy Creek	372
Joffre Creek	539
Giles creek	598
Munjina Creek	767
Caliwingina Creek	796
Coondiner Creek	883
Mungarathoona Creek	895
Upper Angelo River	1,225
Weelumurra Creek	1,419
Spearhole Creek	1,431
Fortescue south Creek	1,480
Caves Creek	1,532
Boolgeeda Creek	1,623
Weeli Wolli Creek	1,736
Upper Hardy River	1,844
Upper Beasley River	2,053
Duck Creek	2,149
Upper Robe River (bungaroo creek)	2,204
Marillana Creek	2,230
Turee Creek East Branch	2,284
Seven Mile Creek	2,585
Turee Creek	6,753

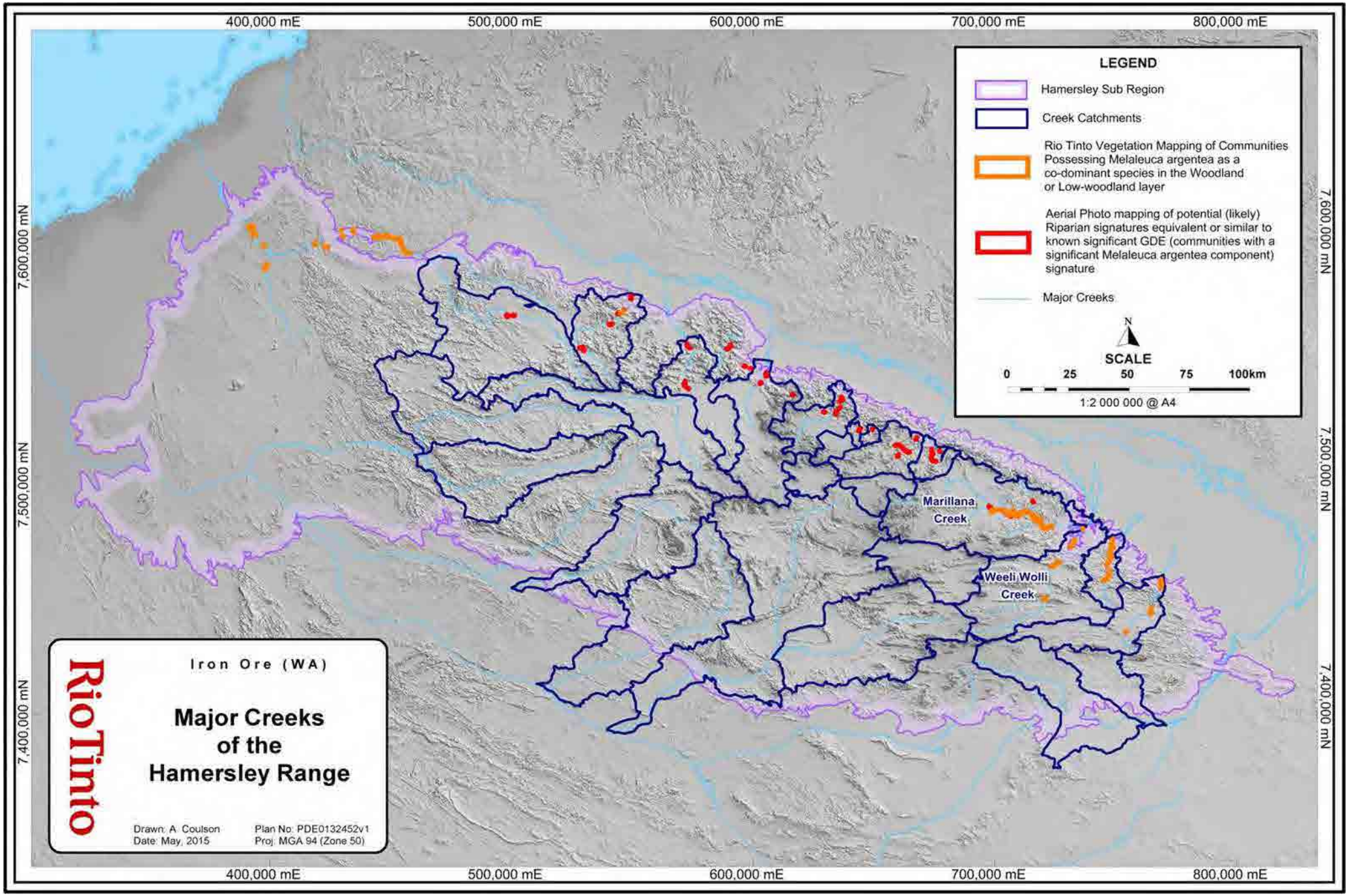


Figure 2-1: Major Creeks of the Hamersley Range

2.2 THE MARILLANA AND WEELI WOLLI CREEK SYSTEMS

2.2.1 Marillana Creek

The Marillana Creek catchment covers approximately 2200 km^2, with the creek flowing in an easterly direction between ranges of Brockman Iron Formation. The mid to upper catchment comprises a broad alluvial plain with several large areas of calcrete, and some clay pan zones. In the lower catchment, the drainage is well-defined due to topographical constraints, with the creek merging with Yandicoogina Creek and Weeli Wolli Creek prior to entering the Fortescue Marsh. The creek is generally ephemeral and only flows between 30 and 60 days per year. The Marillana Creek catchment contributes approximately 50% of the flow into the Fortescue Marshes from the Weeli Wolli Creek system (Aquaterra 2001). Marillana Creek therefore contributes approximately 5% of the surface water inputs to the Fortescue Marsh.

Marillana Creek typically comprises a gravel and calcrete aquifer that subparallels and meanders across the Channel Iron Deposit (**CID**) palaeodrainage at several locations. The CID or pisolitic limonite aquifer is aligned with the eroded keel of the Yandicoogina Syncline and is underlain by the Weeli Wolli Formation. The Marillana Creek CID forms a strip aquifer with a total length of 70 km, width of 800 m and saturated thickness of 60 m. The Marillana Creek CID aquifer merges with the Weeli Wolli Creek CID aquifer, which together contribute groundwater flow northward into the Fortescue Valley.

Marillana Creek is gauged by the Department of Water (DoW) at Flat Rocks (WRC number 708001) which is approximately 27 km west of the existing Rio Tinto Yandicoogina Project and upstream of the BHPBIO operations. Daily flow data for the gauging station is available from August 1967 to the present with occasional missing data. Before mining commenced in the Rio Tinto Yandicoogina locality in the early 1990s, stream flow in Marillana Creek was intermittent and largely dependent on rainfall. From 1975 to 2008 the annual number of flow days ranged between 10 and 365 (with a mean of 212) at the Flat Rocks gauging station. Continual flow at this location was recorded between 2000 and 2004 mainly due to saturated catchment conditions from abnormally high rainfall in 2000 (970 mm recorded at Flat Rock station) and the influence of the Munjina Clay pan (DoW 2015). Flat Rocks is an atypical stretch of Marillana Creek (as indicated by the name) in that the geology of the area appears to be influencing the patterns of surface water expression. The proximity of geological substrates and associated alluvial profiles in the vicinity of the Rio Tinto operations are significantly different, and are likely to determine that surface expressions of water moving through the catchment occur less frequently. Evidence of this can also potentially be attributed to the significant mature *Melaleuca argentea* woodlands which naturally occur in and upstream of the flat rocks vicinity, and which were sighted as part of field work completed for this study.

2.2.2 Weeli Wolli Creek

The Weeli Wolli Creek catchment, including Marillana Creek and Yandicoogina Creek, represents a significant surface water flow (10%) into the Fortescue Marshes (Aquaterra 2001). Weeli Wolli Creek is generally an ephemeral creek system which can be divided into three zones: an upper catchment (above Weeli Wolli Springs); a lower catchment (trunk drainage between Weeli Wolli Springs and the Hamersley Ranges escarpment); and broad outwash on the Fortescue Plain. The entire Weeli Wolli

catchment (including Marillana Creek) equals approximately 4,000 km^2, but without the Marillana Creek component equates to approximately 1800 km^2. The upper catchment comprises a number of tributaries that flow between east-west trending ranges before flowing through a narrow gorge in the Packsaddle Range at Weeli Wolli Springs. Weeli Wolli Spring has formed by the concentration of flow through a relatively narrow gap in the Brockman Formation outcrop and changes in topographic gradient. This 'damming' effect of groundwater flow results in an apparent "underground reservoir" that discharges over the shallow basement forming the spring. The spring is a permanent water feature that is supported by groundwater discharge. Surface water flow disappears about 2 km downstream of the spring as a result of seepage and evaporation. The area often experiences periodic heavy rainfall during summer because of both monsoonal effects and cyclones. Although the average surface flow is 2.8 GL/year it has been as high as 22 GL during an exceptional flood year. The pisolite and calcrete, where present below the water-table, constitute a significant aquifer which is recharged via direct rainfall infiltration and creek-line infiltration (Johnson & Wright 2001).

Weeli Wolli Creek continues its path downstream into the lower Weeli Wolli Creek catchment where it joins with Marillana Creek to the west and then drains onto a wide alluvial floodplain 20 to 30 km across in the Fortescue Valley. The reach of Weeli Wolli Creek which emerges from the Packsaddle Range north of the springs, and continues to the vicinity of the confluence with Marillana Creek, is generally represented by a relatively incised creek channel (with a consistently favoured low flow channel pathway), flanked by a clear and broad open floodplain. Downstream of the confluence with Marillana Creek, the incised channel zone of Weeli Wolli becomes much broader with multiple low flow channels emerging in a braided arrangement to provide a much greater area of meandering creek bed habitat. In addition, this reach possesses a less consistent and clearly formed adjacent floodplain to that present south of the confluence. The flows of Weeli Wolli Creek terminate at the Fortescue Marsh, an internally draining basin of the Upper Fortescue River catchment.

Weeli Wolli Creek is currently gauged by DoW at two locations: Waterloo Bore; and Tarina. The Tarina station sits on the upstream boundary of the study area within Weeli Wolli Creek, while Waterloo bore sits just downstream of the study area boundary. This station's proximity to Weeli Wolli springs (4km downstream) means its data is somewhat influenced by perennial flows in and immediately downstream of the spring. Despite this, data from both Tarina and Waterloo suggest flows in Weeli Wolli Creek downstream of the springs is generally ephemeral, with an annual number of flow days in the same range but with a lower average of flow days.

2.3 PREVIOUS SURVEYS

A significant amount of survey work has been conducted in the Yandicoogina locality since mining development began in the 1990's. Table 2-2 outlines the flora and vegetation surveys which have been conducted in the area since this time. The majority of the recent survey work has been conducted by Biota Environmental Sciences. This body of work has essentially sampled/surveyed a riparian environment which had already seen some degree of impact from mining/pastoralism and particularly from surplus dewater discharge and historical grazing. The group of surveys conducted by Mattiske and including Integrated Environmental Services (1981), were generally conducted in a pre-mining development scenario (although within an environment already exposed to extensive grazing influence), and as such can provide useful insight to the pre-discharge environment.

Figure 2-2 illustrates the survey boundaries of the key pre and post-discharge flora and vegetation surveys conducted in the vicinity of the study area.

Table 2-2: Summary of vegetation and flora surveys contributing to the previous vegetation mapping dataset

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth4)	Available Data
Yandicoogina Vegetation and Flora Integration Report (Biota 2014a)	19,351 ha	Integration of existing data with a further botanical survey to provide additional information on the values associated with the complete development envelope for the HI Yandi project.	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandicoogina Billiards – Phase 1 and Phase 2 (Yandi PBS) (Biota 2014b)	8,640 ha (8,640 ha)	Two phase (seasonal) vegetation and flora survey of the PBS survey area to expand the existing data for the area to a Level 2 standard. 8 – 20 March 2014 (favourable); 7 – 11 July 2014 and 14 July 2014 (favourable).	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandicoogina JSW/Oxbow Vegetation and Flora Integration Report (Biota 2014c)	2,133 ha (2,192 ha)	Integration of existing data with a further botanical survey to provide additional information on the values associated with the JSW and YOX survey areas. 27 February – 4 March 2012 (favourable).	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandicoogina Additional Areas (Biota 2014d)	2,807 ha (2,828 ha)	Establish additional quadrats to validate vegetation mapping of additional areas around the JSW and YOX deposits to match the project footprint. 12 – 18 June 2012 (favourable).	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandicoogina Additional Vegetation Mapping (Biota 2011a)	2,806 ha (3,030 ha)	Mapping of additional areas around the JSW and YOX deposits to match the project footprint. 29 November – 3 December 2010 (unfavourable).	– Mapping notes. – Vegetation mapping. – Conservation significant flora and weeds. – Vegetation condition assessment. – Species list.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth4)	Available Data
Vegetation and Flora Surveys of the Oxbow and Junction South West Deposits, near Yandicoogina. (Biota 2010a).	YOX: 665 ha (725 ha) JSW: 1,460 ha (1,460 ha)	Two phase (seasonal) vegetation and flora survey of the JSW and YOX survey areas. YOX: 27 July-6 August 2008 (unfavourable); 3-9 June 2009 (favourable). JSW: 4 – 16 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable).	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
A Flora and Vegetation Survey of the Billiards Deposit, near Yandicoogina. (Biota 2009a)	1,512 ha (1,512 ha)	Two phase (seasonal) vegetation and flora survey of the Billiards survey area. 11 – 20 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable).	– Quadrats/relevés/mapping notes. – Weed records. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandicoogina Waste Dumps, Topsoil Stockpiles and Haulroads Native Vegetation Clearing Permit Report. (Biota 2009b)	406 ha (406 ha)	Single phase vegetation and flora survey of four development areas to support a Native Vegetation Clearing Permit. 4 – 7 September 2008 (unfavourable).	– Conservation significant flora records. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Vegetation Mapping and Rare Flora Searches of Yandicoogina Backfill Hill. (Biota 2005).	189 ha (189 ha)	Vegetation mapping and systematic rare flora searches of the Yandi Backfill Hill survey area. 31 May – 2 June 2005 (unfavourable).	– Vegetation mapping. – Vegetation condition assessment. – Species list.
Yandi Expansion Vegetation and Flora Survey. (Biota 2004a).	2,245 ha (2,245 ha)	Single phase vegetation and flora survey of the Yandicoogina Expansion area, near the YJC deposit. 30 August – 5 September 2004 (unfavourable).	– Quadrats/relevés. – Conservation significant flora and weeds. – Vegetation mapping. – Species list.
Flora and Vegetation Survey of the Hope Downs Rail Corridor Extension through the Hamersley Range. (Biota 2004b).	1,492 ha (3,977 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor Extension through the Hamersley Range. April 2003 (favourable).	– Quadrats. – Weed records. – Vegetation mapping. – Species list.
Vegetation and Flora of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek.	805 ha (2,774 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli. 25 April – 14 May 2001 (favourable); 29 May – 10 June 2001 (favourable).	– Quadrats. – Weed records. – Vegetation mapping.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth4)	Available Data
(Biota 2002).			– Species list.
Hope Downs Rail Corridors Biological Survey. (Halpern Glick Maunsell 2000).	2,594 ha (16,420 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridors. 25 November – 3 December 1999 (unfavourable).	– Quadrat. – Vegetation mapping. – Species list.
Flora and Vegetation: Yandicoogina Junction Area. (Mattiske 1995a).	3,591 ha (3,745 ha)	Single phase vegetation and flora survey of the YJC survey area. January and March 1994 (unknown) February 1995 (unknown).	– Quadrat. – Vegetation mapping. – Species list.
Flora and Vegetation: Northern Transport Corridor, Yandicoogina Junction Project Area. (Mattiske 1995b).	3,035 ha (24,703 ha)	Single phase vegetation and flora survey of the Yandi Northern Transport Corridor. February 1995 (unknown).	– Quadrat. – Vegetation mapping. – Species list.
Flora and Vegetation: Southern Transport Corridor, Yandicoogina Junction Project Area. (Mattiske 1995c).	2,450 ha (30,103 ha)	Single phase vegetation and flora survey of the Southern Transport Corridor. January and March 1994 (unknown) February 1995 (unknown).	– Quadrat. – Vegetation mapping. – Species list.
Ecological appraisal of the Yandicoogina Project Area. (Integrated Environmental Services 1981)	25,000 ha	Single phase Flora, fauna and vegetation survey of the area in favourable conditions.	– Conservation significant flora records. – Quadrats. – Weed records. – Vegetation mapping. – Species list.

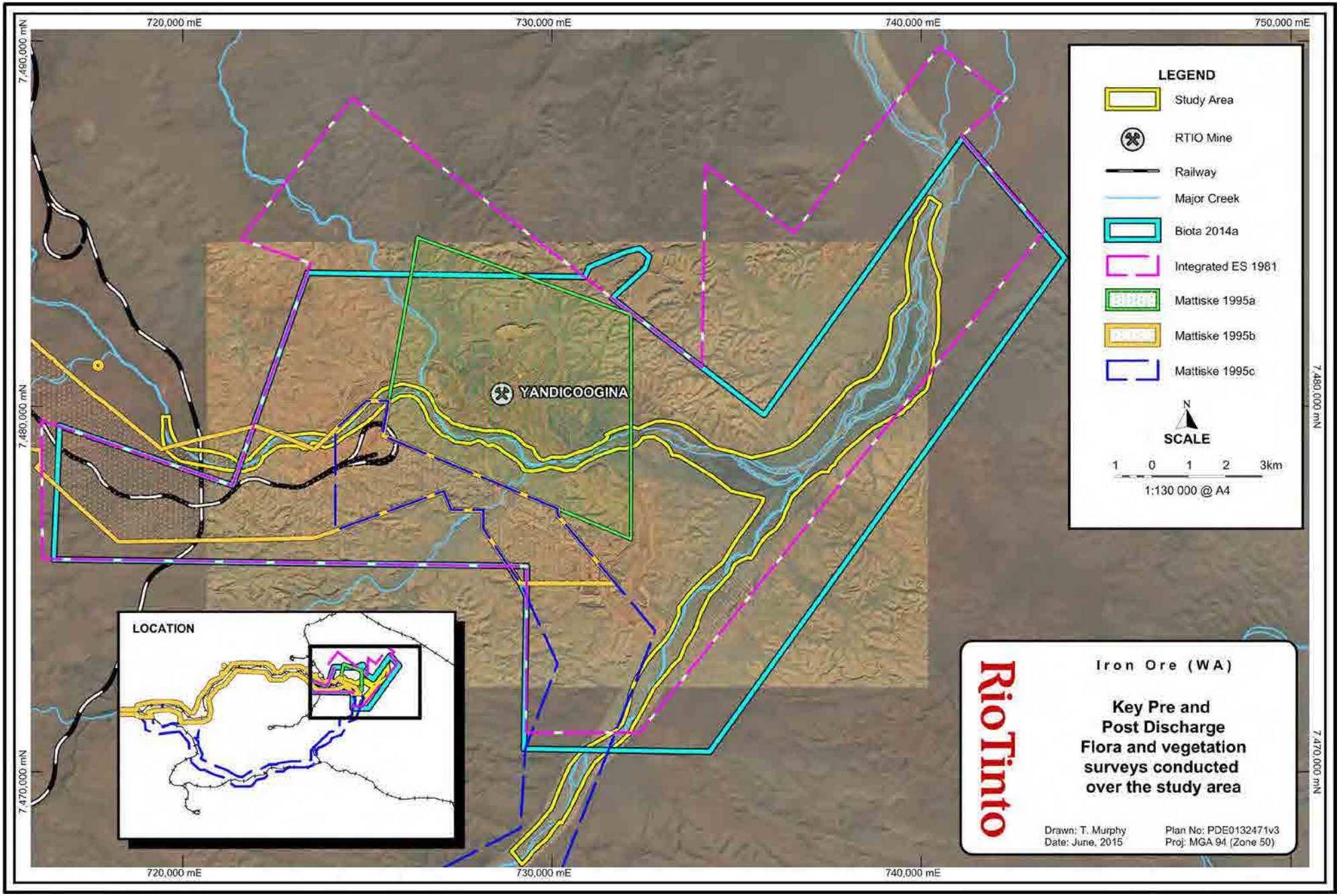


Figure 2-2: **Map illustrating the boundaries of the Key pre and post-discharge flora and vegetation surveys conducted within the vicinity of the study area.**

2.3.1 Resultant Vegetation Mapping and Inherent Issues

Previous vegetation mapping covering the study area has been completed at a resolution commensurate with the environmental impact assessment (**EIA**) objectives for which it was commissioned. Generally, flora and vegetation surveys conducted for the purpose of EIAs are commissioned with the aim of sampling and documenting all values present. Consequently sampling effort is spread widely and the level of detail attained is typically proportionate to the size of the area, number of landforms present, and the extent of areas of elevated ecological value.

Previous surveys conducted by Biota, and summarised in the "Yandicoogina Vegetation and Flora Integration Report" (2014), provide a well-integrated vegetation model for area. This mapping provides an important platform for the current study however the objectives of this study determined that mapping at a much finer resolution was required.

Despite the significant number of surveys conducted over Marillana and Weeli Wolli Creeks the detail of the vegetation mapping acquired has essentially been relatively broad. In the case of development at Yandicoogina, potential impacts to the riparian zone as a result of hydrological changes remains the key area of focus. As a consequence it was identified that improving the detail of riparian vegetation mapping would help increase knowledge in the riparian zone and increase the understanding of the environmental values, and hence increase the effectiveness of environmental management. The key area of vegetation refinement required to meet the objectives of this study, is the separation of areas of Obligate Phreatophytic Vegetation (**OPV; defined in section 2.4**) from non-OPV and to differentiate areas containing different size-classes of *M. argentea*.

A key distinction relating to OPV vegetation and the previous mapping provided by Biota (2014) relates to the C1 vegetation unit. Previous mapping by Biota within the study area described the C1 community to be present (Biota 2014a) and described this community to be represented by *Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* woodland over *Melaleuca argentea*, *M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland. Biota identified this community to inhabit scoured creek beds and channels of the wetter parts of Marillana and Weeli Wolli Creeks throughout the study area. As discussed later, this community appears to be an amalgamation of two separate communities (associations) occurring in this same area but possessing significantly differing distributions. It is this difference in distribution which is an important distinction required for the adequate consideration of the significance and distribution of OPV within the study area.

2.4 PHREATOPHYTIC VEGETATION AND SPECIES, AND GROUNDWATER DEPENDENT ECOSYSTEMS IN THE PILBARA

Riparian systems of the Pilbara bioregion are subjected to extremely seasonal and variable hydrologic regimes in which stream flow typically occurs following cyclonic rainfall events (Ruprecht and Ivanescu 2000). Large flow events can result in the formation of isolated pools, replenish floodplain soil moisture and recharge groundwater within the riparian system.

In creeks and rivers of the Pilbara, groundwater is typically contained within shallow, unconsolidated sedimentary aquifers close (<20 m) to the surface (Landman 2001). In some instances, groundwater reaches the surface and natural springs are formed, maintaining permanent surface water pools. These shallow aquifers and springs often support groundwater dependent ecosystems (**GDE's**); natural ecosystems that require access to groundwater to meet some or all of their water

requirements to maintain their communities of plants and animals, and ecological processes (Sommer and Froend 2011).

GDE's comprise plant species that, in the absence of rainfall, rely directly on groundwater (and associated surface expressions) but may also contain grass and herbaceous species relying on recent precipitation (Sommer and Froend 2011). Plant species which draw water from the saturated zone (the phreatic zone) or capillary fringe of the water table are known as phreatophytes and the presence of GDE's is often inferred from the presence of such species (Eamus *et al.* 2006). Phreatophytes can usually be found along streams where there is a steady flow of surface or groundwater, or consistent still pools in areas where the water table is near the surface.

At the opposite end of the scale is a "xerophyte", which is essentially a species of plant which has adapted to survive in an environment with little access to water (Salisbury and Ross 1991). Terms used to describe the water use strategies of plants occupying various positions within the Phreatophyte to Xerophyte scale are: "Obligate Phreatophyte"; "Facultative Phreatophyte"; and "Vadophyte".

It is generally considered that any vegetation that uses groundwater is potentially at risk of impact if it occurs in a location where the groundwater would be lowered beyond assumed natural groundwater variation. However, the impact on vegetation from lowering the groundwater table is likely to be relative to the species' dependence upon groundwater, and on the alternative sources of moisture available to it in any one situation. For example, plants that rely on water sourced directly from the groundwater table (phreatophytes) are more likely to show signs of decline or be lost than those that can rely on sources of soil moisture (i.e. vadophytes) such as precipitation and soil pore moisture anomalies from other sources. An assessment of the groundwater dependence of species present within the study area has been informed by a desktop literature review, with specific reference to previous vegetation association mapping and an understanding of the surface water and underlying groundwater environment.

Not all phreatophytic species display the same degree of dependency on groundwater and the dependency within species has been shown to vary both spatially and temporally (Eamus and Froend 2006). Obligate phreatophytes are those species for which access to groundwater is critically important to their presence in the landscape. Such species can only inhabit areas where they have access to groundwater in order satisfy at least some proportion of their environmental water requirements (**EWR**) (Eamus *et al.* 2006). Facultative phreatophytes, on the other hand, are plant species for which access to groundwater is not necessarily important to their presence in the landscape. Facultative phreatophytes may utilise groundwater to satisfy a proportion of their EWR but, if required, may also satisfy their total EWR via stored soil water reserves (Eamus *et al.* 2006).

The tree species *Eucalyptus camaldulensis subsp. refulgens* Brooker & M.W. McDonald (River Red Gum), *Eucalyptus victrix* L.A.S.Johnson & K.D.Hill (Coolibah) and *Melaleuca argentea* W.Fitzg (Silver Cadjeput – historically identified as *M. leucadendra*) are the three most common phreatophytic species within riparian systems of the Pilbara bioregion. The presence of these species is often used to infer the presence of a Groundwater Dependant Ecosystem. The three species vary in their degree of dependence on groundwater and this variation has a strong influence on their patterning and abundance within riparian systems.

Melaleuca argentea is a tree which grows to approximately 20 meters and is found along larger watercourses of the Pilbara. *Melaleuca argentea* is thought to be depend on groundwater almost

exclusively to meet its water requirements and is therefore considered to be an obligate phreatophyte (Lamontagne *et al.* 2005, Graham *et al.* 2003, Landman *et al.* 2003, O'Grady *et al.* 2006). Due to its dependence on groundwater, this species is typically found in parts of creeks and rivers characterised by permanently inundated pools and springs or where the water table is permanently close to surface (McLean *et al.* 2013). *Melaleuca argentea* is generally considered to be the plant taxon within the Hamersley Ranges at highest risk of impact through changes to groundwater availability associated with mining drawdown. *Melaleuca argentea* has previously been recorded within the study area at varying quantities and while certain parts of the study area are considered to possess occurrences of shallow groundwater or consistent surface water features, in many cases these levels or sources have been increased and decreased as a result of development in the area. Consequently, it is considered that while vegetation associations at high risk from groundwater drawdown are present in the study area, it appears that not all were present pre-development, and many are not showing influence from draw down due to consistent surface water inputs from surplus water discharges. Table 2-3 presents the different classes of groundwater dependence (water use strategies) relevant to plant groups in the Pilbara, and the most relevant species considered being attributable to each.

Table 2-3: Tree species dependence on groundwater

Species dependence on Groundwater	Plant Physiology/water use strategy	Relevant Species in the Pilbara
High	Phreatophyte	*Melaleuca argentea*
Moderate	Facultative phreatophyte (sometimes a vadophyte)	*Eucalyptus camaldulensis, Melaleuca glomerata*
Low to Moderate	Vadophyte (in anomalous cases can be a Facultative phreatophyte	*Eucalyptus victrix and Eucalyptus xerothermica*
Low (virtually negligible)	Xerophyte	E.g. Eucalyptus leucophloia, *Corymbia hamersleyana*, Corymbia deserticola. Etc…

Vegetation associations occurring along the main drainage channel and associated flood plains within the study area support three native tree species that are considered to be at moderate risk from groundwater drawdown: *Eucalyptus camaldulensis* subsp. *refulgens*; *Eucalyptus victrix* (moderate risk); and *Eucalyptus xerothermica* (minimal risk). These tree species are classified as vadophytes or facultative phreatophytes. *Eucalyptus camaldulensis subsp. refulgens* is the most widespread of Australian Eucalypt species and is known to tolerate an apparently wide range of water regimes (Colloff 2014). River Red Gum is considered a facultative phreatophyte as it obtains its water for transpiration via three main sources: groundwater, river flooding (which over tops creek and river banks thereby replenishing floodplain soil moisture), and rainfall (Wen *et al*. 2009). The degree to which River Red Gum depends on groundwater and soil moisture has been found to vary both spatially and temporally (Mensforth *et al*. 1994, O'Grady *et al*. 2009, Wen *et al*. 2009, O'Grady *et al*. 2010).

E. camaldulensis typically occurs along inland rivers and may be dependent on shallow groundwater for survival, although the root system may penetrate considerably deeper than 10 m. Studies in the Pilbara indicate that *E. camaldulensis* occurring along the larger drainage lines may have access to groundwater up to 21 m below the surface (AGC 1992). Investigations at Marillana Creek found the vigour of large *E. camaldulensis* trees (>10 m tall) declined in response to lower groundwater levels caused by test pumping of water, while the vigour of smaller *E. camaldulensis* remained unchanged

(Onshore Environmental 2013). This observation suggests that the species is capable of being both a vadophyte and a phreatophyte, using the former strategy when young and the latter strategy when mature (Halpern Glink Maunsell 1999). Muir environmental (1995) indicates that River red gum (*E. camaldulensis*) and Coolibah (*E. victrix*) are generally not restricted in their occurrences along Marillana Creek and thus cannot be considered as being true phreatophytes, but as vadophytes (i.e. primarily unsaturated soil dependent). In the case of *E. camaldulensis*, general observations in the Pilbara by Rio Tinto Botanists suggests that there is some degree of restriction to the distribution of this species along large creeks, and so the concept that this species can be both a phreatophyte and a vadophyte (depending on the circumstances) is probably most accurate.

Eucalyptus victrix is a small to medium sized eucalypt which typically occurs on smaller creeklines and floodplain habitats throughout semi-arid Western Australia. Like River Red Gum, *E. victrix* is also considered to be a facultative phreatophyte. This species has been shown to access groundwater in areas where the depth to groundwater is low (O'Grady *et al.* 2009) but in non-riparian habitats, has also been shown to exploit shallow soil water to meet is transpiration needs (Grigg *et al.* 2008). *Eucalyptus victrix* is known to inhabit an ephemeral wetland (i.e. Mount Bruce Flats, Karijini National Park) despite the absence of a permanently saturated regolith (Rio Tinto 2011a). Comparisons of groundwater and stem xylem water stable isotope compositions as well as pre-dawn and midday leaf water potential measurements suggest that *E. victrix* within the Mount Bruce Flats in Karijini National Park uses water drawn from the unsaturated soil profile during extended dry (Rio Tinto 2011a). Further to this, *Eucalyptus victrix* and *Eucalyptus xerothermica* are generally considered to be examples of vadophytes being relatively drought tolerant but susceptible to decline when groundwater becomes limiting (Muir Environmental 1995).

The water use characteristics of *E. camaldulensis, E. victrix* and *M. argentea* may also influence their response to mining related impacts such as dewatering and discharge. Dewatering, which causes localised lowering of groundwater levels, may be expected to have a significant impact on the health of *M. argentea* but lesser impacts on *E. victrix* or *E. camaldulensis*, provided adequate soil moisture is maintained from periodic, rainfall-generated stream flow. On the other hand however, artificial discharge of surplus groundwater along ephemeral creeks and rivers may favour *M. argentea* (resulting in increased recruitment and vigour) by creating a perennial hydrologic regime. Change from a steady-state ephemeral hydrologic regime to a more perennial one may adversely impact *E. victrix* and to a lesser extent *E. camaldulensis*. Florentine (1999) found that *E. victrix* exhibits some tolerance to waterlogging (e.g. production of adventitious roots) but overall growth, transpiration rate and net photosynthesis are negatively affected under waterlogged conditions. By contrast, *E. camaldulensis* is considered to be one of the most waterlogging-tolerant eucalypt species (Bell 1999; van der Moezel *et al.* 1988), though empirical studies of River Red Gum waterlogging tolerance in the Pilbara bioregion are lacking and may be somewhat dependent on subspecies. At the local scale the impacts of excess water will differ depending on the substrate and channel morphology and thus the relative position of trees (particularly on a vertical plane) to available water.

Probably the most important point to consider when classifying the water use of plant species by attributing particular species to one of the above described water use strategies, is that typically plants and their associated environments do not always behave in definite manners. While the physiological constraints and demands of the plant tend to be quite definite, the way in which the environment provides for this physiology and the way in which the plant acquires its needs from the environment can vary quite considerably in time and space (O'Grady *et al*. 2009). The most relevant area of variability in relation to the risk of death from changes in water availability is represented by

a plants ratio of resource allocation between its canopy and root systems. The size and distribution of a plants root system (and conversely the size of its canopy and associated water demands) has a direct link to its ability to acquire sufficient moisture when soil conditions change (Salisbury and Ross 1991). The rate of water availability change therefore has important consequences for the ability of a plant to re-allocate these resources in time and therefore potentially to transition between the bounds of a phreatophyte and a vadophyte.

Another important point to consider when assigning species or communities to phreatophytic water use strategies is the source of moisture. While phreatophytic species are considered to be dependent on groundwater this is not always accurate in the context of the typical definition for groundwater. Groundwater is often considered to be defined as the underlying water table, but in the case of plant water use it is more accurately any source of water on, in or under the ground as long as its presence remains fairly consistent. For example; phreatophytic species can establish because stream morphology and/or underlying geology are such that specific areas sustain consistent alluvial water bodies or surface water pools and patches of moisture which are perched well above the underlying groundwater table. Subsequently these communities can be sustained by consistent fluvial flows regardless of the behavior of deeper groundwater bodies. The reason such distinctions are important, is that in an impact assessment scenario potential changes to clearly detectable and therefore more broadly evident groundwater aquifers often comprise the measurable features of hydrological influence acting on riparian systems. However despite such a focus, changes to broad scale groundwater features can often occur with little or no influence on small scale aquifers and surface water features consistently present in certain fluvial situations.

The resounding message which becomes apparent when considering phreatophytic species is that not all phreatophytic species are equal. Each species considered has evolved in a different habitat, and each habitat has varying degrees of water availability. An additional layer of complexity is represented by the various niches which these species have adapted to take advantage of within each habitat. Consequently species like *Eucalyptus victrix* and *E. camaldulensis* have quite different adaptive capabilities and as such can survive and prosper in quite different water availabilities.

GDE's and their associated species and landforms represent features of elevated ecological value. Phreatophytic species often represent fast growing pioneers which are highly resistant to disease. They also provide, shelter, specialised foraging grounds, and nesting/denning areas for native fauna. Phreatophytes are also known to be indicators of potable groundwater, and to provide water purification services, as their roots are known to fix heavy metals via the provision of bacteria driven filtration (World heritage Encyclopedia 2014).

GDE's, generally represent areas with relatively permanent water, and as such tend to support relatively dense and diverse vegetation communities. Such vegetation tends to contain an above average proportion of mesic perennial and ephemeral species diversity, and so represents repositories of genetic diversity which are often restricted in their distribution and areal extent. Coupled with the diversity of fauna species (particularly avifauna, and nocturnal invertebrate fauna) which they support, their value is generally accepted to be high. It is for this reason that those species which are considered obligate phreatophytes, and therefore most dependent on water permanence, are those species which are the best indicators for the presence of these high value ecosystems. In the Pilbara, that species is known to be *Melaleuca argentea*, and consequently the distribution, abundance and age structure of this species in the environment is often the best available measure for the presence and quality of high value groundwater dependent ecosystems.

However, communities which occur in generally ephemeral habitats, and which do not possess an obligate phreatophytic species such as *Melaleuca argentea*, but instead only possess facultative phreatophytes such as *Eucalyptus camaldulensis* can also be described as groundwater dependent Communities or GDE's. For this reason it becomes important to make the distinction between general groundwater dependent ecosystems/vegetation, and those which are more specifically highly groundwater dependent, or "truly phreatophytic".

In the Pilbara, *M. argentea* is widely considered a strict obligate phreatophyte, and because of the potentially variable water use strategies of some of the other phreatophytic species in the Pilbara (namely facultative phreatophytes), *M. argentea* clearly represents the best indicator for true groundwater dependence. Therefore to provide a term which can be used to make the distinction between the less significant often facultative types of phreatophytic vegetation (general GDE's) and those possessing "true" or obligate phreatophytes, the term "Obligate Phreatophytic Vegetation" (OPV) is proposed.

For the purpose of this study, the term "Obligate Phreatophytic Vegetation" is defined as representing communities which:

> *Encompass vegetation associations and sub-associations, whose structure is at least co-dominated by one obligate phreatophyte, namely Melaleuca argentea (i.e. possesses vegetation described as being dominated by one or more species within the tree or tall shrub stratum and which includes the species Melaleuca argentea as one of these described dominant species). Note: this is not an well recognized term, and has been created for the purpose of this study from associated, well accepted terms such as "Obligate Phreatophytes" & "Groundwater Dependent Vegetation").*

The distinction this term makes is important for this study, as communities which this species comprises a significant component of, are best placed to indicate perennial water availability, and therefore indicate the distribution of ecological values associated with permanent water availability. By making this distinction this study can then differentiate between OPV and the more commonly distributed GDE's represented by facultative phreatophytic vegetation such as *Eucalyptus camaldulensis* woodlands which tend to surround OPV. Consequently, for the purpose of this study, and to aid in the process of assessing riparian significance and the distribution of significant riparian communities in the study area; we will consider communities and vegetation associations/sub-associations within which *Melaleuca argentea* forms a co-dominant species, to be called OPV (Obligate Phreatophytic Vegetation). The remaining communities possessing other phreatophytic species, and including those possessing *M. argentea* as an associated species only, are from here on in to be termed "Facultative Phreatophytic Vegetation" (**FPV**).

2.5 FACTORS CONTRIBUTING TO BIOLOGICAL SIGNIFICANCE

The set of statutory listings for vegetation communities and ecosystems by the WA State or Commonwealth Government are not exhaustive and are generally based on a system of nomination, such that they do not represent a systematic treatment of features of high value or significance. Therefore unlisted flora and vegetation may be locally or regionally significant for similar reasons to those features chosen or nominated for listing.

Based on Guidance Statement 51 (Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia)(EPA 2004), and other sources; vegetation may be significant because its areal extent is below a threshold level and a range of other reasons, including:

- scarcity;
- high diversity;
- high diversity within special functional plant groups (e.g. mesic species, ephemeral taxa, xerophytic taxa etc.);
- unusual species, or range extension species;
- novel combinations of species (associations);
- a role as a refuge;
- a role as a key habitat for threatened species or large populations representing a significant proportion of the local to regional total population of a species;
- being representative of the range of a vegetation association (particularly; a good local and/or regional example of an association in "prime" habitat, at the extremes of known range, recently discovered range extensions, or isolated outliers of the main range);
- of restricted distribution or occupying a rare landform; and
- exceptional condition.

Vegetation communities are often considered locally significant if they contain multiple Priority Flora species or contain a range extension of a particular taxon outside of the previously known distribution. They may also be locally significant if they are restricted to one or two locations or occur as small isolated communities. In addition, vegetation communities that exhibit unusually high structural and species diversity are also locally significant.

Vegetation communities are regionally significant where they are limited within the bioregion to specific and relatively rare landform types, are generally very uncommon or restricted plant community types within the regional context, or support significant populations of threatened flora. Communities can also be rated at the sub-regional scale for the same reasons but confined to certain areas within one or multiple sub-regions. Determination of significance for flora and vegetation may be applied at various scales, for example, a vegetation community may be nationally significant and governed by statutory protection as well as being locally and regionally significant (EPA 2004).

2.6 RELEVANT HIGH-VALUE RIPARIAN VEGETATION COMMUNITIES WITHIN THE HAMERSELY'S AND THEIR ASSOCIATED DISTRIBUTION

The climate of the Pilbara is essentially classified as arid-tropical possessing an average precipitation to evaporation ratio of less than 0.2 (McKnight 2000). With precipitation generally falling within the range of 250-450 mm the Pilbara can be mistaken for being semi-arid, but with high average temperatures and an average evaporation rate in the vicinity of 2000 mm per year, the effective precipitation in the region is minimal. Because of such climatic factors, water gaining sites which are exposed to surface water supply from larger catchments and which can lock away significant amounts of water from evaporation, become quite important. Such fluvial systems create riparian corridors which provide refuge for a diversity of moisture loving species which wouldn't otherwise be present in areas possessing a similar climate classification. Consequently these features provide

value to the region as custodians of biological diversity through their provision of ecological services and habitat diversity/complexity.

Beyond the general importance and functions of large creek systems in hot and often dry climates such as that of the Pilbara; drainage systems which provide the right catchment size and environmental conditions (generally related to underlying geology, elevation, slope, meander shape and creek profile etc.) to create surface or groundwater permanence are considered most valuable because of the restricted vegetation communities they can sustain, and by association the fauna assemblages they support. The permanence of the water present ensures the landforms ability to create and sustain obligate phreatophytic species (e.g. *Melaleuca argentea*), vegetation of a high structural and species diversity, and potentially associated conservation significant fauna assemblages. These attributes in turn create value and therefore significance due to the restricted distribution of these perennial habitats. With respect to conservation significance, features such as this tend to possess elevated conservation significance as they are generally few in number, restricted to small areal extents, and sensitive to perturbation.

2.6.1 The Role of Phreatophytic Vegetation/Groundwater Dependent Ecosystems

Within the Pilbara, riparian habitats which provide permanent surface or groundwater are commonly present along sections of the regions large river systems. While these systems are not common, they are large, and OPV is generally common along parts of their length. Beyond the river systems of the Pilbara, the remaining representations of OPV are quite restricted to parts of those large creek systems which provide the right catchment and substrate conditions to maintain perennial surface and groundwater sources. In the Hamersley Range subregion such areas are often restricted to the rocky uplands and perched valleys of the Hamersley plateau. The unique landforms and geological substrates of these riparian examples also provide another distinction to which significance can be attributed given their restricted distribution.

As discussed earlier; in the Pilbara obligate phreatophytes such as *Melaleuca argentea* are essentially dependant on moisture permanence to survive. Without it, they will almost certainly die, and as a result of this dependence this species is considered one of the best indicators of water permanence in the Pilbara. In general the structure and composition of creekline vegetation tends to be driven by the degree of moisture present, and so vegetation is an important indicator of surface water permanence, potentially providing insight into the degree of permanency and therefore associated value and significance. This means of insight is important as there are often no good alternatives (at a finer scale) for establishing water permanence in an area. Human records are generally not extensive or detailed enough to truly determine if a site actually possesses surface or groundwater permanency. Furthermore, climatic factors can have a strong influence from year to year, and the underlying water table heights established from an often limited array of bores are hard to accurately interpolate. Generally the best and often only true indicator is the composition and structure of vegetation present.

In the Pilbara, a list of sub-perennial to perennial water indicating species might contain the following list of species in order of importance (Western Australian Herbarium 2015). Consequently, riparian zones or water gaining sites which contain Melaleuca argentea and varying proportions of the following species are considered to provide good evidence of water permanence (bold species indicated best indicators):

- ***Melaleuca argentea***
- *Samolus spp.*

- ***Acacia ampliceps***
- ***Eucalyptus camaldulensis***
- ***Typha domingensis***
- ***Muehlenbeckia spp.***
- *Melaleuca glomerata*
- *Melaleuca bracteata*
- *Atalaya hemiglauca*
- *Sesbania formosa*
- *Cyperus vaginatus/iria*
- *Imperata cylindrica*
- *Marsilea spp.*
- *Potamogeton spp.*
- *Acacia coriacea subsp. pendens*
- *Eucalyptus victrix*
- *Melaleuca linophylla*
- *Acacia citrinoviridis*
- *Acacia sclerosperma*
- *Gossypium robinsonii/sturtianum*
- *Lobelia spp.*
- *Stylidium spp.*
- *Sesbania spp.*
- *Stemodia spp.*
- *Sorghum spp.*

So while it is clear that the species composition of vegetation provides a significant insight into water permanency, an additional level of detail about water permanency is provided by the structure of vegetation. This essentially involves making inferences about the degree and extent of permanency based on the age structure of any obligate phreatophytic species which might be present. It is postulated that if water remains permanently available to these phreatophytic species then at least a percentage of the population is likely to be present as "semi-mature" to "mature" individuals of approximately 40-100 cm diameter (see Table 3-1 for trunk diameter definitions of the semi-mature and mature size class terms used for this report). While environmental perturbations such as floods and similar peak flow events will have an influence on the age structure, it is still considered likely that mature trees (older large individuals) will remain to provide insight into the stability of the moisture conditions present over reasonable temporal scales.

In the Pilbara evidence of such an age structure can be seen at the well-known and long studied Weeli Wolli springs. This spring is well known for its permanent surface water expression by both more recent land-managers and the long term traditional owners of the area who indicate that the spring has been used for hundreds of years. A report by Gavin Jackson P/L, dates many sites at hope downs (right beside the spring) as thousands of years old, and also provides an in-depth justification for inland Pilbara (particularly near the spring) as being settled near the last glacial maximum (Jackson P/L 2003). The spring is represented by a stretch of creek possessing generally permanent surface water as a result of and groundwater being forced to the surface by geological and topographical features. In the wetter parts of the spring the vegetation is broadly comprised of a *Melaleuca argentea* and *Eucalyptus camaldulensis* woodland (to open forest in places). A woodland is defined as being comprised of trees from 10-30 m tall and having a combined cover abundance of 10-30% (open forest being 30-70%) (Aplin 1979). Given this structure, and the observed size/age structure of this community, it is clear that a significant proportion of the obligate phreatophytic trees (*Melaleuca argentea*) in this area are considered to be mature and large in size. Such structure combined with recognition of long-term perennial water availability at Weeli Wolli Spring supports the concept that there is a direct relationship between the maturity of age structure shown by obligate phreatophytes in a community and the degree of moisture permanency present. Additional evidence for this relationship can be seen by the reducing maturity of age structure and more restricted distribution (restricted to minor populations lining the low flow channel) of *Melaleuca argentea* moving downstream and away from the permanent water source of Weeli Wolli spring.

In the case of the Marillana and Weeli Wolli creek systems and other similar systems in the Hamersley's, the most significant riparian communities are those containing a substantial *Melaleuca argentea* component such as:

- Weeli Wolli springs PEC;
- parts of some of the larger gorge systems flowing north out of Karijini National Park (e.g. Munjina Creek or Joffre Creek);
- some of the lesser known sections of Marillana creek (upstream of the study area) such as at and upstream of Flat Rocks; and
- small patches of other east and north western Hamersley Range Creek systems such as Mindy Mindy, Coondiner, and Southern Fortescue Creeks.

What all these areas have in common is the presence of varying sized representations of large mature *M. argentea* and *E. camaldulensis* woodland (similar to vegetation identified in the C1AA community). What these areas also have in common, is that in most cases the woodland is not represented by a sometimes very thin (almost single tree width) strip of this woodland which often forms on the banks of some permanent-to near permanent surface pools. Instead the relevant vegetation is spread across a broader lateral range of the creek indicating more general groundwater permanence through a larger proportion of the creek profile, and thus providing greater habitat and structural diversity values. Broader (laterally) representations like this appear quite restricted in their distribution within the Hamersley subregion, and consequently they can be considered sub-regionally significant.

Recent aerial photo interpretation (by Rio Tinto Botanical specialist Jeremy Naaykens) of most large creek systems in the Northern zone of the Hamersley sub-region (See figure 2-1) recognised and mapped relevant aerial signatures and some DMSI (where available) signatures likely to represent GDE's similar to or equivalent to this community (after comparison with signatures of known representations). By combining this recent aerial photo signature mapping with previous Rio Tinto vegetation mapping, a conservative figure for the current areal extent of similar representations of *M. argentea* and *E. camaldulensis* woodlands was created. From this mapping it was estimated that only 1/5 of the aerial signatures mapped are likely to accurately represent this community, and consequently no more than 10 km^2 or 0.0002% of the sub-region is represented by it.

Beyond these more extensive and significant stands of *M. argentea/Eucalypt* spp. woodland, where water availability is generally perennial; surface and groundwater availability in the remaining sections of the larger Hamersley Range creek systems are generally more variable. However at the smaller scale, landforms and features such as creek bends & corners, constricted channels and small scale geological anomalies can combine to more consistently retain surface water (or close proximity groundwater and small perched alluvial aquifers) than the majority of the general creek bed. In such cases, narrow isolated patches of OPV (similar to association C1AA) can be found lining large pools or occupying low points. However, such vegetation is more typically represented by a less significant community similar to the previously recognised C1 community (Biota 2014a). This comparatively less significant community tends to be a woodland to open woodland of *Eucalyptus camaldulensis* and *E. victrix* with *M. argentea* co-dominating in the low woodland or tall shrubland layer with other moisture loving species such as *Melaleuca glomerata*, *Acacia coriacea subsp. pendens*, *A. ampliceps*, *Atalaya hemiglauca* etc. Within the creek profile, this community is comparatively more restricted,

often concentrated around low flow channels and other consistently moist zones within the creek profile. This community is generally only considered locally significant, with a reduced suite of ecological values, and a slightly more widespread distribution. Recent desktop mapping exercises estimated that, excluding representations on major river systems, there is likely to be approximately 50km^2 of similar vegetation within the Hamersley subregion (0.0009% of the sub-region). This is purely an estimate, but as can be seen in Figure 2-1 this vegetation type is scattered throughout the Northern Half of the Hamersley's, and likely to be represented by isolated patches in the southern half of the Hamersley sub-region.

The remainder of the phreatophytic vegetation and generally significant but well represented units of the study area are essentially represented by; an open woodland (to woodland in places) of *E. camaldulensis* and *E. victrix* over patches of mixed low open woodland/tall open shrubland scattered throughout anna-branching channels and broad open creek bed zones. This vegetation community is typically one of the more common of the larger more topographically confined riparian systems within the Hamersley ranges (i.e. those dissecting significant range systems rather than occupying the finer soils of plains and broad alluvial valleys). The other more common and least significant community on systems such as these is represented by low open woodland (to scattered low trees) of *Eucalyptus victrix* over mixed *Acacia* spp. tall open shrublands (broadly equivalent to the previously mapped C3 unit mapped throughout the area (Biota 2014)).

2.7 SENSITIVITY OF LOCAL RIPARIAN COMMUNITIES TO HYDROLOGICAL IMPACTS

When considering development and associated impacts, it is pertinent that a measure of sensitivity/resilience be considered and attributed to features of significance so that an element of risk can be attributed to their ultimate significance.

While *Melaleuca argentea* co-dominated communities generally represent the most significant of the Marillana and Weeli Wolli Creek riparian communities because of their associated values and perennial water availability, it is this dependence on a perennial water source which makes them the most sensitive to anthropogenic hydrological changes. Despite the inherent sensitivity of these communities the age structure and distribution of the respective sub-associations of *M. argentea* co-dominated communities present in the Marillana and Weeli Wolli creek has some degree of influence on their sensitivity to impact. The most significant and mature representations of *M. argentea/Eucalypt spp. woodland* are likely to be most sensitive to change due to their generally higher water demands, broader lateral distribution within the creek profile, and mature age structure. At the other end of the scale is the community which possesses a youth dominated *Melaleuca argentea* age structure which is generally restricted in its distribution to lining key surface water features and low flow channel margins. Assuming a relatively regular regime of surface water flows, this community should be comparatively resilient to changes in groundwater availability when compared to the mature woodland community. *Melaleuca argentea* communities which fall in between these two ends of the scale of sensitivity will generally possess sensitivities commensurate to their water demands, predominant age and maximum distance from low flow channels.

2.8 FRAMEWORK FOR SIGNIFICANCE

For the purpose of incorporating a sense of "quantification" to the process of attributing significance to riparian communities within the study area, the following "framework for Significance" is proposed as a means of providing a systematic qualitative assessment of significance:

Key steps for considering the relevant factors/attributes are:

1. Part one - consider the number and magnitude of ecological values associated with or provided by a biological feature.

2. Part two - determine the distribution and therefore degree to which it is restricted in the environment, the degree of representation (the degree to which a vegetation unit is represented by other communities outside of the study area), and potential rarity of this feature within local, sub-regional, and regional scales.

3. Part three – consider the condition of the biological feature, and its inherent resilience to perturbation.

Once determined, the combined consideration of these three key attributes is used to determine a significance rating. The inherent sensitivity or resilience of a feature to perturbation will tend to increase or decrease the likelihood of impact, as well as the consequences of the impact. In addition, the current condition of the feature at the time of consideration will have an influence on its significance. In order to incorporate sensitivity/resilience and locally known potential anthropogenic impacts into the resultant significance, it is proposed that for this study, the term "Development Significance" will be created and used to attribute an alternative and only locally relevant significance to the biological features of the study area. In addition this term will incorporate the condition of the feature as well and the inherent risks and consequences of development on this feature into the attributed significance. The "Development Significance "will in turn provide more measured guidance to management and mitigation as development is undertaken or continued.

The resultant significance is to be attributed to one of the levels in the following scale, via the process of assigning a measure of the factors presented for each level below:

1. Low (generally common and well represented, and with no additional values identified and commonly highly resilient to perturbation).

2. Minor (generally common and well represented, but with additional values identified).

3. Minor-Moderate (Somewhat restricted or uncommon, or possessing some key local values).

4. Moderate, (Locally restricted, and possessing some key local values).

5. Moderate-High, (Local to broader scale degree of restriction and possessing key ecological values (often along with and some degree of reduced resilience or sensitivity)).

6. High, (At least sub-regional scale degree of restriction and possessing multiple key ecological values and often a degree of sensitivity to perturbation).

7. Very-High (Potentially regionally restricted, multiple key ecological values identified, and often possessing a well-known social-biological value or proven to support key populations of Threatened flora/fauna, and often with an inherent degree of sensitivity to perturbation).

Importantly it should be noted at this point, that the above is a relative scale, and while it presents a system for defining the different levels in the scale, some of the factors presented to determine if a biological feature is attributed to a level may be perceived as arbitrarily assigned. What is important

is that it provides a scale of enough detail to allow for the various available combinations of those factors described as influencing the determined significance (i.e. degree of restriction, values etc.).

This report does not attempt to deal with the term conservation significance; this is an additional level of subjectivity which is not proposed in the context of this study. However, it is noted that in many flora and vegetation assessments the most significant features (potentially equivalent to the High to Very-High significance ratings presented in this report) are often determined to be conservation significant. As a consequence, avoiding direct impacts to features of high significance is generally important, while avoiding or minimising significant indirect impacts should at least be an objective where practicable.

2.9 HISTORY OF DEWATER DISCHARGE IN THE VICINITY OF THE STUDY AREA

Discharge of surplus dewater from the BHPBIO Yandicoogina mine operation into Marillana Creek began in May 1991 (see Figure 3-5 to 3-11 for the location of the various surplus water discharge locations). In 1998 Rio Tinto started releasing surplus dewater into Marillana Creek and by December 2006 the combined operations were discharging at an average rate of 34 ML/day-1. Release of surplus dewater directly into Weeli Wolli Creek began in 2006 (pre-mining discharge from Hope Downs and intermittent discharges from JSE), with expansion of the Rio Tinto JSE mine and development of the Hope Downs 1 operation, approximately 20 km upstream of Yandicoogina. In addition to this, an array of re-injection bores were brought on-line in 2007 re-injecting surplus-discharge into the local aquifer immediately to the east of Weeli Wolli Creek in the vicinity of the proposed PBS project area (this ceased in late 2014). In 2009, approximately 49 GL of surplus dewater was discharged into Marillana and Weeli Wolli Creeks, consisting of:

- ~14 GL into Marillana Creek from the Hamersley Yandicoogina operations;
- ~5 GL into Marillana Creek from the BHPBIO Yandicoogina operations; and
- ~30 GL into Weeli Wolli Creek from Hope Downs 1 mining operations (~20 km upstream from the Marillana Creek confluence).

The combined discharges of the various mining projects in the catchment have resulted in continuous (perennial) stream flow and potential saturated creek bed conditions in the downstream sections of the Marillana and Weeli Wolli Creek systems (the study area). Since 2008, the surface water discharge footprint, defined as the extent of surface water expression, extends to up to ~8 km beyond the confluence of the Marillana and Weeli Wolli Creeks. The surface wetting front fluctuates over a distance of approximately 5-9km, depending on climatic conditions and surplus water discharge rates.

Sub-catchment areas in the vicinity of the Rio Tinto and BHPBIO operations have been modified by the construction of diversion structures, mine pits and haul/access road crossings. Changes to the direction and pattern of surface flows have resulted, with an overall reduction in flow contributions to Marillana Creek compared with the pre-disturbance regime. Hydrological modelling undertaken by Rio Tinto indicates that the existing operations have caused only minor reductions in flow contributions to Marillana Creek; in the order of 1% of the pre-disturbance flow volumes (Rio Tinto 2010).

2.10 SURPLUS DEWATER DISCHARGE, VEGETATION AUGMENTATION AND PHREATOPHYTIC VEGETATION DISTRIBUTION IN THE STUDY AREA

For riparian vegetation communities present in the study area, the resultant scale of significance attributed to these communities is largely a product of scales of water availability, such that the more perennial surface and groundwater becomes the more significant the vegetation, flora and associated habitats tend to become. An unavoidable outcome of this is that 'significant' vegetation communities will establish where development artificially increases the availability of water. Assigning significance to such vegetation communities, as they are artificially augmented by altered hydrological conditions, can be problematic.

Evidence on Marillana Creek, in the vicinity of the Rio Tinto Yandicoogina operations, suggests that surplus dewater discharge can and has facilitated the establishment of abundant *Melaleuca argentea* populations in certain highly restricted creek zones. However, if *M. argentea* is the species most sensitive to groundwater changes, and it is observed to be flourishing in an environment where groundwater tables are heavily reduced (i.e. locations surrounding the mining pits), it is most likely being sustained and established by surface water discharges, which in effect irrigate these trees. While this surface water discharge is likely to maintain a shallow depth to groundwater within close lateral proximity to surface flows, in general the distribution of this groundwater appears highly restricted. These observations suggest that *M. argentea* it is more accurately highly moisture dependent rather than reliant on the presence of local groundwater aquifers. Therefore in general, the source of water (i.e. regional or local aquifer groundwater, perched aquifer or alluvial pore-water or surface water flows) is likely to be less important than the consistency of its availability and the ability of obligate phreatophytic components of the vegetation to access it. In the case of patches of OPV immediately downstream of discharge points on Marillana creek such as the BHPBIO discharge, it is postulated that:

> *If this vegetation was a product of natural historical groundwater presence it is most likely that its distribution within the creek system would be less laterally restricted to the low flow channel and spread more laterally within the broader incised creek channel (such as is present in other stretches of Marillana Creek and at well-known examples like Weeli Wolli spring).*

However this concept should not be overstated and it is possible the available surface and ground water in certain pre-discharge circumstances was confined to the immediate low-flow channels and therefore not available across the broader channel under baseline conditions. However the assumption is that in general, under baseline conditions, areas of perennial water availability are most often associated with laterally broader subsurface water availability than that generally apparent within stretches of the study area being artificially irrigated via surface water discharge.

Weeli Wolli spring is characterised as a GDE with significant stands of OPV supported by the surface expression of the local groundwater table. In the vicinity of the spring a significant proportion of OPV possesses a relatively broad lateral distribution within the creek profile, a more evenly distributed age structure and the common presence of large/old trees.

Based on observations at Weeli Wolli Spring and other known areas of groundwater dependent OPV, it would be expected that the majority of GDE vegetation established under baseline groundwater and surface water conditions, would exhibit an age structure similar to that observed at Weeli Wolli Spring; that is, an even frequency distribution of size classes from saplings to large mature trees. In

addition it would also be expected to see a reduced degree of lateral restriction in the distribution of OPV within the typical creek profile. By extension, GDE vegetation which occurs mainly as thin strips lining the low flow channel, and dominated by a young unevenly distributed age structure, is likely to have established following the onset of discharge. Comparison of flora and vegetation surveys before and after commencement of discharge, interpretation of temporal changes in aerial imagery and observations of present day riparian ecology generally support this interpretation.

What is observed in many cases along Marillana and Weeli Wolli creeks, are thin strips of OPV lining the low flow channel and possessing an age structure, which is disproportionately represented by young individuals. Furthermore, within such representations of OPV in the study area, the distribution patterns of larger/older individuals (while typically still quite young by comparison with other known representations) appear to show a positive correlation with proximity to discharge points, such that decreasing and relatively minimal to negligible numbers of older individuals are seen as distance downstream from discharge points increases.

Differing aerial photo signatures shown in photography acquired from the area before and after surplus water discharge commenced in the study area show apparent trends in vegetation augmentation surrounding the key low flow features evident within the creek profiles of Weeli Wolli and particularly Marillana Creek. Best available aerial photography from Marillana creek around the time when discharge was initiated in that area (1994-1995 from the BHPBIO discharge point) shows a distinct lack of similar dense-vegetation signatures surrounding low flow features when compared to present day aerial photos. Furthermore, vegetation mapping from the 8 km stretch of creekline downstream of the BHPBIO discharge point channel completed by Mattiske in 1995, did not indicate the presence of OPV lining the low flow channels of the riparian corridor (Mattiske 1995a). In addition to this evidence, photos taken along this same stretch from a helicopter recconnaisance of the area in 2010 provide addiitonal temporal information. These photos show a thickening strip of vegetation along the low flow channel which appeared to contain populations of young *M. argentea* individuals, but also shows a lack of this species in the remainder of the adjacent vegetation occuring within the broader creek bed and associated secondary channels.

The pattern of evidence available, suggests that the pre-impact distribution of OPV communities in the study area, communities similar to the C1 association identified as part of Biota's post-discharge surveys (Biota 2014a), was highly restricted, such that its presence in Marillana and Weeli Wolli creeks was quite uncommon and generally very small in spatial extent.

The potential that a substantial proportion of the significant riparian communities of the area are artificially augmented, and previously absent from the majority of the development area is an important insight when considering the potential impacts of anthropogenic hydrological changes. It appears likely that the surplus water discharge associated with development can provide the conditions necessary to promote and establish OPV in areas where the natural generally ephemeral water availability of the existing environment is unlikely to have supported OPV. This raises the question; if a community is established to be artificially augmented such that it is now considered to represent OPV, is the potential Impact to it now considered significant (beyond the values of the pre-discharge community) given the values and significance generally associated with OPV. To answer this, the first step is to establish that the original community was one that was significantly less mesic, was supported by generally ephemeral water availability, and therefore did not possess a substantial *Melaleuca argentea* component. Once this is established then the logical conclusion would be that regardless of the significance of the resultant community; if the pre and post mining

environment cannot support it (i.e. it did not provide perennial water availability) then impact to the community is inevitable. In such cases the important distinction is that those impacts defined as inevitable are confined to impacts associated with the removal of the additional values/significance attributed to the augmented community. Furthermore; while these impacts may extend to those community changes resulting from the successional processes likely to occur in the transition to ephemeral water availability (e.g. high mortality rates likely among recruitment etc.), the final or climax community which results should be quite similar to the community which existed pre-discharge.

Given the historical influence of development in the area, a key goal of this study is to attempt to establish the location and actual significance of the higher value riparian communities in the area. As a result a significant part of the following study is aimed at gaining detailed information about the composition and distribution of vegetation in the present riparian environment so that it can be used in conjunction with other sources of information to shed light on the composition of the pre-discharge environment. Once this is done, it is predicted that the path to determining the baseline riparian values of the area and the true consequences of impacting the present environment as a result of mining-related impacts will become clear.

2.11 GROWTH RATE PROJECTIONS AND THE DISTRIBUTION OF OPV IN THE PRE-DISCHARGE ENVIRONMENT

An important objective of this study is to contextualise the significance of vegetation communities both currently and historically present, but also contextualising the potential impacts from proposed development on these communities. A key concept requiring exploration is the concept that in some cases, the presence of highly sensitive groundwater dependant species such as *Melaleuca argentea,* and associated OPV communities, may essentially be a product of vegetation augmentation by surplus-water discharge. What this suggests in certain areas is that; historically the generally ephemeral water availability is unlikely to have sustained OPV, and it is only since the provision of perennial surface water-flows (from continuous surplus-water discharge) that the associated fluvial environment has enabled their establishment.

To explore this concept further and demonstrate whether the provision of perennial surface water flows are likely to have significantly influenced the distribution of OPV in the study area, the key question requiring exploration is:

> *Which present day patches of Melaleuca argentea co-dominated community (OPV) if any, present a "young" age structure of consistently uneven frequency distribution, such that it could easily be inferred to have established since mining discharge has provided perennial water?*

Consequently to determine in any particular area whether present-day populations of *Melaleuca argentea* indicate their likely pre-discharge presence, the following questions must be addressed:

1. Using tree trunk size as a proxy for age, how is an individual/population likely to grow in 9 (Weeli Wolli Creek) and 15 years (Marillana Creek) post seedling establishment? (Measured in average DBH change of *Melaleuca argentea* individuals present in the Pilbara and growing under near-optimal conditions).

2. With this figure in mind; what average DBH for the larger individuals of a resident population of this species would represent the upper limit of DBH considered likely to have only established since discharge commenced?

By answering the first and then the second question, a DBH figure which can be compared to the data collected in the study area can be attained. This comparative DBH figure then provides cut-off figure for use in demonstrating which potentially discharge augmented OPV patches are likely to have been absent in the pre-discharge environment.

The following detailed vegetation mapping refinement exercise and associated field data will form the framework with which to answer these questions and make inferences about the distribution and historical significance of local riparian communities.

3 METHODOLOGY

3.1 MAPPING REFINEMENT

3.1.1 Introduction

The vegetation mapping refinement component of this work focused on addressing apparent disparities in the previous mapping of vegetation units consistent with and associated with phreatophytic vegetation (or GDE's), and with a particular emphasis on those most sensitive to surface and groundwater hydrological changes associated with mining (i.e. OPV). As discussed earlier, within the Pilbara it is generally accepted that the most hydrologically sensitive communities are those possessing a significant component of *Melaleuca argentea*. With awareness of this point, an initial review was undertaken to identify tools suitable for identifying the likely distribution of such OPV communities at a desktop level. A field plan capable of ground-truthing the predicted and potential spatial distribution markers for OPV communities in the study area was developed following completion of the desktop mapping process. This field plan was also developed with the aim of compiling additional fine scale information about the spatial distribution and composition of other less sensitive/significant vegetation communities (FPV) within the study creek systems, for the purpose of supplementing the vegetation mapping refinement process.

Together the desktop work and field plan would allow for a more comprehensive refinement of the spatial distribution (mapping) of key riparian vegetation communities throughout the study area. Quite importantly this desktop/field-based work would also be designed in a way which collected information which would provide a framework for contextualising and incorporating historical changes into the resultant vegetation model.

It should be noted that the refinement of vegetation boundaries and descriptions was only conducted on riparian units occurring within the major creek system riparian habitats of the study area (essentially the "C" coded units). As a result of this refinement some of the original riparian vegetation codes (C1, C2, and C3 coded vegetation - Biota 2014a) have been slightly altered to help them fit within the new vegetation-mapping framework. In an effort to maintain the logic and intent of previous mapping unit delineation and coding, the original codes and the hierarchy of significance which they attempt to convey have been maintained as much as possible while still allowing them to reflect the new findings and resultant structure.

The vegetation and flora field survey conducted as part of this study was undertaken in accordance with the requirements outlined in the EPA guidance documents (EPA 2002, 2004a). With respect to data collection methods; this survey acknowledged the large amount of Quadrat/Relevé based data collection which has previously been conducted within the study area. Coupled with knowledge that riparian species composition can both stay relatively consistent and vary significantly over small spatial scales, it was concluded that the degree of information on the associated floristic composition of riparian communities already captured within the study area was sufficient to meet the objectives of this study. Following this conclusion, it was identified that "mapping Traverses" was the data collection tool most effective for the purpose mapping refinement and the tool which hitherto had been used to a lesser extent in the riparian zone of the study area. Mapping traverses, generally comprise walking through the target area and regularly taking notes and spatial information on the apparent vegetation associations/sub-associations present and the location and pattern of boundaries which separate them. By aligning these traverses to maximise their potential

to regularly test the spatial position of these boundaries, such a technique quickly establishes an effective database with which to correlate these patterns with similar patterns in aerial imagery. It is for these general reasons that this is one of the most effective techniques for refining vegetation mapping. The use of mapping traverses oriented to repeatedly intersect vegetation boundaries allowed a focus on the establishment of vegetation boundaries and hence development of robust fine scale vegetation mapping for the areas investigated.

It should be noted that typical vegetation mapping is essentially a model, such that the spatial validity of boundaries and the vegetation associations depicted to lie within is only true a portion of the time. In general the proportion of time which the model is correct is directly correlated to the amount of ground-truthing which is done per unit area of the model, and the scale of the community descriptions created. The third influencing factor is generally considered to be the complexity of environmental factors influencing vegetation ecology, but for the surveyor this is an uncontrolled factor and is therefore not generally considered in detail. For the vegetation mapping model presented as a part of this study, it was a requirement that it provide a very high degree of accuracy in relation to the spatial location and distribution of OPV communities. As a consequence the degree of ground-truthing effort planned and conducted within the riparian zone (particularly the incised channel zone) was very high, such that the mapping is considered to be significantly more accurate than typical vegetation mapping undertaken in typical flora and vegetation surveys within WA. Despite this spatial confidence, and despite the spatial scale and detail within vegetation associations descriptions having increased (become finer) the vegetation map is still a model, and so the accuracy of the vegetation descriptions modelled to be present at any one point in the map is still variable to some degree. However in the case of the model presented, it is considered to be significantly more accurate than previous models due to the additional modelling effort which has been conducted.

3.1.2 Tools Developed at a Desktop Level for use in the Field

Photosynthesising vegetation cover on both Marillana and Weeli Wolli creeks was assessed using Normalised Difference Vegetation Index (NDVI) images generated from high resolution (0.5 – 1 m pixel) remotely sensed digital multispectral imagery (**DMSI**). NDVI relies on the fact that photosynthetic organisms have the unique characteristic of reflecting nearly all infra-red electromagnetic radiation, and absorbing significant amounts of the red visible wavelength of electromagnetic radiation (used for photosynthesis)(Specterra Services 2010). As a result an index calculating the ratio between the intensity of the two wavelength ranges provides a simple measure of vegetation cover/density. NDVI imagery of the relevant creek stretches were visually assessed by a specialist botanist for occurrences of high-density vegetation signatures (i.e. areas where a comparatively high degree of vegetation cover was evident in comparison to surrounding riparian vegetation cover signatures) likely to indicate presence of mesic conditions and therefore potentially GDE's. GDE's such as OPV are recognized to be associated with a high degree of groundwater presence, thus given the consistent presence of moisture, combined vegetation cover associated with these areas is often relatively dense (i.e. canopy cover, combined with cover related to shrub and groundcover strata combine to provide aerially dense cover signatures) and often possesses a comparatively denser canopy cover in relation to surrounding more widespread riparian vegetation. Consequently areas of the creek system showing comparatively higher measures of vegetation cover are often the areas where groundwater is close to the surface and species such as *M. argentea* are present in significant numbers. Plate 1 shows one example of a high density NDVI signature and one example of a sparse NDVI signature. High vegetation cover signatures were identified and

mapped throughout the study area. Plate 2 and Plate 3 show two examples of the PCD signature mapping which was conducted across the study area for the purpose of ground-truthing. Figure 3-1 to 3-5 present the NDVI imagery and distribution of high PCD signatures present across the study area, which was used as a supporting tool for the GDE interpretation and ground-truthing process.

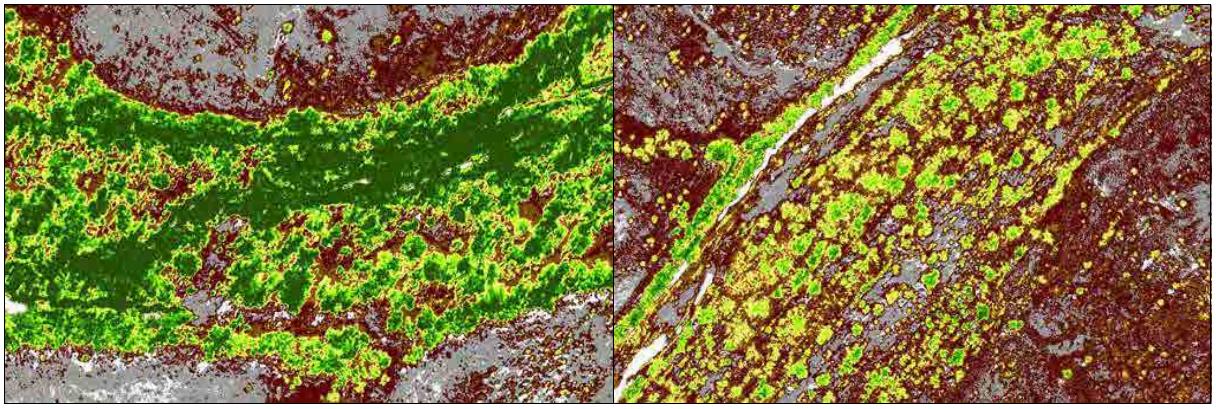


Plate 1: Samples of NDVI image showing a high density NDVI (vegetation cover) signature on the left and a sparse cover NDVI signature on the right

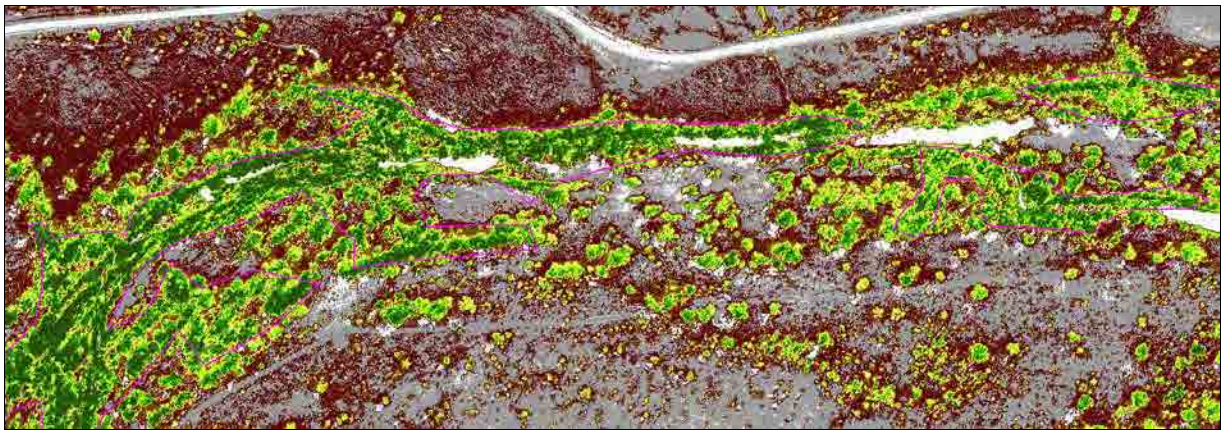


Plate 2: Example 1 of dense cover NDVI signatures digitised (pink bordered polygons) and delineated from more typical creek vegetation densities/canopy covers along two sections of creek

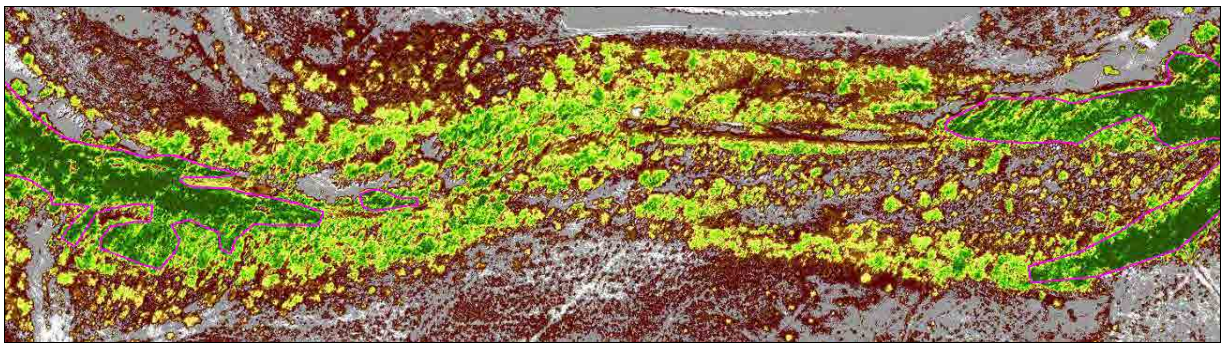


Plate 3: Example 2 of dense cover NDVI signatures digitised (pink bordered polygons) and delineated from more typical creek vegetation densities/canopy covers along two sections of creek

In addition to the high cover NDVI signature mapping, pre-discharge impact historical aerial photography was visually assessed to identify and map areas of dense vegetation and consistently formed canopy cover. Through an analysis of available aerial photography by an experienced Pilbara botanist, dense vegetation signatures were mapped to create digital polygons identifying general areas of elevated vegetation-density/canopy-cover. In addition, and as part of this process, an

alternative set of digital polygons were produced which represented the “particularly dense and more anomalous swathes of historical vegetation” detected.

Polygons digitised from both NDVI images and historical aerial photography were uploaded to GPS as transparent polygons and overlaid onto the actual NDVI image. In addition to this, polygons of previous mapping of significant riparian vegetation units were also uploaded to GPS as transparent polygons. To facilitate the effective use of ground-truthing tools in the field, separate GPS units were used in the field to avoid clutter and obstruction on the GPS screen while traversing the creek system. Three separate GPS units were used; one for ground-truthing (the NDVI map and associated digitised polygons), one for waypoint creation (approximately 1400 waypoints were created during this exercise), and another for navigation throughout the area (tracks, infrastructure, and riparian zone delineation).

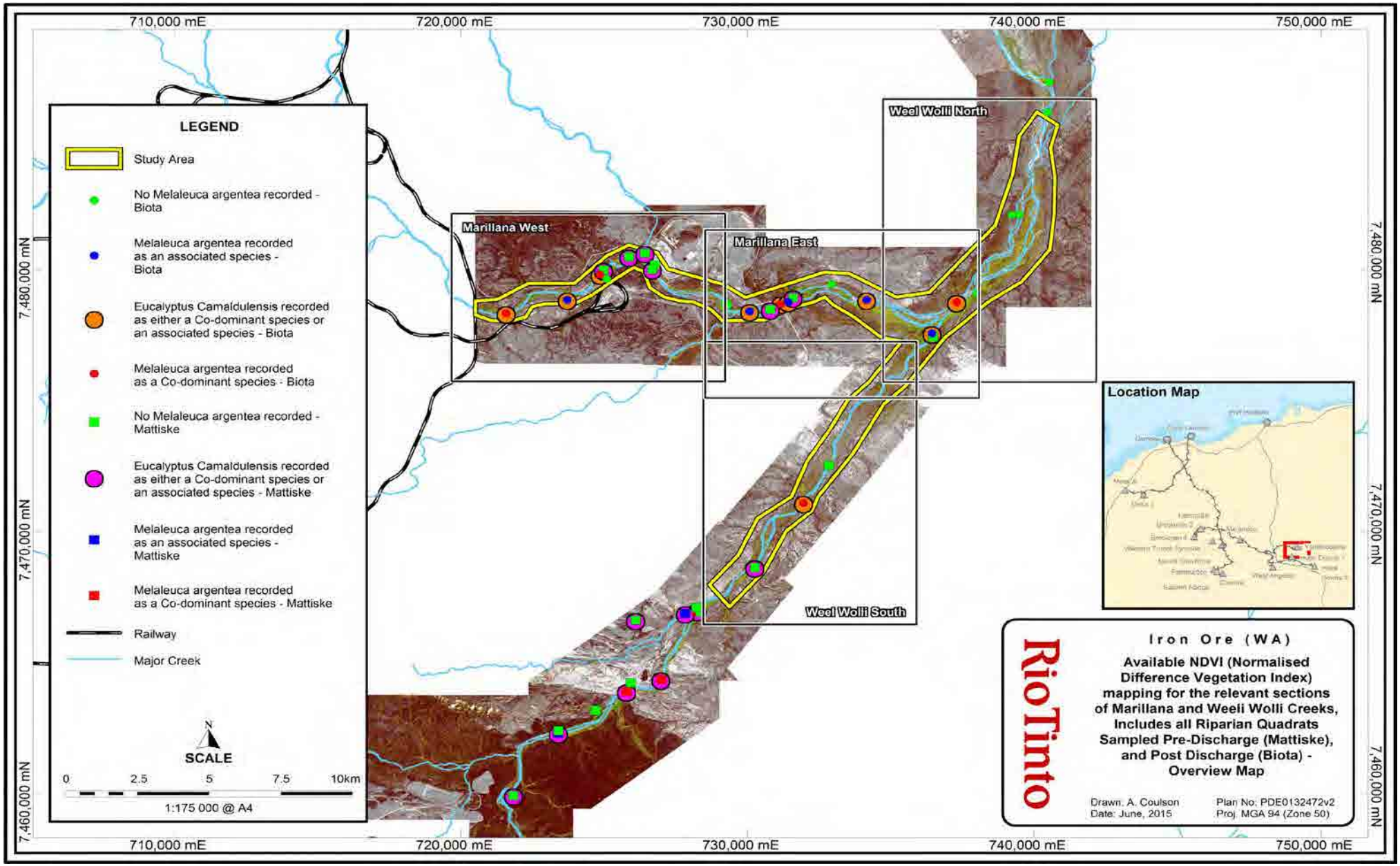


Figure 3-1: Overview map showing available NDVI imagery maps for Marillana, Weeli Wolli North, and Weeli Wolli South study area reaches

These maps also display the location of the most relevant riparian quadrats sampled as part of previous flora and vegetation survey work conducted in the study area. Labelling of these quadrats indicates the presence/absence of Melaleuca argentea and Eucalyptus camaldulensis at the time of survey, and the timing of sampling based on a pre and post discharge timeline. NDVI imagery from Nov 2010

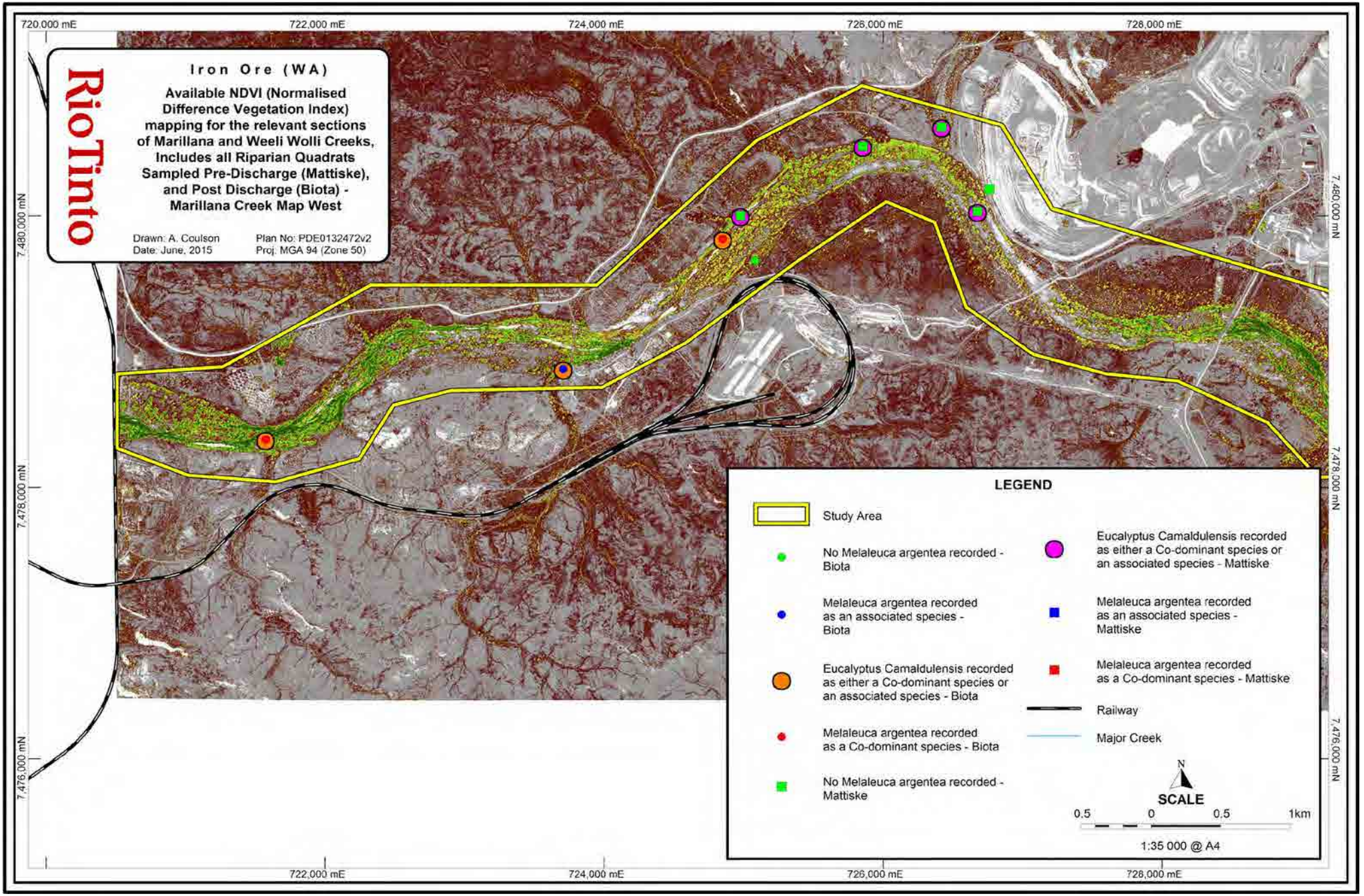


Figure 3-2: NDVI imagery map for the Marillana Creek reach of the study area. Includes riparian quadrats previously sampled and an indication of key phreatophytic species presence

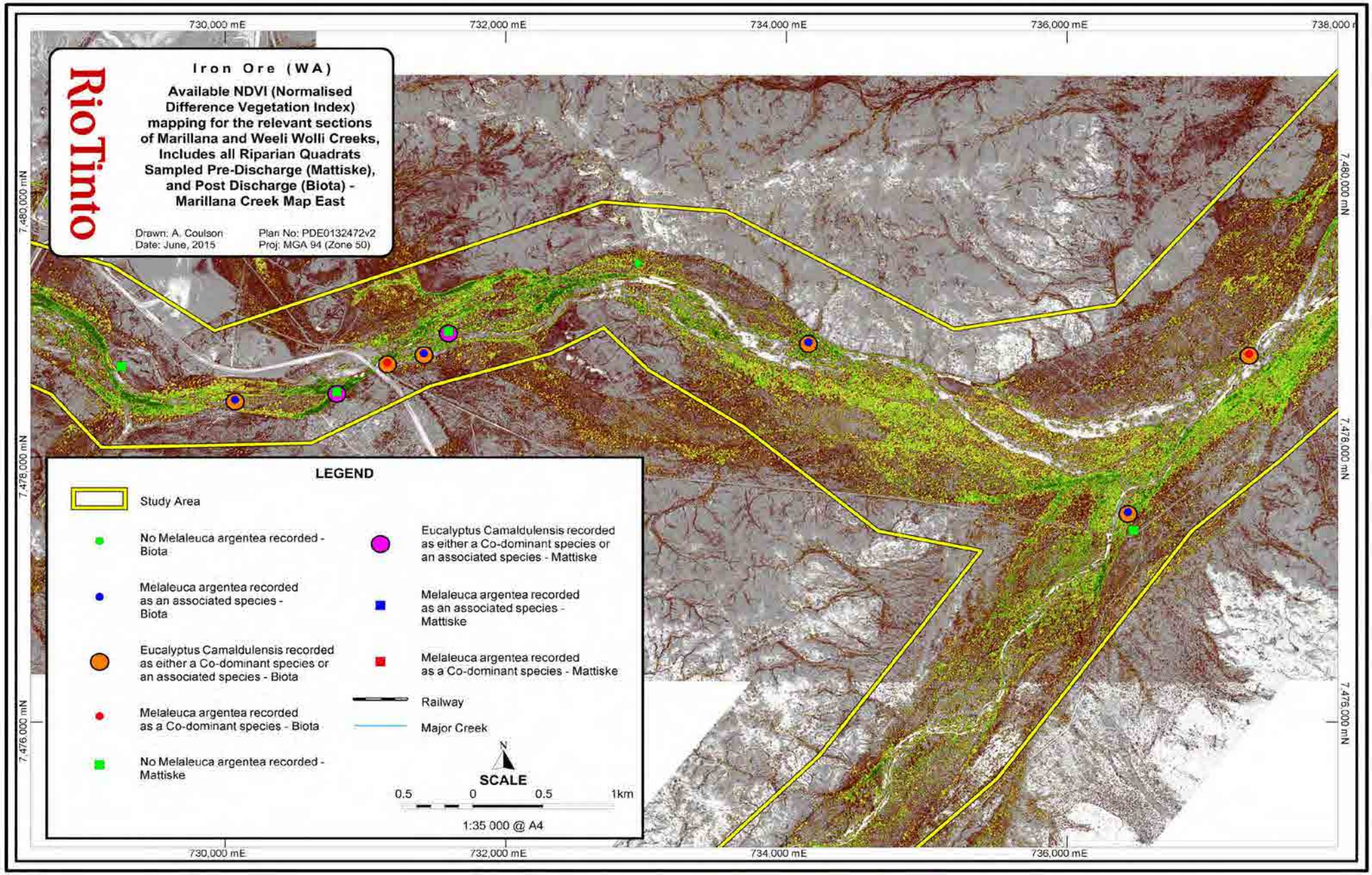


Figure 3-3: NDVI imagery map for the Weeli Wolli Creek North study area reach. Includes riparian quadrats previously sampled and an indication of key phreatophytic species presence

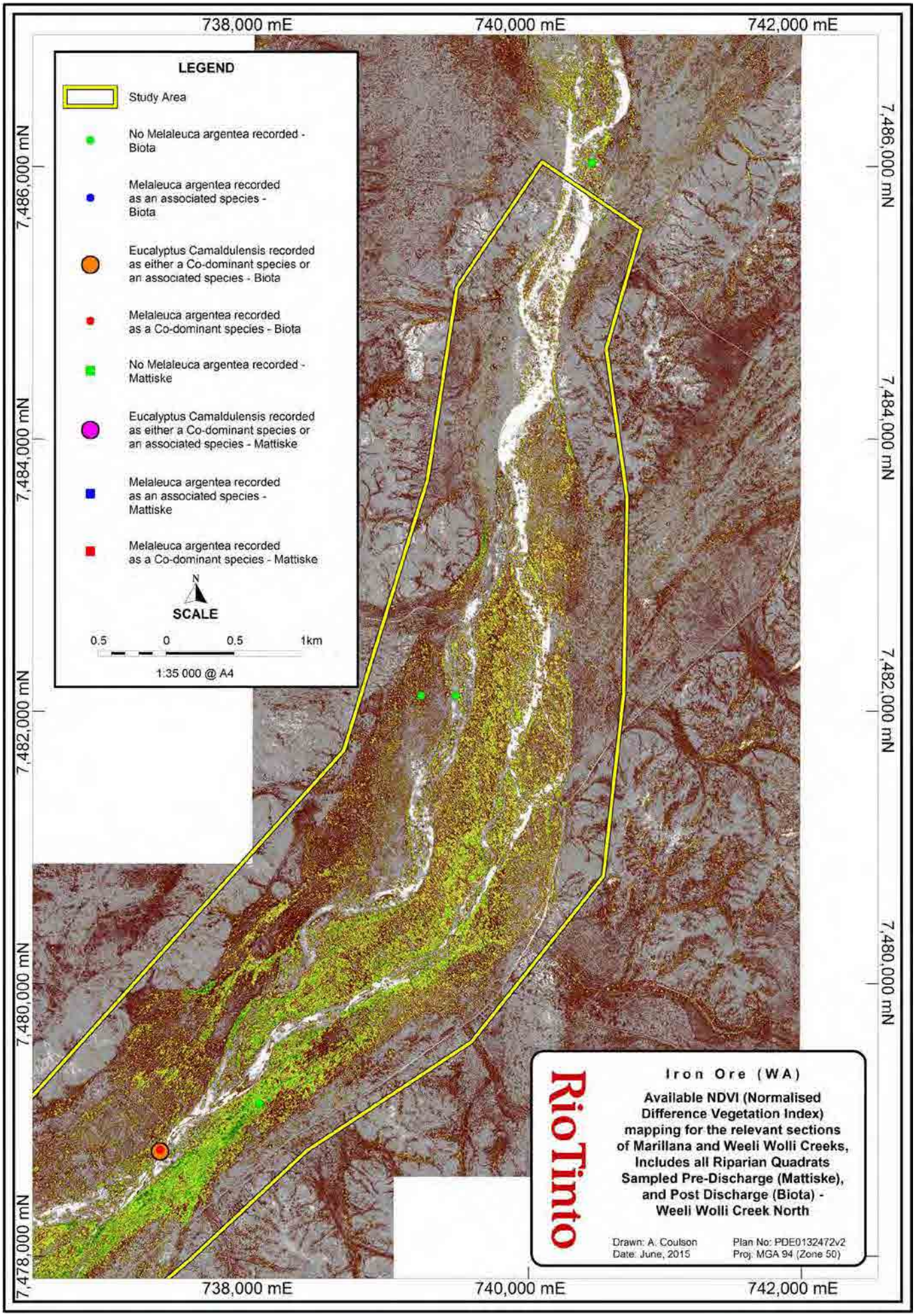


Figure 3-4: NDVI imagery map for the Weeli Wolli Creek North study area reach. Includes riparian quadrats previously sampled and an indication of key phreatophytic species presence

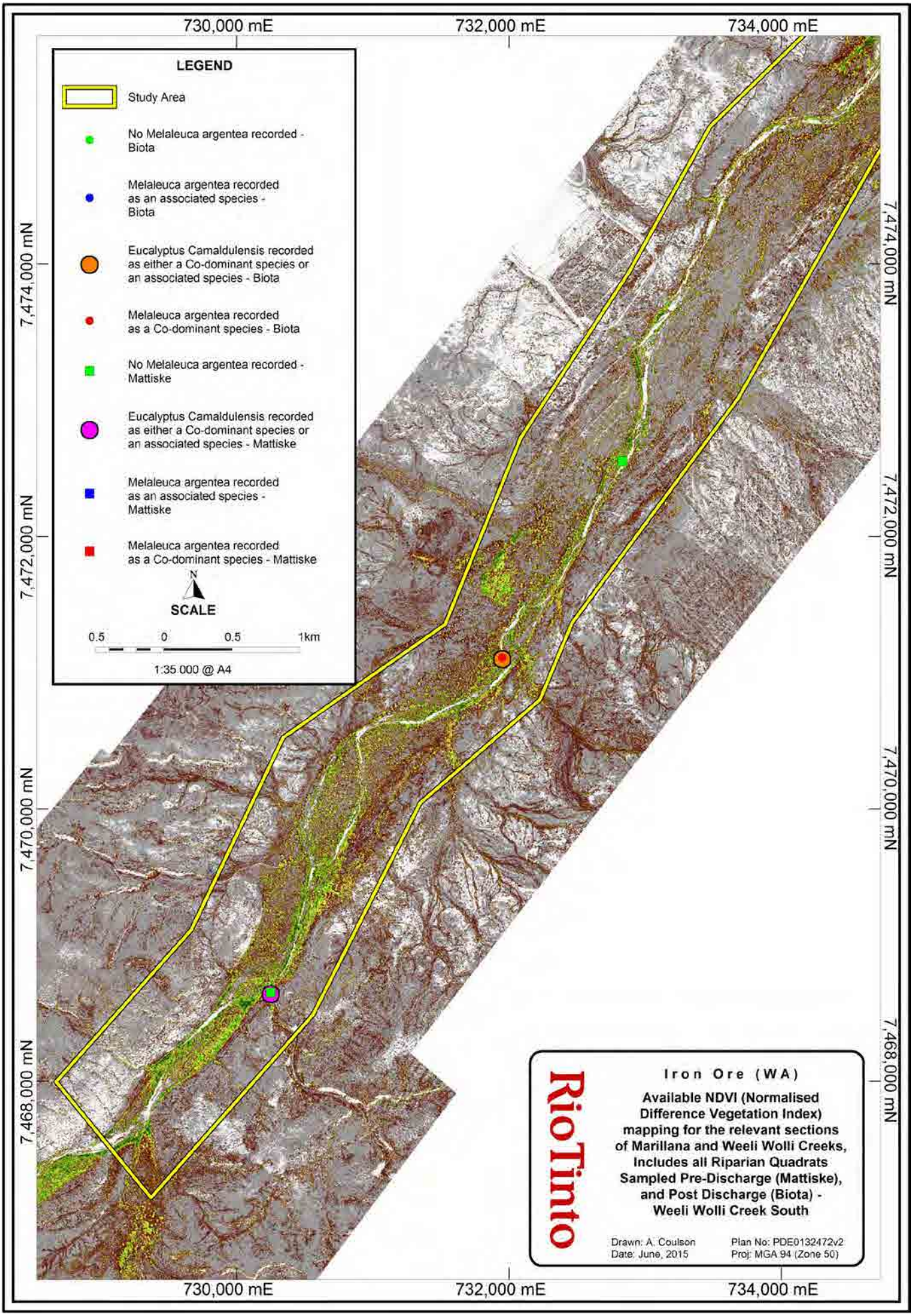


Figure 3-5: NDVI imagery map for the Weeli Wolli Creek South study area reach. This map also includes riparian quadrats previously sampled and an indication of key phreatophytic species presence

3.1.3 Ground-truthing and Mapping Refinement Field Work

With the above tools in place a field data collection framework was devised and focused on the following key tasks:

Within the study area (local stretches of Marillana and Weeli Wolli creeks):

1. Traverse the entire length of the incised creek profile (while periodically intersecting the inner portion of the adjacent floodplains) to gain an understanding of the ecology and distribution of significant communities present within its boundaries. In addition to this; gaining an overarching awareness of the variability, morphology and spatial distribution of the different creek profiles and associated substrates present throughout.

2. The ground-truthing of identified NDVI signatures, and historical aerial photo mapping of dense-vegetation to confirm the presence/absence of phreatophytic species (namely *Melaleuca argentea*, and to a lesser extent useful GDE indicator species such as *Eucalyptus camaldulensis, Acacia ampliceps* and *Typha domingensis*).

3. Record specific data about the spatial boundaries/distribution and age structure of *Melaleuca argentea* populations encountered throughout while searching for and way-pointing any old/large mature individuals present.

Note: the "incised channel zone" is defined by URS (2015) as the zone between the main lower elevation channel banks. According to URS, the incised channel width is variable but assumed to be in the order of 100 m wide, and inundated by 1-year and 2-year ARI stream flow events. This zone is described to be flanked by the riparian zone floodplain, which is assumed to be approximately 400 m wide and inundated by 2-year to 5-year ARI stream flow events (URS 2015).

It was anticipated that these key tasks would be carried out by directing field effort in a way which ultimately was a product of the interaction of four key drivers to traverse pattern:

1. Firstly; it was determined that typically vegetation distribution patterns were likely to be aligned in a linear fashion parallel to the direction of flow and along and adjacent to associated primary/secondary and minor flow channels. In acknowledgment of this fact, a traversing pattern which intersected these perceived boundaries in a perpendicular fashion was deemed most appropriate to ground-truth digitised polygons and collects the best spatial data for vegetation unit extrapolation at a fine scale. Therefore a zig-zag traverse pattern was determined the best technique to use when traversing the creek.

2. The second process was the use of the NDVI image and desktop NDVI and aerial photo signature mapping to influence the surveyor's fine scale traversing movements when zig-zag traversing the creek profile. Essentially this meant continuing to generally move in a zig-ag fashion while aiming successive meanders across the creek to intersect vegetation features of most relevance identified using the desktop tools described above or particular NDVI image patterns identified while in the field.

3. The density of the vegetation present would determine that not every part of the creek could be viewed and assessed for the presence of phreatophytic vegetation, so the direction and

path of successive meanders would be influenced by the visual cues to these communities which were assessed each time the surveyor moved through sections of the creek which allowed view of vegetation over longer distance (typically the open low flow channel zones and scoured bed creek portions).

4. The final driver to traverse pattern was the general morphology and variability of the creek profile. Of the two creeks surveyed, Marillana was generally much broader in its incised channel zone and narrower in its floodplain zone, while Weeli Wolli was the opposite. Consequently it was perceived (and observed in the field) that OPV (and to a lesser extent FPV) in Marillana Creek would at times be more widely distributed around multiple low flow channels within the incised channel zone, and in Weeli Wolli creek they would be narrowly distributed around a single low flow channel within the incised channel zone. Therefore in Weeli Wolli creek much smaller wavelength zig-zag traverse patterns were generally employed, meaning lateral traverse distances were typically much smaller allowing a much greater degree of focus on particular portions of the incised channel zone. In Marillana creek the opposite was true.

As a consequence of the key tasks and the additional drivers to traverse pattern, the resultant traverse pattern and data capture array realised in the field is presented in Figures 3-6 to 3-13 below, as track logs and data points recorded via GPS. Throughout this traverse pattern the following data was recorded at the resultant array of waypoints within the Riparian zone of the study area.

1. "Present" or "Structurally Absent" of *Melaleuca argentea* – "**Presence**" equating to a cover/abundance considered as comprising a dominant structural component of the stratum which it occupies (within vegetation in the vicinity of the surveyor; approximately 20-30m radius), and not generally representing a cover/abundance below 1-2 %. "**Structurally Absent**" represents either not detected within the vicinity of the record whatsoever or only present as an associated species. For the purpose of this work, and more generally; associated species are defined as not comprising a dominant structural component of vegetation and not generally representing a cover/abundance below 1-2 % max.

2. If *M. argentea* was noted as "Structurally absent", but where this species was not strictly absent and instead was present as an associated species; the record was prefixed with an "N" cover/abundance so that its cumulative distribution could be considered spatially.

3. The intersected boundary location of any populations deemed to represent a "Presence". This at times included (where appropriate) the surveyor purposefully walking along the perceived boundary and making multiple boundary waypoints for a portion of the boundary length, so as to provide data on its length, orientation and variability.

4. The position (and where able to be easily conveyed; the dimensions) of any sizeable "Patches", "strips", or "thin strips" of riparian vegetation where *M. argentea* was considered to be a co-dominant/dominant component of the vegetation present. In most cases, where appropriate, the close alignment/association of such "patches" with bodies of water on the Low Flow channel was noted in the data recorded.

5. Areas where *M. argentea* was "present" on the bank directly opposite to that of the recorder (where access was restricted).

6. The cover/abundance of any *M. argentea* populations recorded as a "presence" (i.e. representing a dominant/co-dominant member of the vegetation).

7. The size class (as a proxy of age) and location of any individuals identified to possess a trunk diameter at Knee to waist height of approximately 30 cm and above. These individuals would form a database of "mature" individuals (not strictly from a reproductive sense, and as opposed to populations).

8. The size class (as a proxy of age) of any populations recorded as a "presence" (where appropriate) – In all cases the recordings were for the population in the vicinity of the recorder such that the size class recorded was a classification of the size range of many individuals (i.e. the entire population visible). In the vicinity of the recorder was defined as generally a 20-40m radius, but at times a larger area where vegetation density or movement by the surveyor allowed assessment of greater radius. These size classes were inferred based on a visual assessment of the average trunk diameter, or the average range of trunk diameters present within the population in sight. The size class/range determined at data points was allocated to populations (and individuals) via the use of terms which represented the various size classes used. In many cases (where appropriate – i.e. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where size structure was more variable a range was given (i.e. Young to Semi-Mature-minus). The size class terms used were:

    - 'Mature' (M);
    - 'Semi Mature Plus' (SM+);
    - 'Semi Mature' (SM);
    - 'Semi Mature Minus' (SM-);
    - and 'Young' (Y).

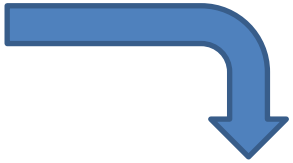
    The definition of each of these size classes and the representative terms used in the field are presented in Table 3-1.

9. Mapping notes – general notes on vegetation present at point locations. This often involved purely assigning vegetation to pre-captured associations/sub-associations or previously identified and mapped riparian communities/units.

10. Photo points – points where multiple photos (minimum 4) were taken of the vegetation surrounding the record.

The above data collection framework was used to collect data in the field over two field trips conducted by Rio Tinto Botanist Jeremy Naaykens and with the assistance of RTIO Environment staff Greg Richter and Ken Kennedy. The first field trip focused on Marillana creek and was conducted from the 30th of March till the 3rd of April, while the second field trip focussed on Weeli Wolli Creek and was conducted from the 9th till the 12th of April.

Table 3-1: **Definitions for the size classes used to classify the average trunk diameter (or range of trunk diameters) of *Meleleuca argentea* populations encountered in the field, and allocate these populations to a percieved age class (or age class range). Also included are inferences made about the degree to which individuals/populations of each size class would be expected to be present in the Pre-discharge Riparian environment. These inferences are presented based on comparative assesments of monitoring based growth projections presented in Table 4-4.**

Inferences which have been interpreted to be relevant to populations of *Melaleuca argentea* which possess an average size range (and associated age structure) broadly classified as equivalent to one of more of the following age classes (listed in the columns below) are presented below in the far right column and assume that: 		Within riparian vegetation of large creek systems exposed to long term discharge (see above durations), the present day existence (representing a cover/abundance beyond that of an associated species) of *Melaleuca argentea* individuals or populations equivalent in size to the age classes below to the left; **suggests the following about pre-impact vegetation and the likely inclusion of obligate phreatophytes within this vegetation at that time:**
Size classes (as a proxy for age)	***Melaleuca argentea* individuals/populations which were visually estimated to possess:**	**Vegetation which contained individuals/populations of this size (but not larger) scattered within or at greater cover/abundances were considered to :**
M - Mature trees	Trunk diameter(s) at knee to waist height in the **Range of 50cm and above**	Represent areas which would have historically supported vegetation with *M. argentea* as a co-dominant species within the woodland to low-woodland stratum (over-storey stratum).
SM(+) - Semi Mature plus	Trunk diameter(s) at knee to waist height in the **Range of 30-45cm**	Represent areas which would have historically supported vegetation with *M. argentea* as a co-dominant species within the low-woodland stratum and as an associated species in the woodland stratum.
SM - Semi Mature	Trunk diameter(s) at knee to waist height in the **Range of 20-30cm**	Represent areas which would have historically supported vegetation with *M. argentea* as either an associated species or in some cases a co-dominant (minor) in the low-woodland stratum.
SM(-) - Semi Mature minus	Trunk diameter(s) at knee to waist height in the **Range of 10-20cm**	Represent areas which would have historically only supported vegetation with *M. argentea* as an associated species in the Low-woodland or lower strata.
Y - Young	Trunk diameter(s) at knee to waist height in the **Range of less than 10cm**	Represent areas which at best and potentially only on occasion; historically supported vegetation with *M. argentea* as an associated species in the Low woodland or lower strata.

Note: *M. argentea* populations were allocated to size classes in the field based on visual estimates of trunk diameter and as such there is some potential for inaccuracy. In all cases the recordings were for the entire population in view of the recorder. In many cases (where appropriate - ie. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where the size structure was more variable a range was given (ie. Young **to** Semi-Mature-minus). Throughout the creek and wherever encountered; trees which were visually deemed to be consistent with an individual of diameter at least equal to the upper end of the Semi mature age class (30cm and above) were recorded individually (to establish a database of "Mature" trees) and assigned to the Semi-mature or above size classes. Diameter estimates are based on the diameter at knee to waist height of the observer, as the majority of individuals were relatively young and of a branching habit making it impractical to estimate diameter at breast height – a more commonly used standard for tree diameter measurements.

The relevant creeks to which this table is applied have been exposed to surplus water discharge for the following durations:

- **Weeli Wolli Creek:** approximately 9 years from 2006 (upstream of the Marillana-Weeli Wolli confluence)
- **Marillana Creek:** approximately 18-20 years from 1995 (15 years used for the growth projection relevant to this creek stretch)

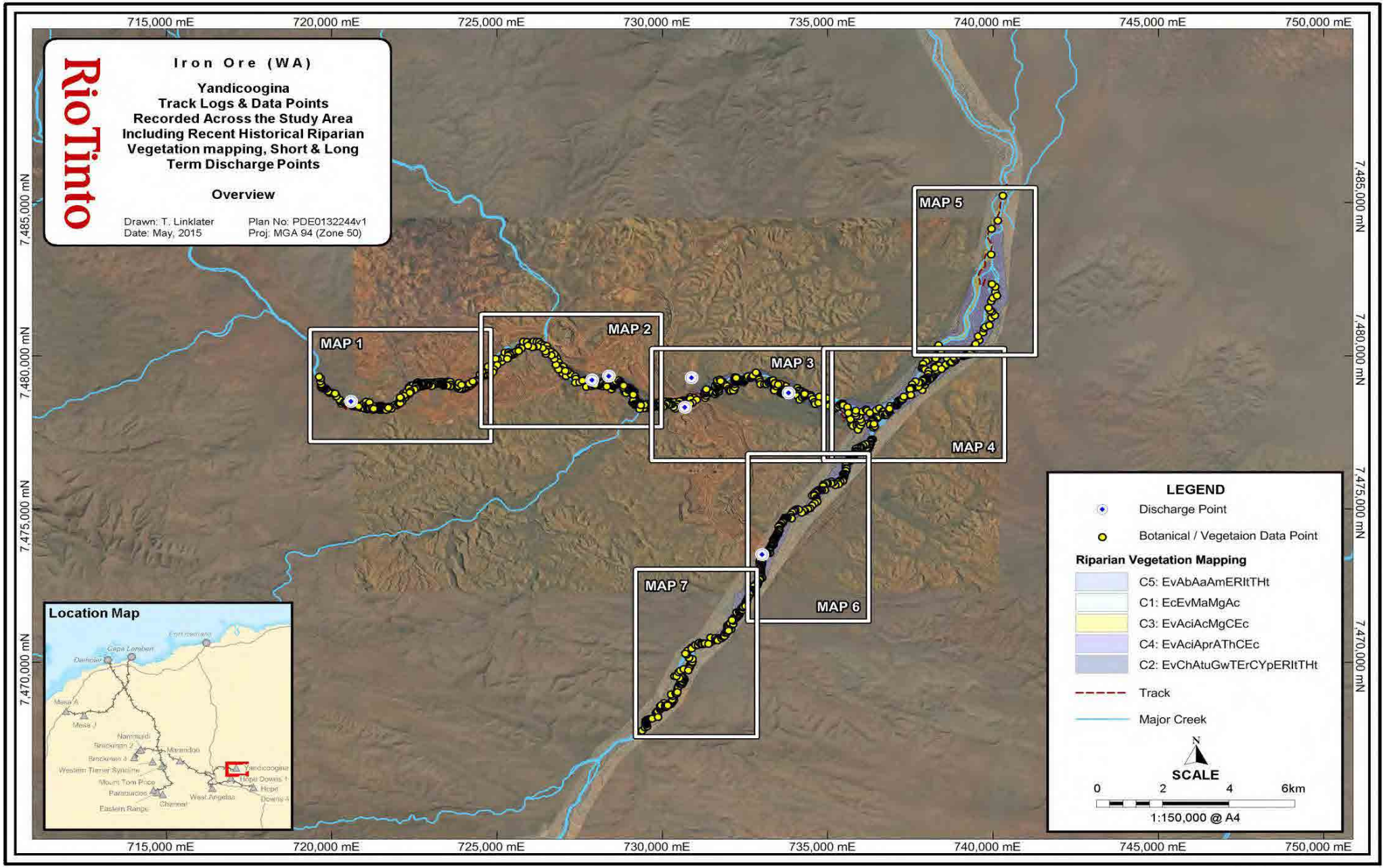


Figure 3-6: Overview of survey effort maps 1 to 7. Maps 1 -7 depict the survey effort conducted within the study area by showing the track logs and data points collected throughout using a GPS. This map also shows the previous riparian vegetation mapping across the study area (Biota 2014a) as well as the relevant discharge points influencing surface water in the study area

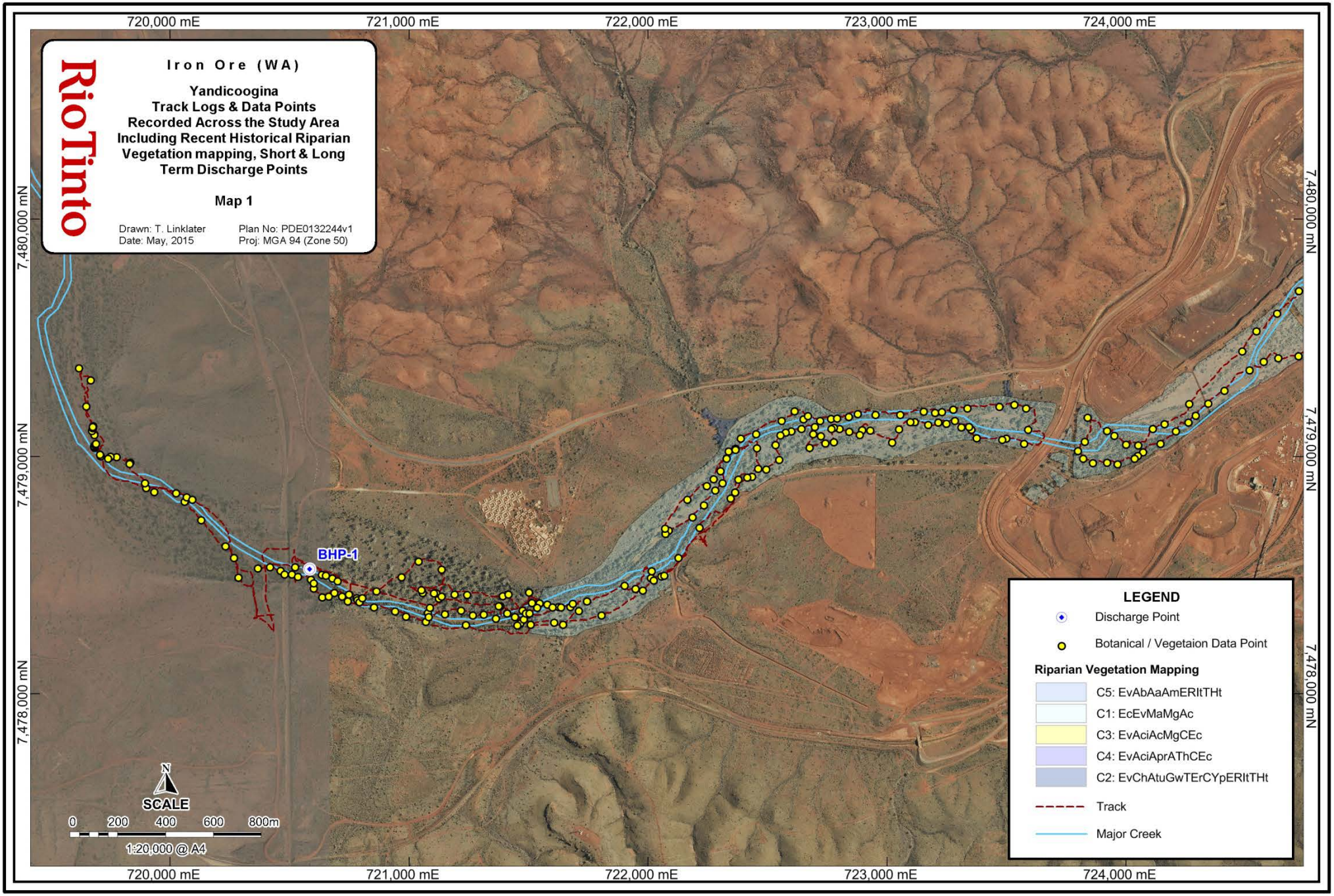


Figure 3-7: Survey effort Map 1 of 7

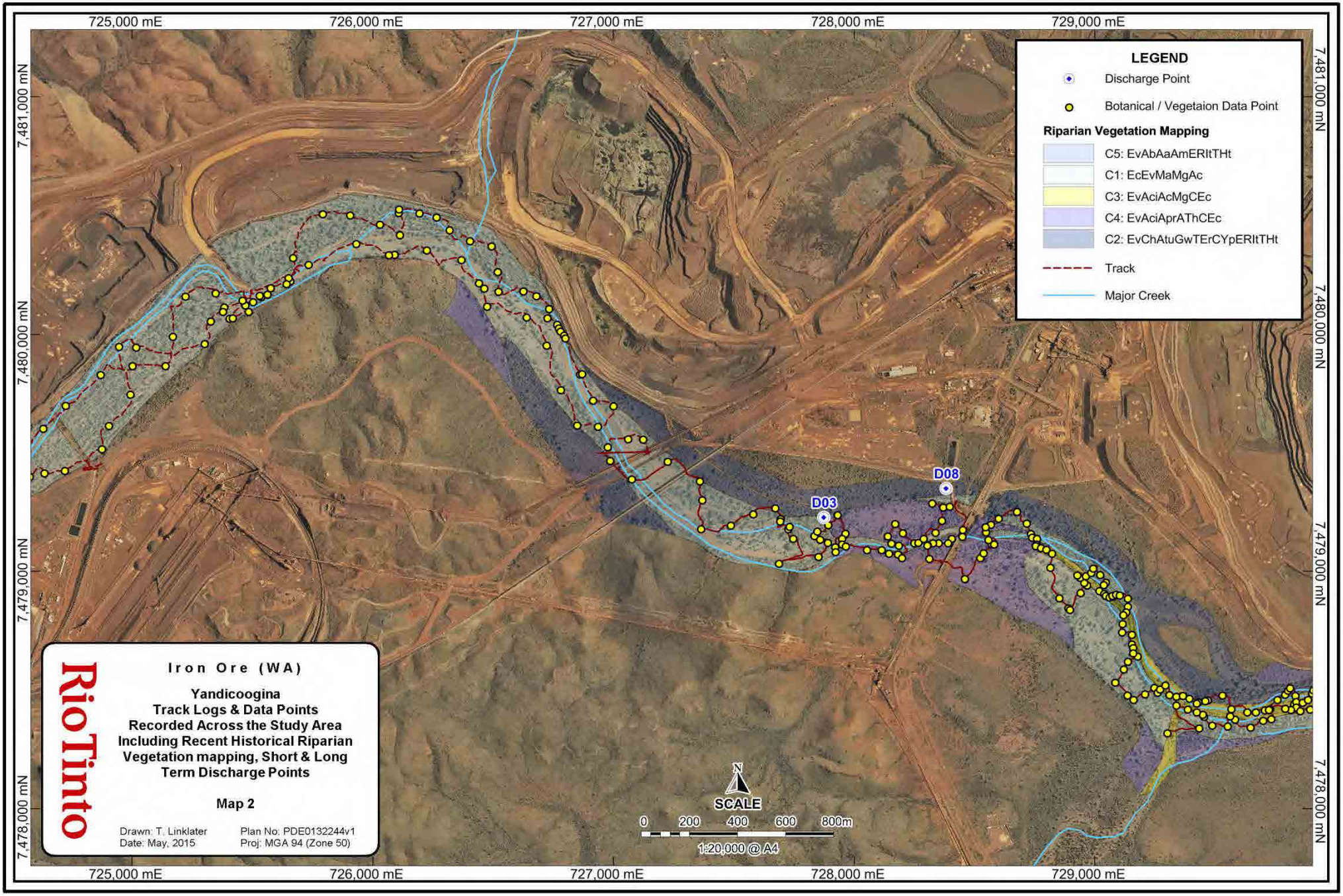


Figure 3-8: **Survey effort Map 2 of 7**

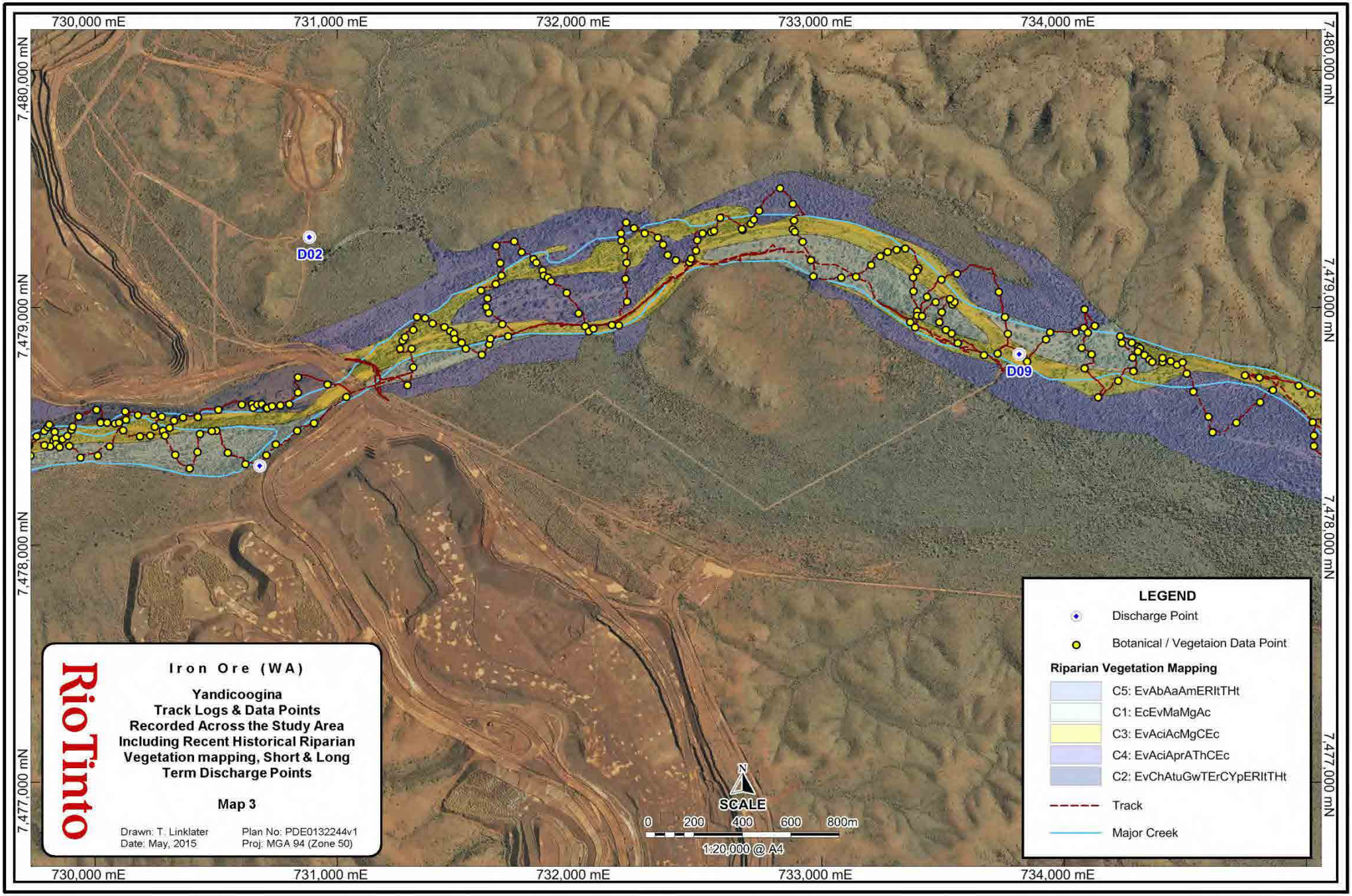


Figure 3-9: Survey effort map 3 of 7

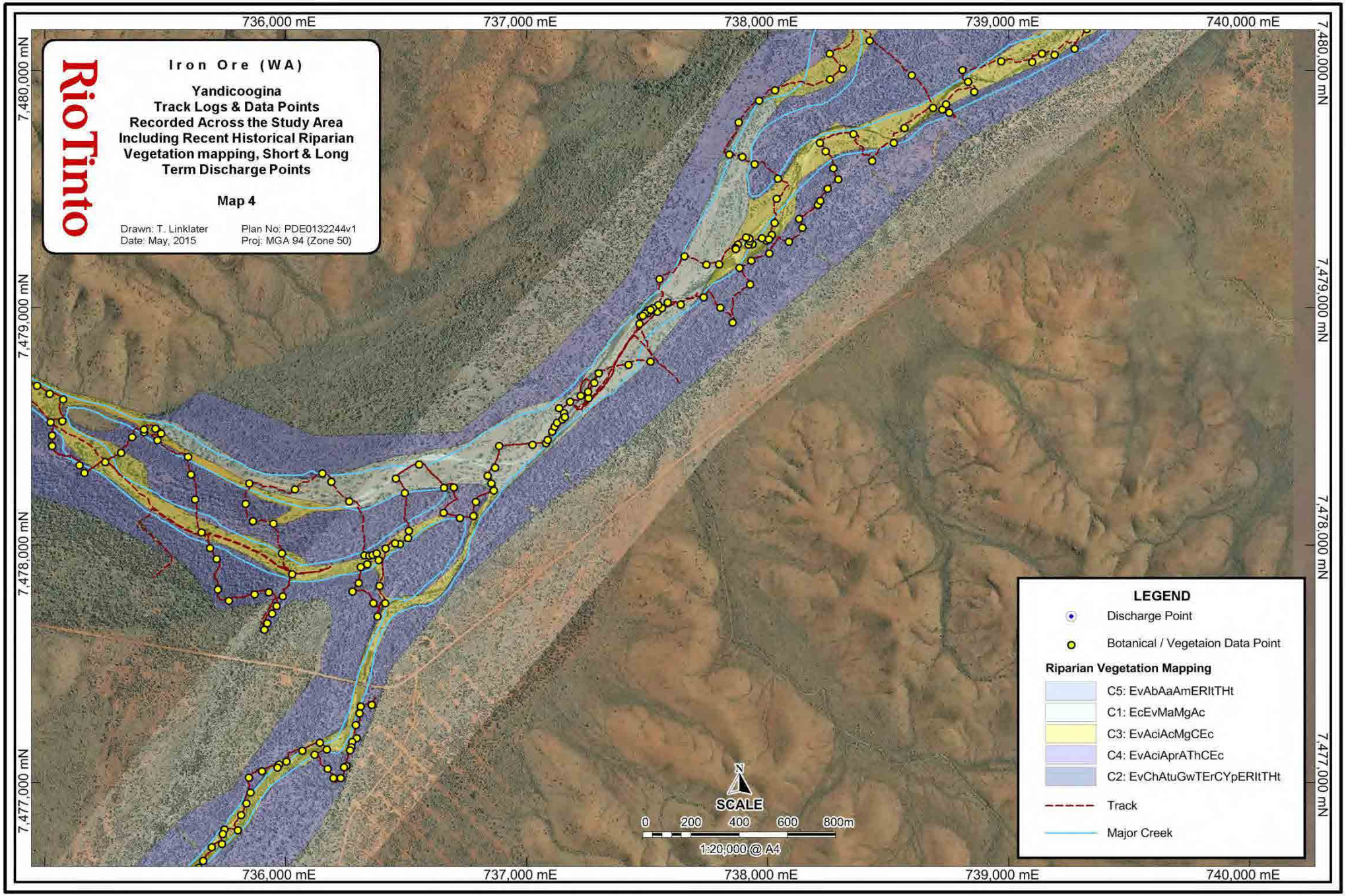


Figure 3-10: Survey effort Map 4 of 7

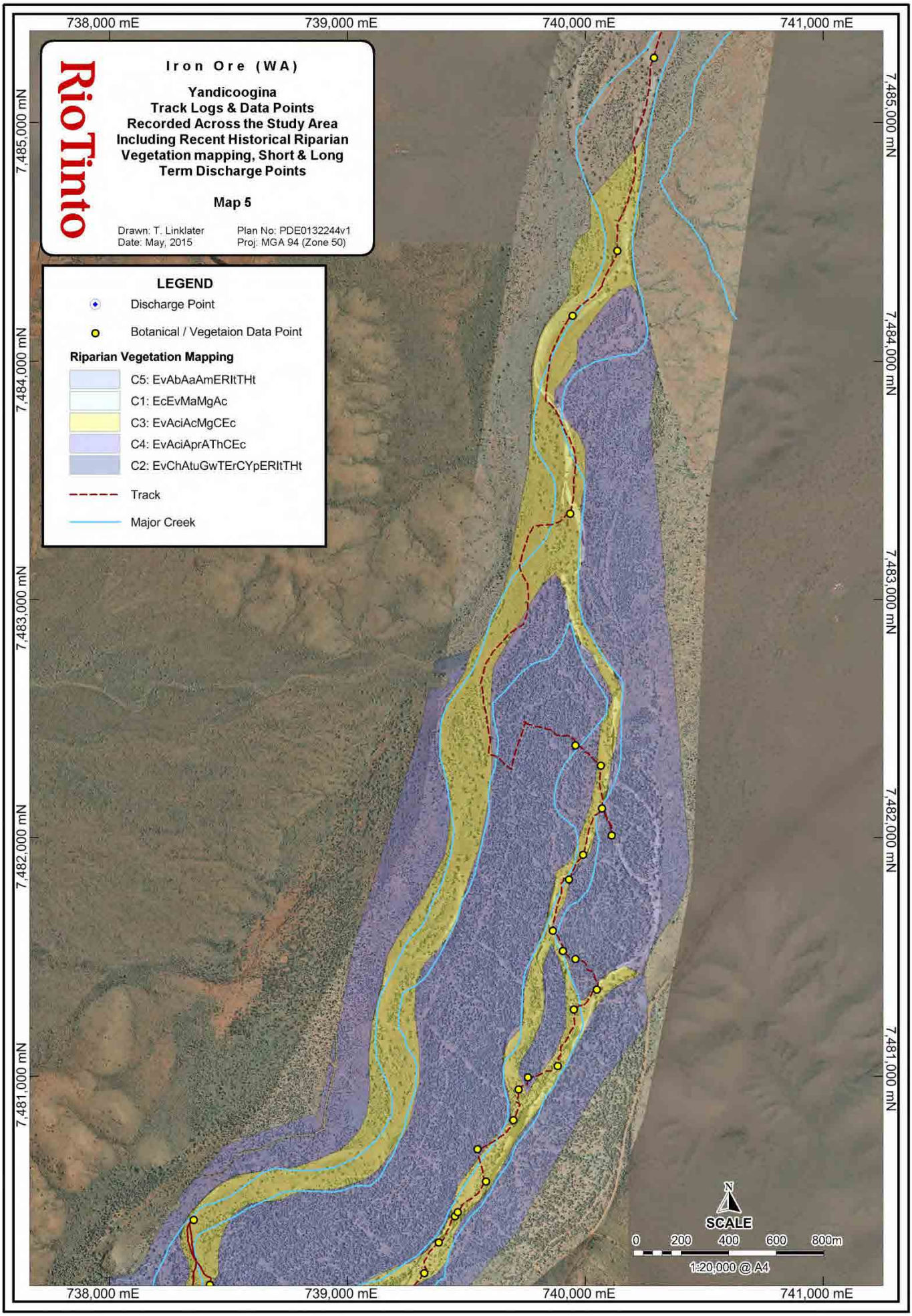


Figure 3-11: Survey effort Map 5 of 7

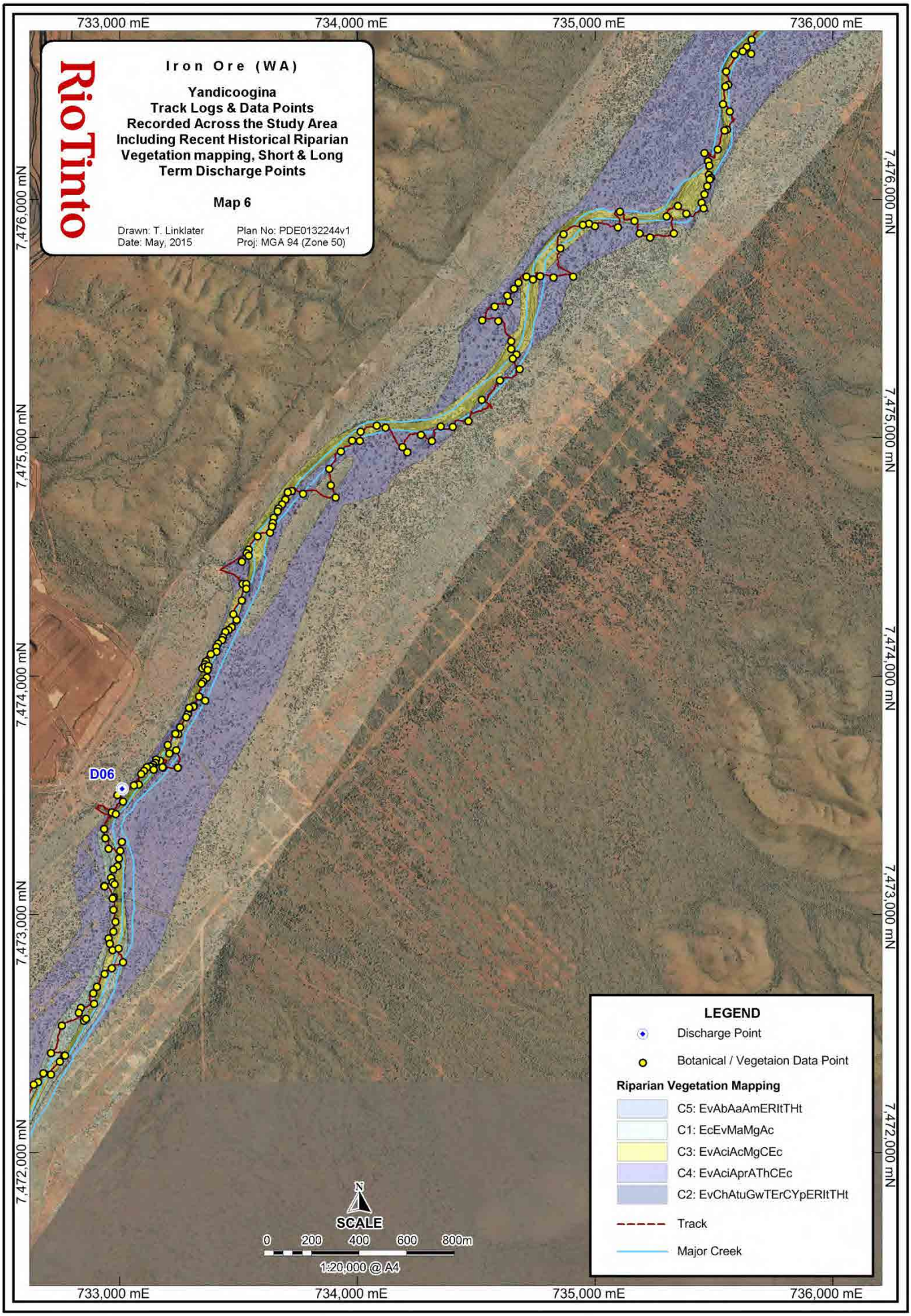


Figure 3-12: Survey effort Map 6 of 7

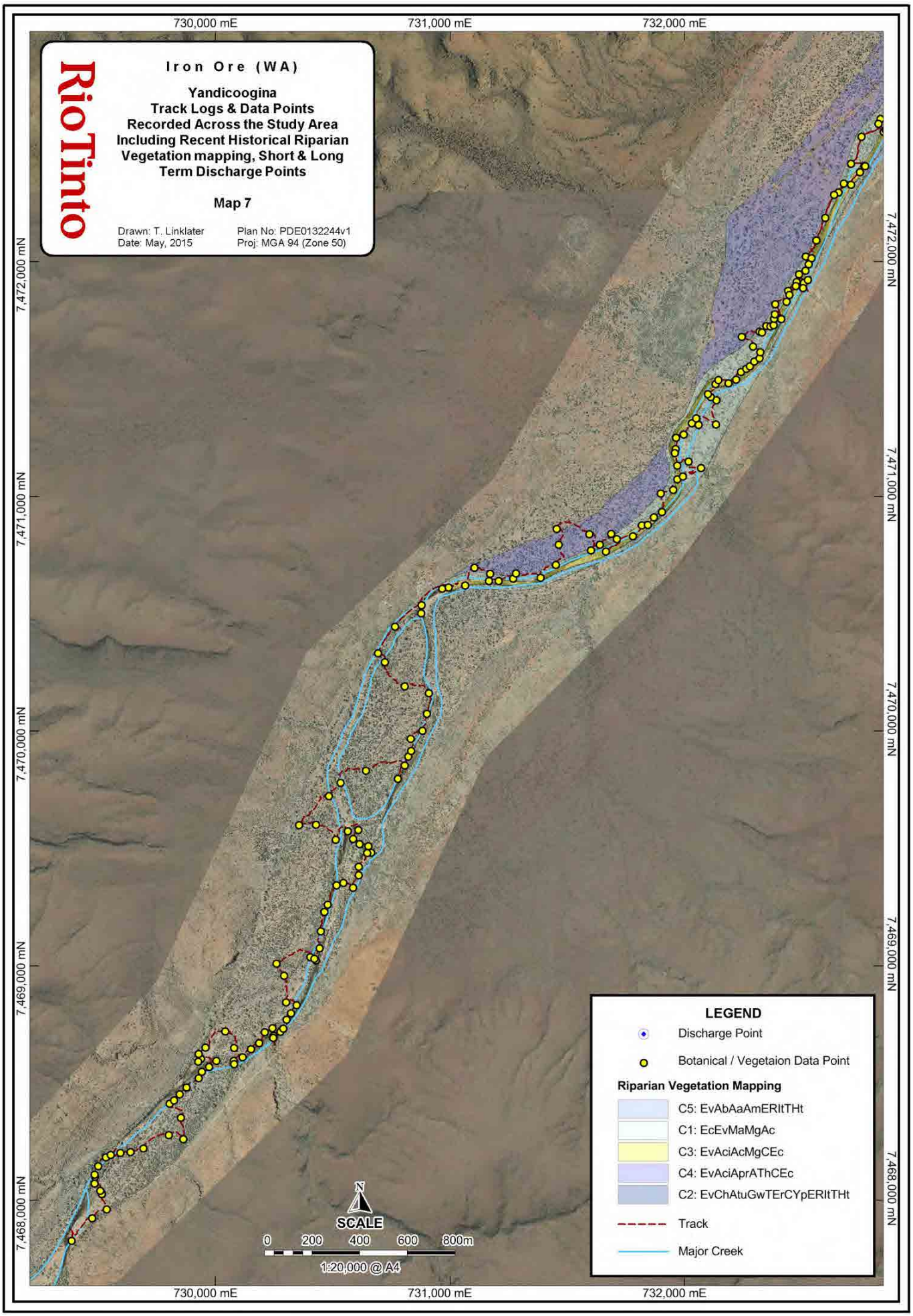


Figure 3-13: Survey effort Map 7 of 7

3.1.4 Post Field Work Mapping Refinement

Classification and assessment of the average size and inferred age structure of *Melaleuca argentea* populations

Following field acquisition, data was entered within Excel and uploaded to a GIS (Mapinfo Pro, Encom Discovery 2011). This GIS data was initially analysed to gain a broad understanding of the distribution of *M. argentea* within the study area. Once general distribution patterns were established and considered in relation to the location of discharge points and broad patterns of creek morphology, all data points which had a size class recorded for the population which they represented, were classified to the following ranges and displayed across the creek system (including all individual "mature" trees way-pointed). The size ranges (as a proxy for age) separately created for this task were "Young", "Young to SM(-)", "SM and older". This process enabled a broad scale size class map for *Melaleuca argentea* within the study area to be created, thus representing a proxy for the spatial distribution of different age classes and their associated age structures for obligate phreatophytes across the study area.

Using the complete dataset and commonly accepted data point correlation and extrapolation techniques, the spatial boundaries of all OPV communities encountered in the study were mapped at a fine scale. Correlation and extrapolation techniques generally involve the correlation of vegetation data with aerial photo signatures and the subsequent extrapolation of that data across the extent of the relevant aerial signature. These polygons were mapped to represent areas where the cover/abundance of *M. argentea* was deemed to comprise a significant component of the resident community's structure and therefore represent a co-dominant/dominant member as opposed to merely an associated species. Once boundaries were established for all mappable occurrences of OPV, the previously produced broad size class map was then used in conjunction with all of the actual (non-grouped) size class data to determine the dominant size class, and therefore inferred age of each patch of this community. This was generally done based on four factors:

1. The variability/range of the inferred age structure present (inferred based on trunk size classes) within a mapped vegetation patch.

2. The average maximum inferred size for each representative vegetation patch.

3. The presence/absence and number of individual "mature" trees recorded in any representative patch/area.

4. The general structure and composition of the vegetation within which the *M. argentea* occurred. For example; in general, younger communities possessed a particular understorey and over-storey vegetation structure, such that their allocation to this size class was reinforced if such characteristic structure/composition was present as well. Various structural/compositional characteristics were typically observed within vegetation possessing certain *M. argentea* size classes and these were consequently taken into account (where noted) in the allocation process.

The four distinct *M. argentea* community "size class ranges" (inferred to broadly represent age structures) determined to be of most relevance, from a current and historical significance perspective, to OPV communities in the study area were established to be:

- M-SM^{plus} populations, (mapped as red class – Mature to semi-mature at times SM+);
- Y-SM(+)* populations (orange class – Young to semi-mature plus*);
- Y-SM(-)*(yellow class – Young to semi-mature minus*); and
- Y* populations (green class – Young*).

See Table 4-3 for complete definitions of these distinct community "size class ranges" for resident *Melaleuca argentea* populations.

In addition to the above population factors two other spatial/historical factors were used to help in the process of attributing each patch of *Melaleuca argentea* co-dominated OPV to a "size class range" (and associated community structure). This attribution process often had to summarise multiple size class data points for each patch of vegetation being considered (often over quite small spatial distances), such that in many cases multiple and sometimes contradictory size classes/ranges needed to be summarised into the corresponding representative size range for the patch. It was in these cases that the following factors played a small part in determining whether; certain data points were anomalies, whether patches needed to be split based on spatial anomalies in size distribution, whether historical aerial photo indicators supported the anomalous size class trends present in certain patches, or whether apparent influence from such factors supported the recorded variations in size class.

1. The proximity or correspondence of the vegetation patch in question to/with the dense historical vegetation polygons (mapped at the desktop phase from pre-discharge aerial photography) previously mapped and classed as representing the "particularly dense and more anomalous swathes of historical vegetation" layer created as part of the desktop assessment.

2. The position of the community/patch in relation to key creek profile/morphology characters. This factor was used in situations such as; where an obvious bend in the creekline occurred at the end of a straight (and at the termination of a large pool), or where surrounding hills confined the creek profile to a much smaller lateral width. Or where the low flow channel transitioned from the far edge of one bank to the other (within the incised channel zone) in a near right angle fashion. All of these situations were postulated to provide more consistent surface and sub-surface water presence along with the mechanical processes associated with running water (as opposed to relatively stagnant surface water).

Mapping refinement of the riparian communities present in the study area

Once all patches of OPV were attributed to one of the four communities "size class ranges" created, vegetation descriptions were formulated for each resulting community sub-association based on mapping data acquired. Following this process; the remaining riparian associations (potentially FPV) co-occurring with and often surrounding the *M. argentea* co-dominated sub-associations (OPV) were refined based on mapping notes, photo points and additional data points collected as part of the field component.

The key task of this final mapping component was to establish, and spatially delineate, a riparian community which is generally represented by a woodland of *Eucalyptus camaldulensis* and *E. victrix (FPV)*, but which does not contain *Melaleuca argentea* as a co-dominant species. Previous mapping along Marillana and Weeli Wolli creeks did not include such a community. Instead, for the purpose of simplification, previous (post-discharge) mapping merged this type of community with occurrences of OPV. It appears that this is the reason the original C1 community was spatially distorted with respect to the distribution of OPV. It should be noted at this point, that the amalgamation described above and the resultant influence this had on the spatial accuracy of OPV in the previous mapping of the study area, is a common product of the inherent decisions to lump or split vegetation associations which the vegetation mapping process requires. For this reason the distinctions hade herein are in no way a criticism, but rather an explanation of the problems of scale occurring between mapping projects undertaken for different objectives.

Along with establishing and delineating the above mentioned community/association the task of refining the remaining generally facultative phreatophytic vegetation (FPV) represented a substantial piece of mapping work. This process was aided significantly by the use of recent high resolution aerial photography. The high resolution imagery enabled individuals/populations of *Eucalyptus camaldulensis* to be identified on aerial photography and therefore accurately mapped. Consequently, mapping was conducted using the combination of field data (point based notes and photos) and aerial photo interpretation. Individuals or groups of *Eucalyptus camaldulensis* within the riparian environment were distinguished from *E. victrix* on the basis of:

1. the generally larger (spatial extent) canopy footprint of *E. camaldulensis*;

2. the generally denser canopy cover signature of *E. camaldulensis*;

3. the generally dissimilar branch signature of *E. camaldulensis* canopy architecture; and

4. the generally darker green canopy colour signature *E. camaldulensis*.

The available aerial photography was considered to be of a quality suitable for the application of the above described visual assessment and was found to be robust when ground-truthed using field data. Some more obvious and presentable examples of the aerial signature of *E. camaldulensis* trees are provided below in Plate 4. The examples presented in plate 15 were generally chosen due to their location on an open floodplain, where canopy density is reduced and as such surrounding canopy species don't inhibit the display of the above described characters, thus making them easier for the reader to appreciate/visualise (for those not versed in making such assessments).

Once the key riparian vegetation units which were the focus of this work were refined, they were overlain on previously mapped riparian vegetation units (C1-C5 – Biota 2014a). The new units were integrated into the old mapping by superseding the mapping they spatially intersected and now represented. The resulting map was then cleaned and refined so as to remove any artefacts of scale produced during the intersection of the two models.

All vegetation communities whose structure was refined as part of this study, were described using Aplins' (1979) framework for "Vegetation Structural Classes". This framework is presented in Appendix 1, along with the Vegetation condition scale of Trudgen (1988), which is used in this study. As such all communities (those presented in Table 4-1 with a Bolded new vegetation code) established as part of this study are generally considered to represent sub-associations. Community

descriptions were created by identifying dominants (where present) for all strata available, rather than restricted to the three traditional strata, such that they represent complex vegetation descriptions, approximately equivalent to level 6 mapping within the National Vegetation Information System (NVIS). It should be noted that while the remaining vegetation communities, which are maintained from previous vegetation mapping (Biota 2015), and which tend to occur outside of the study area; more generally represent complex vegetation units of the sub-association scale, some are more accurately described as associations, and as such the scale presented is somewhat variable. Such apparent variability in vegetation description scale is typical of Pilbara vegetation surveys, and in many ways is a product of the inherent patterns in vegetation structure which are generally present.

Plate 4: Aerial photos showing *Eucalyptus camaldulensis* canopies (inside orange polygon) on parts of Weeli Wolli Creek

Beyond the more obvious shrub features, the majority of the remaining eucalypt canopies present in these plates are considered to be *E. victrix* as indicated by the obvious white branch and trunk colouration, open branching habit and lighter foliage colour

3.2 GROWTH RATE PROJECTION CALCULATIONS FOR *MELALEUCA ARGENTEA* UNDER 2 TEMPORAL DISCHARGE REGIMES

3.2.1 Deductive Process and Assumptions Made

One of the key secondary aims of this study was to determine which present day *Melaleuca argentea* co-dominated communities/patches if any, present a trunk size structure consistent enough and young enough that it could easily be inferred to have established since surplus-water discharge ensured perennial water availability. To enable this to be determined, the first task is to determine the annual growth rate of this species under favourable conditions (in a Pilbara creek system with perennial water availability), and compare this to the growth realised by populations present in the study area.

The average range of trunk sizes, visually approximated in the field for any *M. argentea* population, was created as a proxy for the age and the relevant associated age structure characters. Once fine scale knowledge of resident size structure is acquired via field work, the next step in the process is to determine the average amount of 2-dimensional (i.e. a horizontal cross-section) trunk biomass (growth) added by this species each year. This figure would be represented by a cm^2 increase in trunk cross-sectional area per year. Once such a figure is attained the next step is determining a "reasonable maximum average trunk diameter" which would be likely to establish/grow over either a 9 or 15 year time scale in a scenario where:

> **A generally ephemeral creek habitat** (likely to be comprised mainly of vegetation equivalent to the C2A or C2Asb community), **which likely only (at best) contained *Melaleuca argentea* as an associated species** (i.e. no more than isolated to scattered small populations or individuals of generally young size and structure), **was then provided perennial surface water input representing ideal growth conditions for initiating and sustaining the germination and establishment of larger more substantial populations of *M. argentea*** (constituting the inclusion of this species as a co-dominant in a developing OPV) **as long as discharge was maintained.**

This "reasonable maximum trunk diameter" was created to represent a relatively conservative "cut-off figure" whereby:

> **If present day populations possessed at least regular** (on average at least scattered individuals i.e. 1-2% within the resident sighted population) **individuals of equivalent or greater diameter then; that population** was considered to presently possess an upper size-class or old enough age structure to indicate that *M. argentea* was potentially present as a co-dominant component (in various structural forms) of the resident pre-discharge community.

Once attained, the "reasonable maximum trunk diameter" (from herein referred to as the "Cut-off figure") would be used to compare with the "size class range" of the various patches of *M. argentea* co-dominated riparian community recorded throughout the study area. For patches which possessed

a relatively narrow trunk diameter range and an upper size class below that of the cut-off figure, it would be inferred that this present day OPV community was:

> **Unlikely to have been present in the pre-discharge riparian environment, and instead a FPV community which at best only contained *M. argentea* as an associated species was present in its place.**

For example: if the "reasonable maximum trunk diameter" equals a diameter of 25 cm, and a population of *M. argentea* within a present day patch of OPV was attributed a "size class range" of Y-SM(-), then the upper size class is SM(-), which equates to a 10-20 cm field estimate, and which is below the "cut-off figure" (reasonable maximum trunk diameter) of 25 cm. Consequently this patch of present day OPV is unlikely to have possessed *M. argentea* as a co-dominant component of the pre-discharge vegetation.

The above described process of deduction relies on a cut-off value (the reasonable maximum trunk diameter), and therefore making decisions on which side of the cut-off mark certain patches of present day OPV communities will fall. Because of this, it is important to note that there may be cases where the upper size class of the OPV patch being considered may fall either side of the cut-off, or just below, such that a "grey-area" becomes evident. It is this 'grey-area' and the potential issues associated which influenced the community "size class ranges" created for the refined OPV communities.

The field data acquired appeared to support the production of four general size and physical structure groupings. The spread of the data meant that 2 levels of age structure sat either side of the cut-off mark. Having communities representing key intermediate age structures sitting either side of the cut-off enabled the conclusions to incorporate some conservative conclusions in relation to the pre-discharge environment.

The methodology described above and the proposed data sources used to calculate the projected growth rates assumes the following things about the populations they are proposed to project growth for:

1. That the perennial surface water conditions, general climate, and direct impact scenario they occupied represented fairly favourable growth conditions.

2. That growth rates while somewhat influenced by winter temperatures were not limited by water or nutrient availability given the typical conditions within a large perennial Pilbara creek system.

3. The larger individuals are often the ones which have managed to get off to a better start due to them by chance being; less shaded than others, less influenced by adjacent competition, positioned such that they are protected from flood damage, etc.. Therefore these individuals are most likely to possess growth rates closer to that representative of ideal conditions. It is these individuals which are deemed most important when considering the maximum age of a population rather than some of the small, outcompeted or stunted individuals which are likely to be inconsistent in their associated size to age ratios.

4. That populations assumed to establish after surplus-water discharge commenced, have begun establishing almost immediately (following commencement of discharge), from either; young

isolated to scattered in-situ individuals, in-situ, seedlings, germination of propagules in-situ, or germination of propagules transported from other populations upstream.

Despite the inherent assumptions and limitations associated with this process of deduction, it is considered the best available technique for interpreting the pre-discharge environment from short term field data collection within the present day environment. In addition, the field data being used in the process is considered sound and highly detailed, such that it is considered to represent an appropriate set of ground-truthed data with which to make informed and conservative enough judgements about the pre-discharge environment.

3.2.2 *M. argentea* Growth Projection Calculations

For the purpose of this study, annual growth rates for *Melaleuca argentea* are required so that this growth rate can be projected over the two temporal discharge regimes relevant to Marillana and Weeli Wolli creeks. It is determined that the best way to do this (in a short time scale) is to gather field based monitoring data which provides recordings of trunk DBH of *M. argentea* (or similar *Melaleuca* species) individuals at different time intervals for varying sized individuals Five sources of available data were found: 2 from unpublished Rio Tinto Melaleuca argentea monitoring sites (Unpublished data collected for Rio Tinto by Mattiske consulting along East Pilbara creeks including Marillana and Weeli Wolli (Mattiske 2014), and Unpublished data from one Rio Tinto monitoring site in the Kimberley (Rio Tinto 2013)), 1 from a study of Melaleuca argentea patterns of water use in the Pilbara (Mclean, 2013), and two from forest or cultivation based data indicating growth rates for cultivated or forest based populations of Melaleuca quinquinervia (as a final DBH for particular ages; generally 40 years) (Benson and McDougall 1998; Conde 1979).

All of these data sources provided either two temporal monitoring points with DBH for both and an associated time interval, or in the case of Benson & McDougall (1998), and Conde (1979), an average or upper-percentile diameter after a 40 year time span. Given that the key metric of concern is the increase in 2 dimensional trunk biomass over a particular unit of time (i.e. the change in cross-sectional area over a year) the most appropriate way to calculate an average increase in this measure of biomass per year is to convert all DBH figures to a cross sectional area. The key reasoning for this is that for example: a 5cm increase in DBH on a 10cm diameter tree results in a change in cross sectional trunk area of 390 cm^2 while a 5cm increase in DBH to a 30cm diameter tree equates to a 1020 cm^2 change in cross-sectional area DBH. For this reason changes in DBH compared between trees of different size are not equivalent with regards to change in trunk Biomass and so converting to a cross sectional area provides an equivalent measure when comparing between different sized trees.

Consequently the steps required for this calculation were.

1. Convert DBH for each tree at both the start and end monitoring times to a cross sectional area in cm^2. **Using: $A=Pi*r^2$**.

2. Calculate the difference in cross sectional area over time by subtracting the start time cross-sectional area from the end time cross-sectional area. **Using: Area B – Area A** (where “B” is the later (end) monitoring time and “A” is the earlier (start) monitoring time).

3. Convert this cross sectional difference to a change in cross sectional area per year, by dividing the Change in area by the number of years between the start and end monitoring points. **Using: Change-in-area / (number of months/12).**

4. Times this change in area per year by the number of years over which discharge active (one figure for 9 years discharge and a separate one for 15 years). This gives us the amount of biomass in cross sectional trunk area which the tree projected from would likely grow in 9 and 15 years. **Using: (Delta-Area)*(Discharge years).**

5. Convert this resultant cross sectional area to a resultant DBH. **Using: DBH = 2*(Square root of (Area/Pi)).**

6. To allow for likely differences in the potential for an individual to add trunk biomass per year which could result from age and therefore size (root and canopy resources), group the resultant individual projected biomass figures (in DBH) by the ranges evident in the spread of the original DBH figures of the monitoring trees.

7. For each range of original monitoring tree DBH (eg.1-3cm, 3-6cm, 6-9cm DBH, etc.) calculate the average projected DBH for each range and for the two discharge time spans (9 and 15 years). **Using: Sum(DBH)/(#-of-trees)** (#-of-trees = Number of individual monitoring trees in relevant original DBH range).

8. Determine the most relevant average projected DBH for the discharge time span by analysing the spread of the data in relation to the DBH of the original trees. Determine an average figure for each time span.

9. To be conservative and to allow for differences in growth rate due to competition, climatic variability and local impacts/perturbations - Subtract 25% from this figure to provide a more conservative figure. **Using: 0.75 * DBH.**

Once all the above calculations were made a comparative figure would be produced. The results of this process are presented below in section 4.3.2.

3.3 REMOTE SENSING TOOLS USED TO COMPARE VERTICALLY VISIBLE VEGETATION SIGNATURES AND TEMPORAL SIGNATURE CHANGES IN AND BETWEEN THE PRE AND POST DISCHARGE ENVIRONMENTS

Two key remote sensing tools were used as part of this study to observe the vegetation signatures present within the riparian zone of the pre and post discharge temporal environment of the study area. In addition one remote sensing tool was used to provide a quantitative measure of vegetation changes which have gone on in the respective riparian zones between 2006 and 2014.

The first is represented by visible spectrum “aerial photography”. Aerial photography acquired in 1994 for Marillana Creek, and 2006 for Weeli Wolli Creek was used to observe the pre-discharge environment of the respective riparian creek habitats. This was compared with aerial photography for the entire study area which was acquired in 2014.

The second tool is represented by DMSI change detection Imagery. This type of imagery is explained as being created by, and representing:

Digital Multispectral Imagery (**DMSI**) is a remote sensing tool used to provide maps of indicative change in vegetation condition, health and cover over time and across extended areas of interest. DMSI samples reflected electro-magnetic energy in fixed wavelength bands, providing spectral information for all vertically visible ground features. Healthy vegetation has unique spectral properties, with its high chlorophyll content absorbing a large proportion of red energy and its structure strongly reflecting infra-red energy. This spectral characteristic can be exploited to provide information on the relative density and health of vegetation via the calculation of a "vegetation index"; the simple ratio of the infra-red and red reflectance. This index is known as the Simple Vegetation Index or the Plant Cell Density (**PCD**) Index.

Where multiple acquisitions of DMSI with minimal solar angle variation are co-registered spatially, the change in PCD index can be calculated for each pixel and displayed for visual interpretation as a Composite Change Detection Image. In these images vegetation which has lost or gained density and health between the two acquisition periods is displayed in hues of red to blue respectively; such that the deeper the hue of red or blue, the greater the magnitude of change that has occurred.

In this study DMSI change detection imagery is used to determine the distribution of positive (and negative) vegetation change anomalies within the riparian zone, and then establish whether correlations exist between the distribution of this positively anomalous vegetation change and the distribution of different types of OPV within the study area. The principle DMSI change detection imagery used for this study is represented by an image which depicts vegetation change from 2006 to 2014, based on yearly acquired 1m pixel imagery. This image is perfect for consideration of this influence of discharge on the study area stretch of Weeli Wolli creek. Surplus-water discharge initially commenced within Marillana Creek in approximately 1995, and as such this image has reduced application within this creek system. Issues with the acquisition of DMSI and production of change detection imagery around this time led to the decision to rely on the 2006-2014 imagery.

During the late 1990's and early 2000's issues pertaining to the low reliability of image calibration and spatial correlation from year to year determined that the use of change detection imagery was problematic. In addition, this period represented a time when the acquisition and application of DMSI was in its infancy, and as such the resolution and spatial extents of acquisition were quite variable from year to year. The inherent and local issues relating to DMSI imagery acquired in the period 1995-2005, become apparent when analysing and comparing local NDVI imagery, change detection, and true and false colour imagery, from this time period. Consequently it was determined that using the 2006-2014 change detection imagery was the safest and most spatially extensive option for presenting trends in vegetation cover within the study area.

3.4 LIMITATIONS OF THIS STUDY

Overarching

- The survey area was easily accessed
- Rainfall/seasonal conditions, and flowering/fruiting conditions were favourable for conducting this type of survey.

Desktop and Field Data Acquisition Tools

- Size classes attributed to *M. argentea* populations are only an estimate, so potentially inaccurate in some cases.
- Some issues became apparent when using NDVI as a marker for GDE presence, as the NDVI signature for OPV communities of old age (mature) were hard to distinguish from that of more common mature *Eucalypt* spp. FPV communities. In these cases relatively comprehensive creek coverage was relied on to make sure such representations were not missed.

Ground Truthing and Mapping Refinement Field Work

- Amount of flowing-water in the creek at the time of survey restricted movement across creek in some situations
- All species of interest were in good condition, with key eucalypt species fruiting in many cases at the time of survey, making identification in the field easy

Post Field Work Mapping Refinement Process

- Data quantity and resolution was more than adequate
- Coverage was more than adequate

Growth Rate Projection Calculations for *Melaleuca argentea* Trees

- Only used a sample size of 54 monitoring trees over 1-4 years (generally only 1-1.5 years). A larger sample size would be better, with longer average monitoring period.
- Some natural tropical data sources from different habitats show reduced growth rates to that shown by the monitoring trees used for the projection. Despite this fact, the differing habitats (dry monsoon forest vs Perennial creek system) could easily explain such differences.

Interpretation of likely presence of present day OPV in the pre-discharge environment

- For the purpose of this study the influence of Climatic variability or changing trends in climate averages are unable to be considered in any detail in relation to the use of growth projections for predictions on the pre-discharge presence of OPV.

4 RESULTS

4.1 MAPPING REFINEMENT

In relation to the predicted outcomes of the vegetation mapping refinement process, the resultant mapping is considered to be well aligned with previously observed trends in vegetation distribution. Despite this fact, some relatively unexpected patches of mature OPV were identified as part of this process. Results such as this are considered important as they represent valuable features which otherwise might not have been identified. Furthermore, such features can now become part of a more accurate and spatially discrete framework for management of impacts to communities of significance.

Table 4-1 below presents the refined vegetation associations developed as part of the mapping refinement process. Table 4-2 presents multiple representative photos of all the "C" coded riparian vegetation units refined as part of this work. While more broadly presented in the following tables and figures, the mapping units from previous vegetation surveys are maintained despite the fact that they generally fall outside of the study area. The effort invested in accurately integrating the new riparian mapping with the broader vegetation model determined that it was worthwhile to present the complete vegetation model.

Vegetation Coding

Compared to previous mapping, the most significant degree of change has occurred to the previously mapped and coded C1 vegetation unit (Biota 2014a) and the communities which were substituted in its place. In addition these changes resulted in significant displacement of units such as Biota's previously mapped C3 and to a lesser degree C4 units (Biota 2014a). Prior to this study, the C1 unit essentially represented an amalgamation of the relatively common *Eucalyptus camaldulensis* and *E. victrix* woodlands of the area with the highly restricted OPV variant of this community, which possessed a significant *Melaleuca argentea* tree component. Consequently on separation, the spatially restricted *M. argentea* OPV variant maintained attribution to the C1 riparian class, and the FPV *E. camaldulensis/victrix* community was transferred to the C2 riparian class. The C1 riparian class was then split into 4 key groups depending on the physical "size class range" and inferred broad age structure of the community recorded. It is this separation into key "size class ranges" which is used further on to interpret and infer which of these OPV communities were likely to be naturally present in the pre-discharge environment. In addition to their likelihood of presence, it was also used to infer the likely physical size and age structure of such communities in the pre-discharge environment.

With the relatively common *Eucalyptus camaldulensis* and *E. victrix* woodlands of the area being transferred to the C2 riparian class, the C2 code structure also saw a significant degree of change. Within previous mapping the C2 and C3 classes were the domain of purely *E. victrix* overstorey dominated riparian communities, and so the inclusion of *E. camaldulensis* communities to the C2 class, while relevant, meant the coding was re-structured to incorporate this community and any closely affiliated communities recorded as part of the refinement process. As previously mentioned, vegetation description and spatial location changes were only made to riparian communities, and the communities which received changes at both these levels are delineated in Table 4-1 by bolding

of the new vegetation code. Beyond the communities which were refined in both their description and boundaries, a number of communities (those both part of the riparian zone and some fringing it) had purely their spatial boundaries altered, and in nearly all cases these changes were very minimal and generally a product of a scale changes. Table 4-3 below present's information which has been summarised about the "size class range" and physical structure/characters of populations of *Melaleuca argentea* within communities mapped as possessing or potentially possessing this species. In addition it also presents summaries of the inferred age structure, notes on presence/abundance, and average stem sizes for *Melaleuca argentea* populations present in those OPV communities which this species comprises a significant component of. Despite this table being created to present information about OPV (and to a lesser extent FPV) communities; for completeness, the table also includes the same information (where available) for all communities in which this species is either a known associated or potentially associated species.

Given the catchment sizes and at times quite topographically constrained creek profiles of Marillana and Weeli Wolli creeks a significant proportion of the incised creek bed is periodically represented by generally scoured alluvial beds with minimal vegetation. The significantly reduced biomass and typically increased surface water input frequency of these zones (based on the lack of groundcover and general understorey vegetation) determines that they are generally less sensitive to changes in groundwater availability when compared to their closely affiliated and more densely and structurally complex equivalents (C2A, and C3A). As a consequence these areas were delineated in the mapping refinement process to create the major creek bed communities; C2A, and C2Asb ("sb" denotes 'scoured bed'), representing *Eucalyptus camaldulensis and E. victrix* dominated creek bed communities, and the C3A and C3Asb communities representing the *E. victrix* dominated creek bed communities.

Vegetation Mapping

Figures 4-1 to 4-8 present the resultant vegetation map for the riparian study area, and include the surrounding broader project area mapping, which has been perpetuated from previous surveys. The vegetation maps presented constitute a modelled interpretation of the spatial distribution of described vegetation communities within the study area and, as with any model, are likely to contain some errors. Mapping errors have been minimised through extensive ground-truthing. The degree of ground-truthing effort conducted for the included groundwater dependent communities is such that the mapping is considered to be significantly more accurate than vegetation mapping typically undertaken within riparian areas. This fact can be attributed to the requirement to provide a very high degree of accuracy in relation to the spatial location and distribution of OPV communities.

Table 4-1: Summary of Vegetation Types Recorded in the Study Area. Includes old and new vegetation mapping codes to indicate which units have been refined (Bolded Veg codes in the new veg codes column are those which have had their description and boundraies refined)

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
Vegetation of Major Creeklines and Tributaries						
C1	**C1A**	15.7	**Small patches of *Melaleuca argentea* Woodland** Eucalyptus camaldulensis subsp. refulgens, *E. victrix* and *Melaleuca argentea* woodland (to open woodland) over Eucalyptus camaldulensis *Melaleuca argentea* and *Acacia coriacea subsp. pendens* low open woodland, over scattered to tall open shrubland of *Melaleuca glomerata*.	Fringing large pools of scoured creekbeds and channels in some of the wettest parts of Marillana Creek. No representations present in Weeli Wolli Creek.	1 quadrat: OXB06(Biota), Mapping Notes (JN).	Very Good to Good.
C1	**C1AA**	14.9	**Larger representations of Historical *Melaleuca argentea* Woodland** Eucalyptus camaldulensis subsp. refulgens, *E. victrix* and *Melaleuca argentea* woodland (M. argentea generally represented by scattered trees), over Eucalyptus victrix, *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over scattered to tall open shrubland of *Melaleuca glomerata* and *Acacia ampliceps*, over mixed low open shrubland and outcrops of *Cenchrus ciliaris* open tussock grassland.	Scoured creekbeds and channels in the wetter parts of the upper stretch of Marillana Creek located in the North West corner of the study area.	No Quadrats Occurs outside of tenure. Mapping Notes (JN).	Very Good to Good.
C1	**C1B** **- Marillana**	4.1	**Marillana - M. argentea Semi Mature low open woodland** Eucalyptus camaldulensis subsp. refulgens, and *E. victrix* woodland, over Eucalyptus camaldulensis, *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over tall open shrubland of *Melaleuca argentea*, *M. glomerata* and *Acacia ampliceps*, over mixed low open shrubland.	Marillana Creek: In the wetter parts of scoured creekbeds and channels of the primary low flow zone.	1 quadrat: YBI23(Biota), Mapping Notes (JN).	Very Good to Good.
C1	**C1B** **- Weeli Wolli**	8.9	**Weeli Wolli - M. argentea Semi Mature low open woodland** Eucalyptus camaldulensis subsp. refulgens, and *E. victrix* woodland, over Eucalyptus victrix, *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over tall open shrubland of *Melaleuca argentea*, *M. glomerata* and *Acacia coriacea subsp. pendens*, over mixed low open shrubland.	Weeli Wolli Creek: In the wetter parts of scoured creekbeds and channels, particularly on bends or low flow channel transitions at the end of creek straights.	1 quadrat: YBI23 (Biota), Mapping Notes (JN).	Very Good to Good.
C1	**C1/C2-A** **- Marillana**	19.89	**Marillana - M. argentea Young to Semi Mature low open woodland** Open woodland of Eucalyptus camaldulensis subsp. refulgens and *E. victrix,* over low woodland (generally dominated by saplings to young trees) of E. camaldulensis subsp. refulgens and *Melaleuca argentea*, over scattered tall-shrubs (to tall open shrubland) of *Melaleuca argentea*, *M. glomerata*, *Atalaya hemiglauca*, Stylobasium spathulatum and Sesbania cannabina, over very open sedgeland of Cyperus vaginatus and often accompanied by fringing strips of Typha domingensis	Marillana Creek: In the wetter parts of scoured creekbeds and channels, where it generally flanks the primary low flow channel.	1 quadrat: OS086 (Mattiske), Mapping Notes (JN).	Very Good to Good.

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
C1	**C1/C2-A - Weeli Wolli**	3.21	**Weeli Wolli - M. argentea Young to Semi Mature low open woodland** Scattered trees of Eucalyptus camaldulensis subsp. refulgens and *E. victrix*, over low woodland (generally dominated by saplings to young trees) of E. camaldulensis subsp. refulgens and *Melaleuca argentea* (and to a lesser extent *E. victrix*), over scattered tall-shrubs (to tall open shrubland) of *Melaleuca glomerata*, *Atalaya hemiglauca*, *Acacia coriacea subsp. pendens*, and Stylobasium spathulatum over very open sedgeland of Cyperus vaginatus and often accompanied by fringing strips of Typha domingensis	Weeli Wolli Creek: In the wetter parts of scoured creekbeds and channels, where it generally flanks the primary low flow channel.	1 quadrat: OS086 (Mattiske), Mapping Notes (JN).	Very Good to Good.
C1	**C2/C1 -Marillana**	20.7	**Marillana - M. argentea Young low open forest** **Strips of vegetation generally lining the low flow channel of:** Scattered Eucalyptus camaldulensis trees, over low open forest (generally dominated by saplings to young trees) of Eucalyptus camaldulensis and *Melaleuca argentea*, over tall open shrubland (to scattered tall-shrubs/shrubs) of *Acacia ampliceps*, *Melaleuca argentea*, *Melaleuca glomerata*, *Atalaya hemiglauca* and Sesbania cannabina, over open to very open sedgeland of Cyperus Iria and Cyperus vaginatus, often accompanied by fringing strips of dense Typha domingensis.	Marillana Creek: In the wetter parts of scoured creekbeds and channels, where it generally flanks the primary low flow channel.	1 quadrat: TS115 (Mattiske), Mapping Notes (JN).	Very Good to Good.
C1	**C2/C1 – Weeli Wolli**	13.7	**Weeli Wolli - M. argentea Young low open forest** **Strips of vegetation generally lining the low flow channel of:** Low woodland to low open forest (generally dominated by saplings to young trees) of Eucalyptus camaldulensis subsp. refulgens and *Melaleuca argentea* (and to a lesser extent *E. victrix*), over scattered tall-shrubs/shrubs of *Melaleuca glomerata*, *Atalaya hemiglauca*, and Stylobasium spathulatum, over very open sedgeland of Cyperus vaginatus and often accompanied by fringing strips of Typha domingensis	Weeli Wolli Creek: In the wetter parts of scoured creekbeds and channels, where it generally flanks the primary low flow channel.	1 quadrat: TS115 (Mattiske), Mapping Notes (JN).	Very Good to Good.
C1/C3/C4	**C2A**	412.1	**E. camaldulensis and *E. victrix* bank/bed community** Eucalyptus camaldulensis subsp. refulgens, *E. victrix* open woodland (to woodland in places), over Eucalyptus victrix, *Acacia coriacea subsp. pendens*, *Atalaya hemiglauca* and *Acacia citrinoviridis* low open woodland (to scattered low trees), over *Melaleuca glomerata* and *Acacia citrinoviridis* tall open shrubland (to scattered tall shrubs), over mixed shrubland/low shrubland typically dominated by *Corchorus crozophorifolius* and Tephrosia sp. Fortescue creeks and outcrops of *Cenchrus ciliaris* open tussock grassland.	Creekbeds and channels of Marillana and Weeli Wolli Creek, and some parts of major tributaries of Marillana and Weeli Wolli Creeks.	1 quadrat: YEX39(Biota), mapping notes (JN).	Very Good to Good.

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
C1/C3/C4	**C2Asb**	152.5	**E. camaldulensis and *E. victrix* Scoured bed community** Eucalyptus camaldulensis subsp. refulgens, and *E. victrix* open woodland (to woodland/low woodland in places)over scattered tall shrubs of *Melaleuca glomerata*, over scoured beds of the main and large secondary channels of Marillana Creek. (Some areas are less scoured and slightly raised possessing a mixed low open shrubland typically dominated by *Corchorus crozophorifolius*, Tephrosia sp. Fortescue creeks and others).	Scoured creekbeds and channels of Marillana and Weeli Wolli Creek, and some parts of major tributaries of Marillana and Weeli Wolli Creeks.	4 quadrats: YB130S (Biota), Mattiske: OS085 & OS030, TS103, Mapping Notes (JN).	Very Good to Good.
C2/C1	**C2B**	11.4	**Weeli Wolli - *E. victrix* E. camaldulensis Floodplain community** Eucalyptus victrix and E. camaldulensis subsp. refulgens low open woodland (with scattered trees), over *Acacia citrinoviridis*, *A. pruinocarpa*, and *Atalaya hemiglauca* Tall shrubland (to tall open shrubland) over **Cenchrus ciliaris* tussock grassland	Some parts of the broader Weeli Wolli Creek Floodplain	Mapping notes (JN)	Very Good to Good.
C2	C2C	177.3	Eucalyptus victrix, (*Corymbia hamersleyana*¥) scattered low trees over Acacia tumida var. pilbarensis, *Grevillea wickhamii* tall shrubland over Tephrosia rosea var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus*, *C. procerus*, *Eriachne tenuiculmis*, *Themeda triandra* very open tussock grassland ¥ *C. hamersleyana* was a dominant species in tributaries but not in the main channels of Marillana Creek.	General flood out zones of the upper and outer creekbeds (initial floodplain feature) of Marillana Creek, (south of the YJC mine) and the main channel vegetation of major tributaries of Marillana and Weeli Wolli Creeks throughout the study area.	6 quadrats: BIL02^, BIL31^, OXB16^, YEX25, YSW01 (cleared), YVI09.	Very Good to Good.
C3/C4	**C3Asb**	155.5	***E. victrix* scoured beds community** Eucalyptus victrix scattered trees to low open woodland over scattered tall shrubs of *Melaleuca glomerata* and *E. victrix* (saplings), over scoured beds of the Main and large secondary channels of Weeli Wolli creek. (Some areas are less scoured and slightly raised possessing a mixed low open shrubland typically dominated by *Corchorus crozophorifolius*, Tephrosia sp. Fortescue creeks and others).	Scoured creekbeds and channels of Marillana and Weeli Wolli Creek, and sections of major tributaries of Marillana and Weeli Wolli Creeks.	1 quadrats: YBYBI01(Biota), Mapping Notes (JN).	Good to Very Poor.
C3	C3A	170.5	***E. victrix* Bank/bed community** Eucalyptus victrix scattered trees over *Acacia citrinoviridis*, A. coriacea subsp. pendens, *Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	Anabranching creekbeds found along the main channel of Weeli Wolli Creek and some channels in the eastern parts of Marillana Creek. Also occurred in two major tributaries of Marillana Creek.	4 quadrats: , YEX39, BIL30^, YEX28, YSW04. 2 relevés: YEX-K, YBI-RRWB.	Very Good.
C4	C4	1283.6	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland	Creek banks and floodplains of the major channels of Marillana and Weeli Wolli Creeks throughout the study area. Also occurred in two tributaries of Weeli Wolli Creek near the proposed PBS development.	13 quadrats: HAD09^, H050^, H051 (cleared), YAQ12^, YAQ13, YAQ21, YBI03, YBI04, YBI08^, YEX02^, YEX17, YEX29. 5 relevés: YAQ-CSRA, YBI-RBMK, YBI-RPHB, YBI-RPHA, YEX-M.	Good to Very Poor.

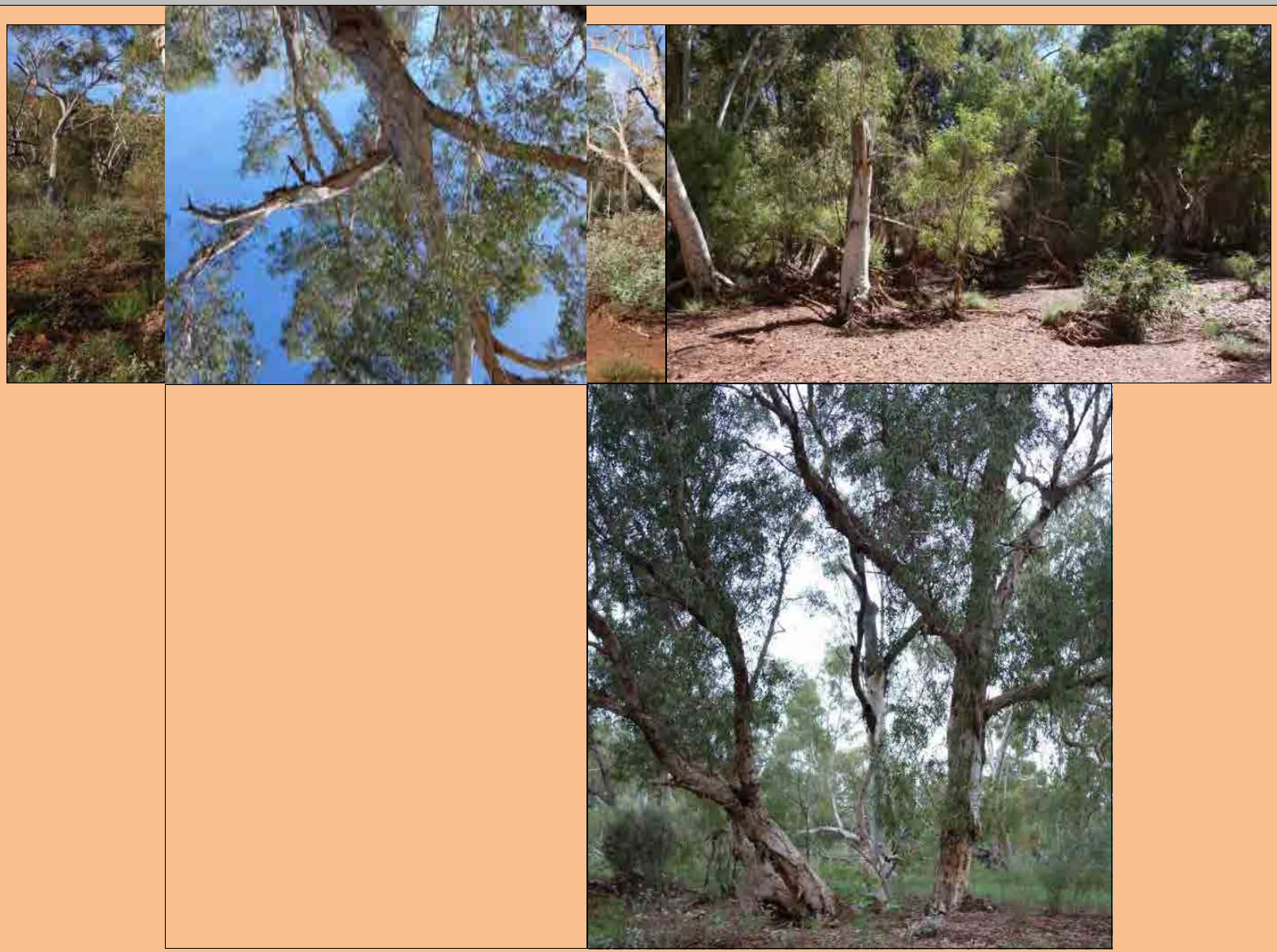
Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
C5	C5	26.05	*Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	Several major tributaries feeding into Marillana Creek around the JSW and YJC mines.	2 quadrats: YVI15, YSW19S^.	Very Good.
Vegetation of Minor Creeklines, Floodplains and Valleys						
F1	F1	414.8	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland	Floodplains and minor creeklines throughout the study area.	13 quadrats: BIL16^, OXB04^, YAQ03, YAQ05, YAQ20, YBI20^, YBI25, YBI35S^, YSW05, YSW18S^, YVI11, YVI12, YVI13. 3 relevés: BIL-RCFC, BILRSWA, YBIRBME.	Very Good to Good.
F2	F2	333.5	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland	Floodplains and some minor tributaries of Weeli Wolli Creek.	4 quadrats: BIL23^, BIL24^, YAQ30^, YEX38^. 4 relevés: YAQ-CSRC, YAQ-CSRD, YBI-RBMF, YBIRBMH.	Poor to Very Poor.
F3	F3	260.8	*Eucalyptus leucophloia, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland	Minor creeklines flowing between low hills. Mainly distributed around the JSW and YJC mines.	7 quadrats: BIL35^, BIL36^, YEX07 (cleared), YEX08^, YEX11 (cleared), YEX26, YEX34 (cleared). 2 relevés: YAQ-RPLA, YEX-G.	Good.
F4	F4	41.7	*Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland.	Occurred north of the proposed PBS development on the west side of Weeli Wolli Creek, on a flood-out that was located on a plain and fed by minor creeklines flowing through low hills to the east.	3 quadrats: BIL11^, BIL14, BIL46^.	Very Good.
F5	F5	31.4	*Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland.	Occurred near the proposed PBS development, east of Weeli Wolli Creek in a small area of floodplains and flood-outs.	2 quadrats: BIL21^, BIL47.	Good.
Vegetation of Hills, Ridges, Gorges and Breakaways						
H1	H1	2,840.3	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland	Widespread throughout the study area on elevated hill crests and some rocky hill slopes.	38 quadrats: BIL05, BIL17, BIL19, BIL20, BIL28, BIL34, BIL37, BIL43, OXB01^, OXB05^, OXB10^, OXB11^, YAQ01, YAQ07, YAQ09, YAQ10, YAQ11, YAQ14, YAQ25, YAQ27, YBI18, YBI31S^, YBI33S^, YEX01^, YEX06^, YEX10 (cleared), YEX13 (cleared), YEX18 (cleared), YEX24 (cleared), YEX30, YEX35, YEX36 (cleared), YEX37, YSW03, YSW13, YSW15, YVI07, YVI14. 1 relevé: YVI-RMMA.	Excellent.

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
H2	H2	5,858.6	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland	Widespread throughout the study area on rolling stony hills and slopes.	25 quadrats: BIL03, BIL15^, BIL26, BIL27, BIL29, BIL39^, BIL40, BIL44, HDA16, HDA24^, OXB02^, YAQ02, YAQ04, YAQ06, YAQ08, YAQ15, YAQ18, YAQ19, YBI05^, YBI32S^, YBI36^, YSW06^, YSW17S^, YVI01, YVI02. 1 relevé: BIL-RCFA.	Excellent.
H3	H3	210.4	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland	Slopes and crests of a range of low stony hills northeast of the proposed PBS development.	2 quadrats: BIL01^, BIL06^. 1 relevé: BIL-RPCA.	Excellent.
H4	H4	74.3	*Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland	Crests of two low stony hills northeast of the proposed PBS development.	2 quadrats: BIL04^, YBI24^.	Excellent.
H5	H5	27.6	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis, Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade (M.E. Trudgen 2471), *T. triandra* open tussock grassland	Found throughout the study area on narrow ridgelines with free face and breakaway slopes.	4 relevés: BIL-RCFB, BIL-RCFD, YEX-F, YEX-J.	Very Good.
H6	H6	7.4	*Eucalyptus leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland	Slopes and crests of some hills near the JSW and YOX mines.	2 quadrats: OXB13^, YSW20S^.	Excellent.
H7	H7	32.9	*Eucalyptus leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana, T. pungens* open hummock grassland	Low stony hills, mainly fringing Marillana Creek near the YOX and JSW mines.	4 quadrats: YSW09, YSW16, YVI05 (cleared), YVI16.	Very Good
H8	H8	1.2	*Acacia monticola* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* closed hummock grassland	Recorded from a single area along a breakaway on a hillslope, near Marillana Creek. It has since been dissected by drill lines associated with the JSW mine.	1 quadrat: YSW14.	Excellent.
H9	H9	13.8	*Corymbia hamersleyana* scattered low trees over *Gossypium robinsonii, Androcalva luteiflora, Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* shrubland over *Themeda triandra, Cymbopogon ambiguus* open tussock grassland	Recorded in a single gorge southwest of the YOX mine. Also mapped from two other similar-sized gorges (one near the Yandi camp and the other south of the Oxbow deposit), however these areas have not been ground-truthed.	1 quadrat: OXB03.	Very Good.
H10	H10	25.0	*Acacia inaequilatera* scattered tall shrubs over *Eremophila fraseri* subsp. *fraseri* scattered shrubs over *Triodia pungens* very open hummock grassland	Located on a single hill adjacent to Marillana Creek, north of the JSE mine.	1 quadrat: YAQ17.	Good.

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
Vegetation of Stony Plains						
P1	P1	395.9	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland	Undulating colluvial plains throughout the study area.	11 quadrats: BIL38^, BIL39, OXB03^, OXB09^, YEX05 (cleared), YSW07, YSW11, YSW12, YVI04 (cleared), YVI08, YVI10. 1 relevé: YSW-RBMA.	Excellent to Very Good.
P2	P2	1,065.3	*Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland	Occurred broadly over plains in the eastern half of the study area, fringing the floodplain on the southern side of Marillana Creek and on both sides of Weeli Wolli Creek.	14 quadrats: BIL07^, BIL08, BIL09, BIL10^, YAQ16^, YAQ24, YAQ29, YBI10^, YBI26, YEX14 (cleared), YEX19, YEX20, YEX23, YEX27. 2 relevés: YBI-RBMC, YBI-RBMD.	Good.
P3	P3	177.9	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland	Occurred along either side of Weeli Wolli Creek, fringing the floodplains along the central section of the creek.	3 quadrats: HDA14 (cleared), YBI11^, YBI17^. 1 relevé: YBI-RBMJ.	Very Good (some small areas Poor).
P4	P4	352.1	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland	Occurred in the southern half of the study area along Weeli Wolli Creek, where it fringed the floodplains on both sides of the creek.	6 quadrats: HDA07 (cleared), HDA15 (cleared), YBI19 (cleared), YEX03 (cleared), YEX04^, YEX32 (cleared). 1 relevé: YAQ-CSRB	Excellent to Good.
P5	P5	1547.2	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland	Occurred broadly over the stony plains of the Billiards area along either side of Weeli Wolli Creek, and also in small areas around the JSW and YJC mines.	18 quadrats: BIL18, BIL33^, HDA12 (cleared), YAQ23^, YBI06^, YBI07^, YBI09^, YBI14, YBI16, YBI21, YBI22, YBI27^, YBI28, YBI29, YBI34S^, YEX15, YEX33 (cleared), WW30. 4 relevés: YBI-RBMA, YBIRBMB, YBI-RROA, YEX-N.	Excellent to Good.
P6	P6	144.1	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland	Occurred only in the Billiards area, mainly in narrow stands adjacent to the floodplains along Weeli Wolli Creek; several small patches of this vegetation also occurred on plains and hill crests.	8 quadrats: BIL32^, HDA08^, HDA13, YBI12^, YBI13, YBI15^, YEX09 (cleared), YEX12 (cleared). 2 relevés: BIL-RSPA, YBI-RBMI.	Good.

Old code	New Veg code	Area (ha)	Main Vegetation Description	Distribution	Flora Sampling Sites	Vegetation Condition
P7	P7	35.6	*Eremophila fraseri* subsp. *fraseri* open shrubland over mixed very open grassland	Occurred on three small areas of plain with a calcrete substrate near the proposed PBS development.	2 quadrats: BIL25^, BIL48. 1 relevé: YBI-RBMG.	Good.
P8	P8	32.4	*Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland	Gently sloping pediment slopes and colluvial plains at the base of a range of low hills north of the proposed PBS development.	2 quadrats: BIL22^, BIL42^.	Excellent.
P9	P9	380.1	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland	Occurred broadly over the plains on the western side of Weeli Wolli Creek, north of Marillana Creek.	6 quadrats: BIL12^, BIL13, BIL41^, BIL45^, YEX31 (cleared), YEX33 (cleared).	Very Good.
Disturbed	Disturbed		N/A	Clustered around infrastructure and mining, scattered elsewhere	N/A	Heavily Disturbed

Table 4-2: representative photographs of the key riparian vegetation units present in the study area

New Veg code	Vegetation Type and Description	Representative Photos
C1AA	**Larger representations of Historical *Melaleuca argentea* and *Eucalyptus camaldulensis* Woodland** *Eucalyptus camaldulensis subsp. refulgens* and *Melaleuca argentea* woodland, over *Eucalyptus victrix*, *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over tall open shrubland of *Melaleuca glomerata* and *Acacia ampliceps*.	

New Veg code	Vegetation Type and Description	Representative Photos
C1A - Marillana	**Small patches of *Melaleuca argentea* and *Eucalyptus camaldulensis* Woodland** *Eucalyptus camaldulensis* subsp. refulgens, *E. victrix* and *Melaleuca argentea* woodland over *Eucalyptus camaldulensis, Melaleuca argentea* and *Acacia coriacea subsp. pendens* low open woodland.	

New Veg code	Vegetation Type and Description	Representative Photos
C1B - Marillana	**Marillana – *E. camaldulensis* and *E. victrix* woodland over *M. argentea* Semi Mature low open woodland** *Eucalyptus camaldulensis* subsp. refulgens, and *E. victrix* woodland, over *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over tall open shrubland of *Melaleuca argentea*, *M. glomerata* and *Acacia ampliceps*.	

New Veg code	Vegetation Type and Description	Representative Photos
C1B – Weeli Wolli	**Weeli Wolli - *E. camaldulensis* and *E. victrix* woodland over *M. argentea* Semi Mature low open woodland** *Eucalyptus camaldulensis* subsp. refulgens, and *E. victrix* woodland, over *Melaleuca argentea*, and *Acacia coriacea subsp. pendens* low open woodland, over tall open shrubland of *Melaleuca argentea*, *M. glomerata* and *Acacia coriacea subsp. pendens*.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1/C2A - Marillana	**Marillana - *E. camaldulensis* and *E. victrix* open woodland over *M. argentea* and *E. camaldulensis* Young to Semi Mature low open woodland** Open woodland of *Eucalyptus camaldulensis subsp. refulgens* and *E. victrix*, over low woodland of *E. camaldulensis* subsp. refulgens, *Melaleuca argentea* saplings, over scattered tall-shrubs of *Melaleuca argentea*, *M. glomerata*, and *Atalaya hemiglauca*.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1/C2A - Weeli Wolli	**Weeli Wolli – *E. camaldulensis* and *M. argentea* Young to Semi Mature low open woodland** Low woodland of *Eucalyptus camaldulensis subsp. refulgens* and *Melaleuca argentea* (and to a lesser extent *E. victrix*) saplings to young trees (with scattered trees), over scattered tall-shrubs (to tall open shrubland) of *Melaleuca glomerata*, *Atalaya hemiglauca*, *Acacia coriacea subsp. pendens*.	

New Veg code	Vegetation Type and Description	Representative Photos
C2/C1 - Marillana	**Marillana - *M. argentea* and *E. camaldulensis* Young low open forest,** ***(Generally represented by thin Strips of vegetation lining the low flow channel)*** Scattered *Eucalyptus camaldulensis* trees, over low open forest of *Eucalyptus camaldulensis* and *Melaleuca argentea* saplings/young-trees, over tall open shrubland of *Acacia ampliceps*, *Melaleuca argentea*, *Melaleuca glomerata*, and *Atalaya hemiglauca* generally accompanied by fringing strips of dense Typha domingensis.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2/C1 - Weeli Wolli	**Weeli Wolli - *M. argentea* and *E. camaldulensis* Young low open forest,** ***(Generally represented by thin Strips of vegetation lining the low flow channel)*** Low woodland of *Eucalyptus camaldulensis subsp. refulgens* and *Melaleuca argentea* saplings/young-trees, over scattered tall-shrubs of *Melaleuca glomerata*, *Atalaya hemiglauca*, and Stylobasium spathulatum.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2A	***E. camaldulensis* and *E. victrix* woodland bank/bed community** *Eucalyptus camaldulensis* subsp. refulgens, *E. victrix* open woodland, over *Acacia coriacea subsp. pendens*, *Atalaya hemiglauca* and *Acacia citrinoviridis* low open woodland, over *Melaleuca glomerata* and *Acacia citrinoviridis* tall open shrubland, over low shrubland typically dominated by *Corchorus crozophorifolius* and Tephrosia sp. Fortescue creeks.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2Asb	***E. camaldulensis* and *E. victrix* woodland Scoured bed community** *Eucalyptus camaldulensis* subsp. refulgens, and *E. victrix* open woodland over scattered tall shrubs of *Melaleuca glomerata* on scoured beds of the main and large secondary channels of Marillana Creek.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2B	***E. camaldulensis* and *E. victrix* Floodplain community** *Eucalyptus victrix* and *E. camaldulensis* subsp. refulgens low open woodland/open woodland, over *Acacia citrinoviridis*, *A. pruinocarpa*, and *Atalaya hemiglauca* tall shrubland over **Cenchrus ciliaris* tussock grassland.	

New Veg code	Vegetation Type and Description	Representative Photos
C2C	*Eucalyptus victrix* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland.	
C3A	***E. victrix* Bank/bed community** *Eucalyptus victrix* scattered trees over *Acacia citrinoviridis*, A. coriacea subsp. pendens, *Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C3Asb	***E. victrix* scoured beds community** *Eucalyptus victrix* scattered trees to low open woodland over scattered tall shrubs of *Melaleuca glomerata* and *E. victrix*, on scoured beds of the Main and large secondary channels of Weeli Wolli creek.	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C4	*Eucalyptus victrix low open woodland over Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca low woodland over *Cenchrus ciliaris tussock grassland*	

New Veg code	Vegetation Type and Description	Representative Photos
C5	*Eucalyptus victrix scattered low trees over Acacia bivenosa, A. ancistrocarpa, A. maitlandii tall open shrubland over Eriachne tenuiculmis, Themeda triandra very open tussock grassland*	

Table 4-3: Summary of the *Melaleuca argentea* size class, size/age structure, and vegetation structure data attributed to the various communities which possessed or potentially possessed M. argentea in the study area

New Veg code (M=Marillana, W=Weeli Wolli)	Condensed Vegetation Description	Generalised *M. argentea* Age Class/Range	Notes on *Melaleuca argentea* presence	Average stem sizes - *Melaleuca argentea*
C1AA	*Eucalyptus camaldulensis subsp. refulgens, E. victrix and Melaleuca argentea woodland, over Eucalyptus victrix, Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca glomerata and Acacia ampliceps.*	**M-SM(+)** Generally M (to SM+) aged trees present.	Strong evidence (large trunks in situ) indicates the historical presence of Regular Mature to at least Semi-Mature/Mature individuals in the creek bed	Average Stem diameters of 40-100cm for the older age classes present, while young individuals were not present in normal numbers (some areas possessed young, but overall they were generally absent)
C1A	*Eucalyptus camaldulensis subsp. refulgens, E. victrix and Melaleuca argentea woodland over Eucalyptus camaldulensis Melaleuca argentea and Acacia coriacea subsp. pendens low open woodland.*	**M-SM** Generally M to SM classed trees present, but including the full range of age classes.	Presence of regular/scattered mature to at least Semi-Mature/Mature individuals in a section of the creek bed vegetation.	Average Stem diameters of 40-90cm for the older age classes present, while young individuals are still present and common ranging from 20-40cm
C1B - M	*Eucalyptus camaldulensis subsp. refulgens, and E. victrix woodland, over Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca argentea, M. glomerata and Acacia ampliceps.*	**Y-SM Plus*** Y-SM to Y-SM(+) classed; often some individual “Mature” trees present (*), but generally not ‘M’ class (mature) and if ‘M’ class then only 1 to 2 max.	Presence of either: Populations generally classed in the Y-SM and Y-SM(+) age ranges as well as Multiple (3 or more recorded) individual "Mature" trees of SM **to** SM(+) age class (and rarely above – 1 to 2 individuals maximum) OR; at least some populations classified as SM(+) as well as the presence of at last one "Mature" tree (SM to SM(+)) and a spatial correlation or proximity to a patch(s) of Dense historical vegetation (desktop mapping from 1994 aerial photo)	Average Stem diameters of the older age classes present ranging from 25-40cm (young individuals in the 10-25cm range are still present in significant numbers) with some older outlier individuals present in the range of 40-50cm

New Veg code (M=Marillana, W=Weeli Wolli)	Condensed Vegetation Description	Generalised *M. argentea* Age Class/Range	Notes on *Melaleuca argentea* presence	Average stem sizes - *Melaleuca argentea*
C1B - W	*Eucalyptus camaldulensis subsp. refulgens, and E. victrix woodland, over Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca argentea, M. glomerata and Acacia coriacea subsp. pendens.*	**Y-SM plus*** Y-SM to Y-SM(+) classed; often some individual "Mature" trees present (*), but generally not 'M' class and if 'M' class then only 1 to 2 max.	Presence of either: Populations generally classed in the Y-SM age range often including Multiple (2 or more recorded) individual "Mature" trees of SM **to** SM(+) age class OR; at least some populations classified as Y-SM combined with populations no younger than Y-SM(-) as well as the presence of at least one "Mature" tree (SM to SM(+)) and a spatial correlation with a patch(s) of Dense historical vegetation (desktop mapping from 1994 aerial photo), or on a typical creek profile which tends to enhance water availability (i.e. bend at the end of a straight in a confined creek profile).	Average Stem diameters of the older age classes present ranging from 15-35cm (young individuals in the 5-15cm range are still present in significant numbers) with multiple older outlier individuals present in the range of 30-45cm (other age class structures also apply - see adjacent cell)
C1/C2-A - M	*Open woodland of Eucalyptus camaldulensis subsp. refulgens and E. victrix, over low woodland of E. camaldulensis subsp. refulgens, Melaleuca argentea saplings, over scattered tall-shrubs of Melaleuca argentea, M. glomerata, Atalaya hemiglauca.*	**Y-SM(-)*** Generally Y-SM(-) classed; occasionally up to Y-SM(*), with occasional 'SM' individual "Mature" trees present.	Presence of : Populations generally classed in the Y-SM(-) age range (occasionally with infrequent Y-SM age class recordings) as well as Multiple (2 or more recorded) individual "Mature" trees of SM **to** SM(+) age class (and above) OR; at least some populations classified as SM as well as the presence of at last one "Mature" tree (SM to SM(+)) and a spatial correlation or proximity to a patch(s) of Dense historical vegetation (desktop mapping from 1994 aerial photo)	Average Stem diameters of the older age classes present ranging from 10-25cm, while young individuals in the <10cm range are present and generally dominant. Generally requires the presence of multiple recorded "Mature" tree individuals present in the range of 30-45cm (other age class structures also apply - see adjacent cell)
C1/C2-A - W	*Low woodland of Eucalyptus camaldulensis subsp. refulgens and Melaleuca argentea (and to a lesser extent E. victrix) saplings to young trees (With scattered trees), over scattered tall-shrubs (to tall open shrubland) of Melaleuca glomerata, Atalaya hemiglauca, Acacia coriacea subsp. pendens.*	**Y-SM(-)*** Y-SM(-) classed, occasionally up to Y-SM (*), with occasional 'SM' "Mature" trees present	Presence of : Creek sections possessing populations with a relatively variable age class and generally classed in the young and Y-SM(-) age range and often including thin strips of vegetation fringing the Low flow channel and dominated by young individuals. These areas are also often correlated with typical creek profiles which tend to enhance water availability (i.e. bend at the end of a straight in a confined creek profile) but with reduced numbers of individuals representative of the upper end of the Y-SM(-) age class .	Average Stem diameters of the older age classes present ranging from 10-20cm, while young individuals in the <10cm range are present and generally dominant. Generally requires the presence of multiple recorded "Mature" tree individuals present in the range of 30-45cm (other age class structures also apply - see adjacent cell)

New Veg code (M=Marillana, W=Weeli Wolli)	Condensed Vegetation Description	Generalised *M. argentea* Age Class/Range	Notes on *Melaleuca argentea* presence	Average stem sizes - *Melaleuca argentea*
C2/C1-M	***Strips of vegetation lining the low flow channel of:*** *Scattered Eucalyptus camaldulensis trees, over low open forest of Eucalyptus camaldulensis and Melaleuca argentea saplings/young-trees, over tall open shrubland of Acacia ampliceps, Melaleuca argentea, Melaleuca glomerata, and Atalaya hemiglauca generally accompanied by fringing strips of dense Typha domingensis.*	**Y*** YOUNG classed individuals present; with some slightly older individuals occasionally present (*)	Presence of: Creek sections possessing populations with a somewhat variable age class and generally classed in the young age range but including strips with ages generally restricted to a age classes no higher than Y-SM(-), and often including extensive linear strips of vegetation fringing the Low flow channel and dominated by dense recruitment consisting mainly of young individuals of Both *Melaleuca argentea* and *Eucalyptus camaldulensis*.	Average stem diameters of the main population considered young, and ranging from 5-10cm, with scattered individuals with stem diameters of 10-15cm present. Individuals recorded with a stem diameter above 20cm are generally absent.
C2/C1-W	***Strips of vegetation generally lining the low flow channel of:*** *Low woodland of Eucalyptus camaldulensis subsp. refulgens and Melaleuca argentea saplings/young-trees, over scattered tall-shrubs of Melaleuca glomerata, Atalaya hemiglauca, and Stylobasium spathulatum.*	**Y*** YOUNG classed individuals present; with some slightly older individuals occasionally present (*)	Presence of : Creek sections possessing populations with a relatively consistent age class and generally classed in the young age range. In some areas small outcrops of generally young populations with low numbers of sm(-) individuals present were attributed to this vegetation unit. This unit is often represented by very thin strips of Melaleuca co-dominated vegetation fringing the Low flow channel and dominated by young individuals. These areas are also often correlated with the fringes of longer creek pools and sections of fast flowing water.	Average stem diameters of the main population considered young, and ranging from 5-10cm, with scattered individuals with stem diameters of 10-15cm present. Individuals recorded with a stem diameter above 20cm are generally absent.
C2A	*Eucalyptus camaldulensis subsp. refulgens, E. victrix open woodland, over Acacia coriacea subsp. pendens, Atalaya hemiglauca and Acacia citrinoviridis low open woodland, over Melaleuca glomerata and Acacia citrinoviridis tall open shrubland, over low shrubland typically dominated by Corchorus crozophorifolius and Tephrosia sp.* Fortescue creeks.	No Data beyond their general absence from the community (but may be present in some areas as young individuals)	Only Present as an associated species	N/A

New Veg code (M=Marillana, W=Weeli Wolli)	Condensed Vegetation Description	Generalised *M. argentea* Age Class/Range	Notes on *Melaleuca argentea* presence	Average stem sizes - *Melaleuca argentea*
C2Asb	*Eucalyptus camaldulensis* subsp. *refulgens, and E. victrix open woodland* over scattered tall shrubs of *Melaleuca glomerata on scoured beds of the main and large secondary channels of Marillana Creek.*	No Data beyond their general absence from the community (but may be present in some areas as young individuals)	Only Present as an associated species	N/A
C2B	*Eucalyptus victrix* and *E. camaldulensis* subsp. refulgens low open woodland/open woodland, over *Acacia citrinoviridis*, *A. pruinocarpa*, and *Atalaya hemiglauca* tall shrubland over **Cenchrus ciliaris* tussock grassland.	No Data beyond their general absence from the community	Not Present (very low potential for presence)	N/A
C2C	*Eucalyptus victrix* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland.	No Data beyond their general absence from the community	Not typically present, but present as an associated in some rare situations.	N/A
C3A	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis*, A. coriacea subsp. pendens, *Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	No Data beyond their general absence from the community	Not typically present, but present as an associated in some situations.	N/A
C3Asb	*Eucalyptus victrix scattered trees to low open woodland* over scattered tall shrubs of *Melaleuca glomerata and E. victrix, on scoured beds of the Main and large secondary channels of Weeli Wolli creek.*	No Data beyond their general absence from the community	Not typically present, but present as an associated in some situations.	N/A

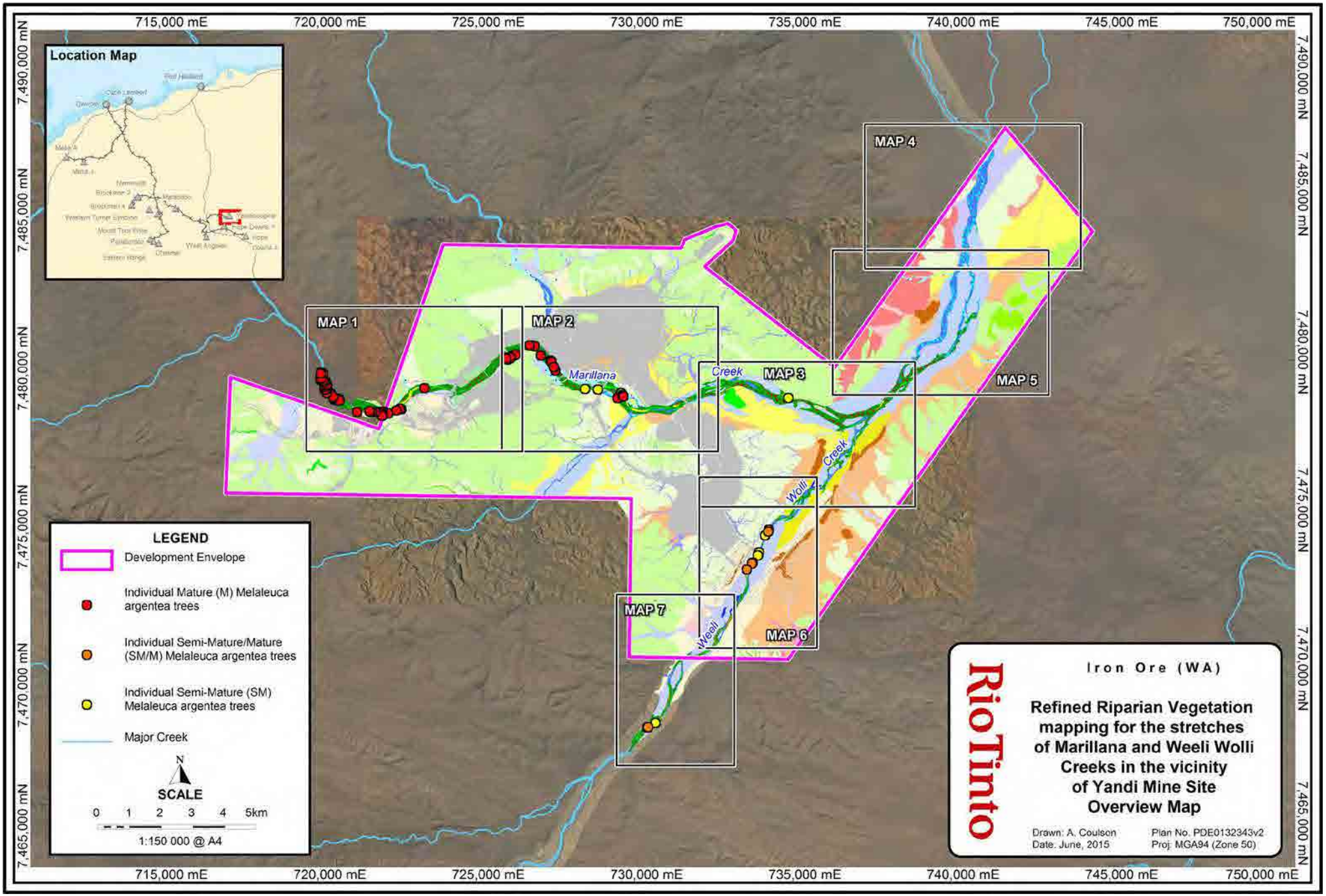


Figure 4-1: **Overview map showing the layout of the 7 maps showing the results of the refined riparian vegetation mapping exercise.**

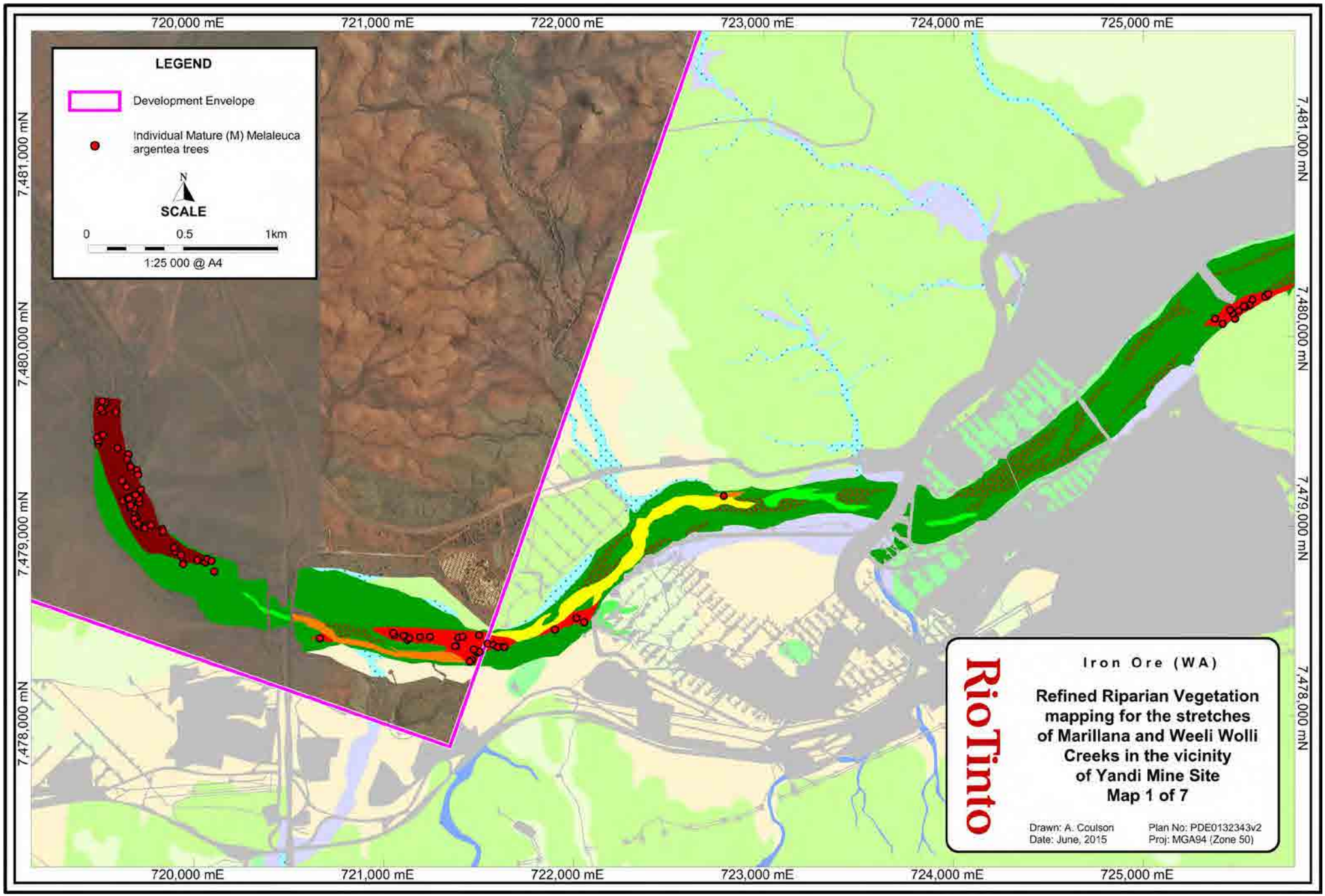


Figure 4-2: **Results of the refined riparian vegetation mapping Map 1 of 7**

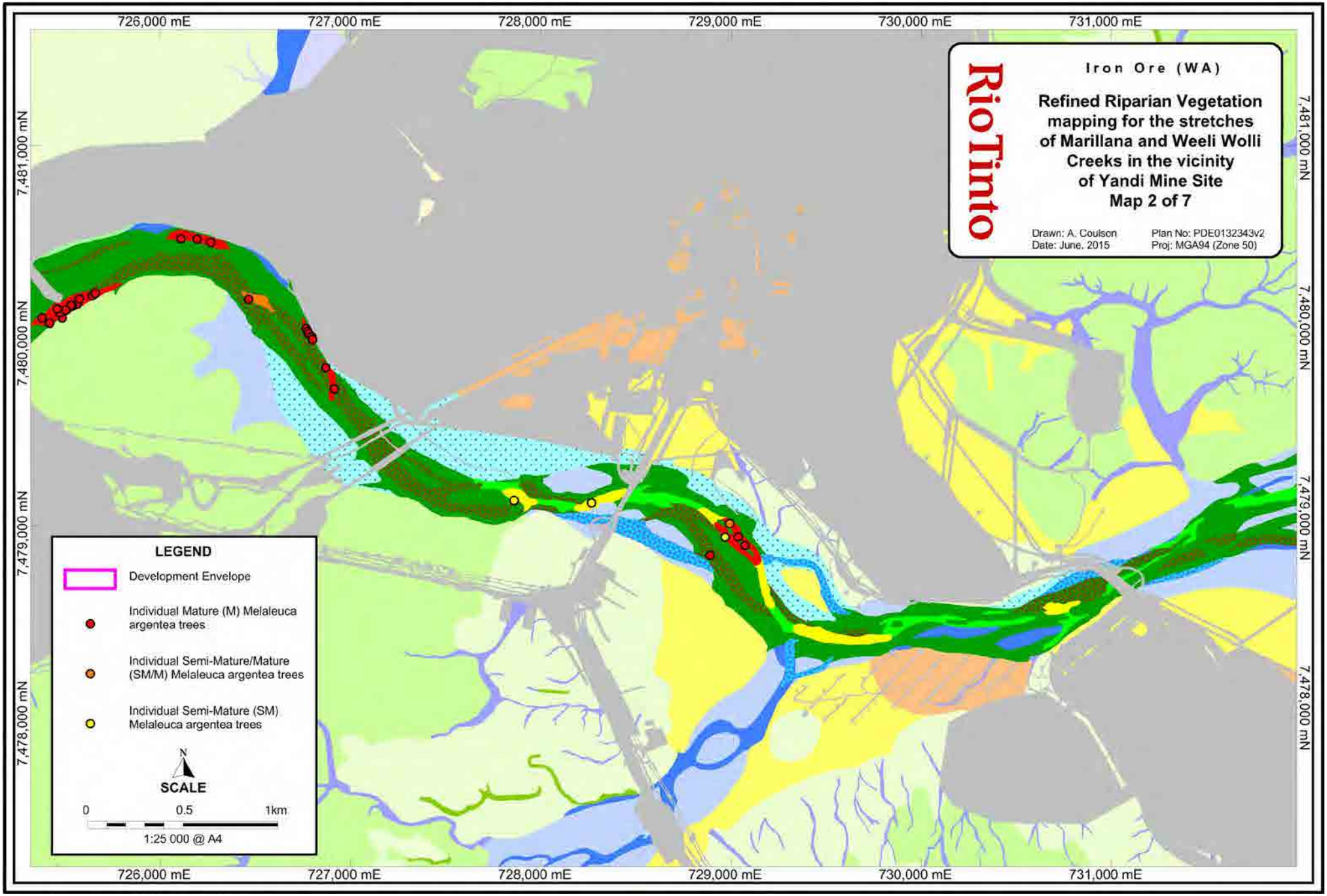


Figure 4-3: Results of the refined riparian vegetation mapping Map 2 of 7

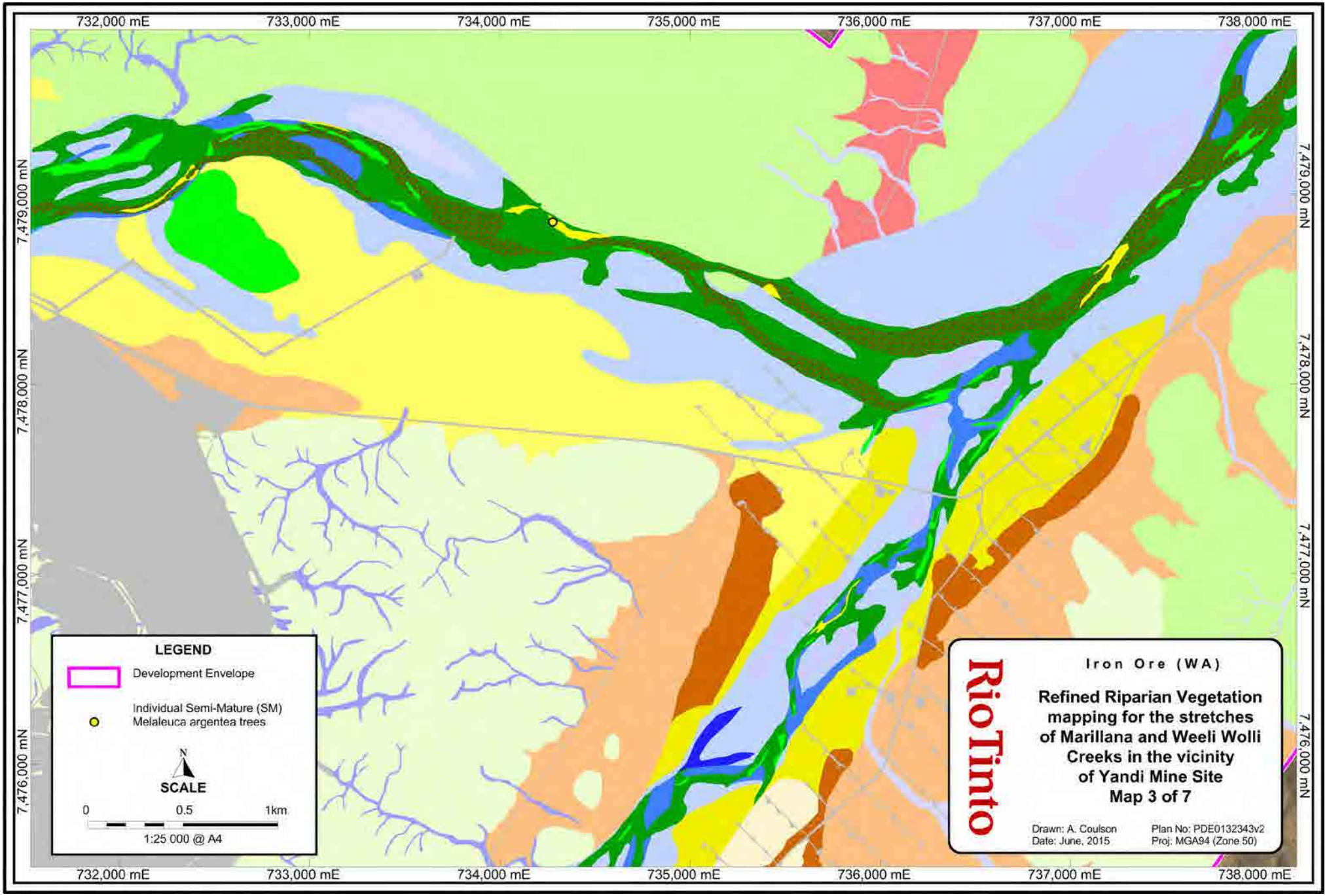


Figure 4-4: Results of the refined riparian vegetation mapping Map 3 of 7

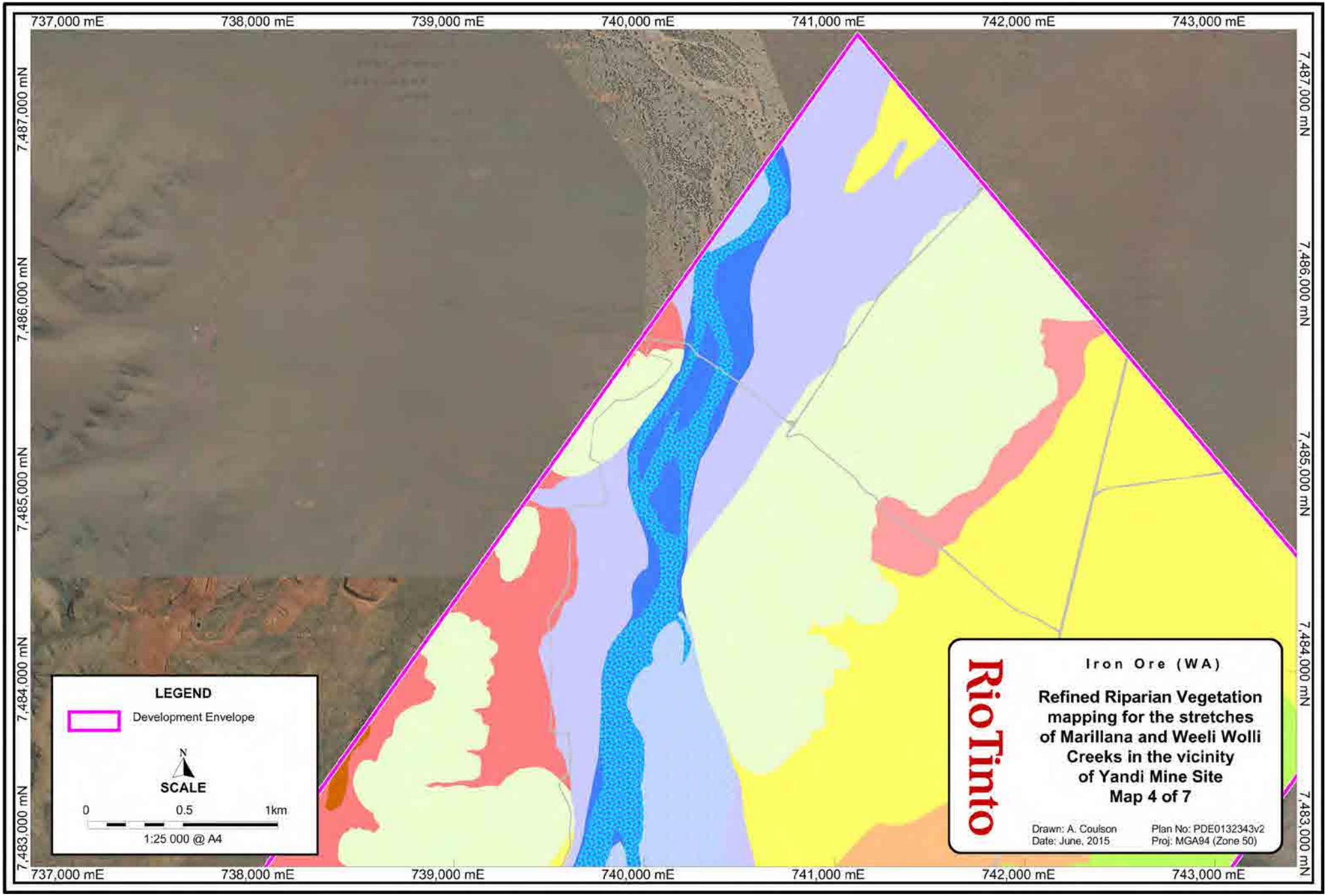


Figure 4-5: Results of the refined riparian vegetation mapping Map 4 of 7

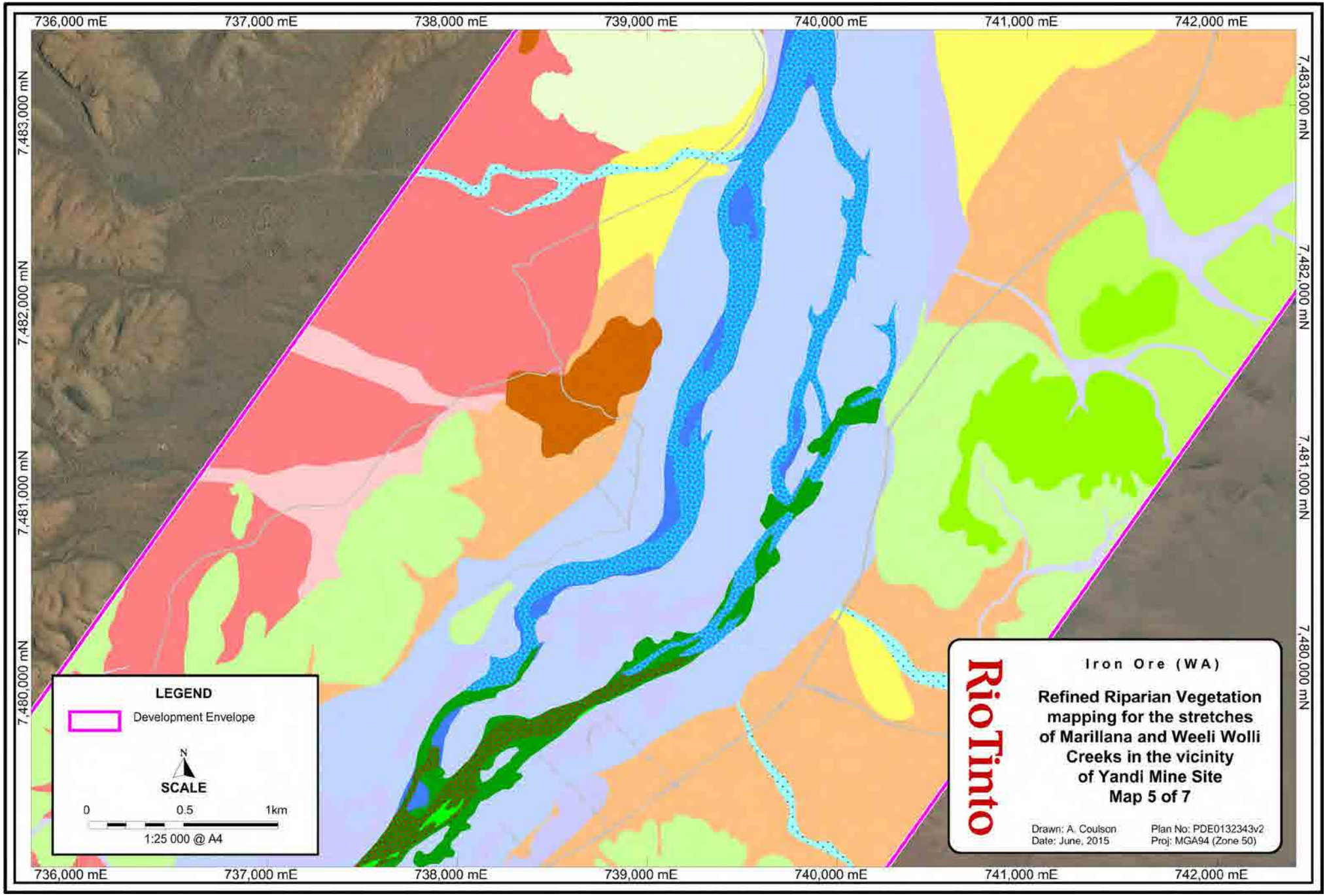


Figure 4-6: Results of the refined riparian vegetation mapping Map 5 of 7

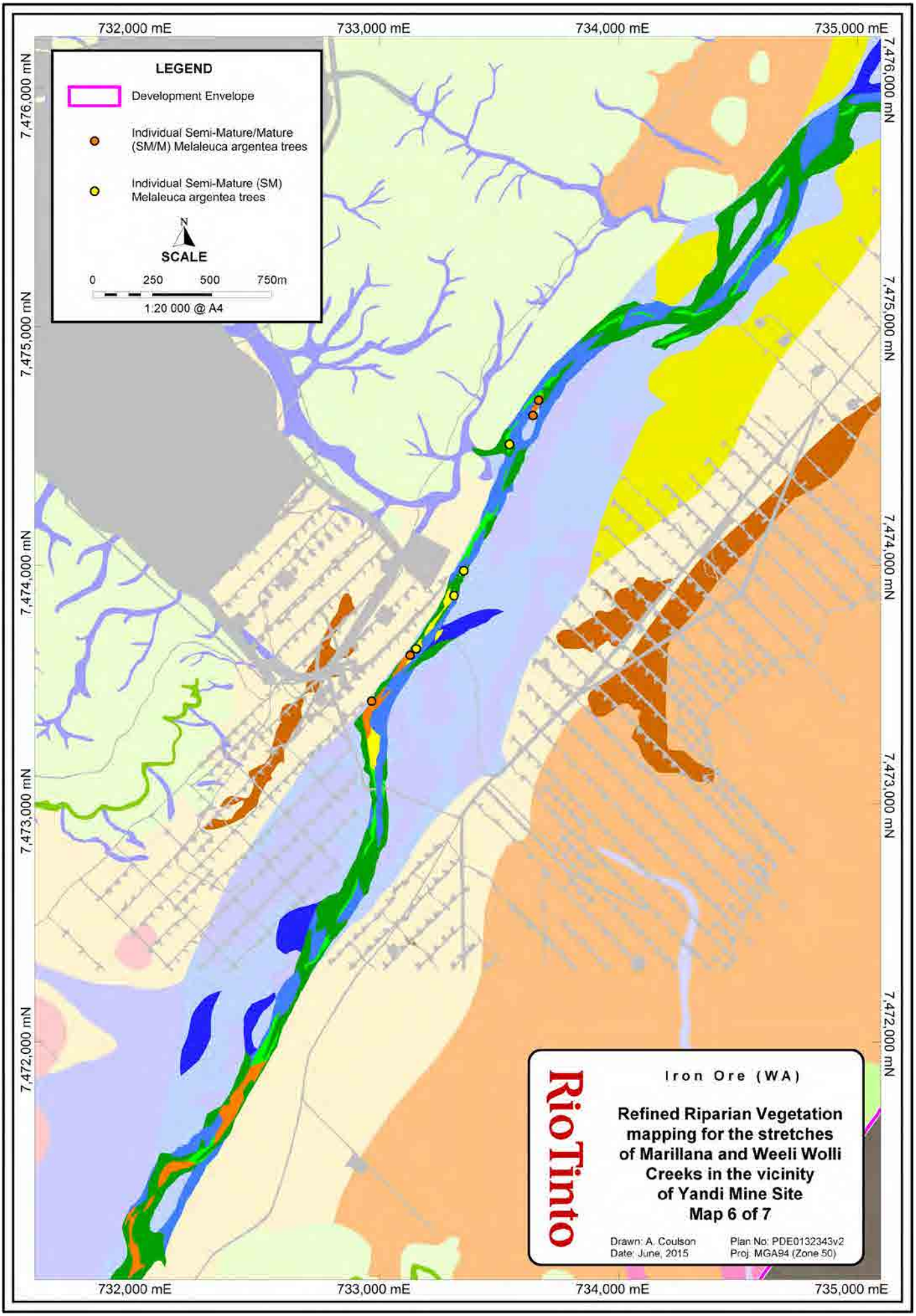


Figure 4-7: **Results of the refined riparian vegetation mapping Map 6 of 7**

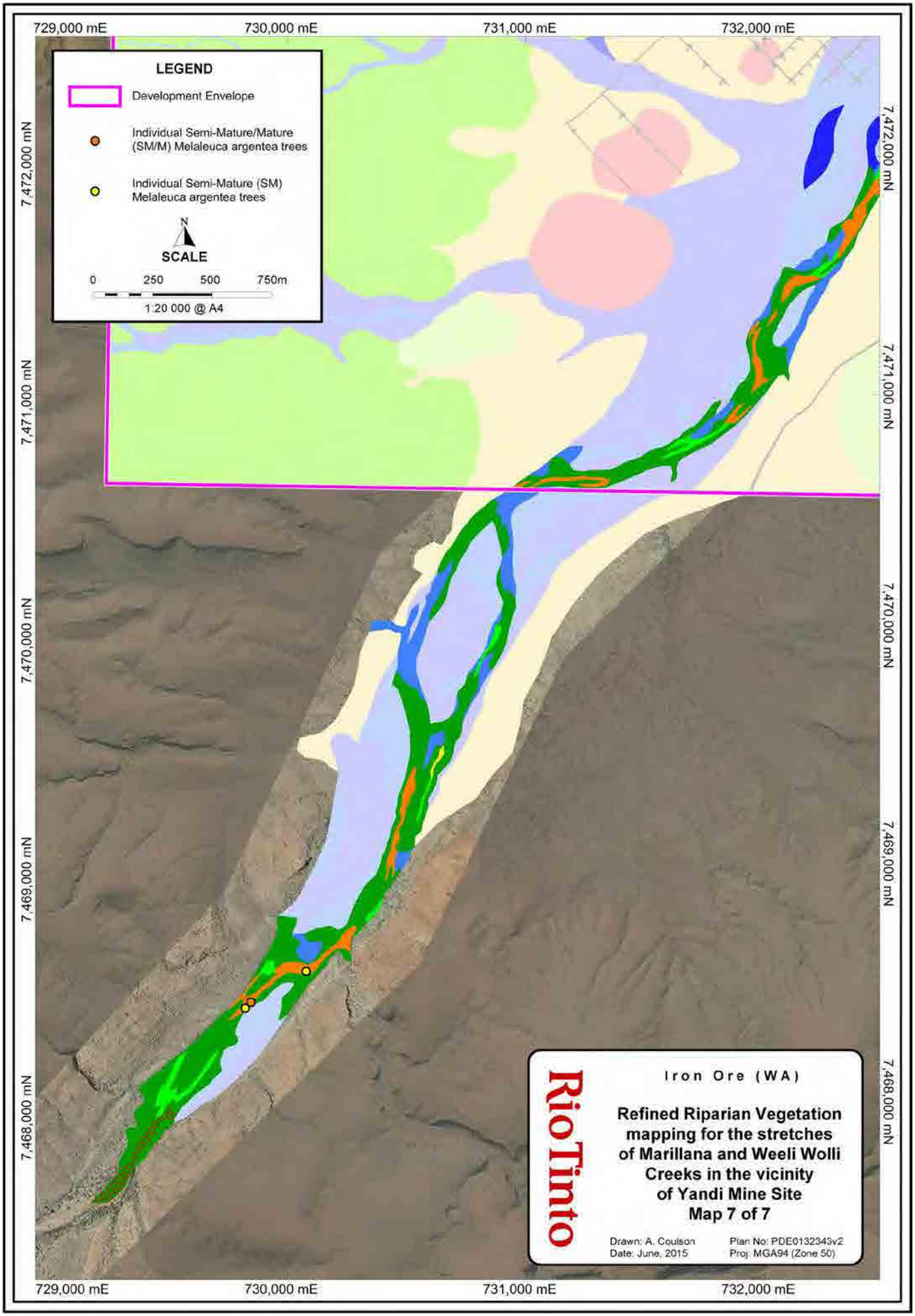


Figure 4-8: Results of the refined riparian vegetation mapping Map 7 of 7

VEGETATION LEGEND

Rio Tinto

Part 2 - Riparian Vegetation of Marillana and Weeli Wolli Creeks

Mapping Refinement and Assessment of Values and Significance

4.2 HISTORICAL SURVEY AND QUADRAT BASED EVIDENCE FOR THE DISTRIBUTION OF MELALEUCA ARGENTEA IN THE PRE AND POST DISCHARGE ENVIRONMENT

For the purpose of assessing the significance of riparian vegetation within the study area, it was determined that part of this process involved building a picture of the pre-discharge riparian environment. This involved a comparison of the presence of obligate phreatophytes and facultative phreatophytes as well as OPV within data and outputs from recent survey work conducted in the study area by Biota (multiple surveys summarised in; Biota 2014a), and historical surveys conducted in the study area by Mattiske (1995a, 199b, 1995c) pre-discharge. Figures 3-1 to 3-5 presented earlier in the document display the location of the most relevant riparian quadrats sampled as part of these flora and vegetation surveys conducted in the study area. Figure 2-2 presents a map illustrating the boundaries of the Key pre and post-discharge flora and vegetation surveys conducted within the vicinity of the study area. This map helps to interpret the spatial location of data patterns presented in this section. The quadrat locations depicted in Figures 3-6 are represented by two separate sets of symbols for the surveys conducted by Mattiske (1995a, 1995b, and 1995c) in the pre-discharge environment, and Biota (2003-2014) in the post-discharge environment. Labelling within each set of symbols indicates the presence/absence of *Melaleuca argentea* and *Eucalyptus camaldulensis* at the time of survey. More specifically they combine to depict which quadrats:

- did not possess *Melaleuca argentea*;
- possessed *M. argentea* only as an associated species within the sampled area;
- were described to possess *M. argentea* as a co-dominant species within the recorded vegetation description; and
- were either described to possess *Eucalyptus camaldulensis* as a co-dominant species within the recorded vegetation description, or only as an associated species within the sampled area.

Given that a number of the sampled quadrats presented are located outside of the current study area, and that water availability in these areas may be different (especially upstream of the study area within Weeli Wolli Creek) to that discussed in this report, their location within or outside of the study area has been differentiated so as to avoid confusion about the trends displayed by the data. Of these quadrats, Mattiske sampled 11 within and 11 outside of the study area (1995a, 1995b, 1995c). Biota (2004-2014 summarised in; Biota 2014a) sampled 15 quadrats within and 2 outside of the study area over various survey periods. Of the Mattiske quadrats sampled pre-discharge 0/11 of the quadrats within the study area and 3/11 outside of the study area described *M. argentea* as a co-dominant species within the sampled vegetation. Furthermore, of the Mattiske quadrats; 0/11 within the study area, and 2/11 outside the study area, only recorded *M. argentea* as an associated species in the sampled vegetation. *Eucalyptus camaldulensis* was recorded to be either a co-dominant or an associated species within a total of 7/11 quadrats within and 7/11 quadrats outside of the study area.

The broad trends shown by the Mattiske data indicates that within the pre-discharge vegetation of the study area, *Melaleuca argentea* appears highly restricted in its distribution such that sampled quadrats failed to detect it. Also, as expected; quadrats further south, and out of the study area on Weeli Wolli Creek (closer to Weeli Wolli Springs and sampled by Mattiske pre-discharge; Mattiske 1995c), were the only pre-discharge sampled quadrats to record *M. argentea* as a co-dominant

species. Furthermore, as expected, the Mattiske quadrats indicated that *Eucalyptus camaldulensis* was relatively widespread in its distribution throughout the study area.

In the post-discharge environment, some significant differences in the quadrat data, when compared to the pre-discharge data, were apparent (note that there are also some survey area spatial differences relating to this comparison). Of Biotas quadrats sampled pre-discharge (Biota 2014a), 5/15 of the quadrats within the study area and 0/2 outside of the study area described *M. argentea* as a co-dominant species within the sampled vegetation. Furthermore, of the Biota quadrats; 5/15 within the study area, and 0/2 outside the study area, only recorded *M. argentea* as an associated species in the sampled vegetation. *Eucalyptus camaldulensis* was recorded to be either a co-dominant or an associated species within a total of 9/15 quadrats within and 0/2 quadrats outside of the study area. The broad trends shown by the Biota quadrat data indicates that within the post-discharge vegetation of the study area, *Melaleuca argentea* appears to be significantly less restricted in its distribution, when compared to pre-discharge quadrats, such that sampled quadrats recorded this species 2/3 of the time (only 1/3 of the quadrats recording this species as a co-dominant component of the vegetation). As expected *E. camaldulensis* was relatively widespread in its distribution within the study area. While the proportion of sampling sites possessing *E. camaldulensis* are approximately the same in the pre and post-discharge study area, it's expected that discharge related vegetation augmentation is likely to have increased the distribution of sub-mature to mature populations of this species.

Some of the patterns displayed by this quadrat data, and relating to the distribution of OPV in the pre and post-discharge environment, are also be demonstrated by the conclusions, observations and vegetation mapping produced as part of this previous survey work. Vegetation mapping conducted by Mattiske (1995) for three separate Flora and Vegetation surveys within the Yandicoogina Project area, covered a significant proportion of the riparian environments of the current study area (Yandi Junction Central (1995a), Northern transport corridor (1995b) and Southern Transport corridor (1995c)). Within the current study area, the relevant vegetation mapping created as part of these surveys, did not identify a riparian vegetation unit which contained *Melaleuca argentea* as a co-dominant species. Instead Mattiske (1995) identified that this species (previously identified as *Melaleuca leucadendra*) was only present in small patches within certain zones of the large creek systems in the area. The relevant vegetation unit which was instead mapped in these areas was the "2d" coded community of *Eucalyptus camaldulensis* woodland. This is the same community which was missing from the Biota vegetation mapping in similar areas. The following plate is an excerpt from the Junction Central Report (Mattiske, 1995a), and mentions the very restricted distribution of *Melaleuca leucadendra* (Now *M. argentea*) within the relevant stretch of Marillana creek.

Community 2d (Recording Sites - OS030, OS033, OS085, OS086, OS092, TS103)

Woodland of *Eucalyptus camaldulensis*, lying in the major flow-lines which occur within the Yandicoogina Junction area. The occasional *Melaleuca leucadendra* occurs in minor scattered pockets within this community near the junction of the Marillana Creek with the side main creek (west of the exploration camp, 748300mN - 726000mE) and near the crossing on the eastern side of the survey area (7478800mN - 731900mE).

The understorey species are very diverse, with species ranging from grasses through to dense shrubs. Associated species included *Eucalyptus victrix, Cyperus* spp., *Cleome viscosa, Acacia citrinoviridis, Acacia coriacea, Atalaya hemiglauca, Melaleuca glomerata, Indigofera monophylla, Corchorus walcottii, Ptilotus obovatus, Cymbopogon ambiguus* and *Triodia pungens*. Opportunistic Site OS030 occurs slightly west of the boundary on the vegetation map on Figure 3.

This community is relatively habitat restricted to major creek beds which flood in cyclonic events, but it does occur regularly throughout the Pilbara Region.

Plate 5: Excerpt describing the 2d vegetation unit from the vegetation section of the report: 'Flora and Vegetation: Yandicoogina Junction Area' (Mattiske, 1995a)

Community 2d (Recording Sites - TS139, OS141, OS145, OS146, OS160, OS175)

Woodland of *Eucalyptus camaldulensis*, lying in the major flow-lines which occur within the Southern Transport Corridor. Pockets of *Melaleuca leucadendra, Melaleuca argentea* spp. *argentea* and *Melaleuca glomerata* occurs in minor scattered pockets within this community.

The understorey species are very diverse, with species ranging from grasses through to dense shrubs. Associated species included *Eucalyptus victrix, Cyperus* spp., *Cleome viscosa, Acacia citrinoviridis, Acacia coriacea, Atalaya hemiglauca, Melaleuca glomerata, Indigofera monophylla, Corchorus walcottii, Ptilotus obovatus, Petalostylis labicheoides, Abutilon fraseri, Dicladanthera forrestii, Eulalia aurea, Cymbopogon ambiguus* and *Triodia pungens*.

This plant community is relatively habitat restricted to major creek beds which flood in cyclonic events, but it does occur regularly throughout the Pilbara Region.

Plate 6: Excerpt describing the 2d vegetation unit from the vegetation section of the report: 'Flora and Vegetation: Southern Transport corridor, Yandicoogina Junction Project' (Mattiske, 1995c)

It should be noted that the Southern Transport corridor vegetation mapping does recognise a *Melaleuca leucadendra* (*M. argentea*) woodland community (unit 2f), but the last occurrence of this community is mapped as ending at the upstream boundary of the current study area. The following excerpt from this report describes the 2f community.

Community 2f (Recording Sites - TS143, OS148, OS150, OS154, OS167)

Woodland of *Melaleuca leucadendra* occurs on Weeli Wolli Creek; including very large trees and pockets of denser cover (which at times approximates a forest in structure). This denser stand is very atypical and is not replicated within the Pilbara Region and therefore is significant both locally and regionally.

Associated species include *Melaleuca glomerata, Melaleuca argentea* ssp. *argentea, Acacia coriacea, Acacia citrinoviridis, Cleome viscosa, Eucalyptus camaldulensis, Eucalyptus victrix, Stemodia grossa, Tephrosia* spp., *Flaveria australasica, Gossypium robinsonii, Sesbania cannabina, Cyperus* spp., *Stylobasium spathulatum, Rhynchosia* cf. *minima* and *Senna* spp.

These woodlands occur as pockets along Weeli Wolli Creek, however the main occurrence near the main crossing of Weeli Wolli Creek is distinctive due to its structural features which are not replicated in other areas of the Pilbara.

Plate 7: Excerpt describing the 2f vegetation unit from the vegetation section of the report: 'Flora and Vegetation: Southern Transport corridor, Yandicoogina Junction Project' (Mattiske, 1995c)

Despite the conclusions which the Mattiske pre-discharge surveys seem to present, it should be noted, these surveys only cover a 4km section of Weeli Wolli Creek at the upstream end of the study area (The Southern Transport Corridor survey 1995c). As a result, despite it being likely, there is no guarantee that the vegetation patterns mapped in this section continued north throughout Weeli Wolli in the pre-discharge environment.

The 1981 survey by integrated Environmental services titled "Ecological Appraisal of the Yandicoogina Project Area (1981)", also covered a significant proportion (the greatest; at approximately 90%) of riparian communities within the current study area. After describing the vegetation mapped within the study area and determining that no *M. argentea* dominated communities were identified, the vegetation section of this report provides some concluding statements, the following one of which relates to *Melaleuca* distribution within the study area.

Some vegetation types known to be present are too limited in extent, or are not sufficiently developed, to be classified as plant communities of the area. Elements of gorge vegetation do occur in rocky microhabitats and along drainage features but these do not form the assemblages known from elsewhere in the Hamersley Ranges. The species in the area include native fig *Ficus platypoda*, ant bush *Capparis spinosa* and the iron-ore palm *Astrotricha hamptonii*. The cadjeput *Melaleuca leucodendron* forms a forest at Weeli-Wolli Springs but only scattered clumps of this tree occur along the major creeks within the study area.

Plate 8: Excerpt about vegetation scales within the Yandicoogina project area from the Vegetation section of the report: 'Ecological appraisal of the Yandicoogina Project area (Integrated Environmental Services, 1981)'

The pre and post-discharge quadrat based sampling sites, and comparisons between pre and post-discharge vegetation mapping, seem to present relatively clear patterns in the distribution of obligate phreatophytic species and associated vegetation within the study area. The pattern which

has emerged is that riparian vegetation in the study area appears to have transitioned somewhat. OPV, while still considerably restricted, is transitioning to become less restricted in its distribution within the study area. Furthermore the conclusions and observations presented in pre-discharge surveys and provided above represent additional support for these conclusions.

4.3 DETERMING THE LIKELIHOOD OF PRESENCE FOR OPV COMMUNITIES IN THE PRE-DISCHARGE RIPARIAN HABITATS OF THE STUDY AREA

4.3.1 Application of the Deductive Process

The data acquired within the field component, and which created the refined vegetation mapping; supported the production of four general "size class ranges" (i.e. Inferred age) and physical-structure units for OPV communities within the study area. The spread of the field data acquired meant that 4 levels of inferred age structure became apparent, and as a consequence of the respective position of the growth projection figures, two sat either side of the cut-off points (the "reasonable maximum trunk diameter") for growth projected under two temporal discharge regimes. Having communities representing key intermediate age/physical structures sitting either side of the cut-off figures enabled the interpretations to incorporate some conservative conclusions in relation to the pre-discharge environment. The mapped OPV community directly below the cut-off figure (The C1/C2A community) was interpreted to represent areas pre-discharge that possessed a young transient and at times potentially co-dominant *M. argentea* component which comprised a minimal structural contribution within the broader community. The mapped OPV community immediately above the cut-off figure (The C1B community), was interpreted to represent areas pre-discharge that possessed a young (to semi-mature; at best) but consistently co-dominant *M. argentea* component most likely to be a significant part of the low open woodland strata of the community. What this dissection of the community groups also enabled, was a buffer of size class range between the cut-off mark and the communities clearly interpreted to be absent (the C2/C1 community) or present (the C1A community) in the pre-discharge environment.

4.3.2 Growth Rate Projections under Two Key Discharge Regimes – Seedlings Onwards

The projection of growth rates for *Melaleuca argentea* within Pilbara perennial creek habitats is an important piece of work which feeds into one of the key aims of the study: to interpret the likely presence and distribution of OPV in the pre-discharge environment. The monitoring data used to project these growth figures utilised *M. argentea* trees from a range of sizes, and while monitoring trees scored to be in healthy condition were favoured, in general the trees used represented a spread of condition ratings from healthy to severely stressed.

From this data the graph in figure 4-9 presents the calculated trends in predicted growth rate for the respective DBH ranges of the monitoring trees used. From this graph, a relevant range of projected growth for both time scales (9 and 15 years) was chosen as the rate to be used for drawing conclusions about the pre-discharge environment. Given that the growth rates used are based on changes in 2-dimensional trunk biomass, in this study, the cut-off growth rate chosen is influenced by the fact that different aged/sized trees generally produce different growth rates. This relationship can be seen in figure 4-9, as the trending growth rates projected from monitoring trees of varying DBH indicate a positive relationship between size (inferring age) and projected growth rates, suggesting that older/larger trees generally grow faster (in a two-dimensional biomass measure). This relationship is most likely to be a result of the increased canopy and root resource

which a larger tree (when compared to a smaller/younger tree) can utilise to add biomass per unit of time. According to a study by Stephenson et al., (2014) a global analysis of 403 tropical and temperate tree species, showed that for most species mass growth rate increases continuously with tree size. Therefore, based on the projected growth rate graph, and the plateau in growth rate projections between the 7-11 cm & 11-18 cm DBH ranges it was determined that from a seedling, 9 and 15 years of cumulative growth suggest that realised DBH would be in the vicinity of 30 cm. Consequently, it was assumed that the majority of trees in that population would be able to realise a projected growth rate of no greater than that which a 30cm tree could realise. From the graph in figure 4.9, the projected growth rate for a 30 cm tree (i.e. a tree falling within the 18-45 cm DBH range) would be approximately 35 cm for 9 years and 45 cm for 15 years. Consequently, in an effort to provide a conservative size boundary (cut-off figure), it was decided to round this figure to 30 cm for the 9 year growth period (Weeli Wolli Creek Discharge scenario) and 40 cm for the 15 year period (the Marillana discharge scenario). As discussed in the methods, to allow for degrees of potential error or bias in the projection data, and therefore add an additional degree of conservancy, calculated grow projections were reduced by 20%.

Final growth prediction cut-off figures (incorporating an additional 20% reduction) for obligate phreatophytic species populations (*M. argentea*) under the two discharge timelines are:

1. Weeli Wolli Creek communities (9 years of perennial stream flow) = 24cm DBH

2. Marillana Creek communities (15 years of perennial stream flow) = 32cm DBH

For the purpose of this study these figures are proposed to represent: The average maximum DBH (an average of the upper diameter size class present in a population) within a population which can be confidently attributed to growth in the relevant time period. The monitoring tree data used and the calculations made from this data to create the above presented growth projections are presented in Appendix 2.

4.4 INTERPRETATIONS OF THE PRE-DISCHARGE PRESENCE OF MAPPED VEGETATION COMMUNITIES, AND RESULTANT CONCLUSIONS ON THE DISTRIBUTION OF OPV COMMUNITIES IN THE STUDY AREA

Based on the deductive process presented, and the growth projections and associated which supported this process, an interpretation of the likelihood of communities being present in the pre-discharge environment (in at least a functionally similar form) was conducted on all of the Riparian communities of the study area. Based on the techniques, assumptions and growth projections used, as well as the ecological limitations constraining the interpretations, it is anticipated that the process was approached in as conservative a manner as was practicable (while still being able to make relatively straightforward conclusions).

Table 4-4 below presents the resulting interpretations of the likelihood that each mapped vegetation sub-association occurred in the pre-discharge environment in its current or similar form. Brief notes about the pre-discharge form of vegetation units are also provided in this table where appropriate. It should be noted that as previously explained; the results are purely an interpretation of likelihood, and as such are a best estimate based on field data, monitoring based growth projections, historical quadrat data, and knowledge of vegetation ecology, hydrogeology and broad fluvial processes.

Based on the presented interpretations, a number of conclusions about the distribution of OPV within the study area can be made. Firstly, in general; OPV with a high likelihood of being present in the natural pre-discharge environment (i.e. without the effects of discharge augmentation) is highly restricted within the study area. Representing approximately 2% of the study area, these communities are represented by the C1A, and C1B vegetation units. Within the study area these communities are generally restricted to small patches of vegetation fringing the main low flow channel on bends or at the end of long pools/straights within Weeli Wolli Creek, and similar positions within the more variable and often multiple low flow channels of Marillana creek.

4.5 RESULTANT SIGNIFICANCE ATTRIBUTED TO THE RIPARIAN COMMUNITIES IN THE STUDY AREA

The results of the included mapping refinement along with the above interpretations of likely presence in the pre-discharge environment were used to contribute to an assessment of significance for each of the riparian vegetation community (sub-associations) mapped as part of this study. The significance value attributed to each community is based on the significance framework presented in section 2.8. This Framework incorporates an assessment of the ecological values provided, the distribution or degree to which it is represented in the environment (local, sub-regional, regional), the condition, and the sensitivity to impact of each community mapped within the study area.

The resultant significance attributed to each riparian vegetation unit is initially assigned to one of the following significance ratings.

(1) Low, (2) Minor, (3) Minor-Moderate, (4) Moderate, (5) Moderate-High, (6) High, (7) Very-High

An additional “development significance” is also provided for each riparian unit mapped as part of this study.

The results of the significance assessment are presented in Table 4-5 below. It should be noted that Table 4-5 does not provide an indication of conservation significance as this is an additional level of subjectivity which is not considered valuable in the context of this study.

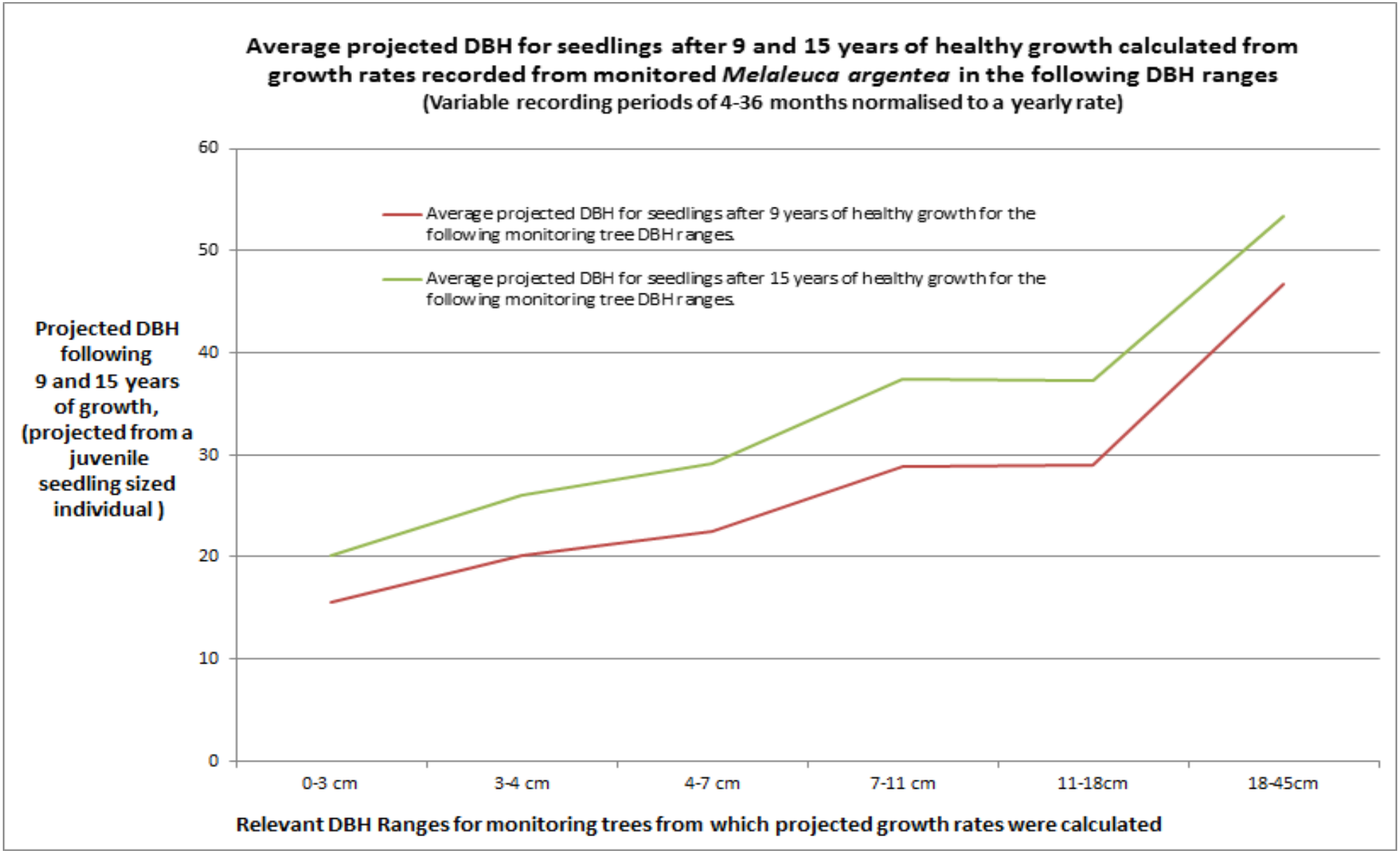


Figure 4-9: Graph showing the growth rate projections calculated from monitoring tree data (and two other minor data sources). The two blue arrows delineate the monitoring tree DBH zone from which an average projected growth rate was taken for the purpose of deducting conclusions about the pre-discharge riparian environment in Marillana and Weeli Wolli Creeks

Table 4-4: Interpretations of the likely presence of mapped and refined vegetation communities of the current study area within the pre-discharge environment

New Veg code (M=Marillana, W=Weeli Wolli)	Vegetation Type	Interpreted presence in the Pre-Discharge Environment	Notes about the Pre-discharge presence
C1AA	**Larger representations of Historical *Melaleuca argentea* and *Eucalyptus camaldulensis* Woodland**	**Clearly present in the Pre-discharge environment**	**Present in the same or a very similar form to the present day community, in both Structure and composition.**
C1A	**Small patches of *Melaleuca argentea* and *Eucalyptus camaldulensis* Woodland**	**Clearly present in the Pre-discharge environment**	**Present in the same or a very similar form to the present day community, in both Structure and composition.**
C1B - M	**Marillana – *E. camaldulensis* and *E. victrix* woodland over *M. argentea* Semi Mature low open woodland**	**Potentially present in the Pre-discharge environment in this form.**	**Likely present with a younger in a younger more transient form of *M. argentea* population but still comprising a significant component of the broader community.**
C1B - W	**Weeli Wolli - *E. camaldulensis* and *E. victrix* woodland over *M. argentea* Semi Mature low open woodland**	**Likely to be present in the Pre-discharge. Environment.**	**Likely present in a very similar form to the present day community.**
C1/C2-A - M	**Marillana - *E. camaldulensis* and *E. victrix* open woodland over *M. argentea* and *E. camaldulensis* Young to Semi Mature low open woodland**	**Unlikely to have been Present in the Pre-discharge Environment in this form.**	**Instead Likely to have been represented by a lower value community, most likely either the C2/C1 or C2A community.** **Potentially represented by a community with transient (coming and going over time with climatic phases and successive floods) young populations of *Melaleuca argentea* in these areas. Likely that *M. argentea* may not have formed a co-dominant component of the vegetation.**
C1/C2-A - W	**Weeli Wolli – *E. camaldulensis* and *M. argentea* Young to Semi Mature low open woodland**	**Unlikely to have been Present in the Pre-discharge environment in this form.**	**Instead Likely to have been represented by a lower value community, most likely either the C2/C1 or C2A community.** **Potentially represented by a community with transient (establishing and de-establishing over time with climatic phases and successive floods) young populations of *Melaleuca argentea* in these areas. Likely that *M. argentea* did not have form a co-dominant component of the vegetation.**
C2/C1 - M	**Marillana - *M. argentea* and *E. camaldulensis* Young low open forest,** ***(Generally represented by thin Strips of vegetation lining the low flow channel)***	**Not Present in the Pre-discharge environment in this form.**	**Instead most likely represented by the C2A or C3A community**

New Veg code (M=Marillana, W=Weeli Wolli)	Vegetation Type	Interpreted presence in the Pre-Discharge Environment	Notes about the Pre-discharge presence
C2/C1 - W	**Weeli Wolli - *M. argentea* and *E. camaldulensis* Young low open forest,** ***(Generally represented by thin Strips of vegetation lining the low flow channel)***	**Not Present in the Pre-discharge environment in this form**	**Instead most likely represented by the C2A or C3A community**
C2A	***E. camaldulensis* and *E. victrix* woodland bank/bed community**	**Present in the Pre-discharge environment.**	**The representations present in the present day study area are generally discharge "altered"; therefore the pre-discharge form of this community may be slightly different.**
C2Asb	***E. camaldulensis* and *E. victrix* woodland Scoured bed community**	**Present in the Pre-discharge environment.**	**The representations present in the present day study area are generally discharge "altered"; therefore the pre-discharge form of this community may be slightly different.**
C2B	***E. camaldulensis* and *E. victrix* Floodplain community**	**Present in the Pre-discharge environment.**	Current and Pre-discharge representations of this community are highly likely to be very similar if not virtually identical.
C2C	***Eucalyptus victrix* low woodland/ Acacia shrublands of the upper and outer creekbeds and tributaries**	**Present in the Pre-discharge environment.**	Current and Pre-discharge representations of this community are highly likely to be very similar if not virtually identical.
C3A	***E. victrix* Bank/bed community**	**Present in the Pre-discharge environment.**	**The representations existent in the present day study area are generally discharge "altered"; therefore the pre-discharge form of this community may be slightly different.**
C3Asb	***E. victrix* scoured beds community**	**Present in the Pre-discharge environment.**	**The representations present in the present day study area are generally discharge "altered"; therefore the pre-discharge form of this community may be slightly different.**

Table 4-5: Assessment of resultant Riparian significance for the riparian vegetation units mapped within the study area

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
C1AA	*Eucalyptus camaldulensis subsp. refulgens, E. victrix and Melaleuca argentea woodland, over Eucalyptus victrix, Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca glomerata and Acacia ampliceps.*	**M-SM(+)**	• Mature mesic woodland habitat. • Perennial water availability (at present and Pre/post-discharge). • High mesic flora species diversity. • Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python, Northern Quoll, and potentially the Ghost Bat and PLNB). • Cryptic and conservation significant flora species habitat (for Stylidium Weeli Wolli). • High subsurface aquatic invertebrate diversity. • High local avifauna and bat species diversity (potentially including the Chocolate bat). • Some reduced value from cumulative impact. • Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk. • Good Potential for elevated sedge diversity, and possibly including cryptic species such as Fuirena ciliaris and Eleocharis geniculata, as well as a suite of habitat specific sedges, grasses and herbs. (Note: allot of these values are known from the similar well studied community associated with Weeli Wolli springs – while not proven in all other representations of an equivalent/similar community these values are likely to be present in substantial sized representations of this community – smaller representations are likely to contain only some of these values (info regarding the values associated with Weeli Wolli springs is provided in Appendix 3; DEC 2009b).	**Sub-regionally restricted and significant** The rocky rangeland creek variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion. **The representation present in the study area is relatively large, extends outside of the study area, off tenement, and has suffered impact from adjacent mining operations (not Rio Tinto operations).** **Clearly present in the Pre-discharge environment, potential re-establishment post impact.**	**High**	**Good to Poor** (significant anthropogenic structural impacts from enhancement)	**High** (moderate to low at present; historically high)	**High**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
C1A - Marillana	*Eucalyptus camaldulensis subsp. refulgens, E. victrix and Melaleuca argentea woodland over Eucalyptus camaldulensis Melaleuca argentea and Acacia coriacea subsp. pendens low open woodland.*	**M-SM**	• Relatively mature mesic woodland habitat • Perennial water availability (at present and Pre/post-discharge). • Above average to High mesic flora species diversity. • Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python, Northern Quoll, and potentially the Ghost Bat, and Chocolate Wattle Bat). • Cryptic and conservation significant flora species habitat (for Stylidium Weeli Wolli). • High subsurface aquatic invertebrate diversity. • High local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk. • Some potential for elevated sedge diversity, and possibly including cryptic species such as Fuirena ciliaris and Eleocharis geniculata, as well as a suite of habitat specific sedges, grasses and herbs. (Fuirena ciliaris has not been detected in previous flora and vegetation surveys in the study area, but Eleocharis geniculata has been found once in 2004).	**Sub-regionally restricted** The rocky rangeland creek variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion. **The representations present in the study area are all quite small and disjunct, with the patch immediately downstream of the BHPBIO discharge point representing the largest and most significant.** **Clearly present in the Pre-discharge environment.**	**Moderate-high** (Smaller representations – Moderate)	**Very Good to Good** (some anthropogenic structural impacts from enhancement)	**High**	**High**
C1B - Marillana	*Eucalyptus camaldulensis subsp. refulgens, and E. victrix woodland, over Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca argentea, M. glomerata and Acacia ampliceps.*	**Y-SM Plus**	• Discharge augmented Semi-mature mesic woodland/low-woodland habitat. • Perennial water availability (at present and potentially Pre/post-discharge). • Above average mesic flora species diversity. • Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python, and potentially the Northern Quoll. Also some potential for the Ghost Bat, and Chocolate Wattle Bat to forage here). • Cryptic and conservation significant flora species habitat (potentially for Stylidium Weeli Wolli). • Above average subsurface aquatic invertebrate diversity. • High local avifauna diversity.	**Locally to Sub-regionally restricted** The rocky rangeland creek variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion. **The representations present in the study area are all quite small thin and**	**Moderate** (small areas) **Moderate-High** (larger patches)	**Good** (moderate anthropogenic structural impacts from enhancement)	**Moderate to high**	**Moderate** (Small patches) **Moderate-High** (larger patches, or small patches fringing the C1A unit)

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
			• Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**disjunct patches scattered among the broader riparian communities.** **Potentially present in the Pre-discharge environment in this form. Likely present in a younger more transient form. Potentially represented by a lower value community.**				
C1B – Weeli Wolli	*Eucalyptus camaldulensis subsp. refulgens, and E. victrix woodland, over Melaleuca argentea, and Acacia coriacea subsp. pendens low open woodland, over tall open shrubland of Melaleuca argentea, M. glomerata and Acacia coriacea subsp. pendens.*	**Y-SM Plus**	• Semi-mature mesic woodland/low-woodland habitat. • Perennial water availability (at present and potentially Pre/post-discharge). • Above average mesic flora species diversity. • Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python, and potentially the Northern Quoll. Also some potential for the Ghost Bat, and Chocolate Wattle Bat to forage here). • Cryptic and conservation significant flora species habitat (potentially for Stylidium Weeli Wolli). • Above average subsurface aquatic invertebrate diversity. • Above average local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Locally to Sub-regionally restricted** The rocky rangeland creek variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion. **The representations present in the study area are all small thin and disjunct patches scattered among the broader riparian communities.** **Likely Present in the Pre-discharge environment in a similar form.**	**Moderate** (all examples are relatively small and somewhat disjunct)	**Good** (moderate anthropogenic structural impacts from enhancement)	**High**	**Moderate**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
C1/C2A - Marillana	*Open woodland of Eucalyptus camaldulensis subsp. refulgens and E. victrix, over low woodland of E. camaldulensis subsp. refulgens, Melaleuca argentea saplings, over scattered tall-shrubs of Melaleuca argentea, M. glomerata, Atalaya hemiglauca.*	**Y-SM(-) Plus**	• Discharge augmented Semi-mature mesic woodland/low-woodland habitat. • Perennial water availability (at present, low potential Pre/post-discharge). • Above average mesic flora species diversity. • Cryptic and Mesic Fauna habitat (May include the Pilbara olive python). • Cryptic flora species habitat (may include Stylidium Weeli Wolli). • Above average subsurface aquatic invertebrate diversity. • Above average local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Locally restricted** The rocky rangeland creek variant of this community is uncommon within the Hamersley sub-region, and relatively restricted to Larger creek systems. The unique substrates and adjacent rocky habitats make it relatively unique when compared to similar riverine communities occurring in the wider Pilbara Bioregion. **The representations present in the study area are all small thin and disjunct patches scattered among the broader riparian communities.** **Unlikely to have been Present in the Pre-discharge environment in this form. Instead Likely to have been represented by a lower value community (C2A community).**	**Moderate**	**Good** (significant anthropogenic structural impacts from enhancement)	**Moderate**	**Minor-Moderate**
C1/C2A – Weeli Wolli	*Low woodland of Eucalyptus camaldulensis subsp. refulgens and Melaleuca argentea (and to a lesser extent E. victrix) saplings to young trees (With scattered trees), over scattered tall-shrubs (to tall open shrubland) of Melaleuca glomerata, Atalaya hemiglauca, Acacia coriacea subsp. pendens.*	**Y-SM(-) Plus**	• Discharge augmented Semi-mature mesic woodland/low-woodland habitat. • Perennial water availability (at present, low potential Pre/post-discharge). • Above average mesic flora species diversity. • Cryptic and Mesic Fauna habitat (May include the Pilbara olive python). • Cryptic flora species habitat (may include Stylidium Weeli Wolli). • Above average subsurface aquatic invertebrate diversity. • Above average local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Locally restricted** The rocky rangeland creek variant of this community is uncommon within the Hamersley sub-region, and relatively restricted to Larger creek systems. The unique substrates and adjacent rocky habitats make it relatively unique when compared to similar riverine communities occurring in the wider Pilbara Bioregion. **The representations present in the study area are all small thin and disjunct patches scattered among the broader riparian communities.** **Unlikely to have been Present in the Pre-discharge environment in this form. Instead Likely to have been represented by a lower value community (C2A community). Likely present with a more transient young *Melaleuca argentea* population.**	**Moderate**	**Good** (significant anthropogenic structural impacts from enhancement)	**Moderate to high**	**Minor-Moderate**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
C2/C1 - Marillana	***Strips of vegetation lining the low flow channel of:*** *Scattered Eucalyptus camaldulensis trees, over low open forest of Eucalyptus camaldulensis and Melaleuca argentea saplings/young-trees, over tall open shrubland of Acacia ampliceps, Melaleuca argentea, Melaleuca glomerata, and Atalaya hemiglauca generally accompanied by fringing strips of dense Typha domingensis.*	**Y**	• Discharge augmented young mesic woodland/low-woodland habitat. • Generally ephemeral water availability (at present perennial). • Elevated mesic flora species diversity • Mesic Fauna habitat. • Cryptic flora species habitat. • Elevated subsurface aquatic invertebrate diversity. • Above average local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Locally restricted** The Pre-discharge version of this community is relatively common within the Hamersley sub-region. However such communities are restricted to the larger creek systems of the Hamersley sub-region. In some cases the substrates and adjacent rocky habitats are relatively unique. **The representations present in the study area are all small thin and disjunct patches scattered among the broader riparian communities.** **Not Present in the Pre-discharge environment in this form. Instead most likely represented by the C2A or C3A community**	**Moderate**	**Good to Poor** (substantial anthropogenic structural impacts from enhancement, with some weed impact)	**Minor-moderate**	**Minor-Moderate**
C2/C1 – Weeli Wolli	***Strips of vegetation generally lining the low flow channel of:*** *Low woodland of Eucalyptus camaldulensis subsp. refulgens and Melaleuca argentea saplings/young-trees, over scattered tall-shrubs of Melaleuca glomerata, Atalaya hemiglauca, and Stylobasium spathulatum.*	**Y**	• Discharge augmented young mesic woodland/low-woodland habitat. • Generally ephemeral water availability (at present perennial). • Elevated mesic flora species diversity • Mesic Fauna habitat. • Cryptic flora species habitat. • Elevated subsurface aquatic invertebrate diversity. • Above average local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Locally restricted** The Pre-discharge version of this community is relatively common within the Hamersley sub-region. However such communities are restricted to the larger creek systems of the Hamersley sub-region. In some cases the substrates and adjacent rocky habitats are relatively unique. **The representations present in the study area are all small thin and disjunct patches scattered among the broader riparian communities.** **Not Present in the Pre-discharge environment in this form. Instead most likely represented by the C2A or C3A community**	**Moderate**	**Good to Poor** (substantial anthropogenic structural impacts from enhancement, with some weed impact)	**Low to moderate**	**Minor-Moderate**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
C2A	*Eucalyptus camaldulensis subsp. refulgens, E. victrix open woodland, over Acacia coriacea subsp. pendens, Atalaya hemiglauca and Acacia citrinoviridis low open woodland, over Melaleuca glomerata and Acacia citrinoviridis tall open shrubland, over low shrubland typically dominated by Corchorus crozophorifolius and Tephrosia sp.* Fortescue creeks.	N/A	• Relatively mature and at times discharge augmented woodland/low-woodland habitat. • Generally ephemeral water availability (at present perennial in places). • Elevated mesic flora species diversity. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Somewhat locally restricted** This community is relatively common within the Hamersley sub-region, but generally restricted to larger creek systems. In some cases the substrates and adjacent rocky habitats are relatively unique. **The representations present in the study area are often at least partially discharge** augmented **which can jeopardise its value through susceptibility to fast paced hydrological change.** **Present in the Pre-discharge environment.**	**Moderate** (all relatively substantial sized representations)	**Good to Poor** (moderate to substantial influence from Buffel grass and grazing as well as the presence of other weeds such as Mexican poppy)	**Low to moderate**	**Minor-moderate**
C2Asb	*Eucalyptus camaldulensis* subsp. *refulgens, and E. victrix open woodland* over scattered tall shrubs of *Melaleuca glomerata on scoured beds of the main and large secondary channels of Marillana Creek.*	N/A	• Relatively mature and at times discharge augmented woodland/low-woodland habitat. • Generally ephemeral water availability (at present perennial in places). • Elevated mesic flora species diversity. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Common but Somewhat locally restricted** This community is relatively common within the Hamersley sub-region, but generally restricted to larger creek systems. In some cases the substrates and adjacent rocky habitats are relatively unique. **The representations present in the study area are often at least partially discharge** augmented **which can reduce jeopardise its value through susceptibility to fast paced hydrological change.** **Present in the Pre-discharge environment.**	**Moderate**	**Good to Very Good** (minor influence from Buffel grass, grazing and Mexican poppy, some anthropogenic enhancement)	**Low**	**Minor-Moderate**
C2B	*Eucalyptus victrix* and *E. camaldulensis* subsp. refulgens low open woodland/open woodland, over *Acacia citrinoviridis*, *A.*	N/A	• Relatively mature and at times discharge augmented low-woodland habitat. • Ephemeral water availability. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity.	**Locally restricted** This community is relatively common within the Hamersley sub-region, but floodplain representations are restricted to larger creek systems. **The representations present in the**	**Minor-Moderate**	**Poor** (good in some areas) (substantial influence from Buffel grass and	**Moderate**	**Minor-Moderate**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
	pruinocarpa, and *Atalaya hemiglauca* tall shrubland over **Cenchrus ciliaris* tussock grassland.		• Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**study area are potentially discharge** augmented **and may be sensitive to fast paced hydrological change.** **Present in the Pre-discharge environment.**		grazing)		
C2C	*Eucalyptus victrix* scattered low trees over Acacia tumida var. pilbarensis, *Grevillea wickhamii* tall shrubland over Tephrosia rosea var. Fortescue Creeks low shrubland over *Cymbopogon ambiguus*, *C. procerus*, *Eriachne tenuiculmis*, *Themeda triandra* very open tussock grassland.		• Relatively mature and at times discharge augmented low-woodland (generally scattered low trees) habitat. • Ephemeral water influence. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Common representation of the floodplain vegetation associated with Major Creeklines of the Pilbara Ecosystem at Risk.	**Relatively common and generally not restricted locally.** This community is common within the Hamersley sub-region, and is often present within most of the lower sized local drainage systems. **The representations present in the study area are unlikely to be discharge** augmented**, but regardless their sensitivity to fast paced hydrological change should be minimal.** **Present in the Pre-discharge environment.**	**Minor**	**Very Good to Good.** (moderate influence from Buffel grass and grazing)	**Low**	**Minor**
C3A	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis*, A. coriacea subsp. pendens, *Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	N/A	• Relatively mature and at times discharge augmented low-woodland (generally scattered low trees) habitat. • Ephemeral water availability (Perennial in some areas at present). • Elevated mesic flora species diversity. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Common representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**Common but somewhat locally restricted** This community is common within the Hamersley sub-region, but it can be restricted to larger creek systems or their main tributaries. **The representations present in the study area are potentially discharge** augmented **and may have some sensitivity to fast paced hydrological change.** **Present in the Pre-discharge environment.**	**Minor-Moderate**	**Good to Very Good** (some influence from Buffel grass and grazing as well as the presence of other weeds such as Mexican poppy)	**Low**	**Minor** (low in some severely Buffel grass infested areas)
C3Asb	*Eucalyptus victrix scattered trees to low open woodland* over scattered tall shrubs of *Melaleuca glomerata and E.*	N/A	• Relatively mature and at times discharge augmented low-woodland habitat. • Ephemeral water availability (Often Perennial in areas at present). • Elevated mesic flora species diversity. • Mesic Fauna habitat.	**Common but somewhat locally restricted** This community is common within the Hamersley sub-region, but it can be restricted to larger creek systems or their main tributaries. **The**	**Minor**	**Good to Very Good** (minor influence from Buffel grass,	**Low**	**Minor**

New Veg code	Condensed Vegetation Description	Generalised *M. argentea* "Size Class Range"	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pre-Discharge Environment	Significance	Condition	Sensitivity to relevant impacts	Development significance
	victrix, on scoured beds of the Main and large secondary channels of Weeli Wolli creek.		• Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Common representation of the Major Creeklines of the Pilbara Ecosystem at Risk.	**representations present in the study area are potentially discharge** augmented **and may have some sensitivity to fast paced hydrological change.** **Present in the Pre-discharge environment.**		grazing and Mexican poppy)		
C4	*Eucalyptus victrix* low open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland	N/A	• Relatively mature and at times discharge augmented low-woodland habitat. • Ephemeral water influence. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Common representation of the floodplain vegetation associated with Major Creeklines of the Pilbara Ecosystem at Risk.	**Relatively common and generally not restricted locally.** This community is common within the Hamersley sub-region, and while it is generally restricted to moderate to large creek systems or their main tributaries, these habitats are common enough for it to be relatively unrestricted locally. **The representations present in the study area are potentially discharge** augmented**, but their sensitivity to fast paced hydrological change should be minimal.** **Present in the Pre-discharge environment.**	**Minor**	**Poor** (good in some areas) (substantial influence from Buffel grass and grazing)	**Low**	**Minor**
C5	*Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	N/A	• Relatively mature and at times discharge augmented low-woodland habitat. • Ephemeral water influence. • Mesic Fauna habitat. • Elevated subsurface aquatic invertebrate diversity. • Elevated local avifauna diversity. • Some reduced value from direct impacts. • Some increased value from discharge enhancement. • Common representation of the floodplain vegetation associated with Major Creeklines of the Pilbara Ecosystem at Risk.	**Relatively common and generally not restricted locally.** This community is common within the Hamersley sub-region, and is present within most sizes of local drainage systems. **The representations present in the study area are unlikely to be discharge** augmented**, but regardless their sensitivity to fast paced hydrological change should be minimal.** **Present in the Pre-discharge environment.**	**Minor**	**Very Good** (minor influence from Buffel grass and grazing)	**Low**	**Minor**

4.6 HISTORICAL DMSI CHANGE DETECTION IMAGERY ASSESSMENT FOR USE IN THE INTERPRETATION OF THE PRE-DISCHARGE ENVIRONMENT

Figures 4-10 to 4-13 Present maps of the change detection Imagery for the period 2006-2014, created from yearly-acquired DMSI imagery of the study area. Using DMSI, a comparative analysis of embedded visible and infra-red electromagnetic radiation intensities produces a measure (index) of vegetation cover for each year. The change in this index of vegetation cover from year to year is measured and spatially amalgamated to provide an image of cumulative change over this period. The resultant change detection image is represented by a thematic colour map, which depicts positive and negative change in vegetation cover as different colour palates. Plate 9 provides a legend for the thematic colour mapping presented in the change detection imagery, the summary of which is that red equates to a clear loss of vegetation cover, white is no change and Blue equates to a clear increase in vegetation cover.

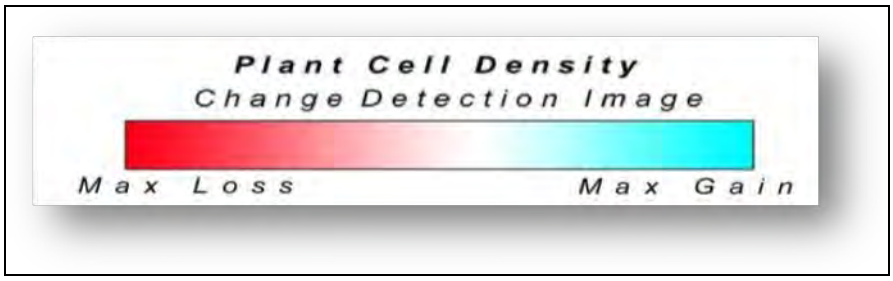


Plate 9: Legend for the thematic colour mapping presented in DMSI Change detection imagery

Key vegetation cover trends evident within Marillana Creek include, positive cover changes in low flow channel zones within areas downstream of discharge points, with negative cover changes in some of the areas positioned laterally away from discharge, or where additional discharge points have been removed. It should be noted that in the case of Marillana Creek a large proportion of vegetation augmentation likely to have occurred following discharge commencement, would have most likely occurred in the period prior to the acquisition timing of the DMSI image used (1995-2005). Despite this fact issues presented in section 3.3 outline the reasons behind the decision to rely on the 2006-2014 change detection imagery for presenting trends in vegetation cover within the study area.

Along Weeli Wolli Creek, the vegetation cover trends are generally more clearly and consistently positive within the main incised bed and bank zones. Despite this fact some clear vegetation cover loss anomalies are present in the vicinity of the confluence with Marillana Creek and in the scoured beds downstream of the confluence. Because all discharge related vegetation augmentation is likely to have taken place in the 2006-2014 period, the 2006-2014 DMSI change imagery is the best imagery for showing both positive and negative vegetation change within the Weeli Wolli Creek stretch of the study area. While similar trends to those shown in Weeli Wolli Creek are shown by change detection imagery for Marillana Creek, the trends are less consistently distributed, and appear harder to correlate with the distribution of various community boundaries mapped as part of this study. For this and other reasons the pre and post discharge aerial photography comparisons may present the best visual evidence for vegetation augmentation within the Marillana creek stretch of the study area.

Figures 4-10 to 4-21 are provided to present finer scale (spatially) examples of vegetation cover change detected by DMSI (2006-2014) of the study area. The presented examples are indicative of vegetation change trends noticed throughout the study area. Overlain on top of the change

detection imagery of these examples are two separate layers of vegetation mapping of most relevance to the study area. The "Vegetation Mapping units C1A and C1B combined" mapping polygons represent OPV mapped as part of this study and interpreted as highly likely to have been present in the pre-discharge environment. With both of these OPV units being interpreted to be part of the pre-discharge environment, and possessing somewhat similar structure and significance, they were combined for this mapping exercise to help provide visual simplicity when being analysed for correlation with patterns in the change detection imagery. The "Vegetation Mapping units C1/C2A and C2/C1 combined" mapping polygons represent present day OPV which is considered highly unlikely to have been present in the pre-discharge environment, and therefore is considered an augmented or artificial form of the pre-discharge community. These mapping polygons have been overlain to highlight the regular and often substantial degree of correlation between the boundaries and distribution of mapped OPV, and the boundaries and spatial distribution of positive vegetation change anomalies (potential vegetation augmentation).

The correlation evident between OPV mapping and positive vegetation change anomalies demonstrate that the spatial distribution of recent vegetation changes aligns with the distribution of communities interpreted as likely to be artificial and therefore not likely present in the pre-discharge environment in the same form. This spatial alignment lends weight to the accuracy of the interpretations made (section 4.4) about the historical presence of certain present day OPV communities. The provision of alternative evidence for the validity of interpretations made about the pre-discharge environment from present day field data is important for the process of firming up these interpretations and ultimately providing confident conclusions about the value and significance of riparian communities present in the study area.

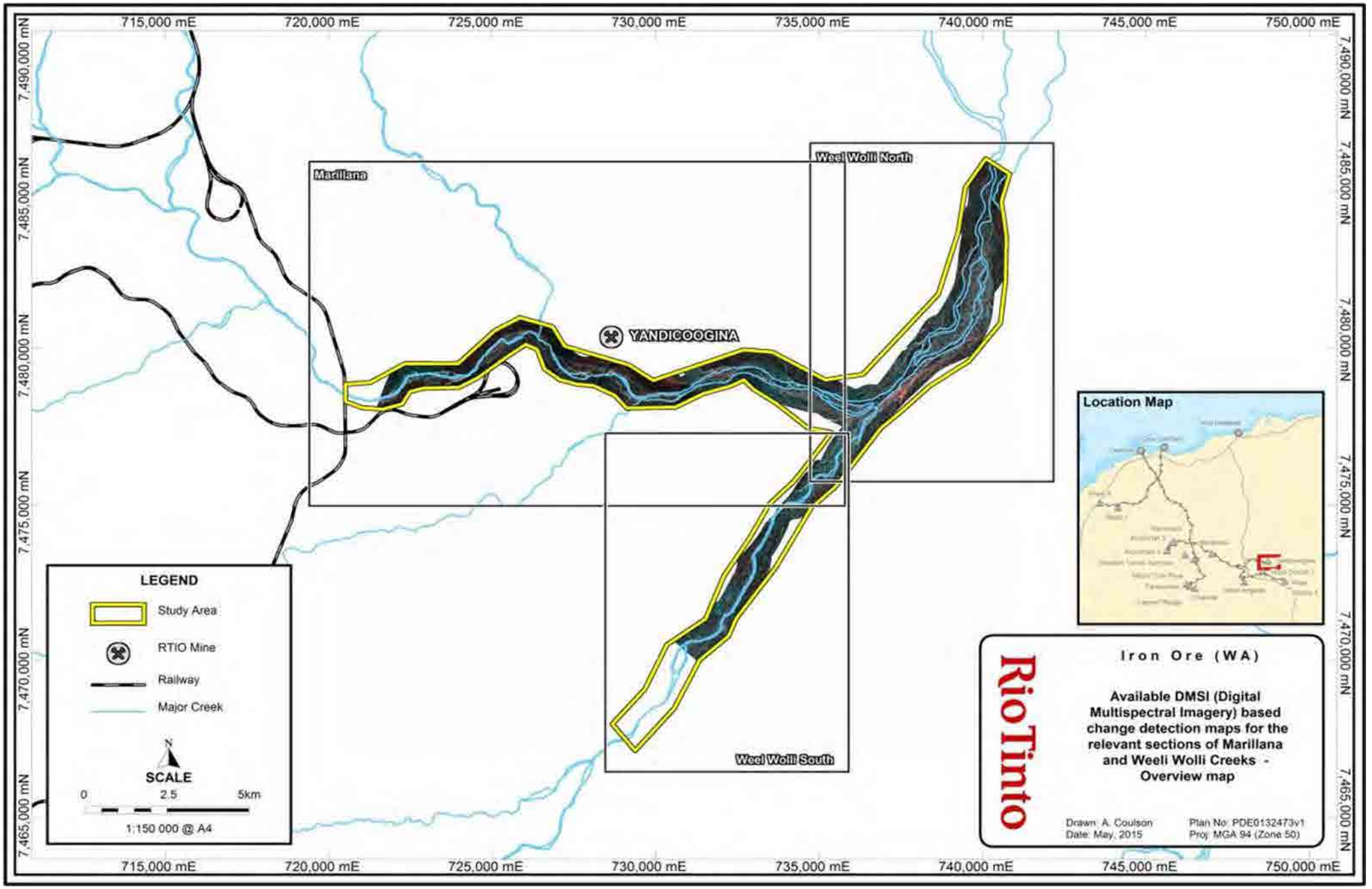


Figure 4-10: Available False colour Infra-red vegetation change maps of the study area (2006 to 2014), created from Digital Multispectral imagery acquired by Specterra

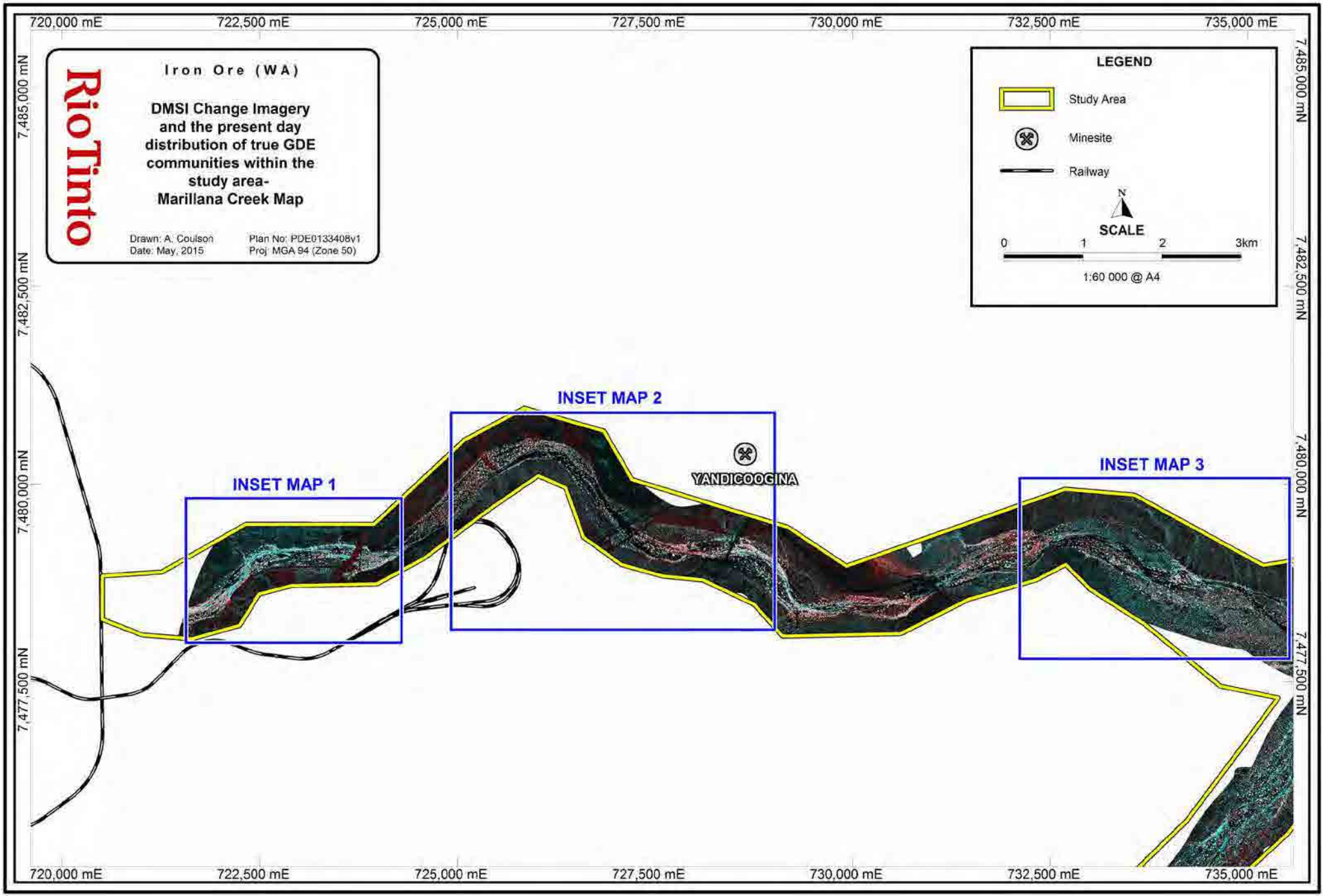


Figure 4-11: **Marillana Creek map; False colour Infra-red vegetation change maps (2006 to 2014), created DMSI imagery acquired by Specterra**

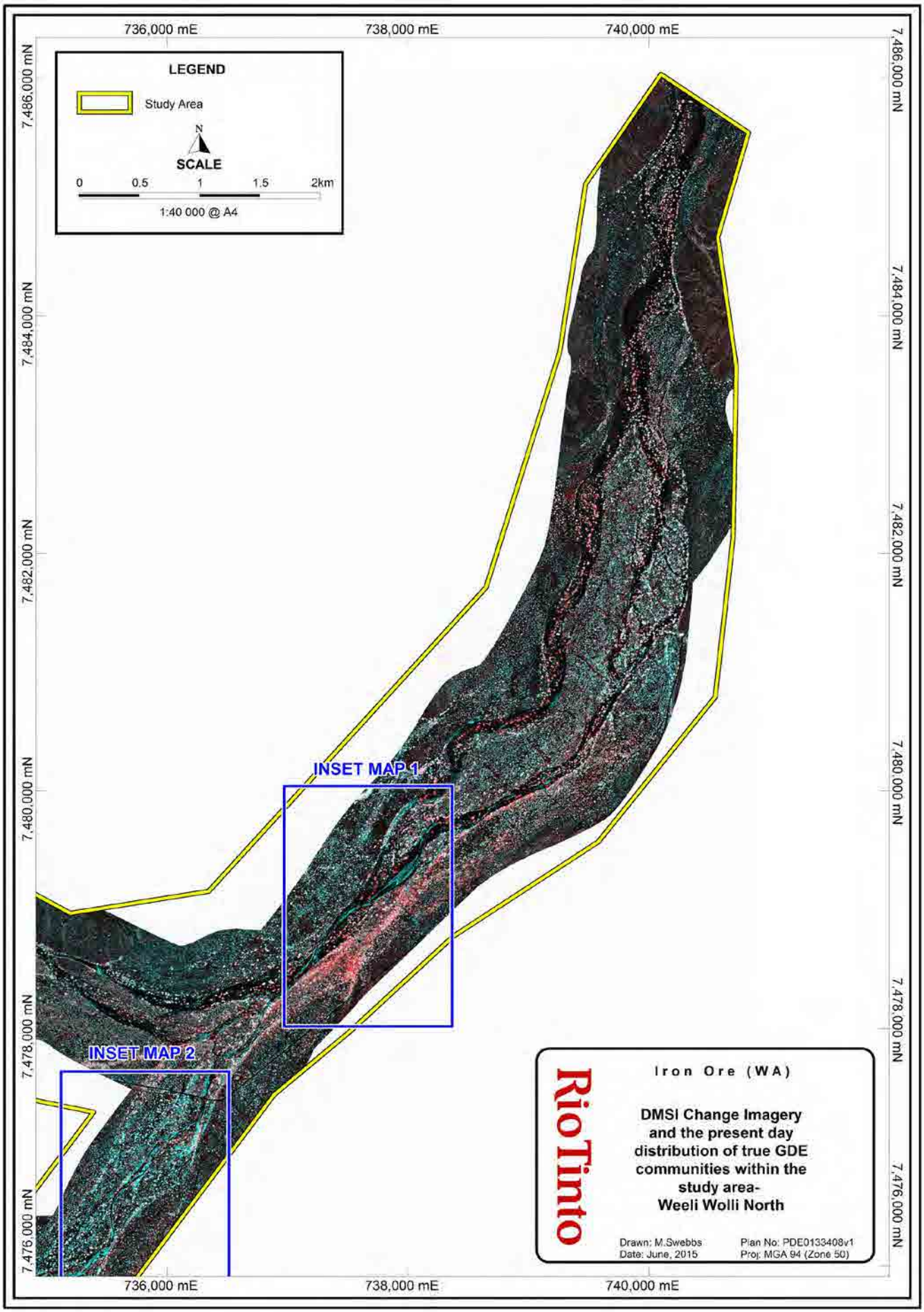


Figure 4-12: Weeli Wolli North; False colour Infra-red vegetation change maps from the period 2006 to 2014 (DMSI imagery acquired by Specterra).

Includes an index for associated inset maps showing fine scale change trends.

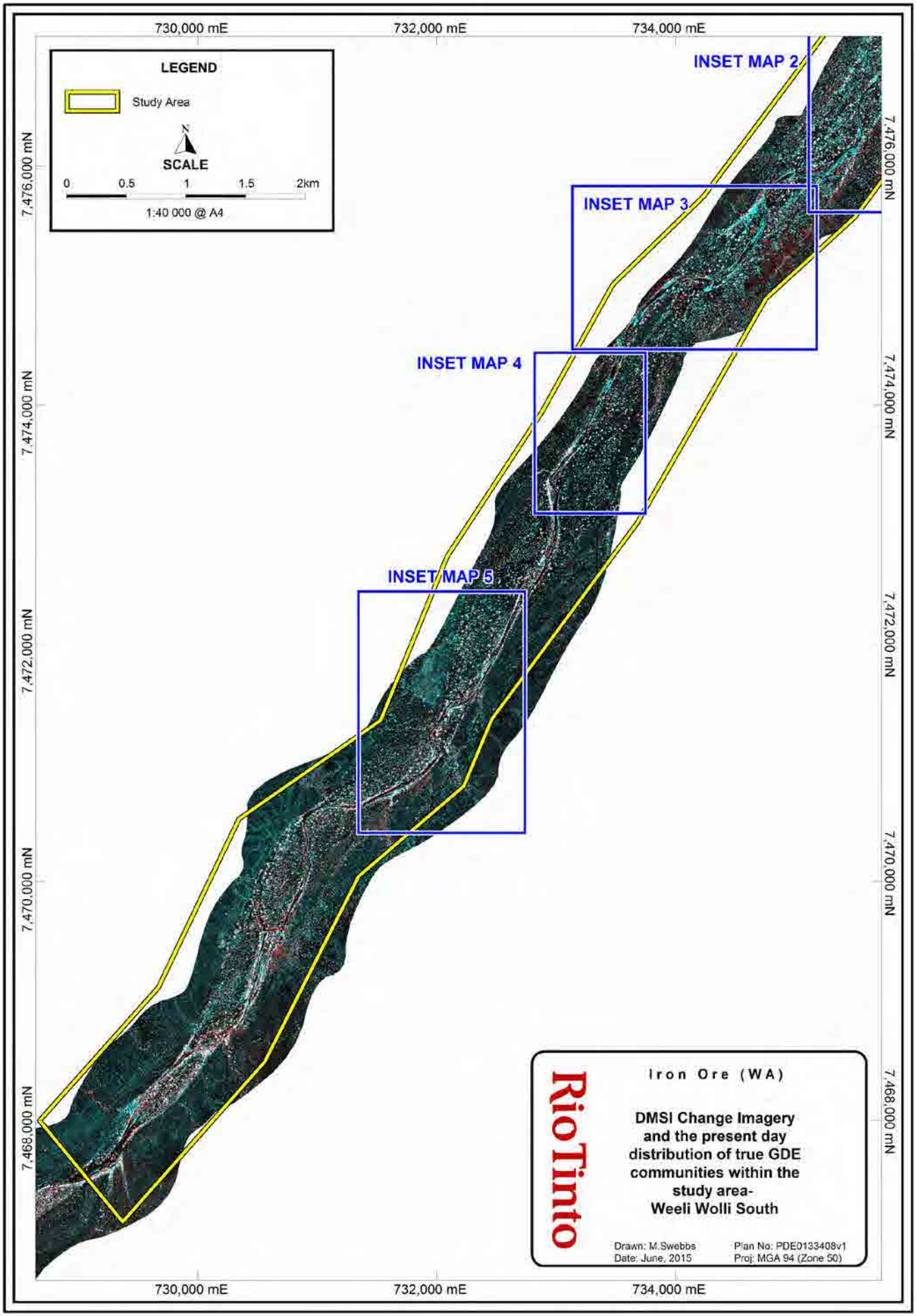


Figure 4-13: Weeli Wolli South; False colour Infra-red vegetation change maps from the period 2006 to 2014 (DMSI imagery acquired by Specterra).

Includes an index for associated inset maps showing fine scale change trends.

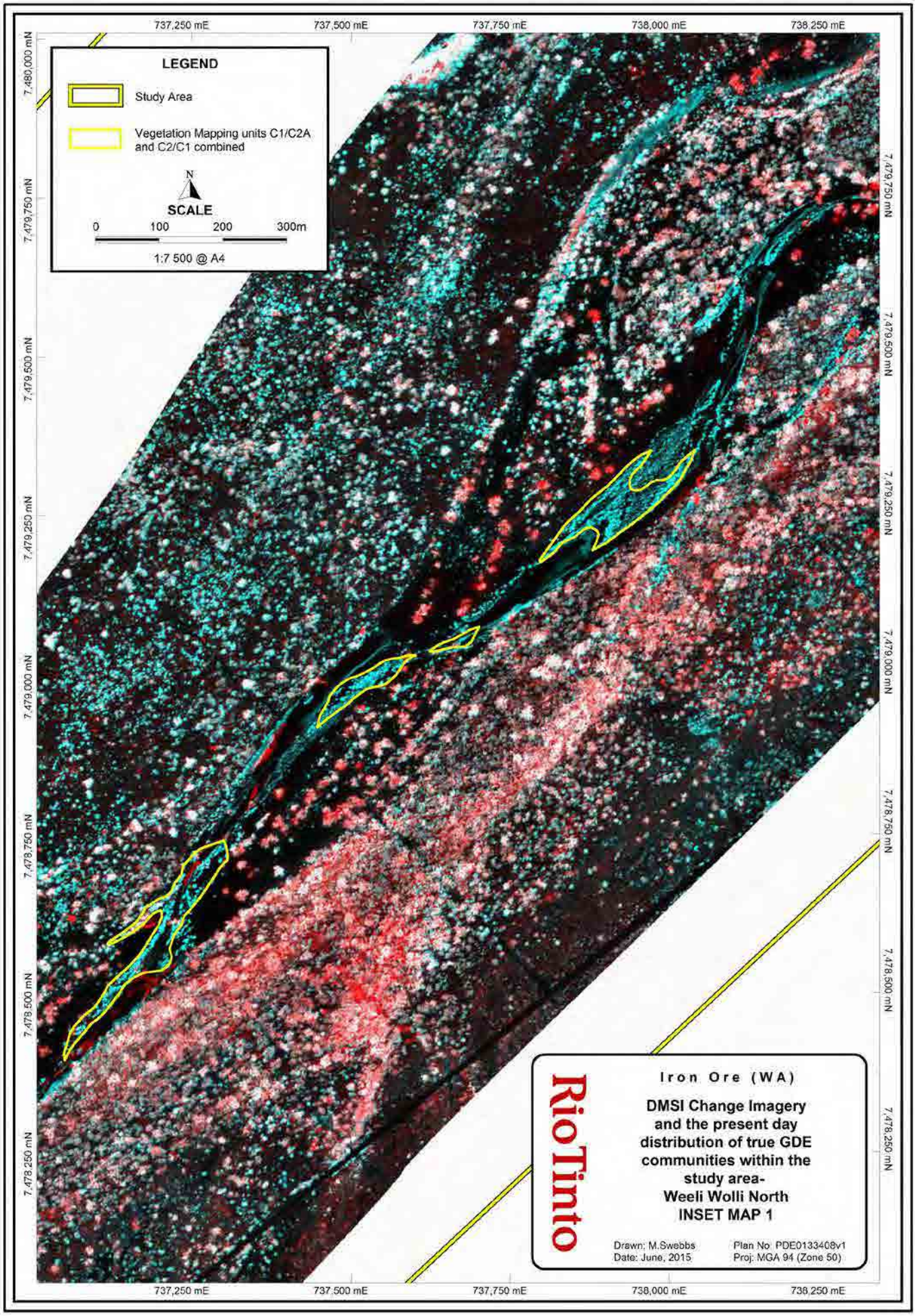


Figure 4-14: **Inset map 1 - Weeli Wolli Creek. Examples of DMSI change trends and their correlation with the distribution of OPV mapping within the study area**

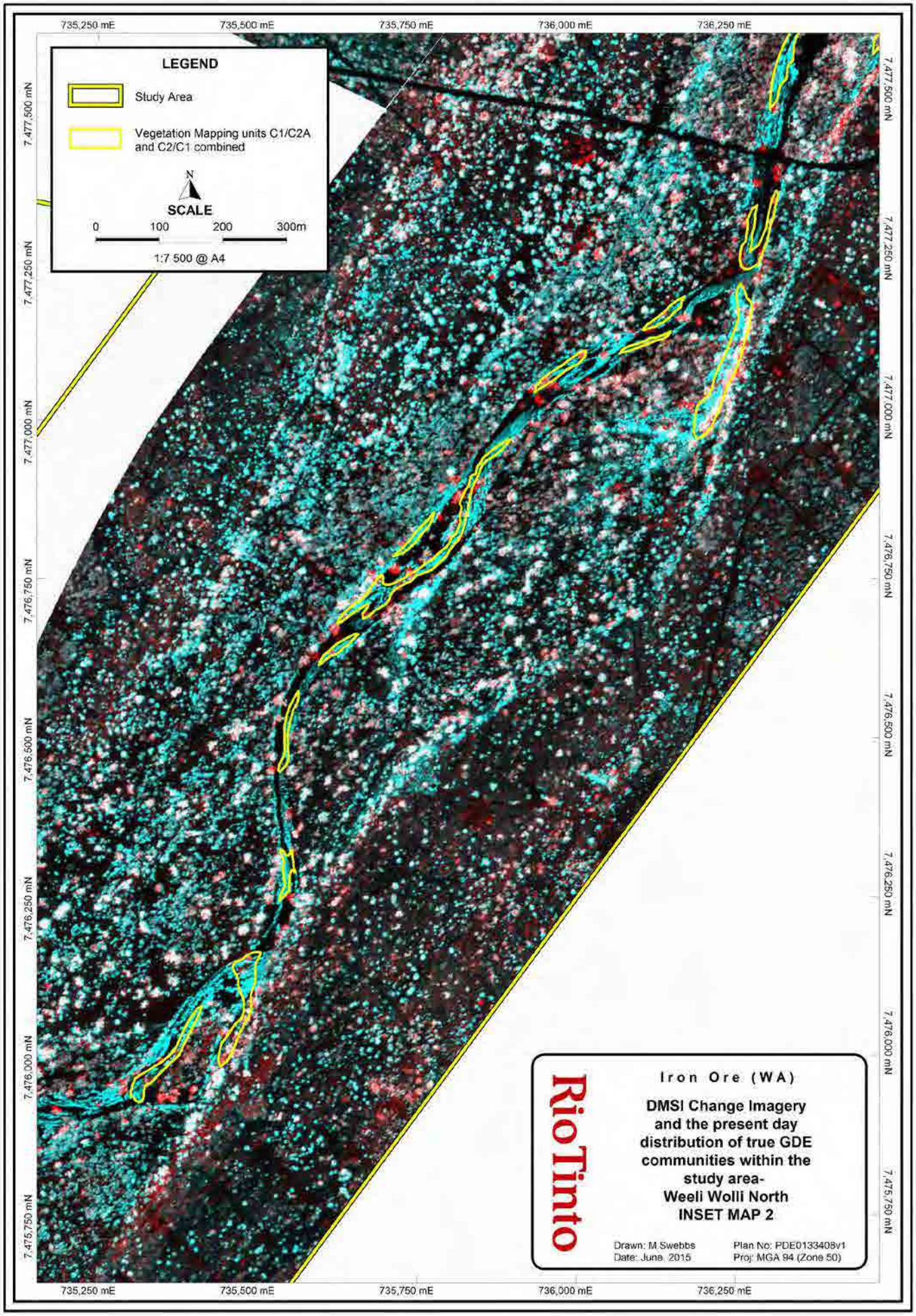


Figure 4-15: Inset map 2 - Weeli Wolli Creek

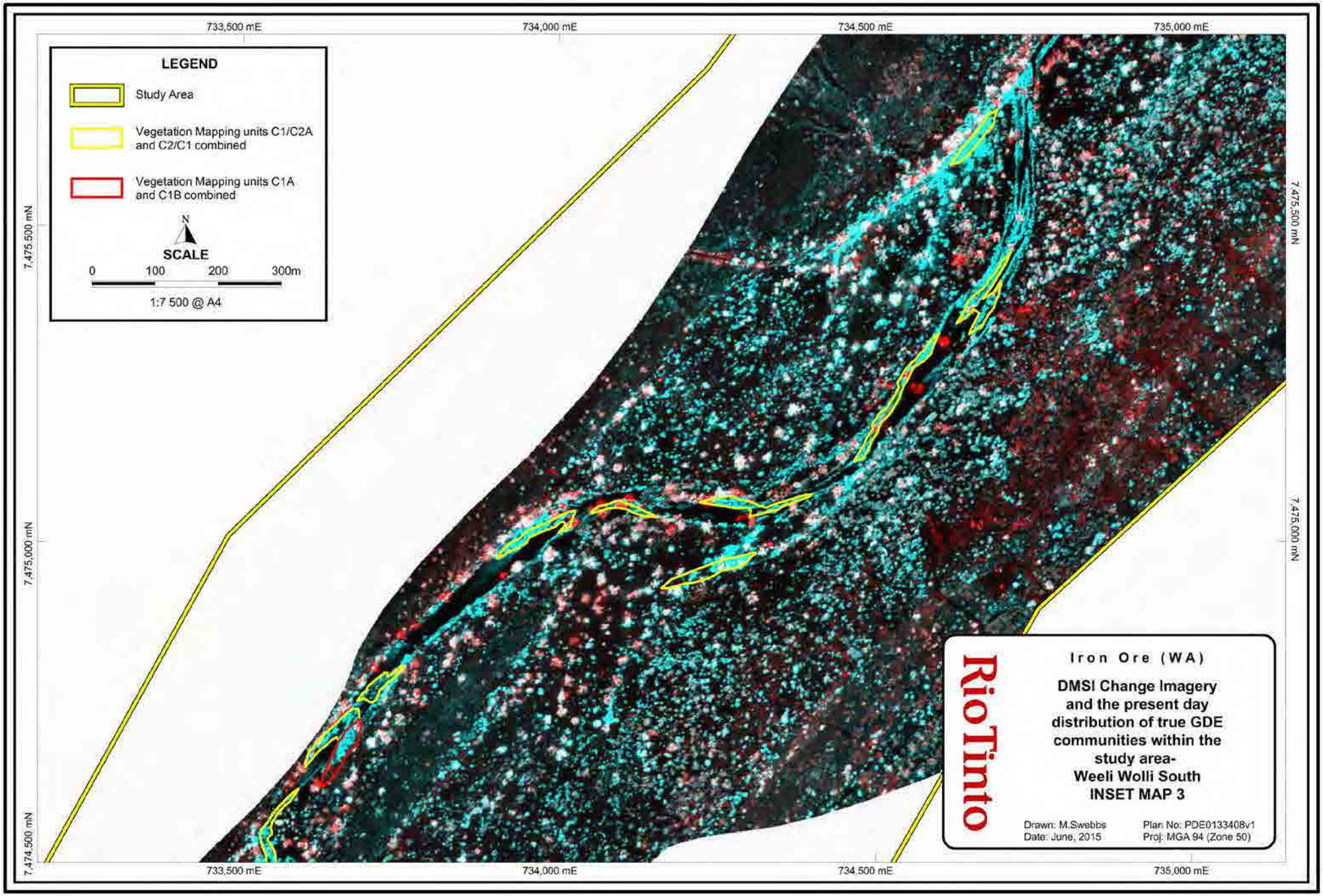


Figure 4-16: Inset map 3 - Weeli Wolli Creek

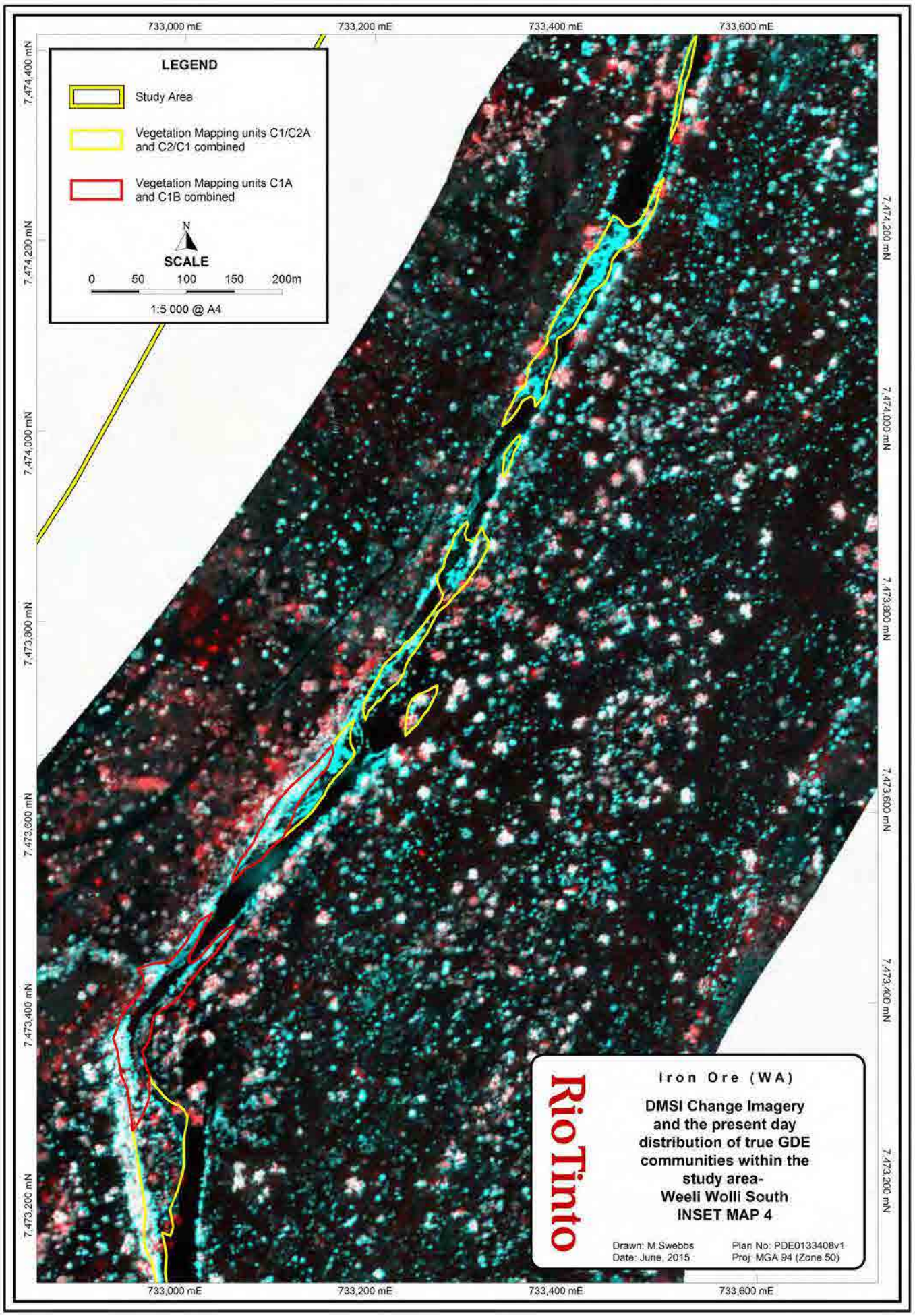


Figure 4-17: Inset map 4 - Weeli Wolli Creek

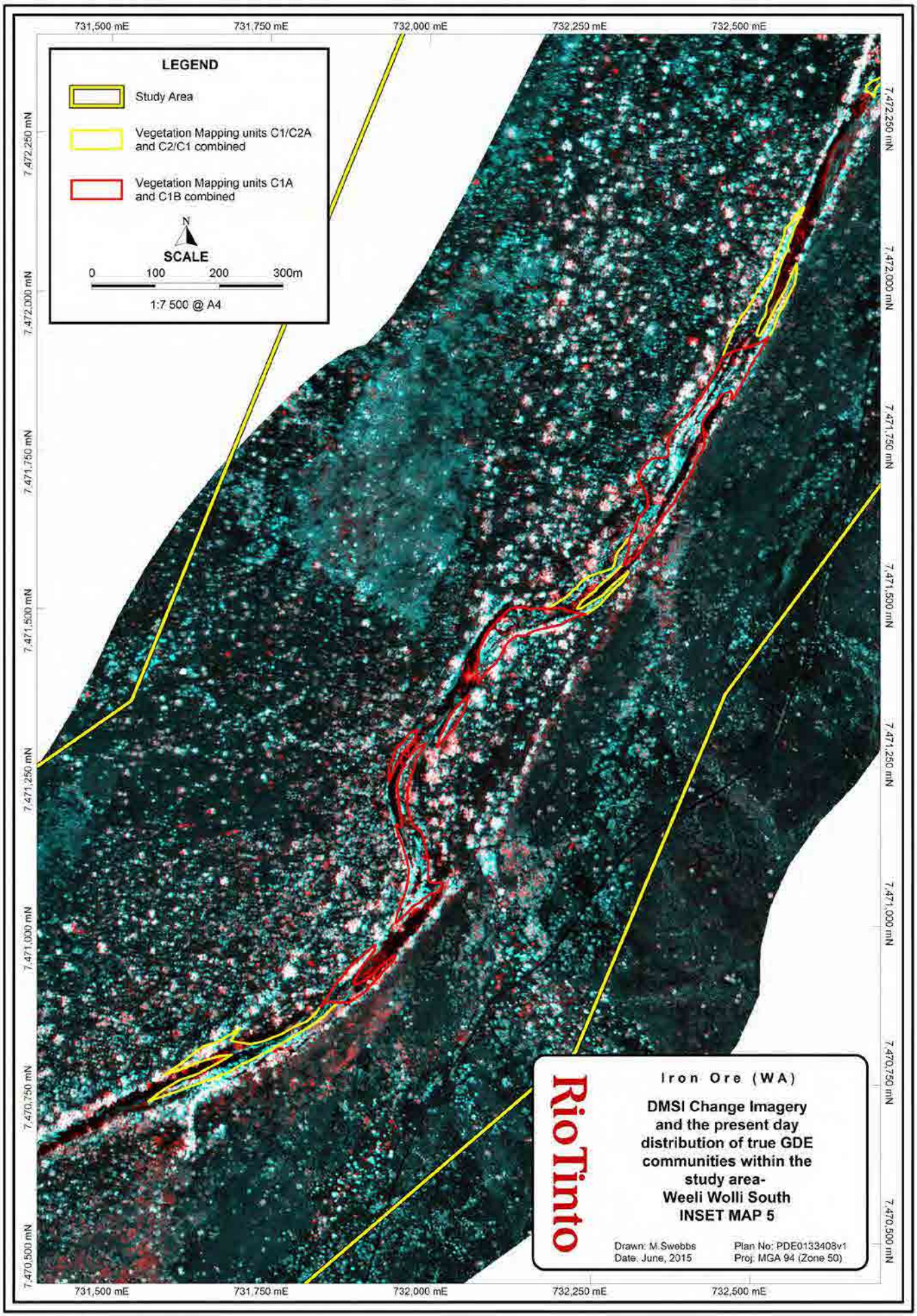


Figure 4-18: Inset map 5 - Weeli Wolli Creek.

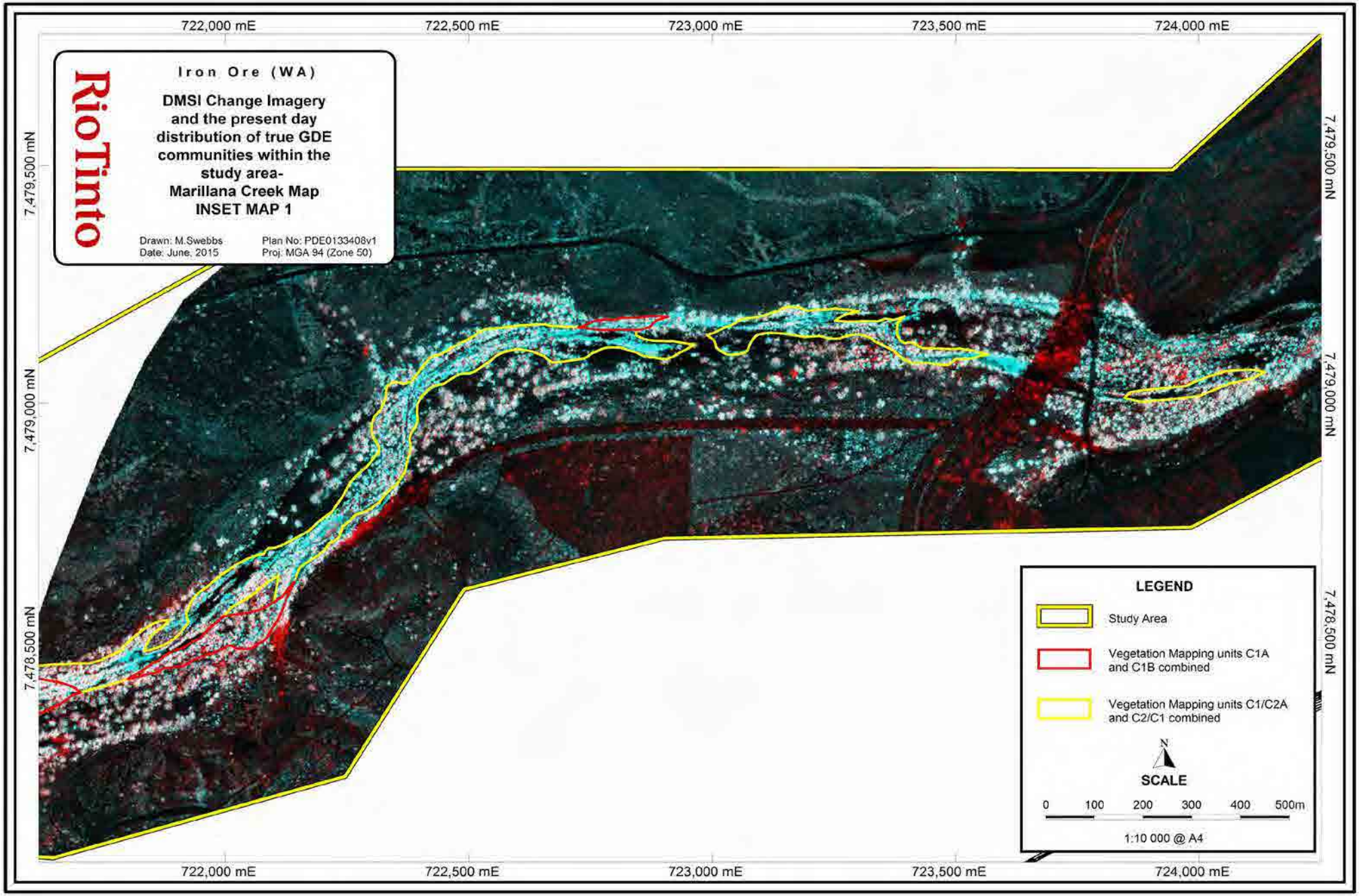


Figure 4-19: Inset map 1 – Marillana Creek

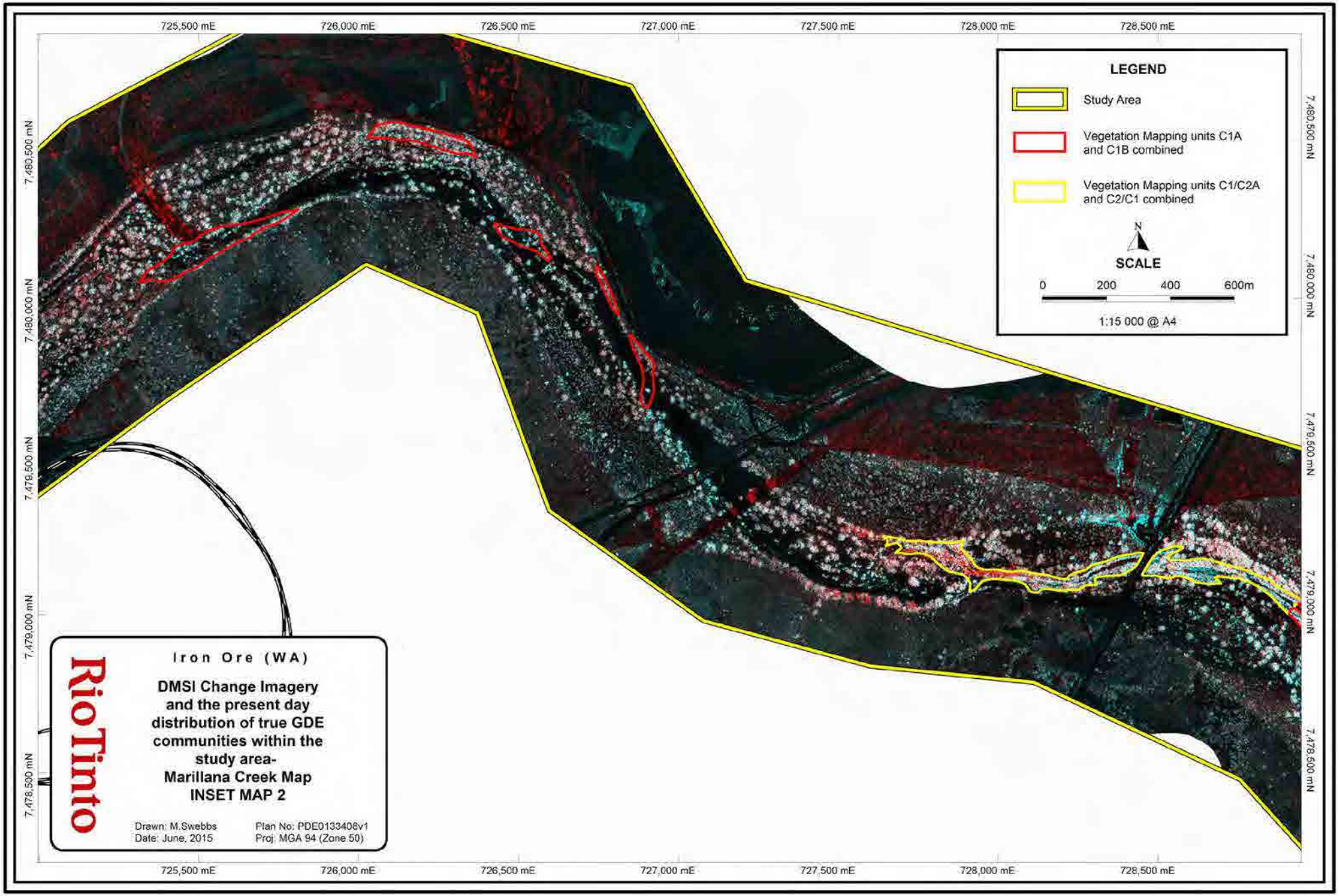


Figure 4-20: Inset map 2 - Marillana Creek

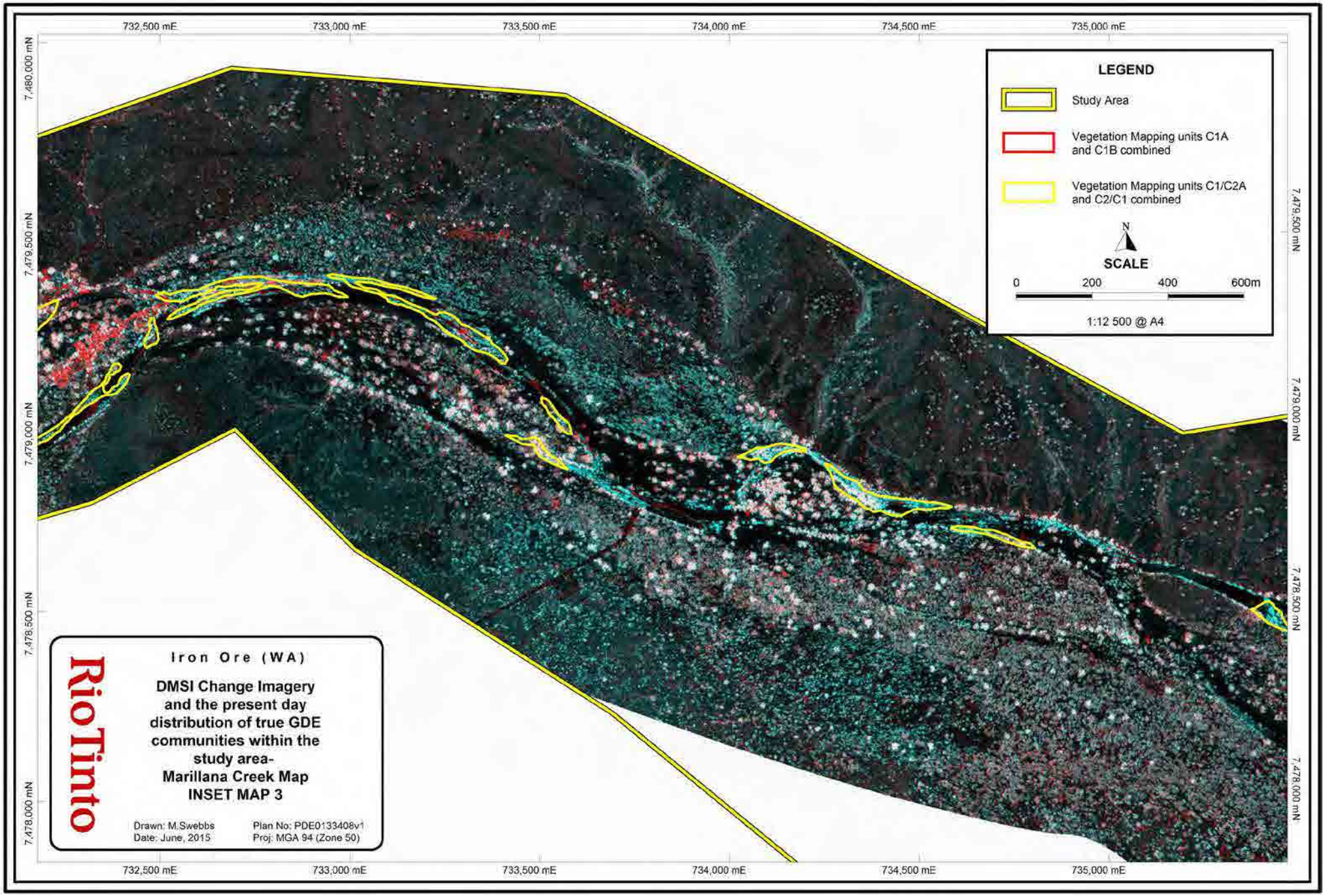


Figure 4-21: Inset map 3 - Marillana Creek

4.7 PRE AND POST-DISCHARGE AERIAL PHOTOGRAPHY COMPARISON PROVIDING EVIDENCE OF DISCHARGE BASED VEGETATION AUGMENTATION AND INFLUENCE ON THE DISTRIBUTION OF OBLIGATE PHREATOPHYTIC VEGETATION (OPV)

The above presented DMSI change detection imagery helps to establish that present day OPV mapping shows a reasonable degree of spatial correlation with vegetation cover change anomalies existent in the post discharge environment. However, comparing the visual density and extent of vegetation present within pre-discharge aerial photography with the spatial position of presently mapped OPV appears to represent another piece of supportive evidence to these observations. Based on the below presented temporal comparisons of aerial photography, it can be seen in many cases that present day vegetation signatures occurring within the mapped boundaries of OPV communities, don't appear to be present in same spatial boundaries on the respective pre-discharge aerial photo. In such cases, these and similar spatial observations clearly appear to support interpretations that certain representations of OPV (particularly the C1/C2A and C2/C1 communities) are unlikely to have been present prior to surplus-water discharge commencing.

In the case of Marillana creek; strong disparities between aerial photo signatures from 1994 and 2014 are evident. These differences appear to suggest that a substantial amount of discharge sourced vegetation augmentation has occurred. However, reduced aerial photography quality along with reduced confidence in DMSI change detection imagery in the late 1990's diminish the confidence attributed to supporting trends apparent in these data sources. Weeli Wolli creek on the other hand, has generally only been subject to significant surplus-water discharge, and potential augmentation since 2006, and consequently confidence attributed to supporting trends apparent in these data sources is high. Furthermore; new development proposals present within this area are increasing the need for accurate information about the value, significance and sensitivity of riparian communities within the Weeli Wolli Creek stretch of the study area. As a consequence, the following comparative examples of pre and post discharge aerial photography for Weeli Wolli creek (and Marillana Creek) present promising aerial signature trends which appear to support previous conclusions made about the distribution of OPV in the study area.

Figures 4-22 to 4-32 present relatively small-scale examples of vegetation cover change via side-by-side comparison of available aerial photography from 1994 and 2014 for Marillana Creek, and from 2006 and 2014 for Weeli Wolli Creek. By presenting aerial photography side by side and at a small scale the figures are able to provide enough detail that the various zones of the creek profile (and their associate vegetation) are clearly able to be identified. Consequently the viewer is often able to clearly establish the changes to vegetation which have occurred between the two snapshots in time. In most cases, the presented examples aren't unusual anomalies, but rather good and easily presentable examples, and as such similar trends are to be noticed throughout the study area. Overlain on top of the comparative aerial photos are two separate layers of OPV mapping for the study area. The "Vegetation Mapping units C1A and C1B combined" mapping polygons represent OPV mapped as part of this study and which has been interpreted to possess a high likelihood of being present within the pre-discharge environment in a similar form. The "Vegetation Mapping units C1/C2A and C2/C1 combined" mapping polygons represent present day OPV which has been interpreted to possess a high likelihood of not being present within the pre-discharge environment. These mapping polygons have firstly been overlain show that the vegetation signature present in the post-discharge environment within (and often around and adjacent to) the bounds of the relevant phreatophytic vegetation polygons, is often clearly absent within the same polygon boundaries of

the pre-discharge aerial photography. Secondly this mapping has been overlain to help the viewer to establish identical spatial position within comparative aerial photos.

Beyond the clear differences between different temporal aerial photo signatures (vegetation) occurring within overlain mapping polygons, the comparative approach helps to illustrate the amount of vegetation augmentation which is apparent in both creek systems since discharge has commenced. Combined with the DMSI change detection imagery, the aerial photo comparisons (and the relevant time periods they cover) help to establish the following things about riparian vegetation within various parts of the study area:

(1) The distribution of apparent vegetation augmentation within the study area (Source: DMSI).

(2) Whether said augmentation patterns show positive correlations with mapping boundaries for significant vegetation (Source: DMSI, and to a lesser extent aerial photography).

(3) The timeline and spatial location of said augmentation (Source: DMSI and aerial photo).

(4) Whether areas of augmentation (evident in 2014) were represented by very minimal vegetation or vegetation of a significantly different aerial signature in the pre-discharge environment (Source: Aerial Photography).

(5) In situations where present day vegetation augmentation patterns correlate spatially with the C1/C2A and C2/C1 vegetation mapping units, and relevant aerial photo signatures instead suggest very minimal or significantly different vegetation was present in the pre-discharge environment, the combination of data supports the previous conclusion in that situation that the significant community is a result of augmentation, and was not present in the Pre-discharge environment.

Put simply, one of the key distinctions here is that using a combination of aerial imagery has the potential to first, using DMSI change detection imagery, attribute vegetation change to a specific spatial boundary over a particular time frame, and then using aerial photo comparison determine the likelihood that the vegetation currently present (in the same spatial bounds), was not present at the beginning of the relevant time period. So through combination, being able to confidently make such conclusions may play an important part in the process of establishing the likely source of change.

Based on the combination of DMSI change detection imagery and aerial photo comparison in the pre and post-discharge environment, the patterns evident within both seem to in many cases, clearly support conclusions made so far about the distribution and extent of OPV. Furthermore, the patterns evident within both data sources also appear, in most situations to support the interpretations made about which OPV communities are likely a product of discharge based vegetation augmentation and were not likely to be present in the pre-discharge environment.

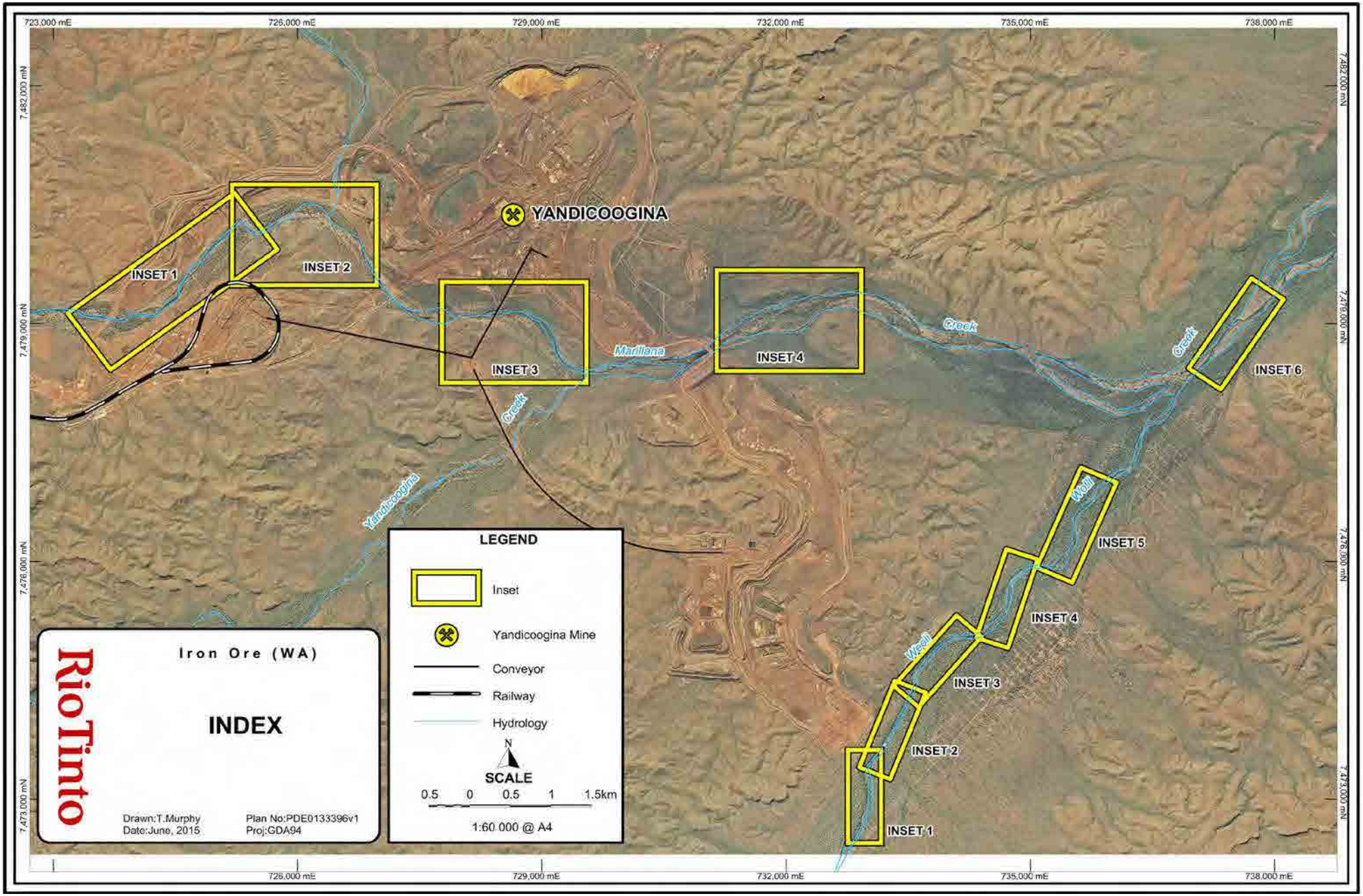


Figure 4-22: Index map showing the aerial photography comparison insets chosen within the study area

Figure 4-23: Weeli Wolli Creek inset map 1; Aerial photography comparison between 2006 and 2014 aerial photo

Figure 4-24: Weeli Wolli Creek inset map 2; Aerial photography comparison between 2006 and 2014 aerial photo

Figure 4-25: Weeli Wolli Creek inset map 3; Aerial photography comparison between 2006 and 2014 aerial photo

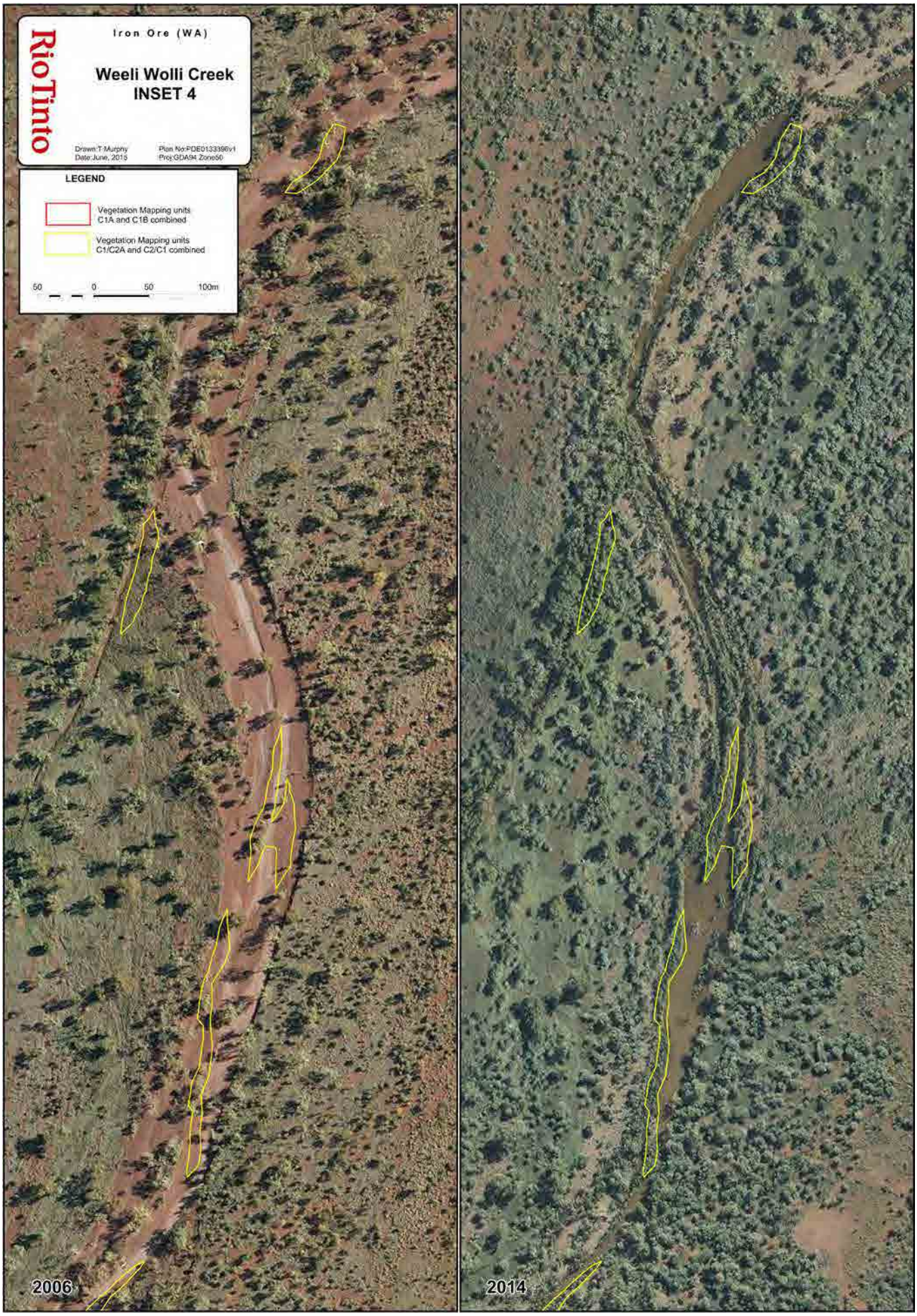


Figure 4-26: Weeli Wolli Creek inset map 4; Aerial photography comparison between 2006 and 2014 aerial photo

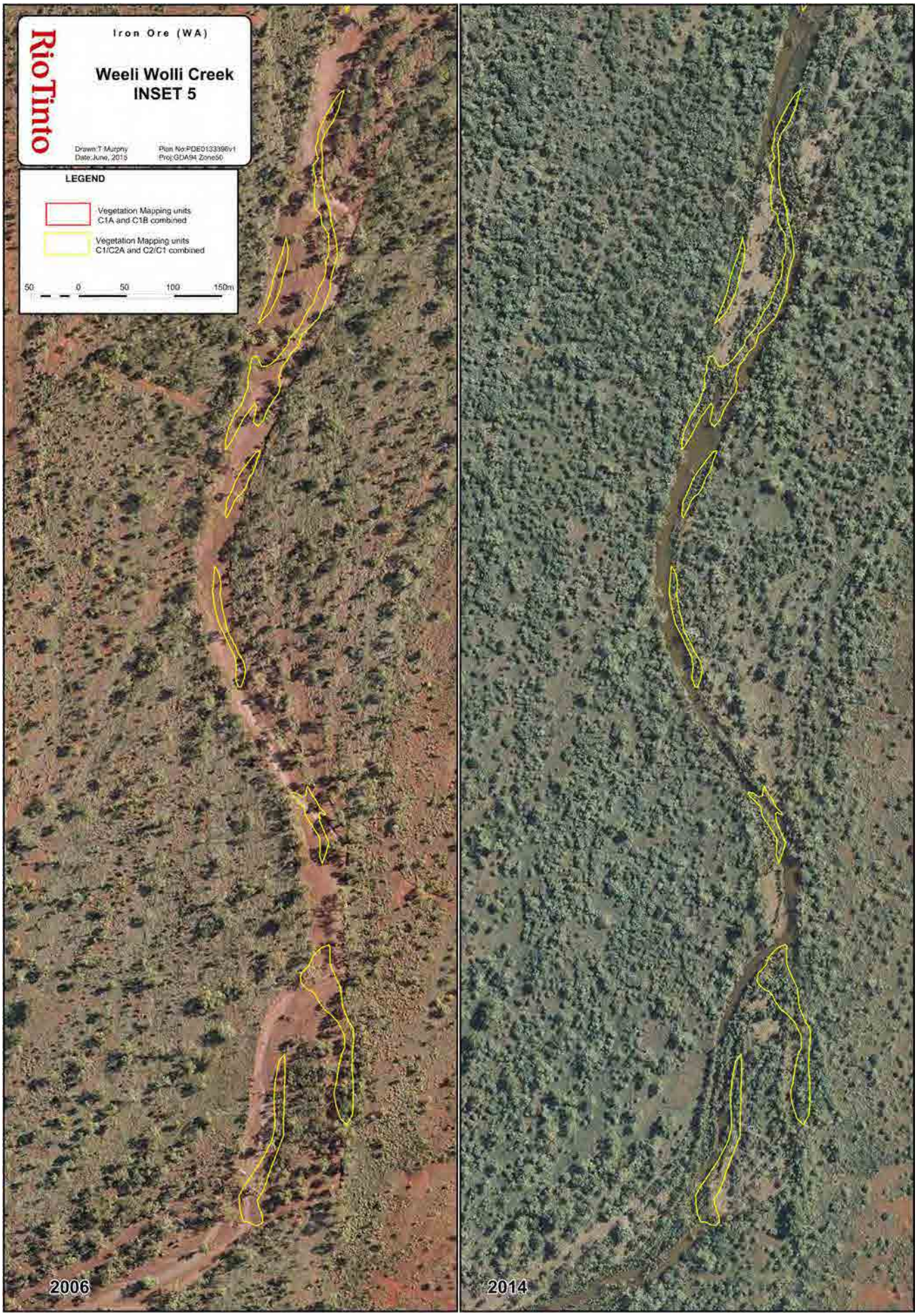


Figure 4-27: Weeli Wolli Creek inset map 5; Aerial photography comparison between 2006 and 2014 aerial photo

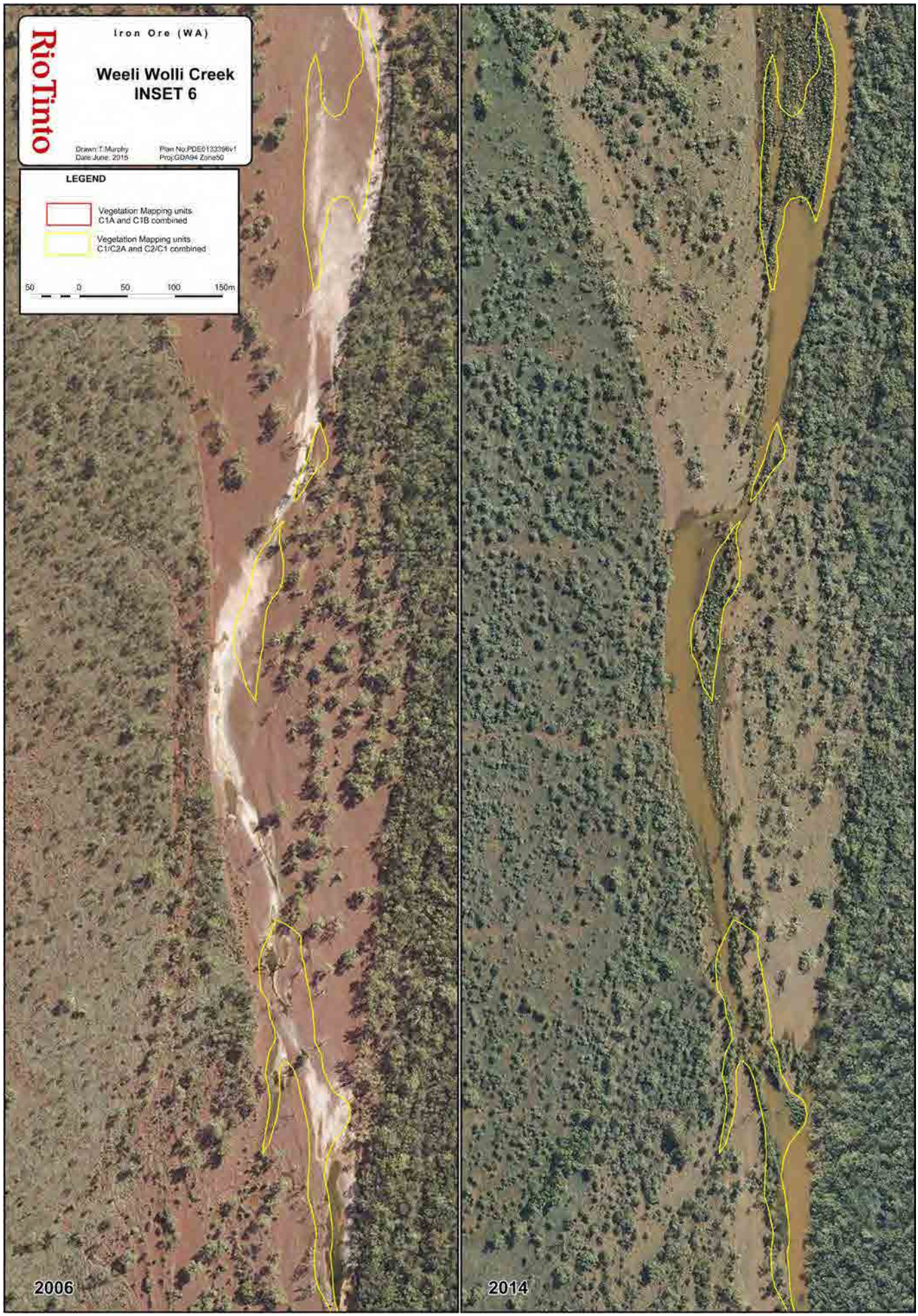


Figure 4-28: Weeli Wolli Creek inset map 6; Aerial photography comparison between 2006 and 2014 aerial photo

Figure 4-29: Marillana Creek inset map 1; Aerial photography comparison between 1994 and 2014 aerial photo

Figure 4-30: Marillana Creek inset map 2; Aerial photography comparison between 1994 and 2014 aerial photo

Figure 4-31: Marillana Creek inset map 3; Aerial photography comparison between 1994 and 2014 aerial photo

Figure 4-32: Marillana Creek inset map 4; Aerial photography comparison between 1994 and 2014 aerial photo

4.8 PERCEIVED "SENSITIVITY" TO HYDROLOGICAL IMPACTS ATTRIBUTED TO LOCAL RIPARIAN VEGETATION BASED ON A COMBINATION OF HYDROLOGICAL SENSITIVITY, PROXIMITY TO POTENTIAL HYDROLOGICAL IMPACTS, AND ATTRIBUTED SIGNIFICANCE

The above sections have made available a set of resultant significance ratings to context the value present within the local riparian environment and associated communities in light of historical changes. Rather than purely map out these significance ratings to present the distribution and magnitude of significance within local riparian communities, it was deemed to be more useful to produce a summary map which presents a measure of the "sensitivity" to hydrological impacts which is perceived to be attributed to riparian communities mapped within the study area. The resultant "sensitivity" scale represents a combination of multiple factors:

(1) Dependency of each riparian community on past/present/future surface and groundwater sources (moisture dependency).

(2) Potential for significant (in the context of each community) changes to surface and groundwater availability throughout their mapped distribution under current and proposed development scenarios.

(3) The significance (perceived value) of each riparian community in the pre-mining environment (which is a combination of values, degree of restriction, and condition), and therefore the importance of maintaining similar forms of each community in the present day environment.

This "sensitivity" rating is in no way a prediction for impact, but rather a more holistic scale of importance for directing management effort to the most worthy and potentially susceptible/at-risk biological features present. The key learnings made about which OPV communities are most likely to have been present pre-discharge and their associated sensitivities form a significant component of the sensitivities attributed to communities depicted in illustrated sensitivity scale.

The "moisture dependency" factor used for the "sensitivity" rating is applied through a combination of broad knowledge of the requirements of key species associated with each community (as presented in section 2.4), the influence of biomass (associated with each community) on water requirements, and the influence of a communities spatial position within riparian habitats on general water availability under various scenarios. The second factor (listed above) relating to potential for changes to water availability is applied through broad local knowledge of current and proposed changes to natural and artificial water sources (some of which are a product of altered catchments and associated changes to hydrological regimes), as well as awareness of broad potential trends in natural water availability based on the best current information sources. The majority if information relating to potential changes to water availability in the study area is sourced from the URS report titled "Riparian Zones Environmental Risk Assessment" (URS 2015).

Figures 4-33 to 4-37 present the resultant spatial distribution and scale of "sensitivity" attributed to the most relevant Riparian communities of the study area (the C coded riparian units presented in this study).

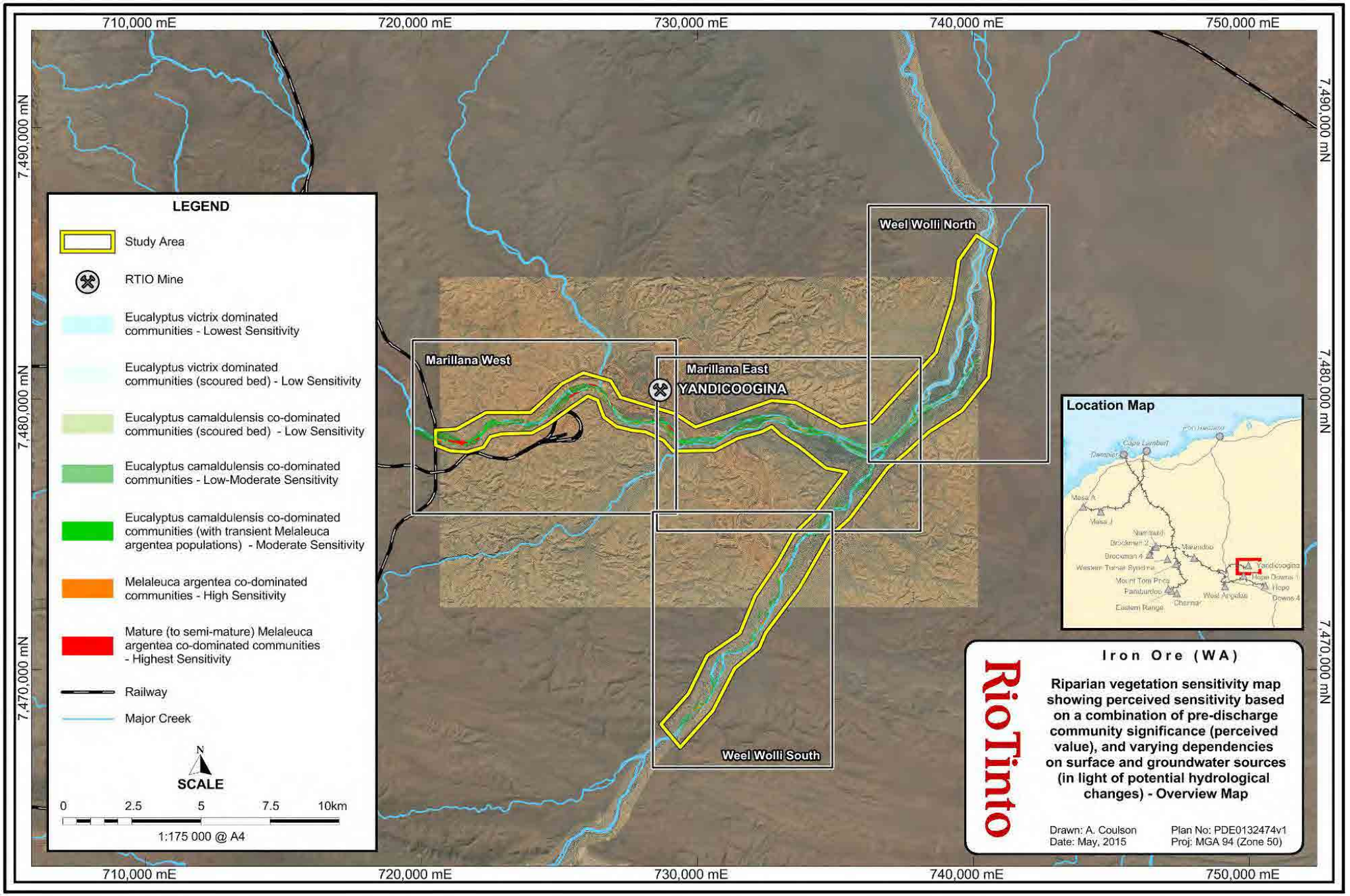


Figure 4-33: "Sensitivity" map overview

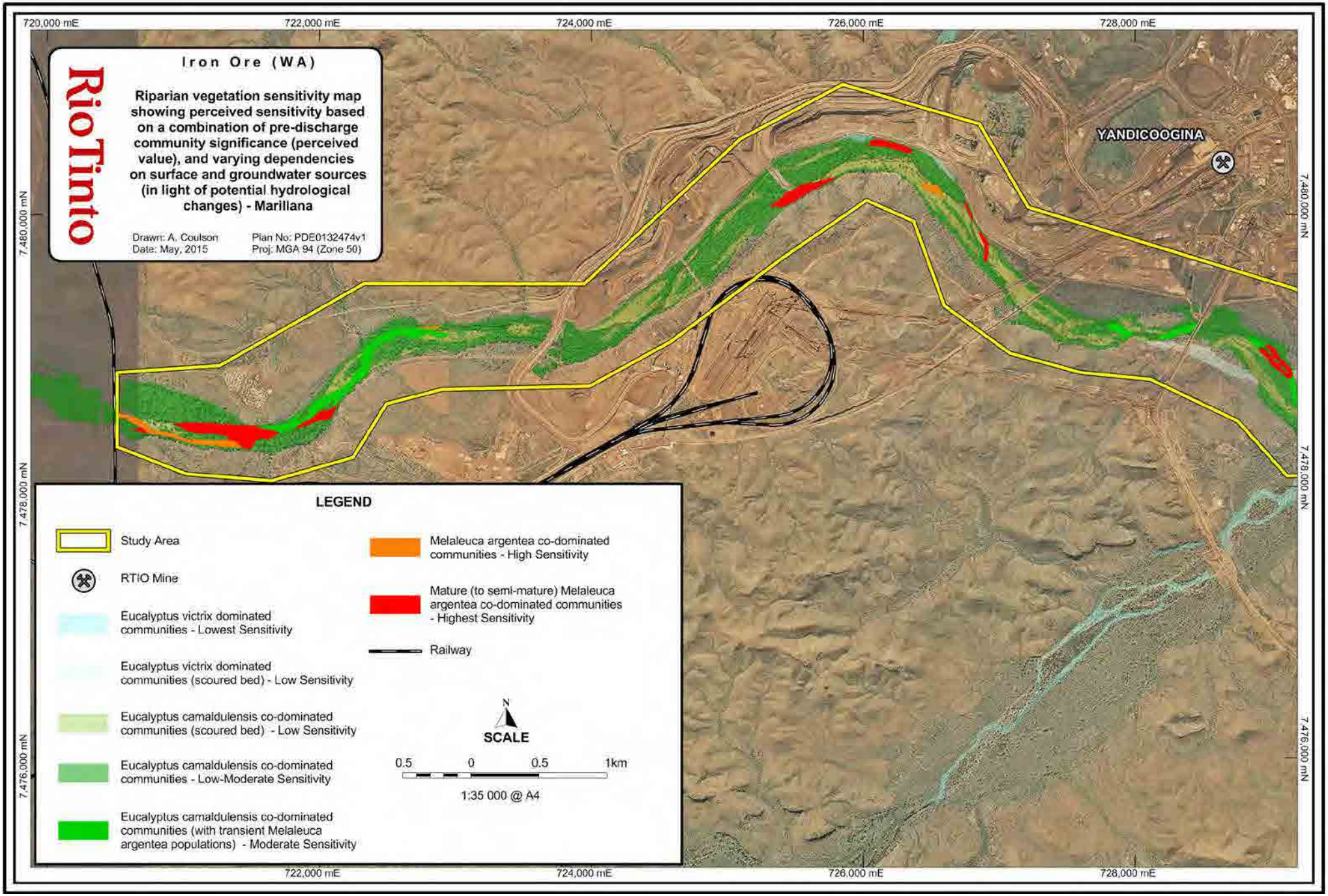


Figure 4-34: "Sensitivity" map; Marillana Creek West Reach

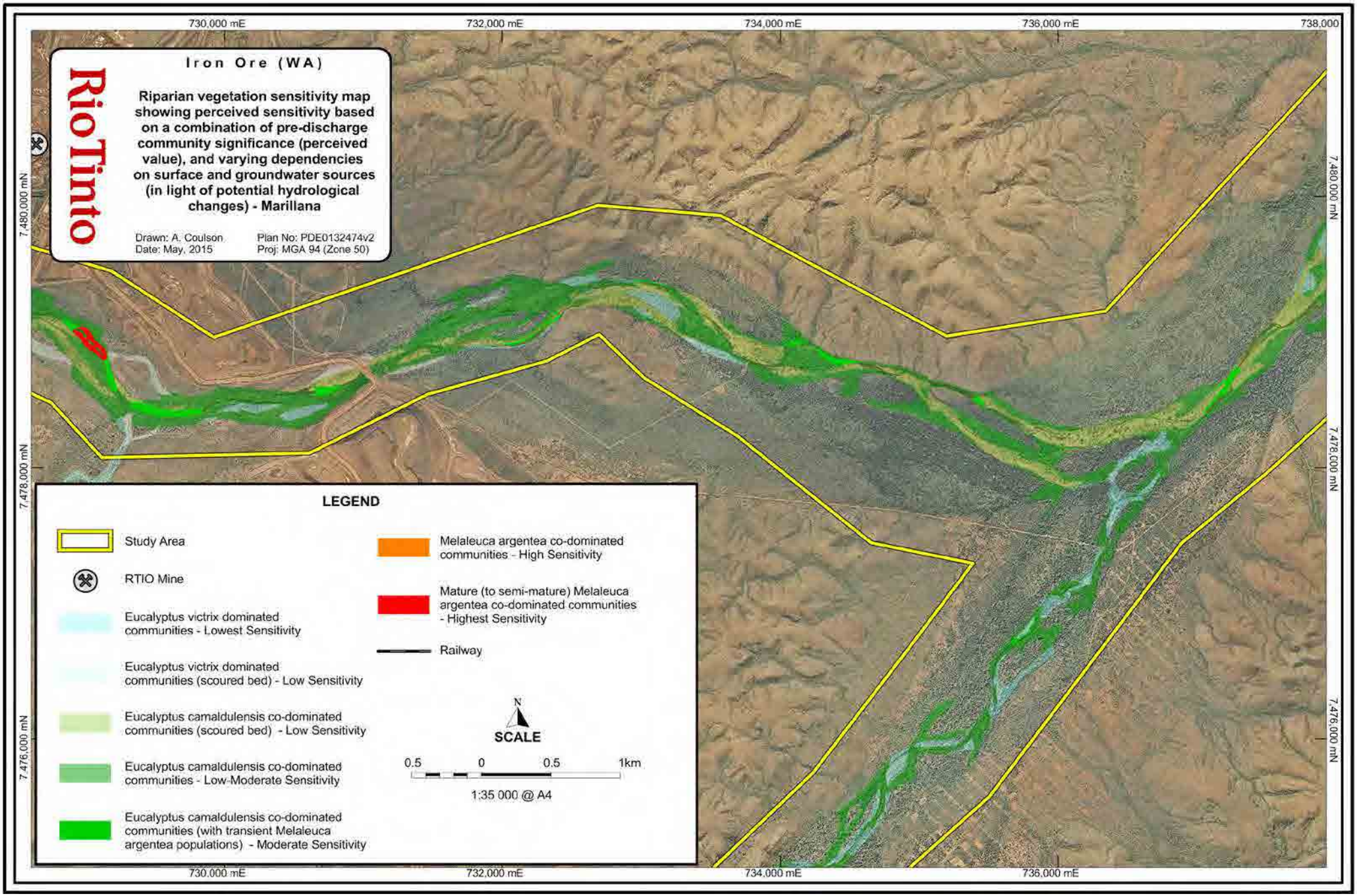


Figure 4-35: "Sensitivity" map; Marillana Creek East Reach

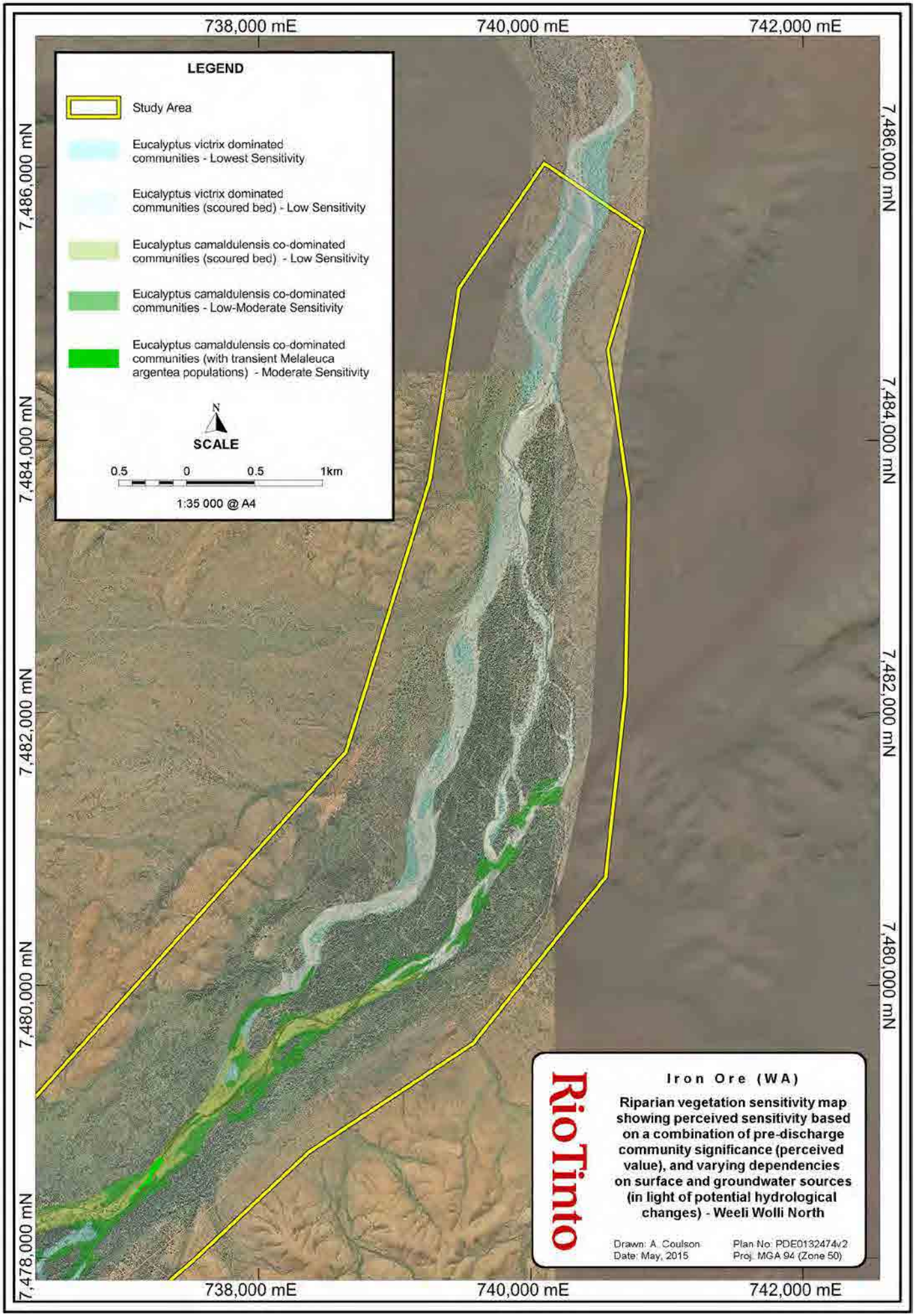


Figure 4-36: "Sensitivity" map; Weeli Wolli Creek North Reach

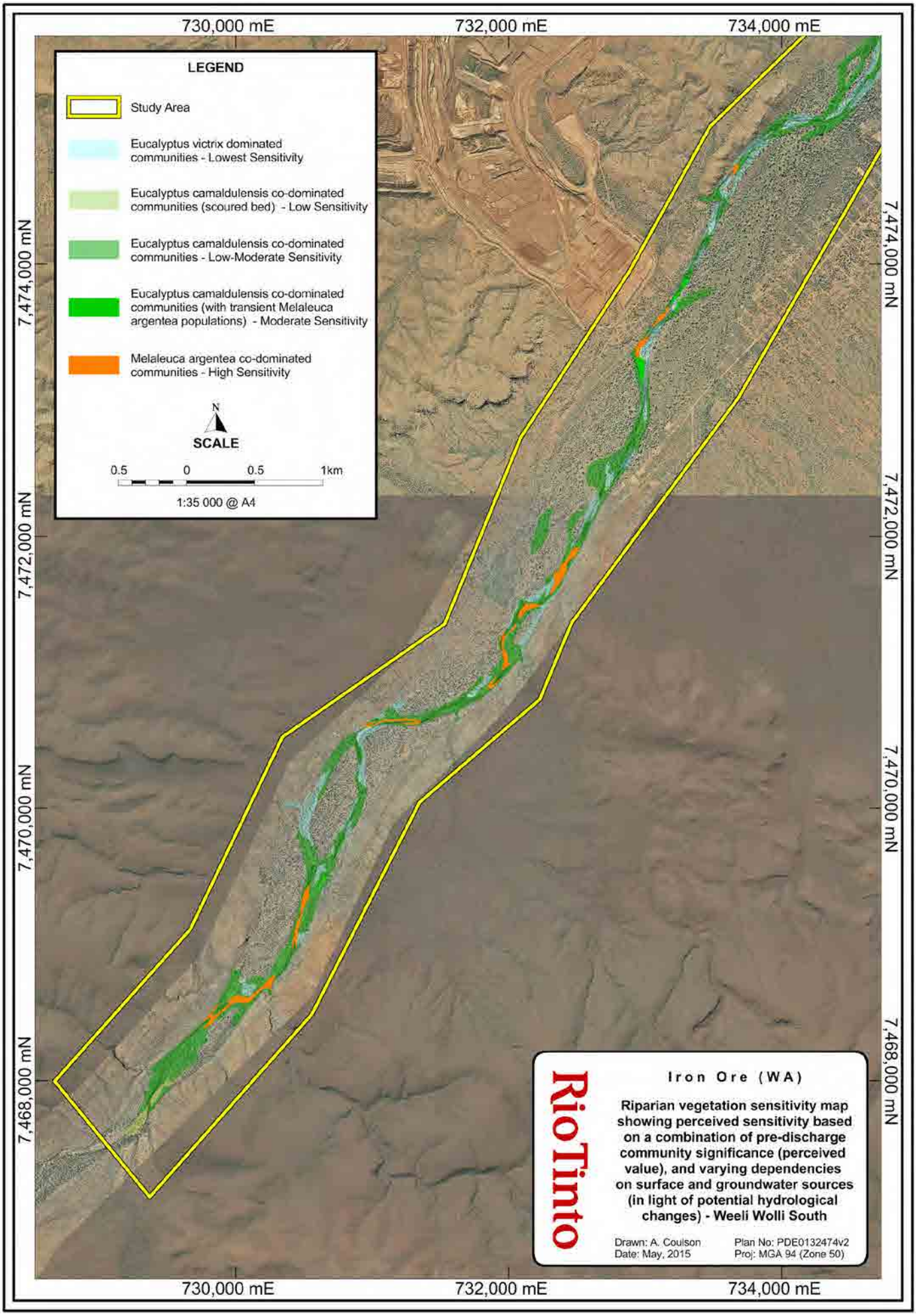


Figure 4-37: "Sensitivity" map; Weeli Wolli Creek South Reach

4.9 SUMMARY OF KEY RESULTS

Beyond the refined vegetation model presented as part of this study, the following key conclusions have been interpreted from the results:

From the above results and it has been determined that at present there are approximately 1.01 km2 of riparian vegetation within the study area which can be considered to represent OPV communities. Of this 1.01 km; the results and interpreted conclusions of this study suggest that only 0.44 km2 (the C1AA, C1A, and C1B riparian vegetation units of this study) can be confidently considered to represent OPV communities likely to have been present in the pre-discharge environment (i.e. Pre-mining), and in a similar form. What this essentially determines is that 0.57 km^2 of mapped riparian communities (the C1/C2A and C2/C1 communities) were deemed to possess a present day *Melaleuca argentea* "size class range" below the projected "cut off figure" for a *Melaleuca argentea* population capable of comprising a significant component of pre-discharge vegetation.

Of the 0.44 km^2 of OPV mapped to occur in the study area, only 0.29 km^2 (29 ha) is represented by OPV within Rio Tinto tenure, as the C1AA unit is located off tenure. Of this 0.29km^2 (the C1A and C1B vegetation units) only 0.16 km^2 (16ha or approximately 0.8% of the study area riparian vegetation) represents the C1A community. Based on the findings of this study, the C1A vegetation unit is the community most accurately defined as being equivalent to the community described in the Yandicoogina "High Level Values statement (Rio Tinto 2011b). Based on the systematic qualitative assessment of significance conducted as part of this study, the C1A community is the only vegetation unit presented as part of the mapping refinement to be attributed the "development significance" rating of High. The remaining community determined likely to be representative of OPV within the pre and post-discharge environment, and which was attributed a Moderate-High "development significance", is the C1B vegetation unit. This unit, while still highly confined and restricted to fine scale riparian habitats, is more widely scattered through the study area, and represents 0.13 km^2 (13 ha or approximately 0.65% of the study area riparian vegetation). The two remaining present day OPV units (C1/C2A & C2/C1 vegetation units), have been interpreted as unlikely to represent OPV in the pre-discharge environment, and as a result of multiple factors have been attributed a "development significance" of Minor-Moderate. This significance rating essentially places them on "par" with the C2A community. Based on the results of this study, the C2A community; represents the community interpreted as most likely to be existing in the place of the C1/C2A and C2/C1 vegetation units pre-discharge (i.e. these communities now possess a significance equivalent to the C2A community).

Given the number of topics covered and the many components presented as part of the results, a recap of what has been explored and conducted so far is included at this point to aid the following discussion through the provision of enhanced awareness of the work conducted in this study.

As part of this study the following topics have been explored:

- The study area, large creek systems of the Hamersley Ranges, Marillana and Weeli Wolli Creeks and how they compare.
- Previous flora and vegetation surveys conducted in and around the study area and associated vegetation mapping.

- The definition of phreatophytic species, OPV, FPV and Groundwater Dependant Ecosystems.
- Factors contributing to biological significance.
- Relevant high-value/significant riparian vegetation communities within the Pilbara and their associated distribution.
- The inherent sensitivity of local Riparian communities, and more specifically GDE/OPV, to Hydrological impacts.
- The history of anthropogenic surface water discharge in the study area.
- The influence of surplus-water discharge on riparian vegetation and phreatophytic vegetation distribution.
- *M. argentea* Growth rate projections under artificial irrigation.
- Remotely sensed imagery and its role in illustrating the potential augmentation of riparian vegetation by surplus-water discharge.
- Establishing a Framework for significance to use in a qualitative assessment process for attribution biological significance.

As a result of field work conducted in this study we have:

- Presented the results of the mapping refinement exercise.
- The mapping refinement has resulted in the production of a riparian vegetation map which determines the fine scale distribution of OPV and FPV communities present throughout the study area.
- Presented the results and general trends relating to phreatophytic vegetation of pre and post discharge historical vegetation surveys conducted in the study area.
- Produced average *Melaleuca argentea* growth projections for 9 and 15 year time periods and applied a deductive theory to determine the likelihood for this species' pre/post discharge presence in riparian habitats of the study area.
- From growth projections and deductive theories, made conclusions about the potential distribution of OPV communities in the pre-discharge Riparian habitats of the study area.
- Conducted a systematic qualitative assessment of the significance of riparian communities of the study area based on associated ecological values, local and regional distribution/restriction, condition, and likelihood of presence pre-discharge.
- Presented remote sensing based evidence to support the conclusions made about the distribution of OPV in the pre and post discharge environment of the study area.
- Interpreted anomalies within DMSI change detection imagery based on learnings about the distribution of pre-discharge OPV and discharge augmented vegetation.
- Created a "sensitivity" to impact map for the study area, which presents a combination of significance, hydrological sensitivity, and proximity to potential hydrological impacts for all riparian communities mapped within the study area.

5 DISCUSSION

5.1 COMPARISON OF HISTORICAL FLORA AND VEGETATION SURVEY DATA

Comparisons of the pre-discharge surveys of Mattiske (1995a, 1995b, 1995c) and Integrated Environmental Services (1981), with the multiple post-discharge surveys of Biota (2004-2014, summarised in; Biota 2014a) were conducted as part of this study.

The clear conclusion which these surveys present, with relation to the distribution of OPV in the current study area, is that; beyond small isolated pockets of vegetation where this species was observed to be associated with or a co-dominant of resident *E. camaldulensis* woodlands, this species was not typically present in the pre-discharge riparian environment. Conversely its distribution in the post-discharge environment as either a co-dominant component of OPV or merely an associated species within *Eucalyptus* spp. woodlands/open-woodlands distribution appears to be significantly increased, but in general still quite restricted. While some comments have been made about the relatively broad scale of the vegetation mapping conducted as part of the pre-discharge surveys (Mattiske 1995a; 1995b; 1995c), the sampling effort conducted in both pre and post-discharge surveys appear relatively equivalent, and so it would be expected that the quality and representativeness of both vegetation models would be relatively similar.

The absence of pre-discharge quadrat data and associated vegetation mapping (sourced from Mattiske 1995c), in the stretch of Weeli Wolli Creek most relevant to the proposed Pocket-Billiards study area (**PBS**) does raise some questions. Namely; what might comparative patterns pre to post-discharge in this area show if pre-discharge surveys had covered this creek stretch? The important distinction in this case is that the Southern Corridor survey of Mattiske (1995c) did survey the 4 km upstream stretch of Weeli Wolli just south of the PBS project where Weeli Wolli Creek emerges from the Packsaddle Range. This stretch of Weeli Wollli Creek does represent the tail end of the zone immediately downstream of the springs, and which could be easily interpreted as the creek stretch in the vicinity of the PBS project most likely to have possessed near perennial water availability pre-discharge (see Figure 2-2 for illustration of this creek stretch; represented by the overlap between the current study area and Mattiske's "Southern Transport Corridor" survey area, (Mattiske 1995c)). Essentially; the broad perceived pre-discharge trend in surface/sub-surface water availability through this area, is that it was reducing when moving downstream (away from the spring) and out of the packsaddle range to the confluence with Marillana Creek.

Mattiske quadrats located in the stretch of Weeli Wolli Creek immediately upstream of the study area boundary (see figure 3-1), show *M. argentea* co-dominance within the vegetation of some quadrats. However, moving downstream from this stretch, further away from the spring, and essentially out of the Packsaddle Range (through the 4 km stretch of overlapping study area boundaries), *M. argentea* is no longer recorded in the pre-discharge quadrats. In light of the above described broad water availability trend and its likely influence on OPV, it is important to note that patterns in pre-discharge *M. argentea* distribution through the same area (shown by pre-discharge quadrat sampling data), tend to support the trend and support its observed influence on OPV distribution. Furthermore, despite surplus-water discharge providing perennial water availability, more subtle present day patterns in *M. argentea* distribution and structure also tends to support the broad trends in pre-discharge water availability. Consequently it is postulated that downstream of the last available pre-discharge quadrats (within the PBS project area), broad trends in pre-discharge

M. argentea and associated OPV distribution were likely to follow the patterns shown in the Mattiske (1995c) sampled zone immediately upstream. This pattern suggests that; beyond minor populations present in very small and isolated occurrences of OPV (as shown by the C1B community distribution), *Melaleuca argentea* is most likely to have been relatively absent throughout the stretch of Weeli Wolli Creek which runs through the PBS project area.

5.2 THE MAPPING REFINEMENT EXERCISE

Previously; due to the broad scale nature of mapping in the area, and inherent OPV mapping inaccuracies resulting from community aggregation, mapping indicated that OPV communities in the study area (the previously coded C1 vegetation unit) represented a combined area in the order of 260ha or 2.6km^2. The new figures of 1.01km2 of post discharge OPV and 0.44km^2 of inferred pre-discharge OPV represent a significant change in the distribution and extent of this type of riparian community, and both pre and post discharge quadrat data tend to support this result along with the trends present in DMSI imagery, historical aerial photography, and historical observations. Consequently, based on the present day total of 19.5 km^2 of riparian vegetation associated with large creek habitats of the study area, only approximately 2.3% of this area is likely to represent OPV present in the pre and post-mining environment.

A key conclusion of the results is that the C1A and C1B communities, possessed a "size class range" above the "cut off figure", and were interpreted to represent those refined communities likely to be present in the Pre-discharge environment. Conversely the C1/C2A & C2/C1 vegetation units fell below the "cut off figure" and were interpreted as absent. It should firstly be noted that the C1/C2A and C1B communities are those communities which possess a maximum *M. argentea* size class which respectively falls immediately below and above the "cut off figure" for determining likely presence in the pre-discharge environment. This essentially means that the "size class range and inferred age structure for *M. argentea* populations in both these communities determines that, beyond the inferred pre-discharge presence/absence, they alternatively have a low potential of being present (in the case of C1/C2A) or absent (in the case of C1B) in the pre-discharge environment. Put simply;

- In many cases the **C1B** OPV community **may not** have been present pre-discharge; in which case it is likely that the C1/C2A & C2/C1 were correctly inferred to be absent as well;
- Alternatively, in many cases the **C1/C2A** OPV community **may** have been present pre-discharge; in which case it is likely that the C1A and C1B were correctly inferred to be present as well.

The key distinction here is that there is a low potential for these scenarios to be correct, but while low there is still potential, and as such a caveat is placed on pre-discharge interpretations attributed to these two communities (the C1B, and C1/C2A communities). This caveat essentially reminds the that; in some cases patches of present day OPV represented by the C1/C2A mapping unit may have represented OPV pre-discharge, and conversely some patches of the C1B mapping unit may not have represented OPV pre-discharge. While minimal, this potential variability in the accuracy of the inferences/interpretations about the presence of OPV pre-discharge, is purely a product of the maximum *M. argentea* population size class for each community falling above and below the "cut off figure". This relative position is illustrated in Plate 10, along with the relative confidence in the inferences/interpretations attributed to each present day OPV community. While this distinction is

an important one, an equally important distinction should be made for the opposing C1A and C2/C1 vegetation units. In both cases, the degree of size separation between the "cut off figure" and the estimated "size class range" of these units (see Plate 10 for an illustration), determined that the confidence in the attributed inference of likely pre-discharge presence as OPV, is high. Consequently it is concluded that the interpretations of pre-discharge OPV presence attributed to the C1A and C2/C1 units are considered most accurate, and that in some situations a degree of uncertainty remains about the interpretations attributed to the C1B, and C1/C2A vegetation units.

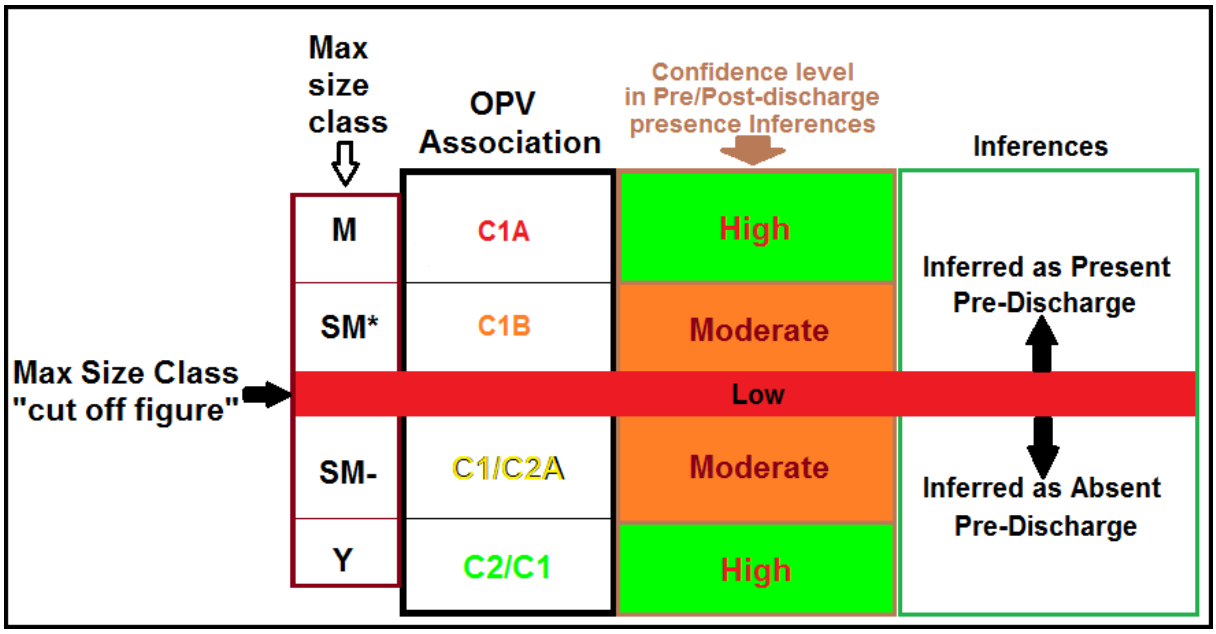


Plate 10: Presents an illustration of the relative position of mapped OPV communities in relation to the maximum size class "cut off figure" and the associated confidence levels for the relevant pre/post-discharge inferences/interpretations which have been attributed to each community.

5.3 LIMITATIONS AND ASSUMPTIONS INVOLVED IN INTERPRETING THE LIKELY PRESENCE OF OPV IN THE PRE-IMPACT ENVIRONMENT

The problem of how to determine the presence and distribution of a significant community in a pre-impact environment is not a typical one. Furthermore; to solve this problem, studies would typically rely on historical information collected about the about the pre-impact environment. In the case of the study area, the historical information did not cover the entire study area, and was generally not detailed enough to provide sufficient insight to fully resolve the problem. Therefore in lieu of adequate pre-impact information this study used present day field data combined with growth projection data and a deductive process of comparative interpretation to enable an understanding of the pre-mining environment. This technique has various inherent limitations and assumptions which have to be made to provide an interpretation of likely pre-impact presence. Consequently, the interpretive process used could easily be classed as atypical, however it provides the best available measure for interpretations and inferences in the absence of adequate historical information. With this in mind, some of the pertinent limitations, and potential issues with the technique used are important discussion points to be addressed.

The accuracy of the assumption that *Melaleuca argentea* is the primary indicator species for determining if a community represents OPV may be questioned. While *M. argentea* is considered to be an obligate phreatophyte and the tree species most sensitive to changes in water availability in

the Pilbara. *Eucalyptus camaldulensis* is considered to be a facultative phreatophyte which at times has been suggested to be an obligate phreatophyte in certain circumstances (Wen et al. 2009). The important distinction here is that in many cases *E. camaldulensis* can survive when the water table or availability of surface water fluctuates significantly. It is for this reason that the use of this species as an indicator for true (obligate) ground or surface water dependency is considered problematic. However, *M. argentea* is considered to be intolerant of similar changes in hydrology, and therefore a more consistent indicator of perennial water availability (Graham et al. 2003). Furthermore, in most if not all cases, the two species are associated, and so it is rare to find *M. argentea* without *E. camaldulensis* present. However the opposite is not true and it is quite common to find *E. camaldulensis* without *M. argentea*. Therefore the presence of *E. camaldulensis* without *M. argentea* indicates some degree of moisture dependency, but the addition of *M. argentea* in any situation generally indicates an increased degree of moisture dependency. It is for this reason *M. argentea* was used as the key indicator for the existence of OPV or true GDE.

Alternatively, a relevant question might be; does the presence of one obligate phreatophytic species determine that a community is considered to be OPV. Assuming the phreatophytic species represents a dominant/co-dominant species within the community, the answer must be yes, as the community description would change if its presence was removed or significantly reduced due to reducing water availability. In turn the reduction in water availability, combined with the dominant/co-dominant absence of the phreatophyte, would determine that the remaining community was not dependent on perennial water availability, and the OPV tag would no longer be applicable.

Influence of the physical environment

A second discussion point and potential point of contention is represented by the deductive process and assumptions used to interpret the likelihood of present day OPV communities occurring in the pre-discharge environment as OPV. This process essentially assumed that if the vast majority of the stems within a population were below a minimum DBH or “cut off figure” (that average DBH which a seedling is projected to grow to in the time available since discharge), then it was unlikely that the population in question represented a relatively mature population likely of being present in a similar form in the pre-discharge environment. While this assumption is logical, it may not be true in all situations. For example there may be situations within the creek profile where the morphology of the creek has changed significantly since discharge, such that it may no longer provide the same hydrological conditions, and therefore may not be able to support OPV without discharge inputs. There is some potential for this and other similar effects to influence the results of this study (potentially causing a false negative result). However, assuming they are the result of natural physical changes, most probably at fine scales within the creek system, then the resulting changes to the distribution of OPV is also a natural one, and the results remain correct. There are potential situations where these changes may be a result of anthropogenic changes to hydrology. In such cases, observations and evidence (both physical and biological) suggesting the changes are anthropogenic are relied upon to determine the true cause of vegetation changes. In the case of this study, there were no obvious biological changes detected which might be attributable to moderate scale changes in creek morphology. Furthermore, from a physical sense, regular visitors to the creek system have not reported any obvious and atypical physical changes to creek morphology.

Influence of the biological environment

Changes to the biological environment may also provide other potential sources of contention to the deductive assumptions used. One such source of contention might be surrounding the validity of inferences made from the size structure and inferred age structure of a community at any one time. For the purpose of this report the age structure (and conversely size structure) of a population is defined as the distribution and frequency of individuals among various potential age (or size) groups. In graphic form, age structure is portrayed as an age pyramid whose relatively broad base indicates the number of young individuals while the peak reflects the increasing likelihood of death as individual's age. A population whose age structure has a very broad base and a sharp narrow peak is said to be "young" (or un-stable), while a structure whose base is not much wider than the rest of the pyramid is considered "mature" (or stable) and possesses a relatively even frequency distribution (Barbour et al. 1987).

In the case of this study, the key size/age structure of value when trying to determine presence/absence pre-impact would be one with a broad base, and a sharp peak with a significant proportion of the potential pyramid height not represented by any individuals (i.e. no individuals which fall into the upper size/age classes are present). It could be perceived that a major impact event such as a 100 year flood could strip a creek of the majority of its resident *M. argentea* population, such that the population which established post flood-impact would be quite small/young and of a very consistent size/age structure.

It is this same average size, and size structure which would, in this study, generally be interpreted as a population likely to have established as a result of augmentation post-discharge. While there is no doubt that such an event would influence the data of this type of study, it is highly likely that the flood event and its impacts would be known about and taken into account when attempting to set up the study. In this case, there are no known events in recent history where flood waters have stripped significant proportions of tree populations resident in the study area. It is also considered that such an event may lead to larger more mature trees being one of the key groups of survivors, and consequently the results would be skewed in the opposite direction.

5.4 LIMITATIONS AND ASSUMPTIONS ASSOCIATED WITH THE GROWTH PROJECTIONS

Another potential source of contention may be the validity of the growth projections. For this study it was considered that the best way to determine the average amount of growth which *M. argentea* would likely realise in 9 and 15 years is to measure individuals of this species in the same or very similar environments for at least 9 years (preferably 15). However, this type of data has not been collected, and while a significant amount of monitoring has been conducted in Weeli Wolli and Marillana Creeks, no long term DBH data is easily accessible for individual trees. This is because trees are generally only recorded with a distance along and a distance out from the transect. Consequently, when the data is scrutinised, it quickly becomes clear that determining which trees are which for longer periods of time is quite problematic.

In nearly all cases, mostly due to tree number labels being lost in the field, the degree of confidence that DBH measurements were from the same tree decreased with successive monitoring rounds. It is for this reason that the monitoring data used in this study for growth projections, generally only used a one to a few years of monitoring data for each tree. So what of the validity of the growth projections? The first obvious question relates to the validity of the technique used. For this study it was deduced that the use of the change in horizontal two dimensional (cross-sectional) trunk area would be the most relevant and consistent figure to use for projections, especially when considering that the field data collected in both cases was essentially trunk diameters. Obviously the use of

diameters (in that form) to compare and project growth was not wise, as change in DBH for different sized trees represents significantly different increases in trunk biomass. Consequently, the decision to convert diameter changes to changes in two-dimensional trunk biomass was a clear choice of comparative measure given the base data was represented by changes in diameter.

From a mathematical sense the logic used seems sound, but the pertinent question remains, does the projections calculated actually represent average growth? It is obvious that the monitoring data used for the projections, does not take into account the number of trees which either died, or for many years suffered damage, disease or insect attack and so did not increase trunk diameter at normal rates (or at all). While this is a legitimate consideration, in some ways it is not considered relevant to the technique used. The technique used in this study assumed that regardless of how slow some individuals grew (due to a combination of environmental factors and chance), the important and most determining parameter was that growth exhibited by individuals which represents a relatively average to above average growth rate (sustained by similarly average/above-average conditions). By focusing on this figure the assumption was that in any population, a certain percentage in individuals would grow at relatively optimal rates, and therefore these individuals would often represent the larger of the individuals present in a population.

Therefore by assessing and classifying populations by the average size range present in a population, one would in turn get a reading for the average maximum size (i.e. the upper size class within the attributed “size class range”). Thus the individuals in a population whose size represents the average maximum size of the population should provide an indication of the size realised by average to above average growth rates relevant to the population. Finally, it is assumed that; by comparison of average growth rates per year of monitoring trees, to the trunk cross-sectional area (2-D biomass) realised by the larger trees of an in-situ population, a division calculation can provide an estimate for the number of years the larger trees took to grow.

The final assumption is that for this comparison to provide an indication of how long that population might have been present in relation to the time period of focus; the in-situ population must lack the presence of individuals of a size equivalent to at least a few of the typical/expected upper size classes. The typical/expected upper size classes are those sizes/ages which the species is typically known to realise, but which in such cases have not yet been realised due to the average age of the population. Plate 11 shows two basic examples of age structure (conversely size structure), with the left representing a relatively even and stable population. The age/size structure on the right is one broadly equivalent to that of a population which might be assumed to be relatively young and have established following a recent perturbation. This structure possesses an un-even frequency distribution, but more importantly lack individuals in the upper size/age classes typically known to be realised by the species in question. It is this pattern in age/size structure which is inferred by this study to indicate a lack of maturity within a population and therefore a potential for the population to have only established since surplus-water discharge commenced.

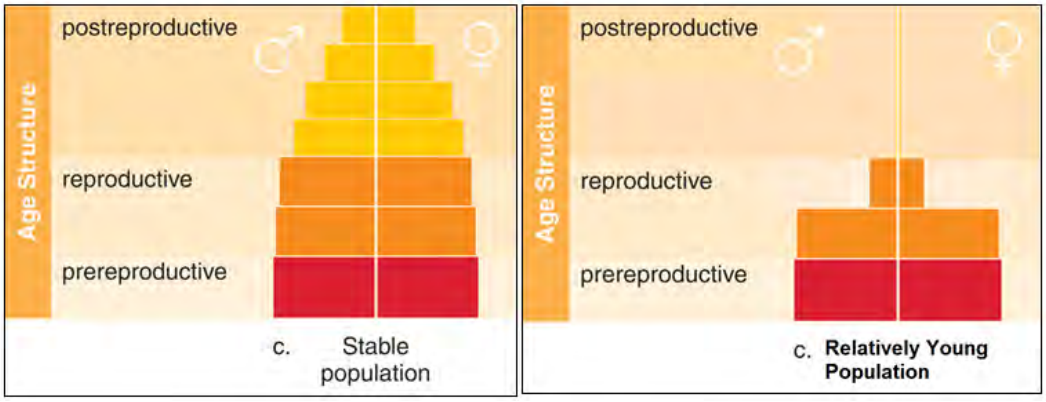


Plate 11: Presents a theoretical age structure for a relatively stable and mature population on the left, and for a relatively young, unstable and non-climax population on the right

It is an acknowledged limitation of this method that within this group of the largest individuals, a number may have taken a significantly longer time period to reach that size (possessing stunted growth: due to whatever reason) than the time period indicated by projected figures to be associated with their diameter. In some ways this effect was allowed for by factoring in a buffer to the growth projections; in this case the actual data was reduced by 20%.

To allow an additional degree of conservancy and therefore further allow for this effect; when deciding which side of the projected diameter cut off figure (for both temporal growth regimes) a population would be classified to fall, the upper limits of diameter observed for that population were required to be clearly below the cut off, and not falling too close to the "cut off figure" set. Given these allowances, it appears unlikely that the stunted growth effect would significantly influence the age of individuals in the upper size class (for a population), beyond the margins allowed for. Consequently For the purpose of this study it is considered that these allowances are sufficient to take this effect into account.

An additional allowance, and therefore degree of conservatism is represented by the USE of DBH for growth projections and "diameter at knee to waist height" for trunk size data estimated in the field. Given that diameter reduces from the knee/waist-height to breast-height, the figures used for the "size class ranges" are **larger** than their actual respective DBH, and so when this slightly inflated figure was compared to the "cut off figure", which is in DBH it allowed for an additional buffer of conservatism. For example if the biggest individual in a population has a diameter of 20 cm (at knee to waist height) and we compare it to a 24 cm "cut off figure" (in DBH), rather than comparing 20cm with 24 cm (tree to cut-off), it's likely that in fact we may be comparing 18 cm to 24 cm (tree to cut-off). The quantitative size of this effect is unclear, but when combined with other sources of conservatism the result is an increased confidence in the conclusions made for populations deemed to be under the "cut off figure" and therefore deemed unlikely to be present in the pre-discharge environment as OPV.

An additional degree of confidence in the deductive process used and the resultant conclusions is represented by the supporting inferences which can be made from the age structure of a community, regardless of the maximum upper age class observed. It is assumed that if the age structure is skewed towards the younger age classes, and therefore the majority of the population is represented by very similar aged individuals, then the population is more likely to have grown in response to a change in environmental conditions. Plate 12 below shows an example of a population of *M. argentea* with an equivalent age structure.

Generally it is the populations with these age structures which possess the lower maximum age class which are likely to determine that the population will fall below the projected "cut off figure" (DBH) and therefore potentially be classified as only occurring post impact. In situations where there appeared to be a greater range of age classes present and a more even spread of numbers of individuals across the age structure (such as that illustrated in the left side of plate 11), caution was taken when deciding which side of "cut off figures" these populations would be classified to fall within. In most cases populations with such an age structure would inevitably be decided to represent an "age class range" falling above the "cut off figure", and therefore present pre-discharge. However, in general, the use of caution involved the consideration of additional size class and size/age-structure characteristics and criteria when determining the broad "size class range" to which populations were attributed (see Table 4-3 for details).

Plate 12: Example of a population of minimal size variation, and therefore representing a very uneven age structure dominated by young individuals of a similar age

Assumptions of maintaining optimal growth

Further to the effect discussed above, it is important to consider the potential that; because of the general process of attrition and the changing sources and magnitudes of perturbations associated with the fluvial environment (most particularly, variably sized flood events), the likelihood of individuals reaching size classes considered semi-mature and mature (based on size definitions provided in this study) may be quite low. As a consequence, it is possible that the individuals of a similar size (i.e. approximately semi-mature to mature) which are present within a population, may in general be much older than that age predicted by growth projections for their DBH. Therefore, the conservative allowances discussed above may be insufficient to allow for the potential difference. The sources of delay to growth which might result in a potential failure to consistently reach demonstrated growth potential over a mature individual's life span, are likely to be many and variable in their effect and duration. While such an effect on long term growth is possible, a key observation which does not support this being likely is the existence of *M. argentea* populations dominated by relatively mature and large individuals. There are many examples of this age structure in the Pilbara, and their existence indicates that it is unlikely that most older large *M. argentea* individuals are unable to have achieved that size in an efficient time span. In most cases, the variability surrounding the distribution of these older individuals appears to be driven by a combination of fine scale spatial variability in the provision of suitable moisture and shelter (from flood damage) conditions and the chance that an individual's position coincides with these conditions.

Beyond the effect discussed above, it should also be considered that maybe the absence of older individuals within a population may not always be an indication of how long the population has been sustained in that area. If this line of argument is considered, it seems possible that in certain situations the environmental conditions of a site are not suitable enough to support older individuals, and instead a young age structure may have been sustained in that area for a long time. Such a situation is typically considered to be likely in areas where, for example, *M. argentea* are generally only present as an associated species. In these areas it appears as though the availability of moisture is a limiting factor such that individuals establish in small niches for short periods of time, but do not tend to last long enough to contribute to an increasing sized population. Despite this the important distinction is to be made in situations where; young individuals get to a significant density, such that they reach a cover/abundance sufficient enough to comprise a co-dominant component of the surrounding community (and are distributed more widely). In such situations it is assumed that the increased density of individuals (and inferred recruitment success rates) indicates that the resident population is not limited by environmental conditions such as moisture availability, and will consequently continue to grow towards maturity (assuming conditions do not change considerably).

In areas where *M. argentea* is a co-dominant member of a resident community; it is this latter described tendency for the environment to support growth to maturity (in at least a small portion of the communities areal extent), which is considered most likely to occur in the natural environment. Regardless of the reality, it is an important principle of this study that a large part of the significance of these riparian communities is attributed to the values associated with their structural and compositional diversity. In general, structural and compositional diversity tend to be greatest when a community reaches maturity, or possesses a population age structure representing a stable population; such as that depicted in Plate 11. This principle determines that in situations where the environment is not able to support a more mature community, then the values attributed to that community are reduced when compared to areas where mature communities are able to be supported. Therefore it is assumed that; if a *M. argentea* population is a co-dominant community member, but the population continues (somewhat indefinitely) to be represented by a consistently young age structure, then it's likely to be inconsequential that this study wrongly interprets its likelihood of presence in pre-discharge environment. Reason being, that its value/significance in reality and its value/significance attributed in this study are likely very similar, given that the values/significance attributed in this study are to a large degree, a product of characters associated with mature, and potentially climax communities.

5.5 SIGNIFICANCE OF RIPARIAN COMMUNITIES

Riparian maturity and significance

When it comes to values associated with a community, the above identified link with maturity or the degree to which an ecosystem represents a climax community is often a focus of consideration when attributing significance to riparian communities. The "High Values Statement" for the Yandi project area, attests to this focus. Within this Statement and under the heading of Flora and vegetation; one community is listed to possess high values in the area. Described as; "riparian woodland of *Eucalyptus victrix*, *Eucalyptus camaldulensis*, *Melaleuca argentea*, *M. glomerata"*, this riparian community essentially represents a mature and potentially climax community, whose *Melaleuca argentea* component exists in the woodland layer determining that it is made up of mature trees between 10-30m tall (Low-woodland = trees under 10m tall, Woodland = trees 10-30m tall) (Aplin

1979). If we look at the equivalent community in the refined mapping produced as part of this study, the very closely associated equivalents to the community described in the High values statement are the C1AA, and C1A vegetation units. The C1AA community is situated off tenure, and while it represents the largest representation of "high value" riparian vegetation in the study area (15 ha; potentially larger as it appears to extend beyond the study area boundary), its values are presently reduced due to mining related drawdown currently in effect as a result of BHPBIO mining activities. Within the study area, the C1A community is represented by a number of quite small representations all of which occur on Marillana creek. Totalling 16 ha in areal extent, the largest and most significant representation of this community in the study area covers 7 ha and occurs directly downstream of the BHPBIO discharge point. This patch appears to be associated with the large bend in the creek and the underlying CID deposit which intersects the subsurface of the creek in this area. The remainder of the representations of the C1A community are all relatively small, with the second largest covering approximately 2.7 ha, (50X500 m long). As a consequence of the generally smaller spatial extent of the remaining areas, in many cases they possess a reduced number of values or reduced quality of resident associated values, when compared to larger occurrences. This reduced number/quality of values is generally attributed to the influence areal extent can have on these factors, such as its effect on the likelihood of an area supporting conservation significant flora and fauna. One example of such a factor might be the population of chocolate bats known to occur at Weeli Wolli springs, and which is likely to occur there due to the size and subsequent appeal of the riparian community present.

Beyond the above two discussed communities which are essentially equivalent to that listed in the "Yandi High Values Statement" (Rio Tinto 2011b), the next closest (or similar) community is represented by the C1B community. This community is scattered throughout parts of both Marillana and Weeli Wolli creeks, and is considered to be fairly equivalent to Biota' previously mapped C1 community (Biota 2014a). In comparison with the C1A community, the C1B community is a eucalypt woodland which possess *M. argentea* as a co-dominant species in the low-woodland layer (trees under 10 m), and therefore represents a community with a less mature population of *M. argentea*. It is believed that this difference is likely to be associated with a reduced consistency in perennial water availability in these areas (more likely a product of differences in ground as opposed to surface water availability) when compared to other areas such as those mapped as the C1A or C1AA community. The C1B community covers a total area of approximately 13 ha, with the largest single representation also associated with the area directly downstream of the BHPBIO discharge point (3.5 ha). The remainder of the representations of this community are all quite small and are generally restricted to occurring within close proximity of the low flow channel. The second largest representation of this community covers 1.7ha, while the remainder of the larger patches cover between 0.4 and 0.8 ha.

This pattern of reducing areal extent as the estimated maturity of the associated *M. argentea* component reduces, appears consistent with the theory that the maturity of the resident community is a measure of the consistency of perennial water availability. The reasoning is assumed to be; that areas where the water table is broadly responsible for maintaining perennial water availability are often few, and their influence is often wider in its areal extent; hence the small number of larger areal extent representations of OPV. As a result the majority of perennial water sources which remain are often reliant on quite small scale topographical or geological features which enhance water availability through; mounding, small perched alluvial aquifers, consistent surface water pooling, or the provision of anomalously low points in the broader environment. These secondary sources of perennial water generally occur over small often disjunct spatial scales,

with these same physical/topographic characters often leading to slightly reduced consistency in perennial water availability, which in-turn influence the cover/structure of the resident obligate phreatophytes. Consequently the observation that, as the maturity of the OPV reduces, so too does the areal extent and distribution, aligns with the observation that; as you transition from zones of perennial water availability to zones of ephemeral water availability the areal extent of zones possessing perennial water also tend to reduce in size and distribution.

Riparian Significance and water availability

As discussed previously, with respect to the significance of riparian communities in the Pilbara, it appears generally true that the more consistently perennial the water availability is and the greater the areal extent of this water availability (with special mention to broad and long examples), the higher the number and quality of the ecological values associated with the vegetation supported by such areas. Furthermore, the distribution of large occurrences of consistently perennial water availability, and their associated vegetation, is quite restricted, very uncommon, and generally associated with small stretches/portions of the riparian habitats of large creek systems. Together these two key sets of inherent attributes combine to ensure that the larger good quality examples of OPV will generally remain the more significant of the riparian communities within the Hamersley ranges. Therefore the range of examples of reducing degrees of perennial water availability (perennial through to ephemeral) and associated reducing degrees of phreatophytic vegetation quality and maturity will essentially tend to represent the reducing degrees of significance attributed to riparian communities within the Hamersley Ranges.

With this in mind, it is noted that the fine scale of the phreatophytic vegetation mapping produced as a part of this study provides good examples of this range or scale in riparian community significance and their associated changes in distribution within the riparian zone. The significant survey-effort conducted to produce this mapping, and the resultant strict treatment of OPV, and to a lesser extent FPV units which resulted, provides a relatively complete set of communities with which to consider the value and significance of phreatophytic vegetation within the study area. Consequently it is believed that the quality of information which it provides creates an effective framework and associated spatial model for the management and mitigation of potential impacts to sensitive phreatophytic vegetation in the study area. While the initial focus of this study was on the most sensitive of the phreatophytic species (*Melaleuca argentea*), the study has also provided significant additional information on the distribution and structure of *Eucalyptus camaldulensis* and *Eucalyptus victrix* woodlands/low woodlands of the study area. In addition to this we have a relatively comprehensive set of location data for the "mature" *Melaleuca argentea* individuals of the study area which also help with the process of management and mitigation, and give good insight into the hydrological processes/anomalies which are operating in the sub-surface and surface zones of the relevant fluvial habitats.

5.6 CREEK MORPHOLOGY AND ASSOCIATED VEGETATION DISTRIBUTION

What was previously observed, and what this study has continued to highlight, is that the relevant stretches of these two creeks possess significantly different morphologies, and associated vegetation community distributions. Through much of the relevant stretch of Marillana Creek, the surrounding topography seems to prevent the formation of fringing floodplain landforms and associated communities. This restriction to floodplain morphology obviously has a significant influence on the morphology of the incised channel zone and the distribution and composition of communities within

it. From the field work conducted, it appears as though the resultant flow confinement creates a comparatively level surface within the incised channel zone, where the surface flow routes are less predictable. Consequently multiple low flow channels are observed to have formed, and the distribution of OPV tends to be spread more broadly/laterally within the incised channel profile.

The relevant stretch of Weeli Wolli creek on the other hand, tends for the most part to possess a clear and relatively broad floodplain landform, with a relatively narrow, and often comparatively V shaped incised channel morphology upstream of the confluence. Downstream of the confluence clear floodplains flank a much more broadly braided incised channel landform, overlying what appears to be deeper and therefore more transmissive layers of alluvium. These differences, existent within and between the respective individual creeks, highlight the complexity of the ongoing struggle to decipher how the inner workings of these fluvial systems influence water availability, and community distribution. Deciphering this puzzle seems hard enough. However, an additional degree of complexity is present when attempting to decipher what changes to water availability and community distribution might occur with the onset of hydrological influence from mining (and changing degrees of influence from mining).

Incised channel morphologies and *E. camaldulensis* distribution

The distinctions made above, about the differences between the morphologies of the stretch of Weeli Wolli creek south of the confluence and the Marillana Creek stretch highlights how differing morphologies can influence water availability and community distribution. Within the southern stretch of Weeli Wolli creek; the low flow channel remains singular and positioned in an often clearly lower (i.e. somewhat etched into a V shaped incision) incised low flow channel within the broader incised channel zone. What this appears to do is determine that the route of the low flow channel remains relatively constant, and predictable, and that OPV is clearly restricted to this feature. Knowing the requirements of OPV, it is clear that the restriction of such communities to the singular low flow channel of this creek stretch is a result of the increased consistency of perennial water availability which a relatively constant low flow route can provide. With relation to FPV such as *Eucalyptus camaldulensis* woodlands, the distribution of this community can be more variable, but what is known is that it would tend to establish around such features which seemingly provide comparatively more consistent water availability.

This observation is interesting when you consider that previous mapping (based on significantly reduced riparian survey effort) suggested that *E. camaldulensis* co-dominated communities were extensive along the relevant stretch of Marillana Creek, but were for the most part absent from the relevant stretches of Weeli Wolli creek (particularly that stretch upstream of the confluence). Recent mapping work indicated that while such communities were comparatively less laterally distributed within Weeli Wolli (as would potentially be expected), they were however present along the entire length of the stretch upstream of the confluence. For the author of the refined mapping, the apparently large difference between the two vegetation models was somewhat perplexing. Despite walking the most relevant parts of this entire stretch of the creek and the collection of a fairly extensive array of data points, the often minor visual differences between *E. camaldulensis* and *E. victrix* can tend to create doubt as to the actual extent of *E. camaldulensis* co-dominated communities. However, in relation to the relevant stretch of Weeli Wolli creek upstream of the confluence; observations made about stream morphology seemed to support the significant change to the mapped distribution of this community within the refined mapping produced. The above broad scale observations about stream morphology, in combination with small scale on ground

observations, indicate that the fine scale position/route of the incised channel zone had remained constant for substantial time periods. Such a consistency in the distribution pattern of surface water input within a creek system of this catchment size is considered likely to encourage the establishment of FVP. This fact would therefore tend to support the refined vegetation mapping and the distribution of an *E. camaldulensis* co-dominated community surrounding the bed and banks of the described low flow channel.

Incised Channel morphologies and augmentation

Another conclusion that the above described patterns to the stream morphology within Weeli Wolli creek tends to support, is that the creek section south of the confluence appears to feature a fairly consistent distribution and degree of augmentation to resident vegetation. The apparent consistency in the path of surface water flows, and therefore in the distribution of perennial water availability, is considered likely to initiate and sustain the process of vegetation augmentation. Given that this established flow path is known to have been consistent at least throughout the period which surplus-water discharge inputs are known to have occurred, it is likely that it is has played a significant role in the distribution and degree of vegetation augmentation apparent. Plate 133 shows an example of the vegetation which often tightly fringes the present day water line of the low flow channel within Weeli Wolli creek. Successive examples of this vegetation along the stretch of Weeli Wolli south of the confluence possess a vegetation structure, composition, size structure, and distribution which indicates it is most likely to be a product of recent perennial water availability and resultant augmentation. Plate 144 and Plate 155 below show two examples of apparent vegetation augmentation within Weeli Wolli Creek, with significant sized patches of the C2/C1 vegetation unit being present and absent at the different time sequences (pre and post-discharge).

Plate 13: Example of apparently augmented C2/C1 vegetation on Weeli Wolli Creek

Plate 14: Comparative aerial photo example (2014 left side; 2006 right side) of a patch of apparently augmented vegetation on Weeli Wolli Creek North. Yellow polygon represents the present day C2/C1 vegetation unit (Location; E: 737995, N: 7479291)

Plate 15: Comparative aerial photo example (2014 left side; 2006 right side) of a patch of apparently augmented vegetation on Weeli Wolli Creek South (yellow polygon represents the C2/C1 vegetation unit (Location; E: 733406, N: 7474109)

5.7 SYNTHESIS

A clear conclusion of this study has been that; within riparian habitats, the more consistently water is available the more significant the vegetation and associated habitats tend to become. Based on this conclusion and the results of the mapping refinement, in general the C1A and C1AA communities were determined to top the "development significance" scale for riparian communities mapped in the study area. With *M. argentea* forming a co-dominant member of the woodland layer, these two units were determined to be of high developmental significance, while the reduced phreatophytic species maturity of the C1B communities led to a "development significance" rating of

moderate. Communities of a different but similar composition, such as the C1/C2A, and C2/C1 coded vegetation mapping units, deemed in their current form to represent OPV, were also deemed to possess *M. argentea* populations of such age and physical structure that in the pre-discharge environment they were unlikely to have represented OPV. Consequently these units were attributed a present day significance and pre-discharge composition/structure essentially equivalent to that of the C2A *Eucalyptus camaldulensis*/*E. victrix* open woodland community (Minor-moderate development significance). It should be noted that despite the conclusion that communities such as the C1A, and C1B coded vegetation units were present in a similar form in the pre-discharge environment, all of the communities discussed in the above paragraph have experienced un-natural degrees of perennial water availability for between approximately 9 and 20 years. It therefore seems inevitable that like the C1/C2A, and C2/C1 vegetation units they too have experience significant augmentation, and their resultant significance is somewhat commensurately and un-naturally augmented.

Beyond the C2A *Eucalyptus camaldulensis*/*E. victrix* open woodland community (Minor-moderate development significance), the final riparian community of note on the scale of significance is represented by the C3 coded *Eucalyptus victrix* low open woodland community. This community was attributed a "Minor development significance" due to its widespread distribution, lower diversity, and generally ephemeral nature. As previously discussed; on the scale of significance these communities highlighted in the mapping refinement and assessment conducted as part of this study all fall below the significance attributed to the large areal extent representations of OPV. The well-known and most obvious example of such large areal extent OPV representations is that of Weeli Wolli Springs. While there are sure to be other similar quality examples present within the Hamersley Ranges, with somewhat similarly large areal extent representations known to occur in the vicinity of flat rocks, it is noted that the closest but still significantly reduced example in the study area is the C1AA community. Despite this fact the values of this community are already reduced by the effects of development associated with neighbouring stakeholders.

Conclusions

The final conclusions of this study are:

- Based on the mapping refinement, the present day distribution and areal extent of OPV in the study area is significantly reduced from 2.6 km^2 to 1.01 km^2 (260ha to 101ha), when compared to previous broader scale vegetation mapping.

- Following an assessment of the degree to which presently mapped OPV is likely to be a result of surplus-water related discharge augmentation, the amount of this vegetation now considered to represent pre-mining baseline and occur within tenure has been interpreted to be approximately 0.29 km^2 or 29 ha, which is less than half of the OPV mapped as currently present during the vegetation mapping refinement process (1.01 km^2 or 101 ha).

- Consequently, three vegetation units (C1A, C1AA, and C1B) are now considered to represent true and therefore obligate phreatophytic vegetation likely to have been present (in the study area) in a similar form within the pre-mining environment.

- These units all also represent vegetation which is somewhat augmented (through increased biomass, and increases in structural and compositional diversity) by mining related discharge and nearly all representations of relevance to ongoing development in the area are quite small

in their areal extent. However, despite this fact, and despite the other negative anthropogenic impacts (both mining and grazing related) on them, they are still perceived to possess high to moderate "development significance", and are all highly sensitive to hydrological changes. Consequently they should be afforded effective management measures where practicable.

- Only the C1A and C1B units are of key relevance to potential impacts of proposed development within the study area. These two units only represent a small portion of the study area (approximately 2% of the areal extent of the riparian communities) which includes stretches of approximately 20km within both the Marillana and Weeli Wolli Creek systems.

- The distribution of these two key units of significance is highly spatially restricted to the confines of the low flow channels within the study area. Consequently; assuming mining related discharge is maintained in these creek systems throughout the various phases of development, the potential impacts associated with drawdown appear unlikely to be realised within these very small and often disjunct communities.

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7 APPENDICES

Appendix 1: Vegetation structure and condition scale used for vegetation description and mapping formulated within this study.

Vegetation Structure and Condition Scale

Vegetation Structural Classes*

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970): Aplin T.E.H. (1979). The Flora. Chapter 3 In O'Brien, B.J. (ed.) (1979). *Environment and Science*. University of Western Australia Press; Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum*, Suppl. No. 3; Specht R.L. (1970). Vegetation. In: *The Australian Environment*. 4th edn (Ed. G.W. Leeper). Melbourne.

Vegetation Condition Scale*

E = Excellent (=Pristine of BushForever)
Pristine or nearly so; no obvious signs of damage caused by the activities of European man.

VG = Very Good (= Excellent of BushForever)
Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Sonchus oleraceus* or **Cucumis* spp., or occasional vehicle tracks.

G = Good (= Very Good of BushForever)
More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Cenchrus* spp.

P = Poor (= Good of BushForever)
Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Cenchrus* spp.

VP = Very Poor (= Degraded of BushForever)
Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species such as **Prosopis* spp.

D = Completely Degraded (= Completely Degraded of BushForever)
Areas that are completely or almost completely without native species in the structure of their vegetation; ie. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 2: Growth projection data and calculations for the 15 year temporal regime (marillana creek), showing the average projected growth diameter for each initial monitoring tree dbh range

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measurements	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
C12	C REF	764326	7442920	SS	Melaleuca argentea	550	1.00	1.75	3.11	46.70	14.86	3.86	7.71
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	2.08	1.775	3.75	56.32	17.93	4.23	8.47
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.58	1.85	5.61	84.15	26.79	5.18	10.35
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.00	1.925	1.56	23.41	7.45	2.73	5.46
C12	C REF	764326	7442920	S	Melaleuca argentea	600	1.42	2.275	11.22	168.25	53.56	7.32	14.64
C12	C REF	764326	7442920	SS	Melaleuca argentea	600	1.00	2.625	24.96	374.34	119.16	10.92	21.83
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.00	2.8	5.08	76.13	24.23	4.92	9.85
WW12	Reach 3	733144	7473685	SS	Melaleuca argentea	415	1.00	3	447.02	6705.26	2134.35	46.20	92.40
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	300	1.67	3	19.53	292.92	93.24	9.66	19.31
WW17	Reach 4	737423	7478668	SS	Melaleuca argentea	300	1.67	3	44.28	664.16	211.41	14.54	29.08
Mclean (2013) 50% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	1.15	6.90	103.55	32.96	11.48
Mclean (2013) 80% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	1.84	11.07	166.03	52.85	14.54
Mclean (2013) 100% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	2.42	14.52	217.74	69.31	16.65
												Average Diameter	**20.1**
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	1000	1.00	3.15	3.04	45.59	14.51	3.81	7.62
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	700	1.00	3.15	25.57	383.59	122.10	11.05	22.10
C12	C REF	764326	7442920	SS	Melaleuca argentea	700	0.50	3.175	10.37	155.51	49.50	7.04	14.07
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	600	2.00	3.3	11.27	169.00	53.79	7.33	14.67
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	700	0.25	3.35	65.09	976.41	310.80	17.63	35.26

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measurements	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	400	1.00	3.35	17.55	263.30	83.81	9.15	18.31
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	400	1.00	3.4	9.05	135.72	43.20	6.57	13.15
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	400	0.58	3.5	68.67	1029.99	327.86	18.11	36.21
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	400	0.25	3.5	444.35	6665.20	2121.60	46.06	92.12
WW07	Reach 2	726335	7463903	SS	Melaleuca argentea	350	1.00	3.5	23.73	355.90	113.29	10.64	21.29
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	450	1.00	3.5	13.05	195.68	62.29	7.89	15.78
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	400	1.00	3.5	5.69	85.41	27.19	5.21	10.43
WW27	Reach 3	734609	7475178	H	Melaleuca argentea	400	1.00	3.5	27.99	419.87	133.65	11.56	23.12
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	700	1.00	3.55	19.85	297.82	94.80	9.74	19.47
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	550	2.00	3.7	26.88	403.20	128.34	11.33	22.66
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	750	0.25	3.85	115.45	1731.80	551.25	23.48	46.96
WW22	WW REF	720295	7448604	H	Melaleuca argentea	600	1.00	3.9	27.65	414.69	132.00	11.49	22.98
WW27	Reach 3	734609	7475178	H	Melaleuca argentea	300	1.00	3.95	53.05	795.80	253.31	15.92	31.83
												Average Diameter	**26**
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	600	0.33	4	66.35	995.26	316.80	17.80	35.60
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	600	0.25	4.15	258.87	3883.01	1236.00	35.16	70.31
C12	C REF	764326	7442920	SS	Melaleuca argentea	750	1.00	4.475	11.75	176.24	56.10	7.49	14.98
WW23	WW REF	720330	7448685	H	Melaleuca argentea	600	1.00	4.6	25.13	376.99	120.00	10.95	21.91
C12	C REF	764326	7442920	SS	Melaleuca argentea	600	1.00	5.075	16.73	250.93	79.88	8.94	17.87
WW11	Reach 2	729168	7467688	H	Melaleuca argentea	500	1.83	5.1	72.06	1080.91	344.07	18.55	37.10
WW17	Reach 4	737423	7478668	H	Melaleuca argentea	700	1.00	5.4	17.75	266.25	84.75	9.21	18.41
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	900	1.00	5.9	25.42	381.35	121.39	11.02	22.04
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	650	1.00	6	52.03	780.49	248.44	15.76	31.52

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measurements	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	650	1.00	6.05	19.79	296.88	94.50	9.72	19.44
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	600	1.00	6.7	65.09	976.41	310.80	17.63	35.26
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	600	1.00	6.9	34.28	514.24	163.69	12.79	25.59
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	1100	0.50	6.95	40.57	608.61	193.73	13.92	27.84
												Average Diameter	**29.1**
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	650	1.00	7.35	62.64	939.53	299.06	17.29	34.59
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	900	0.33	7.75	205.84	3087.56	982.80	31.35	62.70
C18	C REF	764706	7444955	H	Melaleuca argentea	900	0.33	8.175	11.61	174.15	55.43	7.45	14.89
WW11	Reach 2	729168	7467688	H	Melaleuca argentea	750	0.33	8.2	47.22	708.27	225.45	15.01	30.03
WW11	Reach 2	729168	7467688	SS	Melaleuca argentea	700	1.00	8.6	147.78	2216.71	705.60	26.56	53.13
WW23	WW REF	720330	7448685	H	Melaleuca argentea	900	1.00	8.95	84.89	1273.29	405.30	20.13	40.26
C18	C REF	764706	7444955	SS	Melaleuca argentea	900	0.50	10.13	80.30	1204.49	383.40	19.58	39.16
C12	C REF	764326	7442920	S	Melaleuca argentea	1500	2.08	10.97	31.01	465.17	148.07	12.17	24.34
C12	C REF	764326	7442920	SS	Melaleuca argentea	800	1.00	11	73.48	1102.18	350.84	18.73	37.46
												Average Diameter	**37.4**
C12	C REF	764326	7442920	SS	Melaleuca argentea	1500	1.00	11.1	88.22	1323.24	421.20	20.52	41.05
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	800	0.33	11.5	110.74	1661.12	528.75	22.99	45.99
WW13	Reach 3	736231	7477271	H	Melaleuca argentea	1000	1.00	12.35	204.33	3064.94	975.60	31.23	62.47
C18	C REF	764706	7444955	H	Melaleuca argentea	900	1.00	15.55	44.60	669.04	212.96	14.59	29.19
C12	C REF	764326	7442920	S	Melaleuca argentea	1400	1.00	16.55	93.39	1400.90	445.92	21.12	42.23
C12	C REF	764326	7442920	SS	Melaleuca argentea	2000	0.33	16.8	79.76	1196.36	380.81	19.51	39.03
C15	C REF	768895	7454529	S	Melaleuca argentea	2200	1.58	17.05	46.57	698.62	222.38	14.91	29.82

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measurements	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
C15	C REF	768895	7454529	SS	Melaleuca argentea	2000	1.00	17.675	9.65	144.77	46.08	6.79	13.58
C15	C REF	768895	7454529	S	Melaleuca argentea	1500	1.00	17.95	57.18	857.65	273.00	16.52	33.05
												Average Diameter	**37.3**
C15	C REF	768895	7454529	SS	Melaleuca argentea	1300	1.00	18.5	52.94	794.16	252.79	15.90	31.80
C12	C REF	764326	7442920	VS	Melaleuca argentea	1400	0.92	22.85	63.20	947.96	301.75	17.37	34.74
C12	C REF	764326	7442920	S	Melaleuca argentea	1400	0.33	23.5	150.80	452.39	2160.00	46.48	62.00
MM01	M REF	746701	7462535	SS	Melaleuca argentea	1700	2.00	27.33	204.73	102.37	488.76	22.11	44.22
WW08	Reach 1	725047	7463028	S	Melaleuca argentea	1700	0.50	39.7	303.85	607.71	2901.60	53.87	77.00
WW08	Reach 1	725047	7463028	SS	Melaleuca argentea	2000	3.00	44.6	913.90	304.63	1454.51	38.14	76.28
Cultivated - Hawaii 1 - Average Growth Rate 50 cm DBH in 40 years				H	Melaleuca quinquinervia	1500+	40	1	1806.42	45.16	677.41	215.63	29.37
Cultivated - Hawaii 2 - Upper Percentile Growth Rate 90cm DBH in 40 years				H	Melaleuca quinquinervia	1500+	40	1	6078.98	151.97	2279.62	725.63	53.87
Cultivated - Australia 1 - Upper Percentile Growth Rate - 85cm DBH in 40 years				H	Melaleuca quinquinervia	1500+	40	1	10818.07	270.45	4056.78	1291.31	71.87
												Average Diameter	**53.4**

Appendix 3: Growth projection data and calculations for the 9 year temporal regime (weeli wolli creek), showing the average projected growth diameter for each initial monitoring tree dbh range.

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measurements	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
C12	C REF	764326	7442920	SS	Melaleuca argentea	550	1.00	1.75	3.11	46.70	14.86	3.86	7.71
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	2.08	1.775	3.75	56.32	17.93	4.23	8.47
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.58	1.85	5.61	84.15	26.79	5.18	10.35
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.00	1.925	1.56	23.41	7.45	2.73	5.46
C12	C REF	764326	7442920	S	Melaleuca argentea	600	1.42	2.275	11.22	168.25	53.56	7.32	14.64
C12	C REF	764326	7442920	SS	Melaleuca argentea	600	1.00	2.625	24.96	374.34	119.16	10.92	21.83
C12	C REF	764326	7442920	SS	Melaleuca argentea	500	1.00	2.8	5.08	76.13	24.23	4.92	9.85
WW12	Reach 3	733144	7473685	SS	Melaleuca argentea	415	1.00	3	447.02	6705.26	2134.35	46.20	92.40
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	300	1.67	3	19.53	292.92	93.24	9.66	19.31
WW17	Reach 4	737423	7478668	SS	Melaleuca argentea	300	1.67	3	44.28	664.16	211.41	14.54	29.08
Mclean (2013) 50% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	1.15	6.90	103.55	32.96	11.48
Mclean (2013) 80% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	1.84	11.07	166.03	52.85	14.54
Mclean (2013) 100% Soil Saturation		22.91° S, 119.21° E		H	Melaleuca argentea	<150	0.17	0.5	2.42	14.52	217.74	69.31	16.65
												Average Diameter	**20.1**
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	1000	1.00	3.15	3.04	45.59	14.51	3.81	7.62
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	700	1.00	3.15	25.57	383.59	122.10	11.05	22.10
C12	C REF	764326	7442920	SS	Melaleuca argentea	700	0.50	3.175	10.37	155.51	49.50	7.04	14.07
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	600	2.00	3.3	11.27	169.00	53.79	7.33	14.67
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	700	0.25	3.35	65.09	976.41	310.80	17.63	35.26

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measure ments	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	400	1.00	3.35	17.55	263.30	83.81	9.15	18.31
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	400	1.00	3.4	9.05	135.72	43.20	6.57	13.15
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	400	0.58	3.5	68.67	1029.99	327.86	18.11	36.21
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	400	0.25	3.5	444.35	6665.20	2121.60	46.06	92.12
WW07	Reach 2	726335	7463903	SS	Melaleuca argentea	350	1.00	3.5	23.73	355.90	113.29	10.64	21.29
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	450	1.00	3.5	13.05	195.68	62.29	7.89	15.78
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	400	1.00	3.5	5.69	85.41	27.19	5.21	10.43
WW27	Reach 3	734609	7475178	H	Melaleuca argentea	400	1.00	3.5	27.99	419.87	133.65	11.56	23.12
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	700	1.00	3.55	19.85	297.82	94.80	9.74	19.47
WW08	Reach 1	725047	7463028	H	Melaleuca argentea	550	2.00	3.7	26.88	403.20	128.34	11.33	22.66
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	750	0.25	3.85	115.45	1731.80	551.25	23.48	46.96
WW22	WW REF	720295	7448604	H	Melaleuca argentea	600	1.00	3.9	27.65	414.69	132.00	11.49	22.98
WW27	Reach 3	734609	7475178	H	Melaleuca argentea	300	1.00	3.95	53.05	795.80	253.31	15.92	31.83
												Average Diameter	**26**
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	600	0.33	4	66.35	995.26	316.80	17.80	35.60
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	600	0.25	4.15	258.87	3883.01	1236.00	35.16	70.31
C12	C REF	764326	7442920	SS	Melaleuca argentea	750	1.00	4.475	11.75	176.24	56.10	7.49	14.98
WW23	WW REF	720330	7448685	H	Melaleuca argentea	600	1.00	4.6	25.13	376.99	120.00	10.95	21.91
C12	C REF	764326	7442920	SS	Melaleuca argentea	600	1.00	5.075	16.73	250.93	79.88	8.94	17.87
WW11	Reach 2	729168	7467688	H	Melaleuca argentea	500	1.83	5.1	72.06	1080.91	344.07	18.55	37.10
WW17	Reach 4	737423	7478668	H	Melaleuca argentea	700	1.00	5.4	17.75	266.25	84.75	9.21	18.41
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	900	1.00	5.9	25.42	381.35	121.39	11.02	22.04

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measure ments	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	650	1.00	6	52.03	780.49	248.44	15.76	31.52
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	650	1.00	6.05	19.79	296.88	94.50	9.72	19.44
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	600	1.00	6.7	65.09	976.41	310.80	17.63	35.26
WW12	Reach 3	733144	7473685	H	Melaleuca argentea	600	1.00	6.9	34.28	514.24	163.69	12.79	25.59
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	1100	0.50	6.95	40.57	608.61	193.73	13.92	27.84
												Average Diameter	**29.1**
WW07	Reach 2	726335	7463903	H	Melaleuca argentea	650	1.00	7.35	62.64	939.53	299.06	17.29	34.59
WW06	Reach 1	726273	7463942	H	Melaleuca argentea	900	0.33	7.75	205.84	3087.56	982.80	31.35	62.70
C18	C REF	764706	7444955	H	Melaleuca argentea	900	0.33	8.17	11.61	174.15	55.43	7.45	14.89
WW11	Reach 2	729168	7467688	H	Melaleuca argentea	750	0.33	8.2	47.22	708.27	225.45	15.01	30.03
WW11	Reach 2	729168	7467688	SS	Melaleuca argentea	700	1.00	8.6	147.78	2216.71	705.60	26.56	53.13
WW23	WW REF	720330	7448685	H	Melaleuca argentea	900	1.00	8.95	84.89	1273.29	405.30	20.13	40.26
C18	C REF	764706	7444955	SS	Melaleuca argentea	900	0.50	10.13	80.30	1204.49	383.40	19.58	39.16
C12	C REF	764326	7442920	S	Melaleuca argentea	1500	2.08	10.97	31.01	465.17	148.07	12.17	24.34
C12	C REF	764326	7442920	SS	Melaleuca argentea	800	1.00	11	73.48	1102.18	350.84	18.73	37.46
												Average Diameter	**37.4**
C12	C REF	764326	7442920	SS	Melaleuca argentea	1500	1.00	11.1	88.22	1323.24	421.20	20.52	41.05
WW10	Reach 2	727937	7466538	H	Melaleuca argentea	800	0.33	11.5	110.74	1661.12	528.75	22.99	45.99
WW13	Reach 3	736231	7477271	H	Melaleuca argentea	1000	1.00	12.35	204.33	3064.94	975.60	31.23	62.47
C18	C REF	764706	7444955	H	Melaleuca argentea	900	1.00	15.55	44.60	669.04	212.96	14.59	29.19
C12	C REF	764326	7442920	S	Melaleuca argentea	1400	1.00	16.55	93.39	1400.90	445.92	21.12	42.23

Transect & Reach / Source & type		Easting	Northing	Condition (H - heathy, SS - Somewhat stressed, S - Stressed, VS - Very Stressed)	*Confirmed name*	Height (cm)	# of years between DBH measure ments	RBH cm (Radius at Breast height)	Change in 2D Area (cm^2) between monitoring rounds	Change in Area converted to change per year	Change per year times 15 years	Convert 15 year area change (area/pie)	Square root of (area/pie) converted to Diameter
C12	C REF	764326	7442920	SS	Melaleuca argentea	2000	0.33	16.8	79.76	1196.36	380.81	19.51	39.03
C15	C REF	768895	7454529	S	Melaleuca argentea	2200	1.58	17.05	46.57	698.62	222.38	14.91	29.82
C15	C REF	768895	7454529	SS	Melaleuca argentea	2000	1.00	17.67	9.65	144.77	46.08	6.79	13.58
C15	C REF	768895	7454529	S	Melaleuca argentea	1500	1.00	17.95	57.18	857.65	273.00	16.52	33.05
												Average Diameter	**37.3**
C15	C REF	768895	7454529	SS	Melaleuca argentea	1300	1.00	18.5	52.94	794.16	252.79	15.90	31.80
C12	C REF	764326	7442920	VS	Melaleuca argentea	1400	0.92	22.85	63.20	947.96	301.75	17.37	34.74
C12	C REF	764326	7442920	S	Melaleuca argentea	1400	0.33	23.5	150.80	452.39	2160.00	46.48	62.00
MM01	M REF	746701	7462535	SS	Melaleuca argentea	1700	2.00	27.33	204.73	102.37	488.76	22.11	44.22
WW08	Reach 1	725047	7463028	S	Melaleuca argentea	1700	0.50	39.7	303.85	607.71	2901.60	53.87	77.00
WW08	Reach 1	725047	7463028	SS	Melaleuca argentea	2000	3.00	44.6	913.90	304.63	1454.51	38.14	76.28
Cultivated - Hawaii 1 - Average Growth Rate 50 cm DBH in 40 years				H	Melaleuca quiquinerva	1500+	40	1	1806.42	45.16	677.41	215.63	29.37
Cultivated - Hawaii 2 - Upper Percentile Growth Rate 90cm DBH in 40 years				H	Melaleuca quiquinerva	1500+	40	1	6078.98	151.97	2279.62	725.63	53.87
Cultivated - Australia 1 - Upper Percentile Growth Rate - 85cm DBH in 40 years				H	Melaleuca quiquinerva	1500+	40	1	10818.07	270.45	4056.78	1291.31	71.87
												Average Diameter	**53.4**

Appendix 4: Weeli wolli springs fact sheet

Department of Environment and Conservation (2009b), Science Division, Information Sheet 3 / 2009, Biodiversity values of Weeli Wolli Spring: A priority ecological community.

http://www.dpaw.wa.gov.au/images/documents/about/science/pubs/infosheets/sdis003.pdf

Department of Environment and Conservation

Our environment, our future

Information Sheet 3 / 2009
Science Division

Biodiversity values of Weeli Wolli Spring: A priority ecological community

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Background

Weeli Wolli Creek in the central Hamersley Range supports a permanent series of pools which are fed by Weeli Wolli Spring. This arid zone wetland supports a unique community of plants and animals some of which are endemic to the Spring. Grazing by livestock, inappropriate fire regimes and alteration to surface water flows and groundwater levels as a result of mining pose a significant threat to this unique Pilbara community. Consequently the community has been listed as a Priority 1 Ecological Community.

The Spring, which has considerable spiritual and cultural significance to traditional owners of the Hamersley Range, is located at the base of a large banded ironstone ridge that intersects the Creek providing an impermeable barrier to the subsurface downstream flow of water. The subsequent surface expression of water at the spring varies from a trickle to a significant flow which is expressed as pools and billabongs on the surface for up to 10 km.

Ironstone barrier at Weeli Wolli Spring

The vegetation of the spring and surrounding creek channel is typical of most Pilbara drainage features that support permanent water.

It is dominated by a fringing forest or tall woodland of Silver paperbark (*Melaleuca argentea*) and River Red gum (*Eucalyptus camaldulensis*) over trees of Coolibah (*E. victrix*) and a dense shrub layer dominated by an assortment of wattles, in particular Pilbara Jam (*Acacia citrinoviridis*). The presence of permanent water and very moist sediment also provides suitable habitat for many sedges and herbs. The area is a haven for birds and other fauna including many bats and also supports a rich community of surface and subsurface aquatic invertebrates.

Findings

The biodiversity values of Weeli Wolli Spring are high. Among the 120+ native plant species known from Weeli Wolli, apart from the majestic Silver cajuputs there are several species of conservation interest including a trigger plant named after the Spring – *Stylidium weeliwolli*. Botanical values also include a hybrid zone between two native cotton (*Gossypium*) species which has attracted significant commercial interest from multinational companies in the quest for a biological control agent of the pink bollworm, a serious predator of commercial cotton throughout the world.

The diversity of habitats in close proximity to the Spring also provides a haven for birds with over 60 species recorded along the creek. The Spring is recognised as a focal point for Pilbara birds and is promoted by local and State tourism agencies. Similarly the diversity of habitat types and rough landscapes provide many opportunities for bats, with the Spring being the only known Pilbara and most northern locality for the Chocolate Bat (*Chalinolobus morio*). The Ghost bat (*Macroderma gigas*) a threatened species, has also been recorded foraging above pools downstream of the Spring.

Water Mite - *Australiurus* sp. P1

The most significant biological values of the spring and its creek system are associated with the aquatic invertebrates that inhabit the Spring, pools and the underground water body. Three species of water mite (*Wandesia* sp. P1 (nr *glareosa*), *Austraturus* P1, *Guineaxonopsis* sp. P1 (PSW)) are only known from Weeli Wolli Creek and one other locality in the Pilbara. Similarly two underground aquatic invertebrates, a water mite (*Arrenurus* sp. nov. 1 (PSS), and a oligochaete (*Ainudrilus* sp. WA26 (PSS)), are only know from Weeli Wolli while three other crustaceans (*Gomphodella* sp. 4 (PSS), *Maarka* n. sp. *'wolli'* ms, *Meridiescandona* sp. 3' (PSS)) are only known from Weeli Wolli and one other locality in the Pilbara.

Management Implications

DEC is currently working with industry and traditional owners to manage impacts on Weeli Wolli Creek and the Spring from water abstraction and discharge associated with the Hope Downs mine. The primary objectives of these efforts are to protect cultural values and maintain the biological assets of the area. To this end the State Government will establish a reserve at Weeli Wolli in 2015 to protect and manage the values of the spring and several kilometres of the downstream creek.

For additional information on the flora and fauna of the Pilbara please visit the Pilbara Biological Survey website at http://www.dec.wa.gov.au/science-and-research.

Silver Cajuput (*Melaleuca argentea*) in Weeli Wolli Creek

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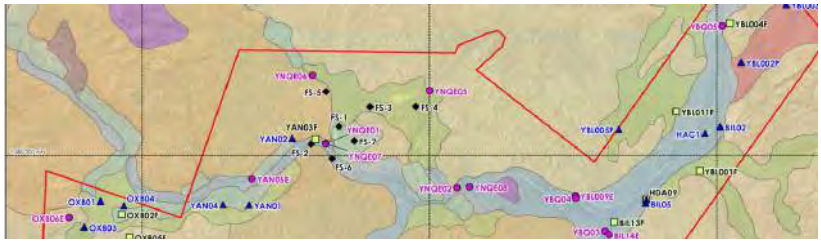
Biota Environmental Sciences

Yandi Terrestrial Fauna Integration Report



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1.0 Summary

1.1 Introduction

Rio Tinto's Yandicoogina (Yandi) iron ore project is located approximately 90 km northwest of Newman, in the Pilbara region of Western Australia and is currently operated by Hamersley Iron Pty Ltd – Yandi Pty Ltd (Hamersley Iron).

Biota Environmental Sciences (Biota) was commissioned by Rio Tinto to undertake a review of terrestrial fauna information available for the Yandi development envelope, which covers a total of 19,351 ha. The development envelope includes or intersects sections of the following individual Rio Tinto terrestrial fauna study areas:

- Yandi Junction Central (JDM study area: 3,733 ha);
- Hope Downs Rail Corridor Extension (HDR study area; 3,977 ha);
- Junction South East (JSE study area: 2,245 ha);
- Junction South West (JSW study area: 1,707 ha);
- Yandi Oxbow (YOX study area: 724 ha);
- Yandi Billiards (BIL study area: 4,410 ha); and
- Pocket and Billiard South (PBS study area: 8,639 ha).

1.2 Methodology

The collated Yandi fauna data used in this report were sourced from 14 separate studies from 2004 to 2014, some of which comprised seasonal survey phases. These surveys used a combination of systematic sampling and other methodologies, all conducted in accordance with relevant Environmental Protection Authority (EPA) policy and the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* (EPA 2002, 2004, 2009, EPA and DEC 2010, DSEWPaC 2011).

The systematic sampling effort in the Yandi development envelope comprised 54 trapping sites, collectively representing 7,138 trap nights of systematic effort. Avifauna censuses were carried out at a total of 49 sites across the development envelope, and the census time from all phases of survey work totalled approximately 107 hours (6,410 minutes).

Bat sampling was conducted in areas deemed mostly likely to yield bat records. This effort therefore focused on rocky free-face landforms (particularly where caves or other potential roost site features were present in gorges) and along larger drainages (particularly where water was present). Bat sampling effort totalled 62 survey nights across 21 sites.

Additionally, searches were conducted at a minimum of 42 sites to target invertebrate groups with the potential to contain Short Range Endemic (SRE) species:

- Mygalomorphae (trapdoor spiders);
- Diplopoda (millipedes);
- Scorpiones (scorpions);
- Pulmonata (land snails); and
- Pseudoscorpiones (pseudoscorpions).

1.3 Faunal Habitats and Assemblages

Fauna habitats were determined considering locality and broad-scale factors such as regional surface geology, land systems and landforms. PRIMER analyses of faunal assemblage were conducted using rationalised and transformed faunal abundance data. For herpetofauna and ground mammals, seven faunal assemblage clusters were identified at the 30% similarity level. Only five fauna assemblage clusters were identified for avifauna.

Non-metric Multi-Dimensional Scaling (NMDS) of the herpetofauna dataset showed separation of clusters, indicating that fauna assemblages could be placed into groups that were fundamentally different to each other. The best relationship between the seven herpetofauna assemblages and the site habitat factors was provided by 'survey locality', with the herpetofauna composition recorded from the PBS survey being noticeably different to data obtained from the other localities. It appears that this is an artefact of greater sampling effort, resulting in greater recorded species richness and abundance at the PBS sites, rather than a real trend based on sampling location.

NMDS plots indicated that, on the whole, bird assemblages were not fundamentally different between sites. In contrast, the ground mammal assemblage were fundamentally different between sites, but these differences could not be attributed to locality, land systems, geology or landform factors.

1.4 Fauna

A total of 206 vertebrate fauna species were recorded from the development envelope during the combined surveys. This total comprised three amphibians, 69 reptiles, 103 avifauna species, 15 native ground mammals, 10 bats and six introduced mammals.

The recorded herpetofauna species comprised three frogs and 69 reptiles. The reptile species comprised six dragons (family Agamidae), 12 geckos (Gekkonidae, Diplodactylidae and Carphodactylidae), seven legless lizards (Pygopodidae), 27 skinks (Scincidae), eight monitors (Varanidae), two blind snakes (Typhlopidae), two pythons (Boidae) and six front-fanged snakes (Elapidae). The gecko *Diplodactylus conspicillatus* (n=77 individuals) and the skinks *Ctenotus duricola* (n=68) and *Ctenotus saxatilis* (n=59) were the most abundant herpetofauna species recorded in the development envelope.

Twenty-one ground mammals, comprising 15 native and six introduced species, were recorded from the development envelope. This total comprised six carnivorous marsupial species (Dasyuridae), three kangaroo species (Macropodidae), six rodent species (Muridae), one cat (Felidae), one canine (Canidae), two equine species (Equidae), one cattle species (Bovidae) and one camel species (Camelidae). The introduced mammals recorded in the development envelope comprised the house mouse (*Mus musculus*), feral cat (*Felis catus*), donkey (*Equus asinus*), horse (*Equus caballus*), European cattle (*Bos taurus*) and camel (*Camelus dromedarius*). The most abundant mammals in the development envelope were the introduced house mouse *Mus musculus* (n=45 individuals), the Common Rock Rat *Zyzomys argurus* (n=30), and the Sandy Inland Mouse *Pseudomys hermannsburgensis* (n=29).

A total of 103 avifauna species from 40 families were recorded from the development envelope, comprising 53 passerine and 50 non-passerine species. The most speciose families were the Meliphagidae (honeyeaters and chats) with 11 species recorded, and the Accipitridae (raptors) with seven species recorded. The most abundant species were the Zebra Finch *Taeniopygia guttata* (n=142 individuals) and Weebill *Smicrornis brevirostris* (n=107), both of which were recorded from the majority of survey sites.

Of the eight prospective SRE taxa recorded within the development envelope, four mygalomorph spider putative species are considered to be potential SREs, as they have known distributions not exceeding the accepted 10,000 km^2 threshold (Harvey 2002). These species comprise Idiopidae sp. I1, Idiopidae sp. I9, Nemesiidae sp. N42 and Nemesiidae sp. N44. None of these species are confined solely to the development envelope.

1.5 Threatened Fauna

Nine vertebrate species of elevated conservation significance were recorded from the development envelope (Figure 4.16). This included five Schedule species listed under the *Wildlife Conservation Act 1950,* four of which are also listed under the Commonwealth *EPBC Act 1999*:

- Pilbara Olive Python, *Liasis olivaceus barroni* (State: Schedule 1; Commonwealth: Vulnerable)
  One individual was recorded opportunistically swimming in Weeli Wolli Creek. This species is not commonly observed.
- Rainbow Bee-eater, *Merops ornatus* (State: Schedule 3; Commonwealth: Migratory)
  This species was recorded from 23 locations within the Yandi development envelope across all source surveys. It showed little preference for specific land systems, being represented in five different types.
- Fork-tailed Swift, *Apus pacificus* (State: Schedule 3; Commonwealth: Migratory)
  Nine individuals were recorded flying overhead at a single location. This species is expected to be a transient visitor only, and would not rely on any terrestrial habitats within the development envelope.
- Eastern Great Egret, *Ardea modesta* (State: Schedule 3; Commonwealth: Migratory)
  A single bird was observed flying in the vicinity of Weeli Wolli Creek. This single observation within the development envelope during multiple phases suggests that the Eastern Great Egret is either uncommon or is an irregular visitor to the development envelope.
- Peregrine Falcon, *Falco peregrinus* (State: Schedule 4)
  One individual was recorded within the development envelope. This record is likely to represent a transitory or foraging individual.

Four species listed as Priority 4 by the Department of Parks and Wildlife were also recorded from the development envelope:

- Western Pebble-mound Mouse *Pseudomys chapmani:* pebble-mounds were recorded at 22 locations within the development envelope (Figure 4.16).
- Australian Bustard *Ardeotis australis*: observed on 17 occasions from 11 locations within the development envelope.
- Star Finch *Neochmia ruficauda subclarescens*: a total of 13 records were noted at two locations within the development envelope during the combined surveys.
- Brush-tailed Mulgara *Dasycercus blythi:* burrows of this species were recorded within the development envelope, however no individuals were captured. The burrows were thought to be inactive, as no signs of fresh diggings, scats or tracks were noted.

1.6 Conclusions

The combined Yandi fauna surveys represent a comprehensive sampling effort with 54 systematic sampling sites being conducted across 10 studies spanning 11 years, many of which had seasonal sampling components. The full range of habitats present in the development envelope was sampled.

Species accumulation curves generated from the data demonstrated asymptotic patterns, indicating few additional species would be added with further sampling using the same techniques. Non-parametric estimates for the vertebrate assemblage predict that 85% of the fauna are likely to have been documented via the methods used during the surveys.

The combined fauna assemblage of 206 vertebrate species recorded from the Yandi development envelope is extensive, but is typical of that which would be realistically expected for an area of similar size in this locality, subjected to a similar samoling effort. Although the development envelope contains habitat and species of conservation value, the suite of species present is representative of the fauna commonly recorded within both the Pilbara bioregion and the Hamersley subregion.

This study has documented the existence of potential SRE fauna within the broader Yandi development envelope. Eight species were recorded from two broad taxonomic groups with the potential to include SREs (pseudoscorpions and mygalomorph spiders), and four putative species of mygalomorph spider were identified as potential SREs. All of these taxa are also known to occur outside of the development envelope and as a result, there is a reduced risk that disturbance inside the development envelope will adversely affect these species populations.

2.0 Introduction

2.1 Project Background

Hamersley Iron Yanid currently operates the Yandi iron ore mine as part of its Pilbara Iron operations. The Yandi mine is situated approximately 90 km northwest of Newman in the Pilbara region of Western Australia (Figure 2.1). Construction of the original Yandi mine, Junction Central (YJC), started in 1997 with the first shipment of ore occurring in 1999. An expansion to the existing mining operations was later proposed in 2005 in the form of Junction South East (JSE). A number of other sustaining operations have subsequently been approved and are progressing, including at the Junction South West (JSW) deposit and the proposed Oxbow deposits (YOX).

Rio Tinto plans to sustain their existing Yandi operations by opening a new pit to replace the exising operational pis as they are depleted. The proposed development includes a feasibility study for development of the Channel Iron Deposits (CIDs) at Pocket and Billiard South (PBS), located approximately 7 km east of the existing Yandi mine.

The combined extent of these components represents the overall Yandi integrated development envelope (hereafter referred to as the "development envelope"), as shown in Figure 2.1 and Figure 2.2. The development envelope covers a total of 19,351 ha, including or intersecting sections of the following individual Rio Tinto study areas:

- Yandi Junction Central (JDM study area: 3,733 ha);
- Hope Downs Rail Corridor Extension (HDR study area; 3,977 ha);
- Junction South East (JSE study area: 2,245 ha);
- Junction South West (JSW study area: 1,707 ha);
- Yandi Oxbow (YOX study area: 724 ha);
- Yandi Billiards (BIL study area: 4,410 ha); and
- Pocket and Billiard South (PBS study area: 8,639 ha).

The proposed PBS development will be formally assessed under the State *Environmental Protection Act 1986* (Biota 2014a). In order to assist with these environmental impact assessments (EIA), Biota was commissioned to integrate the above Yandi Billiard terrestrial fauna surveys into a broader reference framework for the wider Yandi development envelope of Ministerial Statement 914.

2.2 Purpose and Scope of this Report

This report has been prepared as a supporting document for EIA of the proposed PBS development. It consolidates all data from the individual studies completed for various components of the broader Yandi development envelope into a consistent format and provides a synthesised framework and integrated summary of the data from the individual studies.

By integrating the Yandi fauna surveys into a consolidated document, potential impacts of the PBS deposits development can be placed into appropriate context to support the forthcoming EIA. This provides a better-informed view of the terrestrial faunal values of the development envelope. Additionally, records of vertebrate species of conservation significance and potential SRE invertebrates are placed into better context than provided by individual supporting studies. Integration also allows habitat definition to be rationalised and better informed by the more robust faunal assemblage data set.

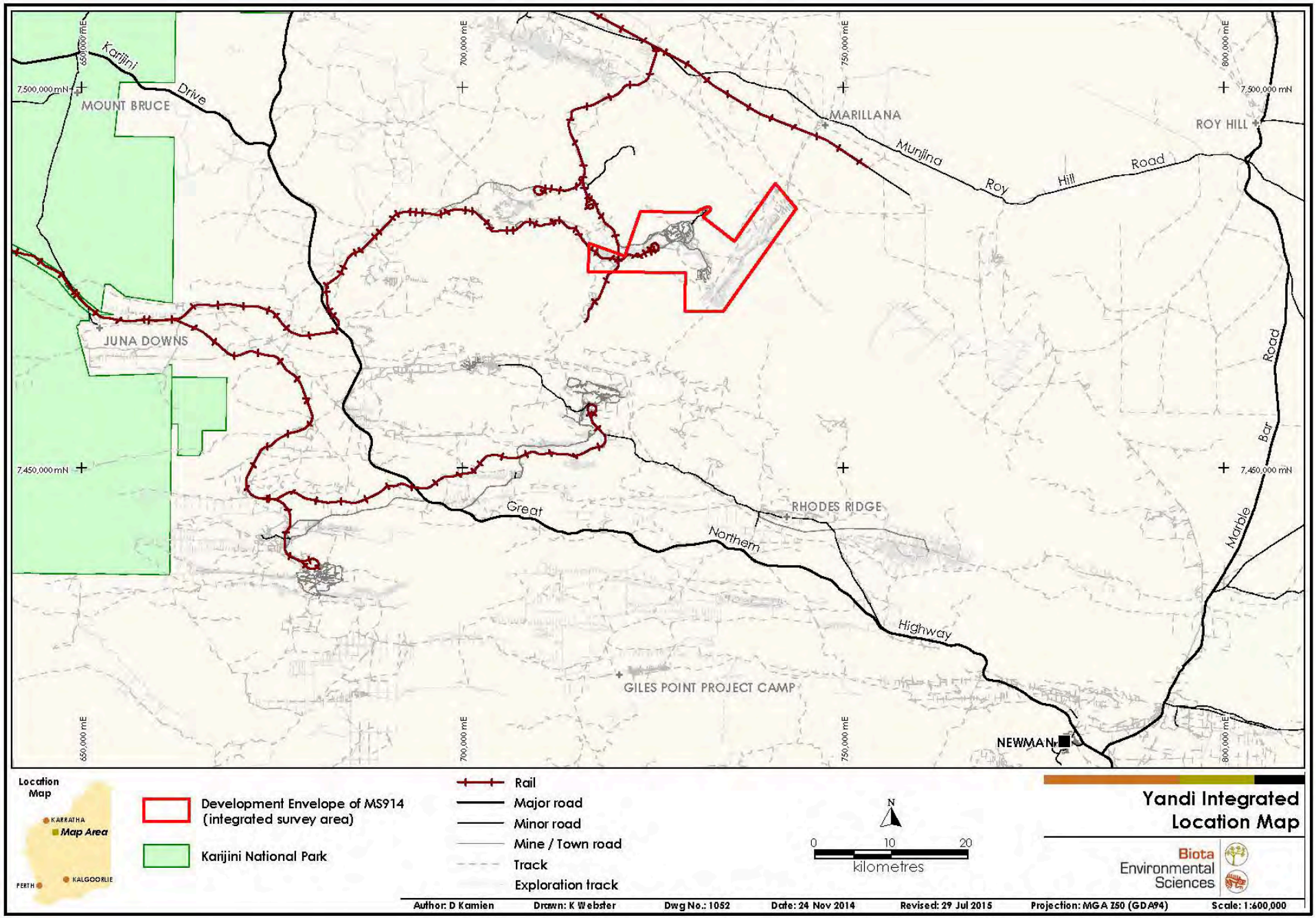

Figure 2.1: Location of the Yandi development envelope.

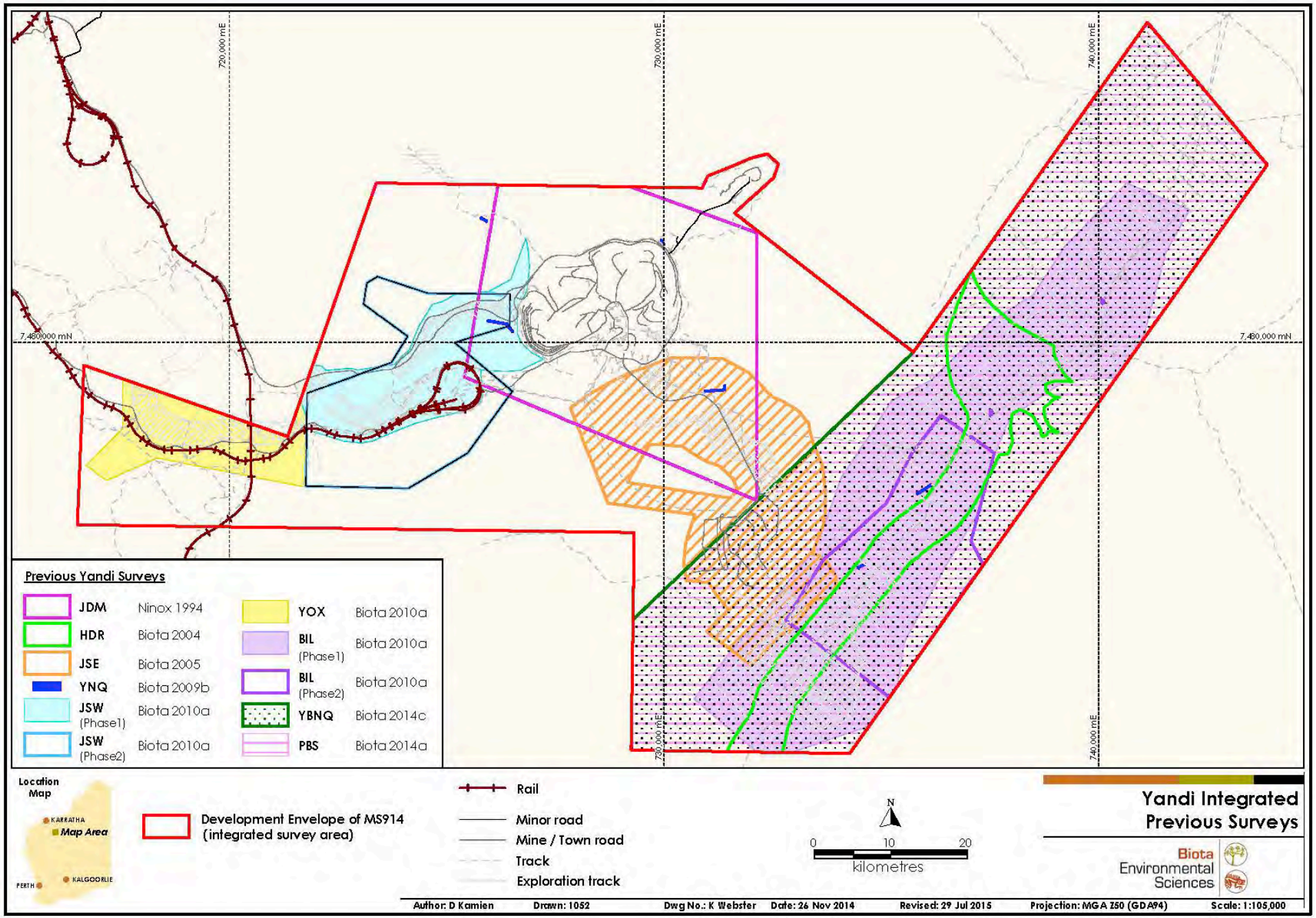

Figure 2.2: Spatial extent of individual studies covering the Yandi development envelope.

2.3 Fauna Background

2.3.1 Vertebrate Fauna

Although the primary purpose of this report is to consolidate all data from the individual studies completed for various components of the broader Yandi development envelope (see Section 2.2), it is important to note that certain species hold greater importance than others from an EIA perspective.

Fauna species listed as Threatened under the Commonwealth *EPBC Act 1999* constitute a Matter of National Environmental Significance (MNES). A significant impact to MNES species requires approval from the Australian Government Minister for the Environment. In cases where Threatened fauna are recorded, it is advisable to refer proposals to the Commonwealth Department of the Environment (DotE) to determine if the likely impacts are considered significant. Three threatened fauna species that are relevant at both State and Commonwealth levels are the Northern Quoll (*Dasyurus hallucatus*), Orange Leaf-nosed Bat (*Rhinonicteris aurantius*) and Pilbara Olive Python (*Liasis olivaceus barroni*).

2.3.1.1 Northern Quoll (*Dasyurus hallucatus*)

The Northern Quoll (Plate 2.1) is listed as Schedule 1 under the WA *Wildlife Conservation Act 1950* and Endangered under the Commonwealth *EPBC Act 1999*. It is a carnivorous dasyurid marsupial, which formerly occurred across much of northern Australia but is now considered to be restricted to six broad areas, including the Hamersley subregion in the Pilbara (DSEWPaC 2011).

The Northern Quoll favours rocky gorges, rocky free faces and hills, usually of high relief, and secondarily favours drainage lines (Biota 2009a, DSEWPaC 2011). Adjacent plains and vegetated areas provide habitats suitable for foraging and dispersal of young (van Dyck and Strahan 2008), but are considered to be of less importance for the species' conservation.

Plate 2.1: Northern Quoll, *Dasyurus hallucatus.*

2.3.1.2 Orange Leaf-nosed Bat (*Rhinonicteris aurantius*)

The Orange Leaf-nosed Bat (Plate 2.2) is listed as Schedule 1 under the WA *Wildlife Conservation Act 1950* and Vulnerable under the Commonwealth *EPBC Act 1999*. It is a relictual monotypic genus of the family Hipposideridae. An isolated population is found in the Pilbara region of Western Australia (van Dyck and Strahan 2008), although the species' wider distribution also includes the Kimberley region of Western Australia, the Northern Territory and north-western Queensland (Churchill 2008).

Occurrence of this species is influenced by the availability of suitable roost caves that offer high humidity and a stable temperature (Churchill et al. 2008). In the Pilbara, they are thought to be restricted to caves where semi-permanent or permanent water is nearby. Foraging typically occurs over open grasslands in gorges, low hills and on plains (Churchill et al. 2008).

Plate 2.2: Orange Leaf-nosed Bat, *Rhinonicteris aurantius*.

2.3.1.3 Pilbara Olive Python (*Liasis olivaceus barroni*)

The Pilbara Olive Python (Plate 2.3) is listed as Schedule 1 under the WA *Wildlife Conservation Act 1950* and Vulnerable under the Commonwealth *EPBC Act 1999*. It has a known distribution that approximately coincides with the Pilbara bioregion (Environment Australia 2000, Department of the Environment 2015). It occurs in rocky areas, showing a preference for gorges containing water in streams and rock pools (Wilson and Swan 2010).

Plate 2.3: Pilbara Olive Python, *Liasis olivaceus barroni.*

2.3.2 SRE Terrestrial Invertebrates

SRE invertebrates are groups of invertebrate fauna that display naturally small distributions (less than 10,000 km^2; Harvey 2002) These invertebrates often possess similar ecological and life-history characteristics, and are in part characterised by low fecundity, slow growth and poor dispersal capabilities (Harvey 2002). Examples exist from a range of groups including freshwater snails (Ponder and Colgan 2002) land snails (Johnson et al. 2004), and mygalomorph spiders (Main et al. 2000).

SRE invertebrates are often confined to disjunct 'refugial' habitats, having persisted from a time when moist conditions were more evenly distributed throughout the Australian landscape (Harvey 2002). Given their predisposition to restriction at small spatial scales, SRE fauna are more likely to experience population extinctions than more widely distributed taxa (Harvey 2002). As a result, the assessment of SRE taxa is therefore an important component of EIA (EPA 2009).

2.4 Threatened and Priority Ecological Communities

2.4.1 Threatened Ecological Communities

Threatened Ecological Communities (TECs) are defined by the Western Australian Department of Parks and Wildlife as naturally occurring biological assemblages, located in a particular habitat, which are under threat of modification or destruction from various processes.

No TECs occur within the development envelope. The nearest mapped TEC, the "Themeda grasslands on cracking clays (Hamersley Station, Pilbara)", is located approximately 30 km northeast of the development envelope. There is no suitable habitat for this TEC in the development envelope (Biota 2014b).

2.4.2 Priority Ecological Communities

Priority Ecological Communities (PECs) are vegetation and/or fauna communities that are recognised to be of significance, but do not meet the criteria for a TEC. The only PEC in the locality is the "Brockman Iron cracking clay communities of the Hamersley Range", which is known from approximately 30 km to the northeast of the development envelope (Biota 2014b). There is no suitable habitat (clay plains) for this PEC in the development envelope.

The Fortescue Marsh is located approximately 30 km northeast of the development envelope. The Fortescue Marsh is the largest ephemeral wetland in the Pilbara and is listed in the Directory of Important Wetlands in Australia (Environment Australia 2001). It is listed by the Department of Parks and Wildlife as a Priority 1 PEC.

3.0 Approach and Methods

3.1 Surveys and Timing

The collated Yandi fauna data used in this report were sourced from 10 separate studies, many involving two survey phases. A summary of the studies, survey timing and supporting reports is provided in Table 3.1. The spatial extents of the supporting surveys are shown in Figure 2.2.

Details on the individual survey teams and weather conditions are provided in the relevant supporting reports listed in Table 3.1. Aside from one targeted Northern Quoll survey, all components of the development envelope were surveyed at least once during warm conditions (March, September or October (Table 3.1). This timing was optimal from the survey adequacy perspective, particularly March sampling which occurred in months following summer rain. A summary of the survey methods used and combined sampling effort is provided in Section 3.2.

Table 3.1: Summary of Yandi surveys contributing to the collated data set.

Study (Reference)	Job Code	Survey Timing
Junction Deposit Mine and the Central Pilbara Transport Corridor (Ninox Wildlife Consulting 1994)	JDM	March 1994
Hope Downs Rail Corridor Extension - Hamersley Range (Biota 2004)	HDR	April 2003
Yandi Junction South East (Biota 2005)	JSE	August 2004
Yandicoogina Targeted Quoll Survey (Biota 2009b)	YNQ	October 2009
Yandi Junction South West (Biota 2010a)	JSW	Phase I: July 2008 Phase II: March 2010
Yandi Oxbow (Biota 2010a)	YOX	Phase I: July 2008 Phase II: March 2010
Yandi Billiards (Biota 2010a)	BIL	Phase I: July 2008 Phase II: March 2010
Yandi Billiards Targeted Quoll Survey (Biota 2014c)	YBNQ	August 2014
Pocket and Billiards South (Biota 2014a, 2014d)	PBS	Phase I: March 2014 (Biota 2014d) Phase II: September 2014 (Biota 2014a)
Yandi Oxbow E8 (Biota 2014e)	YOXE8	Phase I: September 2014

Other relevant reports that were reviewed but did not contribute additional data comprised:

- Yandicoogina Expansion Northern Quoll Position Paper (Biota 2010b);
- Yandi Billiards Terrestrial Fauna, Flora and Vegetation Desktop Assessment (Biota 2014f); and
- Yandi Billiards Interim Report on Conservation Significant Fauna (Biota 2014g).

3.2 Summary of Survey Methods

The fauna surveys completed at Yandi comprised a combination of systematic sampling and other methodologies (Sections 3.2.1 and 3.2.2). All sampling work was completed in accordance with relevant EPA and *EPBC Act 1999* policy, specifically:

- EPA Position Statement No. 3: "Terrestrial Biological Surveys as an Element of Biodiversity Protection" (EPA 2002);
- EPA Guidance Statement No. 56: "Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia" (EPA 2004);
- EPA Guidance Statement No. 20: "Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia" (EPA 2009);

- Technical Guide - Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment (EPA and DEC 2010); and
- *EPBC Act 1999* referral guidelines for the endangered northern quoll, *Dasyurus hallucatus* (DSEWPaC 2011).

3.2.1 Terrestrial Vertebrates

The systematic census component of the fauna surveys primarily comprised trapping transects. Each trap line was located within an identified landform and comprised:

- Pit lines: a single row of 10 pitfall traps arranged as alternating 20 litre buckets and 150 mm diameter x 600 mm high PVC tubes, spaced at approximately 10 m intervals and connected with a 90 m length of 300 mm high flywire fence (see Figure 3.1).
- Elliott lines: trapping transects consisting of a combination of medium and large Elliott box traps spaced at approximately 10 m to 15 m intervals (between 18 and 50 traps per line). Elliott traps were baited with a universal bait mixture of peanut butter and oats.
- Funnel lines: funnel traps placed in pairs at approximately 10 m intervals adjacent to a 100 m length of 300 mm high fly wire fence (see Figure 3.2).

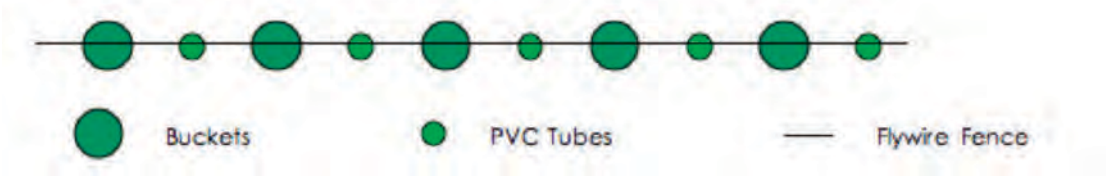

Figure 3.1: Layout of pit trapping transects.

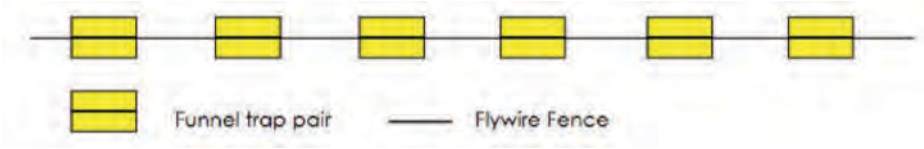

Figure 3.2: Layout of funnel trapping transects.

Pit trap lines sample the majority of the ground fauna with smaller body size, and were used in all accessible habitats across the development envelope. Funnel traps were used in selected locations where hard substrates made pit installation impractical, and were most effective at sampling snakes, legless lizards and geckos. Elliott traps were used primarily to target *Dasyurus hallucatus* (Northern Quoll) in areas prospective for this species (rocky gorges and breakaways).

3.2.1.1 Avifauna Sampling

Avifauna sampling during the surveys used a combination of techniques including:

- unbounded area searches (30-40 minutes duration) conducted at systematic trapping sites;
- unbounded area searches at opportunistic locations in habitats likely to support previously unrecorded species; and
- opportunistic observations of birds.

Individual censuses were confined to discrete landforms, typically corresponding to vegetation type at each trapping site. Censuses were usually conducted between 6:00 am and 11:00 am. Bird species were identified by sight or call.

3.2.1.2 Bat Sampling

Bat sampling was undertaken during the surveys using Anabat SD2 (Titley Scientific, NSW) and SM2 SongMeter (Wildlife Acoustics Inc, USA) echolocation call recorders, in addition to the direct capture method of harp traps. Sampling equipment was placed in locations considered likely to

provide records of a range of species, including at cave or rock shelter entrances, adjacent to standing water or in potential flyways through vegetation.

Echolocation calls were recorded continuously at all sites using either an LS-10 Professional PCM Recorder (Olympus, Japan) in conjunction with the Anabat SD2 unit, or using an SM2 SongMeter. COOL EDIT 2000 software (Syntrillium) was used to display continuous call sequences for identification. Calls were analysed using methods recommended by the Australasian Bat Society (2006) in conjunction with available reference data (Bullen and McKenzie 2002, McKenzie and Bullen 2003, 2009). Only sequences containing good quality search phase calls were considered for identification.

3.2.1.3 Non-Systematic Sampling of Vertebrate Fauna

Non-systematic fauna sampling was also undertaken to supplement trapping and investigate additional habitats and microhabitats identified during the course of the surveys. This included:

- searches of specific habitats, including plains, rocky gorge free faces and pools or streams, for Schedule and Priority listed fauna species;
- searching of microhabitats for reptile, frog and small mammal species not commonly recorded through trapping (e.g. by raking leaf litter and turning rocks and logs);
- opportunistic sightings;
- nocturnal work including road spotting and head-torching;
- identification of road kills and other animal remains found during the surveys;
- recording and identification of secondary trace signs (where possible) including tracks, scats and diggings; and
- the use of remote infrared cameras (Bushnell cameras) which are triggered by movement.

3.2.1.4 Nomenclature

Species nomenclature for herpetofauna and mammals follows the standards of the Western Australian Museum (WAM) fauna taxonomic checklist, in accordance with the requirements of the EPA and DEC (2010). Avifauna nomenclature used also meets this guidance and follows Christidis and Boles (2008).

3.2.2 Short Range Endemic Fauna

Sampling of the development envelope for SRE fauna involved both systematic (pit-trap transects) and non-systematic (targeted searching) sampling methods. Full details of terrestrial fauna sampling methods and sampling effort are provided in the source reports listed in Section 3.1, with a summary overview of the components relevant to SRE fauna provided below.

The relevant surveys targeted those invertebrate groups with the potential to contain SREs that were considered most likely to occur in the development envelope:

- Mygalomorphae (trapdoor spiders);
- Diplopoda (millipedes);
- Scorpiones (scorpions);
- Pseudoscorpiones (pseudoscorpions); and
- Pulmonata (land snails).

Pit traps were checked on a daily basis as part of the terrestrial vertebrate fauna surveys, during which time potential SRE fauna specimens were collected and curated in accordance with the procedures in Sections 3.2.2.1 to 3.2.2.5.

Targeted searching for potential SRE fauna was also conducted. These searches actively targeted microhabitats for invertebrate groups considered likely to support SRE taxa.

3.2.2.1 Mygalomorph Spiders

Mygalomorph spider burrows were located visually and were photographed prior to excavation. Holes were dug adjacent to each burrow, allowing the burrow to be followed down with forceps until the spider was located. One leg of each spider collected was removed and placed in 100% ethanol to provision for molecular studies, while the remainder of each spider was preserved in 70% ethanol for morphological studies.

3.2.2.2 Millipedes

Millipedes were located by raking through leaf litter and debris. All specimens collected were preserved in 70% ethanol.

3.2.2.3 Scorpions

Visual searches for scorpion burrows were conducted and scorpions were collected opportunistically while searching under rocks and raking through soil and leaf litter. Specimens were preserved in 70% ethanol.

3.2.2.4 Pseudoscorpions

Searches for pseudoscorpions were conducted by:

- searching on trees and beneath bark;
- searching under rocks;
- raking soil and leaf litter; and
- sieving soil and leaf litter.

Specimens were preserved in 70% ethanol.

3.2.2.5 Snails

Searches for land snails were conducted by:

- excavating leaf litter and soil around the base of spinifex (*Triodia* spp.) hummocks;
- searching under rocks and in rock crevices; and
- sieving soil and leaf litter.

Live free-sealing species were stored in calico bags for later preservation in ethanol for morphological analysis in Perth or lodgement with the WAM.

3.3 Sampling Effort

3.3.1 Systematic Trapping Sites

The systematic sampling effort conducted within the Yandi development envelope comprised 54 trapping sites as outlined in (Table 3.2) and depicted in Figure 3.3. Details of all systematic fauna sampling sites are provided in Appendix 1.

Table 3.2 Summary of Yandi survey systematic vertebrate trapping sites.

Study (Reference)	Job Code	Number and Types of Sites	Total Trap Nights	Site Code
Junction Deposit Mine and the Central Pilbara Transport Corridor (Ninox Wildlife Consulting 1994)	JDM	7 (7 pit/Elliott trap lines)	1,092	FS
Hope Downs Rail Corridor Extension Hamersley Range (Biota 2004)	HDR	4 (3 funnel and pit trap lines)	235	HDD HAC
Yandi Junction South East (Biota 2005)	JSE	0 (Desktop exercise and targeted invertebrate sampling only)	na	YEX

Study (Reference)	Job Code	Number and Types of Sites	Total Trap Nights	Site Code
Yandicoogina Targeted Quoll Survey (Biota 2009b)	YNQ	8 (8 Elliott trap lines)	1,186	YNQ
Yandicoogina Junction South West Fauna Survey (Biota 2010a)	JSW	5 (3 pit trap lines; 1 Elliott trap line; 1 funnel trap line	400	YAN
Yandicoogina Oxbow Fauna Survey (Biota 2010a)	YOX	6 (3 pit trap lines; 1 Elliott trap line, 1 funnel trap line)	693	OXB
Yandicoogina Expansion Billiard Deposit Fauna Survey (Biota 2010c)	BIL	8 (6 pit trap lines; 2 funnel traps lines)	600	BIL
Yandi Billiards Targeted Northern Quoll Survey (Biota 2014c)	YBNQ	5 (5 combination Elliott/cage trap lines)	862	YBQ,
Pocket Billiards South (Biota 2014d)	PBS	11 (5 pit trap lines; 4 funnel trap lines; 2 Elliott trap lines)	2,070	YBL

Sampling periods typically ranged from six to seven nights, and four surveys comprised multiple sampling phases (Section 3.1). The sampling collectively represented 7,138 trap nights of systematic effort in the Yandi development envelope (i.e. the number of traps multiplied by the number of nights that traps were active; see Table 3.2). Further details on individual site opening and closure dates and other specifics are provided in the respective source survey reports cited in Appendix 1.

The Pilbara bioregion is broadly mapped into land system units, which are defined on the basis of a combination of geomorphology, hydrology, soils and vegetation (van Vreeswyk et al. 2004). The distribution of survey sites within the land systems of the Yandi development envelope is shown in Figure 3.3.

The development envelope was spatially dominated by the Newman, McKay, Boolgeeda and River land systems (see Section 4.1). The majority of the systematic survey effort was expended in these units (Table 3.3). The majority of sampling was conducted on the Boolgeeda and River land systems due to their dominance in the individual areas surveyed (Figure 2.2), in combination with development envelope accessibility. All land systems except Rocklea (which comprised only 0.3% of the development envelope) were sampled during the combined surveys.

Table 3.3: Number of systematic trapping sites within land systems in the Yandi development envelope.

Land System	No. of Systematic Trapping Sites	Hectares within Development envelope	Proportion of Development envelope (%)
Newman	5	5,790	29.9
McKay	6	5,282	27.3
Boolgeeda	16	3,760	19.4
River	20	3,264	16.9
Robe	5	706	3.6
Urandy	2	496	2.6
Rocklea	0	53	0.3
Total	54	19,351	100.0

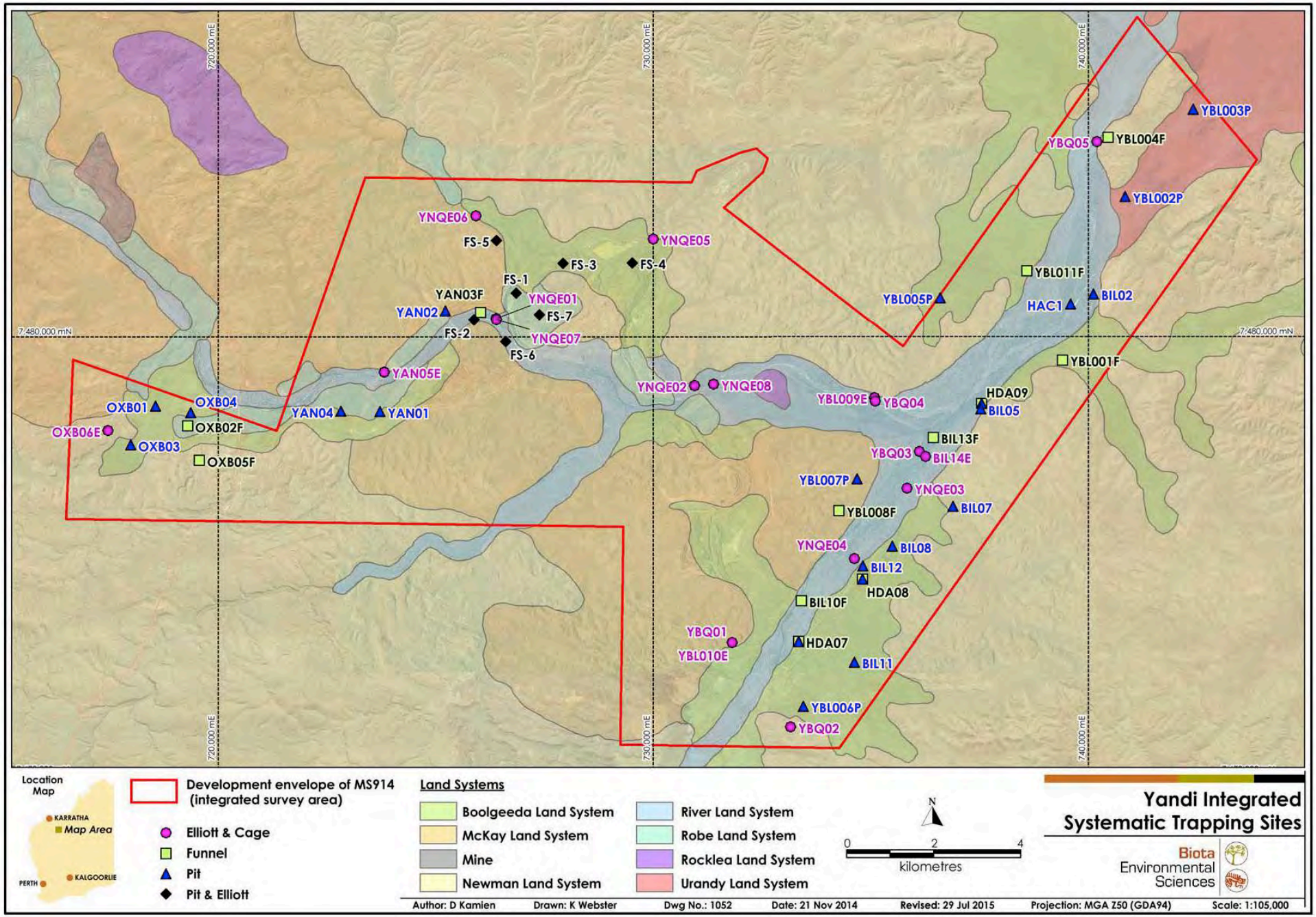

Figure 3.3: Systematic fauna trapping sites and land systems in the development envelope.

3.3.2 Avifauna Sampling

Systematic avifauna censuses were conducted at the majority of fauna trapping sites resulting in good spatial coverage across all components of the development envelope (Table 3.4 and Figure 3.3). A summary of avifauna survey effort is provided in Table 3.4.

Avifauna censuses were carried out at a total of 49 sites across the development envelope, and the census time from all phases of survey work totalled approximately 107 hours (6,410 minutes). Details of the avifauna censuses, including the exact times and dates censuses were carried out, can be found in the individual source reports listed in Table 3.4.

Table 3.4: Summary of Yandi avifauna census sites.

Study (Reference)	Job Code	Number of Sites	Total Census Time (mins)
Junction Deposit Mine and the Central Pilbara Transport Corridor (Ninox Wildlife Consulting 1994)	JDM	7	1,890
Hope Downs Rail Corridor Extension Hamersley Range (Biota 2004)	HDR	14	1,840
Yandi Junction South East (Biota 2005)	JSE	na	na
Yandicoogina Targeted Quoll Survey (Biota 2009b)	YNQ	na	na
Yandicoogina Expansion Billiard Deposit Fauna Survey (Biota 2010c)	BIL	8	600
Yandicoogina Oxbow Fauna Survey (Biota 2010a)	YOX	5	310
Yandicoogina Junction South West Fauna Survey (Biota 2010a)	JSW	4	300
Yandi Billiards Targeted Northern Quoll (Biota 2014a, 2014c)	YBNQ	na	na
Pocket and Billiards South (Biota 2014a)	PBS	11	1,470

"na" indicates avifauna survey not conducted.

3.3.3 Non-systematic Sites

3.3.3.1 Bat Sites

Bat sampling was conducted in areas deemed mostly likely to yield bat records (Section 3.2.1.2). This effort was therefore focused in the rocky free-face landforms, particularly where caves or other potential roost site features were present in gorges, and along larger drainages, particularly where permanent water pools were present (Figure 3.4 and Appendix 1). Bat sampling effort totalled 62 survey nights across 21 sites as summarised in Table 3.5.

Table 3.5: Summary of Yandi bat survey sites.

Study (Reference)	Job Code	Number of Sites	Total Evenings Monitored
Junction Deposit Mine and the Central Pilbara Transport Corridor (Ninox Wildlife Consulting 1994)	JDM	opportunistic	na
Hope Downs Rail Corridor Extension Hamersley Range (Biota 2004)	HDR	4	16
Yandi Junction South East (Biota 2005)	JSE	na	na
Yandicoogina Targeted Quoll Survey (Biota 2009b)	YNQ	na	na
Yandicoogina Expansion Billiard Deposit Fauna Survey (Biota 2010c)	BIL	1	4
Yandicoogina Oxbow Fauna Survey (Biota 2010a)	YOX	1	3
Yandicoogina Junction South West Fauna Survey (Biota 2010a)	JSW	1	3
Yandi Billiards Targeted Northern Quoll (Biota 2014a, 2014c)	YBNQ	6	18
Pocket and Billiards South (Biota 2014a)	PBS	8	18

"na" indicates bat survey not conducted.

3.3.3.2 Motion Camera Sites

Motion cameras were deployed during two studies within the development envelope (Table 3.6).

Table 3.6: Summary of Yandi motion camera sites.

Study (Reference)	Job Code	Number of Sites	Total Evenings Monitored
Yandi Billiards Targeted Northern Quoll Survey (Biota 2014c)	YBNQ	7	22
Pocket Billiards South (Biota 2014d)	PBS	5	17

3.3.4 Short Range Endemic Fauna Sampling

In addition to pit traps (Section 3.3.1), a minimum of 42 sites were non-systematically searched for potential SRE fauna. In many of the historical surveys, SRE searches were conducted opportunistically and the exact search effort was not recorded (Table 3.7). The spatial extent of recorded SRE searches is depicted in Figure 3.5.

Table 3.7: Summary of non-systematic SRE sampling effort within the Yandi development envelope.

Survey (Reference)	Job Code	Number of Search Sites	Search Effort (mins)
Junction Deposit Mine and the Central Pilbara Transport Corridor (Ninox Wildlife Consulting 1994)	JDM	na	na
Hope Downs Rail Corridor Extension Hamersley Range (Biota 2004)	HDR	Opportunistic	na
Yandi Junction South East (Biota 2005)	JSE	12	na
Yandicoogina Targeted Quoll Survey (Biota 2009b)	YNQ	na	na
Yandicoogina Expansion Billiard Deposit Fauna Survey (Biota 2010c)	BIL	Opportunistic	na
Yandicoogina Oxbow Fauna Survey (Biota 2010a)	YOX	Opportunistic	na
Yandicoogina Junction South West Fauna Survey (Biota 2010a)	JSW	Opportunistic	na
Yandi Billiards Targeted Northern Quoll (Biota 2014a, 2014c)	YBNQ	4	980
Pocket and Billiards South (Biota 2014a)	PBS	23	2,705
Yandi Oxbow E8 (Biota 2014e)	YOXE8	3	95

na - indicates SRE survey not conducted.

Opportunistic indicates that dedicated SRE survey sites were not established.

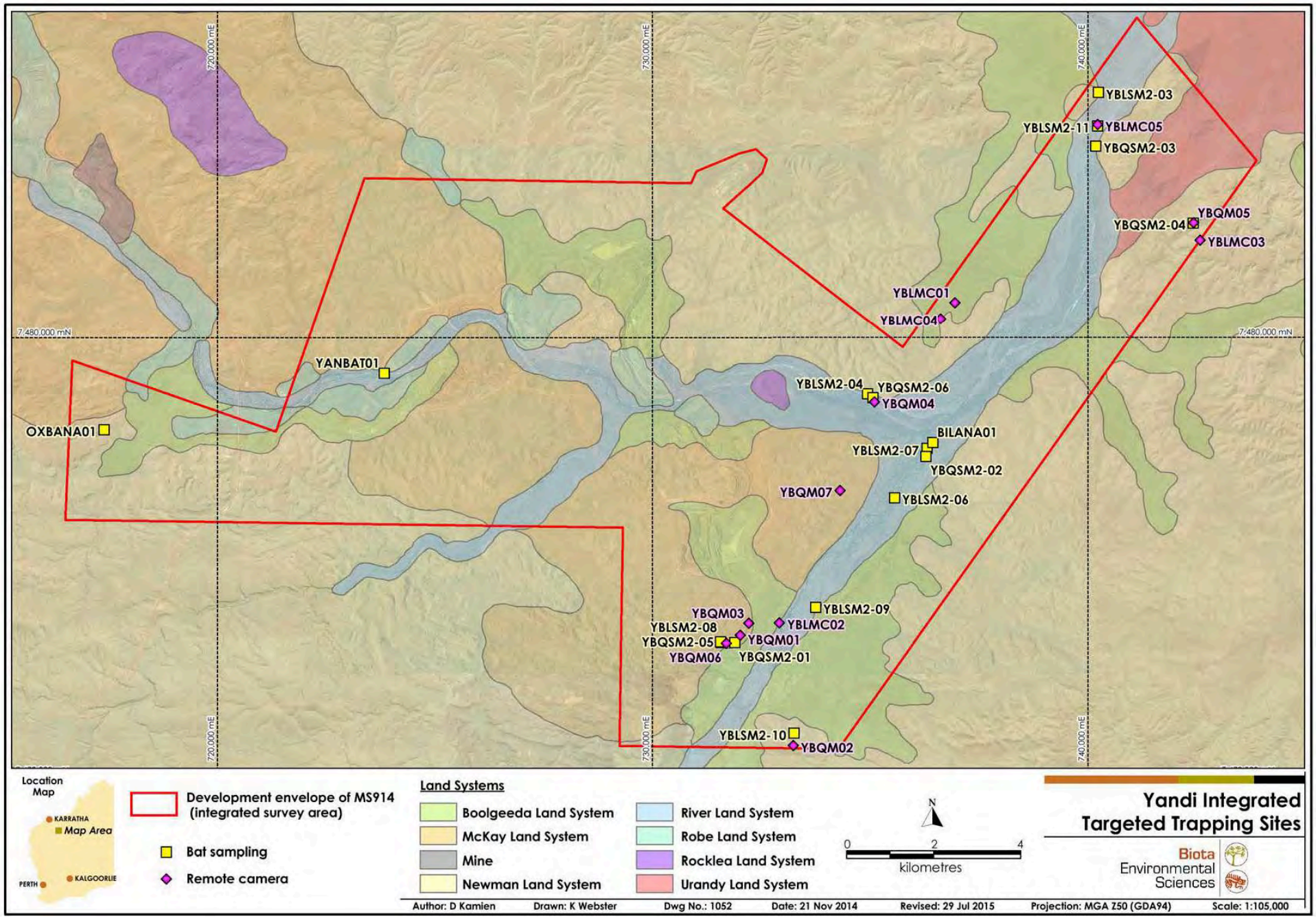

Figure 3.4: Non-systematic fauna sampling sites and land systems in the development envelope.

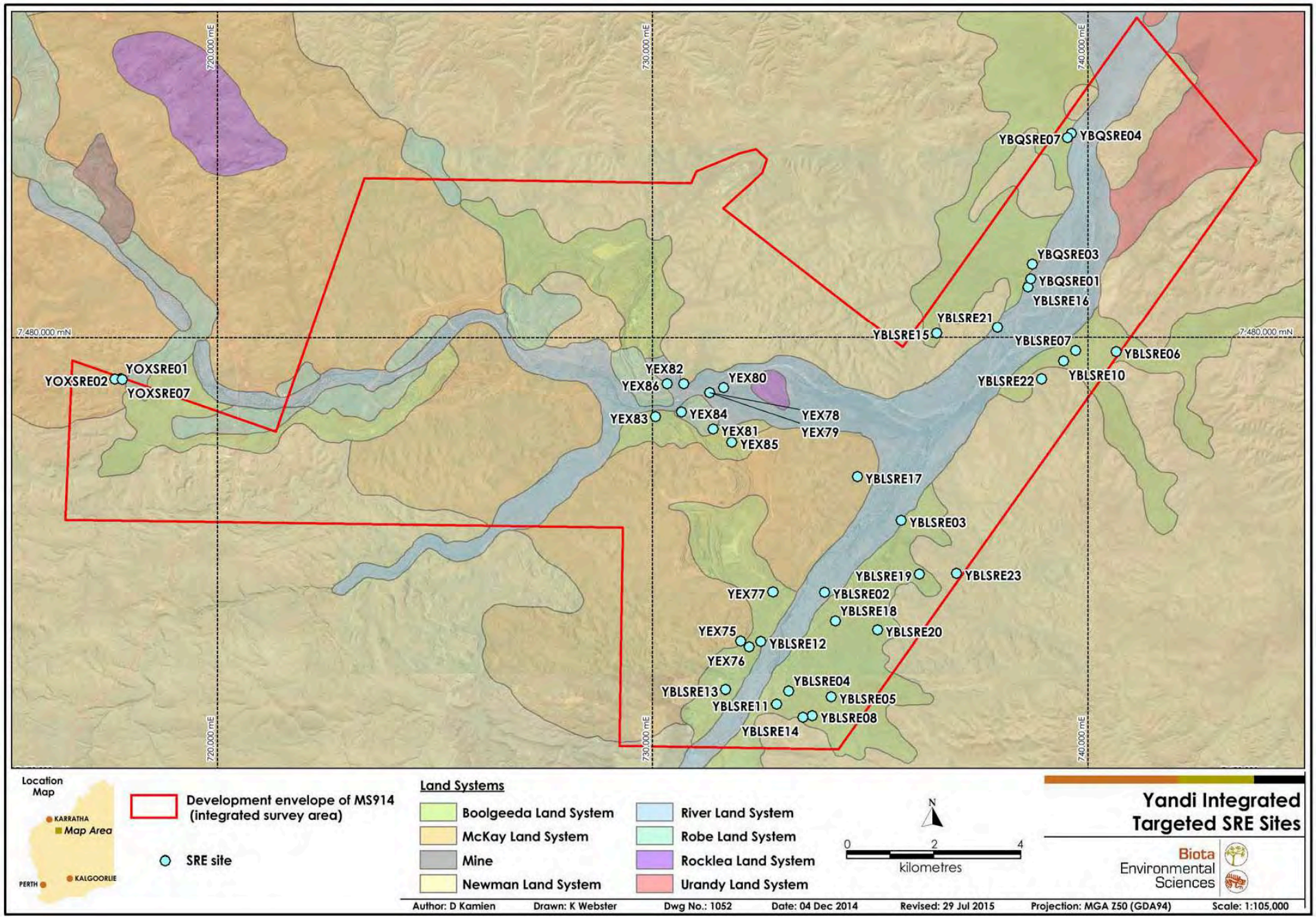

Figure 3.5: SRE fauna sampling sites and land systems in the development envelope.

3.4 Identification and Data Analysis

3.4.1 Vertebrate Assemblage and Habitat Analysis

The combined fauna data set was analysed using PRIMER v6.1 (Clarke and Gorley 2006). Excluding species accumulation curves, records were screened to remove data with the potential to bias the results. The following records were excluded from the analyses:

- opportunistic records that represented chance events and were not derived from equivalent sampling methods across sites;
- records from Elliott traps and Funnel traps for herpetofauna analysis, as these traps typically target specific mammal species;
- large body-size species that would not have been adequately sampled by the trapping sites (such as *Varanus panoptes and Pseudechis australis*), even when sightings occurred at systematic trap sites (i.e. not purely opportunistic records); and
- frog species, as they are prone to large abundance peaks following wet weather conditions, which can skew site resemblance analyses.

Bat records were also excluded from all data analysis including species accumulation analysis as these were determined by echolocation recordings, which cannot be used to calculate abundance.

The screened site by species matrix for each of the faunal groups was imported into PRIMER and square-root transformed to reduce the influence of high abundance species on the similarity analyses. A resemblance matrix was then constructed using the Bray-Curtis similarity index, which produces a similarity value for all pairs of sites based on species representation and transformed abundances. This was then used to generate a non-metric Multi-Dimensional Scaling (NMDS) plot to assist with visualising the groupings amongst the sites based on faunal composition. A 30% similarity level was used to inform assemblage groupings in correspondence with Similarity Profiles (SIMPROF) test results.

Habitat parameters for each site were imported into PRIMER, which comprised:

- surface geology (Thorne and Trendall 2001);
- land system (van Vreeswyk et al. 2004); and
- landform (as documented in the field by the survey zoologists; Section 4.1).

The NMDS plots were coded with various habitat factors to identify any relationships between them and the species assemblages. The consolidated outputs of this approach were then used to define habitats and matching faunal assemblages for the development envelope. Where appropriate, and where the data allowed, Similarity Percentages (SIMPER) analysis was also run in PRIMER to identify the individual faunal species that best characterised and typified each the assemblages.

3.4.2 Species Accumulation

Plots of species accumulation curves and trends in the resultant curves over time can be used to assess sampling adequacy. When a survey has sampled an adequate proportion of the faunal community, the curve should plateau and approach asymptote. PRIMER v6.1 was again used to calculate smoothed species accumulation curves based on 999 random permutations of the species data. Actual observed accumulation curves were also plotted (see Section 4.7).

Species accumulation curves alone cannot be reliably used to extrapolate predicted species richness for future biological sampling. In order to estimate asymptotic richness (i.e. extrapolation of species richness), asymptotic estimators were used (Clarke and Gorley 2006):

- Bootstrap estimator;
- Chao 1 richness estimator; and
- Jack-knife richness estimator.

3.4.3 Short Range Endemic Fauna

3.4.3.1 Morphological Identifications

Collected specimens were lodged at the WAM for taxonomic identification by the following specialists: Corey Whisson (land snails), Mieke Strong and Dr Mark Harvey (pseudoscorpions), and Julianne Waldock (araneomorph spiders). Tissue samples from mygalomorph spiders were lodged with Helix Molecular Solutions (Helix) for molecular analysis, with the remainder of each specimen being lodged with the WAM.

3.4.3.2 Genetic Analysis of Mygalomorph Spiders

Mygalomorph spiders are commonly recorded in the Pilbara bioregion, however very few of these have been resolved to the species level (source: Biota internal database). This report makes use of a broad genetic study into mygalomorph spiders to help infer putative species boundaries and better identify distributions.

Helix carried out the relevant molecular analysis. Sequence data derived from the WAM's collection was used to assign specimens collected from the Yandi development envelope to lineages based on Bayesian analysis of COX1 haplotypes. Previous assessments have been provided based on combining samples into species if they show less than 9.5% sequence divergence (Biota 2012a). This value was discussed with Dr Terrie Finston (Helix) and Dr Mark Harvey (WAM) as a suitably conservative threshold for identifying likely species.

3.4.3.3 Determining SRE Status

Table 3.8 details the criteria used to determine the SRE status of putative species for the purposes of this report.

Table 3.8: Criteria used to determine SRE status.

SRE Status	Defining Criteria
Known SRE	• Species, morphotype or genetic type has a documented range of <10,000 km^2. • Species, morphotype or genetic type is well collected with numerous specimens typed and habitat preference understood.
Potential SRE	• Species, morphotype or genetic type has a documented range of <10,000 km^2 but is poorly sampled. • Specimen may not be formally described or assigned to a morphotype / genetic type. • Short-range endemism may be common in genus or family. • May have been collected from restricted, refugial or isolated habitats.
Unlikely to be an SRE	• Species, morphotype or genetic type has a documented range of <10,000 km^2 but is poorly sampled. • Specimen may not be formally described or assigned to a morphotype / genetic type. • Short-range endemism is not common in genus or family. • Taxon was not collected from restricted, refugial or isolated habitats. • Few other individuals of the taxon collected, but records are separated by long distances (>100 km).
Not an SRE	• Specimen formally described or assigned to a morphotype / genetic type. • Species, morphotype or genetic type has a documented range of >10,000 km^2.
Undetermined	• Taxa where there is insufficient taxonomic framework available to provide any informed comment on the species-level distribution of the fauna or, therefore, the risk of small-scale spatial restrictions.

3.5 Study Team

Overarching fauna assessments of the Yandi development envelope were coordinated by Garth Humphreys and Roy Teale of Biota. Individual survey field team leaders comprised Roy Teale, Dan Kamien, Dr Phil Runham and Dr Stewart Ford (all of Biota). Consistent with regulatory guidelines (EPA and DEC 2010), the team members of the individual surveys are detailed in Table 3.9.

Analysis of bat call recordings was completed by Mr Bob Bullen (Bat Call WA). Paul Sawers, Ash Brown, Melissa Robinson and Kylie Webster (Biota) completed all Geographical Information System analyses and map preparation for the study.

Table 3.9: Details of the Yandi fauna assessment teams and their participation in the source field surveys.

Team Member	Role	Experience (years)	HDR	JSE	YNQ	JSW	YOX	BIL	PBS	YBNQ
Roy Teale	Team leader	24	✓	✓						
Garth Humphreys	Team leader	24	✓							
Dan Kamien	Team leader	16				✓	✓	✓		
Phil Runham	Team leader	16				✓	✓	✓		
Stewart Ford	Team leader	12							✓	
Michael Greenham	Lead Zoologist	10								✓
Zoë Hamilton	Lead Zoologist	8		✓						
Jason Alexander	Lead Zoologist	8			✓				✓	
Erin Harris	Survey Zoologist	5				✓	✓	✓		
David Keirle	Survey Zoologist	6			✓					
Tim Sachse	Survey Zoologist	6								
Jess Cairnes	Survey Zoologist	6			✓	✓	✓	✓		
Penny Brooshooft	Survey Zoologist	2							✓	
Chris Cole	Survey Zoologist	2							✓	
Andrew Sheppard	Survey Zoologist	2							✓	
Jacinta King	Survey Zoologist	2								✓

3.6 Limitations

As this report collates data from source studies, the limitations that apply to each of those studies also apply here. The primary limitations comprise the following:

Vertebrate Fauna

- The habitats within each development envelope were not equally sampled, and sampling effort was not equal amongst the contributing surveys.
- Biases in individual sampling methods may influence richness estimates. For example, Elliott trapping is typically unreliable in sampling herpetofauna, and funnel traps are unreliable in sampling mammals.
- Not every section of the development envelope was ground-truthed or systematically sampled. Parts of the development envelope were inaccessible by vehicle, so installation and regular checking of fauna traps in these areas would not have been possible. Systematic fauna sampling was, however, completed in all habitats considered to represent the range of landforms and land units present in the development envelope (see Table 3.3).
- Targeted trapping of the Northern Quoll *Dasyurus hallucatus* before 2011 was not conducted in accordance with the *EPBC Act 1999* referral guidelines for this species ("EPBC Act policy statement 3.25" (DSEWPaC 2011)).
- Combined data were obtained from surveys undertaken in different seasonal conditions and by different survey teams. This may have confounded the SIMPER analyses results.

SRE Fauna

- Many groups containing SREs do not have a complete taxonomic framework, and there is insufficient taxonomic expertise for many potential SRE invertebrate groups.
- Many taxa are difficult to sample adequately (e.g. mygalomorph spiders are difficult to locate, and morphological identification requires male specimens, which can generally only be collected immediately after rainfall).
- Not all sections of the development envelope were equally ground-truthed or sampled for fauna, as parts of the development envelope were inaccessible. However, SRE fauna searches and sampling were conducted in habitats considered to be representative of the range of units present within the development envelope.
- The survey data presented here and related interpretations are based on reference information available at the time of completing this report. Other genetic sequencing of SRE fauna from the Pilbara bioregion is ongoing and comparisons with records beyond the development envelope have only been made based upon current data. Any significant changes to contextual information affecting the findings may be addressed through the supply of supplementary information or a future revision of this report.

4.0 Results

4.1 Fauna Habitats Framework

Several aspects of fauna habitats were examined in this study, including:

- regional geology;
- land systems; and
- landforms.

The geology of the development envelope was broadly typical of this area of the Pilbara bioregion (Thorne and Trendall 2001). The surface geology of the development envelope is dominated by both young alluvial formations (Qa) and ancient banded iron formations (PLHj) (Table 4.1).

Table 4.1: Surface geology units of the development envelope.

Geological Time Scale				Description	Area (ha)
Eon	Era	Period	Unit		
Phanerozoic	Cenozoic	Quaternary	Qa	Alluvium: unconsolidated silt, sand, and gravel in drainage channels and adjacent floodplains	4,225.8
			Qs	Eolian deposit: sand in sheets and longitudinal dunes.	1.3
			Qw	Alluvium and colluvium: red-brown sandy and clayey soil on low slopes and sheetwash areas.	826.0
		–	Czc	Colluvium: partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits; locally derived.	3,443.7
			Czk	Calcrete: sheet carbonate, found along major drainage lines.	340.6
			Czp	Robe Pisolite: pisolitic limonite deposits developed along river channels.	808.2
			Czr	Hematite-goethite deposits on banded iron-formation and adjacent scree deposits.	8.5
Proterozoic	–	–	PLHb	Brockman Iron Formation: banded iron formation, chert, and pelite.	637.5
			PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills.	9,059.6

The development envelope was dominated by four land systems (van Vreeswyk et al. 2004): Newman. McKay, Boolgeeda and River, which together accounted for 93.5% of the area (Table 4.2). The descriptions of these land systems therefore broadly characterise the habitats of the development envelope:

- Newman – rugged jaspilite plateaus, ridges and mountains supporting hard spinifex grasslands;
- McKay – hills, ridges, plateau remnants and breakaways of metasedimentary and sedimentary rocks supporting hard spinifex grasslands;
- Boolgeeda – stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands; and
- River – active flood plains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.

The land systems of the development envelope are mapped in Figure 3.3, with their wider extent in the immediate locality also shown for context.

Table 4.2: Land systems occurring within the development envelope.

Land System	Extent in Development envelope	Proportion of Development envelope	Extent within Hamersley Subregion	Percent of Land System in the Subregion Occurring in the Development envelope
Newman	5,791 ha	29.9%	1,853,935 ha	0.31%
McKay	5,282 ha	27.3%	80,718 ha	6.54%
Boolgeeda	3,760 ha	19.4%	606,771 ha	0.62%
River	3,264 ha	16.9%	72,628 ha	4.49%
Robe	706 ha	3.6%	103,116 ha	0.68%
Urandy	496 ha	2.6%	42,024 ha	1.18%
Rocklea	53 ha	0.3%	711,645 ha	0.01%

Broad fauna landscape units were also documented for the development envelope, with common landform units and substrate types standardised across the various surveys (Section 3.4.1). Three broad landscapes were identified within the development envelope, with varying representation amongst the source development envelopes (Table 4.3).

Table 4.3: Broad fauna habitat landscape units and survey effort.

Landscape	Number of Survey Sites †								
	JDM	HDR	JSE	YNQ	JSW	YOX	BIL	YBNQ	PBS
Contemporary drainage systems of alluvial deposits with gently inclined slopes to flat land, below hills and raised plains.	2	2	na	6	2	–	5	3	1
Gently sloping lower slopes, stony plains and level alluvial plains.	4	2	na	2	2	4	3	–	6
Mountainous rugged terrain comprising ridges, plateaus, steep hills with free faces and stream channels.	1	–	na	–	1	2	1	2	4

† See Table 3.1 for explanation of job codes.

Within these landscapes, eight landforms were identified from the development envelope using Biota's fauna landscape approach (Biota 2013a), which adopts an amalgamation of landform patterns and specific landform elements that are considered to represent suitable habitats for species, and in particular, species of conservation significance. The identified landforms are comprise:

- major drainage lines (rivers) containing permanent water, with varying substrates including alluvium, clay loam, rock and sandy loams;
- minor ephemeral drainage lines (creeks);
- alluvial plains with clay loam substrate;
- plains with varying substrates including calcrete, loam and clay loams;
- pediment slopes covered with stony loams;
- hillslopes and hillcrests, mostly covered with stony loams or exposed rock;
- free faces with associated debris slope (gorges) on exposed rock; and
- breakaways adjacent to drainage lines.

A map depicting a broad overview of combined landforms is depicted in Figure 4.1). Sites surveyed within each landform are summarised in Table 4.4 with representative landforms provided in Plate 4.1 to Plate 4.8.

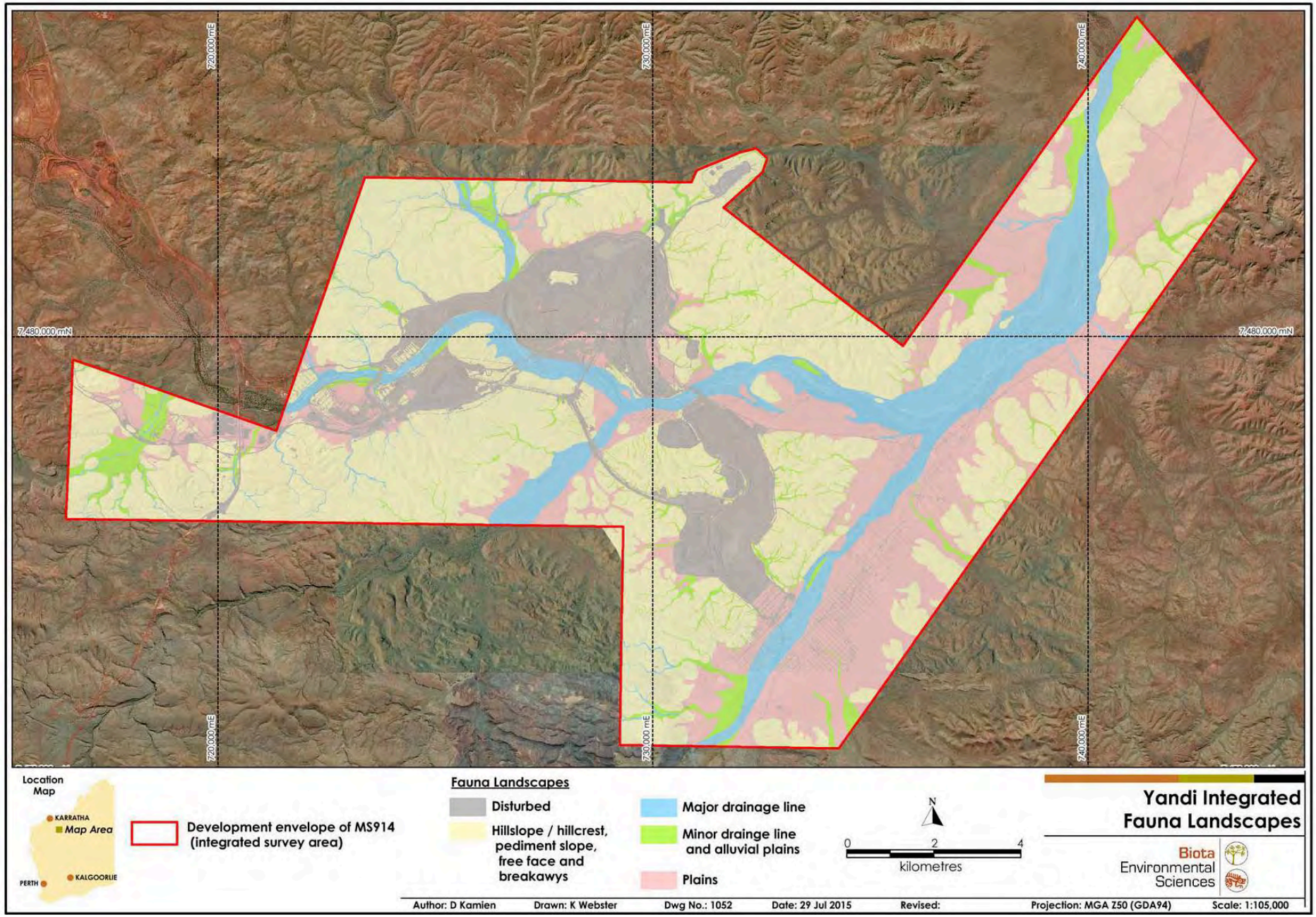

Figure 4.1: Map depicting broad landforms overview

Table 4.4: Landforms and systematic sampling sites within the development envelope.

Landform	No. of Sites	Survey Sites
Major drainage line	19	HAC1, HDA09, YNQE01, YNQE02, YNQE03, YNQE07, YNQE08, BIL02, BIL05, BILF10, BILF13, YANE05, YANF03, YBL009E, FS-2, FS-6, YBQ03, YBQ04, YBQ05
Minor drainage line	1	YBL004F
Alluvial plain	9	YNQE04, YBL002P, YBL003P, YBL005P, YBL006P, YBL011F, FS-1, FS-4, BIL12
Plain	9	YNQE05, YNQE06, OXB01, OXB03, OXBF02, YAN01, YAN04, OXB04, BIL08
Pediment slope	8	HDA07, HDA08, BIL07, BIL11, OXBF05, YBL007P, FS-3, FS-7
Hillslope / hillcrest	4	YBL001F, YBL008F, OXBE06, YAN02
Free face	3	YBL010E, YBQ01, YBQ02
Breakaway	1	FS-5

Plate 4.1: Major drainage.

Plate 4.2: Minor drainage.

Plate 4.3: Alluvial plain.

Plate 4.4: Plain.

Plate 4.5: Pediment slope.

Plate 4.6: Hillslope/crest.

Plate 4.7: Free face.

Plate 4.8: Breakaway adjacent to major drainage.

4.2 Overview of the Fauna

A total of 206 vertebrate fauna species were recorded from the development envelope during the surveys, comprising three amphibians, 69 reptiles, 103 avifauna species, 15 native ground mammals, 10 bats and six introduced mammals (see Appendix 2). A summary of the number of species from each major vertebrate group recorded for each project component, and the development envelope as a whole, is provided in Table 4.5.

Table 4.5: Vertebrate fauna recorded in the Yandi integrated development envelope.

	Number of Species †									
Fauna Group	JDM	HDR	JSE	YNQ	JSW	YOX	BIL	YBNQ	PBS	Development envelope
Amphibians	2	1	na	1	0	0	2	0	3	3
Reptiles	27	16	na	5	8	8	8	1	59	69
Native non-volant mammals	6	3	na	2	2	3	3	5	14	15
Introduced mammals	4	0	na	1	2	0	2	1	3	6
Bats	3	na	na	na	5	4	3	10	9	10
Avifauna	71	64	na	na	42	24	44	3	93	103
"na" indicates taxon search not conducted									Total	206

† See Table 3.1 for explanation of job codes.

A desktop survey (Biota 2013b) indicated that there is the potential for 249 species to occur within the development envelope. The observed species richness of the development envelope comprises almost 83% of this total.

4.3 Herpetofauna

A total of 72 herpetofauna species were recorded from the development envelope comprising three frog species and 69 reptiles. Reptile species comprised six dragons (family Agamidae), 12 geckos (Gekkonidae, Diplodactylidae and Carphodactylidae), seven legless lizards (Pygopodidae), 27 skinks (Scincidae), eight monitors (Varanidae), two blind snakes (Typhlopidae), two pythons (Boidae) and six front-fanged snakes (Elapidae).

The gecko *Diplodactylus conspicillatus* (n=77 individuals) and the skinks *Ctenotus duricola* (n=68) and *Ctenotus saxatilis* (n=59) were the most abundant herpetofauna species recorded in the development envelope.

The Schedule 1 listed Pilbara Olive Python (*Liasis olivaceus barroni*) was recorded opportunistically during the PBS survey, observed swimming downstream in Weeli Wolli Creek during a nocturnal search at YBLNoct04 (zone 50, 740774 mE, 7481941 mN) (Biota 2014a). Several anecdotal sightings of this species have also been made at the existing Yandi operations.

4.3.1 The Assemblage

The SIMPROF test identified seven clusters of sites that were internally consistent based on the reptile species present (frogs were excluded; see Section 3.4.1). The resemblance matrix for the sites based on reptile composition was also used to generate NMDS plots, with sites coded by survey locality, land system, landform and geology (Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5 respectively). For the majority of data, the NMDS plots showed separation of clusters, indicating that fauna assemblages could be placed into groups that were fundamentally different to each other.

The best relationship between the seven herpetofauna assemblages and the site habitat factors was provided by 'survey locality', where the herpetofauna composition recorded from the PBS survey was similar for each survey site, but noticeably different to data obtained in the other localities (Figure 4.2).

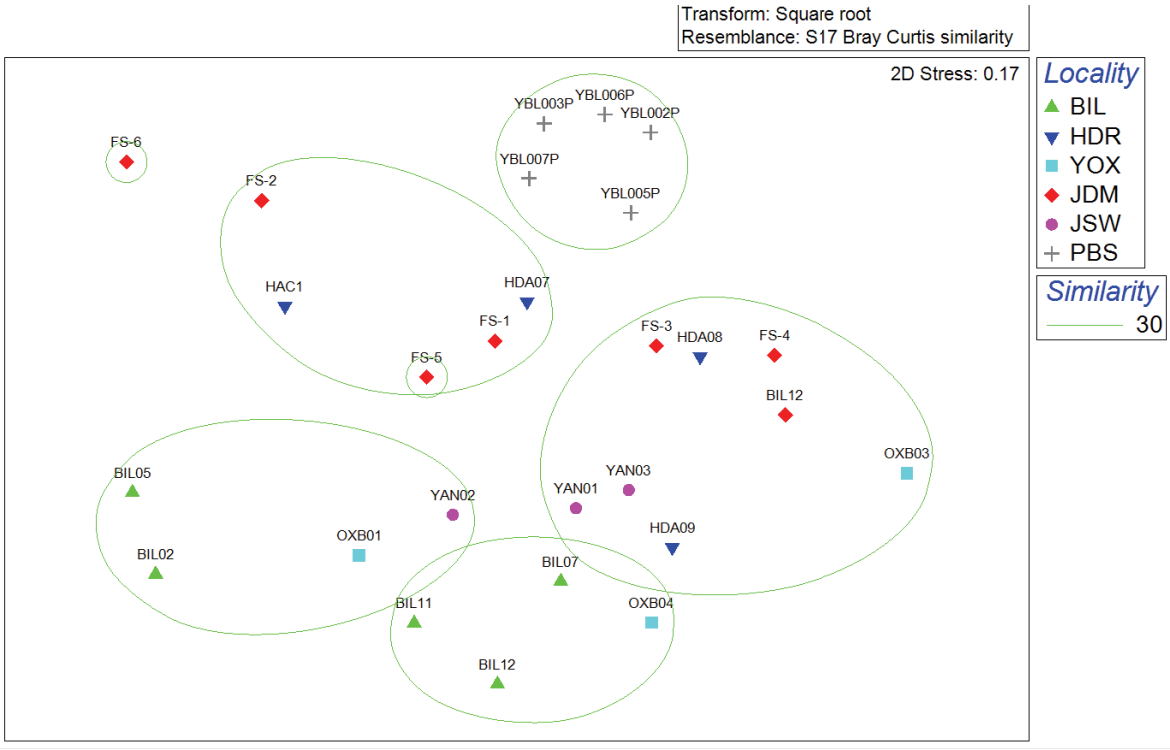

Figure 4.2: NMDS plot of Yandi survey sites based on herpetofauna composition and coded by survey locality.
See Table 3.1 for explanation of locality codes.

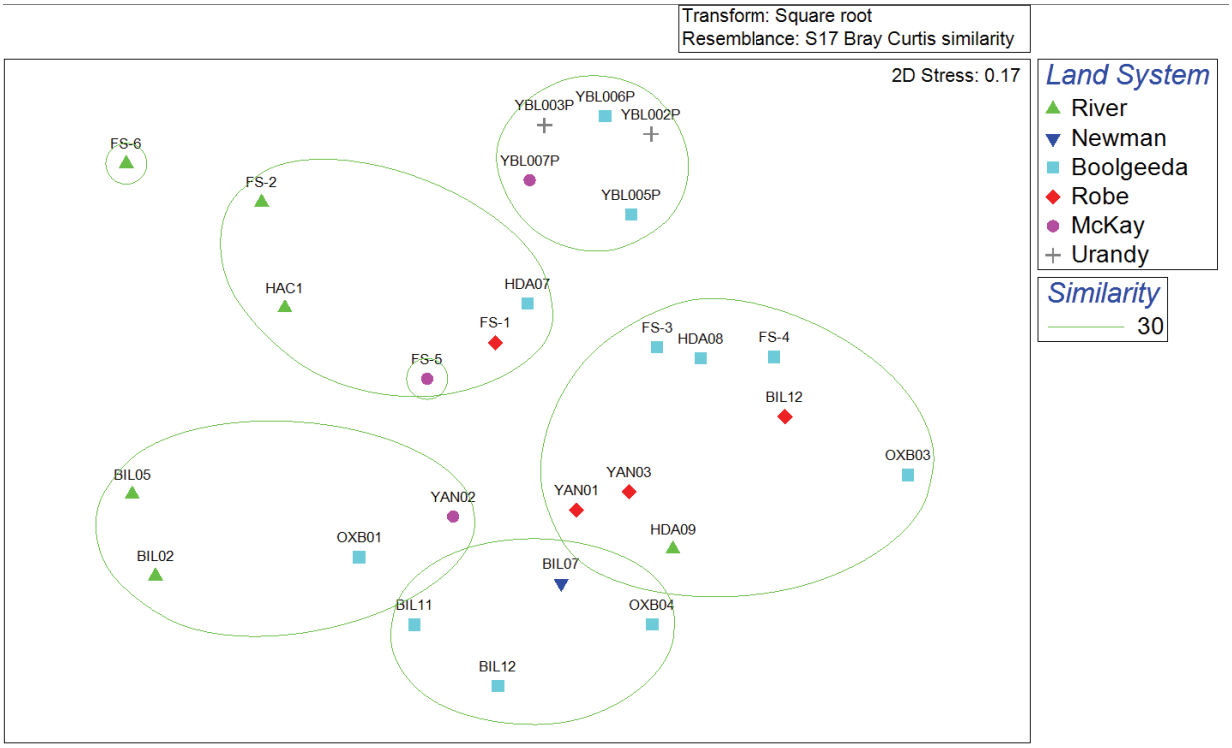

Figure 4.3: NMDS plot of Yandi survey sites based on herpetofauna composition and coded by land systems.

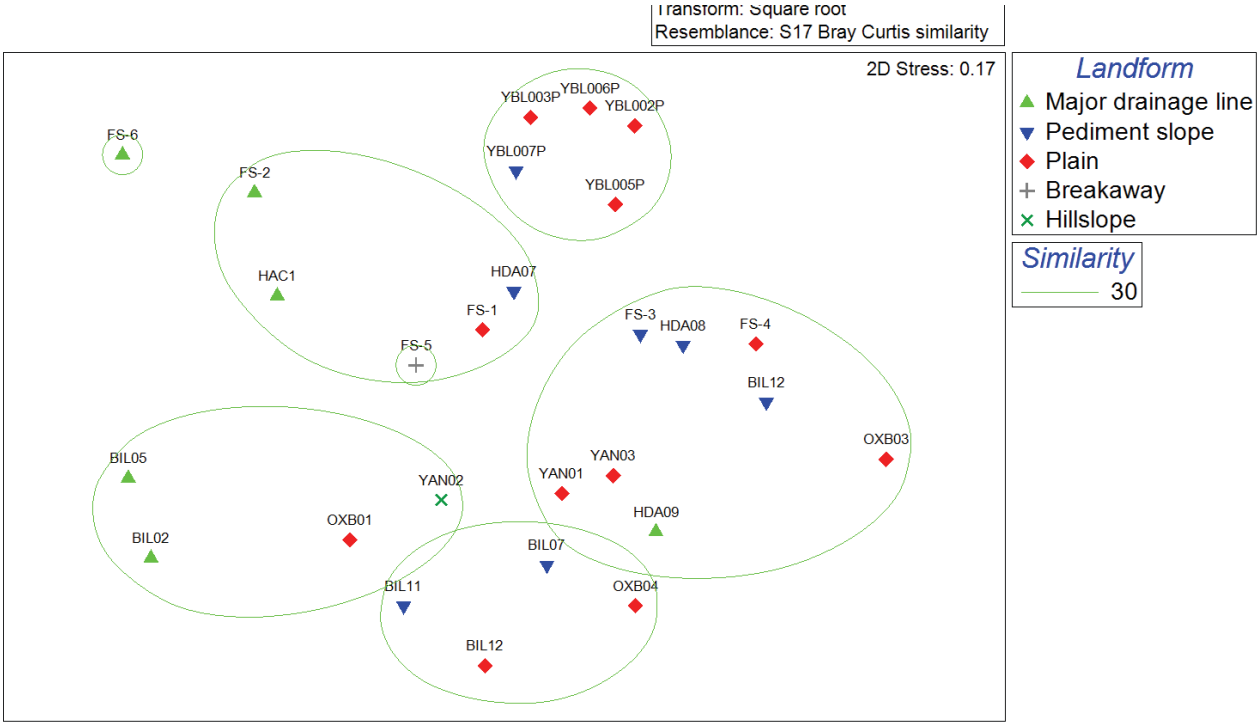

Figure 4.4: NMDS plot of Yandi survey sites based on herpetofauna composition and coded by landform.

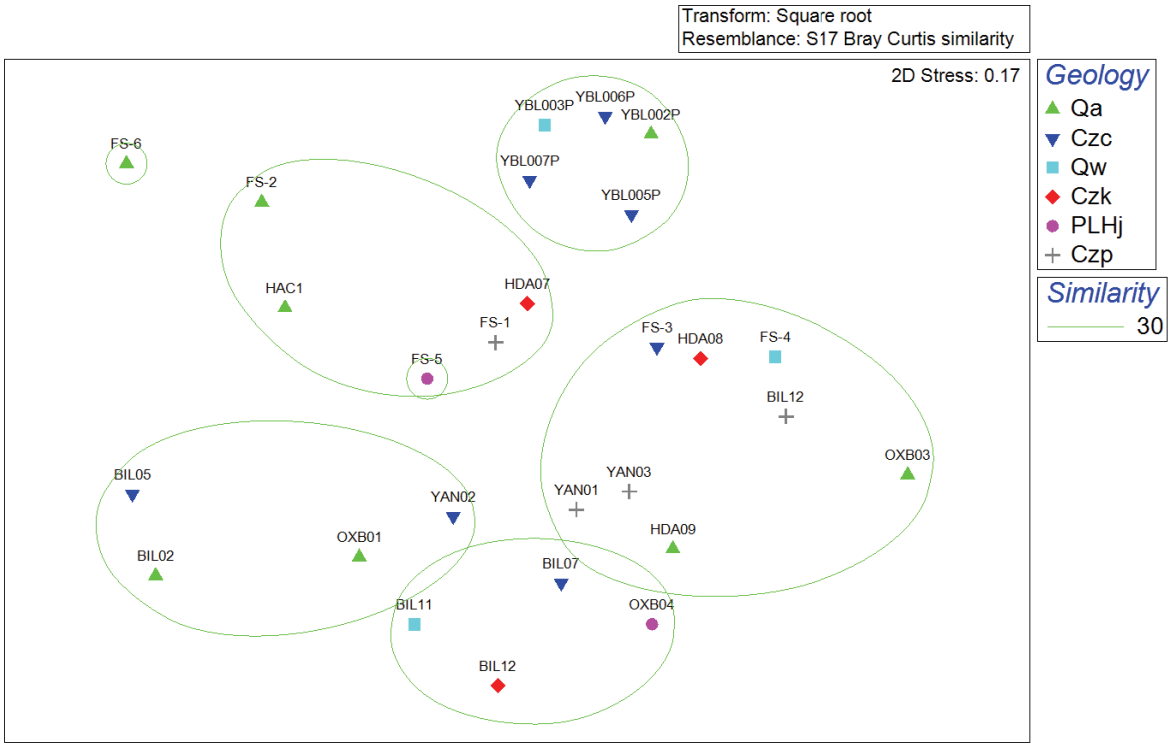

Figure 4.5: NMDS plot of Yandi survey sites based on herpetofauna composition and coded by geology.

A SIMPER analysis was used to identify the species that most strongly characterised each of the assemblages based on landform (Table 4.6). The species characterising each landform type are broadly consistent with the habitats in which they are typically recorded (Cogger 2014). Based on both survey results and previously documented habitat preferences, it is also apparent that certain species such as the dragon *Ctenophorus isolepis* and the skink *Ctenotus pantherinus* occur in a range of landforms and exhibit lower habitat specificity.

Table 4.6: Key herpetofauna species characterising each landform within the development envelope.

Landform †	Indicator Species ¥	Contribution to Group Similarity	Typical Habitats (Cogger 2014)
Major drainage line	*Amphibolurus longirostris*	65.1%	Watercourses.
	Varanus tristis	10.8%	Trees and rocky outcrops.
	Menetia greyii	10.8%	Woodland, shrubland, hummock grassland.
Alluvial plain	*Diplodactylus conspicillatus*	15.2%	Generalist.
	Ctenophorus isolepis	14.3%	Generalist often with hummock grassland.
	Ctenotus duricola	13.1%	Variety of habitats on stony soils.
	Ctenotus pantherinus	12.3%	Variety of habitats on stony soils. Hummock grassland, sandy areas.
Plain	*Ctenotus pantherinus*	52.2%	Hummock grassland, sandy areas.
	Ctenophorus isolepis	38.4%	Generalist, often with hummock grassland.
Pediment slope	*Ctenophorus caudicinctus*	27.2%	Rocky areas.
	Ctenotus pantherinus	25.8%	Hummock grassland, sandy areas.
	Lucasium stenodactylum	13.7%	Generalist
	Ctenotus duricola	12.3%	Variety of habitats on stony soils.
Hillslope	NA – less than two samples.	-	-
Breakaway	NA – less than two samples.	-	-

† Herpetofauna not analysed for free face, minor drainage line or hillcrest landforms due to incompatible trapping methods (see Section 3.4.1).

¥ Species with 10% or more contribution shown.

Although species' habitats are typically defined by the landform in which they most typically occur, it is evident that the habitats within the development envelope represent a continuum for many of the ground species. Landform type may therefore influence species occurrence, however additional variables will also have an influence on species distribution.

4.4 Ground Dwelling Mammals

Twenty-one ground mammals, comprising 15 native and six introduced species, were recorded from the development envelope. This total comprised six carnivorous marsupial species (Dasyuridae), three kangaroo species (Macropodidae), six rodent species (Muridae), one cat (Felidae), one canine (Canidae), two equine species (Equidae), one cattle species (Bovidae) and one camel species (Camelidae). The introduced mammals recorded in the development envelope comprised the house mouse (*Mus musculus*), feral cat (*Felis catus*), donkey (*Equus asinus*), horse (*Equus caballus*), European cattle (*Bos taurus*) and camel (*Camelus dromedarius*).

The most abundant mammals in the development envelope were the introduced house mouse *Mus musculus* (n=45 individuals from 14 sites), the Common Rock Rat *Zyzomys argurus* (n=30 individuals from seven sites) and the Sandy Inland Mouse *Pseudomys hermannsburgensis* (n=29 individuals from 16 sites).

The Priority 4 listed Western Pebble-mound Mouse *Pseudomys chapmani* and Brush-tailed Mulgara *Dasycercus blythi* were the only ground mammal species of conservation significance recorded from the development envelope. Twenty-eight Western Pebble-mound Mouse records were recorded from 22 locations within the development envelope. Three inactive Mulgara burrows were also recorded on an alluvial plain in the northeastern section of the development envelope.

4.4.1 The Assemblage

The SIMPROF test using ground mammal data identified multiple clusters of sites, which were internally consistent at 30% assemblage similarity. This is reflected in the NMDS plot, with many clusters encompassing single sites. This indicates that in most cases mammal assemblages were fundamentally different between individual sites (Figure 4.6). As a result, comparisons between assemblages recorded within different landforms, land systems and geology types were not conducted.

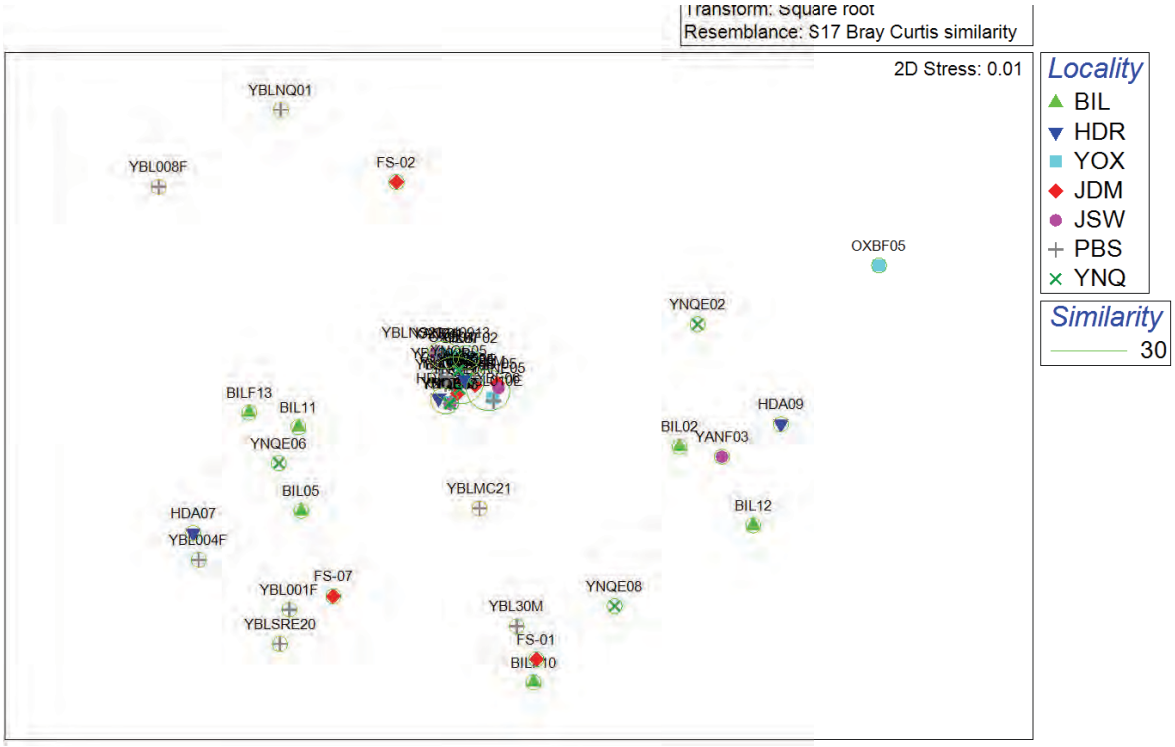

Figure 4.6: NMDS plot of Yandi survey sites based on ground mammal composition and coded by survey locality.

4.5 Bats

Ten bat species were recorded from the development envelope, comprising two species from the family Emballonuridae, three from the family Molossidae and five from the family Vespertilionidae. The most commonly encountered species were Finlayson's Cave Bat *Vespadelus finlaysoni* and Gould's Wattled Bat *Chalinolobus gouldii,* which were both recorded at all six of the survey localities where bat sampling was conducted. All 10 species were recorded from the YBNQ study area, while nine species were recorded from the PBS study area (Table 4.7).

Table 4.7: Occurrence of bat species at each locality within the development envelope.

FAMILY Species Name	Common Name	Locality †					
		JSW	YOX	BIL	JDM	YBNQ	PBS
EMBALLONURIDAE							
Saccolaimus flaviventris	Yellow-bellied Sheathtail Bat	✓		✓		✓	✓
Taphozous georgianus	Common Sheathtail Bat	✓	✓			✓	✓
MOLOSSIDAE							
Chaerephon jobensis	Northern Freetail Bat					✓	✓
Mormopterus beccarii	Beccari's Freetail Bat					✓	✓
Tadarida australis	White-striped Freetail Bat	✓				✓	
VESPERTILIONIDAE							
Chalinolobus gouldii	Gould's Wattled Bat	✓	✓	✓	✓	✓	✓
Chalinolobus morio	Chocolate Wattled Bat					✓	✓
Nyctophilus geoffroyi	Lesser Long-eared Bat					✓	✓
Scotorepens greyii	Little Broad-nosed Bat					✓	✓
Vespadelus finlaysoni	Inland Cave bat	✓	✓	✓	✓	✓	✓

† See Table 3.1 for explanation of locality codes.

4.6 Avifauna

A total of 103 avifauna species from 40 families were recorded from the development envelope. The total comprised 53 passerine and 50 non-passerine species. The most speciose families were the Meliphagidae (honeyeaters and chats) with 11 species recorded, and the Accipitridae (raptors) with seven species recorded. The most abundant bird species were the Zebra Finch *Taeniopygia guttata* (n=142 individuals) and the Weebill *Smicrornis brevirostris* (n=107), both of which were recorded from the majority of survey sites. The diversity of avifauna recorded in the development envelope was high and as a result, the two most abundant species stated above accounted for only 8% and 6% respectively of all avifauna recorded in the development envelope.

Six avifauna species of conservation significance were recorded during the surveys: the Rainbow Bee-eater *Merops ornatus* (Schedule 3, migratory), Fork-tailed Swift *Apus pacificus* (Schedule 3, migratory); Eastern Great Egret *Ardea modesta* (Schedule 3, Migratory); Peregrine Falcon *Falco peregrinus* (Schedule 4), Australian Bustard *Ardeotis australis* (Priority 4) and Star Finch (Western form) *Neochmia ruficauda subclarescens* (Priority 4; see Section 4.9 and Appendix 2).

4.6.1 The Assemblage

A SIMPROF test of avifauna data identified four clusters of sites at the 30% similarity level. However, an NMDS plot shows that the majority of sites group within a single large cluster (Figure 4.7). Apart from two outlier sites, the NMDS resulted in very little separation of the two remaining sites clusters, indicating that the avifauna assemblages at the majority of sites were not fundamentally different. The association of landform, land system and geology type with avifauna assemblage is depicted in Figure 4.8 to Figure 4.10.

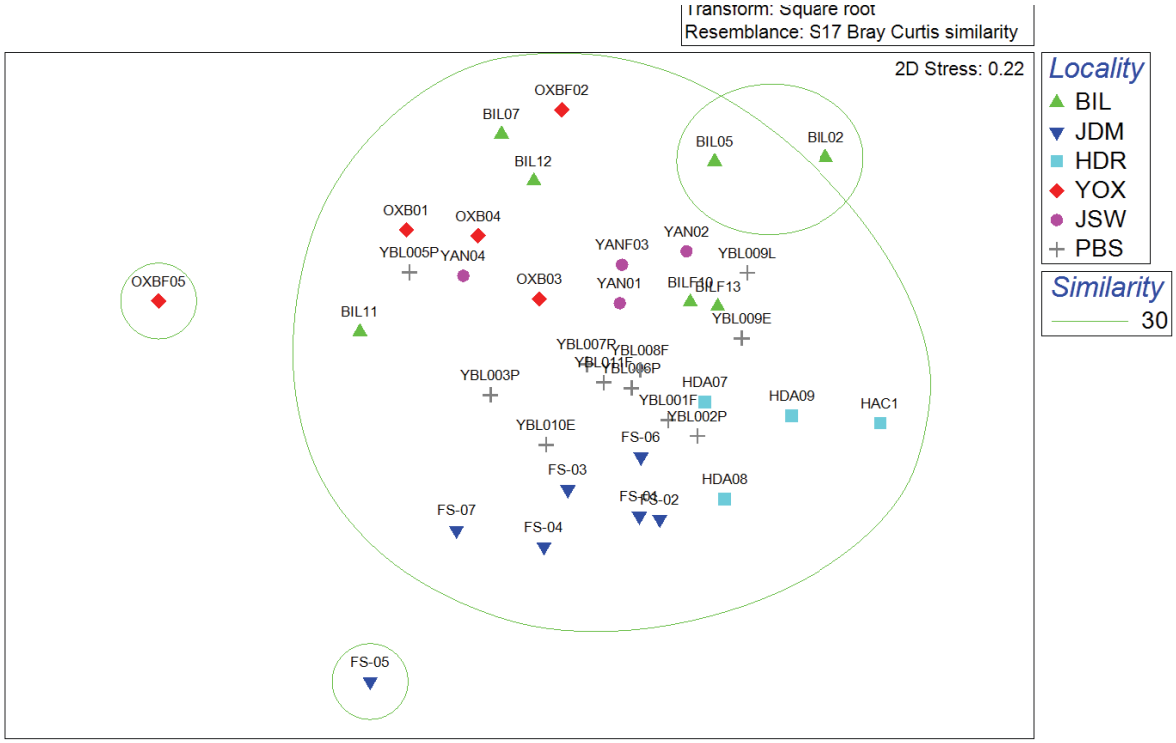

Figure 4.7: NMDS plot of Yandi survey sites based on avifauna composition and coded by survey locality. See Table 3.1 for explanation of locality codes.

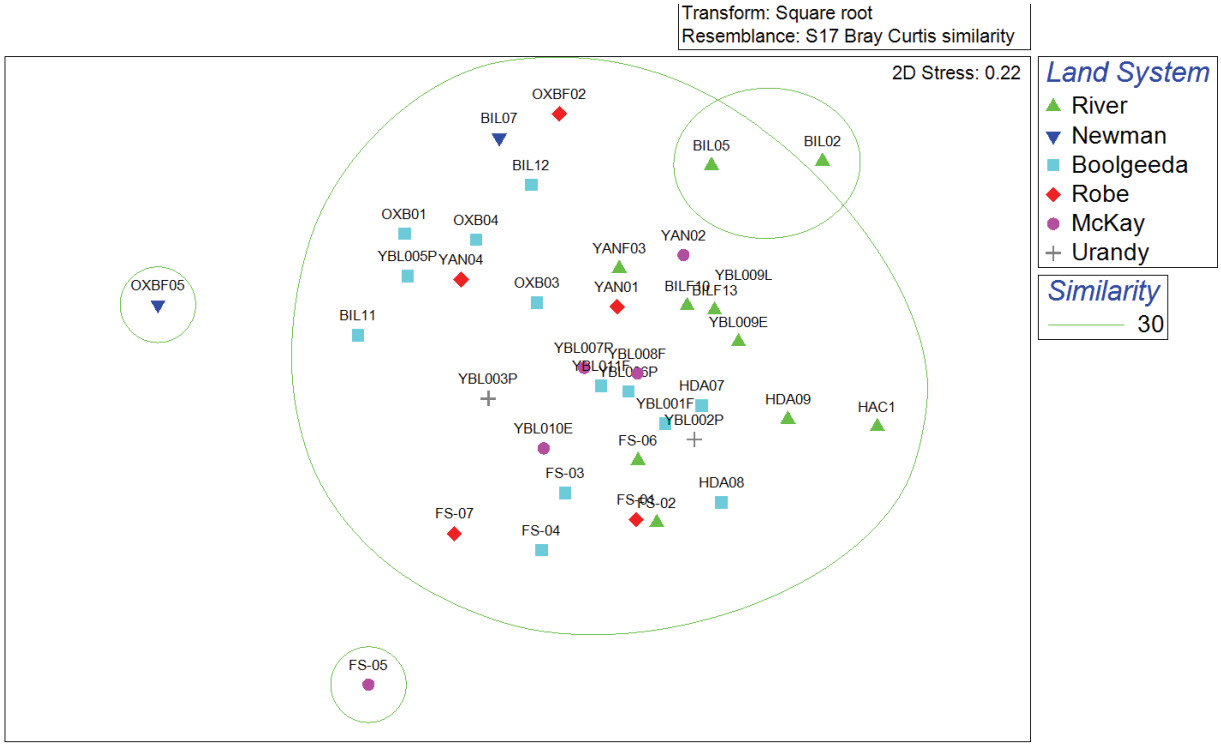

Figure 4.8: NMDS plot of Yandi survey sites based on avifauna composition and coded by land system. See Table 3.1 for explanation of locality codes.

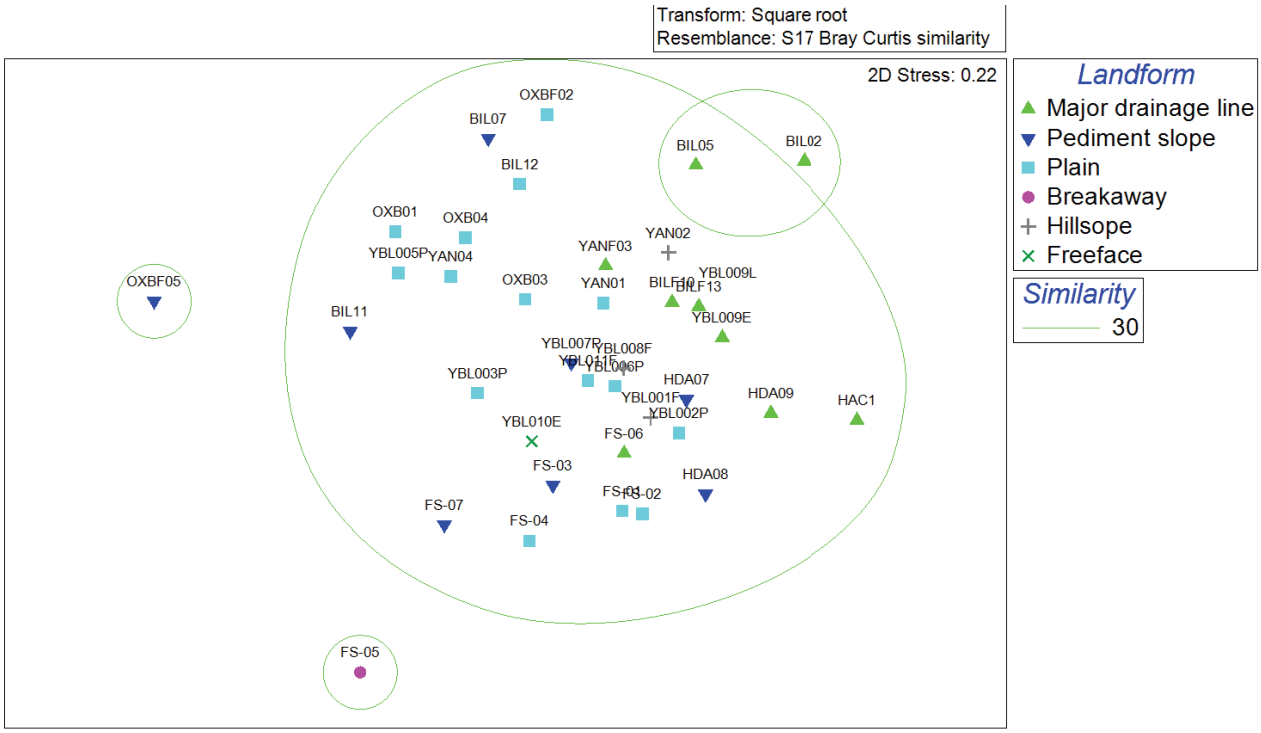

Figure 4.9: NMDS plot of Yandi survey sites based on avifauna composition and coded by landform. See Table 3.1 for explanation of locality codes.

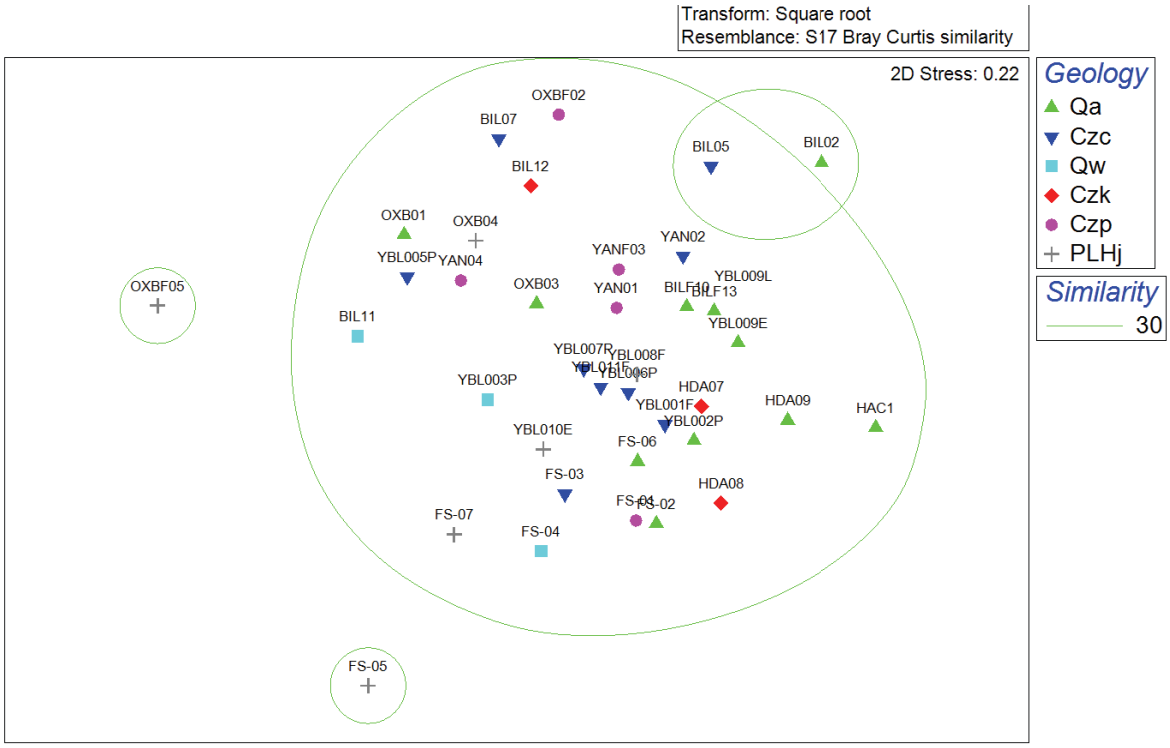

Figure 4.10: NMDS plot of Yandi survey sites based on avifauna composition and coded by geology. See Table 3.1 for explanation of locality codes.

4.7 Species Accumulation

Species accumulation curves for herpetofauna, avifauna and non-volant mammals are presented in Figure 4.11, Figure 4.12 and Figure 4.13 respectively. In all cases, the randomised curves generated by the Chao 1 and Jackknife 1 indices are asymptotic, indicating that few species are likely to be added with additional sampling effort. This indicates that the development envelope has been adequately sampled using the methods outlined in Section 3.2.

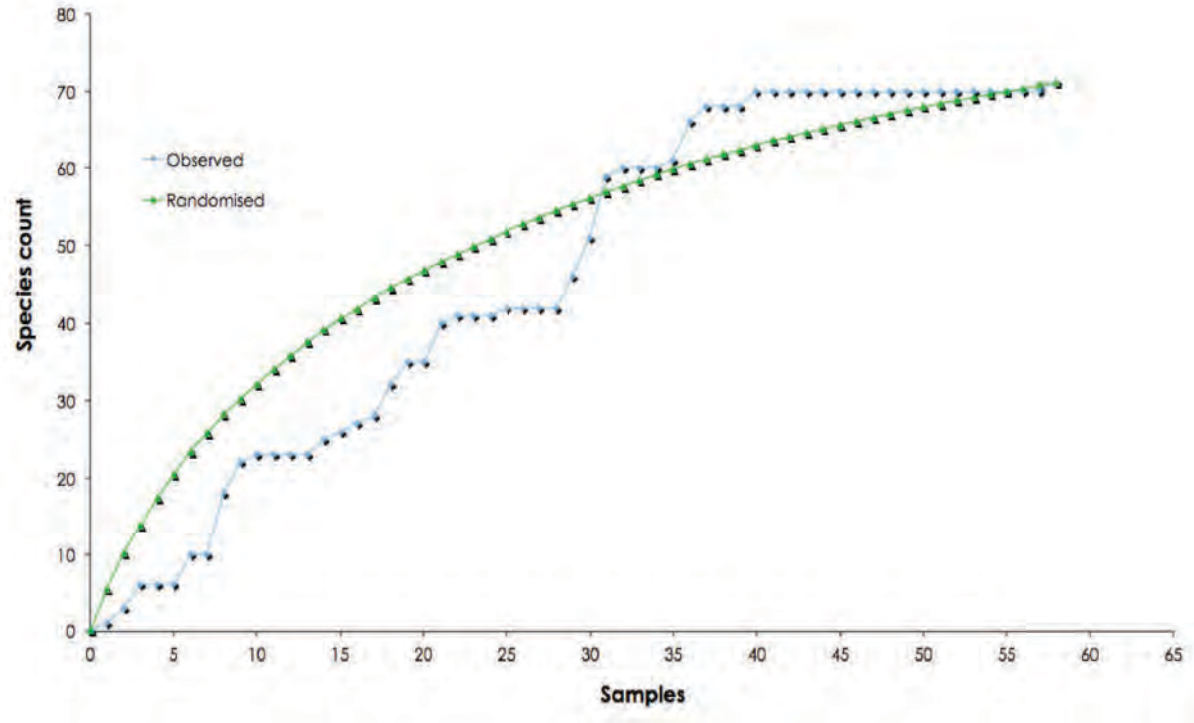

Figure 4.11: Yandi development envelope species accumulation curve for herpetofauna.

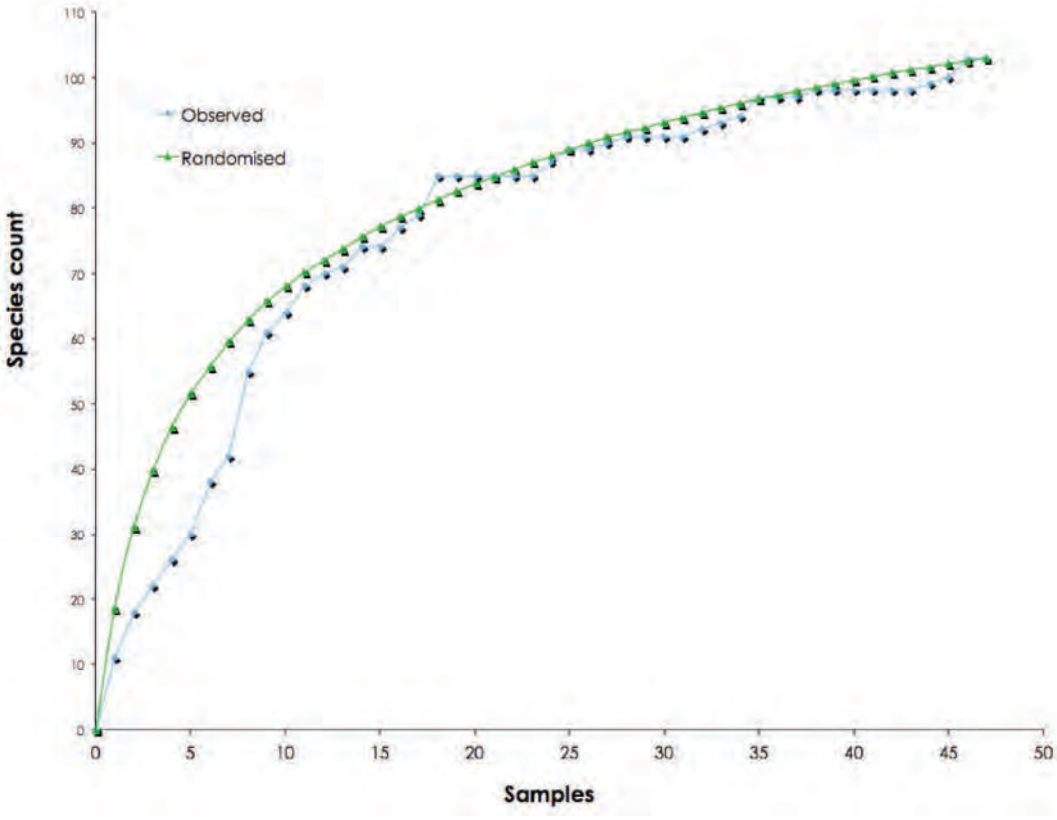

Figure 4.12: Yandi development envelope species accumulation curve for avifauna.

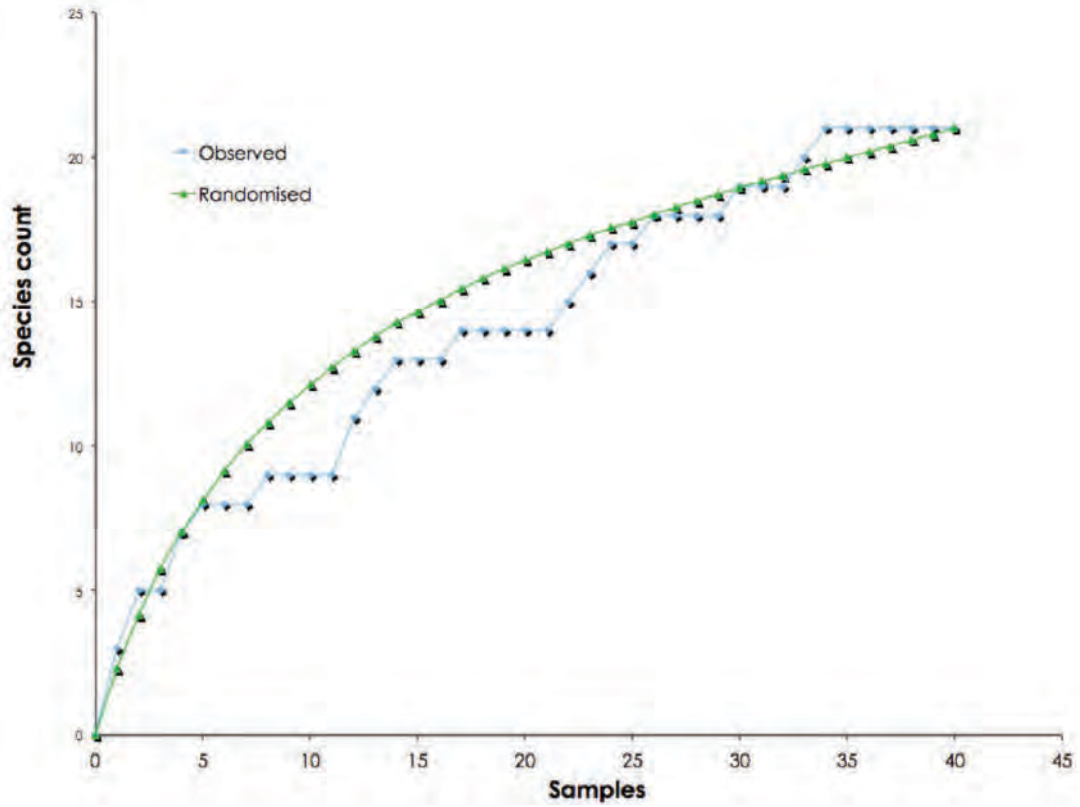

Figure 4.13: Yandi development envelope species accumulation curve for non-volant mammals.

The observed species richness for each vertebrate class was in accordance with the non-parametric estimators (Table 4.8). The total of 196 species recorded (excluding bats) represented approximately 85% of the mean estimates of total species richness, which suggested that on average 230 vertebrate species could occur in the development envelope (Table 4.8).

Table 4.8: Comparison of observed vertebrate species richness with estimator predictions.

		Estimators			
Group	Observed	Chao 1	Jackknife 1	Bootstrap	Mean
Herpetofauna	72	88	93	82	88
Ground mammals	21	21	28	24	24
Avifauna	103	118	124	113	118
Total	*196	227	245	219	230

*Note: accounting for recorded bat species, the total observed species count is 206 (see Section 4.2. As bat data are not quantitative, they could not be used in the species accumulation analysis.

4.8 Short Range Endemic Invertebrates

Two higher-order taxonomic groups with the potential to include SRE species were collected within the development envelope, comprising the pseudoscorpions and mygalomorph spiders. Sections 4.8.1 and 4.8.2 provide accounts of each group and detail the SRE status of each species (where known). Table 4.9 summarises the records by sites, components of the development envelope and land systems.

Table 4.9: Summary of potential SRE invertebrate fauna recorded from the development envelope.

Invertebrate Group Family	Taxon	No. of Specimens	Land Systems Represented	Development envelope	Sites Recorded in Development envelope	SRE Status	Occurs Outside of Development envelope?
Pseudoscorpions							
Olpiidae	*Beierolpium* sp.	6	River	PBS	YBLSRE02	Unlikely to be an SRE	Unknown
	Indet.	11	Boolgeeda, Newman, Robe	Oxbow	OXB04, OXBF05, OXBSRE05	Unlikely to be an SRE	Unknown
Mygalomorph Spiders							
Idiopidae	Idiopidae sp. I1	2	River	*Jinidi to Mainline	JML26	Potential SRE	Yes
	Idiopidae sp. I9	1	River	*Jinidi to Mainline	JML26	Potential SRE	Yes
Nemesiidae	Nemesiidae sp. N1	1	Boolgeeda	PBS	YBLSRE15	Not an SRE	Yes
	Nemesiidae sp. N16	6	Boolgeeda, McKay, River	PBS; and *Jinidi to Mainline	YBLSRE08, YBLSRE10, YBL007P, JML26, JML27	Not an SRE	Yes
	Nemesiidae sp. N42	3	Boolgeeda, River, Urandy	PBS; and *Jinidi to Mainline	YBLSRE21, YBL05P, JML20	Potential SRE	Yes
	Nemesiidae sp. N44	13	Boolgeeda, Newman, River	PBS; and *Jinidi to Mainline	YBLSRE04, YBLSRE19, YBLSRE20, JML23, JML26, JML27	Potential SRE	Yes

* Jinidi to Mainline refers to a survey conducted on behalf of BHP, which was subsequently assessed by the EPA at API level (Biota 2013c).

4.8.1 Pseudoscorpions

One family was represented amongst the pseudoscorpions collected from the development envelope. None of the pseudoscorpions recorded are considered to represent SREs.

4.8.1.1 Olpiidae

Beierolpium sp.

A total of 17 pseudoscorpion specimens of the family Olpiidae were recorded from the development envelope from underneath tree bark and rocks (Table 4.9). Specimens recorded during the YOX survey were not identified beyond the family level, however specimens recorded from the PBS survey were tentatively identified as belonging to the genus *Beierolpium.*

The taxonomic resolution of many Olpiids is deficient and as such, the distribution of putative species is uncertain (Mieke Strong, Biota, pers. comm. 2014). As a result, the SRE status of members of this family remains undetermined. However, the majority of pseudoscorpions collected from under surface rocks and tree bark are currently regarded as unlikely to have restricted ranges due to their phoretic (animal-assisted) mode of dispersal. This means that this taxon is not currently considered to represent an SRE.

4.8.2 Mygalomorph Spiders

4.8.2.1 Idiopidae

Idiopidae sp. I1 (genus *Aganippe*)

Distribution

Two specimens of Idiopidae sp. I1 (Plate 4.9 and Plate 4.10) were recorded from one sampling location within the development envelope (Table 4.9 and Figure 4.14). Morphologically, Idiopidae sp. I1 appears to be of the genus *Aganippe*. This putative taxon is known from 19 recorded specimens, the majority of which occur outside the development envelope. It has a documented distribution roughly concurrent with the Weeli Wolli Creek drainage, including its broader catchment in the vicinity of The Governor and Mt Robinson and the alluvial fan south of the Fortescue Marsh (Figure 4.14). Records occupy a minimum spanning area of approximately 2,559 km^2.

Habitat

Idiopidae sp. I1 has been recorded in heavy soils in areas low in the landscape, such as valley floors, drainage lines and alluvial fans.

SRE Status

This taxon has a relatively small known distribution and qualifies as a potential SRE species.

Plate 4.9: Idiopidae sp. I1 (Biota 2013c).

Plate 4.10: Idiopidae sp. I1 representative burrow entrance (Biota 2013c).

Idiopidae sp. I9 (genus *Eucyrtops*?)

Distribution

Idiopidae sp. I9 (Plate 4.11 and Plate 4.12) was recorded on one occasion within the development envelope. It is known from only four individuals recorded across three locations in the locality (Table 4.9 and Figure 4.14). Records occupy an area of approximately 65 km^2.

Habitat

The sites from which this taxon has been recorded are characterized by clay loam soils and support an overstorey that includes isolated stands of *Acacia aneura* (Mulga).

SRE Status

Given the limited known distribution of Idiopidae sp. I9 and its occurrence in isolated Mulga habitat, it is considered to be a potential SRE.

Plate 4.11: Idiopidae sp. I9 (Biota 2013c).

Plate 4.12: Idiopidae sp. I9 representative burrow entrance (Biota 2013c).

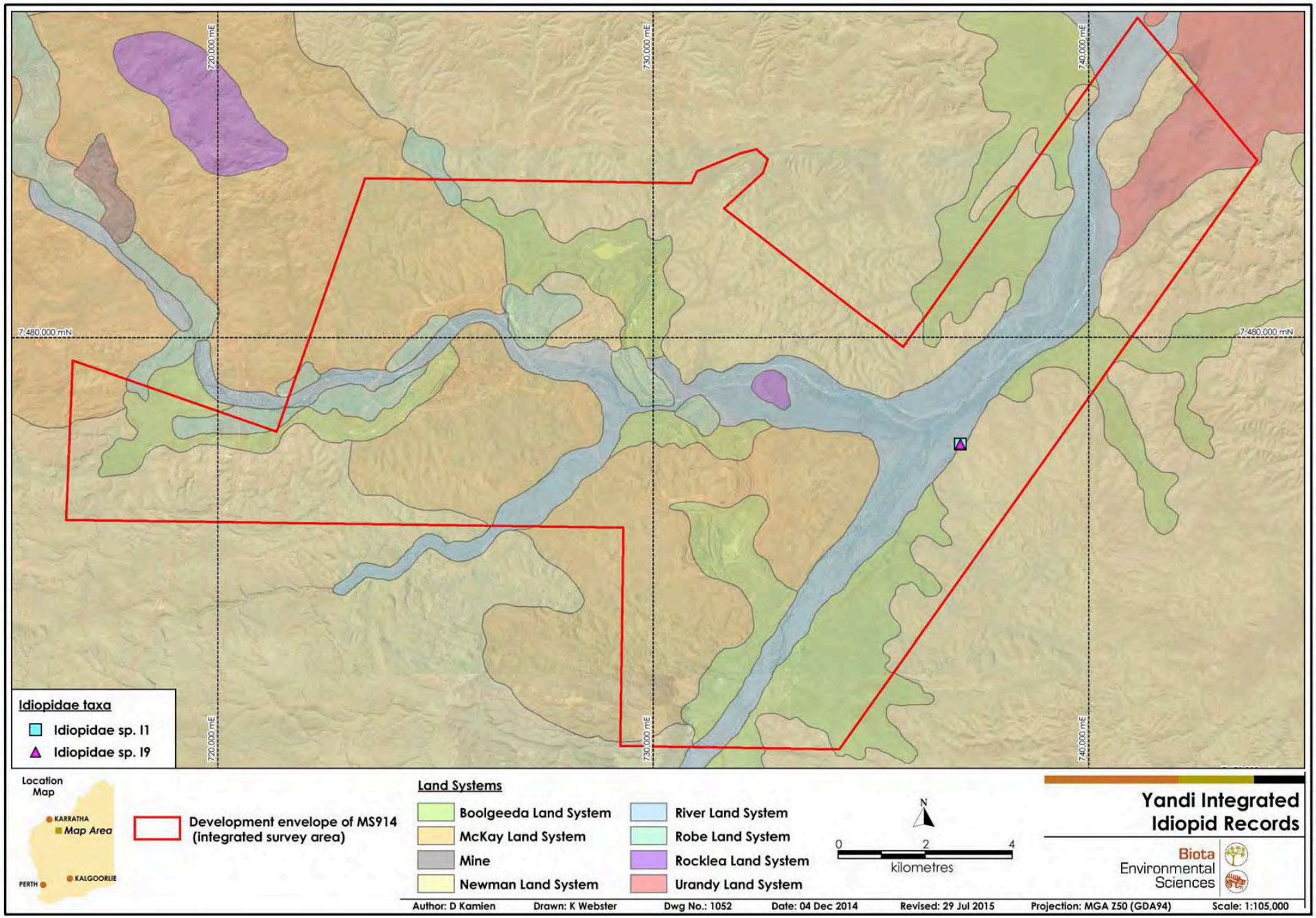

Figure 4.14: Distribution of Mygalomorph spiders of the family Idiopidae recorded in the development envelope.

4.8.2.2 Nemesiidae

Nemesiidae sp. N1

Distribution

Nemesiidae sp. N1 (Plate 4.13) is represented by one individual recorded at a single location in the northeast of the development envelope (Table 4.9 and Figure 4.15). This taxon belongs to the genus *Aname* and creates a hooded burrow entrance (Plate 4.14). To date, 108 individuals of this putative species have been recorded from 71 locations in the Central Pilbara (Biota 2012 and Biota internal database). The minimum spanning area is currently known to be approximately 13,913 km^2 (Figure 4.15).

Habitat

Nemesiidae sp. N1 is associated with clay loam soils in Mulga-dominated communities, as well as clay loams on alluvial and colluvial fans and broad plains.

SRE Status

The current known distribution of this putative species is greater than 10,000 km^2 and as a result it is not considered to be an SRE taxon as defined by Harvey (2002).

Plate 4.13: Nemesiidae sp. N1 (Biota 2012).

Plate 4.14: Nemesiidae sp. N1 representative burrow entrance (Biota 2012).

Nemesiidae sp. N16 = 'Hooded' = 'MYG001' (*Aname mellosa*; Harvey et al. (2012)).

Distribution

Nemesiidae sp. N16 (Plate 4.15) is represented by six individuals recorded at five locations within the development envelope (Table 4.9 and Figure 4.15). This putative molecular species forms part of the species complex currently known as *Aname mellosa* (Castalanelli et al. 2014) which creates a hooded burrow entrance (Plate 4.16). To date, 222 individuals of Nemesiidae sp. N16 have been recorded at 200 locations in the Central Pilbara (Biota 2012 and Biota internal database). The minimum spanning area is currently known to be approximately 12,836 km^2 (Figure 4.15).

Habitat

Specimens have been collected from loams soils in narrow drainage floors, and also from adjacent landforms (e.g. low slopes and stony plains) where a suitable soil profile exists. Within the development envelope, it was recorded from alluvial plains and slopes.

SRE Status

The current known distribution of this putative species is greater than 10,000 km^2 and as a result it is not considered to be an SRE taxon as defined by Harvey (2002).

Plate 4.15: Nemesiidae sp. N16 (M20140317YBL007P-02).

Plate 4.16: Nemesiidae sp. N16 representative burrow entrance.

Nemesiidae sp. N42 (genus *Kwonkan*)

Distribution

Nemesiidae sp. N42 (Plate 4.17 and Plate 4.18) is represented by 22 specimens in the Pilbara, of which three specimens were recorded from three sites within the development envelope (Table 4.9). The distribution of Nemesiidae sp. N42 exhibits a minimum spanning area of 113 km^2 (Figure 4.15).

Habitat

Specimens are typically recorded from loams or sandy loams in habitat that is not considered to be isolated or restricted.

SRE Status

Based on the current known distribution and habitat preferences, Nemesiidae sp. N42 may potentially be an SRE.

Plate 4.17: Nemesiidae sp. N42 (M20140313YBLSRE21-01).

Plate 4.18: Nemesiidae sp. N42 representative burrow entrance.

Nemesiidae sp. N44 (genus *Kwonkan*)

Distribution

Nemesiidae sp. N44 (Plate 4.19 and Plate 4.20) was recorded on 19 occasions from six locations within the development envelope. It is currently known from only two additional locations within 2 km of the development envelope (Table 4.9 and Figure 4.15). Based on known records it occupies a minimum spanning area of on 26 km^2.

Habitat

The specimens were recorded from loamy soils along Weeli Wolli Creek, mostly in the Boolgeeda land system with one record in the River land system.

SRE Status

Based on the current distribution data, this putative taxon is considered to be a potential SRE.

Plate 4.19: Nemesiidae sp. N44 (M20140315YBLSRE04-02).

Plate 4.20: Nemesiidae sp. N44 representative burrow entrance.

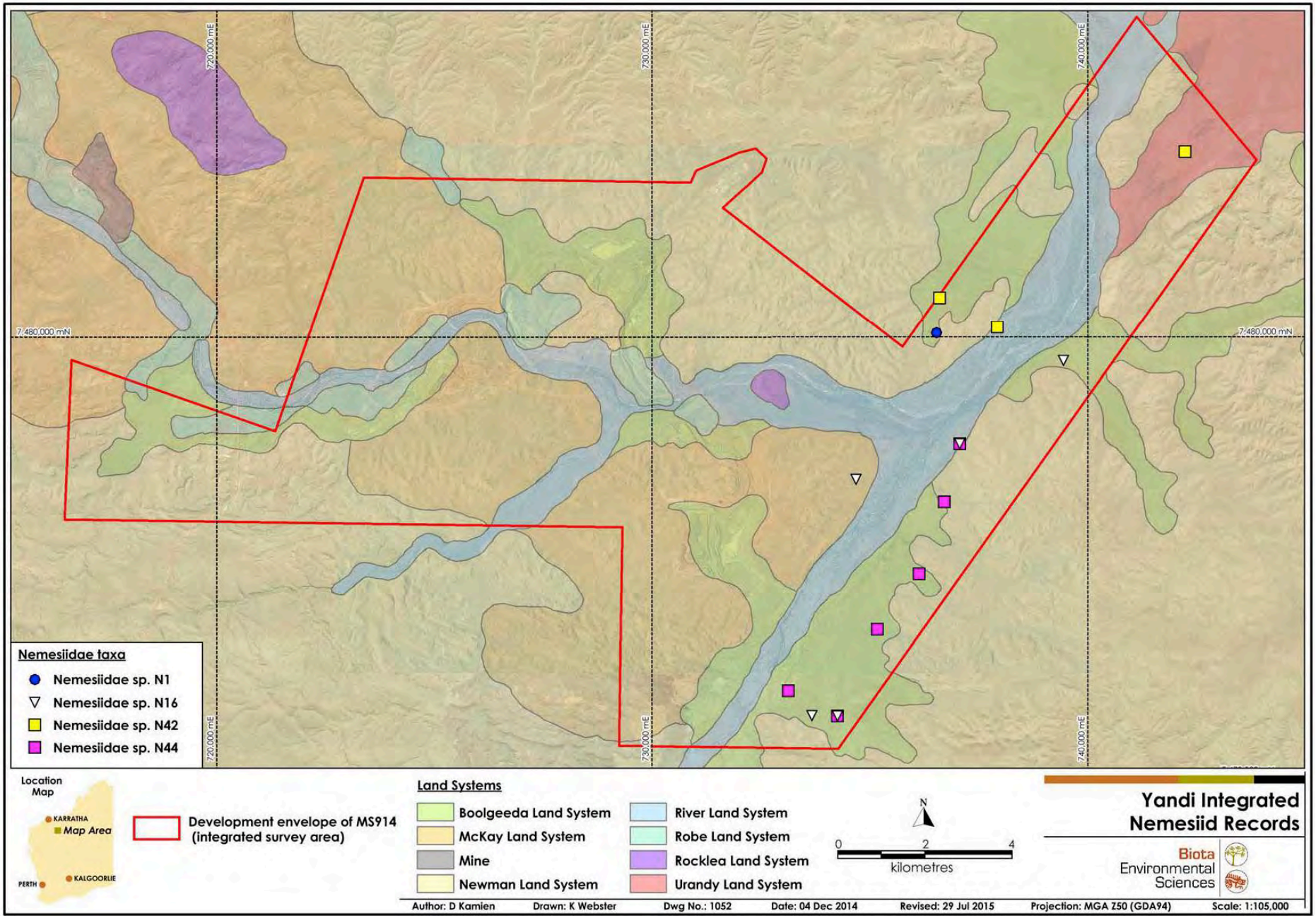

Figure 4.15: Distribution of Mygalomorph spiders of the family Nemesiidae recorded in the development envelope.

4.9 Species of Conservation Significance

A total of five species of elevated conservation significance were recorded from the development envelope (Table 4.10). This total included five Schedule species listed under the State *Wildlife Conservation Act 1950,* four of which are also listed under the Commonwealth *EPBC Act 1999* (Table 4.10).

Four species listed as Priority 4 by the Department of Parks and Wildlife were also recorded from the development envelope. Appendix 3 sets out the conservation categories used at State level in Western Australia.

Table 4.10: Number of individuals of Threatened fauna recorded from the development envelope.

Species Name	Common Name	Conservation Status		Locality					
		State	Commonwealth	JSW	HDA	YOX	BIL	JDM	PBS
Liasis olivaceus barroni	Pilbara Olive Python	Schedule 1	Vulnerable	–	–	–	–	–	1
Merops ornatus	Rainbow Bee-eater	Schedule 3	Migratory	7	12	–	14	2	52
Apus pacificus	Fork-tailed Swift	Schedule 3	Migratory	–	–	–	–	–	9
Ardea modesta	Eastern Great Egret	Schedule 3	Migratory	–	–	–	–	–	1
Falco peregrinus	Peregrine Falcon	Schedule 4	–	–	–	–	–	1	–
Ardeotis australis	Australian Bustard	Priority 4	–	–	1	–	–	1	15
Neochmia ruficauda subclarescens	Star Finch (Western form)	Priority 4	–	1	–	–	–	–	12
Dasycercus blythi	Brush-tailed Mulgara	Priority 4	–	–	–	–	–	–	3
Pseudomys chapmani	Western Pebble-mound Mouse	Priority 4	–	–	–	7	2	1	18

The locations where species of conservation significance were recorded are overlain on land systems mapping in Figure 4.16. The use of land systems in this section allows for records of species of conservation significance to be placed into subregional and regional habitat context, including their relationship with findings from other similar studies (e.g. Biota 2012b, 2012c).

The Rainbow Bee-eater *Merops ornatus* (State: Schedule 3; Commonwealth: Migratory) was the most frequently recorded listed species, with 87 individuals recorded from 23 sites in the development envelope (Appendix 2). The Western Pebble-mound Mouse was also widely recorded with 28 records from 22 locations within the development envelope. This is in keeping with the widespread and common status of these species in the Pilbara bioregion (Biota, unpublished data).

Overview accounts of the species of conservation significance and their occurrence within the development envelope are presented below. More detail is provided in the supporting source reports (Biota 2004, 2010d, 2014a).

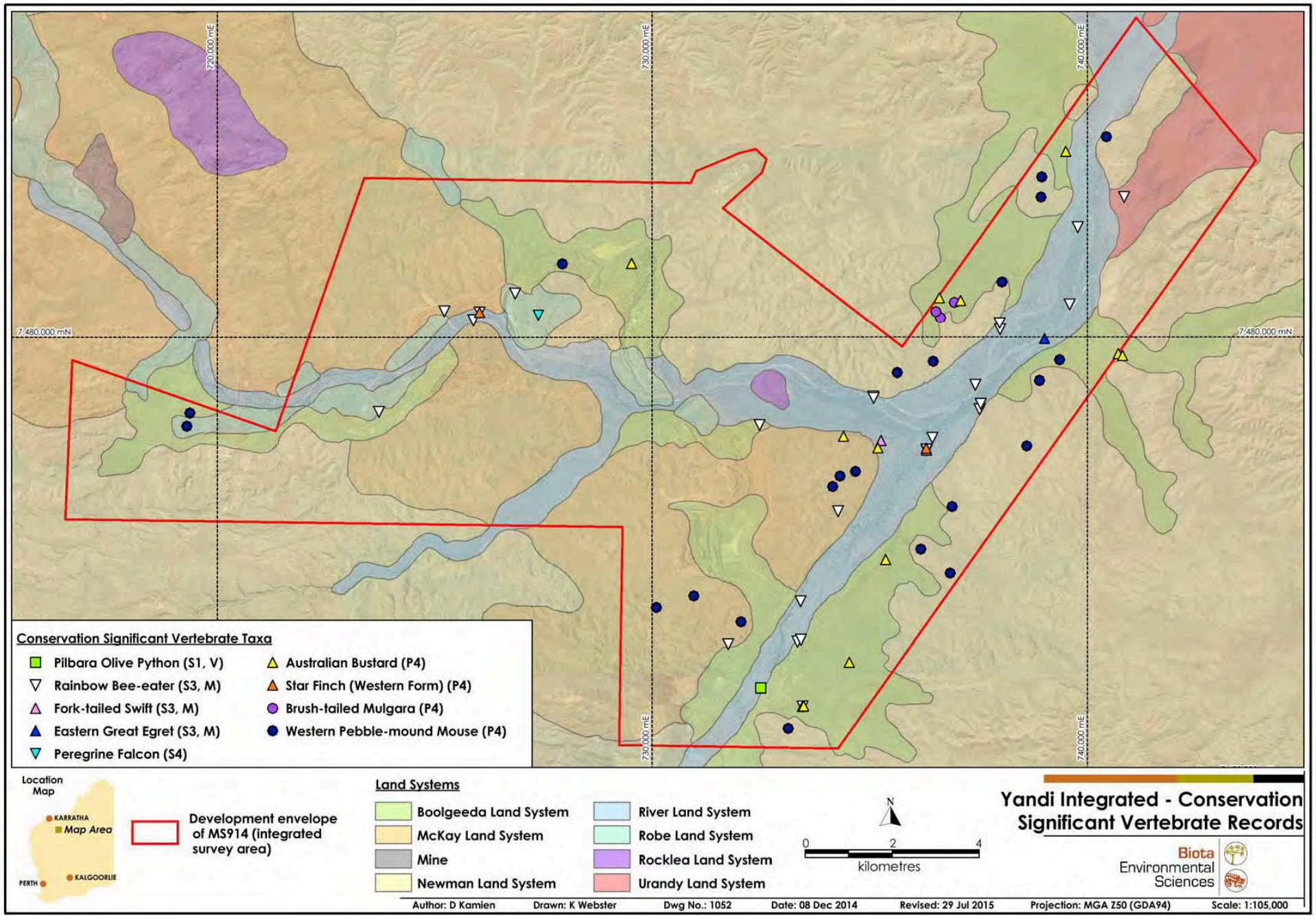

Figure 4.16: Conservation significant vertebrates recorded in the development envelope.

4.9.1 Schedule Species

Pilbara Olive Python *Liasis olivaceus barroni* (State: Schedule 1; Commonwealth: Vulnerable)
Regarded as a Pilbara endemic, this subspecies has a distribution that coincides roughly with the Pilbara bioregion (Department of the Environment 2015). The Pilbara Olive Python (Plate 4.21) typically occurs in rocky areas, showing a preference for gorges containing water in streams and rock pools. One individual was recorded opportunistically swimming in Weeli Wolli Creek (Biota 2014a). This species is not commonly observed.

Plate 4.21: Pilbara Olive Python recorded in the PBS study area (Biota 2014a).

Rainbow Bee-eater *Merops ornatus* (State: Schedule 3; Commonwealth: Migratory)
The Rainbow Bee-eater is a regular breeding migrant to most of Australia, with the exception of Tasmania. The species nests in small holes excavated in sandy banks or flat sandy surfaces, occurring in landforms that provide suitable soil for nesting and a tall stratum of vegetation for perching (Johnstone and Storr 1998).

The Rainbow Bee-eater is very common regionally, with Biota's database including records from over 500 separate locations in Western Australia (Biota unpublished data). Within the Yandi development envelope, this species was recorded from 23 systematic locations across all source surveys (Table 4.10). The species showed little preference for specific land systems, occurring in five different types (Figure 4.16).

Fork-tailed Swift *Apus pacificus* (State: Schedule 3; Commonwealth: Migratory)
The Fork-tailed Swift has a cosmopolitan distribution throughout Australia (Simpson and Day 2004). Fork-tailed Swifts are thought to be exclusively aerial in Australia as they breed in the northern hemisphere, migrating south to the Australasian region from October to April. Irregular summer visitor to the Pilbara during November to early April (Johnstone et al. 2013).

Within the development envelope, nine individuals of this species were opportunistically observed flying overhead during Phase 1 of the PBS survey (zone 50, 735255 mE, 7477626 mN). This species is expected to be a transient visitor to the development envelope and would not rely on any terrestrial habitats within the development envelope.

Eastern Great Egret *Ardea modesta* (State: Schedule 3; Commonwealth: Migratory)
The Eastern Great Egret is largely dependent on the presence of significant water bodies, which may be temporally available in waterways throughout the Pilbara following periods of rainfall, particularly when drying pools result in an accumulation of tadpoles and fish.

An opportunistic observation of this species was made during Phase 2 of the PBS survey, when a single bird was observed flying in the vicinity of Weeli Wolli Creek (739001 mE, 7479968 mN). The single observation within the development envelope during multiple phases suggests that the Eastern Great Egret is either uncommon or is an irregular visitor within the development envelope.

Peregrine Falcon *Falco peregrinus* (State: Schedule 4)
The Peregrine Falcon has an almost cosmopolitan distribution, but is absent from most deserts and the Nullarbor Plain (Johnstone and Storr 1998). It occurs in a wide range of habitats but especially cliffs, rocky outcrops and rocky coastal islands (Pizzey and Knight 2007).

One individual was recorded within the development envelope during the JDM survey (Table 4.10 and Figure 4.16). The species would not be solely reliant on the habitats of the development envelope for breeding as it typically utilises ledges in cliffs and granite outcrops for nesting (Johnstone and Storr 1998). The Peregrine Falcon is considered uncommon and is mostly recorded as single individuals or pairs in the Hamersley Range (Johnstone and Storr 1998).

4.9.2 Priority Species

Western Pebble-mound Mouse *Pseudomys chapmani* (Department of Parks and Wildlife: Priority 4)
The Western Pebble-mound Mouse is typically found on stony hillsides with hummock grasslands (Menkhorst and Knight 2011) and is common to very common in suitable habitat within the Hamersley and Chichester subregions of the Pilbara bioregion.

The Western Pebble-mound Mouse constructs extensive mounds of small stones covering areas from 0.5 to 9.0 square meters (van Dyck and Strahan 2008) (see Plate 4.22). Within the development envelope, pebble-mounds were recorded at 22 locations (Figure 4.16).

Plate 4.22: Active pebble mound recorded within the PBS study area.

Australian Bustard *Ardeotis australis* (Department of Parks and Wildlife: Priority 4)
The Australian Bustard occurs over much of Western Australia, with the exception of the more heavily wooded southern portions of the state (Johnstone and Storr 1998). Bustards are typically nomadic, occupying large home ranges in open or lightly wooded grassland including *Triodia* sandplains. They occur in a relatively broad range of habitats and are considered to be common depending on season and availability of suitable. They are often observed in recently burnt areas, with open groundcover (Marchant and Higgins 1993). Australian Bustards were observed on 17 occasions from 11 locations within the development envelope (see Figure 4.16).

Star Finch Neochmia *ruficauda subclarescens* (Department of Parks and Wildlife: Priority 4)
The western subspecies of Star Finch occurs in the north of Western Australia and into the Northern Territory (Johnstone and Storr 2004). It is most common around major watercourses, and is typically confined to rushes, reed beds and adjacent vegetation communities along major waterways and permanent pools in the Pilbara, where it feeds on the seed of sedges. This species is considered to be resident in most of its range but is generally uncommon and is patchily distributed in the Pilbara. In total, 13 records were noted at two locations within the development envelope during the combined surveys.

Brush-tailed Mulgara *Dasycercus blythi* (Department of Parks and Wildlife: Priority 4)
The Brush-tailed Mulgara occurs in spinifex sand plain habitat across the arid zone of Western Australia, the Northern Territory and Queensland. Mulgara were formerly widespread in sandy deserts but they are now rare and patchily distributed. Recent records include those occurring in the Pilbara bioregion (NatureMap database).

The Brush-tailed Mulgara inhabits spinifex grasslands, and larger colonies coincide with relatively well-watered areas such as paleo-drainage channels or drainage lines in sandplain or sand dune habitats (Maxwell et al. 1996). Their diet includes small vertebrates and larger invertebrates. Mulgara burrows were recorded in both phases of the PBS survey (Appendix 2), however no individuals were captured. The burrows were thought to be inactive, as no signs of fresh diggings, scats or tracks were noted. The records were made at three locations in close proximity in the northeastern section of the development envelope.

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5.0 Discussion

5.1 Survey Adequacy

The combined Yandi survey effort across the development envelope of MS914, comprised two targeted surveys, four single-phase surveys and four two-phase surveys encompassing seven localities (see Section 3.1). With 54 systematic vertebrate sampling sites, the surveys provided coverage of the range of habitats present in the development envelope. In regards to the surveys' spatial extent, adequate sampling of vertebrate fauna was conducted within the development envelope, however the eastern side of the development envelope (the PBS study area) was sampled more thoroughly than other sections of the development envelope (Figure 3.3 and Figure 3.4).

Dedicated SRE sampling was conducted even more extensively in the east of the development envelope compared to the west (Figure 3.5), which is a function of the greater emphasis on SREs in recent years. That is, more surveys were conducted recently in the east of the development envelope, while more of the historic surveys were conducted in the west at times when SREs were not a primary focus of EIA.

The timing of the survey work was optimal, with the majority of contributing surveys including at least one phase undertaken during warm to hot conditions following the wet season. This is the period in which the greatest faunal diversity is typically recorded.

The species accumulation curves demonstrated asymptotic patterns, indicating that few additional species (approximately 34 vertebrate species; Section 4.7) would be added with further sampling using the same techniques. The non-parametric estimates for the entire vertebrate assemblage imply that 85% of the fauna are likely to have been documented via the methods used during the surveys. This is consistent with the species tallies relative to other comparable scale surveys in the Pilbara bioregion (Table 5.1), and consistent with the relatively high proportion of the theoretical total species assemblage for the locality that was recorded (see Section 4.7).

Table 5.1: Comparison of Yandi surveys with other large-scale Pilbara vertebrate fauna assessment surveys.

Survey (Reference)	No. of Sites	Total Area Surveyed (ha)	Herpetofauna	Mammals	Avifauna	Total Species
Yandi (current study)	54	19,351	72	31	103	206
Koodaideri (Biota 2012c)	133	67,857	92	36	95	223
Hope Downs Railway (Biota 2002)	54	69,135	79	38	125	242
West Pilbara Iron Ore Project (API 2010)	46	36,035	75	20	87	184
Mesa A Transport Corridor (Biota 2006)	54	7,272	67	21	93	181
Solomon Project (Coffey 2008)	70	Unspecified	62	18	65	145
Cloud Break Mine (BCE 2005)	8	Unspecified	29	25	99	153

5.2 Conservation Significance

When considering the faunal value of the fauna habitats within the development envelope, the following criteria may be used to assess areas of higher habitat value:

- habitat supporting fauna of conservation significance;
- habitat that is uncommon in the region; and
- habitat supporting unique faunal assemblages.

5.2.1 Vertebrate Fauna

When assessing the value of habitat in the development envelope, it is prudent to determine the core habitat of individual species. Core habitat for species of conservation significance equates to "habitat critical to the survival of a species" (DEWHA 2009, DSEWPaC 2011, DotE 2013). Such habitat includes those that are known, or are likely to be utilised by listed species for key ecological activities such as denning, roosting, breeding, refugia and important foraging areas. As a result, it is assumed that some proportion of this habitat must be maintained across the species' range to ensure the persistence of the species in the region.

Using the above criteria, major drainage lines, free faces and breakaway habitats in the development envelope are considered to be the landforms that represent the habitat of highest value to conservation significant fauna. Specifically, these habitats represent core habitat for the Pilbara Olive Python (*Liasis olivaceus barroni*), which was the only Schedule 1 species recorded within the development envelope, as well as the Northern Quoll (*Dasyurus hallucatus*) and Orange Leaf-nosed Bat (*Rhinonicteris aurantius*). The major drainage lines also represent core habitat for the Priority 4 Star Finch *Neochmia ruficauda subclarescens*. None of these landforms are confined to the development envelope and none are uncommon in the region.

Regarding the Schedule 3 (Migratory) species recorded within the development envelope, the Rainbow Bee-eater is widespread throughout much of Australia and typically occurs in open country in most vegetation and landform types (Johnstone and Storr 1998). The Fork-tailed Swift would not rely on any terrestrial habitats within the development envelope. The habitats in the development envelope are therefore not considered to be core habitat for these species. Although the Eastern Great Egret is largely dependent on the presence of significant water bodies, such habitats are not confined to the development envelope.

Four Department of Parks and Wildlife Priority 4 listed species were recorded from the development envelope:

1. Australian Bustard – common throughout most of Australia;
2. Western Pebble-mound Mouse – relatively common on stony country in much of the Pilbara, particularly in the Hamersley Range;
3. Star Finch – common about major watercourses, but typically confined to rushes, reed beds and adjacent vegetation communities along major waterways.
4. Brush-tailed Mulgara – habitat specific in that they occur in spinifex sandplain habitat across the arid zone, and as such, they are patchily distributed.

Although there are no TECs or PECs present, the Weeli Wolli and Marillana Creeks are recognised as having high conservation value as a fauna habitat. Areas such as this containing water for extended periods are considered to represent significant refugia for many fauna species in the Pilbara bioregion, especially during dry years. The habitat would also provide resources for conservation significant fauna, as described above.

NMDS analysis of the herpetofauna assemblage revealed seven clusters of sites, which were grouped based on the 30% assemblage similarity level. Survey locality was the only factor influencing species composition, with the assemblage recorded at the PBS sites being noticeably different to that recorded at other sites during other surveys. It appears that this result is caused by a significantly greater number of species and higher abundance of herpetofauna recorded during the PBS survey compared to the other surveys (Table 4.5). This is likely to be an artefact of greater sampling effort, rather than a real trend based on sampling location, as the trapping effort used during the PBS survey was almost double that of the survey with the next greatest trapping effort (Table 3.2).

NMDS plots of the mammal and avifauna assemblages showed no indication that different assemblages were determined by the factors of interest (locality, land systems, geology and landform). Additionally, the avifauna assemblage showed a limited number of clusters, with the majority of sites grouped into one cluster, thus indicating that in most cases bird assemblages were not fundamentally different between sites. Conversely, the ground mammal assemblage

was separated into many clusters, often with one site in each cluster, indicating that in most cases, assemblages were fundamentally different between sites.

At many of the sites surveyed, no or very few mammals and birds were recorded, thereby compromising the robustness of the data. That is, rather than emphasizing trends in the data, the analysis highlighted the weakness of the dataset from an analysis perspective. As a result, analyses of these assemblages in regards to environmental factors were ineffectual.

The combined fauna assemblage of 206 vertebrate species recorded from the Yandi development envelope is extensive (Section 5.1), but also typical of that which would be realistically expected for an area of similar size in this locality. Although the development envelope contains habitats and species of conservation value, the suite of species present is representative of the fauna commonly recorded within both the Pilbara bioregion and the Hamersley subregion.

5.2.2 Short Range Endemic Invertebrates

This study has documented the existence of potential SRE fauna within the broader Yandi development envelope. Two broad taxonomic groups with the potential to include SREs (pseudoscorpions and mygalomorph spiders) were recorded. Of these, only the mygalomorph spiders included species that potentially represent SREs:

- Idiopidae sp. I1 – This taxon was recorded in the River land system within the development envelope. It occurs in seven different land systems within its recorded distribution (Biota database). It has been recorded in heavy soils in areas low in the landscape, such as valley floors, drainage lines and alluvial fans.
- Idiopidae sp. I9 – This taxon was recorded in the River land system within the development envelope. It is known from three different land systems in its broader distribution, all on alluvial plains or drainage line landforms.
- Nemesiidae sp. N42 – This taxon was recorded in the Boolgeeda, River and Urandy land systems within the development envelope. Specimens are typically recorded from loams or sandy loams in habitat that is not considered to be isolated or restricted. However, records also exist from the Newman land system in rocky habitat.
- Nemesiidae sp. N44 – Specimens were recorded from loamy soils in the vicinity of Weeli Wolli Creek, mainly in the Boolgeeda land system.

All potential SRE taxa recorded within the survey are also known to occur outside of the development envelope. As a result, there is a reduced risk that disturbance within the development envelope will adversely affect these species populations.

All of the potential SRE mygalomorph spiders have been recorded from multiple land systems, and varying substrate types suggesting a lower level of dependence on specific landscape-scale habitat units and therefore a lower risk of small-scale restrictions in the distribution of these species.

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6.0 Glossary

API	Assessment on Proponent Information.
Biota	Biota Environmental Sciences.
DotE	Commonwealth Department of the Environment.
EIA	Environmental Impact Assessment.
EPA	Environmental Protection Authority of Western Australia.
EPBC Act 1999	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*
IBRA	Interim Biogeographic Regionalisation for Australia.
Landform	A geomorphological unit that is largely defined by its surface form and location in the development envelope.
MNES species	Species of National Environmental Significance under the *EPBC Act 1999*.
NMDS	Non-metric Multi-Dimensional Scaling.
Non-volant mammal	Mammal that cannot fly.
PEC	Priority Ecological Community.
SIMPER	Similarity Percentages analysis.
SIMPROF	Similarity Profiles test.
SM2	SongMeter 2 acoustic bat call recorder.
SRE	Short Range Endemic.
sp. (plural: spp.)	Abbreviation of “species”.
Systematic sampling	Sampling using trapping transects (including pitfall traps, Elliott traps or funnel traps) and avifauna censuses in defined habitats.
Taxon (plural: taxa)	A taxonomic entity, typically at species level or below.
TEC	Threatened Ecological Community.
Volant mammal	Mammal capable of flying.
WAM	Western Australian Museum.

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Appendix 1

Details of Fauna Sampling Sites

Systematic Trapping Sites

Site Name	Easting	Northing	Trap Type	Job Code	Geology Code	Landform	Land System	Vegetation Code	Vegetation Description
HAC1	739586	7480760	Pitfall Trap	HDR	Qa	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
HDA07	726391	7480413	Pitfall and funnel	HDR	Czk	Pediment slope	Boolgeeda	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
HDA08	730950	7478878	Pitfall and funnel	HDR	Czk	Pediment slope	Boolgeeda	Disturbed	Rio Tinto disturbance as at Dec. 2013
HDA09	735829	7476521	Pitfall and funnel	HDR	Qa	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
YNQE01	734614	7474900	Elliott Trap	YNQ	Qa	Major drainage line	River	C1	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
YNQE02	729997	7482248	Elliott Trap	YNQ	Qa	Major drainage line	River	C6: EvAciAprAThCEc	*Acacia citrinoviridis, A. coriacea* subsp. *pendens* low open forest over *Acacia pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius*, *Tephrosia rosea* var. *glabrior* scattered low shrubs to low open shrubland over *Triodia pungens* very open hum
YNQE03	725923	7482783	Elliott Trap	YNQ	Czk	Major drainage line	River	P3: AprAciAiAsclTlo	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* open shrubland over *Triodia longiceps* hummock grassland over **Cenchrus ciliaris* very open tussock grassland
YNQE04	726401	7480398	Elliott Trap	YNQ	Qa	Alluvial plain	River	Disturbed	Rio Tinto disturbance as at Dec. 2013
YNQE05	731390	7478910	Elliott Trap	YNQ	PLHj	Plain	Boolgeeda	4h	Hummock grassland of *Triodia pungens - Triodia angusta* with mixed emergent *Acacia* sp.
YNQE06	726391	7480413	Elliott Trap	YNQ	PLHj	Plain	Boolgeeda	C2: EvAtuGwTErCYpERItTHt	*Eucalyptus victrix* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* low shrubland over *Cymbopogon ambiguus*, *C. procerus, Eriachne tenuiculmis, Themeda triandra* very open grassland.
YNQE07	730950	7478878	Elliott Trap	YNQ	Qa	Major drainage line	River	C1	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
YNQE08	735829	7476521	Elliott Trap	YNQ	Qa	Major drainage line	River	C5: EvAciAcMgCEc	*Eucalyptus camaldulensis* and *E. victrix* scattered trees over scattered mixed shrubs, sedges, tussock grasses and *Triodia pungens*
BIL02	726391	7480413	Pitfall Trap	BIL	Qa	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
BIL05	730950	7478878	Pitfall Trap	BIL	Czc	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
BIL07	736885	7476102	Pitfall Trap	BIL	Czc	Pediment slope	Newman	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees *over Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Triodia* sp. *Shovelanna Hill* (S. van Leeuwen 3835) hummock grassland
BIL08	735490	7475184	Pitfall Trap	BIL	Czk	Plain	Boolgeeda	P6: AapERfoERl/G	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
BIL11	734617	7472530	Pitfall Trap	BIL	Qw	Pediment slope	Boolgeeda	P5: ElEgAbAaTb	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees *over Acacia bivenosa*, *A. ancistrocarpa* open shrubland over Triodia basedowii open hummock grassland
BIL12	734812	7474730	Pitfall Trap	BIL	Czk	Alluvial plain	Boolgeeda	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
BILF10	733398	7473929	Funnel Trap	BIL	Qa	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
BILF13	736431	7477689	Funnel Trap	BIL	Qa	Major drainage line	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
OXB01	718566	7478410	Pitfall Trap	YOX	Qa	Plain	Boolgeeda	C4	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland
OXB03	718566	7478410	Pitfall Trap	YOX	Qa	Plain	Boolgeeda	C4	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland
OXB04	719368	7478259	Pitfall Trap	YOX	PLHj	Plain	Boolgeeda	H1	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla*, *Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Triodia* sp. *Shovelanna Hill* (S. van Leeuwen 3835) hummock grassland
OXBE06	717465	7477844	Elliott Trap	YOX	PLHj	Hillslope	Newman	H2	*Eucalyptus leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over Triodia wiseana (T. sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
OXBF02	719368	7478259	Funnel Trap	YOX	Czp	Plain	Robe	P1	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over A*cacia bivenosa, A. ancistrocarpa, A. dictyophleba* open shrubland to shrubland over *Triodia wiseana, T. pungens* hummock grassland.
OXBF05	717465	7477844	Funnel Trap	YOX	PLHj	Pediment slope	Newman	H2	*Eucalyptus leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* (T. sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
YAN01	723723	7478279	Pitfall Trap	JSW	Czp	Plain	Robe	P1	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over A*cacia bivenosa, A. ancistrocarpa, A. dictyophleba* open shrubland to shrubland over *Triodia wiseana, T. pungens* hummock grassland.
YAN02	725226	7480598	Pitfall Trap	JSW	Czc	Hillslope	McKay	Disturbed	Rio Tinto disturbance as at Dec. 2013
YAN04	722824	7478290	Pitfall Trap	JSW	Czp	Plain	Robe	Disturbed	Rio Tinto disturbance as at Dec. 2013

Site Name	Easting	Northing	Trap Type	Job Code	Geology Code	Landform	Land System	Vegetation Code	Vegetation Description
YANE05	723821	7479192	Elliott Trap	JSW	Qa	Major drainage line	River	C1	*Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
YANF03	726033	7480563	Funnel Trap	JSW	Czp	Major drainage line	River	C1	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
YBL001F	739401	7479456	Funnel Trap	PBS	Czc	Hillcrest	Boolgeeda	P5: ElEgAbAaTb	Scattered low trees of *Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* over scattered tall shrubs of *Hakea lorea* over low mixed *Solanum* and *Senna* shrubland over *Triodia* hummock grassland and *Aristida* sp. tussock grassland.
YBL002P	740842	7483231	Pitfall	PBS	Qa	Alluvial plain	Urandy	P2: ChAprAiAsclApaTp	Low woodland of *Corymbia hamersleyana, Acacia pruinocarpa* and mixed *Acacia* sp. over low shrubland of *Senna* sp. over *Triodia* hummock grassland and *Cenchrus ciliaris* and *Cleome viscosa* open tussock grassland.
YBL003P	742408	7485240	Pitfall	PBS	Qw	Alluvial plain	Urandy	P2: ChAprAiAsclApaTp	Scattered low trees of *Corymbia hamersleyana* over tall shrubland of *Acacia inaequilatera* and *A. bivenosa* over low *Rhynchosia* sp. Shrubland over *Triodia* hummock grassland.
YBL004F	740451	7484593	Funnel Trap	PBS	PLHb	Minor drainage line	Newman	H1: ElHcAiGwTsps	Low open woodland of *Corymbia hamersleyana* over tall open mixed *Acacia* scrub over *Triodia* hummock and *Themeda triandra* tussock grassland.
YBL005P	736591	7480909	Pitfall	PBS	Czc	Alluvial plain	Boolgeeda	P9: ChEgAiAaAprPcTb	Tall shrubland of *Acacia ancistrocarpa* and *Hakea lorea* over low shrubland of *Dampiera* sp. over *Triodia* hummock grassland.
YBL006P	733445	7471518	Pitfall	PBS	Czc	Alluvial plain	Boolgeeda	P5: ElEgAbAaTb	Low open woodland of Eucalyptus gamophylla over open Acacia ancistrocarpa heath over low open shrubland of Ptilotus astrolasius over Triodia melvillei hummock grassland.
YBL007P	734676	7476736	Pitfall	PBS	Czc	Pediment slope	McKay	P5: ElEgAbAaTb	Low open forest of *Eucalyptus gamophylla* over *Acacia pyrifolia* shrubland over low shrubland of *Dampiera* sp. over *Triodia* hummock grassland
YBL008F	734260	7476001	Funnel Trap	PBS	PLHj	Hillslope	McKay	P5: ElEgAbAaTb	Low open woodland of *Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* over tall open shrubland of mixed *Acacia* species over *Triodia* hummock grassland.
YBL009E	735082	7478602	Elliott Trap	PBS	Qa	Major drainage line	River	C3: EvAciAcMgCEc	Open forest to low open woodland of *Eucalyptus victrix* and *E. camaldulensis*
YBL010E	731818	7472976	Elliott Trap	PBS	PLHj	Free face	McKay	H5: ElCfERImTHspp	Scattered tall *Eucalyptus leucophloia* subsp. *leucophloia* trees over low open woodland of *E. l. leucophloia* and *Corymbia ferriticola* over scattered *Senna glutinosa* shrubs and scattered *Ptilotus* sp. low shrubs over mixed *Eriachne* tussock grassland.
YBL011F	738584	7481527	Funnel Trap	PBS	Czc	Alluvial plain	Boolgeeda	P6: AapERfoERl/G	Open forest of *Acacia aneura* over low open shrubland of *Ptilotus* sp. and *Triodia* sp. hummock grassland
YBQ01	731811	7472976	Elliott Trap	YBNQ	PLHj	Free face	McKay	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla*, *Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBQ02	733147	7471040	Elliott Trap	YBNQ	PLHj	Free face	Newman	H5: ElCfERImTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YBQ03	736109	7477362	Elliott Trap	YBNQ	Qa	Major drainage line	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
YBQ04	735098	7478519	Elliott Trap	YBNQ	Qa	Major drainage line	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBQ05	740190	7484499	Elliott Trap	YBNQ	Qa	Major drainage line	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis*, *A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
FS-1	727929	7481687	Pitfall and Elliott	JDM	Czp	Alluvial plain	Robe	5l	Mulga-Eucalypt woodland over mixed shrub layer *and Triodia pungens*
FS-2	725887	7480388	Pitfall and Elliott	JDM	Qa	Major drainage line	River	C1	*Eucalyptus camaldulensis* woodland over shrub layer and mixed grasses
FS-3	729521	7481697	Pitfall and Elliott	JDM	Czc	Pediment slope	Boolgeeda	4a	*Eucalyptus gamophylla* over *Triodia basedowii and T. pungens* hummock grassland
FS-4	726402	7482215	Pitfall and Elliott	JDM	Qw	Alluvial plain	Boolgeeda	2b	Mixed *Acacia* spp over *Triodia basedowii* and *T. pungens* hummock grassland
FS-5	726849	7481007	Pitfall and Elliott	JDM	PLHj	Breakaway	McKay	5k	*E. leucophloia* and *E. camaldulensis* over *Triodia* spp.
FS-6	726607	7479891	Pitfall and Elliott	JDM	Qa	Major drainage line	River	2d	*E. camaldulensis, Melaleuca leucadendra* over *Triodia* spp.
FS-7	727384	7480506	Pitfall and Elliott	JDM	Czp	Pediment slope	Robe	5d	Mixed *Acacia* spp. over *Triodia basedowii* hummock grassland

Targeted Bat Sites

Site Name	Easting	Northing	Trap Type	Job Code	Geology Code	Land System	Vegetation Code	Vegetation Description
BILANA01	736435	7477590	Anabat	BIL	Qa	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
OXBANA01	717400	7477886	Anabat	YOX	PLHj	Newman	5c	Hummock Grassland of *Triodia basedowii* with occasional *Triodia wiseana* with emergent *Acacia* spp. and *Eucalyptus leucophloia*
YANBAT01	723838	7479182	Anabat Harp trap	JSW	Qa	River	C1	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
YBLSM2-03	740236	7485633	SM2	PBS	Qa	Newman	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBLSM2-04	734934	7478706	SM2	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBLSM2-06	735550	7476317	SM2	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBLSM2-07	736297	7477452	SM2	PBS	Qa	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
YBLSM2-08	731561	7473006	SM2	PBS	PLHj	McKay	H5: ElCfERImTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs *over Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YBLSM2-09	733741	7473804	SM2	PBS	Czk	River	C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
YBLSM2-10	733240	7470919	SM2	PBS	PLHj	Newman	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland *over Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBLSM2-11	740220	7484873	SM2	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBQSM2-01	731888	7472988	SM2/Harp trap	PBS	PLHj	McKay	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland *over Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBQSM2-02	736277	7477272	SM2/Harp trap	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBQSM2-03	740182	7484411	SM2/Harp trap	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBQSM2-04	742422	7482643	SM2/Harp trap	PBS	PLHb	Newman	H3: ElGwAarTsps	*Eucalyptus leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill open hummock grassland
YBQSM2-05	731580	7472994	SM2/Harp trap	PBS	PLHj	McKay	H5: ElCfERImTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs *over Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YBQSM2-06	735057	7478624	SM2/Harp trap	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses

Motion Camera Sites

Site Name	Easting	Northing	Trap Type	Job Code	Geology Code	Land System	Vegetation Code	Vegetation Description
YBQM01	732013	7473157	Motion camera	YBNQ	PLHj	McKay	H5: ElCfERImTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs *over Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YBQM02	733224	7470635	Motion camera	YBNQ	PLHj	Newman	H5: ElCfERImTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs *over Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YBQM03	732210	7473433	Motion camera	YBNQ	PLHj	McKay	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland *over Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBQM04	735089	7478526	Motion camera	YBNQ	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
YBQM05	742423	7482645	Motion camera	YBNQ	PLHb	Newman	H3: ElGwAarTsps	*Eucalyptus leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill open hummock grassland
YBQM06	731692	7472970	Motion camera	YBNQ	PLHj	McKay	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland *over Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBQM07	734302	7476490	Motion camera	YBNQ	PLHj	McKay	H1: ElHcAiGwTsps	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* subsp. *hispidula* tall open shrubland *over Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
YBLMC01	736943	7480804	Motion camera	PBS	Czc	Boolgeeda	P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland
YBLMC02	732908	7473447	Motion camera	PBS	Qa	River	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland

Site Name	Easting	Northing	Trap Type	Job Code	Geology Code	Land System	Vegetation Code	Vegetation Description
YBLMC03	742577	7482251	Motion camera	PBS	PLHb	Newman	H3: ElGwAarTsps	*Eucalyptus leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill open hummock grassland
YBLMC04	736611	7480437	Motion camera	PBS	PLHj	Boolgeeda	P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* OHG
YBLMC05	740221	7484904	Motion camera	PBS	Qa	River	C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea subsp. pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses

SRE Sites

Site Name	Easting	Northing	Geology Code	Land System	Vegetation Code	Vegetation Description
YBLSRE02	733947	7474152	Qa	River	Disturbed	–
YBLSRE03	735708	7475805	Czc	River	P6: AapERfoERl/G	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
YBLSRE04	733113	7471891	Qw	Boolgeeda	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
YBLSRE05	734099	7471754	Qw	Boolgeeda	P5: ElEgAbAaTb	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
YBLSRE06	740643	7479666	Czc	Boolgeeda	Disturbed	–
YBLSRE07	739712	7479696	Czc	Boolgeeda	P5: ElEgAbAaTb	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
YBLSRE08	733663	7471318	Czc	Boolgeeda	P5: ElEgAbAaTb	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
YBLSRE10	739439	7479452	Czc	Boolgeeda	P5: ElEgAbAaTb	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
YBLSRE11	732843	7471587	Czc	Boolgeeda	Disturbed	–
YBLSRE12	732489	7473019	Czc	Boolgeeda	P6: AapERfoERl/G	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
YBLSRE13	731680	7471915	Czc	Boolgeeda	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
YBLSRE14	733445	7471285	Czc	Boolgeeda	ElEgAbAaTb	–
YBLSRE15	736521	7480100	Czc	Boolgeeda	ChEgAiAaAprPcTb	–
YBLSRE16	738621	7481175	Qa	River	ElEgAbAaTb	–
YBLSRE17	734700	7476805	Czc	McKay	ElEgAbAaTb	–
YBLSRE18	734193	7473489	Qw	Boolgeeda	Disturbed	–
YBLSRE19	736121	7474567	Czc	Boolgeeda	AapERfoERl/G	–
YBLSRE20	735159	7473289	Qw	Boolgeeda	ElEgAbAaTb	–
YBLSRE21	737921	7480232	Qa	River	EvAciAprAThCEc	–
YBLSRE22	738930	7479047	PLHj	Newman	ElAiTwTsps	–
YBLSRE23	736977	7474584	PLHj	Newman	ElHcAiGwTsps	–
YEX75	732020	7473027	PLHj	McKay	H5: ElCfERlmTHspp	*Eucalyptus leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis* ms., *Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt. Barricade, *T. triandra* open tussock grassland
YEX76	732221	7472892	Czc	Boolgeeda	P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
YEX77	732757	7474158	Czc	Boolgeeda	Disturbed	–
YEX78	731313	7478735	Qa	River	3f	*Acacia citrinoviridis, A. coriacea* subsp. *pendens* low open forest over *Acacia pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius, Tephrosia rosea* var. glabrior scattered low shrubs to low open shrubland over *Triodia pungens* very open hum
YEX79	731313	7478735	Qa	River	3f	*Acacia citrinoviridis, A. coriacea* subsp. *pendens* low open forest over *Acacia pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius, Tephrosia rosea* var. glabrior scattered low shrubs to low open shrubland over *Triodia pungens* very open hum
YEX80	731636	7478854	Qa	River	3f	*Acacia citrinoviridis, A. coriacea* subsp. *pendens* low open forest over *Acacia pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius, Tephrosia rosea* var. glabrior scattered low shrubs to low open shrubland over *Triodia pungens* very open hum
YEX81	731391	7477896	Czp	Robe	2a	*Corymbia hamersleyana* open woodland over *Acacia inaequilatera, A. dictyophleba, A. tenuissima, A. ancistrocarpa, A. sclerosperma, A. pruinocarpa, Hakea chordophylla, Eremophila longiflora* tall open shrubland to open shrubland over *Triodia* spp. mid-de
YEX82	730717	7478944	PLHj	Newman	1e	*Acacia inaequilatera, Grevillea wickhamii* scattered shrubs over *Triodia wiseana* mid-dense hummock grassland and *Paraneurachne muelleri* very open grassland
YEX83	730071	7478180	Czp	Boolgeeda	2a	*Corymbia hamersleyana* open woodland over *Acacia inaequilatera, A. dictyophleba, A. tenuissima, A. ancistrocarpa, A. sclerosperma, A. pruinocarpa, Hakea chordophylla, Eremophila longiflora* tall open shrubland to open shrubland over *Triodia* spp. mid-de
YEX84	730662	7478291	Czp	Robe	1b	*Eucalyptus leucophloia* low open woodland *over Acacia hilliana and A. adoxa var. adoxa* low open shrubland over *Triodia* aff. *basedowii* mid-dense hummock grassland
YEX85	731822	7477598	Czp	Boolgeeda	1b	*Eucalyptus leucophloia* low open woodland *over Acacia hilliana and A. adoxa var. adoxa* low open shrubland over *Triodia* aff. *basedowii* mid-dense hummock grassland
YEX86	730336	7478936	Qa	River	3b	*Corymbia hamersleyana* open woodland over *Acacia tumida var. pilbarensis, A. dictyophleba, A. pyrifolia, Gossypium robinsonii, Petalostylis labicheoides, Grevillea wickhamii, Rulingia luteiflora, Eremophila longifolia* mixed shrubland to open shrubland

Site Name	Easting	Northing	Geology Code	Land System	Vegetation Code	Vegetation Description
YOXSRE01	717784	7479058	Czc	McKay	P1	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *Acacia bivenosa, A. ancistrocarpa, A. dictyophleba* open shrubland to shrubland over *Triodia wiseana, T. pungens.*
YOXSRE02	717649	7479049	PLHj	McKay	H2	*Eucalyptus leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* (T. sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
YOXSRE07	717819	7479041	Czc	McKay	P1	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *Acacia bivenosa, A. ancistrocarpa, A. dictyophleba* open shrubland to shrubland over *Triodia wiseana, T. pungens.*
YBQSRE01	738681	7481359	Qa	River	AapERfoERl/G	–
YBQSRE03	738715	7481697	Qa	Boolgeeda	AapERfoERl/G	–
YBQSRE04	739618	7484698	Czc	Boolgeeda	ChEgAiAaAprPcTb	–
YBQSRE07	739531	7484607	Czc	Boolgeeda	ChEgAiAaAprPcTb	–

Appendix 2

Site by Species Matrices

Herpetofauna

FAMILY Species Name (Conservation Status)	BIL02	BIL05	BIL07	BIL11	BIL12	BILF10	BILF13	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBE06	OXBF02	OXBF05	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	YAN01	YAN–0	YAN04	YANE05	YANF03	YBF08F	YBL01F	YBL02P	YBL03P	YBL04F	YBL05P	YBL06P	YBL07P	YBL08F	YBL09E	YBL01E	YBL011F	YBL02M	YBL03M	YBLMC21	YBLNQ01	YBL0pp	YNQE01	YNQE02	YNQE03	YNQE04	YNQE05	YNQE06	YNQE07	YNQE08	HAC1	Total
MYOBATRACHIDAE																																																							
Uperoleia saxatilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	2
HYLIDAE																																																							
Cyclorana maini	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Litoria rubella	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	6
CARPHODACTYLIDAE																																																						
Nephrurus wheeleri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
DIPLODACTYLIDAE																																																					
Diplodactylus conspicillatus	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	–	1	1	1	–	1	–	–	–	–	–	–	4	22	7	–	4	2–	2	–	–	–	11	–	–	–	–	–	–	–	–	–	–	–	–	56
Lucasium stenodactylum	–	–	–	–	–	–	–	3	3	–	–	1	–	–	–	–	–	–	1	1	–	–	1	–	–	–	–	–	–	3	1	–	5	3	1	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	25
Oedura marmorata	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Rhynchoedura ornata	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	1	3	–	–	1	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	12
Strophurus jeanae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
Strophurus wellingtonae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	1	1	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	6
GEKKONIDAE																																																						
Gehyra pilbara	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Gehyra punctata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Gehyra variegata	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	2	–	–	–	1	–	1	–	–	1	–	–	–	–	–	–	–	11
Heteronotia binoei	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	6	4	2	3	1	1	1	2	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	26
PYGOPODIDAE																																																					
Delma butleri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Delma haroldi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Delma nasuta	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	5
Delma pax	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4
Delma tincta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Lialis burtonis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	1	–	–	3	–	–	–	–	–	–	–	1	–	–	–	–	–	–	7
Pygopus nigriceps	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
AGAMIDAE																																																					
Amphibolurus longirostris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1–	3
Ctenophorus caudicinctus	–	–	1	–	–	–	–	6	4	1	–	–	–	–	–	–	–	–	1	1	1	–	1	1	2	1	–	–	1	–	1	–	1	2	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	29
Ctenophorus isolepis	–	–	–	–	–	–	–	3	1	1	–	1	1	–	–	–	1	–	–	1	–	–	1	1	–	6	–	–	–	–	3	9	–	7	1–	3	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	43
Ctenophorus nuchalis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4
Ctenophorus reticulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Pogona minor	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	4
SCINCIDAE																																																					
Cyclodomorphus melanops	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
Egernia formosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Egernia pilbarensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Tiliqua multifasciata	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Carlia munda	1	3	–	–	–	–	–	1	–	1	1	–	–	–	–	–	1	1	–	–	–	–	–	–	1	–	–	1	1	–	–	2	2	–	–	2	1	–	–	4	–	–	–	–	–	–	–	–	–	–	–	2	25
Carlia triacantha	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Cryptoblepharus plagiocephalus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	2

FAMILY Species Name (Conservation Status)	BIL02	BIL05	BIL07	BIL11	BIL12	BILF10	BILF13	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBE06	OXBF02	OXBF05	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	YAN01	YAN–0	YAN04	YANE05	YANF03	YBF08F	YBL01F	YBL02P	YBL03P	YBL04F	YBL05P	YBL06P	YBL07P	YBL08F	YBL09E	YBL01E	YBL011F	YBL02M	YBL03M	YBLMC21	YBLNQ01	YBL0pp	YNQE01	YNQE02	YNQE03	YNQE04	YNQE05	YNQE06	YNQE07	YNQE08	HAC1	Total
Cryptoblepharus ustulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Menetia greyii	–	2	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5
Morethia ruficauda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Proablepharus reginae	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Ctenotus ariadnae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	7	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	13
Ctenotus duricola	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	1	–	–	–	–	–	–	–	–	–	2	9	8	2	1	14	24	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	68
Ctenotus grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	3	9	–	4	3	3	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	26
Ctenotus hanloni	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	8
Ctenotus helenae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	5
Ctenotus leonhardii	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Ctenotus pantherinus	–	–	1	1	1	–	–	3	1	–	2	–	1	–	2	–	1	–	1	–	1	–	–	4	2	2	–	–	2	6	1	1	1	5	1	3	–	–	–	12	–	–	–	–	–	–	–	–	–	–	–	–	3	58
Ctenotus rubicundus	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Ctenotus saxatilis	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	8	5	5	2	2	1	3	9	1	–	–	20	–	–	–	–	–	–	–	–	–	–	–	–	4	63
Ctenotus schomburgkii	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4
Ctenotus serventyi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	6	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11
Lerista labialis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	1	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
Lerista muelleri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Lerista bipes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Lerista labialis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	4	5	–	1	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	13
Notoscincus ornatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
VARANIDAE																																																							
Varanus acanthurus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4
Varanus brevicauda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	4	2	1	–	2	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	13
Varanus bushi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Varanus eremius	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	–	1	2	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	9
Varanus gouldii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Varanus panoptes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Varanus pilbarensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Varanus tristis	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	1	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	1	–	–	–	–	–	1	9
TYPHLOPIDAE																																																						
Anilios ammodytes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Anilios grypus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5
PYTHONIDAE																																																						0
Antaresia perthensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Liasis olivaceus barroni (S1, VU)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1
ELAPIDAE																																																						
Acanthophis wellsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Brachyurophis approximans	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Demansia psammophis	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	5
Demansia rufescens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Pseudechis australis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	1	4
Parasuta monachus	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	

S = Schedule; VU = Vulnerable.

Ground Mammals

FAMILY Species Name (Conservation Status)	Common Name	BIL07	BILF10	BILF13	HDA08	OXB01	OXB03	OXB04	OXBE06	OXBF02	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	YAN01	YAN02	YAN04	YANE05	YANF03	YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL010E	YBL011F	YBL020M	YBL30M	YBLOPP	YNQE01	YNQE03	YNQE04	YNQE05	YNQE07	Total
DASYURIDAE																																										
Dasycercus blythi (P4)	Brush-tailed Mulgara	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	3
Dasykaluta rosamondae	Little Red Kaluta	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–	1	–	5
Ningaui ridei	Wongai Ningaui	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Ningaui timealeyi	Pilbara Ningaui	–	–	–	–	2	–	2	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	2	2	–	–	5	–	–	–	–	–	–	1	–	–	–	–	–	15
Sminthopsis macroura	Stripe-faced Dunnart	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	1	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	9
MACROPODIDAE																																									
Macropus robustus	Euro	1	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	5
Macropus rufus	Red Kangaroo,	–	1	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	2	–	–	–	–	9
Petrogale rothschildi	Rothschild's Rock-wallaby	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
MURIDAE																																									
**Mus musculus*	House Mouse	–	–	–	–	–	–	–	–	–	–	–	1	1	–	1	–	–	–	–	–	–	–	1	2	2	1	2	–	4	–	–	2–	–	–	5	–	4	1	–	45
Notomys alexis	Spinifex Hopping-mouse	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1
Pseudomys chapmani (P4)	Western Pebble-mound Mouse	1	–	–	–	–	–	6	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	18	–	–	–	–	–	28
Pseudomys desertor	Desert Mouse	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	3
Pseudomys hermannsburgensis	Sandy Inland Mouse	–	–	–	2	–	2	–	–	–	–	–	1	1	–	–	–	–	2	1	–	–	–	–	6	1	1	2	–	–	–	1	–	–	1	6	1	–	–	1	29
Zyzomys argurus	Common Rock-rat	–	–	–	–	–	–	–	12	–	–	–	–	–	1	1	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	13	–	1	–	–	–	–	–	–	30
CANIDAE																																									
Canis lupis	Dingo/Dog	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	–	–	–	5
FELIDAE																																									
**Felis catus*	Cat	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
EQUIDAE																																									
**Equus asinus*	Donkey	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
**Equus caballus*	Horse	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1
BOVIDAE																																									
**Bos taurus*	European Cattle	–	1	1	–	–	–	–	–	–	1	1	–	1	–	1	1	2	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11
CAMELIDAE																																									
**Camelus dromedarius*	Dromedary, Camel	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1

P = Priority.
* indicates non-indigenous species.

Avifauna

FAMILY Common Name (Conservation Status)	Species Name	BIL02	BIL05	BIL07	BIL08	BIL11	BIL12	BILF10	BILF13	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	FS-08	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBF02	OXBF05	YAN01	YAN02	YAN04	YANF03	YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL009L	YBL010E	YBL011F	YBL30M	YBLBRD-01	YBLBRD-02	YBLBRD-03	YBLBRD-04	YBLBRD05	YBLOPP	HAC1	Total
CASUARIIDAE																																																	
Emu	*Dromaius novaehollandiae*	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
PHASIANIDAE																																																	
Stubble Quail	*Coturnix pectoralis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ANATIDAE																																																	
Grey Teal	*Anas gracilis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Pacific Black Duck	*Anas superciliosa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	15	23
COLUMBIDAE																																																	
Common Bronzewing	*Phaps chalcoptera*	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Crested Pigeon	*Ocyphaps lophotes*	0	0	0	0	1	0	4	0	1	1	0	0	0	0	1	0	0	2	1	1	0	0	0	0	0	2	2	0	5	2	0	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	27
Spinifex Pigeon	*Geophaps plumifera*	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	2	1	1	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	35
Diamond Dove	*Geopelia cuneata*	0	0	0	0	0	0	0	0	1	1	1	1	0	2	0	0	8	5	5	0	0	0	0	0	1	0	0	0	5	8	3	0	2	2	1	1	1	1	2	0	1	1	0	1	0	0	1	55
Peaceful Dove	*Geopelia striata*	1	0	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0	2	0	1	0	2	0	0	0	1	1	1	2	1	1	0	0	0	0	0	0	0	0	21
Eurostopodidae																																																	
Spotted Nightjar	*Eurostopodus argus*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Australian Owlet-nightjar	*Aegotheles cristatus*	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Fork-tailed Swift (S3, M)	*Apus pacificus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	9
Australasian Darter	*Anhinga novaehollandiae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	4
Little Pied Cormorant	*Microcarbo melanoleucos*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
White-necked Heron	*Ardea pacifica*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Eastern Great Egret (S3, M)	*Ardea modesta*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
White-faced Heron	*Egretta novaehollandiae*	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
THRESKIORNITHIDAE																																																	
Straw-necked Ibis	*Threskiornis spinicollis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
ACCIPITRIDAE																																																	
Black-breasted Buzzard	*Hamirostra melanosternon*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Whistling Kite	*Haliastur sphenurus*	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	5	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	13
Black Kite	*Milvus migrans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	2
Brown Goshawk	*Accipiter fasciatus*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Collared Sparrowhawk	*Accipiter cirrocephalus*	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Spotted Harrier	*Circus assimilis*	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	10
Little Eagle	*Hieraaetus morphnoides*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
FALCONIDAE																																																	
Nankeen Kestrel	*Falco cenchroides*	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Brown Falcon	*Falco berigora*	0	1	0	0	0	0	0	0	1	0	1	1	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Australian Hobby	*Falco longipennis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Peregrine Falcon (S4)	*Falco peregrinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
RALLIDAE																																																	
Spotless Crake	*Porzana tabuensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	2
Eurasian Coot	*Fulica atra*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
OTIDIDAE																																																
Australian Bustard (P4)	*Ardeotis australis*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	1	0	0	0	0	0	0	0	0	1	0	8	0	17
CHARADRIIDAE																																																
Black-fronted Dotterel	*Elseyornis melanops*	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	10	25		

FAMILY Common Name (Conservation Status)	Species Name	BIL02	BIL05	BIL07	BIL08	BIL11	BIL12	BILF10	BILF13	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	FS-08	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBF02	OXBF05	YAN01	YAN02	YAN04	YANF03	YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL009L	YBL010E	YBL011F	YBL30M	YBLBRD-01	YBLBRD-02	YBLBRD-03	YBLBRD-04	YBLBRD05	YBLOPP	HAC1	Total
Red-kneed Dotterel	*Erythrogonys cinctus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
TURNICIDAE																																																	
Little Button-quail	*Turnix velox*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
CACATUIDAE																																																	
Galah	*Eolophus roseicapillus*	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Little Corella	*Cacatua sanguinea*	0	0	0	0	0	1	4	3	0	0	0	0	0	1	0	0	0	3	9	0	0	0	0	0	2	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	1	0	0	0	0	0	0	29
Cockatiel	*Nymphicus hollandicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0	0	0	0	0	1	1	2	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	16
PSITTACIDAE																																																	
Australian Ringneck	*Barnardius zonarius*	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	3	10
Mulga Parrot	*Psephotus varius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Budgerigar	*Melopsittacus undulatus*	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	0	6	3	5	0	0	0	0	0	0	0	0	0	4	5	0	0	1	1	1	0	1	0	1	0	0	0	0	0	0	0	7	41
CUCULIDAE																																																	
Pheasant Coucal	*Centropus phasianinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Horsfield's Bronze-Cuckoo	*Chalcites basalis*	0	0	0	0	0	0	1	1	1	0	1	0	1	1	1	0	3	1	1	0	0	0	1	0	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2	21
Black-eared Cuckoo	*Chalcites osculans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pallid Cuckoo	*Cacomantis pallidus*	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
STRIGIDAE																																																	
Barking Owl	*Ninox connivens*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Southern Boobook	*Ninox novaeseelandiae*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
HALCYONIDAE																																																	
Blue-winged Kookaburra	*Dacelo leachii*	0	1	0	0	0	0	2	1	0	1	0	0	0	1	0	0	1	0	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	13
Red-backed Kingfisher	*Todiramphus pyrrhopygius*	0	0	0	0	0	1	0	2	1	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Sacred Kingfisher	*Todiramphus sanctus*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	7
MEROPIDAE																																																	
Rainbow Bee-eater (S3, M)	*Merops ornatus*	0	3	0	0	0	0	4	2	1	1	0	0	0	0	0	0	2	0	6	0	0	0	0	0	2	3	0	2	0	4	0	0	1	0	1	3	0	3	0	0	13	15	1	0	1	9	4	81
CLIMACTERIDAE																																																	
Black-tailed Treecreeper	*Climacteris melanura*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
MALURIDAE																																																	
White-winged Fairy-wren	*Malurus leucopterus*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	1	3	0	3	2	2	0	0	1	0	0	0	0	0	0	0	0	19
Variegated Fairy-wren	*Malurus lamberti*	0	2	0	0	0	2	1	0	1	1	1	1	0	1	0	0	4	2	7	1	1	2	0	0	1	0	0	3	1	3	3	2	3	1	2	1	0	0	2	0	0	0	0	1	0	0	1	51
ACANTHIZIDAE																																																	
Weebill	*Smicrornis brevirostris*	1	2	2	2	1	4	2	3	1	1	1	1	1	1	1	0	6	2	4	2	2	2	1	1	4	3	2	2	4	3	0	2	4	5	5	6	1	6	2	0	0	1	0	1	0	0	12	107
Western Gerygone	*Gerygone fusca*	0	0	0	2	0	1	1	1	1	0	0	0	0	0	0	0	1	7	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	5	1	0	0	1	1	0	0	5	32
Slaty-backed Thornbill	*Acanthiza robustirostris*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5
Inland Thornbill	*Acanthiza apicalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
PARDALOTIDAE																																																	
Red-browed Pardalote	*Pardalotus rubricatus*	0	0	0	0	0	0	2	3	0	0	0	1	0	0	0	0	2	0	1	2	2	1	0	0	1	1	1	0	0	3	2	1	0	1	2	1	1	0	0	0	0	0	1	0	0	0	0	29
Striated Pardalote	*Pardalotus striatus*	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	3	1	0	0	0	0	0	0	0	14
MELIPHAGIDAE																																																	
Singing Honeyeater	*Lichenostomus virescens*	0	0	1	5	3	2	2	1	0	1	1	1	0	1	1	0	2	2	1	3	3	1	0	0	3	2	3	2	4	8	4	3	7	4	2	0	0	3	5	0	0	0	0	1	0	0	0	82
Grey-headed Honeyeater	*Lichenostomus keartlandi*	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0	1	2	1	0	1	0	0	0	0	0	0	0	0	2	2	1	0	0	1	0	0	0	0	0	0	0	0	16
White-plumed Honeyeater	*Lichenostomus penicillatus*	3	3	0	0	0	0	7	6	1	1	0	0	0	1	0	0	0	0	8	0	0	1	0	0	2	7	0	7	1	0	0	0	0	0	0	6	2	0	0	0	0	0	0	0	1	0	8	65
White-fronted Honeyeater	*Purnella albifrons*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3

FAMILY Common Name (Conservation Status)	Species Name	BIL02	BIL05	BIL07	BIL08	BIL11	BIL12	BILF10	BILF13	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	FS-08	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBF02	OXBF05	YAN01	YAN02	YAN04	YANF03	YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL009L	YBL010E	YBL011F	YBL30M	YBLBRD-01	YBLBRD-02	YBLBRD-03	YBLBRD-04	YBLBRD05	YBLOPP	HAC1	Total
Yellow-throated Miner	*Manorina flavigula*	0	0	1	11	1	1	0	0	1	0	2	1	1	1	0	0	0	1	0	0	2	0	0	1	4	1	0	1	0	0	0	1	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	35
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	4	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	3	0	0	0	0	1	0	0	0	16
Grey Honeyeater	*Conopophila whitei*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	2
Crimson Chat	*Epthianura tricolor*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Black Honeyeater	*Sugomel niger*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Brown Honeyeater	*Lichmera indistincta*	0	1	3	0	1	4	3	1	0	0	0	0	0	1	0	0	5	5	5	1	2	1	4	0	3	4	1	4	2	3	1	1	1	6	3	4	1	2	2	0	1	1	1	0	0	0	0	78
Black-chinned Honeyeater	*Melithreptus gularis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
POMATOSTOMIDAE																																																	
Grey-crowned Babbler	*Pomatostomus temporalis*	1	0	1	0	0	0	1	4	1	1	0	0	0	1	0	0	1	1	7	0	1	0	2	0	1	0	0	1	1	1	0	0	1	1	1	2	1	0	0	0	0	0	0	0	0	1	0	33
NEOSITTIDAE																																																	
Varied Sittella	*Daphoenositta chrysoptera*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Campephagidae																																																	
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	0	0	0	0	1	0	0	4	1	1	1	0	0	1	1	0	1	4	3	0	2	1	0	0	2	0	1	3	2	1	2	0	0	1	2	3	0	0	2	0	0	0	0	0	0	0	1	41
White-winged Triller	*Lalage sueurii*	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
PACHYCEPHALIDAE																																																	
Rufous Whistler	*Pachycephala rufiventris*	1	2	0	1	0	0	0	2	1	1	1	0	0	1	0	0	2	5	6	0	0	0	0	1	0	2	0	0	0	5	0	0	2	0	1	3	1	0	8	0	0	1	1	0	1	0	11	60
Grey Shrike-thrush	*Colluricincla harmonica*	0	0	0	1	0	0	2	1	1	1	0	0	1	1	0	0	0	1	3	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	19
Crested Bellbird	*Oreoica gutturalis*	1	0	0	0	1	1	1	1	1	0	1	1	0	0	1	0	2	2	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
ARTAMIDAE																																																	
Masked Woodswallow	*Artamus personatus*	0	0	0	50	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54
Black-faced Woodswallow	*Artamus cinereus*	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3	0	0	2	1	0	0	0	0	0	0	0	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	16
Little Woodswallow	*Artamus minor*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	5
Grey Butcherbird	*Cracticus torquatus*	0	0	0	4	0	0	0	0	0	0	1	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9
Pied Butcherbird	*Cracticus nigrogularis*	0	0	0	0	1	0	0	1	1	1	0	0	1	1	1	0	1	2	1	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	17
Australian Magpie	*Cracticus tibicen*	0	0	0	0	0	0	1	0	1	1	1	0	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	1	0	13
RHIPIDURIDAE																																																	
New Zealand Fantail	*Rhipidura fuliginosa*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	
Willie Wagtail	*Rhipidura leucophrys*	0	2	2	0	0	0	5	3	1	0	1	1	0	1	0	0	0	5	5	0	3	0	1	0	0	0	1	2	2	0	1	0	3	1	1	3	1	1	3	0	1	0	0	0	1	0	2	53
CORVIDAE																																																	
Little Crow	*Corvus bennetti*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Torresian Crow	*Corvus orru*	2	1	1	1	0	1	3	2	0	0	1	1	0	1	1	0	2	1	3	0	1	0	0	0	2	1	0	0	2	0	1	0	1	1	0	1	0	3	0	0	1	0	0	0	0	0	0	35
MONARCHIDAE																																																
Magpie-lark	*Grallina cyanoleuca*	0	1	1	1	0	1	6	2	1	1	0	0	0	1	0	0	1	0	4	0	2	0	1	0	4	4	0	2	0	0	0	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	37
PETROICIDAE																																																
Red-capped Robin	*Petroica goodenovii*	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0	1	14
Hooded Robin	*Melanodryas cucullata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2	11
ACROCEPHALIDAE																																																
Australian Reed-Warbler	*Acrocephalus australis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	1	1	0	6
MEGALURIDAE																																																
Rufous Songlark	*Cincloramphus mathewsi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	2	1	0	0	2	0	3	0	0	0	0	0	0	0	0	1	0	0	0	12
Spinifexbird	*Eremiornis carteri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	1	0	8	
HIRUNDINIDAE																																																
White-backed Swallow	*Cheramoeca leucosterna*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

FAMILY Common Name (Conservation Status)	Species Name	BIL02	BIL05	BIL07	BIL08	BIL11	BIL12	BILF10	BILF13	FS-01	FS-02	FS-03	FS-04	FS-05	FS-06	FS-07	FS-08	HDA07	HDA08	HDA09	OXB01	OXB03	OXB04	OXBF02	OXBF05	YAN01	YAN02	YAN04	YANF03	YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL009L	YBL010E	YBL011F	YBL30M	YBLBRD-01	YBLBRD-02	YBLBRD-03	YBLBRD-04	YBLBRD05	YBLOPP	HAC1	Total
Fairy Martin	*Petrochelidon ariel*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Tree Martin	*Petrochelidon nigricans*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
NECTARINIIDAE																																																
Mistletoebird	*Dicaeum hirundinaceum*	4	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	3	0	0	0	1	0	3	1	0	2	0	0	0	0	0	1	1	3	27
ESTRILDIDAE																																																
Zebra Finch	*Taeniopygia guttata*	1	0	0	0	1	0	6	4	1	1	1	1	0	1	1	0	16	6	7	1	6	1	2	0	8	3	5	2	5	10	3	2	7	6	2	8	3	1	7	0	0	1	1	0	1	0	10	142
Star Finch (P4)	*Neochmia ruficauda subclarescens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	11	0	13
Painted Finch (P4)	*Emblema pictum*	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	5	0	1	0	0	0	0	0	0	2	0	0	1	4	1	0	5	6	7	4	1	3	2	0	0	0	0	0	1	0	0	50
MOTACILLIDAE																																																
Australasian Pipit	*Anthus novaeseelandiae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

S = Schedule; P = Priority; M = Migratory.

Appendix 3

Commonwealth and State Conservation Status Categories

Native fauna species that are rare, threatened with extinction, or have high conservation value are specially protected by law under the WA *Wildlife Conservation Act 1950*. In addition, many of these species are listed under the Commonwealth *EPBC Act 1999*.

Commonwealth *EPBC Act 1999*

Fauna species of national conservation significance are listed under the *EPBC Act 1999*, and have been classified as 'critically endangered', 'endangered', 'vulnerable' or 'conservation dependent' (broadly consistent with International Union for Conservation of Nature (IUCN) categories: http://intranet.iucn.org/webfiles/doc/SSC/RedList/redlistcatsenglish.pdf).

Migratory wader species are also protected under the *EPBC Act 1999*. The national List of Migratory Species consists of those species listed under the following International Conventions:

- Japan-Australia Migratory Bird Agreement (JAMBA);
- China-Australia Migratory Bird Agreement (CAMBA);
- Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA); and
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

Western Australian *Wildlife Conservation Act 1950*

Classification of rare and endangered fauna under the *Wildlife Conservation (Specially Protected Fauna) Notice 2013* recognises four distinct schedules of taxa:

Schedule 1 - being fauna that is rare or likely to become extinct and are declared to be fauna in need of special protection;

Schedule 2 - being fauna that is presumed to be extinct and are declared to be fauna in need of special protection;

Schedule 3 - being birds that are subject to an agreement between the government of Australia and the governments of Japan, China and the Republic of Korea relating to the protection of migratory birds and are declared to be fauna that is in need of special protection; and

Schedule 4 - being fauna that is in need of special protection, otherwise than for the reasons mentioned in paragraphs (1), (2) and (3).

In addition, the Department of Parks and Wildlife maintains a list of Priority species (specially protected fauna notice) that have not been assigned statutory protection under the *Wildlife Conservation Act 1950*. Species on this list are considered to be of conservation priority because there is insufficient information to make an assessment of their conservation status or they are considered to be rare but not threatened and are in need of monitoring.

Five Priority codes apply to such fauna:

Priority One – Taxa with few, poorly known populations on threatened lands.
Taxa that are known from a few specimens or sight records from one or a few localities on lands not managed for conservation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Two – Taxa with few, poorly known populations on conservation lands, or taxa with several, poorly known populations not on conservation lands.
Taxa that are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Three – Taxa with several, poorly known populations, some on conservation lands.
Taxa that are known from few specimens or sight records from several localities, some of which are on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Four – Taxa in need of monitoring.
Taxa that are considered to have been adequately surveyed or for which sufficient knowledge is available and which are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. Taxa that are declining significantly but are not yet threatened.

Priority Five – Taxa in need of monitoring.
Taxa that are not considered threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

URS

Report

Environmental Risk Assessment for Riparian Zones on Weeli Wolli Creek

AUSTRALIA

Riparian Zones Environmental Risk Assessment

30 June 2015
42908644/WY/IGB-Wat-0124/PSM/2

Prepared for:
Rio Tinto Iron Ore Pty Ltd

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ABBREVIATIONS

Abbreviation	Description
A	*Acacia*
ANRA	Australian Natural Resources Atlas
ARI	Average Recurrence Interval
BHPBIO	BHP Billiton Iron Ore Pty Ltd
BIF	Banded Iron Formation
BoM	Bureau of Meteorology
CID	Channel Iron Deposits
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation
DoW	Department of Water
E	*Eucalyptus*
EPA	Environmental Protection Authority
EWR	Ecological Water Requirements
GL	Gigalitre
GL/annum	Gigalitres per annum
kL	kilolitres
km	kilometres
km^2	square kilometres
M	*Melaleuca*
m	metre
m AHD	metres above Australian Height Datum
MAC	Mining Area C
mg/L	milligrams per litre
mm	millimetres
Mtpa	Million tonne per annum
No.	Number
PBS	Pocket and Billiard South Project
PEC	Priority Ecological Community
PER	Public Environmental Review
RTIO	Rio Tinto Iron Ore
TDS	Total Dissolved Solids
TRH	Total Recoverable Hydrocarbons
TSS	Total Suspended Solids

EXECUTIVE SUMMARY

The setting of the Pocket and Billiard South (PBS) Project is on the broader floodplain of Weeli Wolli Creek, in proximity to riparian zones. The riparian zones are characterised by comparatively high water availability and likely sensitivity to change in this regard. In this setting the importance of the riparian zones is empathised through Ministerial Statement 914 (2012) relevant to the RTIO Yandicoogina Mine. Further, is the definition of a Riparian Exclusion Zone on Weeli Wolli Creek that is intended to limit disturbances to the highest conservation value riparian floristic stands that extend to distances up to about 600 m from the low-flow channel.

In the baseline settings, the riparian zones on Weeli Wolli Creek were interpreted to be predominantly dependent on surface water and pore water derived from direct rainfall, overland flow and episodic stream flow events. Depths to the water table in the range 12 to 20 m provided low groundwater dependency.

Since about 2007, the discharge of surplus groundwater into Weeli Wolli Creek increased the water availability through the presence of wetting fronts. The wetting fronts represent the transport, dissipation and fates of the surplus groundwater within the local surface water, surface water to groundwater and groundwater receiving environments. Mechanisms for dissipation include infiltration, interception by evaporation and transpiration and, though-flow in the groundwater environment. Since 2007, the surface water wetting front has been waxing and waning over a 4 km reach of Weeli Wolli Creek. This characteristic was interpreted to represent quasi-steady-state conditions wherein the infiltration, evaporation and transpiration mechanisms were reasonably consistent over time. Under these circumstances, the predominant dissipation mechanism is through-flow in the groundwater environment, controlled by the effective transmissivity of the floodplain and CID aquifer system. The cumulative losses due to evaporation and transpiration tend to be comparatively small, amounting to 15 to 25 per cent of the total water balance. Of these losses, evaporation is subordinate to transpiration.

The observed wetting fronts and interpreted fates of the surplus water (Dogramaci, et al., 2015a and, Pettett and Pearcey, 2014) provide indications of a high-transmissivity aquifer system beneath the northern reaches of Weeli Wolli Creek and Poonda Plain. In 2013, this aquifer system transmitted about 54 GL, with comparatively limited expression in terms of the amplitudes in water table mounding.

The changed surface water and groundwater environments provided potential for increased groundwater use (medium dependency) within the riparian zone, commensurate with reduced surface water and pore water dependencies. Decay of water availability to the riparian zones would be inevitable once the discharge of surplus water ceases or is substantially reduced.

The proposed mining at Pocket and Billiard South (PBS) would impose changes to the water availability on Weeli Wolli Creek. Perennial stream flow in the low-flow channel and opportunities for flooding of adjacent riparian zones would be largely undisturbed. Dewatering of the proposed pit would, however, substantially lower the water table, with rate of decline beyond natural variation. Ultimately the water table would be lowered to

below baseline elevations, with associated potential deficits in the available water and declines in potentials for groundwater dependency.

Contextually, the water availability risks to the riparian zone would predominantly have aspects that reflect the adaptability of riparian floristics:

- In drawing from alternative sources when groundwater availability is reduced by 12 to 22 percent from current scenarios.
- Reverting to baseline dependencies on surface water and pore water.
- To net reductions of 3 to 9 per cent in total water availability compared to baseline.
- Waterlogging due to mounding of the water table and persistence of stream flow.

Ecological Water Requirements of the riparian zones on Weeli Wolli Creek would be supported by the following:

- Retention of perennial surface water flows, at least initially.
- Limiting changes to periods of high floodwater.
- Avoidance of drawdown of the water table.

The PBS scenario captures two of these processes, but not retention of groundwater availability. Under these circumstances, the riparian groundwater dependent floristics would probably experience drought-like conditions, with associated water availability stress. The percentage scale of the changes in the water availability has been used to define potential risks. In this regard, low risks reflect changes of less than 10 per cent; medium risks between 10 to 18 per cent; medium-high risks 18 to 25 per cent and high risks greater than 25 per cent.

The interpreted changes in water availability within the riparian zones may be partially off-set by sustaining stream flow in the low-flow channel.

Setting	Change Aspect		Risk Assessment											
			Current to Baseline Scenarios				Baseline to PBS Scenarios				Current to PBS Scenarios			
			Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain
***E. victrix* Increased Water Availability and Waterlogging (beneath the Low-Flow Channel and Incised Channel)[1]**														
Low-Flow Channel	Waterlogging.		Medium High	-	-	-	Low	-	-	-	Medium High	-	-	-
Incised Channel			-	Medium	-	-	-	Low	-	-	-	Medium	-	-
***M. argentea* and *E. camaldulensis* Decreased Water Availability Due to Drawdown[2]**														
Low-Flow Channel[3]	Presence of perennial stream flow.		Low	-	-	-	Low	-	-	-	Low	-	-	-
	Drawdown of the water table below current elevations.		Medium	-	-	-	Low	-	-	-	Medium	-	-	-
Incised Channel	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].	<5 m	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		5 – 10	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		10 – 20	-	Medium High	-	-	-	Low	-	-	-	Medium High	-	-
		>20	-	High	-	-	-	Low	-	-	-	High	-	-
Riparian Flood Plain	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].		-	-	Medium	-	-	-	Low	-	-	-	Medium	-
Broader Flood Plain			-	-	-	Low	-	-	-	Low	-	-	-	Low

1 THE POCKET AND BILLIARD SOUTH PROJECT

1.1 Overview

Brownfield expansion plans for the RTIO Yandicoogina Mine include the development of the Pocket and Billiard South (PBS) Project. Both Pocket and Billiard South deposits represent downstream extensions of the Channel Iron Deposits (CID) currently being developed. The setting of the PBS Project is on the floodplain of Weeli Wolli Creek, near the confluence with Marillana Creek, as shown on Figure 1-1.

The floodplain on Weeli Wolli Creek forms an area of comparatively high water availability which supports a locally significant riparian woodland (Figure 1-2). The mapped riparian areas shown on Figure 1-2 form a Riparian Exclusion Zone wherein disturbance is proposed to be limited. Within the Riparian Exclusion Zone *Eucalyptus camaldulensis* (River Red Gum) and *E. victrix* (Coolibah) form a riparian fringe over-storey along the local reaches of the Weeli Wolli Creek, together with woodlands and open stands of *Acacia citrinoviridis (Black Mulga), A. coriacea subsp. pendens,* and *M. glomerata* with a mix of shrubs and grasses.

Surface water and pore water dependence with a lesser and variable degree of groundwater dependence typically characterise the riparian zone. The floodplain and associated riparian zone is underlain by alluvium and Tertiary detritals, including CID, that form a significant aquifer system. Both surface water and groundwater from the Weeli Wolli Creek flow to the north, traversing the Poonda Plain before terminating within the Fortescue Marsh.

A Public Environmental Review (PER) is in preparation to support regulatory processes in the PBS development. Conservation of the riparian zone is an important element of PBS to be addressed within the PER.

1.2 Context to Historical Mining Activities

The water resources of the PBS setting on Weeli Wolli Creek have been altered by cumulative influences of the BHPBIO Yandi, RTIO Yandicoogina and Hope Downs 1 mines. Each mine extends below the water table and consequently excavations are accompanied by groundwater abstraction to dewater the local aquifer systems. Water surplus to on-site operational and iron ore beneficiation demands has been discharged to Marillana Creek and Weeli Wolli Creek.

Under baseline conditions the occurrence of wetlands, pools and shallow water table on lower Weeli Wolli Creek extended several kilometres downstream from Weeli Wolli Spring. Discharge of the surplus water has contributed to a surface water wetting front on Weeli Wolli Creek that extends for approximately 25 km downstream of Weeli Wolli Spring (Hamersley HMS, 2010), thus about 6 km downstream of the Marillana Creek confluence. The wetting front is characterised by sustained expressions of stream flow and pools on Weeli Wolli Creek.

A brief outline of each mine and associated surplus water discharge is provided below. Locations in context to the PBS Project are shown on Figure 1-3.

1.2.1 BHPBIO Yandi Mine

The BHPBIO Yandi Mine is located on Marillana Creek upstream of the RTIO Yandicoogina Mine. Operations commenced in 1991, including limited surplus water discharge to Marillana Creek at an outlet termed Anniversary Drive. In 2007, the outlet was relocated downstream to the Railway site immediately upstream of RTIO Yandicoogina mine operations on the State Agreement tenement boundary. Typically, about 5GL/annum is discharged into Marillana Creek from the BHPBIO Yandi Mine; however the project is licensed for 15GL/annum, with peaks of 9GL/annum recorded.

1.2.2 RTIO Yandicoogina Mine

The Yandicoogina Mine is located near the junction of the Marillana and Weeli Wolli creeks and commenced open pit operations in 1998. Mining concurrently occurs within the Junction South West, Junction Central and Junction South East deposits (Figure 1-1), each aligned on CID in proximity to Marillana Creek.

Pit dewatering activities at the RTIO Yandicoogina Mine commenced in 1998, predominantly associated with the Initial Mining Area (IMA) and Junction Central settings on Marillana Creek. Dewatering in the vicinity of Weeli Wolli Creek commenced with the operating of the RTIO Yandi Southern Borefield within the Junction South East deposit during August 2006. The date was commensurate with reinjection (RTIO Yandicoogina Billiard Reinjection) of surplus water from the Junction South East Deposit into the CID aquifer beneath Weeli Wolli Creek in the PBS setting. The discharged water has pH 6.8 to 9.6 and TDS concentrations in the range 370 to 780 mg/L.

1.2.3 Hope Downs 1 Mine

The Hope Downs 1 Mine is located within the upper catchment of Weeli Wolli Creek; upstream of Weeli Wolli Spring. Hope Downs Management Services, (2000) predicted groundwater abstraction of up to 38GL/annum to enable reasonably dry mining conditions.

Groundwater abstraction and associated discharge up to 33 GL/annum commenced in late-January 2007. Initial rates of abstraction were comparatively low. Revised forecasts of the peak rates of abstraction from the Hope Downs 1 Mine range up to 40GL/annum (Kellogg Browne and Root Pty Ltd, 2007); a 40 GL/annum rate of abstraction was not achieved prior to 2013.

The predominant fate of the discharged water is the reach of Weeli Wolli Creek downstream of Weeli Wolli Spring. After the first month of discharge, the surface water expression was recorded at a distance of approximately 13 km downstream of the outfall at Weeli Wolli Spring (Kellogg Browne and Root Pty Ltd, 2007). By September 2007, about nine months after commencement of discharge, the surface water expression progressed to approximately 19 km downstream from the discharge outlet.

1.3 Riparian Zone Aspects

1.3.1 Water Availability

Riparian zones are defined as low-lying areas within and adjacent to the low-flow channel of Weeli Wolli Creek and subject to episodic flooding by stream flow and overland flow (sheet flow) (Junk and Welcomme 1990). The low-lying areas form the immediate channel bank settings and may extend up to about 1 km from the low-flow channel. The riparian zone is characterised by comparatively high water availability and likely sensitivity to change in this regard. In the baseline environment, water availability in the riparian zone is supported by:

- Flooding during episodic stream flow events.
- Soil profiles formed by floodplain deposits, with clay and silt beds providing capacity to store soil water (pore water).
- Groundwater where depths to the water table are comparatively shallow.

Commonly, the floristics within the riparian zone are characterised by xeromorphic adaptations; these enable the draw of water from different sources and matching of water demand to available water. Mature eucalypts (such as *E. camaldulensis*) are recognised (Graham, 2001; O'Grady et al. 2005) as having tap-root systems that may extend to deep water table settings. Conversely, *E. victrix, M. argentea* and acacia woodlands have not been observed as having deep tap-root systems in excavations (Batini, 2008). At the Coolibah Woodlands, Marandoo, the conceptualisation of *E. victrix* rooting depths is to about 13 m (Batini, 2009)

Broad-scale distributions of the riparian vegetation on the lower reaches Weeli Wolli Creek are outlined in Table 1-1 and on Figure 1-2a. Recent vegetation mapping has added detail to the riparian floristic community distributions. The results of this detailed mapping are shown on Figure 1-2b. Important attributes of the detailed mapping include:

- The predominance of *E. victrix* open woodland over *Acacia citrinoviridis* within the Riparian Exclusion Zone, particularly in settings outside of the low-flow channel and incised channel of Weeli Wolli Creek.
- Preferable alignment of the *E. camaldulensis, E. victrix* and *M. argentea* woodland communities on the low-flow channel and incised channel of Weeli Wolli Creek.
- Limited distributions of *E. camaldulensis* co-dominated communities on and immediately adjacent to low-flow channel scour beds.
- Limited, discrete and discontinuous distributions of E. camaldulensis co-dominated communities with transient Melaleuca argentea populations on and immediately adjacent to low-flow channel scour beds on Weeli Wolli Creek and Marillana Creek.

Table 1-1 Distributions of Riparian Floristics on Weeli Wolli Creek (April 2010)

Creek Setting	Main Vegetation
WW1 – Narrow riparian vegetation corridor; larger trees line the banks of the creek.	*E. victrix* *Acacia citrinoviridis*
WW2 – Wide floodplain with extensive vegetation growth.	
WW3 – Confluence with Marillana Creek; wide floodplain with extensive vegetation growth.	*E. victrix* *E. camaldulensis*
WW4 – Wide floodplain with extensive vegetation growth.	*E. victrix* *Acacia citrinoviridis*
WW5 – Alluvial plain supporting smaller plant species.	Mulga species Shrublands/grasslands

1.3.2 Ministerial Conditions

The importance of the riparian ecosystems in context of the RTIO Yandi Mine was emphasised through Ministerial Statement 914 (October 2012):

- Condition 6-1: “that the discharge of excess water as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek System”.
- Condition 6-2: “develop an Environmental Values Statement for the Weeli Wolli Creek System that defines the environmental values of the Weeli Wolli Creek System”.
- Condition 6-3: “ensure that dewatering discharge from the Yandicoogina Iron Ore Project – Expansion to include JSW and Oxbow deposits does not cause water flow or pooling further than 17 km downstream from the Marillana Creek and Weeli Wolli Creek system confluence”.
- Condition 7-1: ”that groundwater abstraction does not cause clearing or loss of vegetation for groundwater dependent ecosystems outside Zones 1, 2, 2a, 3, 3a, 4 and 5 as shown in Figure 1”.
- Condition 7-2: “dewatering discharge does not cause clearing or loss of vegetation or groundwater dependent ecosystems outside Zones 1, 2, 2a, 3, 3a, 4 and 5”.
- Condition 7-3: “there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems” within specified reaches along both Marillana and Weeli Wolli Creeks”.
- Condition 7-4: “prepare a Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan”.
- Condition 7-5: ”The Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan shall enable:
  - *The maintenance of the flow paths, quantity and quality of water within Marillana, Yandicoogina and Weeli Wolli Creeks and the underlying aquifers to protect the surface water and groundwater dependent ecological systems.*

- *Identify potential impact monitoring and control sites between the Oxbow pit and the Fortescue Marsh.*
- *Design a survey to acquire baseline biotic data, including health and abundance parameters and environmental data.*
- *Definition of health and abundance parameters.*
- *Identification of criteria to measure any decline in health.*
- *Definition of critical correlative environmental parameters, including groundwater drawdown.*
- *Definition of trigger levels for no impact.*
- *Definition of trigger levels for no irreversible impact".*

1.4 Conservation of Fortescue Marsh

The Fortescue Marsh forms the receiving environment for the Upper Fortescue River and its tributaries, including Weeli Wolli Creek, upstream of terminations formed by Goodiadarrie Hills. It is considered a unique and nationally important wetland (Australian Natural Resources Atlas (ANRA), 2007, Kingsford et al., 2005) and is therefore of high conservation value. Further, the marsh is a species-rich ecosystem with endemic species and refuges for flora and fauna. The Department of Parks and Wildlife (DPaW) also lists the wetland as a Priority 1 Priority Ecological Community (PEC). Further, the marsh meets one Ramsar Convention criterion for listing as a Wetland of International Importance (Jaensch and Watkins, 1999). Fortescue Marsh is also designated as a wetland of national importance under criteria 1, 2, 3 and 6 of the Directory of Important Wetlands in Australia.

From a water-resource perspective, it is understood that the Fortescue Marsh is characterised by:

- Disconnection from the lower Fortescue River Valley by a natural barrier at Goodiadarrie Hills.
- Recharged during flood events. Discharge of surface water and groundwater by evaporation and transpiration. A regional surface water and groundwater sink wherein salt is accumulated.

The Department of Water (DoW) in collaboration with the DPaW, Department of State Development and the Environmental Protection Authority (EPA, 2013) have issued guidelines for management of projects in the vicinity of Fortescue Marsh. The guidelines reflect the importance of the Fortescue Marsh as an environmentally sensitive area and recognise potentials for altered water balances due to cumulative changes linked to mining projects. Management zones defined by the guidelines reflect relative priorities in terms of environmental values (Figure 1-4). The Poonda Plain management areas encroach on the lower reaches of the Weeli Wolli Creek (about 5 km north of the Marillana Creek confluence). On the Poonda Plain the primary water resources management guidelines include:

- Maintaining the natural flow systems of tributaries entering Fortescue Marsh.
- Conservation of the hydrological and ecological integrity of the major tributaries by limiting changes to occurrences and rates of stream flow.

The guidelines recognise that activities, for example by discharge of surplus water, outside of the management zones may impose changes to the hydrology.

1.5 Report Objectives

The scope of work addressed herein is focussed on the delivery of cumulative change and environmental risk assessments associated with development of PBS. These assessments focus on the potential surface water and groundwater changes and risks to sensitive environmental areas of Weeli Wolli Creek and Fortescue Marsh. Discrete assessments provide surface water and groundwater contexts regarding five tasks:

- Footprints where the water table is lowered by groundwater abstraction and or mounded by surplus water discharge in context to ecological water requirements for riparian vegetation on Weeli Wolli Creek and in Fortescue Marsh. The intention is to define the likely net change in available water on reaches of Weeli Wolli Creek in the immediate vicinity of PBS.
- Cumulative influences on the change footprints and environmental risk linked to existing projects (including BHPBIO Yandi, RTIO Yandicoogina and Hope Downs 1 mines) and the development of PBS.
- Potential future cumulative influences on the change footprints and environmental risks linked to concurrent project developments that may include Jinidi, Iron Valley and Nyidinghu.
- Environmental risks of the cumulative change footprints propagating significantly onto the Poonda Plain management zone of the Fortescue Marsh.
- Preparation of an overall summary report on the surface water and groundwater interactions.

In particular, the deliverable (this report) encompasses:

- The baseline surface water and groundwater environments, with relevant contexts to conceptual models and integrated water resources availability to local ecosystems.
- Cumulative change assessments for the surface water and groundwater environments of Weeli Wolli Creek linked to the RTIO Yandicoogina, BHPBIO Yandi and Hope Downs 1 mining projects. These assessments were coupled to the conceptual models to describe how the water resources systems function, together with the mechanisms that have promoted the known changes to date. Both aspects provide analogies that inform future changes to the integrated water resources availability to local ecosystems.
- An environmental risk assessment in context to surface water and groundwater availability changes associated with PBS. This assessment considers potential cumulative changes due to concurrent development of the existing BHPBIO Yandi, RTIO Yandicoogina and Hope Downs 1 operations.
- Consideration of cumulative future changes that may be associated with new mining projects such as the BC Iron's Iron Valley (below water table), Jinidi and Nyidinghu deposits.

2 PHYSICAL SETTING

2.1 Rainfall

Rainfall events in the Pilbara are characteristically widely variable both spatially and temporally. Average monthly rainfall data collected at Tarina (Bureau of Meteorology (BoM) Site No. 505040 approximately 8 km south of the PBS Project) and Waterloo Bore (BoM Site No. 505041, approximately 8 km north of the PBS Project) are presented in Table 2-1 and on Figure 2-1 (with data from Waterloo Bore). The Tarina and Waterloo Bore data indicate local annual average rainfall in the range 360 to 400 mm, with the majority of rainfall occurring between January and March

Table 2-1 Average Monthly Rainfall at Tarina and Waterloo Bore

Month	Rainfall (mm)	
	Tarina[1]	Waterloo Bore[2]
January	79.5	89.1
February	90.0	94.9
March	46.9	62.1
April	21.5	22.9
May	16.1	16.2
June	20.0	22.9
July	11.2	11.0
August	7.7	5.2
September	4.6	3.9
October	5.9	5.3
November	14.8	10.4
December	45.2	53.4
Annual Totals	363.4	397.3
Notes:		
1 Bureau of Meteorology Site No. 505040; data from 1986 to 2013.		
2 Bureau of Meteorology Site No. 505041; data from 1986 to 2013.		

Rainfall is episodic and widely variable; the annual recorded rainfall for the region ranges from 180 to 810 mm. This variability is predominantly due to the random nature of tropical cyclones and localised thunderstorms. The numbers of annual average rain days (BoM website) includes:

- About 30 days for events greater than or equal to 1 mm depth.
- 10 days for events greater than or equal to 10 mm depth.
- 3 to 5 days for events greater than or equal to 25 mm depth.

Larger than average annual rainfall was recorded in the Weeli Wolli Creek Catchment in 1973, 1975, 1994 to 2005, and in 2006. Numerous cyclones and tropical low rainfall systems have passed in vicinity of the catchment in the period 1970 to present, including:

- Kerry in January 1973; Wittenoom and Rhodes Ridge recorded 218 and 215 mm rainfall depth respectively.
- Joan in December 1975; approximately 200 mm rainfall at Weeli Wolli Creek.
- Bobby in February 1995;approximately 200 mm rainfall at Weeli Wolli Creek over four days, including 107 mm on 18 February; 1:20-year ARI.
- Rachael in January 1997; 319 mm over six days; 1:4-year ARI.
- Thelma in December 1998; 175 mm rainfall at Newman over two days.
- John in December 1999; 365 mm over several days including 267 mm on the 15th December; 1:20 to 1:50-year AR1.
- Norman in February 2000; 139 mm.
- Thunderstorms in December 2002.
- Un-named tropical low In January 2003: 321 mm over six days including 234 mm on 25th January; 1:20-year ARI.
- Clare in January 2006; 172 mm.
- Emma in February 2006; 164 mm
- Un-named tropical low in December 2007.
- Tropical Low 2, 23 February to 6 March 2009, with 146 mm rainfall recorded in 1 March.

The period 1985 to 1993 was drier than normal. Conversely, the period 1994 to 2005 was characterised by unusually high rainfall.

2.2 Evaporation Potentials

Evaporation potentials in the Pilbara range from 3,200 to 3,600 mm/annum (Van Vreeswyk, 2004).

2.3 Major Landforms

The major landform units are:

- Hamersley Plateau.
- Fortescue River Valley.

Both landform settings are discussed below and contexts to Weeli Wolli Creek are shown on Figure 1-4.

2.3.1 Hamersley Plateau

The Hamersley Plateau landscape is one of rounded hills and ranges, with escarpments that front onto the Fortescue River Valley. It is a fossil landscape that rises from 550 to 700 m AHD, with hills locally to 1,150 m AHD, and is predominantly stripped of soil cover and incised by major watercourses of the Weeli Wolli, Coondiner and Kalgan creeks.

The plateau landscape reflects differential erosion processes and complex drainage patterns. The dominant landscape features are ephemeral watercourses of the Marillana Creek Catchment that shed surface water east to the confluence with Weeli Wolli Creek, then northerly into the Fortescue Marsh. Erosion and fluvial processes have shaped the fossil landscape, with watercourses meandering between resistant low-lying mesas and rounded hills.

2.3.1.1 Weeli Wolli Creek

The catchment of Weeli Wolli Creek occurs within the Hamersley Plateau physiographic unit. The total Weeli Wolli Creek Catchment area upstream of the Fortescue Marsh is 4,717 km² and is characterised by northward flow on an approximate main stream length of 112 km. Upstream of the Weeli Wolli Spring the catchment area is 1,877 km^2. Weeli Wolli Creek has a linear alignment, possibly controlled by structural fabrics in the underlying bedrock.

Locally at Weeli Wolli Spring, perennial stream flow is enabled by baseflow. The perennial stream flow from Weeli Wolli Spring supports riparian habitats, wetlands, pools and shallow water table on the downstream reaches that under baseline conditions extended several kilometres downstream of Weeli Wolli Creek.

Weeli Wolli Creek drains into the southern Fortescue Marsh approximately 40 km north of the confluence of Weeli Wolli and Marillana creeks. Upon exiting the Hamersley Plateau, the Weeli Wolli Creek has formed an extensive delta that hosts bifurcate channels and ancestral palaeochannels. At present, the main watercourse has a north-westerly orientation across the upper slopes of the delta; the location of this channel would have changed over time. Flow on the deltaic landforms during episodic flood events will occur in numerous channels. From the delta, the Weeli Wolli Creek channels extend northwards into the Fortescue Marsh.

2.3.1.2 Marillana Creek

Marillana Creek, a major tributary of Weeli Wolli Creek, has a total catchment area of 2,230 km^2 and main stream length of 110 km that provides drainage from west to east. Marillana Creek is a wide, gravel-bed watercourse that generally flows only following significant rainfall events.

2.3.2 *Upper Fortescue River Valley*

The Upper Fortescue River Valley occupies a trough between the Hamersley and Chichester plateaus, extending westward to Goodiadarrie Hills. The Goodiadarrie Hills and associated geological characteristics isolate stream flow within the Upper Fortescue River Valley from that of the Lower Fortescue River, leading to the presence of Fortescue Marsh.

The surface water catchments of the Upper Fortescue River Valley are shown in Table 2-2. Groundwater contributions also support the water balance of the Fortescue Marsh.

Table 2-2 Surface Water Catchments of the Upper Fortescue River

Catchment	Sub-Catchment	Approximate Area (km^2)	Percent of Upper Fortescue River Catchment
Fortescue Marsh	-	5,588	19
Upper Reaches of Fortescue River	-	16,783	56
Mindy Mindy and Coondiner Creek	-	2,664	9
Weeli Wolli Creek Catchment	Marillana Creek	2,230	8
	Lower Reaches (below Weeli Wolli Spring and excluding Marillana Creek)	610	2
	Upper Reaches (upstream of Weeli Wolli Spring)	1,877	6
Total		**29,752**	**100**

Within the Upper Fortescue River Valley there are a number of subsidiary landform units that conform to management zones of the Fortescue Marsh. These include sand plains, outwash plains, valley plains and flood-out zones. Typically, the extensive valley plains and flats within the Fortescue River Valley are characterised by earthy clays, with subordinate cracking (gilgai) clays, shallow loams and hard red soils. These subsidiary landform units include:

- Poonda Plain.
- Marillana Plain.
- Calcrete Flats.
- Fortescue Marsh.

Each landform is briefly described below.

2.3.3 Poonda Plain

Poonda Plain hosts the upper slopes of outwash fans of the Weeli Wolli, Coondiner and Kalgan creeks on the perimeter of the Hamersley Plateau and is characterised by alluvial, stony and/or sandy plain intersected by numerous watercourses. The outwash fans provide recharge areas for stream flow and runoff from the Hamersley Plateau and, a hydrological buffer to Fortescue Marsh. Riparian and extensive mulga woodlands with mixed Acacia shrublands dominate the vegetation on heavy alluvial soils; Acacia shrublands and spinifex grasslands prevail on sandy plains. The riparian vegetation provides ecological connectivity to the Marsh from upstream ecosystems.

The shallow groundwater resources beneath upland areas of Poonda Plain tend to be fresh and brackish, but become increasingly saline and hypersaline further north and beneath Marillana Plain.

2.3.4 Marillana Plain

Marillana Plain includes gravelly, sandy and gilgai surfaces on the outwash fan mid-slopes and foot-slopes for the Weeli Wolli, Coondiner and Kalgan creeks. The outwash fans provide areas for rainfall and stream flow infiltration to the water table. Vegetation is dominated by mixed Acacia mulga woodlands and shrublands.

Beneath the plain, significant thicknesses of alluvial floodplain strata provide a large groundwater storage capacity and discharge pathways for the regional groundwater flow systems, including Weeli Wolli Creek.

2.3.5 Calcrete Flats

The calcrete flats predominantly comprise low calcrete platforms and alluvial floodplain/sandplain, with scattered clay pans.

The groundwater environment is characterised by shallow thin brackish lenses in calcrete overlying saline resources, with fresh recharge from episodic rainfall events.

2.3.6 Fortescue Marsh

Fortescue Marsh is an extensive, approximately 100 km long and 10 km wide, episodically inundated samphire marsh. Stream flow is typically ephemeral; surface water flows generated by runoff only occur after short lived episodic rainfall events. Stream flow accumulates in Fortescue Marsh where there is discharge by evaporation and consequent accumulation of salts. The episodic wetting and drying processes result in the cyclic transformation of the Fortescue Marsh from a fresh water lake ecosystem (when water levels are high) through to a saline lake and subsequent playa under influences from progressive drying (Skrzypek et al., 2013; Rouillard et al., 2015).

2.4 Stratigraphy and Lithology – PBS Setting

The Weeli Wolli creek overlies a basement formed of the Hamersley Group comprising a number of Archaean to Early Proterozoic geological formations. Locally, one of these formations known as the Weeli Wolli Formation, forms the majority of the basement and is characterised by Banded Iron Formation (BIF), chert, shale and jaspilite. Further to the north, beneath the Poonda Plain, the Brockman Iron Formation and Wittenoom Formation form the basement. The basement rocks have been folded into a broad syncline (termed the Yandicoogina Syncline) and traversed by faults and intrusive dolerite dykes.

Overlying the basement are Quaternary alluvial and Tertiary detrital sediments. The Tertiary detritals include CID, which is present in steeply incised erosional troughs beneath the present-day watercourses. The CID is reasonably continuous and consistent in thickness (about 50 m) and width; an exception occurs downstream of the Marillana Creek confluence where the depth to bedrock is locally comparatively shallow and the CID less developed. Overlying the CID beneath the floodplain of Weeli Wolli Creek, there are alluvial and colluvial deposits, which are predominantly gravelly clays, but also buried river channels. For example, beneath the present-day watercourses there are often unconsolidated beds of river gravels and conglomerates up to 5 m in thickness that are characterised by clasts of BIF, shale, siltstone and chert.

A 1:10,000 geology mapping investigation (Youngman, 1997) particularly associated with the CID settings on the lower reaches of Marillana Creek, including Yandicoogina Creek and extending beneath Weeli Wolli Creek, defined four predominant lithology and stratigraphic successions. These successions are described in Table 2-3 and typical distributions are illustrated in cross-section with context to Weeli Wolli Creek on Figure 2-2.

Table 2-3 Local Stratigraphy

Age	Group	Formation	Estimated Typical Thickness (m)	Description
Cainozoic	Overburden	Alluvium/Colluvium	5	Unconsolidated gravels in clay matrix
		Weathered CID		
	Tertiary CID	Goethite Vitreous Upper	20	Hydrated iron oxides, predominantly goethite and hematite
		Goethite Vitreous Lower	25	
		Clayey Basal Zone Limonite-Goethite Channel	16	Clay-rich and ochreous limonite
		Altered Basement Basal Clay Conglomerate	8	BIF, chert and shale with clay matrix where weathered
Archaean to Early-Proterozoic	Hamersley Group	Basement Weeli Wolli Formation	Indefinite	

Lithological descriptions include:

- Quaternary and Tertiary overburden: unconsolidated, very coarse, poorly-sorted angular to rounded BIF, chert, reworked CID and dolomite gravels in a sandy clay matrix. Overlying the CID is a weathered channel horizon characterised by low-iron-content pisolite with clayey matrices.
- Early-Tertiary CID: formed of detritals that have been altered by *in situ* chemical precipitation of hydrated iron oxides and variable matrices predominantly of goethite and limonite.
- Clayey basal zone – irregular limonite-goethite channel predominantly formed of clay-rich, yellow ochreous limonite with localised inclusions of vitreous.
- Proterozoic altered basement - basal clay conglomerate: lateritic profiles and weathered basement rocks typically including clasts of BIF, chert and shale in a clay matrix.
- Archaean and early-Proterozoic basement: consisting of BIF, shale, dolerite and dolomite of the Weeli Wolli Formation.

The palaeovalley beneath Weeli Wolli Creek that hosts the CID has a linear alignment and usually consistent channel form. Exceptions occur:

- Below the lower reaches of Weeli Wolli Creek at a distance about 4 km downstream of the Marillana Creek confluence. In this vicinity, the CID channel is substantially diminished on reaches that traverse a resistant bedrock shelf.
- In transition zones from the Hamersley Plateau to Poonda Plain landforms the palaeovalley bifurcates and deepens under the influence of structural fabrics within the bedrocks. The CID persists in the bifurcate channels and includes a basal peat lithology (Fowers et.al; 2013).

2.5 Stratigraphy and Lithology – Poonda Plain

For this study, the understanding of the stratigraphic and lithological profiles beneath Poonda Plain has been informed by:

- Comparatively wide-spaced mineral resource and groundwater exploration investigations by the proposed Marillana Project (Aquaterra, 2010).
- A regional groundwater exploration programme focussed on Fortescue Marsh and associated management zones (McLean and Sanderson, 2013 in draft).
- A transect within the proposed Nyidinghu Project, broadly where Weeli Wolli Creek enters Poonda Plain (Fowers et al.; 2013).

Data from these references have been collated and interpreted to define the broad-scale stratigraphic and lithological units, including:

- Quaternary and Tertiary detritals, alluvium and colluvium. This unit blankets the Poonda Plain, with thickness typically 10 to 20 m, but ranging up to about 45 m. Upper successions are predominantly alluvial and colluvial, associated with the outwash fan from Weeli Wolli Creek. Interspersed within and below these deposits are clay-rich alluvial beds and, hematite and pisolitic detritals.

- Calcrete and facies equivalent CID, pisolitic gravels and hematite detritals. The calcrete tends to be massive and crystalline in thicknesses of 10 to 15 m.
- Tertiary detritals, including palaeochannel successions and basal clay conglomerate that form interspersed beds of alluvium, colluvium, hematite, pisolitic detritals sands and peat. These successions rest on basement and reflect ancestral depositional environments in floodplain and incised palaeovalley settings, representing the downstream extensions of the CID beneath Weeli Wolli Creek. Bottom elevations of the ancestral floodplain settings typically occur in the range 340 to 390 m AHD. The palaeovalley features appear deeply incised; mapping at the Nyidinghu Project (Fowers et al.; 2013) shows bottom elevations of the palaeochannel in the range 270 to 305 m AHD. It is anticipated that the predominant palaeovalley feature is aligned with Weeli Wolli Creek and associated structural defects in the basement.
- Archaean to Early-Proterozoic Hamersley Group, with local predominance of the Wittenoom Formation.

The interpreted distributions of the stratigraphic and lithological profiles are shown in cross-section view on Figure 2-3. Plan views of the data distributions and interpreted elevations for selected basal contacts are shown on Figure 2-4 (a to c).

3 BASELINE SURFACE WATER RESOURCES ENVIRONMENTS

Weeli Wolli Creek is the focus of the baseline assessments of the surface water environment. It occurs in the watershed of Fortescue Marsh and this aspect is also considered.

3.1 Weeli Wolli Creek

3.1.1 Episodic Stream Flow

Long-term stream flow records (1985/1985 to present) at Tarina and Waterloo Bore provide baseline data of surface water flow on Weeli Wolli Creek. Natural perennial flows on the Weeli Wolli Creek occur at Weeli Wolli Spring, located approximately 4.5 km upstream from Tarina.

Historical observations indicate Weeli Wolli Creek was ephemeral, flowing only once or twice per year during episodic rainfall events. Baseline flow was widely variable with the initiation of runoff strongly dependent on antecedent conditions and the intensity and spatial distribution of rainfall. Baseline storm flows tended to be flashy at Tarina with runoff quickly removed or lost to the underlying aquifer. As a result, storm response was widely variable between Tarina and Waterloo Bore with Waterloo Bore, in general, requiring a higher magnitude rainfall event to initiate runoff. On average Tarina experienced 28 days of continuous flow during baseline conditions in comparison to 12 days of continuous flow at Waterloo Bore. Flow events could typically be characterised as 1- to 5-year ARI events. Numbers of days of flow at Tarina and Waterloo Bore, respectively, for selected events (RTIO, 2013) includes:

- February 1995: 1.7 and 4.2 days for 1:20-year ARI rainfall event.
- January 1997: 10 and 25 hours for 1:4-year ARI rainfall event.
- December 1999: 25 and 40 hours for 1:50-year ARI rainfall event.
- January 2003: 20 and 30 hours for 1:20-year ARI rainfall event.

There is historical evidence from pre-mining aerial photographs that Weeli Wolli Creek was characterised by wetlands, pools and a shallow water table on reaches extending several kilometres downstream from Weeli Wolli Spring. As flow is not perennial at Tarina this suggests a large proportion of the overflow from Weeli Wolli Spring is transmitted as through-flow in the groundwater environment.

During dry years, in which less than 300 mm of rainfall was experienced (1989 to 1991 and 1996), surface water runoff was generally not sufficient to generate flow at either Tarina or Waterloo Bore. Based on an analysis carried out by CSIRO (2013), the mean rainfall threshold for runoff commencement at Tarina is 36 mm during a single storm event. This was a mean derived value; the actual runoff threshold for each flow event would depend on the antecedent moisture conditions of the catchment. In the 25-year period from 1985 to 2010, 40 storm events of at least 36 mm depth were recorded, and therefore were likely to have generated stream flow in the catchment. Hence it was likely that at least one flow-generating rainfall event would occur every year. The remaining rainfall events were generally less than 10 mm, as illustrated on Figure 3-1, and therefore unlikely to trigger surface water flows in the system.

The predicted design flood peaks estimated for Weeli Wolli Creek at PBS and confluence of Marillana/Weeli Wolli Creek are outlined in Table 3-1.

Table 3-1 Design Flood Peaks for Weeli Wolli Creek

ARI (year)	Rainfall depth (mm)	Critical duration[1] (hour)	Design flood peaks (m^3/s)		Design flood peaks (GL/year)	
			PBS	Weeli Wolli and Marillana Confluence	PBS	Weeli Wolli and Marillana Confluence
1	42	12	5.2	9.9	164	312
2	54	9	76	110	2,397	3,469
5	90	12	240	440	7,569	13,876
10	112	12	490	1,160	15,453	36,582
20	175	24	950	2,660	29,959	83,886
50	227	24	2,200	6,600	69,379	208,138
100	270	24	4,070	9,810	128,352	309,368

Notes:

1. Critical duration is the duration of a particular storm event that generates the largest flood peak.

Under natural conditions, the rainfall and runoff data indicate that the duration of a stream flow and flood event would be approximately 10 to 14 days (1985 to 1997; Table 3-2), depending on the ARI.

Spot-height bottom elevations of the low-flow channel of the Weeli Wolli Creek are shown on Figure 3-2. A comparison of the flood extents for the 2-, 5- and 10-year ARI design events for Weeli Wolli Creek are shown on Figure 3-3, and a comparison of the respective stream depths at cross section A-A'; (marginally downstream of Marillana Creek confluence) is provided on Figure 3-4.

At cross-section A-A' (Figure 3-3), predicted (Cheng, 2013) water depths during 2-, 5- and 10-year ARI events flood events were 1.6 m, 2.7 m and 3.5 m, respectively. It was anticipated that water depth for the 1-year ARI flood would be about 1.0 m.

Table 3-2 Observed Tarina and Waterloo Bore Baseline Stream Flow Characteristics

Description	Year and Period													
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1985 to 1997 Average
Tarina Gauging														
Average Yearly Flow (m^3/s)	-	-	-	2	-	5	-	7	5	3	3	-	3.54	4
Maximum Flow (m^3/s)	-	-	-	140	-	118	-	76	76	12	484	-	189	156[1]
Number of Flow Days per year	-	0	0	58	0	9	0	4	8	4	143	0	112	28
Waterloo Bore Gauging														
Average Yearly Flow (m^3/s)	-	-	5	16	-	5	-	2	10	8	52	-	20	15
Maximum Flow (m^3/s)	-	-	62	269	-	118	-	11	11	28	2,127	-	445	384
Number of Flow Days per Year	-	0	6	34	0	-	0	6	7	1	29	0	54	13

Notes:

1 This is the mean of the non-zero flows rather than the mean annual maximum flow which should include the no-flow years; under these circumstances it would be 84. This attribute highlights the skew and natural variability in the flow record.

3.2 Surface Water to Groundwater Interactions

Observations of the local water table show a response (rise) after high rainfall and associated episodic flood events. The timing and amplitude of water table rises were synchronised with recharge from flood footprints on Weeli Wolli Creek. Evidently, the episodic flooding re-wet the unsaturated profile recharging the bank of pore water (soil water) beneath riparian zones on Weeli Wolli Creek.

Conceptual models for surface water to groundwater interaction (Winter et al.; 1998) provide three templates that characterise water exchange, infiltration or seepage mechanisms. A losing seepage flux indicates downward flow from surface water to the groundwater environment. The three seepage mechanism templates include:

- Disconnected losing stream, where the seepage flux is transmitted from the stream through an unsaturated profile to the underlying water table. The local and downstream reaches of Weeli Wolli Creek formed a disconnected losing system under baseline conditions. In the Pilbara, disconnected losing systems are typically characterised by episodic presence of surface water and comparatively poorly defined riparian zones. Under these circumstances, the seepage flux is controlled by infiltration and limited to areas wetted by stream flow.
- Connected losing stream, where stream flow is transmitted to a shallow water table that is mounded to provide direct interaction with the stream bed. On Weeli Wolli Creek, the reaches immediately downstream of Weeli Wolli Spring are characterised by permanent pools, dense riparian vegetation and shallow water table conform to a connected losing stream.
- Gaining stream, where the stream represents groundwater providing direct baseflow contributions to stream flow. On Weeli Wolli Creek the permanent water features associated with Weeli Wolli Spring provide circumstances compatible to a gaining stream.

The conceptual models are illustrated on Figure 3-5. The stream flow to groundwater seepage fluxes can vary along a watercourse and also over time in response to episodic flood and associated groundwater recharge events. Most variability commonly occurs in shallow water table settings associated with extended periods of drought or unusual frequency of flood events.

For the disconnected losing stream reaches of Weeli Wolli Creek, the seepage flux can be accessed by riparian vegetation within a limited footprint that has close proximity to the low-flow channel. Episodic events that inundate the floodplain would support the broader riparian zones.

3.3 Fortescue Marsh

Fortescue Marsh forms a large-scale wetland. The water balance reflects a terminal basin within which inflows are predominantly derived from large-volume episodic stream flow events (Skrzypek et.al, 2013). The wetlands are rapidly inundated by fresh water during these events; water may temporarily cover more than 1,000 km^2, with subsequent progressive drying as water loss occurs by infiltration and evaporation. Accompanying the drying is salt accumulation that reflects concentration by evaporation loss.

Weeli Wolli Creek forms about 16 per cent of the watershed of Fortescue Marsh. The gauged flows at Waterloo Bore (Table 3-2) provide indications of the annual stream flow contributions from Weeli Wolli Creek to Fortescue Marsh. There are orders of magnitude differences in the gauged average yearly flows, maximum flow rates and numbers of flow days each year during the period 1985 to 1997. These attributes likely reflect wide variations in contributions to Fortescue Marsh from Weeli Wolli Creek.

4 BASELINE GROUNDWATER ENVIRONMENT

The baseline groundwater environment was characterised in context to the Weeli Wolli Creek, Poonda Plain and Fortescue Marsh settings. Baseline characteristics of each setting are discussed below.

4.1 Weeli Wolli Creek

4.1.1 Aquifer System – Lower Weeli Wolli Creek

The local aquifer system is described in context with three settings:

- Floodplain aquifer.
- CID aquifer.
- Basement - Weeli Wolli Formation Aquifer.

These aquifer systems are schematically presented in a cross-section view of Weeli Wolli Creek on Figure 4-1.

The floodplain and CID aquifer system occurs beneath Weeli Wolli Creek downstream of Weeli Wolli Spring. Typically the aquifer system is developed across widths from 500 to 1,500 m. The floodplain and CID setting is interpreted to be predominantly bounded by low-transmissivity basement formed by the Weeli Wolli Formation, thus forming a channel aquifer system. There may be transmissive structures in the basement aligned beneath Weeli Wolli Creek (Fowers et.al; 2013).

The individual aquifer systems are discussed below.

4.1.1.1 Floodplain Aquifer

The floodplain aquifer is interpreted to form the primary zone for the transmission of rainfall and stream flow recharge to the CID aquifer. The floodplain aquifer system is interpreted to have two contributing successions, including:

- Creek-bed alluvium: coarse colluvium and alluvium, including river gravels, incised into the floodplain sediments and forming the bed of and immediately underlying the low-flow channel of Weeli Wolli Creek. Drill-hole geological sequences suggest alluvial depths of approximately 9 to 40 m beneath Weeli Wolli Creek.
- Floodplain sediments: poorly sorted conglomerates of gravels, sand, silt and clay that unconformably overlie the *in situ* weathered basement adjacent to the CID.

The coarse river gravels of the creek bed alluvium may be highly transmissive; groundwater flow is expected to occur on preferred flow paths within the river gravels and coarser successions within the floodplain aquifer. The floodplain aquifer is expected to be widely anisotropic, commensurate with wide variability in the lateral and vertical distributions of clay, sand and gravel beds.

Clay beds have been locally intersected in drill-holes within the alluvium beneath Weeli Wolli Creek. Lateral extents of the clay beds are unknown. Where present, the clay beds may locally impede vertical infiltration, with consequential potential occurrence of temporary or seasonal perched water tables (Rio Tinto, 2010).

4.1.1.2 CID Aquifer

The CID aquifer has a channel form incised into the Weeli Wolli Formation. Chemical alteration has formed iron ores and provided a typically porous and vuggy texture that has overprinted the original detrital succession's primary porosity and formed preferred groundwater flow paths.

The local CID stratigraphy includes aquifer zones formed by:

- Goethite-vitreous. These beds predominantly form the ore zones.
- Limonite-goethite channel; commonly developed as an undulating surface defining the base of iron ores. The limonite-goethite channel is of variable thickness from 2 to 30 m, average about 16 m.

The limonite-goethite channel typically has a clayey fabric, but may locally include vugs, cavities and transmissive vitreous pods.

Observations show several metre rises in water table elevations after significant episodic rainfall, stream flow and flood events. Discharge from the CID occurs by through-flow beneath Weeli Wolli Creek.

4.1.1.3 Weeli Wolli Formation Aquifer

The Weeli Wolli Formation includes basal clay conglomerate as a weathered and potentially reworked upper expression. The basal clay conglomerate typically has a clayey fabric, but may locally include isolated transmissive vitreous pods. The basement successions are expected to host a remnant structural fabric and locally form a fractured rock aquifer. Groundwater occurrence and flow would preferentially be aligned with zones of preferential weathering on fractures. Effective transmissivity is expected to widely vary, be dependent on remnant structural fabric and weathering characteristics, and show anisotropic attributes.

Massive zones within the weathered and fresh basement profile, where the structural fabric is weak, would tend to be characterised by limited groundwater occurrence and low-transmissivity.

4.1.2 Aquifer Hydraulics

4.1.2.1 Test Pits in Creek-Bed Alluvium

The hydraulic conductivity of alluvium beds of Marillana Creek was measured at three sites using tests pits excavated to 2 m depth (Peck and Associates, 1995). The excavated strata were very poorly sorted alluvial sediments with particle sizes ranging from fine sand or silt to very coarse gravels (rocks to about 100 mm with a few to 300 mm). There was evidence of vertical stratification, including macroscopic layering and flat-bedding of individual pieces of

shale. It was considered likely that the creek bed alluvium consisted of about 2 m of high-transmissivity strata overlying beds of silt and clay.

At each site, unconsolidated sediments collapsed below where the pits intercepted the water table.

Pumping from the individual test pits at rates in the range 320 to 480 kL/day and measurement of associated drawdown enabled estimates of hydraulic conductivity shown in Table 4-1.

Table 4-1 Hydraulic Conductivity of Creek Bed Alluvium

Location	Interpreted Hydraulic Conductivity (m/day)
Pit 1	2,700 to 4,000
Pit 2	18,000 to 24,000
Pit 3	1,800
Average	10,100
Median	4,000
Geometric Mean	6,100

These results show very high hydraulic conductivity of the creek-bed alluvium, consistent with the particle size of the sediments and the low fractions of silt and sand. Notably, the hydraulic conductivity of the creek-bed alluvium varies by up to an order of magnitude between the test pits.

4.1.2.2 Aquifer Tests in Floodplain and CID Strata

Hydraulics characteristics of the floodplain and CID aquifers have been interpreted by numerous projects at RTIO Yandicoogina (Peck, 1998; PPK, 1998; Liquid Earth, 2002 and 2005; and RTIO, 2009 and 2010) and for the proposed Marillana Project on the Poonda Plain (Aquaterra 2010). A summary of interpreted hydraulic conductivity is provided in Table 4-2.

The tabulated data indicate an aquifer system characterised by widely variable and anisotropic preferred groundwater flow paths, predominantly within the river-bed gravels and CID successions.

Table 4-2 Interpreted Aquifer Hydraulics beneath Weeli Wolli Creek

Stratigraphy	Thickness (m)	Hydraulic Conductivity (m/day)		
		Weeli Wolli Creek	Poonda Plain	Vertical
		Horizontal		
Floodplain alluvium	70 - 80	5 - 250	0.2	0.02 - 1.0
Tertiary hematite detritals		-	2 – 5	0.2 – 0.5
Calcrete		-	6	0.6
CID		5 – 60	3 - 25	0.1 – 2.0
Basal clay conglomerate	-	-	-	-
Alluvium and weathered bedrock	Up to 25	-	-	0.5 – 1.0
Fresh Weeli Wolli Formation	220	0.001 – 0.25	0.003	0.0003 – 0.01
Wittenoom Formation	-	-	0.1	0.091

A brief review of recent hydrogeological work (Rio Tinto, 2010) provides supporting data, interpreted to show:

- The CID succession forms the predominant aquifer zone, with comparatively high transmissivity.
- Transmissive successions of the floodplain aquifer provide lateral extensions to the CID aquifer.
- High vertical hydraulic conductivity through the floodplain and CID aquifers. The hydraulic connection between the floodplain aquifer and the CID is consistent throughout the floodplain area.
- Occurrence of a vertically integrated surface water and groundwater environment and potentials for vertical/sub-vertical preferred infiltration and groundwater flow paths.

4.1.3 Recharge

Recharge to the floodplain aquifer predominantly occurs by infiltration of stream flow and flood waters from Weeli Wolli Creek that propagate across the riparian zones. The recharge is predominantly event-based and episodic (Johnson and Wright, 2001; Aquaterra, 2007); recharge from infiltration of rainfall was interpreted to be subordinate.

The estimates of annual recharge in the catchments of the Pilbara typically range from 0.5 to 3 percent of annual average rainfall. Recharge beneath watercourses, riparian zones and shallow water table settings may range up to 5 to 6 percent of annual average rainfall.

A number of specific references regarding recharge rates include:

- 1.2 to 4.8 GL/annum; equivalent to about 0.2 to 0.8 per cent of annual average rainfall (Hedley, et al., 2009).
- 4.8 to 9.0 GL/annum; equivalent to about 0.8 to 1.5 per cent of annual average rainfall based on chloride ion analyses (URS-Parsons Brinckerhoff, 2011).
- 3.85 GL/annum; equivalent to about 0.6 per cent of annual average rainfall (Aquaterra, 2007).

Based on these estimates, a net recharge rate in the range 0.5 to 1.5 per cent of annual average rainfall (377 mm/annum) appears to be reasonable.

The range of interpreted recharge from 0.5 to 1.5 percent of annual average rainfall is analogous to recharge to the water table beneath the lower reaches of Weeli Wolli Creek in the range 1.1 to 2.3 GL/annum.

4.1.4 Water Table Settings beneath Weeli Wolli Creek

A number of studies have used groundwater level data from 1974 and 1999 to interpret the baseline water table elevations beneath the lower reaches of Weeli Wolli Creek. A snapshot (early-1995) interpretation of baseline water table elevations (Rio Tinto, 2010) is shown on Figure 4-1 (cross-section) and Figure 4-2 (plan view) and indicates:

- Interpreted water table elevations of 480 to 485 m AHD beneath the lower reaches of Marillana Creek.
- Typically the water table was hosted by the floodplain aquifer.
- Within RTIO Yandicoogina Junction South East, water table elevations were measured in YM117 and YM118 from March 1991 to November 1997. The observed water table elevations were comparatively steady in the range from about 487 to 495 m AHD prior to 1995, with flow east to southeast toward Weeli Wolli Creek. Subsequently during 1995 to 1997, the water table elevations increased by about 10 m. This increase was predominantly attributed to higher rainfall occurrence with commensurate increases in stream flow and associated recharge to the CID aquifer.
- At the confluence of the Marillana Creek CID and the Weeli Wolli Creek CID, the interpreted early-1995 water table elevation was about 478 m AHD.
- Interpreted water table elevations of 418 to 478 m AHD beneath Weeli Wolli Creek. These interpreted water table elevations were sourced from monitoring bores including 99YYJWB02, 99YYJWB04, YM119 and 99YYJWB01.
- Interpreted water table elevations of 418 m AHD in the vicinity of 99YJWB01. The water table at this comparatively low elevation reflects changes in conditions and hydraulics beneath the northern reaches of Weeli Wolli Creek.
- A typical lateral hydraulic gradient of 0.002 (dimensionless) in the PBS setting.
- Interpreted depths to the water table commonly exceeded 15 m to 20 m, though increase significantly to the north, to about 45 m in the vicinity of 99YJWB01. Figure 4-3 shows the interpreted baseline depths to the water table beneath local reaches of Weeli Wolli Creek.

- The CID aquifer is recharged by vertical downward seepage from the floodplain aquifer.
- It is recognised that the water table elevations show spatial and temporal variations in response to rainfall, stream flow and evapotranspiration.

Across the Pilbara there is evidence of water table responses to episodic recharge events and intervening dry periods that span numerous years. During extended periods of above-average rainfall and/or repetitive occurrence of high rainfall events (with associated occurrence of stream flow), the water balance changes to reflect increased recharge compared to discharge, with outcomes reflected in elevated water table settings. Conversely, if the rainfall and stream flow is comparatively low, then the water table elevations progressively decay in response to reduced recharge. The hydrographs for local monitoring bores indicate water table elevations can rise by up to 8 m, predominantly through the infiltration of stream flow and flood waters associated with episodic high rainfall events. The observed natural rates of water table elevation decline after episodic recharge events include:

- 99YYJWB04, located on Weeli Wolli Creek near the Marillana Creek confluence, with estimated decline of 1.4 to 2.2 m/year.
- YM119, located on the downstream Weeli Wolli Creek, with estimated decline of 2.9 m/year.

4.1.5 Groundwater Quality - Weeli Wolli Creek

Baseline groundwater quality is typically characterised by TDS concentrations of about 500 mg/L.

Groundwater hosted by the floodplain aquifer tends to be comparatively high in salinity, with measured TDS concentrations up to 1,290 mg/L. At greater depth, within the CID aquifer, known groundwater qualities (Kirkpatrick and Dogramaci, 2010) occur in the range 370 to 780 mg/L TDS and pH from 7.2 to 8.5.

Typically, the chloride concentration in the CID aquifer is recognised (Kirkpatrick and Dogramaci, 2010) to be about 30 percent lower than in the floodplain aquifer. This difference is attributed to the processes of direct evaporation and evapotranspiration by riparian vegetation along Marillana Creek, which acts to concentrate salts, over time, in the stream flow, any perched water table setting, and shallow soil water. Residence times of incident waters within zones subject to potential evaporation losses would be needed to enable a 30 percent increase in chloride concentrations. Reasonable residence times may be provided by lateral flow in the floodplain aquifer towards preferred infiltration zones, temporary storage in perched aquifer settings and typical infiltration rates that increase the water availability in the unsaturated profile.

4.2 Poonda Plain and Fortescue Marsh

4.2.1 Aquifer Systems – Poonda Plain

The aquifer systems of the Poonda Plain can be considered as lateral extensions of the floodplain, CID and basement aquifers that prevail beneath Weeli Wolli Creek. For example:

- Floodplain aquifer – hosted by the Tertiary detritals, in palaeochannels and beneath the broader expanses of the deltaic outwash fan in ancestral floodplain settings. The aquifer is widely inhomogeneous, but predominantly characterised by sediments with clay, silt and sand matrices. Ancestral creek-bed deposits form laterally semi-continuous and vertically stacked zones of preferred groundwater flow.
- CID aquifer – hosted within incised palaeochannels that propagate northward from Weeli Wolli Creek. It is anticipated the main palaeochannel propagates north-northeast beneath the plain on a structural alignment compatible to and parallel to Weeli Wolli Creek. There may be bifurcation of and tributaries to the main palaeochannel, including CID mapped by the Marillana Project (Aquaterra, 2010) beneath the foot slopes of the Hamersley Plateau.
- The CID aquifer is poorly defined. It is expected, however, that the major flow paths are aligned with the incised palaeochannels and of high transmissivity.
- Basement aquifer – transitions from Weeli Wolli Formation to Brockman Iron Formation (at the Nyidinghu Project) and Wittenoom Formation beneath the wider Poonda Plain and Fortescue Marsh. The transmissivity of the basement aquifer may be significantly enhanced by structural defects. At the Nyidinghu Project (Fowers et al.; 2013) numerous interpreted faults transverse the basement strata, with the Weeli Wolli Fault system aligned with Weeli Wolli Creek and the Poonda Fault demarking the escarpment to the Hamersley Plateau. The interpreted faults influence the positions of the incised palaeovalley and iron mineralisation.

4.2.2 Aquifer Systems – Fortescue Marsh

Groundwater flows to, and terminates beneath or in, the Fortescue Marsh. The groundwater environment of Fortescue Marsh is a lateral extension of that beneath the Poonda Plain. The groundwater environment beneath the Fortescue Marsh is hosted by:

- Quaternary unconsolidated colluvial and alluvial silt, sand and gravel sediments that form alluvial deltas where the major watercourses, including the Weeli Wolli and Coondiner creeks, traverse the escarpments and enter the Fortescue River Valley. In structural settings, such as beneath Weeli Wolli Creek, palaeovalley features (Fowers et al., 2013) that host thick successions of colluvial, alluvial and lacustrine sediments propagate beneath the Fortescue River Valley from the Hamersley Range escarpment.
- Tertiary lacustrine carbonate (including calcrete), silcrete and mudstone successions of the Oakover Formation (Clout, 2011) deposited in the palaeovalley associated with the Fortescue River.
- The underlying Wittenoom Formation, with associated karstic dolomite successions.

4.2.3 Hydraulics from Falling Head Tests

Falling head tests were conducted in a number of monitoring bores installed by the Marillana Project (Aquaterra, 2008 and 2010). The interpreted results based on analyses by the Hvorslev (1951) method are shown in Table 4-3.

Table 4-3 Interpreted Hydraulics - Falling Head Tests

Monitoring Bore	Strata	Test Interval (m)	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)
Obs 1	Alluvium and Tertiary hematite detritals		0.13	
MRC029		48	0.09	4
MRC066		36	0.006	0.2
MRC004		55	0.1	6
MRC001		33	0.5	18
MRC050		37	0.6	21
MRC050 (#2)		37	0.1	4
MRC057		33	0.3	10
MRC061		46	0.1	6
MRC061 (#2)		46	0.05	2
Obs 5	CID	-	0.1 - 0.4	-
Pz1 deep	Basal clay conglomerate	-	0.2 to 0.3	-
Obs 7	Basement	-	0.007 – 0.1	-

4.2.4 Water Table Elevations beneath Poonda Plain and Fortescue Marsh

Information on the water table beneath the Poonda Plain was predominantly derived from groundwater exploration snapshots associated with the Marillana Project (Aquaterra, 2010) and the Fortescue Marsh groundwater investigation (McLean and Sanderson, 2014 in draft). These data points are wide-spaced. A collage of data from these sources was used to interpret the water table elevations for an early-2010 snapshot (Figure 4-4). The interpreted water table shows a subdued reflection of the topography, with flow to the northeast, sub-parallel to the escarpment of the Hamersley Plateau and towards Fortescue Marsh.

On a local scale, the interpreted water table elevations:

- Show a groundwater discharge configuration within the interpreted incised palaeovalley beneath the lower reaches of Weeli Wolli Creek. This configuration would reflect comparatively high transmissivity within the floodplain and CID channel aquifer system.
- Indicate preferential flow towards the northeast, intuitively aligned with extensions of the incised palaeovalley beneath the Poonda Plain.
- Suggest there is a smaller scale discharge configuration associated with the mapped CID (Aquaterra, 2010) beneath the foot slopes of the Hamersley Plateau.

- Show an interpreted mounded configuration within the alluvial outwash fan of Weeli Wolli Creek in areas adjacent to the incised palaeovalley. The interpreted mounding may indicate:
  - Lower transmissivity on the palaeovalley perimeters crests.
  - A domain of enhanced recharge on the outwash fan, linked to sheet wash during episodic rainfall and flood events.
  - Propagation of the groundwater wetting front, through mounding of the water table and filling storage, from surplus water discharge.

The water table attributes and comparative elevations may change in response to episodic flood events.

Depths to the water table were observed to commonly occur up to 45 m beneath the escarpments to the adjoining ranges and progressively becoming shallower towards Fortescue Marsh. In the middle of the marsh, the water table occurs at the ground surface (Skrzypek et.al, 2013), though this may vary seasonally and/or episodically. These attributes provide indications of surface water and groundwater interaction and connection directly beneath wetland areas of the marsh.

4.2.4.1 Groundwater Quality - Poonda Plain and Fortescue Marsh

Quality data for the water table and Hamersley Group groundwater environments beneath the Poonda Plain and Fortescue Marsh were sourced from the Marillana Project (Aquaterra, 2010), groundwater investigations of Fortescue Marsh (McLean and Sanderson, RTIO; 2014 in draft) and, Skrzypek et.al (2013) based on sampling at 48 locations within the upper Fortescue River Valley during May 2010, October 2010, May 2011 and December 2011. Isohalines interpreted from the water table and Hamersley Group data (McLean and Sanderson, 2014 in draft) are shown on Figure 4-5 and Figure 4-6, respectively. These interpretations show.

- Measured shallow groundwater salinities range from less than 500 to 17,400 mg/L TDS, increasing towards Fortescue Marsh under northeast gradients sub-parallel to the escarpment of Hamersley Plateau.
- Measured Hamersley Group salinities in the range 2,100 to 89,300 mg/L TDS, also increasing towards Fortescue Marsh.
- In both shallow and deep groundwater environments, the lowest salinity profile is aligned to interpreted incised palaeovalley flow paths.
- Lateral and vertical salinity stratification, with wide variations in the stratification gradients. This aspect may reflect different recharge, through-flow and mixing mechanisms together with variations in the vertical integration of aquifer systems and salt source terms.

The 48 locations (Figure 4-7) sampled by Skrzypek et.al (2013) produced 206 samples which were analysed to determine $\delta^{18}O$ and $\delta^{2}H$ concentrations together with TDS, EC and major ion (including chloride, bromide and strontium) concentrations. Results from the sampling showed there is a wide range of groundwater TDS beneath the Fortescue Marsh (Skrzypek et.al, 2013). Typically, the groundwater is fresh directly beneath the escarpments and with trends of increasing TDS on flow paths towards the wetlands in lower elevation settings of the

Fortescue River Valley. There is also vertical TDS stratification, with the water table zone commonly of lower TDS than groundwater in the Wittenoom Formation. At times of episodic inundation, the surface water environment would potentially provide recharge to the water table. Beneath the lower elevation settings, the shallow groundwater was lower in salinity than groundwater in the Wittenoom Formation; which was hypersaline, with TDS concentrations commonly exceeding 100,000 mg/L (ranging up to 190,000 mg/L TDS; Skrzypek et.al, 2013; Dogramaci et al., 2015a). These attributes reflect a salt-sink environment, with salt accumulation over time due to groundwater discharge. A comparative overview of the sampling data is provided in Table 4-4.

Table 4-4 Fortescue Marsh Groundwater Chloride, $\delta^{18}O$ and $\delta^{2}H$ Concentrations

Source	Chloride Concentration (mg/L)	$\delta^{18}O$ Concentration (‰)	$\delta^{2}H$ Concentration (‰)
High Rainfall Events	1.4	-12 to -11	-76.9
Hamersley Basin Groundwater	-	-8.2 ∓ 0.83 -6.46 ∓ 1.28	6.13 ∓ 0.16
Groundwater Beneath Outwash Fans	250	-9.5 to -7.5	-64 to -52
Fresh to Brackish Groundwater	40 to 5,000	-8.0∓ 0.90	-56.2∓ 5.3
Brackish to Saline Groundwater	5,000 to 96,000	-7.2 to +2.5	-10.3 to -51.6
Shallow Groundwater under the Marsh	4,000 to 56,000	-1.6 to +2.5	-33 to -11
Deep Groundwater under the Marsh	Up to 96,000	-1.6 to +2.5	-33 to -11
14-Mile Pool (Wet Season)	40	-2.3	-28.8
14-Mile Pool (Dry Season)	2,920	16.3	72.7

The groundwater sampling also indicated (Skrzypek et.al, 2013):

- Groundwater beneath the outwash fans of the Weeli Wolli and Coondiner creeks was fresh, with $\delta^{18}O$ concentrations of about -9.5‰; characteristic of infiltration from high rainfall events.
- The major ion, $\delta^{18}O$ and $\delta^{2}H$ compositions of the sampled groundwater indicate rainfall-derived origins, with recharge by rapid infiltration after limited volume loss by evaporation. Rates of water loss determined by increasing concentrations of chloride and $\delta^{18}O$ are however different, indicating that other processes combine with evaporation to provide the measured TDS concentrations.
- Fresh to brackish groundwater (TDS less than 10,000 mg/L) is of the magnesium-calcium-bicarbonate type, and chloride/bromide ratios occur in the range 200 to 2,000, commonly higher than those (288) for seawater.
- Brackish to saline groundwater (TDS greater than 10,000 mg/L) is of the sodium-chloride type, and chloride/bromide ratios occur in the range 800 to 12,000.
- The increases in chloride concentrations with depth in the brackish to saline groundwater corresponds to a gradual enrichment in $\delta^{18}O$ and $\delta^{2}H$

- The concentration ratio for chloride/bromide would be similar to seawater if evaporation was the predominant ion enrichment process. That chloride enrichment occurs reflects bromide removal through cyclic drying and precipitation in halite salts. The chloride/bromide ratio subsequently increases in dissolution processes because of the comparatively high chloride/bromide ratio in halite (Dogramaci et al., 2015b).
- Concentration ratios for strontium/calcium, sulphate/calcium and magnesium/calcium increase associated with increasing chloride concentrations (Figure 4-8). The increased ratios may indicate calcite mineral precipitation (thus removal of calcium and bicarbonate from solution) as the TDS concentration increases. A repetitious calcite and gypsum mineral precipitation and dissolution process, due to cyclic wetting, drying and surface water infiltration episodes, is the likely process for the increasing strontium/calcium, magnesium/calcium ratios in the brackish to saline groundwater (Skrzypek et.al, 2013). The progressive precipitation of calcite and gypsum allows the concentrations of sulphate to increase whilst bicarbonate in solution decreases.
- δ^{18}O concentrations for the fresh to brackish groundwater were -8.0 ∓ 0.9 ‰ . The consistency and limited range of these concentrations indicated low evaporation potentials from the shallow groundwater.
- δ^{18}O concentrations in the brackish to saline groundwater from alluvium and Wittenoom Formation beneath the Fortescue Marsh were -1.6 to +2.5 ‰.
- δ^{2}H concentrations for the fresh to brackish groundwater were -56.2 ∓ 5.3 ‰ .
- δ^{2}H concentrations for the brackish to saline groundwater were -10.3 to -51.6 ‰.
- **T**he measured δ^{18}O and δ^{2}H concentrations for the fresh to brackish groundwater fall slightly below the Local Meteoric Water Line and indicate partial evaporation prior to recharge.
- The mixing between relatively fresh surface water recharge with deeper saline groundwater was the only explanation of the observed salinity stratification coupled with a broad range of δ^{18}O enrichment in the brackish to saline groundwater. An isotope and chloride lumped-parameter mixing model was used to replicate measured groundwater compositions. The consolidated results from the mixing model using median input parameters, indicated:
  - Evaporation of about 17 per cent of the rainfall and stream flow volumes prior to recharge, providing δ^{18}O concentration enrichment from -11.6‰ (rainfall) to -7.4‰**.**
  - Mixing of the recharge with saline groundwater (chloride 96,000 mg/L and δ^{18}O concentration enrichment up to +2.5‰ as observed in deep saline groundwater)**.** The mixing would occur in varying ratios and proportions, ranging up to 59 per cent of fresh water to replicate the measured compositions.
  - Mixing would tend to predominantly occur where enabled by lateral and vertical transmissivity. Comparatively high transmissivity zones would promote rapid infiltration of recharge in settings where the vertical groundwater flow is predominant compared to lateral flow.

– Precipitation of calcite and gypsum enables enrichment of sulphate and concurrent diminishment of bicarbonate. For example, the stoichiometry of calcite precipitation indicates the removal of two moles of bicarbonate for each mole of calcium. As such, there would be a comparative enrichment of calcium in solution. The precipitation of calcite alone, however, does not explain the observed increases in strontium/calcium and magnesium/calcium ratios. Continuous precipitation and re-dissolution of carbonate minerals and gypsum, due to cyclic wetting and drying, is required under these circumstances.

A consolidation of the chloride, $\delta^{18}O$ and $\delta^{2}H$ data indicates that Fortescue Marsh temporarily forms a connected surface water and groundwater environment at times after episodic stream flow events. Connection is enabled by vertical infiltration of fresh stream flow that temporarily mounds the water table. Over time, under the influence of evaporation and infiltration, the water table becomes disconnected from the surface water environment.

The marsh forms a salt sink. Evaporation processes, episodic flooding and re-wetting provide flow dynamics driven by hydraulic and density gradients that promote fluxes from the marsh to the groundwater environment and also vertical mixing within the groundwater environment. Vertical mixing within the groundwater environment has manifest as both lateral and vertical salinity stratification beneath the marsh and its surrounds.

5 ALTERED WATER RESOURCES ENVIRONMENTS

5.1 Overview

The mines at RTIO Yandicoogina, BHPBIO Yandi, and Hope Downs 1, extend below the water table. Groundwater abstraction is required to lower the water table and enable mining. Surplus water has historically been discharged to Marillana Creek since 1991, and directly to Weeli Wolli Creek since 2007.

Both the groundwater abstraction and subsequent discharge alter the water resources available to riparian environments on the Weeli Wolli Creek. The groundwater abstraction lowers the water table and removes groundwater from storage. Conversely, the surplus water forms wetting fronts in the surface water and groundwater environments. The wetting fronts represent perennial stream flow in the low-flow channels of Weeli Wolli Creek and recharge to and consequent mounding of the water table.

Drawdown of the water table due to groundwater abstraction potentially limits water availability in the riparian zones. The wetting fronts in the surface water and groundwater environments potentially increase water availability to the riparian zone, including the presence of perennial stream flow. These aspects are discussed below and supporting this discussion is Figure 5-1 that shows relevant transient water balance information since 1991, including:

- A summary of the episodic stream flow events on Weeli Wolli Creek (at Waterloo Bore).
- Dates that indicate commencement of surplus water discharge from the BHPBIO Yandi, RTIO Yandicoogina and Hope Downs 1 mines together with local dewatering and reinjection activities in proximity to or on Weeli Wolli Creek.
- Discretised annual surplus water discharge volumes from the BHPBIO Yandi, RTIO Yandicoogina, and Hope Downs 1 mines.

5.2 Groundwater Abstraction and Drawdown of the Water Table

Groundwater abstraction to enable mining has been focussed on the CID aquifer associated with Marillana Creek. The abstraction has lowered the local water table and removed groundwater from storage. A conceptualised cross-section view of the drawdown linked to groundwater abstraction by the RTIO Yandicoogina Mine is shown on Figure 5-2. At present, the drawdown of the water table is predominantly associated with the CID aquifer in proximity to Marillana Creek.

The drawdown evident in proximity to Marillana Creek has not propagated beneath Weeli Wolli Creek. For example, drawdown from Junction South East operations of the RTIO Yandicoogina Mine has not created a noticeable deficit in perennial stream flow in the low-flow channel on Weeli Wolli Creek derived from the Hope Downs 1 Mine. In essence, the perennial stream flow forms a significant recharge front and the drawdown footprint is sufficient only to intercept a small portion of this front. Therefore, locally on Weeli Wolli Creek within the PBS area, potentials for drawdown of the water table have been off-set by:

- Recharge linked to surplus water discharge at DO6 (Figure 1-3) and from the Hope Downs 1 Mine.
- Injection activities (RTIO Yandicoogina Billiard Reinjection), Figure 1-3.

These factors have contributed to the aquifer system beneath local reaches of Weeli Wolli Creek currently being perennially recharged and full to a natural capacity. When compared to baseline, the water table beneath these reaches is typically mounded by 10 to 15 m (as schematically shown on Figure 5-3).

5.3 Historical Groundwater Discharge

The historical annual abstraction volumes for mines BHPBIO Yandi, RTIO Yandicoogina, and Hope Downs 1 are summarised in Table 5-1 and shown on Figure 5-1. A RTIO comparison of the range of annual water surpluses and design flood volumes for 1-, 2-, 5- and 10-year ARI events (Cheng, 2013) is shown in Table 5-2.

Table 5-1 Annual Volumes of Surplus Water Discharge

Year	Surplus Water Source (GL)				Totals (GL)	
	BHPBIO Yandi Mine	RTIO Yandicoogina Mine		Hope Downs 1 Mine	Annual	Cumulative
		Watercourse	Reinjection			
1991	0.1	-	-	-	0.1	0.1
1992	0.1	-	-	-	0.1	0.2
1993	0.1	-	-	-	0.1	0.3
1994	0.1	-	-	-	0.1	0.4
1995	0.3	-	-	-	0.3	0.7
1996	0.8	-	-	-	0.8	1.5
1997	6.6	-	-	-	6.6	8.1
1998	6.1	5.8	-	-	11.9	20.0
1999	8.1	4.8	-	-	12.9	32.9
2000	13.4	6.0	-	-	19.4	52.3
2001	8.3	4.3	-	-	12.6	64.9
2002	5.9	4.4	-	-	10.3	75.2
2003	5.4	5.9	-	-	11.3	86.5
2004	4.7	4.9	-	-	9.6	96.1
2005	2.5	4.3	-	-	6.8	102.9
2006	7.0	7.0	2.1	0.1	16.2	119.1
2007	7.9	11.9	4.4	17.6	41.8	160.9
2008	5.2	16.3	3.5	20.8	45.8	206.7
2009	4.7	16.1	2.7	24.7	48.2	254.9
2010	2.5	16.6	2.6	32.2	53.9	308.8
2011	5.4	20.2	4.5	31.1	61.2	370.0
2012	10.4	20.2	6.0	35.5	72.1	442.1
2013	8.8	24.9	1.6	36.4	71.7	513.8

Table 5-2 Comparison of Design Flood and Surplus Water Volumes

ARI (year)	Weeli Wolli Creek Design Flood Volumes (GL)	Maximum Annual Surplus Water Volumes (GL)		
	At Confluence with Marillana Creek	1991 to 1997 BHPBIO Yandi Mine	1998 to 2006 BHPBIO Yandi and RTIO Yandicoogina Mines	2007 to 2013
1	312	6.6	19.4	70.1
2	3,469			
5	13,876			
10	36,582			

From the information presented in Table 5-2 it can be seen that the water discharged into the local watercourses represents comparatively small volumes. For example, the discharged groundwater is equivalent to:

- About 2 to 22 per cent of 1-year ARI stream flow volumes on Weeli Wolli Creek at the confluence with Marillana Creek.
- Typically less than 2 per cent of the 2- and 5- year ARI stream flow volumes.
- Typically less than 0.2 per cent of the 10-year ARI stream flow volumes.

The surplus water is transmitted only within the low-flow channel of Weeli Wolli Creek, with resultant stream flow depths typically less than 0.2 m. On a cross-section view (Figure 3-4), the stream flow depth for a 103 GL/annum discharge rate (Cheng, 2013) was approximately 0.12 m and is shown to be significantly lower than simulated stream flow depths of 1.0, 1.6, 2.7 and 3.5 m for 1-, 2-, 5- and 10-year ARI events, respectively. These data show the perennial surface water footprint is comparatively minor in context to the flow depths and volumes (Table 5-2) derived from episodic events.

5.4 Wetting Fronts

Since 2007, the surface water and groundwater environments on Weeli Wolli Creek have changed as a cumulative response to discharge of surplus water. The discharged water forms wetting fronts that represent the processes of assimilation which represent transport and fates within the local receiving environments. Wetting fronts occur in the surface water, surface water to groundwater interaction and groundwater environments. The wetting fronts are linked to:

- Perennial stream flow and or presence of surface water in low-flow channels of Weeli Wolli Creek. The perennial presence of water represents the surface water wetting front.
- Interception and loss of water in the low-flow channels by infiltration, evaporation and transpiration. These aspects represent surface water to groundwater interaction within the unsaturated profile above the water table.

- Infiltration to the water table, with associated saturation of available storage and mounding of the water table beneath Weeli Wolli Creek. The mounding of the water table represents the groundwater wetting front.

The wetting front characteristics are predominantly a function of low-flow channel surface area, infiltration rates, aquifer system hydraulics and aquifer storage.

The wetting front characteristics are discretely discussed below.

5.4.1 Surface Water Wetting Fronts

The cumulative effects of surplus water discharge have included stream flow and saturated creek-bed conditions on local watercourses downstream of the discharge points (RTIO, 2011). The stream flow resultant from the surplus water discharge is perennial and persists only in the low-flow channel of Weeli Wolli Creek, with depths typically less than 0.2 m (Figure 3-4).

The presence of sustained stream flow on Weeli Wolli Creek compares to:

- Average baseline stream flow occurrences at the Tarina and Waterloo Bore gauges of 28 and 12 days/annum, respectively.
- Predicted 10 to 14-day periods of stream flow and flood presence (Cheng, 2013) during episodic events, with variation depending on ARI.
- Up to about 22 per cent of 1-year ARI stream flow volumes on Weeli Wolli Creek.
- Typically less than 2 per cent of the 2-, 5-, and 10- year ARI stream flow volumes.

Since late-2007 and early-2008 (linked to commencement of discharge from the Hope Downs 1 Mine) the surface water wetting front on Weeli Wolli Creek propagated 5 to 7 km downstream of the Marillana Creek confluence. Since 2009 the surface water wetting fronts have varied from confluence to about 6 km beyond the confluence (Figure 5-4).

The waxing and waning of the wetting front over distances of 4 km (as shown on Figure 5-4 for the period 2007 to 2011) depends on climatic conditions and rates of surplus water discharge, but have not steadily propagated to the north since 2007. These attributes tend to reflect steady-state conditions. Under steady-state conditions, there is no change in storage. Therefore the fact that the stream flow is fully dissipated reflects interception by evaporation and transpiration and transmission within the underlying groundwater environment.

It was interpreted (Cheng; 2013) that the discharged surplus water would have minimal influence on the natural hydrological functions in terms of flood peaks, flow volume and flood footprints on the local reaches of Weeli Wolli Creek.

5.4.2 Surface Water to Groundwater Interaction

The surface water to groundwater interaction involves processes of infiltration (recharge) to the water table and interception of water by evaporation and transpiration. Infiltrates progressively wet and saturate the residual storage above the water table and replace volumes lost by evaporation, transpiration and through-flow. The fates of surface water from Weeli Wolli Creek were assessed based on:

- Chloride concentrations and stable isotopes of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) compositions on reaches downstream of Weeli Wolli Spring (Dogramaci, et al., 2015b). This assessment was based on the understanding that all three analytes would become progressively enriched on downstream flow paths as portions of the water resources are intercepted by evaporation and transpiration. Sampling occurred in June and December 2010 and July 2011. Sampling was from 12 surface water points (WW1 to WW20) at 1.0 to 2.5 km intervals extending about 27 km downstream of Weeli Wolli Spring and groundwater monitoring bores 99YJWB04, WWA, YM119, D08YJ188 and 99YJWBO1. The surface water sampling sites included:
  - Sites WW12, WW14, WW16, WW18 and WW20 upstream of PBS, with WW20 closest to Weeli Wolli Spring.
  - Site WW10 upstream of DP2, within the southern limits of PBS.
  - Sites WW1, WW4, WW6, WW8 and WW10 on reaches upstream of the confluence with Marillana Creek, thus adjacent to PBS.
  - Sites WWE, WW3 and WW2 on northern reaches, with WWE northernmost and situated nearby to monitoring bore D08YJ188.

  At the times of sampling, Weeli Wolli Creek was supplemented by 95 and 25 ML/day surplus water discharged from the Hope Downs 1 Mine (referred to as DP1) and the RTIO Yandicoogina Mine (DO6; referred to as DP2), respectively. Perennial stream flow was evident. Given the two different supplementation sources, the sample sites were designated into reaches upstream (Section A) and downstream (Section B) of DP2, respectively.

  The sampling sites are shown on Figure 5-5. Measured chloride, $\delta^{18}O$ and $\delta^{2}H$ concentrations for the surface water samples are shown in Table 5-3 and for the surface water samples on Figure 5-6, with context to distance from DP1. Transient groundwater chloride concentrations in monitoring bores 99YJWB01 and 99YJWB04 are shown on Figure 5-7.

  Loss rates calculated from the chloride and isotope mass balance have been also used to interpret the transpiration, evaporation and recharge components of the local water balance (Bourke el. al., 2014; Dogramaci, et al., 2015b; Bourke el. al., 2014).

- Stream flow measurements on discrete reaches of Weeli Wolli Creek (Pettett and Pearcey, 2014) to enable interpretation of loss rates by infiltration.

  The findings of the interpreted fates of the surplus water are summarised in Table 5-4. The infiltration potentials on Weeli Wolli Creek were interpreted to range from 0.02 to 13.15 ML/km/day. The cumulative losses due to evaporation and transpiration tend to be comparatively small, amounting to 15 to 25 per cent of the total water balance.

  The interpreted transpiration losses increased by nearly an order of magnitude in reach B compared to reach A as does the comparison between transpiration and evaporation losses. The increased transpiration losses may be linked to broadening of the riparian zone and changes in floristics on downstream reaches, particularly north of the Marillana Creek confluence.

The evaporation losses are subordinate compared to those by transpiration and reasonably consistent in the range 0.23 to 0.35 ML/km/day. These losses may progressively decline from upstream to downstream reaches, possibly reflecting reductions to the perennial stream flow channel widths.

The findings of both methods show progressive increases in infiltration rates from upstream to downstream reaches of Weeli Wolli Creek. Also, the interpreted cumulative loss rates over the assessed reaches of Weeli Wolli Creek are similar; 110.3 and 112.7 ML/day.

Within the riparian zones on Weeli Wolli Creek, marginally downstream of the Marillana Creek confluence, a small number of infiltration measurements (Pettett and Pearcey, 2014) provided vertical hydraulic conductivity values in the range 40 to 1,050 m/day. These values indicated potential for the shallow alluvium to vertically transmit large volumes of rainfall and surface water at times when water is present.

Table 5-3 Measured Chloride, $\delta^{18}O$ and $\delta^{2}H$ and Interpreted Water Losses (after Dogramaci et. al, 2015a)

Reach	Surface Water to Groundwater Attributes	Sample Location	Distance from DP1 (km)	Chloride Concentration (mg/L)	$\delta^{18}O$ (‰, VSMOW[1])	$\delta^{2}H$ (‰, VSMOW[1])	Cumulative Volume Loss (per cent)		Calculated Chloride Concentration Due to Evaporation (mg/L)
							Due to Evaporation[2]	Due to Transpiration[3]	
A	Floodplain Aquifer Connected to Weeli Wolli Creek	WW20a	0.4	74	-8.24	-57.1	0.0	-	-
		WW18	3.1	75	-8.20	-56.9	0.2	1.4	74.1
		WW16	5.2	77	-8.06	-56.5	0.8	4.1	74.6
		WW14	7.0	79	-8.03	-57.2	0.9	6.8	74.7
		WW12	9.8	79	-7.98	-55.3	1.1	6.8	74.8
		WW10	11.3	79	-7.98	-54.7	1.1	-	74.8
Surplus Water Discharge		DP2	12.4	100	-7.92	-54.9	-	-	-
B		WW8a	13.2	89	-7.93	-55.0	0.0	-	-
		WW6	15.3	90	-7.77	-53.9	0.6	1.1	89.6
		WW1	18.0	96	-7.69	-54.6	1.0	7.9	89.9
	Transition	WW3	23.2	110	-7.28	-50.8	2.8	23.6	91.5
		WW3a	23.6	110	-7.31	-51.5	2.7	23.6	91.4
	Disconnected	WWE	24.1	120	-7.00	-52.0	4.0	34.8	92.7

Notes:

1 VSMOW refers to Vienna Standard Mean Ocean Water.

2 Derived from isotope mass balance.

3 Derived from chloride mass balance.

Table 5-4 Surface Water to Groundwater Interaction on Weeli Wolli Creek

References	Distance from Weeli Wolli Spring (HD1 Gabion)					
	0 to 5	5 to 10	10 to 15	15 to 20	20 to 25	To 26.5
Infiltration (ML/km/day)						
Dogramaci[1]	0.02			9.41		
Pettett[2]	2.29			4.52	9.24	13.15
Transpiration (ML/km/day)						
Dogramaci[1]	0.27			2.43		
Evaporation (ML/km/day)						
Dogramaci[1]	0.35			0.23		
Notes:						
1 Dogramaci, et. al., 2015a. The data also show increasing loss rates on northern reaches where the water table is disconnected from Weeli Wolli Creek.						
2 Pettett and Pearcey, 2014.						

hydrographs have also been used to characterise the surface water to groundwater interaction. In particular, monitoring bores YM119, 99YJWB01, 99YJWB02, 99YJWB03, 99YJWB04, DO8YJ126, DO8YJ165 and DO8YJ216 provide long-term groundwater level records, and these have been used to define the transient surface water to groundwater wetting front, as summarised in Table 5-5.

Table 5-5 Transient Surface Water to Groundwater Interaction in Selected Monitoring Bores

Monitoring Bore	Surface Water to Groundwater Interaction		
	Baseline	Progressive Wetting	Aquifer Full
Floodplain and CID aquifer associated with Upper Weeli Wolli Creek			
99YJWB002	Disconnected Losing System	From Early-1995 To March 1997	Connected Losing System from March 1997 Episodic wetting overprints from flood events
99YJWB003			
99YJWB004			
D08YJ126			
YM119			
Floodplain and CID aquifer associated with lower Weeli Wolli Creek			
D08YJ216	Disconnected Losing System	From Early-1995 to Date	Approaching a Connected Losing System
D08YJ165			Aquifer Wetting and Not Full
99YJWB001			

The available data indicate that the floodplain aquifer is full and connected to Weeli Wolli Creek in Section A and throughout Section B downstream at least to monitoring bore YM119. Further downstream, the surface water and water table disconnect. Evidently, the discharge of surplus water into Weeli Wolli Creek has predominantly saturated the residual storage in the underlying aquifer system, mounded the water table and over the majority of Weeli Wolli Creek provided circumstances where the surface water wetting front is connected to the water table.

Where the water table is connected to the low-flow channel, the losses can predominantly be attributed to aquifer through-flow. Progressive increases in loss rates to the north, reflect higher aquifer transmissivity (due to broadening and thickening of the alluvium successions together with presence of the CID) and progressive steepening of hydraulic gradients. At the leading edge of the surface water wetting front where the stream flow is disconnected from the water table, the interpreted loss rates are highest; see Figure 5-8 (Dogramaci et.al , 2015a and Table 5-4 – 13.15 ML/km/day; Pettett and Pearcey, 2014). In this setting, in the vicinity of WWE and D08YJ188, there is also:

- A step-change in both chloride and $\delta^{18}O$ enrichment.
- Differences between the surface water and groundwater sample analyses.

Data from 99YJWB01, the northernmost sampling point was dissimilar, forming significant outliers in a disconnected losing system. The groundwater environment intersected by 99YJWB01 was significantly lower in chloride and $\delta^{18}O$ concentrations compared to all other samples and probably reflects a different groundwater genesis and flow environment.

5.4.3 Groundwater Wetting Fronts

In the groundwater environment, the presence and distribution of the groundwater wetting front is evident based on transient changes in water table elevations within selected monitoring bores located adjacent to Weeli Wolli Creek. The baseline water table elevations provide a benchmark for change assessments. Further, the aquifer system beneath Weeli Wolli Creek has finite storage. Therefore, the available storage provides a control on the groundwater wetting fronts; once the available storage above the baseline water table elevation has been filled the surface water and groundwater wetting fronts would progressively propagate downstream.

It was recognised that the baseline environment is dynamic and characterised by episodic recharge fluctuations and subsequent decay in water table elevations. In particular, the period 1994 to 2005 was unusually wet providing episodic recharge to the groundwater environment associated with cyclones Bobby, Rachael, Thelma, John, Norman and Terri together with an un-named tropical low in January 2003. These natural groundwater wetting fronts provided cumulative signatures that masked concurrent changes linked to the groundwater wetting fronts from the surplus water discharge (RTIO, 2010).

The groundwater wetting fronts have been characterised by several means, including:

- Review of monitoring bore hydrographs.
- Aquifer storage assessments.
- Estimation of hydraulic gradients and aquifer through-flow.

- Rates of water table rise.

These aspects are discretely discussed below.

5.4.3.1 *Review of Monitoring Bore Hydrographs*

Monitoring bores (YM117 and YM118) in proximity to Marillana Creek and Weeli Wolli Creek (YM119, 99YJWB01, 99YJWB02, 99YJWB03 and 99YJWB04, DO8YJ126, DO8YJ165 and DO8YJ216) provide longer-term groundwater level records. These records have been used to interpret the groundwater wetting fronts. Also, the collective hydrographs typically show trends that are strongly mimicked from one bore to another. Given this aspect, the monitoring bores were discretised based on representation of:

- Monitoring Bore YM119. This monitoring bore provides a record on Weeli Wolli Creek from 1991 and was used as a template for the wetting fronts on the water table.
- Marillana Creek settings (YM117 and YM118).
- Upper reaches of Weeli Wolli Creek, including PBS area and broad riparian zones extending about 2 km north of the confluence with Marillana Creek (YM119, 99YJWB02, 99YJWB03 and 99YJWB04 and DO8YJ126).
- Lower Weeli Wolli Creek (99YJWB01, DO8YJ165 and DO8YJ216).

The YM119 template was used to differentiate transient changes in the groundwater environment, including:

- Baseline within a disconnected losing stream flow system:
  - Natural cyclic decay of water table elevations under hydraulic mechanisms.
  - Episodic wetting and water table mounding due to infiltration during flood events. Each wetting has unique characteristics. The hydrographs reflect this by demonstrating variable durations over which the wetting provided progressive water table mounding and peaks after selected flood events. For example:
    - Cyclone Bobby in February 1995: 25th February to 1st April, 35 day period of progressive water table mounding.
    - Cyclone Rachael in January 1997: 26th January to 1st March, 34 day period of wetting.
    - Cyclone John in December 1999: 16th December to 1st May, 135 day period.
    - Un-named tropical low in January 2003: 25th January to 2nd February, 9 day period.
- Progressive wetting within a disconnected losing stream flow system:
  - Cumulative wetting due to surplus water discharge, with masking by episodic wetting from repetitive flood events.
  - Cyclic decay by hydraulic mechanisms, without returning to baseline water table elevations.

- Aquifer system full to capacity; cyclic losing and gaining steam flow system with saturated connection due to perennial wetting by surplus water discharge:
  - Episodic wetting from flood events superimposed on a full aquifer.
  - Cyclic decay of the water table elevations by hydraulic mechanisms and discharge to the low-flow channel on Weeli Wolli Creek.

The surface water to groundwater wetting front interpretations from these monitoring bores are illustrated on Figure 5-9 (YM119), Figure 5-10 (YM117, YM118 and YM119), Figure 5-11 (99YJWB02, 99YJWB03 and 99YJWB04, DO8YJ126 and YM119) and Figure 5-12 (99YJWB01, DO8YJ165, DO8YJ216 and YM119). Interpretations from monitoring bore hydrographs show the groundwater wetting front occurs in the upper Weeli Wolli Creek settings from early-1995. Further, the water table becomes connected to the low-flow channel from early-2000 in monitoring bores YM119, 99YJWB02, 99YJWB03 and 99YJWB04. In each monitoring bore, the aquifer system was full or almost full at the time of Cyclone John in January 2000.

Further north in 99YJWB01, DO8YJ165 and DO8YJ216, the wetting front was evident in subtle expressions also from about early-1995. In these settings, however, the aquifer systems have to-date not become full to capacity. This aspect was linked to several factors, including:

- Increase depths to the water table, providing larger storage volumes.
- Lateral changes in aquifer hydraulics and flow gradients in the north, linked to:
  - Higher transmissivity due to increased saturated thickness of the aquifer system.
  - Higher transmissivity due to structural defects within the Hamersley Group.
  - Different aquifer geometry associated with proximity to the escarpment of the Hamersley Plateau and transition to the Fortescue River Valley.

Interpretations of the current cyclic-low and episodic-high water table elevations are shown on Figure 5-13 and Figure 5-14, respectively. The water table elevation peaks during and in short-term after episodic flood events. Thereafter the water table elevations progressively wane over periods that commonly span two to three years. Compatible snapshots of episodic-high and cyclic-low interpreted depths to the water table are shown on Figure 5-15 and Figure 5-16, respectively.

5.4.3.2 Aquifer Storage Assessments

The floodplain and CID aquifer system has finite storage above the water table. Therefore, the available storage provides a control on the groundwater wetting fronts. Once the available storage has been filled the surface water and groundwater wetting fronts would progressively propagate downstream. A reconciliation of available aquifer storage volumes compared to the transient annual surplus water volumes provided indications of potential rates at which the groundwater wetting front would propagate.

The estimation of available aquifer storage was informed by a baseline hydrology assessment for Yandicoogina mine discharge (RTIO, 2012). In this assessment, both the Marillana (downstream of the RTIO Yandicoogina Mine) and lower Weeli Wolli creek were discretised into six reaches, with each reach described in context to length and riparian zone width. These data were used to estimate widths of the floodplain aquifer and typical depths from the low-flow channel to the baseline water table elevation. An outline of the estimated aquifer storage under baseline water table conditions is provided in Table 5-6. It was assumed the specific yield of the unsaturated zone was 0.1 (dimensionless).

The data in Table 5-6 show that where the water table is now connected to Weeli Wolli Creek (on Reach 5 (after Cheng, 2012); also see Figure 1-1), the cumulative baseline storage was estimated at 80.1 GL. Comparisons between the surplus water discharge volumes 513.8 GL; (Table 5-1) and changes in storage from early-1995 (80.1 GL) provide indications of a substantial mismatch. The available storage (up to 45.4 GL) beneath the upper reaches of Weeli Wolli Creek was filled comparatively quickly between early-1995 and early-2000. During this period, the cumulative surplus water volume was 32.9 GL and the wetting fronts were enhanced by episodic recharge from flood events. Subsequently, the wetting provided by the surplus water discharge was not manifest in the same rates of aquifer filling beneath northern reached of Weeli Wolli Creek as observed further south. In the northern settings (within the groundwater environments monitored by DO8YJ216, DO8YJ165 and 99YJWB01) mounding of the water table is evident, but not at rates that:

- Account for the surplus water volumes.
- Off-set the measured infiltration rates from 9.41 to 13.15 ML/km/day (Dogramaci et. al, 2015a; Pettett and Pearcey, 2014).

These attributes indicate a likely change in aquifer hydraulics beneath northern reaches of Weeli Wolli Creek.

Table 5-6 Estimates of Baseline Aquifer Storage

Stream Reaches	Length (m)	Riparian Zone Width (m)	Floodplain Aquifer Width (m)	Depth to Water Table (m)	Estimated Storage (GL)	Sub-Totals Cumulative Storage (GL)
Marillana Creek Downstream of Yandi Mine						
1	1,336	140	280	10	0.4	-
2	2,660	150	300	10	0.8	-
3	3,129	200	400	8	1.0	-
4	5,172	120	450	9	2.1	4.3
5	3,664	280	540	10	2.0	-
6	3,106	460	800	17	4.2	10.5
JC[1] CID	5,714	Not Applicable	800	20	9.1	-
JSE[2] CID	6,857		750	8	4.1	23.7
Weeli Wolli Creek Downstream of Weeli Wolli Spring						
1	4,500	200	400	2	0.4	-
2	8,270	150	400	10	3.3	-
3	2,350	77	800	22	4.1	-
4[3]	4,620	80	1,500	20	13.9	45.4
5[4]	3,000	500	1,500	18	8.2	53.5
5[5]	5,069	Not Applicable	1,500	35	26.6	80.1
6	10,728	280	16,000	25	429.1	509.2
Notes:						
1 and 2 Refer to Junction Central and Junction South East CID zones.						
3 To the confluence with Marillana Creek.						
4 Sections of Reach 5 upstream of the bedrock shelf, thus including the monitoring bore YM119 site.						
5 Sections of Reach 5 downstream of the bedrock shelf, thus including the monitoring bore 99YJWB01, DO8YJ165 and DO8YJ216 sites.						

5.4.3.3 Estimation of Hydraulic Gradients and Aquifer Through-flow

The estimation of hydraulic gradients between selected monitoring bores was used to guide assessments of lateral changes in hydraulics of the aquifer system beneath Weeli Wolli Creek. Data on the water table elevations under baseline conditions and when the water table was connected to Weeli Wolli Creek were used to calculate hydraulic gradients. The estimated hydraulic gradients are shown in Table 5-7.

Table 5-7 Estimated Hydraulic Gradients

Selected Reaches	Reach Chainage (m)	Estimated Hydraulic Gradients				
		Baseline	Local Aquifer Full		Progressive Wetting Aquifer Zones	
			Low-Flow Channel Discharge Point	Peaks during Episodic Flood Events	February 2010	Early-2014
Upstream Reaches of Weeli Wolli Creek						
99YJWB02	0	-	-	-	-	-
99YJWB02 to 99YJWB03	2,100	0.0010	0.0040	0.0048	-	-
99YJWB03 to 99YJWB04	3,814	0.0008	0.0020	0.0016	-	-
99YJWB04 to D08YJ126	2,343	0.0028	0.0024	0.0021	-	-
D08YJ126 to YM119	514	0.0068	0.0068	0.0068	-	-
Average	**-**	**0.0028**	**0.0038**	**0.0038**	**-**	**-**
Transition Zone						
YM119 to D08YJ216	1,543	**0.0159**	-	-	**0.0140**	-
Downstream Reaches of Weeli Wolli Creek						
D08YJ216 to D08YJ165	2,229	0.0067	-	-	0.0066	0.0085
D08YJ165 to 99YJWB01	871	0.0052	-	-	0.0049	0.0080
Average	**-**	**0.0060**	**-**	**-**	**0.0058**	**0.0083**

The hydraulic gradients are comparatively steep (0.0140 to 0.0159) in the transition zone between YM119 to D08YJ216. In this zone, the hydraulic gradients are about 6 times steeper than beneath the upstream reaches of Weeli Wolli Creek. This range from 0.0140 to 0.0159 is probably conservatively low given it considers the entire chainage (1,543 m) from YM119 to D08YJ216; it may be that the gradients within the transition zone are steeper, with the transition occurring over a limited distance.

The hydraulic gradient informs the aquifer through-flow hydraulics based on Darcy's Law:

Q = kiA where:

- Q = total discharge (kL/day) from natural through-flow. Assume this is 53.8 GL (71.7 GL as per surplus water volumes in 2013 in Table 5-1 less 25 per cent losses to evaporation, transpiration and storage). This amounts to about 147,000 kL/day.
- k = bulk or effective hydraulic conductivity (m/day).
- i = hydraulic gradient (m/m). Assume this is 0.014. This estimate is probably conservatively low; it could be an order of magnitude steeper.
- A = cross-sectional area of the flow path. Assume this is 1,500 m width (Table 5-6) x 50 m saturated thickness of aquifer, thus 75,000 m^2.

Solving the equation shows the bulk of effective hydraulic conductivity would be about 140 m/day. Under a steeper hydraulic gradient of 0.14, the hydraulic conductivity would be about 14 m/day. Contextually, these values represent the effective hydraulic conductivity of the floodplain and CID aquifer system. As such, they can be directly compared to the values in Table 4-2.

5.4.3.4 Rates of Water Table Rise and Wetting Front Propagation

The calculated hydraulic gradients (Table 5-7) and observed rates of water table rise in monitoring bores D08YJ216, D08YJ165 and 99YJWB01 (Figure 5-12) have been used to assess the groundwater wetting front beneath northern reaches of Weeli Wolli Creek. For assessments using the calculated hydraulic gradients it was assumed:

- The local hydraulic gradients in the range 0.0049 to 0.0080 (Table 5-7) extend to the north beneath the Poonda Plain.
- The water table mounding in D08YJ165 and 99YJWB01 by early-2014 was of amplitudes 21.5 and 19.0 m, respectively.

By dividing the water table mound heights by the hydraulic gradients it was calculated that the leading edge of the groundwater wetting front would occur in the range 2.4 to 4.4 km north of D08YJ165 and 99YJWB01.

The rates of water table rise inform the groundwater wetting front in regard to:

- Rates of propagation to the north.
- Timetable for the transition from a disconnected system (Figure 5-12) to a connected losing system.

The hydrographs for D08YJ216, D08YJ165 and 99YJWB01 (Figure 5-12) inform the rates of water table rise. In the period from early-2008 to early-2014 (six years) these included:

- D08YJ216: 445 to 463 m AHD; an average annual rise of 3.0 m and total 18 m rise.
- D08YJ165: 433 to 444 m AHD; a rise of 11 m, with average annual rise of 1.8 m.
- 99YJWB01: 430 to 437 m AHD; a rise of 7 m, with average annual rise of 1.2 m.

Assessments of the rates of northern lateral propagation of the wetting front and timetable for filling aquifer profiles to the low-flow channel elevation of Weeli Wolli are summarised in Table 5-8 and Table 5-9, respectively.

Table 5-8 Timetable for Wetting Front Saturation of Local Aquifer Profiles

Monitoring Bore	Annual Rate of Water Table Rise (m)	Local Aquifer Full Elevation (m AHD)	Thickness of Unsaturated Zone (m)	Timetable for Filling of Local Aquifer (years)
D08YJ216	3.0	468	5.0	1.7
D08YJ165	1.8	465	21.0	11.5
99YJWB01	1.2	462	25.0	21.4

Table 5-9 Annual Rates of Wetting Front Propagation to the North

Monitoring Bore	Annual Rate of Water Table Rise (m)	Hydraulic Gradients	Annual Rate of Wetting Front Propagation (m)	
			Maximum	Minimum
D08YJ216	3.0	0.0049 to 0.0080	612	375
D08YJ165	1.8		374	229
99YJWB01	1.2		238	146

These assessments assume the rates of surplus water discharge and recent wetting front characteristics would be retained in the future. Differences in the observed rate of water table rise in D08YJ216, D08YJ165 and 99YJWB01, with progressive decreases beneath the downstream northern reaches of Weeli Wolli Creek are noteworthy. The differences probably reflect:

- Lateral changes in aquifer hydraulics, to higher transmissivity downstream.
- Transition to a broad alluvial delta and high-transmissivity fractured bedrock profile beneath the Poonda Plain.
- The volumes of available storage beneath the Poonda Plain represent a substantial (orders of magnitude) increase from those beneath Weeli Wolli Creek.

5.4.4 Discussion

It is evident that the water table is connected to the low-flow channel on Weeli Wolli Creek for the majority of the length of the surface water wetting front (Figure 5-17). The surface water wetting front on Weeli Wolli Creek has waxed and waned over distances of several kilometres north of the Marillana Creek confluence. There has not been substantial change in the northward propagation of the wetting front due to the commencement of surplus water discharge from the Hope Downs 1 Mine from early-2007. That the wetting front has waxed and waned over several years reflects a near-steady-state condition where the losses from the surface water environment have been balanced by losses through infiltration, evaporation and transpiration, storage in previously unsaturated profile, and through-flow in the local aquifer system. This conceptualisation is illustrated on Figure 5-18. It is only on the northern reaches of Weeli Wolli Creek, over a distance of about 4 km at the leading edge of the surface water wetting front, where the stream flow is disconnected from the water table (Figure 5-18). In this setting, the groundwater wetting front is evident, but propagating to the north at comparatively slow rates.

The findings by Dogramaci *et al.* (2015a) and Pettett and Pearcey (2014) indicate that the surplus water present as surface water is progressively assimilated by infiltration along Weeli Wolli Creek. The groundwater wetting front attributed to cumulative influences of high-frequency stream flow recharge events and surplus water discharges into Marillana Creek. It was anticipated that the groundwater wetting front propagated to beneath Weeli Wolli Creek and filled the local aquifer system to the vicinity of monitoring bore YM119 by early-2000. Upstream of this setting, the water table was connected to the low-flow channel of Weeli Wolli Creek. North of YM119 there is a transition zone within which, the water table becomes disconnected from Weeli Wolli Creek. North of the transition zone, wetting trends are evident from early-2000, but the groundwater wetting front has comparatively limited expression in terms of the amplitudes in water table mounding. Also, within the groundwater environment, aquifer storage in monitoring bores D08YJ215, D08YJ165 and 99YJWB01 is being consumed, albeit at comparatively slow rates. Therefore, the groundwater wetting front in the vicinity of D08YJ165 and 99YJWB01 transmits the majority of the surplus water; there are subordinate volumes intercepted by evaporation and transpiration.

The wetting front attributes together with supporting data provided by measured infiltration rates, aquifer storage assessments, calculations of hydraulic gradients and assessments of rates of water table rise indicate a significant change in the characteristics of the aquifer system beneath the northern reaches of Weeli Wolli Creek. The comparatively limited expression of the groundwater wetting front was interpreted to reflect a significant increase in the effective transmissivity of the aquifer systems.

5.4.5 Altered Groundwater Quality

The increases in water availability and discharge by transpiration and evaporation result in salt accumulation within the groundwater environment. A chloride ion increase of about 50 mg/L along the 27 km surface water wetting front on Weeli Wolli Creek was attributed to salt accumulation due to evaporation and transpiration losses along the flow path (Dogramaci et.al; 2015a).

6 LIKELY CHANGE ASPECTS FROM MINING AT PBS

6.1 Flood Mitigation

The development of PBS would conserve the low-flow channel of Weeli Wolli Creek and the majority of the riparian zone through avoidance measures. Flood protection bunds located about 100 m from the western crests of the proposed pits would not significantly limit flood footprints to the riparian zone; the broader floodplain areas (that host the proposed pits) would not be inundated by episodic events. Diversion drains on the eastern pit limits would intercept surface water shedding from the local catchment.

Designs of the flood protection bunds were informed (Cheng, 2013) by predictive TUFLOW hydraulic simulations. These simulations characterised the baseline flood depths, flood extents and flow velocities under baseline conditions up to a 200-year ARI event, and for the same event, with the flood protection bunds in place. The PBS diversion drains have been sized to convey 50-year ARI flows from local catchments behind the pits into Weeli Wolli Creek. Any flow larger than this event will overtop the drain into the pit. Comparative results of the predictive modelling are shown on Figure 6-1 and indicate:

- Increased depths of stream flow, particularly within the low-flow channel and closely associated bifurcate and or braided channels.
- Changes in stream flow velocity, with broader areas where the velocity was increased compared to baseline.
- Reduced flood footprint, by about 60 per cent, with the flood protection bund limiting inundation of the floodplain to the east of the riparian zone (where the proposed pit would be).
- Interception of flow paths from tributaries and alluvial fans on the eastern perimeter of the floodplain to Weeli Wolli Creek. The diversion drains would intercept flows from a 40.2 square km catchment area; this area represents about 2.5 per cent of the Weeli Wolli Creek catchment upstream of the confluence with Marillana Creek.

Further to these changes, it is recognised that the eastern diversion drains, together with the physical presence of the pits, would interfere with the watersheds from local catchments on the eastern banks of Weeli Wolli Creek. Both would tend to isolate, divert and or intersect surface water, unsaturated zone flows and groundwater originating from the eastern catchments, and associated alluvial fans that front onto the riparian zone along Weeli Wolli Creek.

6.2 Groundwater Abstraction and Discharge

Groundwater abstraction for pit dewatering is intended to lower the water table to near the base of the CID succession. Local drawdown within the floodplain and CID aquifer system would be in the order of 45 to 50 m to enable dry mining conditions. Drawdowns of this magnitude would preferentially propagate along the CID aquifer.

The Yandicoogina – Pocket and Billiard South Model (Lim, 2014) was used to predict groundwater abstraction for pit dewatering. The model was refined and enhanced from an earlier Visual MODFLOW MODSURFACT version (Inverarity, 2011) used to support the RTIO Yandicoogina Mine. One refinement was the inclusion of the Stream Flow Package to

represent perennial and episodic flow events on Weeli Wolli Creek. Model calibration was focussed on groundwater levels evident in monitoring bores from January 1998 to January 2014. This period reflects conditions when the floodplain aquifer was full and connected to Weeli Wolli Creek. Simulated hydraulics provide vertical integration of the floodplain and CID channel aquifers.

Predictions (Lim, 2014) of annual groundwater abstraction to 2032 are outlined in Table 6-1. Note that these volumes include all sources at the RTIO Yandicoogina Mine, including PBS. These forecasts show annual abstraction volumes in the range 37.4 to 82.2 GL, with an average of 54.6 GL.

Table 6-1 Predicted Annual Pit Dewatering Abstraction (2014 to 2032)

Year	Groundwater Abstraction (GL/annum)
2014	39.4
2015	51.3
2016	43.8
2017	49.4
2018	74.4
2019	64.7
2020	70.1
2021	70.3
2022	66.9
2023	82.2
2024	73.7
2025	57.9
2026	51.6
2027	46.7
2028	37.4
2029	39.1
2030	39.5
2031	39.8
2032	40.0
Average	**54.6**
Cumulative	**1,038.2**

The simulated pit dewatering abstractions concurrently drain both the floodplain and CID aquifers. Further, the predicted cumulative abstraction volumes of 1,038 GL is an order of magnitude greater than the estimated storage (derived from Table 5-6; assuming depths to the water table of 40 to 50 m) in the local aquifer systems. This aspect indicates that the abstraction volumes are being substantially supplemented by interception of perennial stream flow from surplus water discharge. In this regard, the model's water balance shows that volumes from 30 to 33 GL/annum are typically intercepted from Weeli Wolli Creek and abstracted as groundwater (thus included in the annual, average and cumulative abstraction

data provided in Table 6-1). These volumes are closely compatible to the simulated abstraction volumes from the Hope Downs 1 Mine. The predicted estimated aggregate volume of surface water predicted to be intercepted from Weeli Wolli Creek was about 608 GL; this volume represents about 60 per cent of the total abstraction.

The predictive simulations provide indications that the pit dewatering abstractions would:

- Draw-down the water table beneath the low-flow channel of Weeli Wolli Creek. A disconnected losing system would occur in the short-term after commencement of groundwater abstraction, as the water table is lowered.
- Promote increased surface water to groundwater interaction, given the disconnection of the stream flow from the water table would provide storage for infiltration.
- Intercept a portion of the perennial stream flow on Weeli Wolli Creek.
- Locally dewater the floodplain and CID aquifers by removal of free-draining groundwater from storage. Predicted transient drawdown snapshots provided by the Yandicoogina – Pocket and Billiard South Model (Lim, 2014) are shown on Figure 6-2 to Figure 6-6, inclusive. These snapshots are for December 2017 (about one year after commencement of abstraction at PBS), December 2019, December 2023, December 2027 and December 2032.
- Potentially intercept through-flow from the local catchment areas on the western and eastern banks of Weeli Wolli Creek. Also, the physical presence of the PBS pits would present a barrier to, and intersect water migrating in, the unsaturated profile.

In several regards, these changes would alter the surface water and groundwater wetting fronts, reverting to circumstances similar to baseline conditions.

Surplus water would be discharged to the lower reaches of Marillana and Weeli Wolli creeks at designated outlets. Forecasts of groundwater abstraction, groundwater use and volumes in excess of demand are summarised in Table 6-2.

Table 6-2 Forecast Groundwater Abstraction, Use and Discharge (to 2043)

Aspect	Groundwater Abstraction, Use and Discharge (GL/annum)				
	Dewatering	Use			Discharge
		Processing	Injection	Total	
Minimum	27.8	5.0	nil	5.0	22.8
Average	46.6	5.3		5.3	41.3
Maximum	82.2	5.9		5.9	76.3

6.3 Groundwater Wetting Fronts

A groundwater model was developed to investigate and inform the potential characteristics of the groundwater wetting front beneath northern reaches of Weeli Wolli Creek. This model domain captured the northern reaches of Weeli Wolli Creek, north of YM119, with objectives of conceptualising groundwater flow paths that extend beneath the Poonda Plain.

Adaption of the Yandicoogina – Pocket and Billiard South Model (Lim, 2014) was undertaken to enable simulation of the groundwater wetting front. Adaptation was required because the original model domain did not extend onto the Poonda Plain and both the model form and parametrisation were predominately based on data from the PBS RTIO Yandicoogina Mine settings. None of these attributes suited the model objectives. Ultimately, the adapted model was simplified, to streamline the required simulations, by excising the domain from the Yandicoogina – Pocket and Billiard South Model.

The model was conceptualised and formulated based on information that included:

- A cross-section transect within the Nyidinghu Project where Weeli Wolli Creek enters Poonda Plain (Fowers et al.; 2013). The cross-section represents the local geology at a distance of 4 to 5 km north of D08YJ165 and 99YJWB01.
- A regional groundwater exploration programme focussed on Fortescue Marsh and associated management zones (RTIO, 2012). This report included groundwater level data beneath the Poonda Plain.

In particular, the cross-section of the Nyidinghu Project (Fowers et al.; 2013) shows the presence of a deeply incised bifurcate palaeovalley aligned with Weeli Wolli Creek and structural defects (northeast striking faults termed the Weeli Wolli Fault System that form a zone of deformation up to 2 km in width) in the underlying bedrocks. The intersected palaeovalley (termed the Weeli Wolli Creek Palaeovalley) shows bottom elevations in the range 270 to 305 m AHD, thus indicating thicknesses of 155 to 190 m assuming ground surface elevation of 460 m AHD. This range of thicknesses shows significant change from settings further south beneath Weeli Wolli Creek where typical depths to basement rocks are about 75 m. A northwest striking Poonda Fault was also described by Fowers et.al. (2013) underlying the scarp of the Hamersley Range.

The model form, capturing the deeply incised and structurally controlled Weeli Wolli Creek Palaeovalley on west to east and south to north cross-sections is illustrated on Figure 6-7 and Figure 6-8, respectively. The west to east cross-sections in particular show the downstream transformation of the palaeovalley in transects from YM119, 99YJWB01 and northern reaches. Baseline data on the groundwater environment are limited and consequently steady-state and transient calibration of the model was based on:

- The perspective that the groundwater wetting fronts beneath southern reaches of Weeli Wolli Creek (represented by YM119) had quasi-steady-state attributes since early-2000, with the water table connected to the low-flow channel of the creek. The water table elevation was 474.7 m AHD.
- D08YJ215 and D08YJ165 being in the transition zone, with increasing northward disconnection between the water table and the low-flow channel.
- Water table data from 99YJWB01 during early-2000. The water table elevation was 424.0 m AHD and disconnected from the water table.
- Interpreted early-2010 water table elevations beneath Poonda Plain (Figure 4-4).
- Both YM119 and 99YJWB01 forming focal points of the calibration. This position was informed, understanding that the nature of the transition zone was poorly defined, as were the actual hydraulic gradients on transect from YM119 to D08YJ165. The calibration hydrographs for both monitoring bores are shown on Figure 6-9.

- Recharge to the water table compatible to the annual abstraction volumes shown in Table 6.1. The recharge was applied only to the northern reaches of Weeli Wolli Creek where the water table was disconnected from the creek. This approach recognised that the majority of the surplus water volumes were being transmitted within the groundwater environment and provided reasonable worst-case attributes to the model.

The transient calibration covered the period from 1997 to 2013, thus reflecting the period when the recharge was highest due to the inclusion of the wettest period over the last two centuries that included four major consecutive cyclones (1994 to 2005; Rouillard et al., 2015).

The calibrated model was run forward in time to predict changes to the groundwater wetting front based on predicted pit dewatering volumes described by the Yandicoogina – Pocket and Billiard South Model (Lim, 2014). The results of the model suggest that the groundwater wetting front would peak within two years after commencement of the PBS abstraction, with subsequent waxing and waning during the period to 2024. After 2024, the predicted wetting front shows steady decay. The 99YJWB01 hydrographs show the local wetting front attributes across a range of hydraulic conductivity sensitivity analyses. These analyses show compatible water table trends with indications that water table elevations in 99YJWB01 would attain a maximum elevation of about 453 m AHD (approximately 10 m above the current elevation). The predictions indicate the nearby low-flow channel (elevation 466 m AHD) would remain disconnected from the water table. The maximum predicted water table is commonly tens of metres below the ground surface and the groundwater wetting front does not connect to Weeli Wolli Creek downstream of the DO8YJ165.

It was recognised that the outlined model form, parameterisation, calibration and predictive outcomes are sensitive to the assumptions regarding the physical attributes of the interpreted palaeovalley, including dimensions (breadth, depth and length; which are unknown north of the Nyidinghu Project) and hydraulics. Whilst the attributes of the palaeovalley are only developed at a conceptual level, they do provide a reasonable fit to the available data, develop logic associated with changes to the hydraulics of groundwater environment beneath northern reaches of Weeli Wolli Creek, and an improved understanding regarding the potential fates of the surplus water discharged to Weeli Wolli Creek.

7 CONCEPTUALISATION OF RIPARIAN ZONE WATER AVAILABILITY

7.1 Overview

Riparian zones are considered as adaptive features of the natural landscape and likely to be sustainable, albeit in different forms, under changing environmental conditions, including variations in actual water availability. In this regard, the riparian zones do not represent a steady-state, rather a snapshot of individual and responses to near-term antecedent conditions, including available water, and other stresses. These characteristics are particularly relevant in the Pilbara where the semi-arid to arid climate and episodic nature of rainfall and stream flow events impart significant controls on the water availability in riparian zones.

Significant temporal and spatial variations in flooding and hence water availability impose a wide heterogeneity within the riparian floristics. As such the riparian zones can be viewed (Stromberg, 2001) as a mosaic of diverse and dynamic habitats (Malanson, 1993, Naiman and Décamps, 1997) that show temporal and spatial variations linked to water and nutrient availability. Typically, riparian habitats comprise complex gradients of predictable vegetation communities that have developed and changed over time depending on flood frequency, depth or duration. In frequently flooded areas, the riparian vegetation is influenced primarily by physical and chemical attributes of the habitats. Younger stands commonly occur in more frequently flooded areas, likely reflecting recruitment in areas of increased water reliability, but also where fluvial disturbances may compromise longevity (Gregory et al., 1991; Pettit et al., 2001). Annual and ephemeral species may be common as they complete their life cycles between inundation events (Menges, 1986; Trebino et al., 1996; Capon, 2003 and 2005). Conversely, however, woody shrubs such as *Acacia* spp. and members of the Chenopodiaceae family can be intolerant of waterlogged soils, dying following long periods of flooding (Pettit et al., 2001; Capon, 2003).

During drought, the composition of riparian vegetation is dependent on competition for available water and nutrients together with herbivory (Blom et al., 1990; Lenssen et al., 1999). Further, the seedling and canopy composition in riparian zones can substantially change depending on water availability provided by flooding. The riparian canopy changes may occur over both short-term and long-term time scales (Jones et al., 1994) depending on transient water availability. Drying trends are accompanied by vegetation composition changes as only species tolerant to arid (xeric) conditions of reduced water availability tend to survive.

Based on the described riparian zone attributes there may be expectation that individual trees and zonation gradients within the broader riparian zones have unique opportunism in how they intercept locally available water and nutrients to sustain life and support growth. Further, this opportunism may change, as the trees mature and water demands increase, and to reflect the preferential use of different water sources at different times depending on availability and competition.

7.2 Riparian Habitats

In baseline settings, the physical attributes of the climate, surface water hydrology, geomorphology and flood frequency are considered the predominant aspects controlling water availability and hence the temporal and spatial riparian vegetation diversity (Gregory et al., 1991; Blom et al., 1994; Naiman and Décamps, 1997; Stromberg, 2001). Flooding is considered to be the primary factor regarding water availability and supporting vegetation in

riparian habitats (Naiman and Décamps, 1997). Even when there is perennial stream flow, as now occurs on Weeli Wolli Creek, the water availability to the broader riparian zones is generally strongly influenced by the frequency and duration of flood events.

The Pilbara climate is semi-arid to arid, with widely varied annual rainfall patterns and distributions. These attributes influence stream flow and flood event frequency and consequently, the riparian zone water availability and habitats. Riparian zones reflect flood event frequency and footprints and also depths to the water table (Loomes, 2013). Accordingly, the riparian zone on Weeli Wolli Creek was subdivided based on physical geomorphology, position in the local landscape and associated likely variations in water availability based on flood footprints (Figure 7-1). In this regard, the discretised riparian zones on Weeli Wolli Creek included:

- Low-flow channel. The low-flow channel transmits a wide range of fluvial events. This was assumed to incorporate:
  - A 6 m width zone that transmits all of the perennial stream flow.
  - A 20 m width corridor either side of the low-flow channel wherein the riparian vegetation is able to gain access to perennial stream flow or associated pore water (pers comm Pauline Grierson, March 2015).
  - An overall total width of 46 m.
- Incised channel. There may be different vegetation habitats between lower elevation channel bank and levee bank settings due to local changes in these attributes (Naiman and Décamps, 1997). The incised channel was assumed to be a 100 m width, inundated by 1-year and 2-year ARI stream flow events.
- Riparian zone floodplain. This zone recognises that the riparian zone is preferentially developed along the main low-flow channel of Weeli Wolli Creek and where captured by secondary braided channels. The riparian zone floodplain was assumed to be a 450 m width, inundated by 2-year to 5-year ARI stream flow events.
- Broader floodplain. Perimeter riparian zones assumed to be 1,800 m in width and infrequently inundated by 5-year to 10-year ARI stream flow events. This habitat diminishes laterally from the low-flow channel dependent on elevation and flood characteristics (Capon, 2003 and 2005).

In this context it was recognised that the low-flow channel, incised channel and riparian zone floodplain domains form the riparian conservation zone shown on Figure 1-2. Within the riparian conservation zone:

- The low-flow channel accounts for about 8 per cent of the overall footprint.
- The incised channel accounts for about 17 per cent of the area.
- The riparian zone floodplain represents about 76 per cent of the conservation zone.

7.3 Weeli Wolli Creek Riparian Floristics

Riparian zones typically have higher soil moisture and nutrient content than neighbouring upland systems (Megonigal et al., 1997). The riparian vegetation communities are distributed, structured and characterised based on the availability of water; watercourses such as the Weeli Wolli Creek, and associated riparian zones are characterised as areas of comparatively high water availability. In these settings, stream flow occurrences are focussed within channels in valley-floor settings and underlain by soils with capacity to store soil water predominantly derived from infiltration of flood water. Spatial patterns in riparian vegetation composition and structure also occur along longitudinal gradients within river catchments (Ward et al., 2002). For example, populations of River Red gums (*E. camaldulensis*) in the riparian zones of numerous Australian rivers are known to depend on floods that promote regeneration (e.g. Bren and Gibbs, 1986; Chesterfield, 1986; Dexter et al., 1986; Bren, 1987 and Bren, 1988). In general, maximum species diversity tends to occur in riparian habitats of the middle reaches or a river catchment. Riparian plant species richness is also often higher in proximity to the main channel rather than on tributaries (Nilsson et al. 1994). Conversely, the extended absence of flood events or major changes to hydrology has had considerable impact on the health of *E. camaldulensis* (Bacon et al. 1993, Mensforth et al. 1994, Stone and Bacon 1994, Thorburn et al. 1994, Stone 1999, Chisholm and Stone 2003).

Commonly, the riparian floristics include phreatophytic communities that source groundwater to meet water demands (Land & Water Australia, 2007a). *M. argentea* is regarded as an obligate phreatophyte which primarily draws water from the water table (Masini, 1988; Graham, 2001; O'Grady et al,,. 2005) and is dependent on shallow groundwater sources and or perennial surface water. An earlier study (AGC Woodward-Clyde, 1992) concluded that the depth to groundwater is crucial to the distribution of *M. argentea* on Marillana Creek and suggested the likely maximum rooting depths of *M. argentea* is less than 5 m.

The larger eucalypt trees potentially have roots that may enable variable dependency on groundwater; for example *E. camaldulensis* and *E victrix* meet water demands predominantly from flood water, with groundwater a subordinate source, with mature trees more reliant on groundwater than young (Overton and Jolly, 2004). Eucalypts are termed facultative phreatophytes where groundwater dependency may be limited, change over time and/or be opportunistic depending on the presence of alternative water sources. These tree species are believed to rely on water available within the soil profile above the water table. This suggests these species prefer unsaturated soil conditions with episodic rewetting from flood waters and direct infiltration of rainfall. *E. camaldulensis* has rooting depths to about 10 m study (AGC Woodward-Clyde, 1992).

On Weeli Wolli Creek, the low-flow channels of major creek lines are characterised by floristics that predominantly include *E. camaldulensis* (River Red Gum), and *E. victrix* (Coolibah) over *M. argentea* (Cadjeput) and *M. glomerata* (Inland Tea-tree) and acacia low open woodlands. The incised channel and broader riparian floodplain supports E. victrix scattered trees over acacia low woodlands and open hummock grassland. A broad-scale summary of the typical potential groundwater dependency of the predominant riparian floristics of Weeli Wolli Creek is provide in Table 7-1 (after Astron, June 2009). It was recognised that numerous natural factors influence the water use by the riparian vegetation and hence local characteristics of riparian zones. These factors may be both causal and responsive given change may occur dependent on water availability. The factors present and/or significant at local or broader scales include:

- Soil properties.
- Individual tree and species morphology.
- Proportional and transient change in water use from different sources.
- Depth to the water table.
- Water quality.

Table 7-1 Typical Potential Groundwater Dependency of Riparian Floristics

Floristics	Potential Groundwater Dependence	Comment
Melaleuca argentea	High	Obligate phreatophyte in settings along watercourses where water table depths are less than 3 m.
Eucalyptus camaldulensis	Medium-High	Facultative phreatophyte generally on creek lines underlain by shallow depth to groundwater.
Melaleuca glomerata	Medium	Facultative phreatophyte on creek lines. This was based on evidence on Kunada Creek, a tributary to Robe River, in west-Pilbara settings.
Eucalyptus victrix	Medium and Low to Medium	Facultative phreatophyte and commonly the dominant over-story species on creek lines and floodplains in settings of lower water availability. There is a widespread distribution of *E. victrix* in Pilbara riparian zones with substantial wide differences in depths to the water table and groundwater availability.
Acacia low woodlands	Low	Not phreatophytic.

Riparian plant species are commonly characterised by physiological or morphological adaptations that enable survival despite significant temporal changes in water availability and/or submergence by flood waters. These adaptations may include:

- Tolerance of different water availability during drought and floods (Lemcoff et al., 2001; Yunusa et al., 2010). The tolerance may be explained by dormancy and/or reduced metabolism during drought and initiation of leaf and flower production in response to rainfall or submergence. For example, *E. victrix* and *E. camaldulensis* limit water demands by closing stomata and reducing transpiration. This is recognised as a common trait for semi-arid and arid plant species (Yunusa et al., 2010).
- Ability to vary transient water sources in response to changes in water availability (Snyder and Williams, 2000; Drake and Franks, 2003).

- Timing of reproduction to coincide with regular flood cycles that reflect periods of improved water availability. Recruitment of riparian trees and shrubs is commonly related to flooding. This aspect is recognised to include:
  - Ability by selected species to delay flowering and seed production until recession of episodic flood waters (Blom et al., 1990).
  - Production of large persistent soil seed banks that lie dormant until occurrence of suitable conditions for germination (Leck and Brock, 2000).
  - Seeds which germinate in conditions (temperature, light and oxygen availability) that occur during recession of episodic floodwater (Leck, 1989; Pautou and Arens, 1994). Riparian trees species including *E. camaldulensis* and *E. victrix* commonly germinate following inundation (Capon, 2002; Woolfrey and Ladd, 2001). Survival of seedlings and saplings is dependent on further flooding (Dexter, 1967).
  - Dispersal of seeds by flood waters.
  - Ability to rapidly elongate stems and petioles upon submergence, allowing plants to emerge from the low light conditions of flood waters (Blom and Voesenek, 1996).
  - Development of plant tissues that host comparatively large spaces between cells (aerenchyma) in stems and roots, enabling storage and diffusion of metabolic gasses.
  - Development of adventitious roots or initiate increased branching of lateral roots when flooding occurs (Blom et al., 1990; Boulton et al., 2010).
  - Ability to alternate metabolic pathways so respiration and growth can continue or occur under anoxic and waterlogged conditions (Hook, 1984; Boulton et al., 2010; Fellman et al., 2011).
  - Unique perforations and arrangement of cells (stomata) in the leaves (Gomes and Kozlowski, 1980; Lemcoff et al., 2001) enabling gas and water exchange, as evident in *E. camaldulensis*.
  - Defoliation and loss of limbs together with stunting of growth during prolonged drought.

7.4 Analogies for Riparian Zone Water Availability

Analogies for riparian zone water availability have been derived from:

- Observations on Weeli Wolli and Marillana creeks. Riparian zones on both creeks are likely to be sustained using water from different sources including soil water, perched groundwater and surface water (Graham et al., 2001 and O'Grady et al., 2009). The sources may vary according to the distribution of specific environmental conditions, therefore influencing the distribution and vigour of the riparian zone.
- Site investigations within the Mt Bruce Coolibah Wetlands. These investigations show increased water availability linked to episodic flood events and associated surface water, surface water to groundwater interactions and groundwater wetting fronts.

Both analogies are discussed below to provide context to potential future changes in water availability to the riparian zones on Weeli Wolli Creek.

7.4.1 Observations on Weeli Wolli and Marillana Creeks

Airborne multispectral imagery has been used since 1993 to interpret potential changes in riparian zone conditions on the lower reaches of Marillana Creek. The observed changes in vegetation patterns were predominantly adjacent to the surplus water discharge outlets and nearby pools where the surface water was attenuated above a shallow water table. This imagery detected:

- Increased density of riparian vegetation associated with prolonged availability of surplus water downstream of discharge outfalls.
- Increases and decreases of the Plant Cell Density Index.

Remote sensing imagery between 2002 and 2008 showed changes in tree canopy cover, density and condition. Interpretations of this imagery (Specterra, 2008) indicated the changes were predominantly linked to fire and tree loss/damage caused by flood events.

Riparian *E. victrix* and *E. camaldulensis* health has been monitored on a quarterly basis since 2005 and 2006 on the Weeli Wolli and Marillana creeks (RTIO, 2012). The monitoring captures 22 sites and 233 trees on Weeli Wolli Creek, and 11 and 144 trees in riparian zones on Marillana Creek.

Monitoring of riparian zone condition and health has also been undertaken by Mattiske Consulting Pty Ltd since 2008. This monitoring has been aligned along Weeli Wolli Creek, including reaches downstream of the confluence with Marillana Creek.

The monitoring has not detected significant differences in riparian vegetation responses in undisturbed settings compared to disturbed settings influenced by drawdown of the water table or surplus water discharge. Overall, the observations from the RTIO Yandicoogina Mine indicate:

- A small percentage of *E. victrix* trees being monitored have declined in health or have died, which appear to be a result of waterlogging due to surplus water discharge. These trees are limited to the areas of permanent water in the low-flow line (incised channel).
- Absence of significant trends in tree density or condition of mature trees.
- That natural fluctuation in riparian tree density and condition seen at reference sites on Weeli Wolli, Mindy Mindy and Coondiner creeks are compatible with changes observed on Weeli Wolli Creek.
- Similarities in foliage cover trends on the Weeli Wolli, Mindy Mindy and Coondiner creeks suggesting drawdown of the water table may not be changing foliage cover at various structural levels within riparian stands.
- No significant discrepancy in understorey richness in comparisons between the reference sites on Weeli Wolli, Mindy Mindy and Coondiner creeks and reaches of Weeli Wolli Creek influenced by drawdown or surplus water discharge.
- Over time, riparian zones subjected to increased water availability, including saturation of root zones and mounded water table elevations commonly aligned with surplus water discharge outlets, may show increased recruitment and increased leaf area index of some species. In particular, an increase in healthy stems of *M. argentea* was recorded within the surface water wetting fronts. Increases in riparian vegetation and sapling

density may also appear to be linked to extended periods of above-average rainfall and frequency of flood events.

- Lowering of the water table and dewatering of the soil profiles beneath riparian vegetation stands (due to pit dewatering) has the potential to decrease water availability and as a consequence induce stress in eucalypts.
- Tree health may selectively decline due to sudden reductions in water availability.

7.4.2 Mt Bruce Coolibah Woodlands

The Mt Bruce Coolibah Woodlands are located in a topographic depression on the Mt Bruce Flats. The woodlands solely comprise *E. victrix* (Coolibah), with a dense understorey of native grasses (Batini, 2008). Locally, the stratigraphy is dominated by Tertiary detrital and palaeochannel successions overlying dolomite of the Wittenoom Formation (Figure 7-2).

The woodlands are temporarily inundated by episodic flood events; inundation occurred in January 2006 (after about 180 mm rainfall), but not subsequently to 2011. The wet soil condition flowing inundation is understood (Florentine, 1999) to initiate germination of *E. victrix* seeds. It was considered (Batini, 2009) that there was considerable storage of soil water which predominantly supported the *E. victrix* stands and enabled survival during periods between flood events. That is, the *E. victrix* was not dependent on groundwater.

There have been a number of site investigations associated with the Mt Bruce Coolibah Woodlands. Those forming the focus of recent assessments (RTIO, 2011) included:

- Interpretation of water table mounding in monitoring bores due to recharge from flooding in January 2006. This concept is shown on Figure 7-3. There is evidence in monitoring bore hydrographs (RTIO, 2011) that flood events provide the predominant source of recharge to the water table. These data indicated flood waters infiltrate the unconfined aquifer beneath the Coolibah Woodlands.

The hydrographs of monitoring bores in the aquifer system beneath Weeli Wolli Creek also show rapid response to recharge from flood events. This reflects vertical integration of the surface water to groundwater flow system, with limited impedance of infiltration of rainfall and or flood water.

- Soil moisture contents (gravimetric) ranged from 5 to 20 per cent in top 5 m (Figure 7-4), tending to increase from 4 to 14 per cent in the top 2 m in individual bores (RTIO, 2011). Below 5 m depth, the moisture contents vary widely.
- Preliminary assessments of tree water use using stable isotope analysis (Grierson and Skrzypek, 2011) showed *E. victrix* twig water collected in November 2010 had $\delta^{18}O$ values of -7.6± 0.8 ‰ (Figure 6-3). These values were consistent with the soil water $\delta^{18}O$ values and considered to reflect the stable isotope composition of the water sources of the trees. The $\delta^{18}O$ values (-7.6± 0.8 ‰) for *E. victrix* were observed in the soil water at depths below 6 to 11 m, depending on where the trees were located within the Woodland. The assessments indicated *E. victrix* generally acquires water from the unsaturated zone, at depths from 6 to 13 m (Grierson and Skrzypek, 2011) or below.

The twig sampling occurred over a number of years after the woodlands were inundated. Pfautsh and Adams (2011) showed that water loss in *E. victrix* using sap flow instruments,

was regulated by climatic conditions, with water use by *E. victrix* declining as availability of soil water declined. These data together with the stable isotope results indicated water use in *E. victrix* was dynamic. At the time of the twig sampling, the trees were sourcing deep soil water rather than groundwater. These data indicated:

- A 5-year ARI flood event may sustain the local *E. victrix* stands.
- Flood events alone may sustain the riparian zone.
- Transient changes in water availability naturally occur, and are reflected in changes in riparian zone distributions, floristics, stress (leaf and canopy density) and mortality.

These characteristics are compatible and supported by evidence on Weeli Wolli Creek which show the riparian zone may wax and wane during periods of increased water availability (flood events) and drought, respectively.

7.5 Factors That May Limit Use of Available Water

There are numerous natural factors that may limit surface water and groundwater use by riparian plant species despite it being present. These factors are likely to include:

- Individual tree and species morphology.
- Different sources being present and changes in sources over time linked to drought and flood.
- Inability for water to enter the root zones, linked to:
  - Infiltration rates.
  - Lateral and vertical flow paths within the unsaturated profile and propensity for perched water tables.
  - Physicochemical composition and characteristics of soils, including porosity, field capacity and moisture retention characteristics.
  - Vertical and lateral hydraulics of the soils which influence the attenuation and wetting front characteristics within the unsaturated profile.
- Depths to the water table.
- Water quality.

Given these perspectives, it was recognised that apparent changes in water availability, such as perennial presence of surface water or mounding of the water table, may be indicative only, and possibly misleading in context to use by riparian zone plant species. For example:

- The presence of perennial water in the low-flow channel of Weeli Wolli Creek does not reflect increased water availability to the majority of the riparian zone. Only trees in the immediate vicinity of the low-flow channel would have direct access to the surface water.
- Mounding or drawdown of the water table does not necessarily reflect change in predominant water source of the riparian zone vegetation. Mounding of the water table may increase water availability, but not necessarily proportional use from this source.

- Opportunistic adaptions by individual trees to source new water sources would not be immediate but could change over time.

Adaptations to intercept new water sources would add to the opportunistic water source options, not exchange one for another. Further, the adaptations would likely provide only a portion of the water demands. This portion may vary from tree to tree and over time.

7.6 Assessments of Water Availability

Water sources that may be available to the riparian zones of Weeli Wolli Creek have been estimated with an objective to characterise potential changes from baseline, current and PBS scenarios. Key attributes of the conceptualisation of water availability include:

- Stream flow in the low-flow and incised channel of Weeli Wolli Creek and flooding of adjacent riparian zones would be largely undisturbed. Flood protection bunds associated with the proposed mining (Figure 6-1) may subtly influence the local hydrology. For example, reductions in overland flow from the east as a result of the diversion drain on the eastern perimeter of PBS have been factored into the water availability assessment. Overall, the flood protection bunds do not significantly change water availability associated with episodic stream flow and flooding events.
- Infiltration from stream flow would predominantly have vertical to sub-vertical flow paths, thus have limited availability at short distances from the low-flow channel. Therefore, the perennial stream flow would not contribute to the available water laterally in the incised channel and riparian zone floodplain domains.
- Dewatering of the proposed pit would lower the water table beneath Weeli Wolli Creek and the riparian zone. Predicted drawdown distributions (Figure 6-2 to Figure 6-3, in particular) were used to define changes in depths to the water table. Schematic cross-section representations of the changes in water table settings from baseline, current and PBS mining situations are shown on Figure 7-5 and Figure 7-6 for the southern (Pocket) and northern (Cue) settings, respectively. In lowering the water table:
  - Stream flow on Weeli Wolli Creek would be intercepted, in part, and the water table would become disconnected from the low-flow channel. The disconnection of the water table from the low-flow channel would broadly replicate the baseline settings, albeit there would be perennial recharge to the water table from stream flow in the low-flow channel. The perennial stream flow would sustain the surface water to groundwater interaction beneath the low-flow channel. Assuming that the interpreted loss rates (0.02 to 9.24 ML/km/day) for local reaches of Weeli Wolli Creek (Dogramaci, et al., 2015a; and Pettett and Pearcey, 2014) remain representative, perennial stream flow on Weeli Wolli Creek would prevail on reaches upstream of the Marillana Creek confluence. Calculations based on the interpreted loss rates indicate that stream flow of 35 GL/annum derived from Hope Downs 1 Mine would progressive dissipate over reaches of Weeli Wolli Creek to distances of 21.7 to 22.6 km downstream of Weeli Wolli Spring. These distances extend about 4 km downstream of the Marillana Creek confluence.
  - Stream flow would sustain the surface water and pore water availability beneath the low-flow channel domain.

- Beneath selected local reaches of Weeli Wolli Creek adjacent to PBS the simulated wetting fronts and other circumstances tend to limit the predicted drawdown as shown on Figure 6-2 to Figure 6-6, inclusive. These reaches were represented with the floodplain aquifer being perennially recharged from stream flow and underlain by low-transmissivity Weeli Wolli Formation.
- Drawdown of the available groundwater sources was predicted to propagate beneath the entire local riparian zone, albeit at different magnitudes and tending to typically increase over time.
- Based on the Figure 6-2 and Figure 6-3 predictive drawdown snapshots was a reasonable worst-case expectation that over a one-year to three-year period, drawdown in the range from 20 to 30 m could occur beneath all of the local riparian stands. Drawdown of this magnitude broadly equates to lowering of the water table at rates of 0.5 to 1.0 m per month. A schematic that provides perspective for the change in water table settings in context to interpreted root depths of *E. victrix* is shown on Figure 7-7.

The water availability assessments have been based on the stream flow and groundwater resources data, with consideration in context to riparian zone water availability. Templates (Figure 7-8) for the conceptualisation of water availability were developed to support this assessment given the presence of surface water and groundwater wetting fronts on Weeli Wolli Creek, and proposed future groundwater abstraction for mining of PBS. The templates conceptually represent the four identified riparian zone domains (low-flow channel, incised-channel, riparian floodplain and broader floodplain) together with the water table settings on a cross-section within the northern portion of the PBS project area. These templates reasonably typify the local water availability circumstances under baseline, current and PBS scenarios. In settings outside of the predicted PBS drawdown footprint, the current water availability circumstances would prevail for the duration of the PBS Project assuming Hope Downs 1 Mine continues to discharge surplus groundwater.

Applications of these data were made recognising a number of reasonable insights and/or assumptions, including:

- Weeli Wolli Creek, as with other creeks, forms a focus for both surface water and groundwater flows. In comparative terms, the associated riparian zone represents a setting of enhanced water availability.
- The riparian zones are mature and sustainable landforms. Therefore the baseline surface water and groundwater availabilities provide reasonable guides on future water demands required to maintain the existing systems.
- The riparian zones may not represent steady-state conditions. It was recognised that water availability varies widely in the natural environment. Episodic flood frequencies together with drought provide influences that cause the waxing and waning of riparian zone distributions and health. Therefore, the riparian zones are considered as adaptive features of the natural landscape and likely to be sustainable, albeit in different forms, under changing environmental conditions, including variations in actual water availability. In this regard, the riparian zones are unlikely to represent a steady-state, rather a snapshot of responses to antecedent conditions, including available water, competition and other stresses. As such there is an expectation that the riparian zones

and associated conditions may wax and wane from a typical distribution and condition depending on water availability.

- Three water sources were interpreted to support the riparian zone, including:
  - Surface water flows, including direct rainfall, stream flow (in the low-flow and incised channels) and overland flow (from the hinterland and from flood events).
  - Surface water to groundwater interaction, thus flow and water in storage in the unsaturated profile represented by pore water in the interstitial fabrics of the alluvial and CID successions.
  - Groundwater from settings below the water table.
- The baseline settings provide indications of riparian zone function, including:
  - Recognition that the riparian zone is preferentially developed along the main low-flow channel of Weeli Wolli Creek and where captured by secondary braided channels.
  - Perimeter zones located away from the major watercourses of Weeli Wolli Creek also provide information on water availability and predominant sources.

  These aspects reinforce the importance of surface water in the riparian zone functionality, particularly, understanding that there is progressive degradation of riparian zone consistency, condition and character in moving away from the surface water source areas. In fundamental terms, the riparian zone functions every day of the year; so there is water available, with surface water being the initial source that episodically rewets the system. Based on this fundamental, there should be a 365 day supply equation. The riparian zones would appear not to be dependent on the presence of surface water because it has limited presence over much of the year. Similarly, deep water table settings are not aligned with themes of groundwater dependency. For example, the perimeter riparian zones are infrequently inundated and underlain by comparatively deep water table settings. By extension, therefore, the predominant water dependency for the riparian zone would be pore water, with contributions from surface water and groundwater being subordinate. These attributes support indications of riparian zone functionality based predominantly on surface water wetting and pore water availability. Riparian zones that are wetted more frequently have similar characteristics, but with increased density and diversity, and improved condition, due to increased pore water availability linked to increased frequency of surface water rewetting events.

- Water availability would be different within the discretised low-flow, incised channel, riparian zone floodplain and broader floodplain domains of Weeli Wolli Creek.
- Direct rainfall provides a source for available water. It was assumed that a 10 mm daily rainfall event was the minimum depth required to contribute to the available water. On average events of 10 mm depth or greater occur during 10 days each year (Chapter 3.1.1 and Chapter 5.4.1)
- The local watershed from catchment areas adjoining the floodplain to Weeli Wolli Creek also contributes to the available water. On average it is assumed that the events of 10 mm depth or greater that provide stream flow also provide overland flow contributions during 10 days each year.
- The records for Tarina and Waterloo Bore provide reasonable baseline attributes for stream flow occurrences on Weeli Wolli Creek. It was assumed that stream flow in the

low-flow channel and incised channel is 20 days per annum, thus between the 13 to 38 day range measured at Tarina and Waterloo Bore.

- Pore water, within the unsaturated zone above the water table, is typically available year-round, but may not be the preferential source during periods of overland flow and/or re-wetting by surface water. This aspect recognised the natural balance between water availability and demand that enables the riparian zone presence. Monitoring bore hydrographs for settings beneath the riparian zone floodplain and broader floodplain show episodic wetting linked to overland flood flows that respond shortly after the rainfall events, peak in terms of recharge to the water table up to six months later, and decay over extended periods of three years or more. It was assumed that similar wetting characteristics could be reasonably applied to the unsaturated zone, understanding that after periods of saturation or high water pore water contents that may occur over six month periods, there would be progressive decay linked to interception by evaporation, vertical drainage and use by riparian vegetation (transpiration and respiration).
- The surface water and pore water sources cumulatively form a year-round (365 day) perennial water availability within the riparian zone settings where there is no groundwater dependency.
- Groundwater was assumed to be a potential perennial year-round source for water table depths to a maximum of 20 m; for depths to the water table greater than 20 m it was assumed that groundwater was unavailable to any component of the riparian zone. It is only Eucalypts that may access the deep groundwater; most floristic components of the riparian zone would not have access to groundwater at this depth. Therefore, for groundwater it was also recognised that there may be variable demand depending on depths to the water table; the groundwater is available year-round but may not be preferentially sourced. In this regard, five water table zones were discretised and used to factor reduced groundwater demand under progressively deeper water table settings. The five discrete water table zones included:
  - 0 to 2 m Depth: It was assumed that groundwater in this setting was available for 85 per cent of each year (310 days).
  - 2 to 6 m Depth: It was assumed that groundwater in this setting was available for 60 per cent of each year (219 days).
  - 6 to 12 m Depth: It was assumed that groundwater in this setting was available for 30 per cent of each year (110 days).
  - 12 to 20 m Depth: It was assumed that groundwater in this setting was available for 10 per cent of each year (37 days).
  - Greater than 20 m depth: It was assumed that groundwater at this depth was not available to support the riparian vegetation.

A consolidation of the interpreted water availability and persistence each year across the four discretised riparian zones for the baseline, current and PBS scenarios is shown in Table 7-2. The conceptualisation of the annual water dependency across the riparian zones is also shown on Figure 7-9, Figure 7-10 and Figure 7-11 for the baseline, current and PBS scenarios, respectively. The available water is also discretised for the three different potential sources. For the PBS scenario the assessment was informed by the overlay of predicted drawdown on the riparian zones as shown on Figure 7-12.

Subsequently, the information in Table 7-2 was used to provide context to potential riparian zones annualised dependency on surface water, pore water and groundwater (Table 7-3). In this regard, each source had a maximum annual availability of 365 days. For the groundwater sources, the 365-day availability described in Table 7-2 was further rationalised assuming decreasing dependency as the depth to the water table increased, as follows:

- Groundwater from the water table at 0 to 2 m depth was assumed to be available for 85 per cent of each year (310 days).
- 2 to 6 m depth: groundwater availability for 60 per cent of each year (219 days).
- 6 to 12 m depth: groundwater availability for 30 per cent of each year (110 days).
- 12 to 20 m depth: groundwater availability for 10 per cent of each year (37 days).

It was recognised that the groundwater availability was probably conservatively high. This recognition was informed by realisation that i) available water would be preferably sourced and depleted from shallow depths before being drawn from deeper groundwater settings; ii) significant portions of the water availability profile would be unaltered in transition from the current to PBS scenarios; iii) the groundwater environment filled from the bottom up (thus not from the top down) and consequently did not enhance surface water and pore water availability throughout the majority of the riparian zone; and iv) groundwater availability is unlikely to reflect use, particularly for the deeper water table settings. With reference to Figure 7-8 it was reconciled that typically:

- The upper-most 25 per cent of the incised channel profile would be unaltered in transition from current to PBS scenarios. In this profile, presumably where the root architecture is preferentially developed the surface water and pore water availability would not be changed.
- Similarly the upper-most 30 and 50 per cent of the riparian zone floodplain and broader floodplain would be unaltered in context to available water.

These aspects were not applied to the low-flow channel due to the persistence of surface water across all scenarios.

These perspectives were used to further limit the groundwater availability from that described above. For the respective incised channel, riparian zone floodplain and broader floodplain, the groundwater availability was reduced 25, 30 and 50 per cent respectively to account for the absence of disturbance to the upper-most root zones. This approach limits some of the conservatism in the estimated groundwater availability and highlights where most change may have or may occur.

Thereafter, the annual dependency for the surface water, pore water and groundwater sources was determined based on the linear interpolation between their availability (days per annum) and the cumulative (total annual availability of all sources) water availability.

In Table 7-4, the annualised water dependencies for the individual sources (from Table 7-3) were collated and compared to reflect:

- Percentage contributions from each source.

- Net percentage changes in the dependency contributions from each source compared to the baseline. This simply reflects the difference between the baseline contributions and corresponding contribution from the current or PBS scenario in the same setting.
- Relative percentage changes in water dependency based on proportional widths of the low-flow, incised channel and riparian zone floodplain domains to the total width of the riparian conservation zone. For example, the low-flow channel domain width is 8 per cent of the total riparian conservation zone width. Therefore for this zone, the net percentage change was multiplied by 0.08.

The tabulated and illustrated (Figure 7-2 to Figure 7-4, inclusive) conceptualisation of water availability, dependency and change provide indications that the discharge of surplus water to Weeli Wolli Creek has enriched water availability. In particular this is evident within the low-flow channel domain where surface water is perennially present together with a shallow water table. The presence of perennial stream flow represents a transparent enrichment of water availability whilst that associated with a shallow water table environments is less apparent.

In settings not influenced by drawdown of the water table due to dewatering of PBS, the current scenario of water availability would prevail whilst the Hope Downs 1 Mine continues to discharge surplus groundwater.

Table 7-2 Interpreted Persistence of Available Water Sources within a One-Year Period

Water Source	Persistence of Potential Riparian Zone Water Sources (days per annum)											
	Baseline				Current				PBS			
	Low-Flow	Incised Channel	Riparian Zone	Broad Plain	Low-Flow	Incised Channel	Riparian Zone	Broad Plain	Low-Flow	Incised Channel	Riparian Zone	Broad Plain
Surface Water												
Direct Rainfall[1]	10	10	10	10	10	10	10	10	10	10	10	10
Local Watershed[2]	10	10	10	10	10	10	10	10	10	10	10	0
Stream Flow[3]	25	0	0	0	365	0	0	0	365	0	0	0
Flood[4]	0	18	12	2	0	18	12	2	0	18	12	0
Total	**45**	**38**	**32**	**22**	**385**	**38**	**32**	**22**	**385**	**38**	**32**	**10**
Surface Water to Groundwater Interaction (Pore Water)												
Pore Water[5]	365	365	365	365	365	365	365	365	365	365	365	365
Water Table Zone[6]												
0 to 2 m Depth	-	-	-	-	365	-	-	-	-	-	-	-
2 to 6 m Depth	-	-	-	-	-	365	365	-	-	-	-	-
6 to 12 m Depth	-	-	-	-	-	-	-	365	-	-	-	-
12 to 20 m Depth	365	365	365	-	-	-	-	-	365	-	-	-
>20 m Depth	-	-	-	365	-	-	-	-	-	365	365	365

Notes:

1 Direct Rainfall of at least 10 mm occurs on average 10 days each year.

2 Local Watersheds were assumed to provide overland flow to the riparian zone at times that daily rainfall exceeds 10 mm depth.

3 Stream Flow in low-flow channel being 25 days per annum, thus midway between the 13 to 38 days range measured at Tarina and Waterloo Bore.

4 Flood events that extend beyond the incised channel (less than 2-year ARI for the incised channel and less frequent than 20-year ARI for the wider floodplain areas.

5 It was assumed that pore water is typically available year-round, but may not be the preferential source during periods of overland flow and or re-wetting by surface water. This assumption was based on monitoring bore hydrographs and understanding that similar wetting characteristics could be reasonably applied to the unsaturated zone, recognising also that after periods of saturation or high water pore water contents that may occur over six month periods there would be progressive decay linked to interception by evaporation, vertical drainage and use by riparian vegetation.

6 Based on observed typical depths to the water table and prediction of drawdown for Billiard South.

Table 7-3 Change Assessment of Water Availability and Interpreted Annualised Dependency

Interpreted Aspects	Change Assessment on Riparian Zone Water Availability (days per annum)											
	46 m Low-Flow Channel			100 m Incised Channel			450 m Riparian Zone Floodplain			1,800 m Broader Floodplain		
	Current	Baseline	PBS	Current	Baseline	PBS	Current	Baseline	PBS	Current	Baseline	PBS
Surface Water												
Availability	365	45	365	38	38	38	32	32	32	22	22	10
Surface Water to Groundwater Interaction (Pore Water)												
Availability	365	365	365	365	365	365	365	365	365	365	365	365
Potential Water Table Zone Dependency												
0 to 2 m Depth	310	-	-	-	-	-	-	-	-	-	-	-
2 to 6 m Depth	-	-	-	164	-	-	153	-	-	-	-	-
6 to 12 m Depth	-	-	-	-	-	-	-	-	-	55	-	-
12 to 20 m Depth	-	37	37	-	37	-	-	37	-	-	-	-
>20 m Depth	-	-	-	-	-	0	-	-	0	-	0	0
Cumulative Potential Water Availability and Dependency												
Availability	1,040	447	767	567	440	403	550	434	397	442	387	375
Interpreted Annualised Riparian Zone Water Dependency[1]												
Surface Water	128	37	174	24	32	34	21	27	29	18	21	10
Pore Water	128	298	174	235	303	331	242	307	336	301	344	355
Groundwater	109	30	18	106	31	0	102	31	0	45	0	0

Notes:

1 This dependency is based on a linear relationship between comparably percentage availability of individual sources and dependency.

Table 7-4 Comparisons of Changes in Water Dependency Compared to Baseline

Interpreted Aspects	Water Dependency Change Assessment Compared to Baseline (percent)											
	46 m Low-Flow Channel			100 m Incised Channel			450 m Riparian Zone Floodplain			1,800 m Broader Floodplain		
	Current	Baseline	PBS	Current	Baseline	PBS	Current	Baseline	PBS	Current	Baseline	PBS
Zone Width	8			17			76			Not Assessed		
Availability[1]	365	100	365	141	100	92	142	100	92	117	100	88
Interpreted Source Contributions to Water Dependency[2]												
Surface Water	35	10	48	7	9	9	6	7	8	5	6	3
Pore Water	35	82	48	64	83	91	66	84	92	83	94	97
Groundwater	30	8	5	29	8	0	28	9	0	12	0	0
Interpreted Net Percentage Changes in Dependency Sources Compared to Baseline[3]												
Surface Water	25	-	38	(2)	-	1	(2)	-	1	(1)	-	(3)
Pore Water	(47)	-	(34)	(19)	-	8	(18)	-	8	(12)	-	3
Groundwater	22	-	(3)	21	-	(8)	20	-	(9)	12	-	0
Relative Percentage Changes Across the Riparian Conservation Zones[4]												
Surface Water	2	-	3	0	-	0	(2)	-	1	-	-	-
Pore Water	(4)	-	(3)	(3)	-	1	(18)	-	6	-	-	-
Groundwater	2	-	0	3	-	(1)	19	-	(6)	-	-	-

Notes:

1 The changes in availability reflect percentage differences in the cumulative potential water availability (days) described in Table 2. Where there is perennial surface water presence, the availability is 365 days.

2 This dependency is based on a linear relationship between comparably percentage availability of individual sources and dependency.

3 The changes in dependency sources compared to baseline are discrete assessments within the specified low-flow channel, incised channel, riparian zone floodplain and broader floodplain domains.

4 The relative changes across the riparian conservation zones rationalise that the interpreted dependency changes in the low-flow channel, incised channel and riparian zone floodplain zones respectively, represent 8, 17 and 76 per cent of the 600 m width Riparian Conservation Zone.

Values in parentheses are negative; less than, compared to baseline.

7.7 Discussion on Water Availability and Dependency

There are a number of other important attributes of the water availability assessments. For the surface water and pore water sources these include:

- The baseline environments reflect surface water and pore water dependencies. The available water was predominantly sourced from direct rainfall and episodic flood events.
- Retention of perennial stream flow in the low-flow channel would sustain the surface water and pore water availability within the low-flow channel domain. As the water table is lowered by pit-dewatering abstractions, the perennial stream flow would provide continuous wetting fronts that in effect provide an irrigation source that replenishes pore water. As a general rule, water availability would remain comparatively high but as pore water and not groundwater.
- There was an assumed reduction in surface water and pore water dependency because of the increased presence of groundwater.

Table 7-5 contextualises the changes in surface water and pore water dependency (low, medium and high) for the different local riparian floristic communities (as shown on Figure 1-2) across the baseline, current and PBS scenarios. The changes in dependency were contextualised based on:

- Cumulative surface water and pore water availability of greater than 85 per cent correlates to High dependency.
- Cumulative water availability of about 60 per cent correlates to Medium-High dependency.
- Cumulative water availability of about 30 per cent correlates to Medium dependency.
- Cumulative water availability of about 10 per cent correlates to Low dependency.

This approach is compatible to that used to determine the groundwater dependency, with similar percentage contributions (Table 7-3) used to define low to high surface water and pore water dependency.

Note that the PBS scenario reflects drawdown of the water table to provide dry mining conditions. In settings where there is no drawdown the current scenario; perennial surface water in the low-flow channel and associated groundwater wetting fronts would prevail.

Table 7-5 Potential Surface Water and Pore Water Dependency of Riparian Floristics

Setting	Floristics[1]	Scenarios and Potential Dependence on Cumulative Surface Water and Pore Water		
		Current	Baseline	PBS
Low-Flow Channel	Major Creek Line: *E camaldulensis* and *E. victrix* woodland over *M. argentea*, *M. glomerata* and Acacia low open woodland.	Medium – High	High	High
	Scoured Creek Channel: *E. camaldulensis* and *E. victrix* scattered trees over Acacia woodlands and *M. glomerata*.			
Incised Channel	Major Creek Line: *E camaldulensis* and *E. victrix* woodland over *M. argentea*, *M. glomerata* and Acacia low open woodland.	Medium - High	High	High
	Scoured Creek Channel: *E. camaldulensis* and *E. victrix* scattered trees over Acacia woodlands and *M. glomerata*.			
Riparian Floodplain	Floodplain: *E. victrix* or *E. xerothermica* scattered trees over Acacia low woodland.	Medium – High	High	High
Broader Floodplain	*E. victrix* or *E. xerothermica* scattered trees over Acacia low woodland.	High	High	High
Notes:				
1 From Figure 1-2.				

For the groundwater environment it was recognised that the dependency was initially based on baseline water availability and subsequently these were applied to altered baseline scenarios. This approach may tend to overestimate groundwater dependencies for the altered baseline scenarios. Also for the groundwater sources there are other attributes of the water availability assessments, including:

- There may be change to the groundwater dependency, with potential deficits due to lowering of the water table.
- Contextually, the most significant changes in water availability are linked to:
  - The presence of perennial stream flow in the low-flow channel.
  - Lowering of the water table due to abstractions for pit dewatering.

As such, the different local riparian floristic communities (as shown on Figure 1-2) were considered in context to potential changes in groundwater dependency (high, medium and low) across the baseline, current and PBS scenarios. This assessment was informed by the changes in depths to the water table outlined in Table 7-3 and Table 7-4 with the understanding that:

- Groundwater availability of greater than 85 per cent correlates to High dependency.
- Groundwater availability of about 60 per cent correlates to Medium-High dependency.
- Groundwater availability of about 30 per cent correlates to Medium dependency.
- Groundwater availability of about 10 per cent correlates to Low dependency.
- Below 20 m depth there is no dependency.

The findings on changes regarding groundwater dependency are outlined in Table 7-6. The tabulated high, medium and low groundwater dependencies reinforce that the baseline settings may be atypical in context to normal expectations for Pilbara riparian zones. In particular, there are noticeable differences between the low-flow channel and incised channel settings where the presence of *M. argentea* and *E. camaldulensis* would indicate high groundwater dependencies, but the baseline water table is comparatively deep. The presence of *E. camaldulensis* and *M. argentea* woodland is limited to the southern project area and possibly attributed to surface water and pore water wettings fronts associated with perennial baseflow from Weeli Wolli Spring. Elsewhere beneath the riparian floodplain and broader floodplain domains, the comparatively low baseline water table settings reflect lower groundwater dependency than typically expected.

These themes are similar to those identified (Loomes, 2010) in determining water level ranges of Pilbara riparian trees.

Table 7-6 Potential Groundwater Dependency of Riparian Floristics

Setting	Floristics[1]	Scenarios and Potential Groundwater Dependence			
		Typical[2]	Current	Baseline	Billiard South
Low-Flow Channel	Major Creek Line: *E. camaldulensis* and *E. victrix* woodland over *M. argentea*, *M. glomerata* and Acacia low open woodland.	High	Medium	Low	Low
	Scoured Creek Channel: *E. camaldulensis* and *E. victrix* scattered trees over Acacia woodlands and *M. glomerata*.	Medium			
Incised Channel	Major Creek Line: .*E camaldulensis* and *E. victrix* woodland over *M. argentea*, *M. glomerata* and Acacia low open woodland.	High	Medium	Low	None
	Scoured Creek Channel: *E. camaldulensis* and *E. victrix* scattered trees over Acacia woodlands and *M. glomerata*.	Medium			
Riparian Floodplain	Floodplain: *E. victrix* or *E. xerothermica* scattered trees over Acacia low woodland	Low - Medium	Medium	Low	None
Broader Floodplain	*E. victrix* or *E.* xerothermica scattered trees over Acacia low woodland	Low - Medium	Medium	None	None
Notes:					
1 From Figure 1-2.					
2 As interpreted from Table 7-1					

The water availability and dependency assessments indicate that the surface water and groundwater wetting fronts have reduced surface water and pore water dependencies, with commensurate increases in groundwater dependency. Further:

- The sustained stream flow within the low-flow channel in the transition from current to PBS scenarios provides the latter scenario with higher water availability compared to the baseline setting.
- There was no change in the interpreted surface water and pore water availability for the incised channel and riparian zone floodplain domains across all three scenarios.
- The interpreted maximum dependency on groundwater ranged from 12 to 30 per cent of the overall water dependency, thus representing a subordinate supply source.
- There are potential deficits in the available water within the incised channel and riparian zone floodplain during the PBS scenario compared to the baseline setting.

A summary of the potential implications of the described changes in water availability and source dependencies is provided in Table 7-7. The perspectives described reflect both changes from baseline and those that would occur linked to the PBS scenario. As such, the changes account for the sustained presence of wetting fronts and conversely drawdown of the water table in different settings on Weeli Wolli Creek. The cumulative changes would reflect:

- Increased water availability in transition from baseline to current scenarios.
- Reduced water availability in the transition from current to PBS scenarios.

Increased water availability was linked to surface water and groundwater wetting fronts providing perennial stream flow and mounding of the water table. In Table 7-4, this change was described as a 25 per cent increase in surface water availability in the low-flow channel and 12 to 22 per cent increases in available groundwater. The cumulative reductions in groundwater availability derived from Table 7-4 range from 12 to 29 per cent.

Reduced water availability was linked to drawdown of the water table and rapid depletion of the available groundwater above the baseline water table. In practise, all of the available groundwater would not dissipate; there would be residual field capacity in the alluvial soils that would initially be available. Therefore it was assumed that about 20 per cent of the 12 to 22 per cent losses would be off-set by the presence of pore water. The 20 per cent reflects typical differences between porosity and wilting point might be expected in alluvial soils. Cumulative reductions in groundwater availability in the transition from current to PBS scenarios have been estimated as:

- Low-flow channel – 21 per cent.
- Incised channel – 25 per cent.
- Riparian zone floodplain – 25 per cent.
- Broader floodplain – 10 per cent.

In relative terms, the implications associated with the incised channel and riparian zone floodplain would be most significant given these two domains account for 17 and 76 per cent of the riparian conservation zone areas, respectively.

Table 7-7 Potential Implications of Changes in Water Availability as a Result of the PBS Project

Setting	PBS Change Aspect	Interpreted Implications	Magnitude of Change	Predicted Ecological Consequence of Change
Low-Flow Channel	Presence of perennial stream flow.	Waterlogging of soils and permanent inundation of deeper root zones on reaches to the north of PBS (from the proposed discharge point on Marillana Creek).	Interpreted 25 per cent increase in surface water and 22 per cent increase I available groundwater, with commensurate decrease in pore water availability in the range 34 to 47 per cent compared to baseline. Waterlogging would be associated with a portion of these changes.	• Decline in canopy cover of mature eucalypts with death of some individuals. • Greater decline and tree deaths for *E. victrix* relative to *E. camaldulensis,* however, *E. camaldulensis* individuals may also exhibit reduced canopy cover. • Increase or no change in canopy cover of mature *M. argentea.* • Increase in juvenile eucalypt and *M. argentea* biomass with increase in relative abundance of *M. argentea* within riparian vegetation community over time. • Increase in understorey vegetation biomass, particularly an increase in cover/abundance of some aquatic macrophytes (e.g. Typha).
		Increased groundwater availability; groundwater dependency raised from Low to Medium.	Groundwater dependency to reduce from Medium to Low.	• Increase in foliage cover of *E. camaldulensis* and *E. victrix*. • Increase or no change in canopy cover of mature *M. argentea.* • Increase in juvenile eucalypt and *M. argentea* biomass with potential increase in relative abundance of *M. argentea* over time. • Increase in understorey vegetation biomass where surface water and pore water availability has increased.
		Increased surface water and pore water availability. Surface water and pore water dependency reduced from High to Medium-High.	Surface water and pore water dependency to increase from Medium - High to High.	
	Drawdown of the water table below current elevations.	Groundwater availability deficit.	Limited assuming the stream flow source is sustained and adequately offsets current dependencies on groundwater.	• Decline in canopy cover of *M. argentea*, *E. camaldulensis* and *E. victrix*. • Stabilisation over time of *M. argentea, E. camaldulensis* and *E. victrix* as majority of individuals acclimatise to stream flow irrigation and baseline natural rainfall and flooding events.
Incised Channel Riparian Zone Floodplain Broader Floodplain	Surface water and groundwater wetting fronts have raised the water table.	Increased groundwater availability from less than 10 to within the range 12 to 30 per cent.	Interpreted 12 to 22 per cent increase in available groundwater, with 8 to 19 per cent reduction in pore water availability beneath the incised channel and riparian zone floodplain compared to baseline. Waterlogging would be associated with a portion of these changes.	• Increase in foliage cover of *E. camaldulensis* and *E. victrix*. • Increase or no change in canopy cover of mature *M. argentea*. • Increase in juvenile eucalypt and *M. argentea* biomass with potential increase in relative abundance of *M. argentea* over time.
		Groundwater dependency change from Low to Medium.		
		Waterlogging of deeper soil profiles and root zones on reaches to the north of PBS.		
	Drawdown of the water table at least 20 m below current elevations.	Rapid depletion of the available groundwater. Short time for adaptation to residual pore water.	Revert to baseline availability on surface water and pore water. Groundwater dependency would reduce from Medium to Low and over time to None.	• Rapid decline in canopy cover of *M. argentea*, and *E. camaldulensis* and *E. victrix* previously accessing groundwater. • Death of *M .argentea* beyond influence of groundwater discharge wetting fronts. • Potential death of some E*. camaldulensis* but stabilisation over time of *E. camaldulensis and E. victrix* as some individuals acclimatise to baseline natural rainfall and flooding events. • Fluctuating eucalypt canopy cover over time in response to rainfall and flood events with potentially significant declines in canopy cover during periods of prolonged drought. • Reduced recruitment of *M. argentea* and eucalypts due to absence groundwater to sustain post-germination growth. • Little or no impact to trees established within the broader floodplain assuming natural rainfall and flood events are maintained.
		Groundwater availability deficit compared to current scenario.	Interpreted decreases ranging from 12 to 22 per cent. A portion of this potential change would be off-set by pore water. It was assumed that pore water would provide a 20 percent off-set to this change, decreasing the future change magnitudes to 10 and 18 per cent.	
	Drawdown of the water table to lower than the baseline elevations.	Water availability deficit.	Groundwater dependency reduced from Low to None.	
			From 3 to 9 per cent compared to baseline.	

Perspectives on potential changes in water availability linked to drought periods and a flood event have been used to provide context for the estimated cumulative reductions in water availability and the range of natural variability. The drought scenarios were derived from measured rainfall and stream flow (Table 3-2) during the period 1989 to 1992, inclusive. This period was characterised by low rainfall (about half the annual average) and low stream flow. Conversely, 1997 had high rainfall and high stream flow. These perspectives based on are shown in Table 7-8.

Table 7-8 Perspectives on Water Availability Changes during Drought and Flood

Water Budget	Percentage Change from Typical Annualised Water Availability			
	Low-Flow Channel	Incised Channel	Riparian Zone Floodplain	Broader Floodplain
1-Year Drought	15	14	14	18
4-Year Drought	27	29	33	54
1997 Flood	8	5	4	2

Based on the data in Table 7-8 it may be expected that the typical natural range of change from one year to the next may be less than 15 per cent. An extended drought would likely lead to significant stress and change given reductions in water availability in the range 30 to 50 per cent from normal (typical) conditions.

8 RIPARIAN ZONE ENVIRONMENTAL RISK ASSESSMENT

8.1 Formalities

The concepts of water availability are significant in regard to understanding the functionality of riparian zones. This risk assessment is based on the understanding of potential changes to water availability. The riparian zone environmental risk assessment is focussed on the receptors formed by riparian zones on Weeli Wolli Creek.

The current surface water and groundwater environments are temporary and cannot be sustained. Future changes would be inevitable once the discharge of surplus water ceases, or is substantially reduced. Under these circumstances, the water availability for the riparian zone associated with Weeli Wolli Creek would decline towards baseline conditions. Reductions to stream flow and associated surface water wetting fronts would occur in immediate terms. Limited changes to the local hydrology would however preserve the surface water and pore water re-wetting mechanisms and hence availability. The water table would progressively return to baseline settings at rates of decline from 2.0 to 2.5 m per annum; this rate would tend to mimic that observed from monitoring bore hydrographs after episodic recharge events.

It is difficult to quantify the potential increase in riparian zone dependency on the enriched water availability, both in context to surface water and groundwater sources. Further, there may be differences in the adaptability of riparian vegetation stands to changes in both water availability and sources of available water. Recent evidence (McLean, Ludwig and Grierson, 2011; McLean, 2013; Argus, Colmer and Grierson, 2014) shows that riparian zone vegetation may respond in different ways to episodic drying and flood cycles and, may be vulnerable (particularly for *M. argentea*) to changes in the availability of surface water and near-surface water sources. This evidence suggests there is not one set of rules that dictates likely responses for individual species, genera or within discrete domains in the riparian zone. As such heterogeneous and unique responses to changes in water availability and sources should be expected. These attributes of the riparian zones make it difficult to benchmark potential risks when there is a change in water source and water availability. In general, however, riparian vegetation is likely sensitive to significant changes in water availability and dependency sources. Therefore, the risk would predominantly depend on the adaptability of riparian floristics:

- To increase surface water and groundwater availability, including potential waterlogging of root zones.
- Perennial presence of stream flow and water table mounding into root zones.
- To alternative water sources in circumstances of reduced groundwater availability.
- To revert to baseline dependencies on surface water and pore water.
- To net reductions in total water availability.

Ecological Water Requirements (EWR) of the riparian zones (Loomes, 2013) on Weeli Wolli Creek may be maintained by the following sources of water availability:

- Retention of perennial surface water flows, at least initially, to support gradual adaption.
- Limiting changes to periods of high floodwater availability.
- Avoidance of drawdown of the water table.

The PBS scenario captures two of these linkages, but not retention of groundwater availability; albeit that it is not a natural occurrence. Lowering of the water table for mining would rapidly deplete the groundwater availability in the CID aquifer, and would also result in lowering of the water table in the alluvial successions supporting the riparian vegetation. There would, however, be an increase in the residual pore water. Under these circumstances, the riparian Eucalypt and Melaleuca floristics would probably experience drought-like conditions. The scale of the changes in the water availability may lead to changes in and decay of riparian floristics, particularly the reduction/loss of groundwater dependent species such as *M. argentea*, and decline of some Eucalypt species (typically over-story species) adapted to the shallow water table. This may also have an impact on riparian vegetation structure. The maintenance of riparian vegetation would be dependent on numerous independent factors, including:

- Influences of sustained and episodic waterlogging of root zones and associated access to and adaptability of riparian vegetation to alternative water sources.
- Actual groundwater dependency. That is, the degree of dependency on existing (increased) groundwater compared to pore water.
- Ability of the riparian vegetation to revert to pore water sources as groundwater availability declines due to drawdown of the water table.
- Pore water availability off-setting the reduction in groundwater dependency.
- Rates of decay of the available groundwater.
- Rates of decay of the available pore water.
- Competition for the available water.
- Abilities of individual trees to become dormant or reduce water demand as water availability declines below critical levels (for example individual trees shedding biomass as water availability declines). It is recognised that this is a trait of *E. victrix*.

Perspectives regarding changes in health and condition of selected riparian tree species under a range of change circumstances associated with lowering of the water table (drawdown) and reductions in groundwater availability have been developed based on observations on Weeli Wolli and Marillana creeks. These perspectives and collated general change themes are described in Table 8-1 and Table 8-2. Note that the outlined perspectives are semi-quantitative. Also, they do not address perspectives linked to increased water availability and waterlogging. Note in context to the changes in depth to the water table that:

- The natural rates of water table decline after episodic events are 2.0 to 2.5 m/annum. Over time these rates decrease as the hydraulic gradients are lowered.
- A fluctuation of 2 to 5 m is within the observed range of episodic mounding of the water table after recharge events.

The observational-based perspectives shown in Table 8-1 and Table 8-2 when considered in context to the detailed vegetation mapping (Figure 1-2b) provide indications that most sensitivity and risk to changes in water availability would be closely aligned with the Low-Flow and Incised Channel settings and associated *E. camaldulensis* co-dominated communities and *E. Camaldulensis* co-dominated communities with transient *M. argentea* populations (Figure 1-2b) that have high and medium-high groundwater and or surface water dependence.

Based on the observational perspectives, the *M. argentea* is most sensitive to reduced water availability, with high-risk thresholds associated with:

- Drawdown of 10 to 20 m, particularly in the absence of perennial stream flow.
    - A drawdown of 10 m is compatible to changes in groundwater availability beneath the Riparian Exclusion Zone from 8 to 17 per cent (Table 7-4).
    - A drawdown of 20 m is compatible to changes in groundwater availability beneath the Riparian Exclusion Zone from 25 to 29 per cent (Table 7-4).
- Reduced groundwater availability by greater than 30 per cent.

The *E. victrix* open woodlands over Acacia low woodlands and tussock grasslands and other *E. victrix* dominated communities appear less sensitive to drawdown of the water table and reductions in groundwater availability. Conversely, it has been recognised that *E. victrix* may be sensitive to waterlogging.

The observational and water availability perspectives tend to focus the risk assessment on:

- The *E. camaldulensis* and *M. argentea* habitats within the low-flow and incised channel settings of Weeli Wolli Creek.
- Settings where drawdown of the water table exceeds 20 m, again with a focus on *M. argentea* and *E. camaldulensis* stands.

In both regards, the *E. camaldulensis* demonstrates more robustness to change when compared to *M. argentea*. The *M. argentea* stands are sensitive and susceptible to reductions in groundwater availability, hosting the highest risk attributes particularly in the absence of proximity to perennial stream flow.

There was recognition that the developed risk assessment metrics are semi-quantitative, providing guidance rather than facts. In applying the metrics to assess the risk, there is intuition that low risk and high-risk domains would not abut in the low-flow channel and incised channel settings. The tendency in these settings was therefore to progressively transition the risk from low to medium, to medium-high and to high rankings dependent on water availability changes and predicted drawdown distributions.

Table 8-1 Perspectives on Riparian Tree Species Change due to Drawdown of the Water Table

Change in Depth to Water Table (m)	Descriptions of Expected Change Circumstances						Descriptions of Expected Change Circumstances – General Themes
	E. victrix	*E. xerothermica*	*E. camaldulensis*	*M. argentea*			
				Within 5 to 10 m of Low-Flow Channel	Within 10 to 25 m of Low-Flow Channel	Limited Proximity to Low-Flow Chanel	
Less than 2	Little to no change.	Little to no change.	Little to no change.	Little or no change.		Reduced condition.	Little influence beyond minor reduction in condition of obligate groundwater dependent species.
2 to 5				Reduced condition of mature trees.		Reduced condition and some potential for defoliation.	Little impact to eucalypts but some minor to moderate reduction in condition of obligate phreatophytes – particularly new recruits and individuals established under current hydrological regime.
5 to 10.	Potential for reduced condition during extended periods without flood flows.		Potential for reduced condition during extended periods without flood flows.	Potential defoliation with low potential for complete defoliation and apparent death (may revive).		Reduced condition and defoliation.	Minor reduction in eucalypt condition manifest during periods of extended drought and significant reduction in condition of obligate phreatophytes – particularly new recruits and individuals established under current hydrological regime.
10 to 15.	Reduced condition during extended periods without flood flows.	Potential for reduced condition.	Reduced condition with potential for defoliation during extended periods without flood flows.	Reduced condition.	Defoliation with potential for apparent death (may revive).	Defoliation likely with potential for fatality.	Minor reduction in eucalypt condition manifest during periods of extended drought and significant reduction and potential death of obligate phreatophytes – particularly new recruits and individuals established under current hydrological regime.
15 to 20.	Reduced condition during extended periods without flood flows.	Potential defoliation in some situations.	Defoliation with potential limb loss and some potential for fatality during extended periods without flood flows in historically enhanced (hydrological) situations.	Reduced condition and potential for defoliation.	Defoliation with increased potential for apparent death (may revive).	Fatality likely in some circumstances.	Moderate decline in eucalypt condition manifest during periods of extended drought and significant reduction and death of obligate phreatophytes – particularly new recruits and individuals established under current hydrological regime.
Greater than 20.	Reduced condition and defoliation during extended periods without flood flows.		Defoliation and limb loss with potential for fatality during extended periods without flood flows both in normal and historically enhanced (hydrological) situations.	Reduced condition and some defoliation.	Defoliation with increased potential for fatality.	Fatality likely.	Significant decline in condition and potential death of eucalypt during periods of extended drought and significant decline and death of obligate phreatophytes – particularly new recruits and individuals established under current hydrological regime.

Table 8-2 Perspectives on Riparian Tree Species Change due to Reduced Water Availability

Percentage Change in Groundwater Availability	Descriptions of Expected Change Circumstances						Descriptions of Expected Change Circumstances – General Themes
	E. victrix	*E. xerothermica*	*E. camaldulensis*	*M. argentea*			
				Within 5 to 10 m of Low-Flow Channel	*Within 10 to 25 m of Low-Flow Channel*	*Limited Proximity to Low-Flow Chanel*	
Less than 10	Little to no change.	Little to no change.	Little to no change.	Little or no change.		Potential for reduced condition.	Little influence beyond minor condition changes to highly groundwater sensitive species.
10 to 20	Potential for reduced condition.		Potential for reduced condition.	Reduced condition likely, some defoliation potential with low potential for complete canopy defoliation (apparent death; may revive).		Reduced condition and defoliation likely.	In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) little influence beyond moderate condition changes and potential for defoliation of highly groundwater sensitive species.
20 to 30	Reduced condition.	Potential for reduced condition.	Reduced condition probable with potential for some defoliation.	Potential for reduced condition.	Some defoliation likely, with potential for complete canopy defoliation (apparent death; may revive).	Defoliation likely with potential for fatality.	In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) potential significant influence on outlying highly groundwater sensitive species, with some potential for influence on sensitive eucalypt condition.
30 to 40		Reduced condition probable with potential defoliation in some situations.	Reduced condition likely with potential for defoliation and some potential for fatality in historically enhanced (hydrological) situations.	Reduced condition likely, with potential for some defoliation.	Varying degrees of defoliation likely with increased potential for complete canopy defoliation (apparent death; may revive).	Fatality likely in some circumstances.	In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) potential fatality for outlying highly groundwater sensitive species, with potential for influence on sensitive (*E. camaldulensis*) eucalypt species particularly where biomass is enhanced.
40 to 50	Reduced condition likely.	Reduced condition likely, with potential defoliation in some situations.	Defoliation probable with potential limb loss and some potential for fatality in normal and historically enhanced (hydrological) situations.		Defoliation likely with increased potential for fatality.		In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) some potential for significant fatality rates within outlying highly groundwater sensitive species populations, with potential for influence on sensitive (*E. camaldulensis*) eucalypt species particularly where biomass is enhanced.
50 to 60	Reduced condition likely, with potential defoliation in some situations.	. Defoliation in some situations likely, some potential for fatality in historically enhanced (hydrological) situations.	Defoliation and limb loss likely with fatalities both in normal and historically enhanced (hydrological) situations likely.	Reduced condition likely, defoliation likely, with potential for fatality increasing.	Defoliation highly likely with fatality likely in some areas.	Fatality likely.	In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) potential significant fatality rates within outlying highly groundwater sensitive species populations (as well as increasing influence on well positioned individuals), with increasing potential for significant influence on sensitive eucalypt species (including fatality) particularly where biomass is enhanced.
60 to 75	Defoliation in some situations likely, some potential for fatality in historically enhanced (hydrological) situations.				Defoliation highly likely with fatality likely.		In the typical spatial distribution zones of these species (in relation to surface and sub-surface water) significant impacts to outlying highly groundwater sensitive species likely (as well as increasing influence on well positioned individuals), with impacts on sensitive *E. camaldulensis* species likely (including fatality), particularly where biomass is enhanced.

The risk assessment applies the water availability (Table 7-3), interpreted water dependency and changes therein (Table 7-4) and the perspectives provided in Table 7-5 and Table 7-6 to rationalise reasonable semi-quantitative outcomes. The matrix on change aspects and interpreted perspectives provided in Table 7-7, Table 7-8, Table 8-1 and Table 8-2 have been used to inform the risk assessment. In this regard it was also rationalised that:

- A drawdown of 5 to 10 m correlated to 10 to 18 per cent reduction on groundwater availability.
- A drawdown of 10 to 20 m correlated to 18 to 25 per cent reduction in groundwater availability.

It is considered that the risk assessment is precautionary, tending to lever more off the *M. argentea* and *E. camaldulensis* aspects rather than *E. victrix*.

For the risk assessment, low, medium, medium high and high risks were categorised for the *E. Victrix* dominated communities and co-dominated floodplain vegetation, *E camaldulensis* co-dominated communities and *M. argentea* co-dominated communities as follows:

Risk Attributes	Percentage Change in Water Availability			
	<10	10 to 18	18 to 25	>25
	Drawdown of the Water Table (m)			
	<5	5 - 10	10 - 20	>20
***E. victrix* Increased Water Availability and Waterlogging (beneath the Low-Flow Channel and Incised Channel)[1]**				
Low		-	-	-
Medium	-		-	-
Medium High	-	-		-
High	-	-	-	
***M. argentea* and *E. camaldulensis* Decreased Water Availability Due to Drawdown[2]**				
Low		-	-	-
Medium	-		-	-
Medium High	-	-		-
High	-	-	-	

Notes:

1 Applicable beneath northern reaches of Weeli Wolli Creek under the current scenario where there is perennial stream flow and the water table s connected to the stream bed. Elsewhere, beneath the local reaches of Weeli Wolli Creek the *E. victrix* dominated communities, open woodlands and co-dominated floodplain vegetation are interpreted as low risk domains.

2 Applicable to the drawdown footprint of PBS beneath the low-flow and incised channel settings.

Further, the risk assessment reflects:

- Changes from the baseline to current scenarios, with increased surface water and groundwater availability.
- Changes from the current scenario in reverting to baseline water availabilities and surface water and pore water dependencies.
- Subsequent changes from the baseline scenario to reflect the Billiard South scenario.

The risk assessment is shown in Table 8-3.

Table 8-3 Riparian Zone Water Availability and Water Dependency Risk Assessment

Setting	Change Aspect		Risk Assessment											
			Current to Baseline Scenarios				Baseline to PBS Scenarios				Current to PBS Scenarios			
			Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain
***E. victrix* Increased Water Availability and Waterlogging (beneath the Low-Flow Channel and Incised Channel)[1]**														
Low-Flow Channel	Waterlogging.		Medium High	-	-	-	Low	-	-	-	Medium High	-	-	-
Incised Channel			-	Medium	-	-	Low	-	-	-	-	Medium	-	-
***M. argentea* and *E. camaldulensis* Decreased Water Availability Due to Drawdown[2]**														
Low-Flow Channel[3]	Presence of perennial stream flow.		Low	-	-	-	Low	-	-	-	Low	-	-	-
	Drawdown of the water table below current elevations.		Medium	-	-	-	Low	-	-	-	Medium	-	-	-
Incised Channel	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].	<5 m	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		5 – 10	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		10 – 20	-	Medium High	-	-	-	Low	-	-	-	Medium High	-	-
		>20	-	High	-	-	-	Low	-	-	-	High	-	-
Riparian Flood Plain	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].		-	-	Medium	-	-	-	Low	-	-	-	Medium	
Broader Flood Plain			-	-	-	Low	-	-	-	Low	-	-	-	Low

Notes:

1 Applicable beneath northern reaches of Weeli Wolli Creek under the current scenario where there is perennial stream flow and the water table s connected to the stream bed. Elsewhere, beneath the local reaches of Weeli Wolli Creek the *E. victrix* dominated communities, open woodlands and co-dominated floodplain vegetation are interpreted as low risk domains.

2 Applicable to the drawdown footprint of PBS beneath the low-flow and incised channel settings.

3 It was assumed that the sustained stream flow source would irrigate the underlying strata and adequately offset current dependencies on groundwater.

4 It was recognised that baseline surface water and pore water availabilities would prevail, which made up more than 90 per cent of the riparian source. Further it was assumed that adaptation from groundwater to pore water dependency would be supported by residual pore water sources that would provide a 20 per cent off-set to potential groundwater deficiencies.

The risk assessment considers reasonable worst-case attributes in broad-brush perspectives. As the magnitude of drawdown beneath Weeli Wolli Creek diminishes with increased distances from the abstraction sources, there is a commensurate reduction in riparian zone water availability risks. Figure 8-1 provides a plan view of water availability risks based on the predicted drawdown footprint in December 2019. The predictive model calculates simulated changes from the current water table elevations under stresses imposed by dewatering of PBS. As such, Figure 8-1 reflects this scenario together with the sustained presence of wetting fronts on and beneath northern reaches of Weeli Wolli Creek. Figure 8-2 provides a plan view of the water availability risks in context to the mapped vegetation communities, particularly those aligned along the low-flow channel and incised channel landforms. The mapped vegetation polygons overlapping the water availability risk domains:

- Adds robustness and transparency to the risk assessment.
- Provides a set of connections to the tabulated drawdown and reduced water availability perspectives on the riparian vegetation outlined in Table 8-1 and Table-2, respectively.
- Reflects that the water availability risk assessments are indicative of the higher risk landforms, but that in several settings (due to local channel form and topography factors) the at risk vegetation stands propagate beyond the conceptual incised channel boundaries.

In this regard, Figure 8-2 illustrates the distributions of the mapped vegetation communities (Figure 1-2b) with comparative risk perspectives (listed in order of high to medium risk) that include:

1 *Melaleuca argentea* co-dominated communities – High Risk.
2 *Eucalyptus camaldulensis* co-dominated communities and *Eucalyptus victrix* and *Eucalyptus camaldulensis* co-dominated floodplain vegetation – Medium Risk.

8.2 Mitigation of Reduced Groundwater Availability

8.2.1 Relevant Perspectives

It was recognised that the water availability change assessments and associated implications for the riparian zones on Weeli Wolli Creek host a number of uncertainties. It is difficult to be quantitative in tying percentage changes in water availability to outcomes in terms of riparian zone conservation and health.

The implications of changes to the water availability and some dependencies may also be influenced by:

- Drought, with associated reduction in surface water and pore water availability.
- Cumulative changes, for example when drought or low rainfall conditions are coupled with reductions to existing available water sources.

From a precautionary perspective, changes in water availability from the current situation are likely to present some risks. It is recognised that the riparian zones have adapted to and become dependent in part on recent increases in water availability linked to surplus water discharge to Weeli Wolli Creek. The current situation is, however, not sustainable. For example:

- Under baseline environments the riparian zones were predominantly sustained by pore water derived from direct rainfall, overland flow and episodic flood events on Weeli Wolli Creek. Flood events that inundate large portions of the floodplain at frequencies of 2- to 5-year ARI were integral to water availability, episodically re-wetting the bank of pore water in the unsaturated profile.
- Surplus water discharge has created a perennial surface water wetting front and raised the water table thus enhancing groundwater availability and potentially increasing dependency on groundwater over time.
- The current water availability scenario is neither natural nor sustainable; it is temporary and dependent on surplus water availability.
- Future change due to cessation of surplus water discharge and groundwater abstraction would result in cessation of the surface water wetting fronts and lower the water table. Both actions would reduce water availability. Rates of change of water availability would be rapid.

With respect to maintenance of water requirements for riparian zones (Loomes, 2013) on Weeli Wolli Creek there are three predominant themes:

- Conservation of local hydrology and flood footprints.
- Presence of perennial stream flow in the low-flow channel.
- Limiting of water table decline, and rates of the decline to within the range of natural variation.

The Project Description enables conservation of the local hydrology and in doing so enables limited change to surface water and associated pore water availability. Also, predictive modelling of the groundwater abstraction for pit dewatering (Lim, 2014) provided indications that the present-day perennial stream flow on Weeli Wolli Creek would be preserved. The predictive model broadly conforms to the interpreted loss rates provided by Dogramaci el.al, 2015a and, Pettett and Pearcey, 2014. There is possibility that the predictive model underestimates stream flow losses by infiltration and hence it may occur that the perennial stream flow is not sustained. This possibility cannot be closely informed in the absence of large-scale groundwater abstraction to lower the local water table.

Limiting water table decline is not compatible with the Project Description. Groundwater abstraction and drawdown is required to enable mining. There is likelihood therefore that drawdown would intercept groundwater upon which the riparian zone has become dependent. Further, the rate of change would exceed natural rates of water table decline after episodic stream flow events, indicating there may be limited capacity for the riparian floristics to respond to the water table decline by usual mechanisms.

8.2.2 Change Mitigation Strategies

The proposed mitigation strategies provide a two-layer defence to limit the risks associated with changes to water availability and rates of change. The mitigation strategies are not designed to avoid the inevitable reversion back to baseline water availability condition from present day water availability conditions; they are intended to support the water requirements for the riparian zones and support the transition from present-day to baseline water availability. The mitigation strategies include sustaining stream flow in the low-flow channel.

Sustained flow in the low-flow channel would maintain the surface water wetting front and provide a recharge boundary that off-sets, in part at least, the magnitude and rate of drawdown of the water table. This is important initially, upon commencement of groundwater abstraction for pit dewatering, but may not be preferable over the entire period of operations.

9 CONCLUSIONS

9.1.1 Overview

The setting of PBS is alongside broader floodplain of Weeli Wolli Creek, with interaction of riparian zones. In this setting the importance of the riparian zones is empathised through Ministerial Statement 914 (2012) relevant to the RTIO Yandicoogina Mine. RTIO defined a broader Clearing Avoidance Zone on Weeli Wolli Creek intended to limit disturbances from existing operations to the broader floristic stands that extend to distances up to about 600 m from the low-flow channel.

In the baseline settings, the riparian zones on Weeli Wolli Creek were interpreted to be predominantly dependent on surface water and pore water derived from direct rainfall, overland flow and episodic stream flow events. Depths to the water table in the range 12 to 20 m provided low groundwater dependency.

Since about 1997, the discharge of surplus water into Weeli Wolli Creek (from the Hope Downs 1 and RTIO Yandicoogina mines) increased the water availability to the riparian zones. The increase was reflected in the presence of perennial stream flow and mounding of the water table to comparatively shallow depths. The changed surface water and groundwater environments provided potential for increased groundwater use (medium dependency) within the riparian zone, commensurate with reduced surface water and pore water dependencies.

The proposed mining at PBS would impose further changes to the water availability on Weeli Wolli Creek, however, perennial stream flow in the low-flow channel and opportunities for flooding of adjacent riparian zones would be largely undisturbed. Dewatering of the proposed pit would, however, substantially lower the water table in the CID with a high rate of decline. Ultimately in the adjacent alluvial floodplain which supports the riparian floristics, the water table would be lowered to below baseline elevations, with associated potential deficits in the available water and declines in potentials for groundwater dependency.

9.1.2 Baseline Environments

For the surface water environment, stream flow records at Tarina and Waterloo provide data for stream flow events on Weeli Wolli Creek. Historic observations indicate Weeli Wolli Creek was ephemeral, flowing only once or twice per year during episodic rainfall events. Baseline flow was widely variable dependent on intensity and spatial distribution of rainfall and, antecedent conditions. On average Tarina experienced 28 days of continuous flow during baseline conditions in comparison to 12 days of continuous flow at Waterloo Bore. Flow events could typically be characterised as 1- to 5-year ARI events. In dry years, surface water runoff may be insufficient to generate stream flow.

The floodplain aquifer system is interpreted to form the primary zone for the transmission of recharge from stream flow to the CID aquifer. The floodplain aquifer system is interpreted to have two contributing successions, including:

- Creek-bed alluvium: coarse colluvium and alluvium, including river gravels, incised into the floodplain sediments.
- Floodplain sediments: poorly sorted conglomerates of gravels, sand, silt and clay.

- Groundwater level data from 1974 and 1999 were used to define baseline water table elevations beneath Weeli Wolli Creek. An early-1995 snapshot from 99YYJWB02, 99YYJWB04, YM119 and 99YYJWB01 (Rio Tinto, 2010) shows baseline water table elevations of 418 to 478 m AHD. Water table elevations of 418 in the vicinity of 99YJWB01 reflect a change in conditions and hydraulics beneath the northern reaches of Weeli Wolli Creek.

Interpreted depths to the water table commonly exceeded 15 m to 20 m beneath the floodplain in the vicinity of PBS, though increased significantly to the north, being about 45 m depth below the ground surface in the vicinity of 99YJWB01 located about 6 km downstream from the northern limit of PBS. Water table elevations can rise by up to 8 m, predominantly through the infiltration of stream flow associated with episodic high rainfall events. The natural rates of water table elevation decline after episodic recharge events are defined in the hydrographs of selected monitoring bores, including:

- 99YYJWB04, located on Weeli Wolli Creek near the Marillana Creek confluence, with estimated decline of 1.4 to 2.2 m/year.
- YM119, located on the downstream Weeli Wolli Creek, with estimated decline of 2.9 m/year.

9.1.3 Wetting Fronts

It was recognised that the baseline environment is dynamic and characterised by episodic stream flow and associated recharge events linked to cyclone and thunderstorms. In particular, the period 1994 to 2005 was characterised by an unusually high frequency of high-rainfall events and recharge associated with cyclones Bobby, Rachael, Thelma, John, Norman and Terri together with an un-named tropical low in January 2003. These events provided cumulative recharge signatures that masked concurrent changes linked to wetting fronts from the surplus water discharge (RTIO, 2010).

Since 2007, surplus water discharged to Weeli Wolli Creek has formed wetting fronts which reflect transport, assimilation and fates within the local receiving environments. The wetting fronts occur in the surface water, surface water to groundwater and groundwater environments. The available storage above the baseline water table provides a control on the wetting fronts; once the available storage has been filled the surface water and groundwater wetting fronts would progressively propagate downstream. Evidently, the surplus water has predominantly wet and saturated the available storage in the underlying floodplain aquifer system, mounded the water table and over the majority of Weeli Wolli Creek provided circumstances where perennial stream flow is directly connected to the water table. The wetting front characteristics are summarised as follows:

9.1.3.1 Surface Water Wetting Fronts

Perennial stream flow in the low-flow channel of Weeli Wolli Creek. Since commencement of discharge from the Hope Downs 1 mine (late-2007 and early-2008), the perennial stream flow has propagated to and waxed and waned at distances 5 to 7 km downstream of the Marillana Creek confluence. The perennial stream flow has not propagated to the north (downstream) since 2007, reflecting quasi-steady-state conditions.

9.1.3.2 *Surface Water to Groundwater Wetting Fronts*

Involve processes that include infiltration (recharge) to the water table and interception of water by evaporation and transpiration. The infiltration potentials were interpreted (Dogramaci, et al., 2015a; Pettett and Pearcey, 2014) to range from 0.02 to 13.15 ML/km/day. The assessments by Dogramaci et al. (2015a) also show cumulative evaporation and transpiration losses range from 3 to 9 per cent of total surplus water volumes on reaches where the stream flow is connected to the water table. In northern settings where the water table is disconnected from the perennial stream flow and assuming all other circumstances are the same, these interpreted losses increase in the range 25 to 40 per cent.

Infiltration measurements (Pettett and Pearcey, 2014) in the range 40 to 1,050 m/day provided data that demonstrate the shallow alluvium has potentials to vertically transmit large volumes of surface water. The stream flow is connected to the water table in settings upstream of YM119. It is only on the leading edge of the surface water wetting front, over a distance of about 4 km north of YM119, where the stream flow is disconnected from the water table. In this setting, there was an associated step-change in both chloride and $\delta^{18}O$ enrichment (Dogramaci et.al, January 2015a) and increasing contrast between the surface water and groundwater sample analyses. Beneath the leading edge of the surface water to groundwater interaction, the quality data from 99YJWB01 form significant outliers, being significantly lower in chloride and $\delta^{18}O$ concentrations compared to all other samples. There data probably indicate a different groundwater genesis and flow environment in the vicinity of 99YJWB01.

9.1.3.3 *Groundwater Wetting Fronts*

Progressive wetting of available storage and mounding of the water table beneath Weeli Wolli Creek has occurred under the cumulative influences of recharge from repetitive flood events and surplus water discharge. Recharge from four major consecutive cyclones during the period 1994 to 2005 (the wettest period for two centuries; Rouillard et. al., 2015) provided significant and cumulative wetting fronts beneath Weeli Wolli Creek. From late-2007 to early-2008, the hydrographs show comparatively limited fluctuations, indicating the groundwater environment is filled to a natural capacity and with outflows balanced by inflows.

Monitoring bore hydrographs were recognised to show compatible signatures and consequently that for YM119 was used to provide a template for transient re-wetting, including the differentiation of:

- Baseline disconnected losing stream with episodic wetting from flood events and cyclic decay under hydraulic mechanisms.
- Progressive wetting, with masking from repetitive flood events.
- Transition to where the water table is connected to perennial stream flow.
- Episodic wetting from flood events superimposed on a full floodplain aquifer.
- Cyclic decay by hydraulic mechanisms and discharge to Weeli Wolli Creek.

The hydrographs show the wetting front occurred beneath Weeli Wolli Creek from early-1995. Further, the water table became connected to the perennial stream flow on Weeli Wolli Creek from early-2000 in monitoring bores YM119, 99YJWB02, 99YJWB03 and 99YJWB04. In each monitoring bore, the floodplain aquifer was full, or nearly so, at the time of Cyclone John in January 2000.

Comparisons between the aquifer storage (509.2 GL), surplus water discharge volumes (513.8 GL) and changes in storage from early-1995 (80.1 GL) provide indications of a substantial mismatch. The available storage beneath Weeli Wolli Creek in the vicinity of PBS was filled comparatively quickly between early-1995 and early-2000. Subsequently, the aquifer system in this setting has predominantly remained full. In the vicinity of 99YJWB01, the groundwater wetting front was interpreted to be evident in subtle expressions from about early-1995. In 99YJWB01, however, the aquifer systems have to date not become full to capacity. These attributes indicate a likely change in aquifer hydraulics beneath northern reaches of Weeli Wolli Creek. These attributes were linked to several factors, including:

- Increase depths to the water table, providing larger storage volumes.
- Deeply incised palaeochannel aquifer geometry beneath Poonda Plain and higher transmissivity due to increased aquifer thickness. A cross-section transect within the Nyidinghu Project (Fowers et al.; 2013) shows the presence a deeply incised bifurcate palaeovalley aligned with Weeli Wolli Creek. The intersected palaeovalley(termed the Weeli Wolli Creek Palaeovalley) shows bottom elevations in the range 270 to 305 m AHD, thus indicating thicknesses of 155 to 190 m assuming ground surface elevation of 460 m AHD. This range of thicknesses shows significant change from settings further south beneath Weeli Wolli Creek where typical depths to basement rocks is about 75 m.
- Higher transmissivity within structural defects in the Hamersley Group. Structural defects, including northeast striking faults terms the Weeli Wolli fault system (that form a zone of deformation up to 2 km in width) and a northwest striking Poonda Fault, are described (Fowers et.al, 2013) in the bedrocks beneath the Nyidinghu Project.

Assessments of the hydrographs for the D08YJ216, D08YJ165 and 99YJWB01 were used to predict rates of northward propagation of the groundwater wetting front and timetable for filling local aquifer profiles to elevations of the low-flow channel of Weeli Wolli Creek. These assessments for 99YJWB01 (the northern most monitoring) showed:

- Lateral wetting front propagation by 229 to 374 m/annum.
- A period of about 21 years for saturation of the 25 m zone above the current water table to the invert elevation of Weeli Wolli Creek.

The increases in water availability and discharge by transpiration and evaporation result in salt accumulation within the groundwater environment. A chloride ion increase of about 50 mg/L along the 27 km surface water wetting front on Weeli Wolli Creek was attributed to salt accumulation due to evaporation and transpiration losses along the flow path (Dogramaci et.al; January 2015a). This represents about a 10 per cent change in salinity.

9.1.4 Groundwater Wetting Front Predictions

A groundwater model was developed to predict the groundwater wetting front beneath northern reaches of Weeli Wolli Creek. This model domain extends north of YM119 in settings where there is limited public domain data. The model was conceptualised based on:

- A cross-section transect of the Weeli Wolli Creek Palaeovalley within the Nyidinghu Project (Fowers et al.; 2013).
- Groundwater exploration data on Fortescue Marsh (McLean and Sanderson, 2012 in draft).

The transient calibration covered the period from 1997 to 2013, thus reflecting the period when wetting fronts were present beneath northern Weeli Wolli Creek.

The calibrated model was run forward in time to predict changes in the groundwater wetting front based on surplus water discharge volumes described by the Yandicoogina – Pocket and Billiard South Model (Lim, 2014).

The predictions indicate that:

- The groundwater wetting front would peak within two years after commencement of the PBS abstraction, with subsequent waxing and waning during the period to 2024. After 2024, the predicted wetting front shows steady decay.
- The water table would remain disconnected from Weeli Wolli Creek in the vicinity of 99YJWB01.

The predictive outcomes show a groundwater wetting front not strongly dissimilar to that currently present.

The groundwater wetting front predictions when viewed in context to the quasi-steady-state aspects of the surface water wetting since 2007 provides indications that the observed high surface water infiltration capacities and high-transmissivity of the floodplain and CID aquifer system limit the propagation of the wetting front. Both of these characteristics together with the predictive module outcomes provide indications of limited future changes and hence low environmental risks in context to wetting fronts propagating significantly onto and beneath the Poonda Plain. Further, the capacity of the local environments and systems to transmit and dissipate the surplus water has not been exceeded beneath northern reaches of Weeli Wolli Creek. This provides a view of low cumulative environmental risks linked to existing projects and the development of PBS.

Given there is limited data that characterises the northern Weeli Wolli Creek Palaeovalley it is difficult to quantify the maximum capacities of surface water infiltration and through-flow in the groundwater environment. Under these circumstances it is difficult to frame the environmental risks that may occur due to concurrent below water table mining developments, such as Jinidi, Iron Valley and Nyidinghu. Of these projects, only Iron Valley is operating, as an above-water table development.

9.1.5 Water Availability

The baseline settings provided perspectives of riparian zone function, including importance of surface water and recognition of preferential development along the main low-flow channel of Weeli Wolli Creek and where captured by secondary braided channels. Three water sources were interpreted to support the riparian zone, including:

- Surface water flows, including direct rainfall, stream flow (in the low-flow and incised channels) and overland flow (from the hinterland and from flood events).
- Surface water to groundwater interaction, thus flow and water in storage in the unsaturated profile represented by pore water in the interstitial fabrics of the alluvial and CID successions.
- Groundwater from settings below the water table.

It was also recognised that water availability would be different within the discretised low-flow, incised channel riparian zone floodplain and broader floodplain domains of Weeli Wolli Creek. In this regard, the discretised riparian zones on Weeli Wolli Creek included:

- Low-flow channel: a 6 m width zone that transmits all of the perennial stream flow and 20 m width corridor either side.
- Incised channel: a 100 m width inundated by 1-year and 2-year ARI events.
- Riparian zone floodplain: a 450 m width zone flooded by 2-year to 5-year ARI events.
- Broader floodplain: 1,800 m in width and infrequently inundated by 5-year to 10-year ARI stream flow events.

The presence of the riparian zones was interpreted to reflect reasonably consistent water availability within an annual (365-day) supply equation. Surface water is the initial source that episodically rewets the system, but has limited persistence and is absent over much of the year. Similarly, deep water table settings are not strongly representative of groundwater dependency. By extension, therefore, the predominant water dependency for the baseline riparian zone would be pore water, with contributions from surface water and groundwater being subordinate.

The derivation of 365-day water availability equations was based on information from the local Weeli Wolli Creek setting including rainfall and stream flow records, simulated footprints for 1-year to 10-year ARI events (Cheng, 2013), infiltration and other loss factors (Dogramaci et al., 2015a and Pettett and Pearcey, 2014) and observed water table settings together with transient responses to episodic recharge events. Applications of these data were made using a number of insights and assumptions. These influence the risk assessment outcomes. In this context the most important assumptions include:

- The surface water and pore water sources cumulatively form a year-round (365 day) perennial water availability within the riparian zone settings where there is no groundwater dependency.
- Groundwater was assumed to be a potential perennial year-round source for water table depths to a maximum of 20 m; for depths to the water table greater than 20 m it was assumed that groundwater was unavailable to the riparian zone. For groundwater it was also recognised that there may be variable demand depending on depths to the water table. As such, four water table zones were discretised and in each zone a factor was applied to characterise potential groundwater availability assuming groundwater would not be the sole source. The four discrete water table zones included:

Depth to Water Table (m)	Groundwater Availability	
	Per Cent	Days per annum
0 to 2	85	310
2 to 6	60	219
6 to 12	30	110
12 to 20	10	37

- It was recognised that the groundwater availability was probably conservatively high. With reference to Figure 7-8 it was reconciled that typically the upper-most 25, 30 and 50 per cent of the incised channel, riparian zone floodplain and broader floodplain profiles respectively would be unaltered in transition from current to PBS scenarios. In these shallow profiles, presumably where the root architecture is preferentially developed, the surface water and pore water availability would not be changed. These perspectives were used to further limit the groundwater availability. For the respective incised channel, riparian zone floodplain and broader floodplain, the groundwater availability was reduced 25, 30 and 50 per cent to account for the absence of disturbance to the upper-most root zones.

The annual dependency for the surface water, pore water and groundwater sources was determined based on the linear interpolation between their availability (days per annum) and the cumulative (total annual availability of all sources) water availability.

9.1.6 Water Availability Risk Assessment

For the water availability risk assessment it is pertinent that the current surface water and groundwater environments are temporary and cannot be sustained. Future changes would be inevitable once the discharge of surplus water ceases or is substantially reduced. Further, it is difficult to gauge the potentials for increased riparian zone dependency on the increased water availability, both in context to surface water and groundwater sources. For example one risk aspect would be dependent on the adaptability of riparian floristics:

- To increase surface water and groundwater availability, including potential waterlogging of root zones.
- Perennial presence of stream flow and water table mounding into root zones.

It was also recognised that EWRs of the riparian zones on Weeli Wolli Creek would be supported by the following processes:

- Retention of perennial surface water flows, at least initially, to offset potential changes due to drawdown of the water table.
- Limiting changes to periods of high floodwater.
- Avoidance of drawdown of the water table.

The water availability risk assessment provides reasonable worst-case attributes based on:

- Stream flow being sustained in the low-flow channel.
- Avoiding disturbances to the low-flow channel.
- Limiting disturbances where practical to the local Riparian Exclusion Zone hydrology.
- Conservatively high groundwater dependency based on water table depths to 20 m.

As such, the PBS scenario captures two of the three EWRs, with avoidance of drawdown not practical. Under these circumstances, the drawdown of the water table is the predominant change mechanism regarding water availability. Contextually therefore, the water availability risks to the riparian zone would predominantly have aspects that reflect the adaptability of riparian floristics:

- In drawing from alternative water sources when groundwater availability is reduced by 12 to 22 percent from the current situation.
- Reverting to baseline dependencies on pore water and surface water.
- To net reductions of 3 to 9 per cent in total water availability due to drawdown below the baseline water table elevations.

Under these circumstances, the riparian groundwater dependent floristics would probably experience drought-like conditions, with associated water availability stress.

Percentage changes in the water availability have been used to define potential risks. In this regard, low risks reflect changes of less than 10 per cent; medium risks between 10 to 18 per cent; medium high risks 18 to 25 per cent and high risks greater than 25 per cent. The risk assessment is shown on the accompanying table for three scenarios:

- Current to baseline scenario.
- Baseline to PBS scenario.
- Current to PBS scenario.

The latter scenario captures the cumulative influences in transitioning from the current environments of increased water availability to deficits from baseline that would temporarily prevail during development of PBS.

The interpreted changes in water availability within the riparian zones may be off-set in part at least by sustaining stream flow in the low-flow channel.

Setting	Change Aspect		Risk Assessment											
			Current to Baseline Scenarios				Baseline to PBS Scenarios				Current to PBS Scenarios			
			Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain	Low-Flow Channel	Incised Channel	Riparian Flood Plain	Broader Flood Plain
***E. victrix* Increased Water Availability and Waterlogging (beneath the Low-Flow Channel and Incised Channel)[1]**														
Low-Flow Channel	Waterlogging.		Medium High	-	-	-	Low	-	-	-	Medium High	-	-	-
Incised Channel			-	Medium	-	-	Low	-	-	-	-	Medium	-	-
***M. argentea* and *E. camaldulensis* Decreased Water Availability Due to Drawdown[2]**														
Low-Flow Channel[3]	Presence of perennial stream flow.		Low	-	-	-	Low	-	-	-	Low	-	-	-
	Drawdown of the water table below current elevations.		Medium	-	-	-	Low	-	-	-	Medium	-	-	-
Incised Channel	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].	<5 m	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		5 – 10	-	Medium	-	-	-	Low	-	-	-	Medium	-	-
		10 – 20	-	Medium High	-	-	-	Low	-	-	-	Medium High	-	-
		>20	-	High	-	-	-	Low	-	-	-	High	-	-
Riparian Flood Plain	Drawdown of the water table below respective elevations and rapid depletion of sources that support groundwater dependency[4].		-	-	Medium	-	-	-	Low	-	-	-	Medium	-
Broader Flood Plain			-	-	-	Low	-	-	-	Low	-	-	-	Low

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11 LIMITATIONS

11.1 Geotechnical and Hydro Geological Report

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Rio Tinto Iron Ore Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the proposals dated 31 March 2014 and 3 September 2014.

The methodology adopted and sources of information used by URS are outlined in this the Report.

Where this report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information unless required as part of the agreed scope of work. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between 28 November 2014 and 30 June 2015.The information in this report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this report. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the uniformity of conditions and on the frequency and method of sampling as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time.

Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

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Report

Environmental Risk Assessment for Riparian Zones on Weeli Wolli Creek

AUSTRALIA

Part 2 - Figures

Riparian Zones Environmental Risk Assessment

30 June 2015
42908644/WY/IGB-Wat-0124/PSM/2

Prepared for:
Rio Tinto Iron Ore Pty Ltd

Prepared by URS Australia Pty Ltd

Hamersley Range

Poonda Plain
Fortescue River Valley

MUNJINA ROY HILL ROAD

Munjina
Claypan

KARIJINI DRIVE

GREAT NORTHERN HIGHWAY

MARILLANA CREEK

WATERLOO BORE

Billiard South (Cue)

Billiard South (Pocket)

TARINA

WEELI WOLLI SPRINGS

WEELI WOLLI CREEK

Reach Transitions
- Marillana Creek
- Weeli Wolli Creek

DoW Stream Gauging
CID Boundary

Billiard South (Cue)
Billiard South (Pocket)
BHP Billiton Tenement
RTIO Tenement

Major Watercourse
Minor Watercourse
Railway

Principal Road
Minor Road
Secondary Road
Track

N
W E
S

Scale: 1:250,000
0 1 2 3 4 Km

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

POCKET AND BILLIARD SOUTH PROJECT SETTING

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THE POCKET AND BILLIARD SOUTH PROJECT

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Figure: **1-1**

Rev. **A** A3

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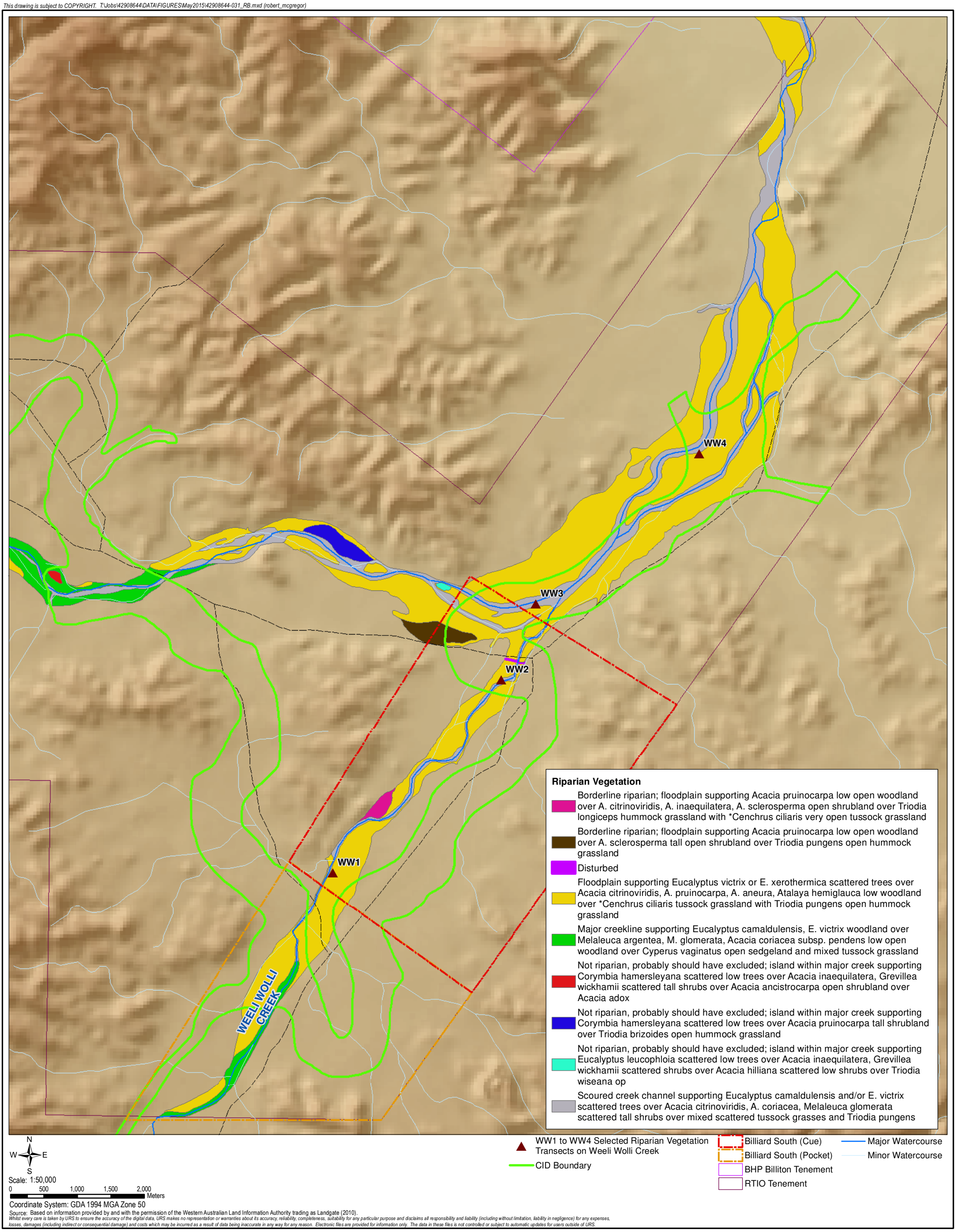

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

RIPARIAN ZONES AND FLORISTICS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **1-2a**

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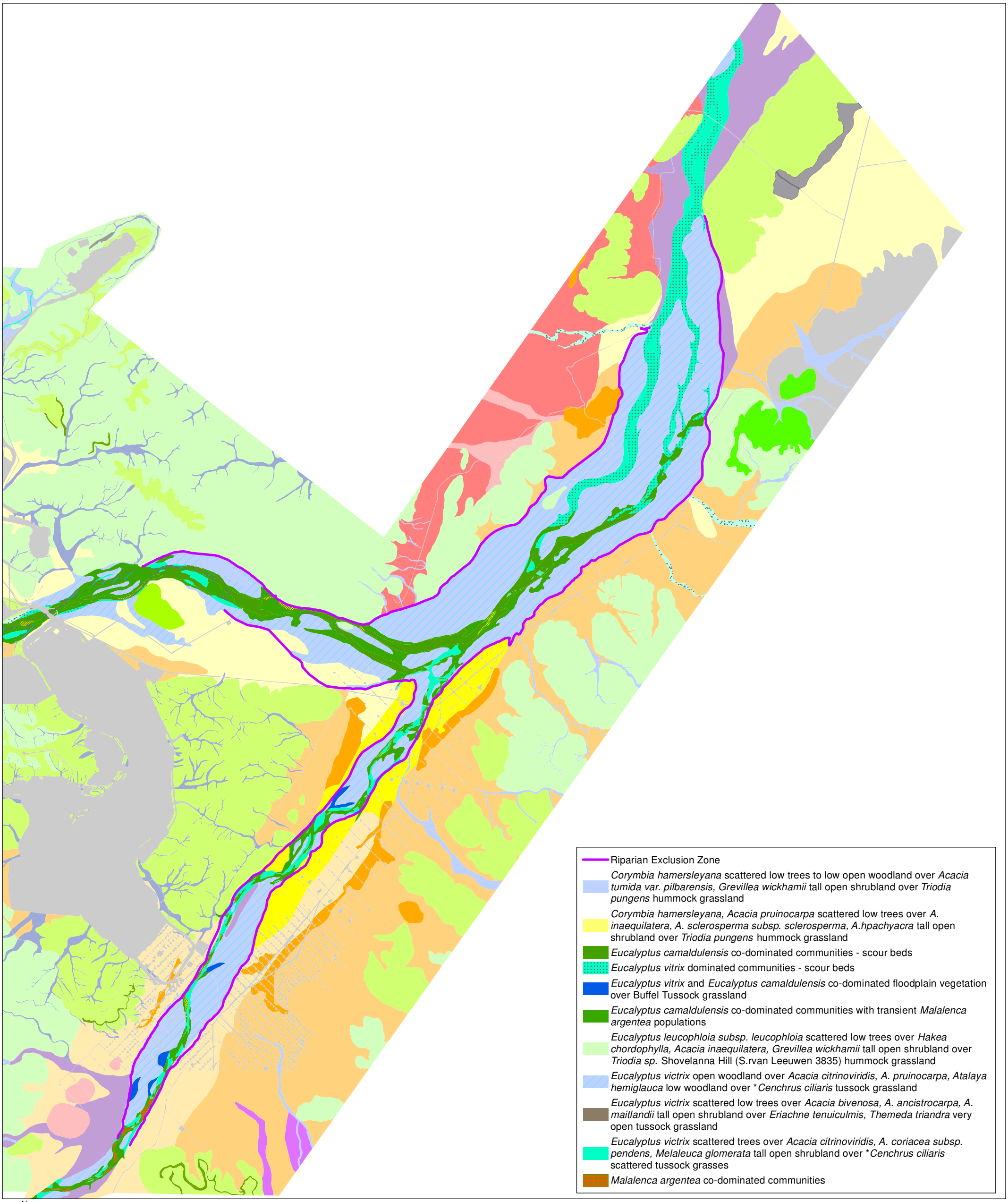

N
W E
S

Scale: 1:50,000

0 500 1,000 1,500 2,000 Meters

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

RECENT DETAILED VEGETATION MAPPING

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **1-2b**

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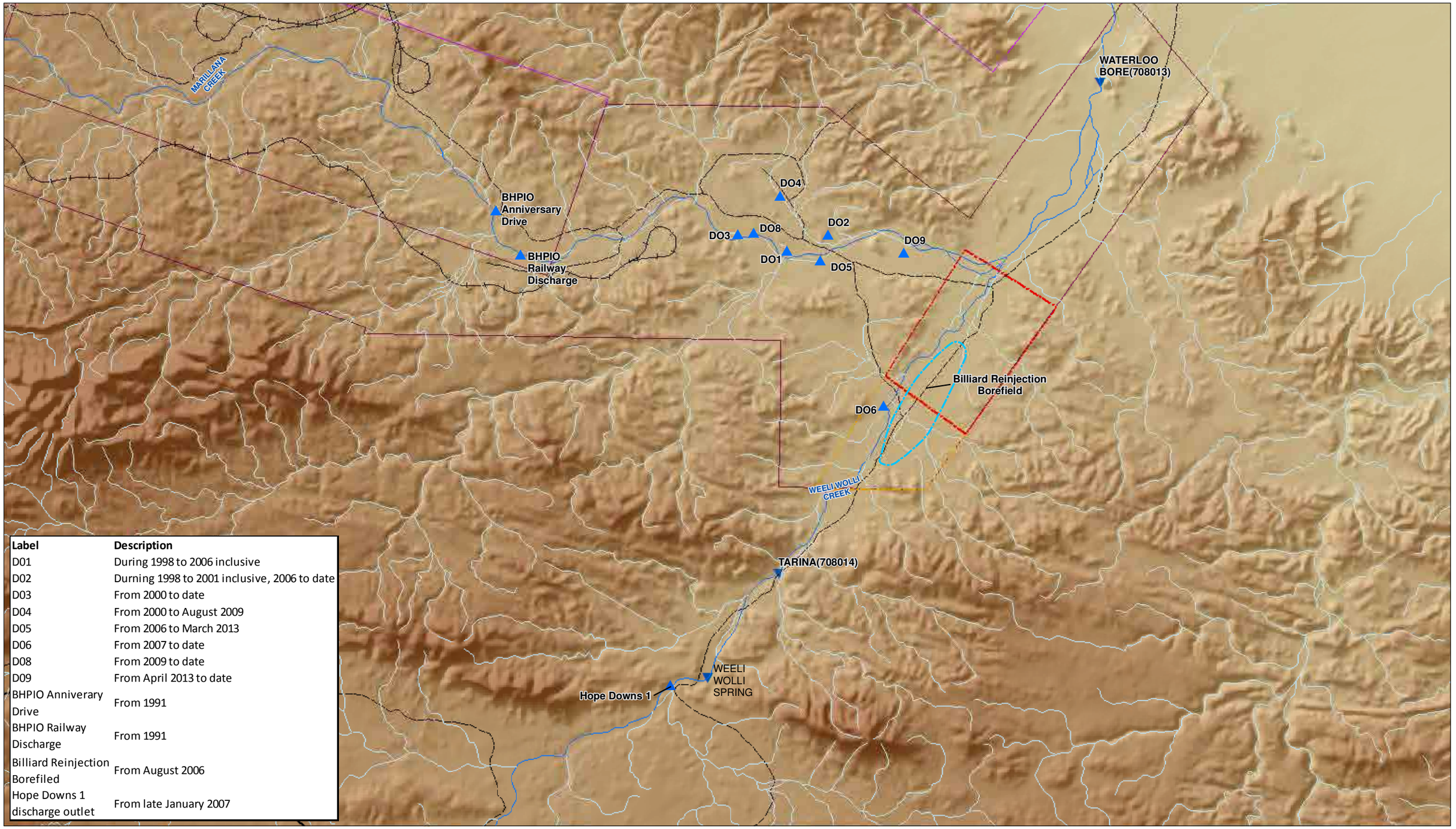

Label	Description
D01	During 1998 to 2006 inclusive
D02	Durning 1998 to 2001 inclusive, 2006 to date
D03	From 2000 to date
D04	From 2000 to August 2009
D05	From 2006 to March 2013
D06	From 2007 to date
D08	From 2009 to date
D09	From April 2013 to date
BHPIO Anniverary Drive	From 1991
BHPIO Railway Discharge	From 1991
Billiard Reinjection Borefiled	From August 2006
Hope Downs 1 discharge outlet	From late January 2007

D06 Surplus Groundwater Disposal Outlets
DoW Stream Gauging
Billiard Reinjection Borefield
Billiard South (Cue)
Billiard South (Pocket)
BHP Billiton Tenement
RTIO Tenement
Major Watercourse
Minor Watercourse
Railway
Minor Road
Track

N
W E
S

Scale: 1:125,000
0 1 2 3 4 Km

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

LOCATIONS FOR HISTORICAL SURPLUS WATER DISCHARGE

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **1-3**

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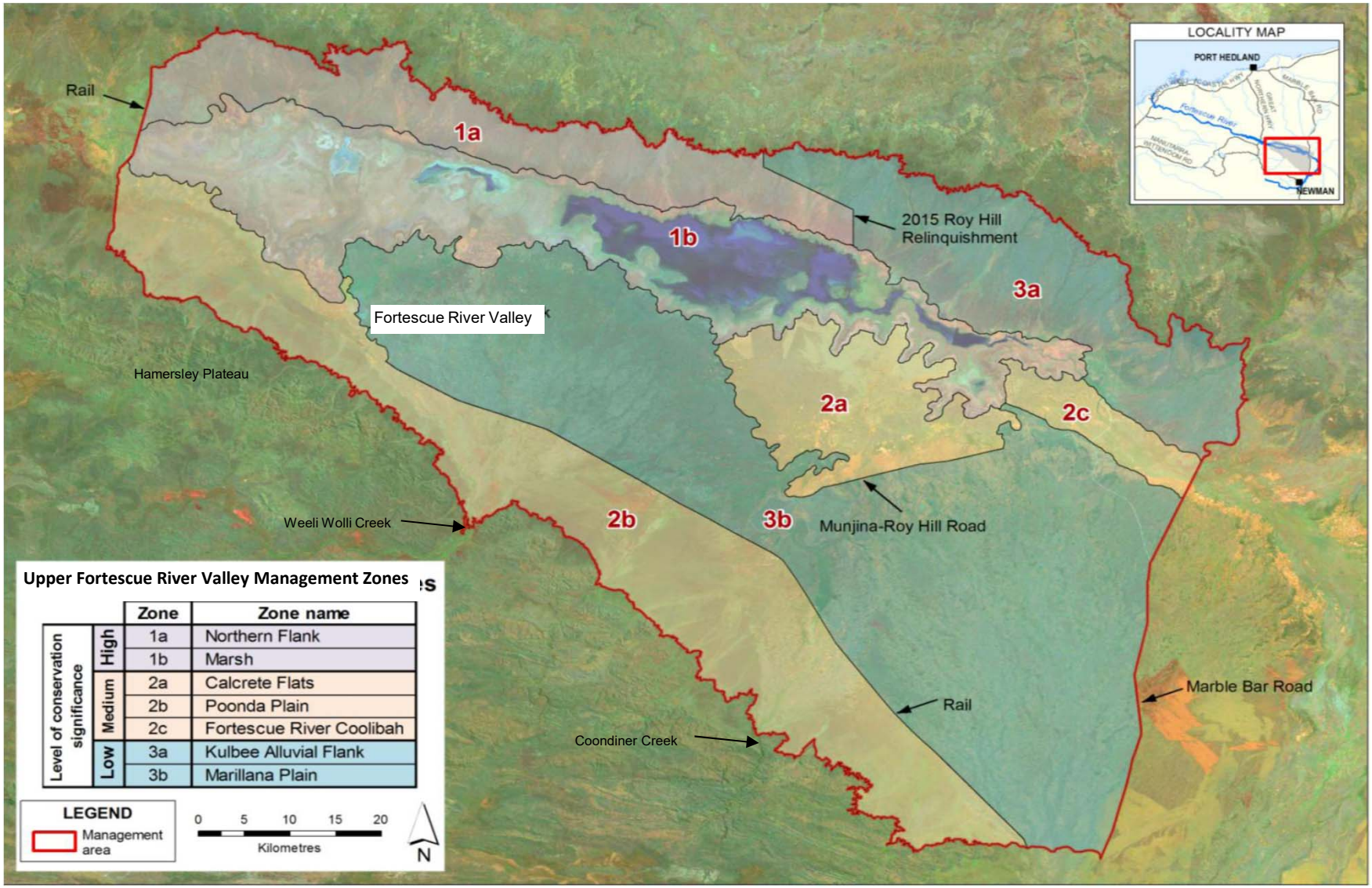

Source: Department of Water, Department of Environment and Conservation and the Office of the Environmental Protection Authority. Version: 1q (September 2011)

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

FORTESCUE MARSH MANAGEMENT ZONES

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **1-4**

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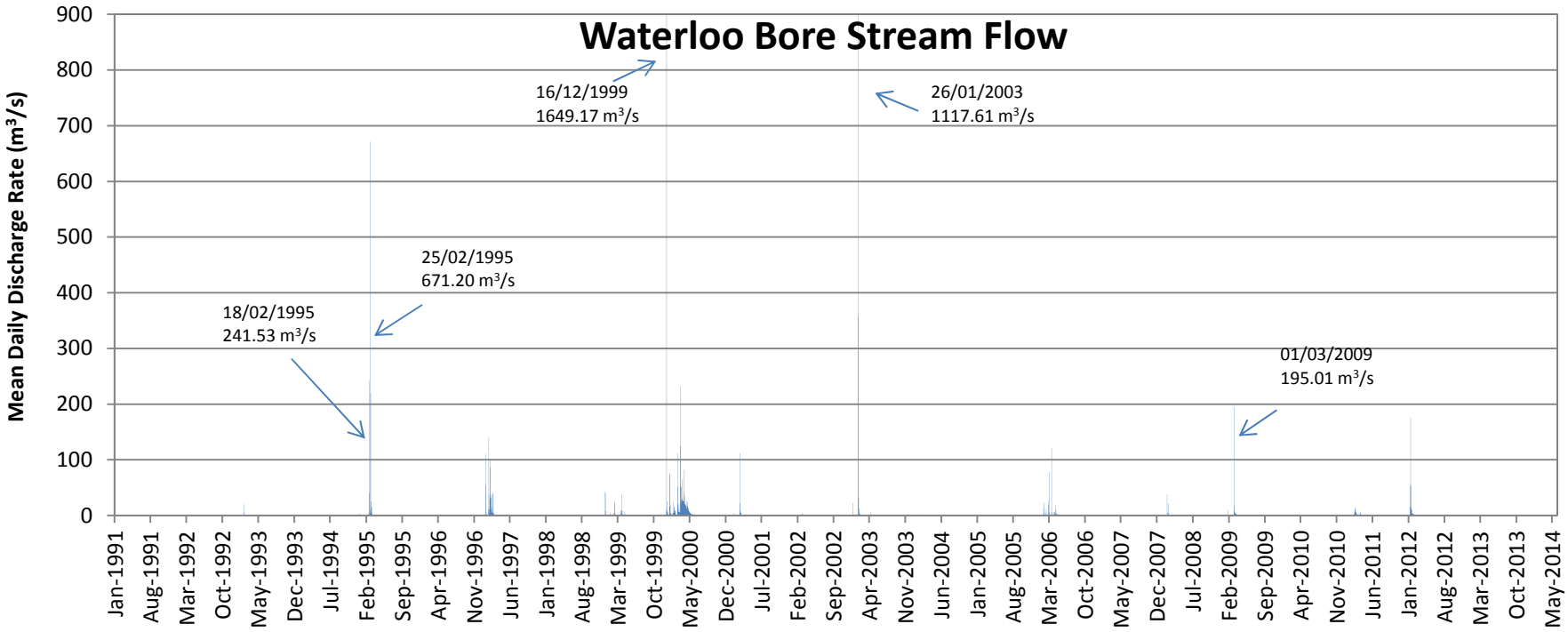

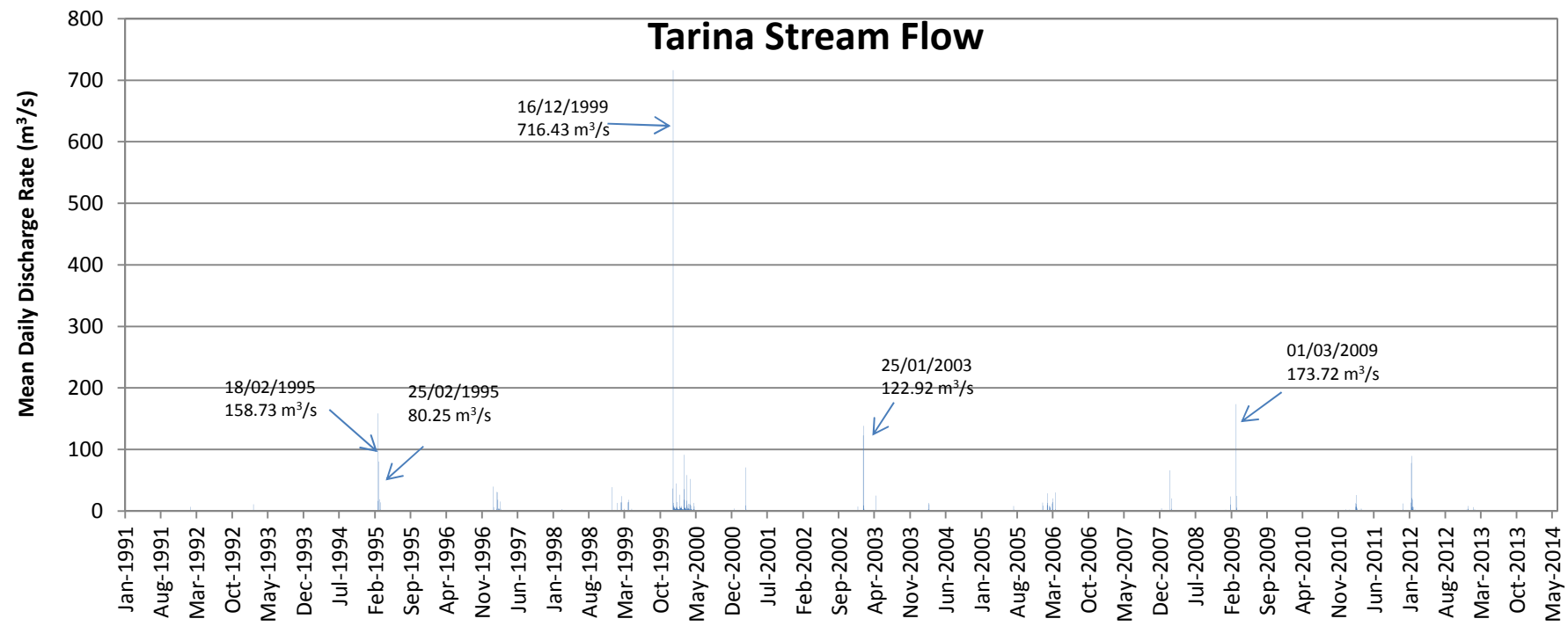

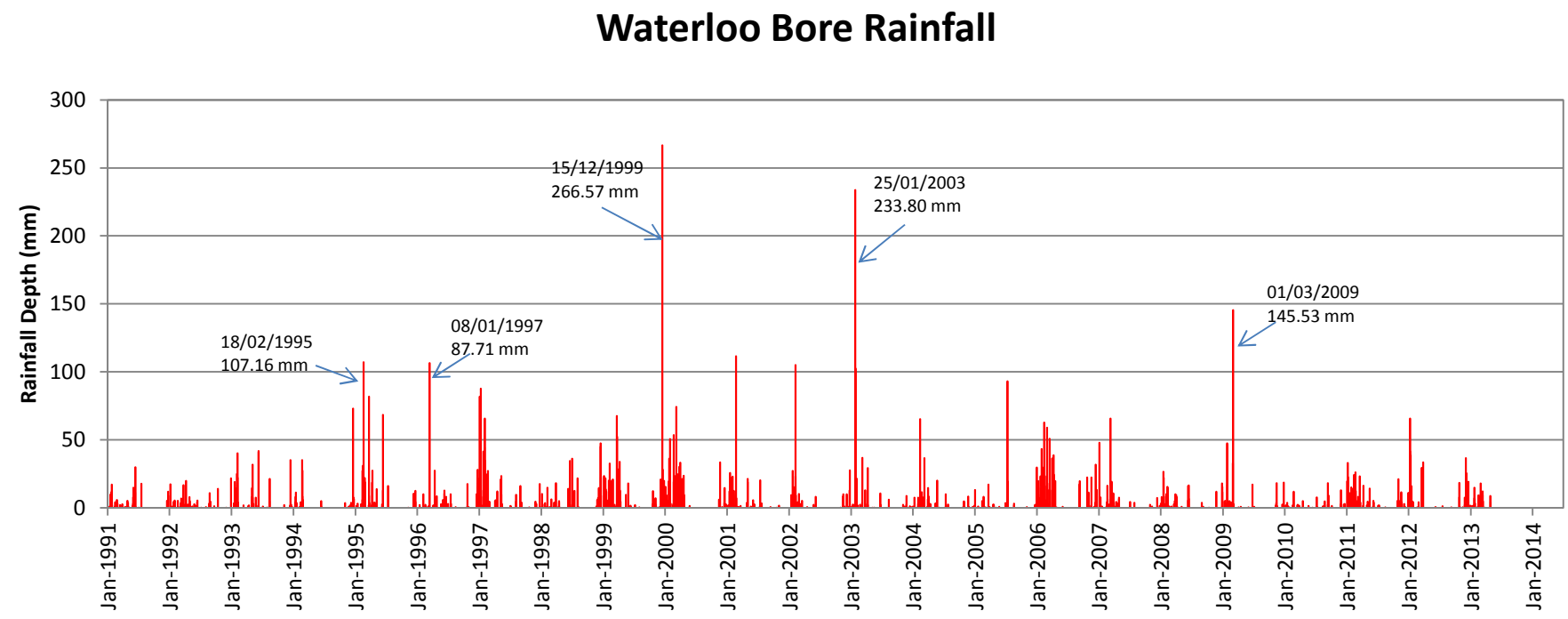

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TARINA AND WATERLOO BORE RAINFALL AND STREAM FLOW

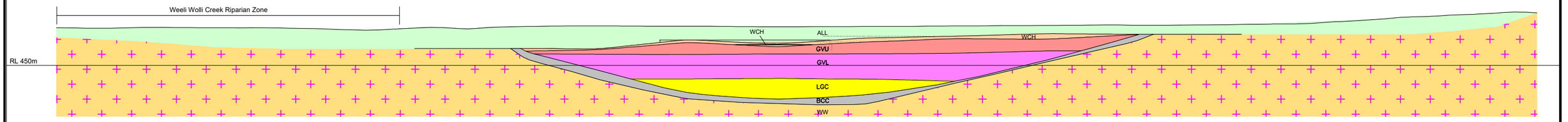
URS

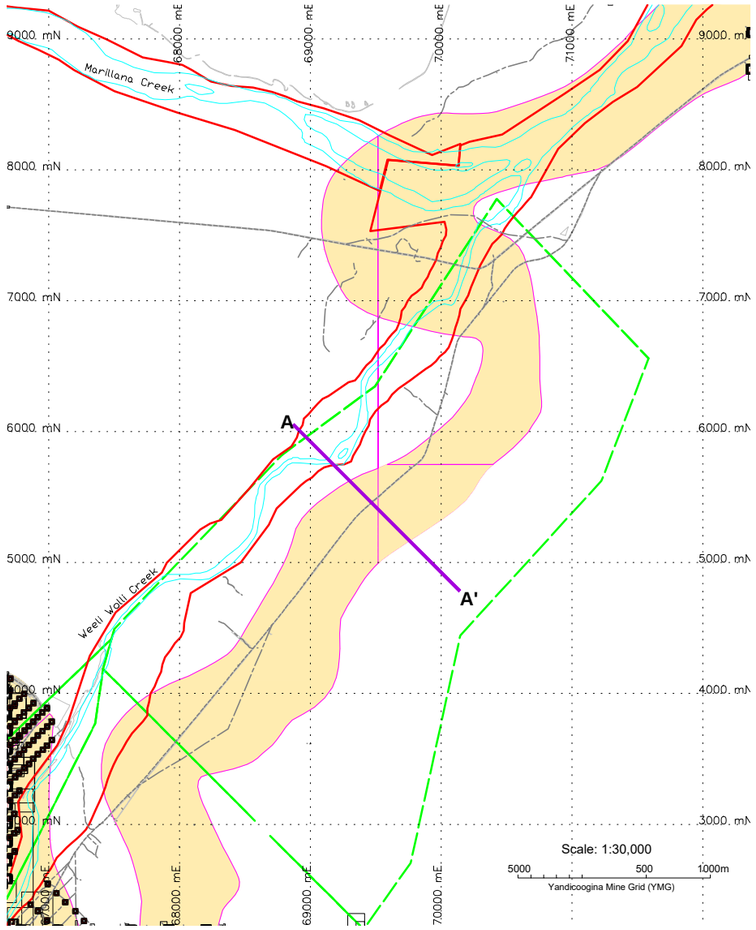
THE POCKET AND BILLARDS SOUTH PROJECT

Figure: 2-1

File No: 42908466-096.xlsx Drawn: JH Approved: IB Date: 21/04/2015

Rev: A A3





Scale 1:2500

50 0 50 100 150m 200m

Horizontal : Yandicoogina Mine Grid (YMG)
Vertical : AHD

Legend

- ALL — Alluvium / Colluvium
- WCH — Weathered CID
- GVU — CID - Goethite vitreous upper
- GVL — CID - Goethite vitreous lower
- LGC — Limonite - Goethite CID
- BCC — Basal Clay Conglomerate
- WW — Weeli Wolli Formation
- Weeli Wolli and Marillana Creeks
- Riparian Exclusion Zone
- CID Palaeochannel
- Billiard South (Cue) Prospect Outline
- Cross-Section Line A - A'

Source: RIO TINTO

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TYPICAL BILLIARD SOUTH LITHOLOGICAL CROSS-SECTION

URS

THE POCKET AND BILLIARD SOUTH PROJECT

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Figure: **2-2** Rev. - A3

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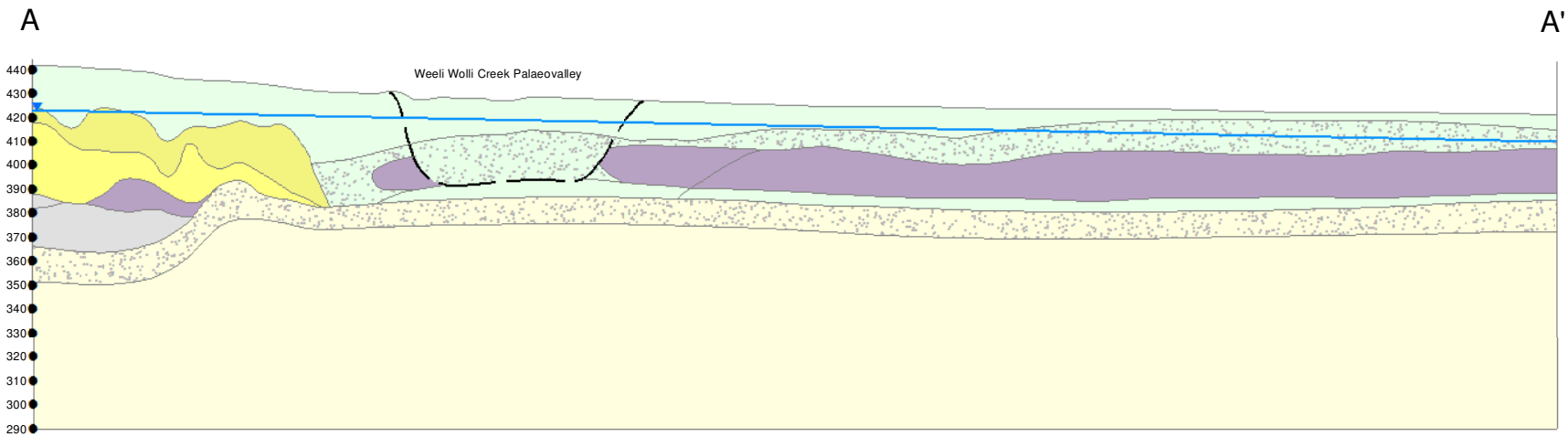

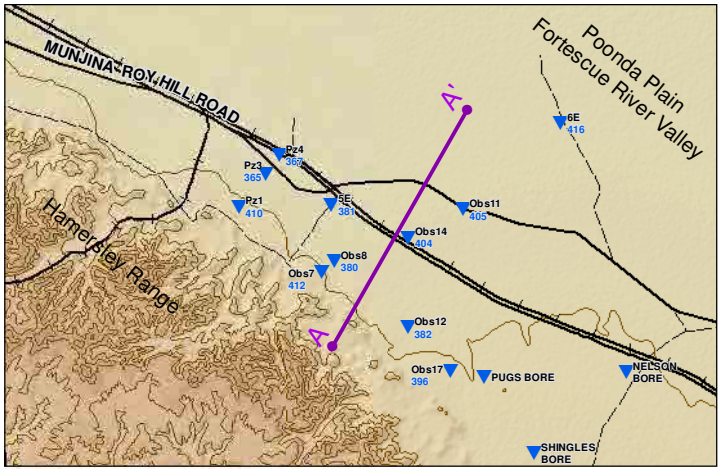

- Alluvium
- Alluvium (Clay-rich)
- Hematite Detritals
- CID / Pisolite Gravel
- Calcrete
- Basal Conglomerate
- Weathered Wittenoom Formation
- Wittenoom Formation

Not To Scale

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

SCHEMATIC LITHOLOGICAL CROSS-SECTION BENEATH POONDA PLAIN

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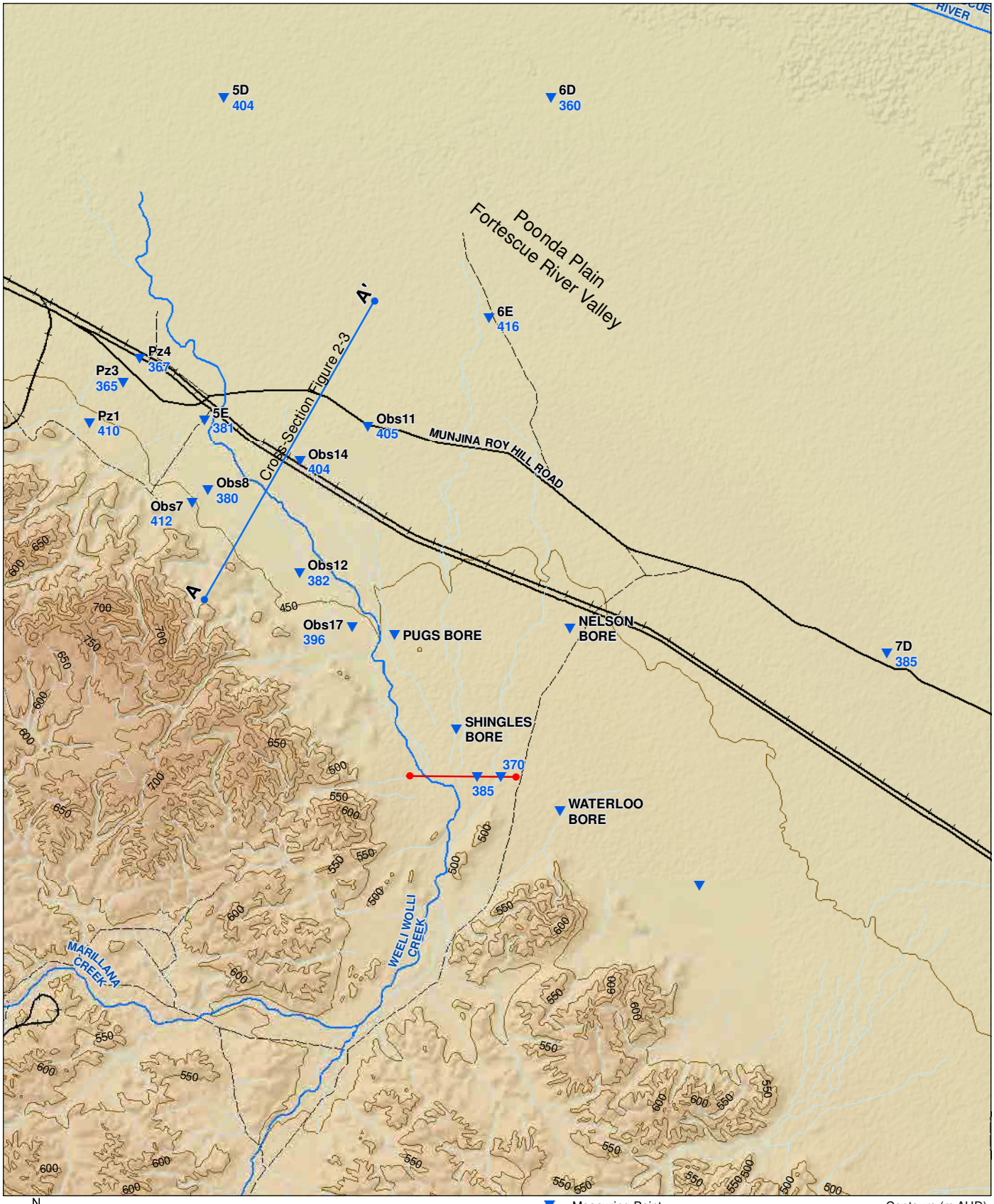
THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **2-3**

File No: **42908644-035.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A4



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

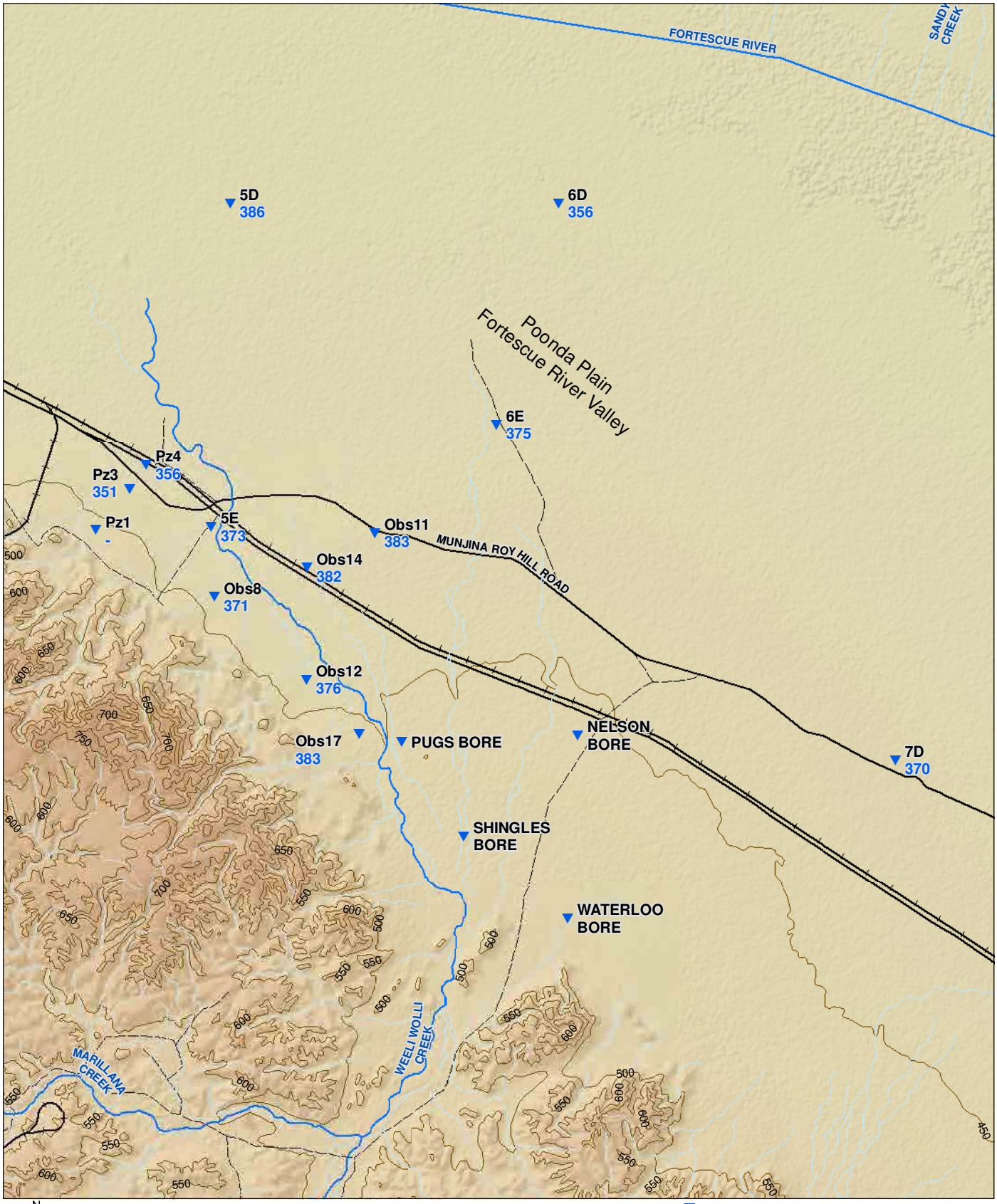
POONDA PLAIN - BOTTOM ELEVATION OF UPPER TERTIARY DETRITALS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **2-4a**

File No: **42908644-045.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A4



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

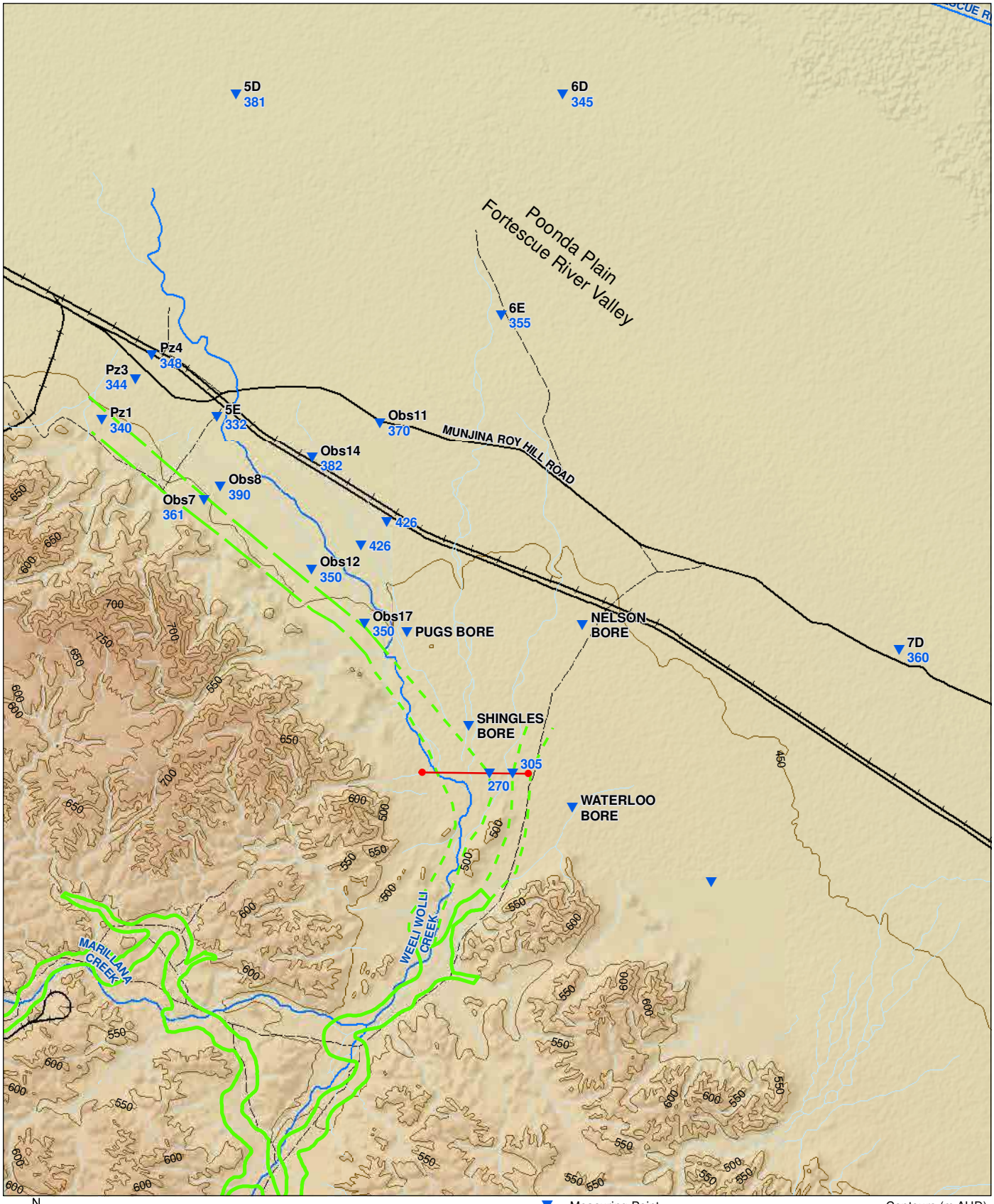
POONDA PLAIN - BOTTOM ELEVATION OF CALCRETE BEDS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **2-4b**

File No: **42908644-043.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A4



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

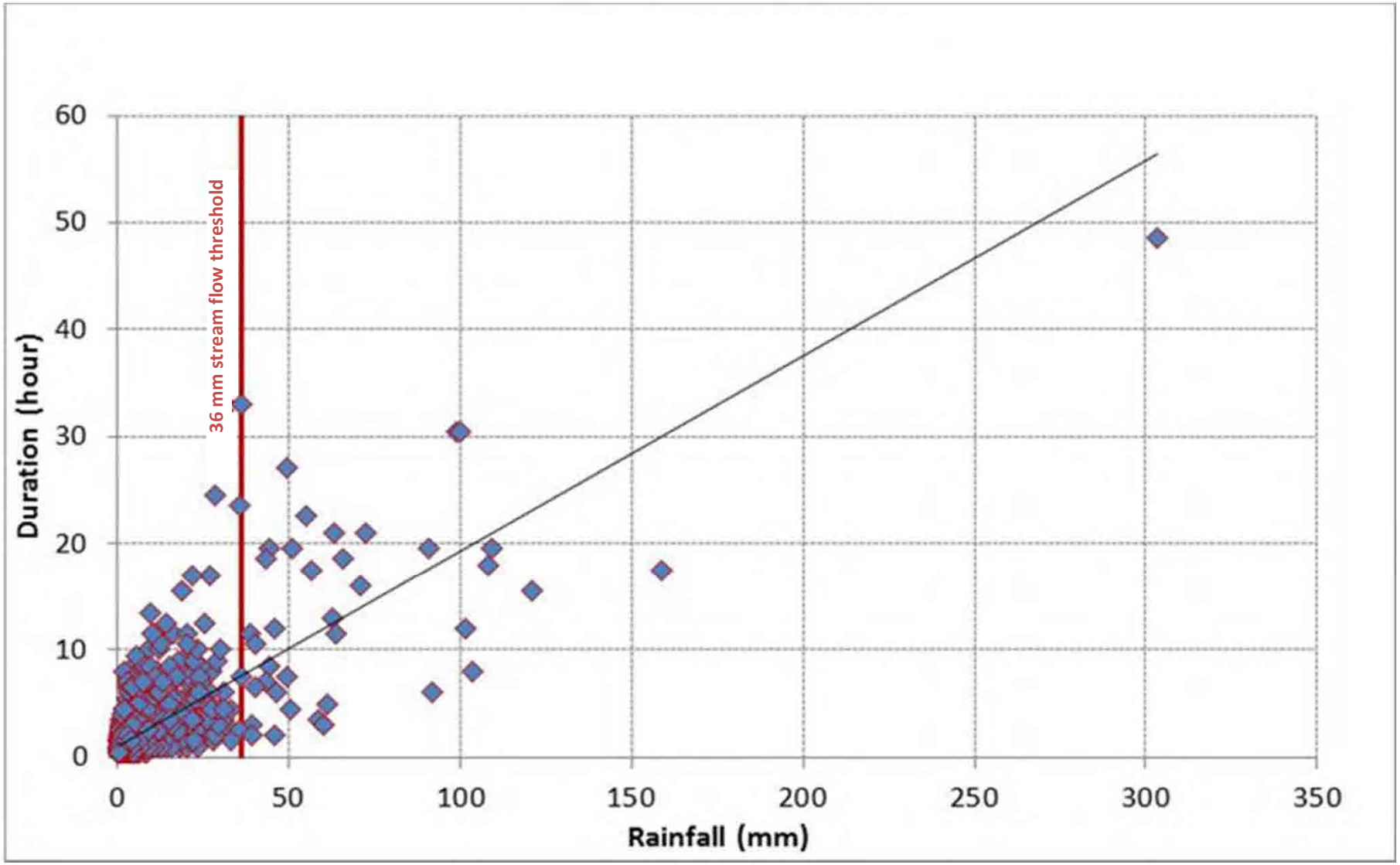
POONDA PLAIN - ELEVATIONS FOR TOP OF HAMERSLEY GROUP

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **2-4c**

File No: **42908644-046.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A4



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Source: Cheng, RTIO; December 2013.

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

RAINFALL MEASUREMENTS AT TARINA (1985 TO 2010)

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **3-1**

File No: 42908644-050.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: **A** A4

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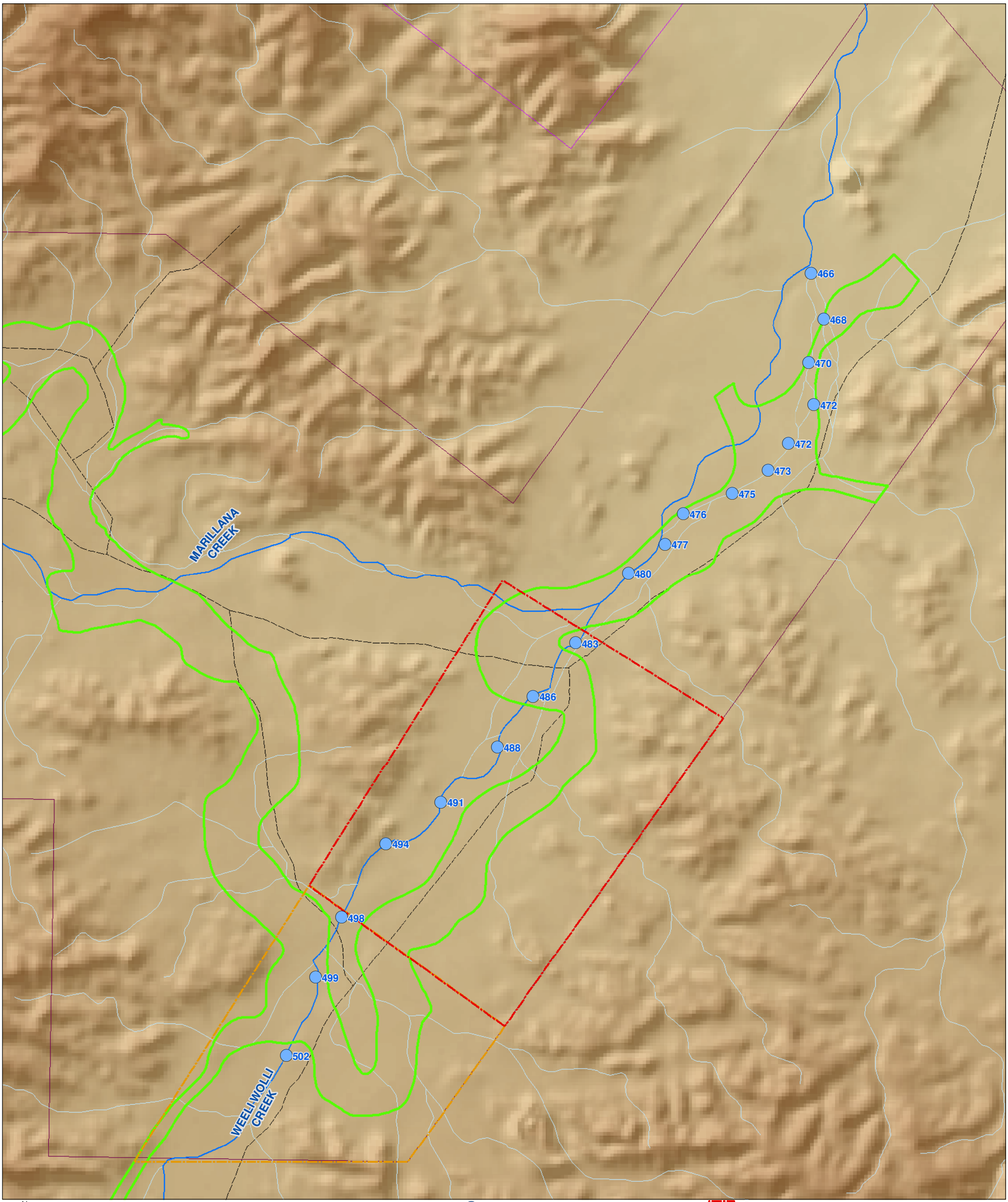

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

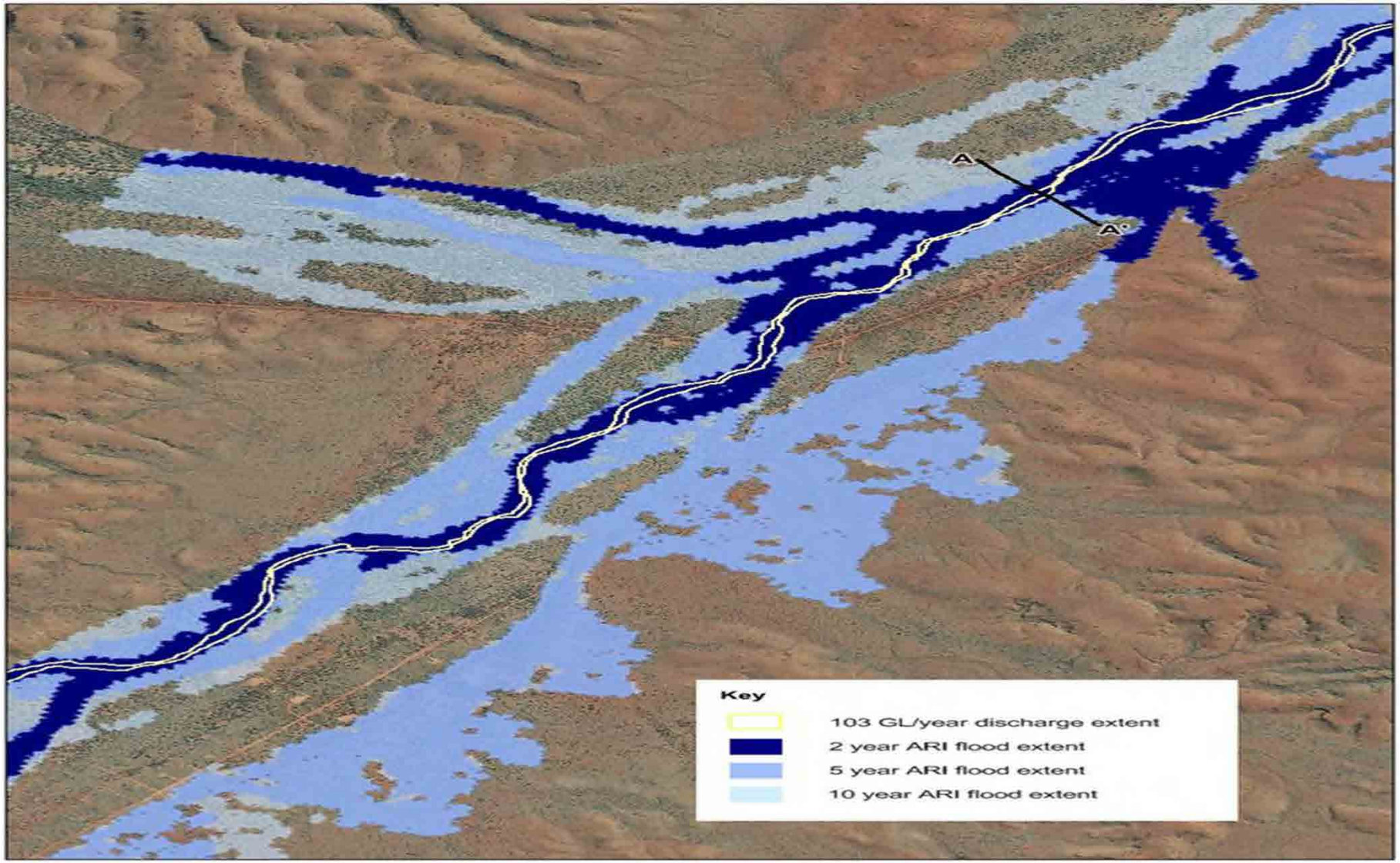
STREAM BED SPOT HEIGHTS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **3-2**

File No: **42908644-036_RB.mxd** Drawn: **RNM\JA** Approved: **IGB** Date: **1/05/2015** Rev. **A** A3



Source: Cheng, RTIO; December 2013

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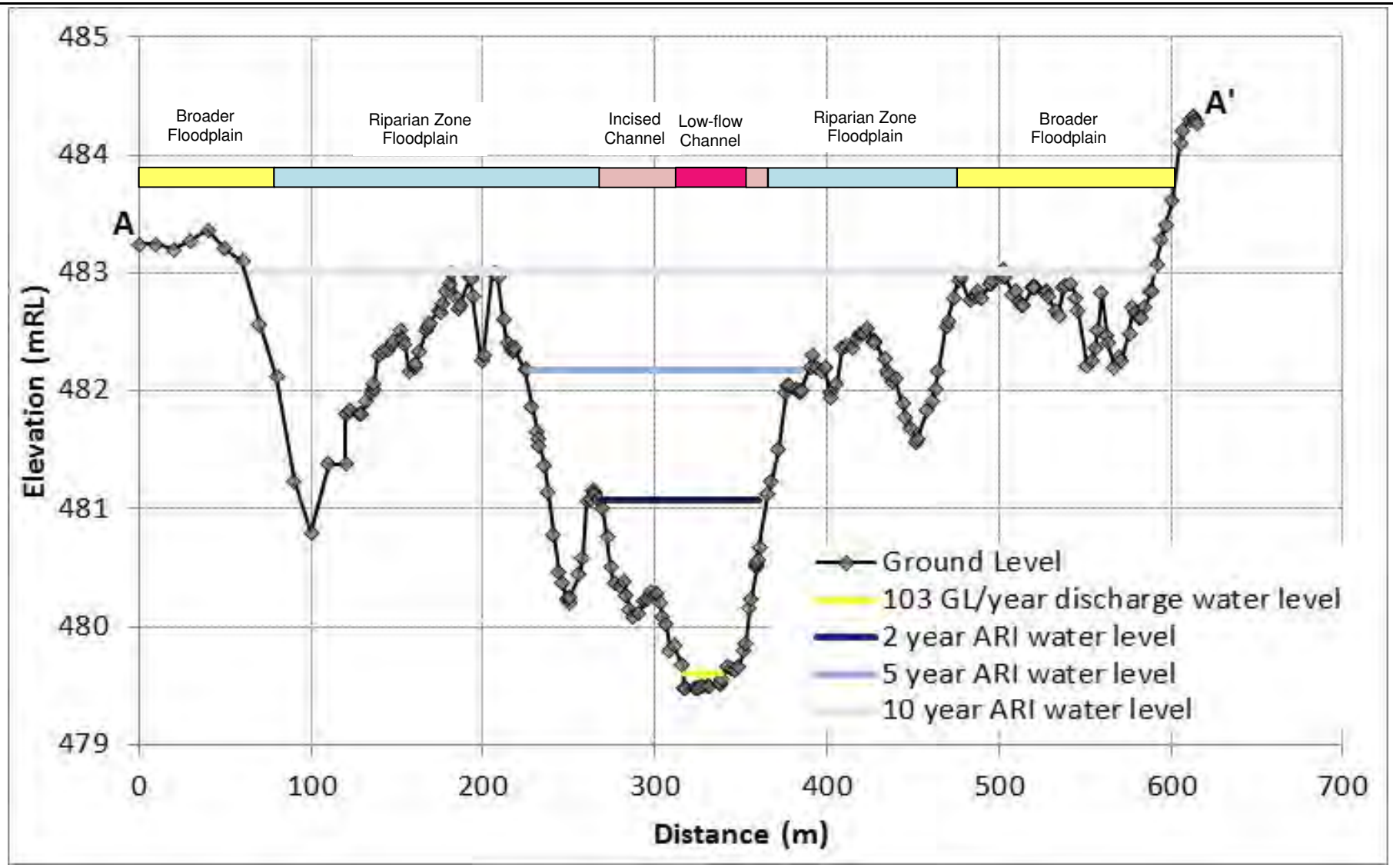
COMPARATIVE FLOOD WATER FOOTPRINTS FOR 2-, 5- AND 10-YEAR ARI EVENTS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **3-3**

File No: 42908644-049.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: **A** A4



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Source: Cheng, RTIO; December 2013

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

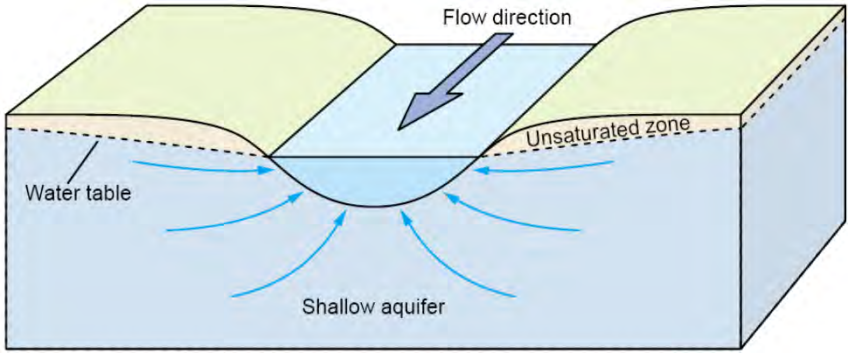
SCHEMATIC CROSS-SECTION OF FLOOD FOOTPRINTS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

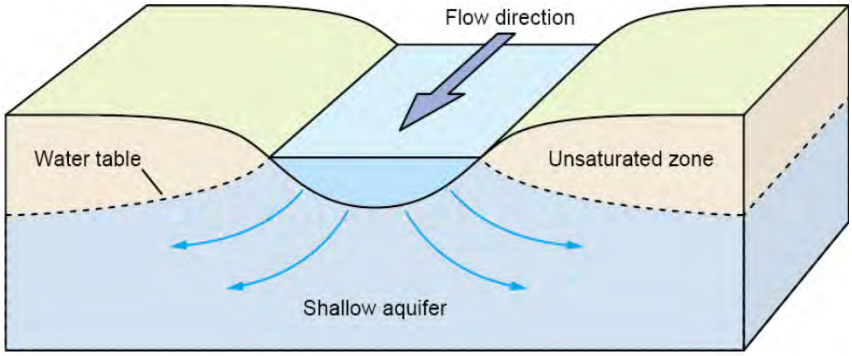
Figure: **3-4**

File No: 42908644-051.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: **A** A4



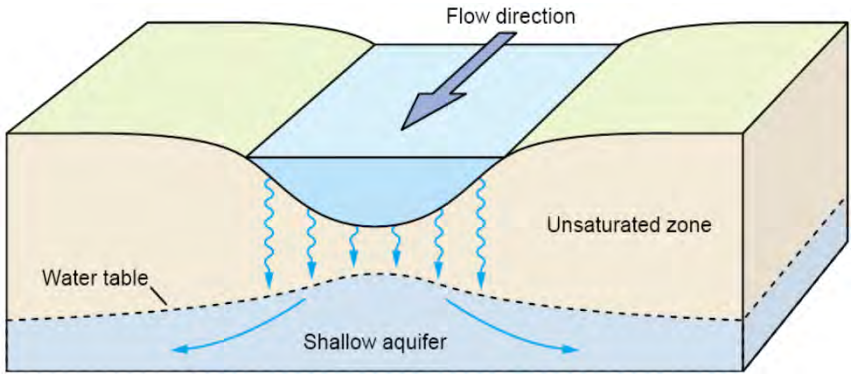
Gaining Stream

Baseline setting of Weeli Wolli Spring



Connected Losing Stream

Baseline reaches of Weeli Wolli Creek extending about 12 km downstream of Weeli Wolli Spring.



Disconnected Losing System

Baseline reaches of lower Weeli Wolli Creek, more than 12 km downstream of Weeli Wolli Spring. Currently, northern reaches of Weeli Wolli Creek.

Source: After Winter et. al., 1998

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

CONCEPTUAL SURFACE WATER AND GROUNDWATER INTERACTIONS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **3-5**

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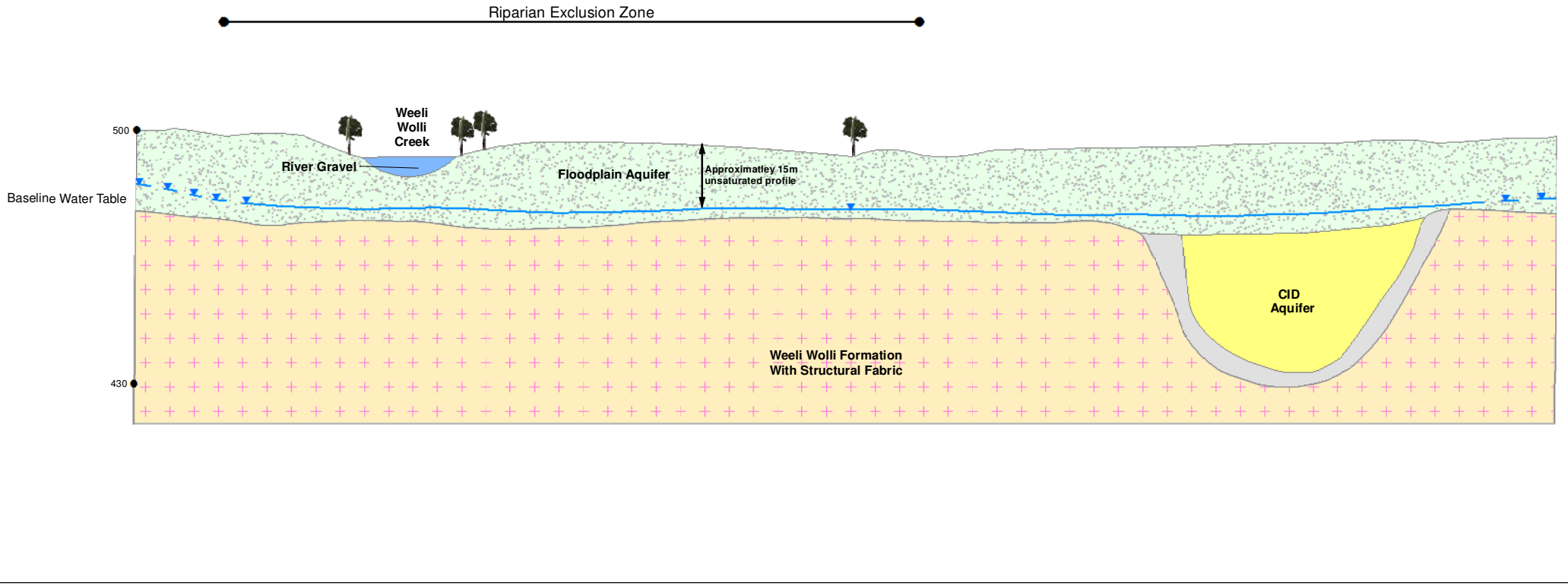

Not To Scale

Source: After kirkpatrick and Dogramaci, RTIO; 2010

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

SCHEMATIC CROSS-SECTION OF AQUIFER SYSTEMS AND BASELINE WATER TABLE

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 4-1

File No: 42908644-052.mxd Drawn: RNM Approved: IGB Date: 1/05/2015 Rev. A A4

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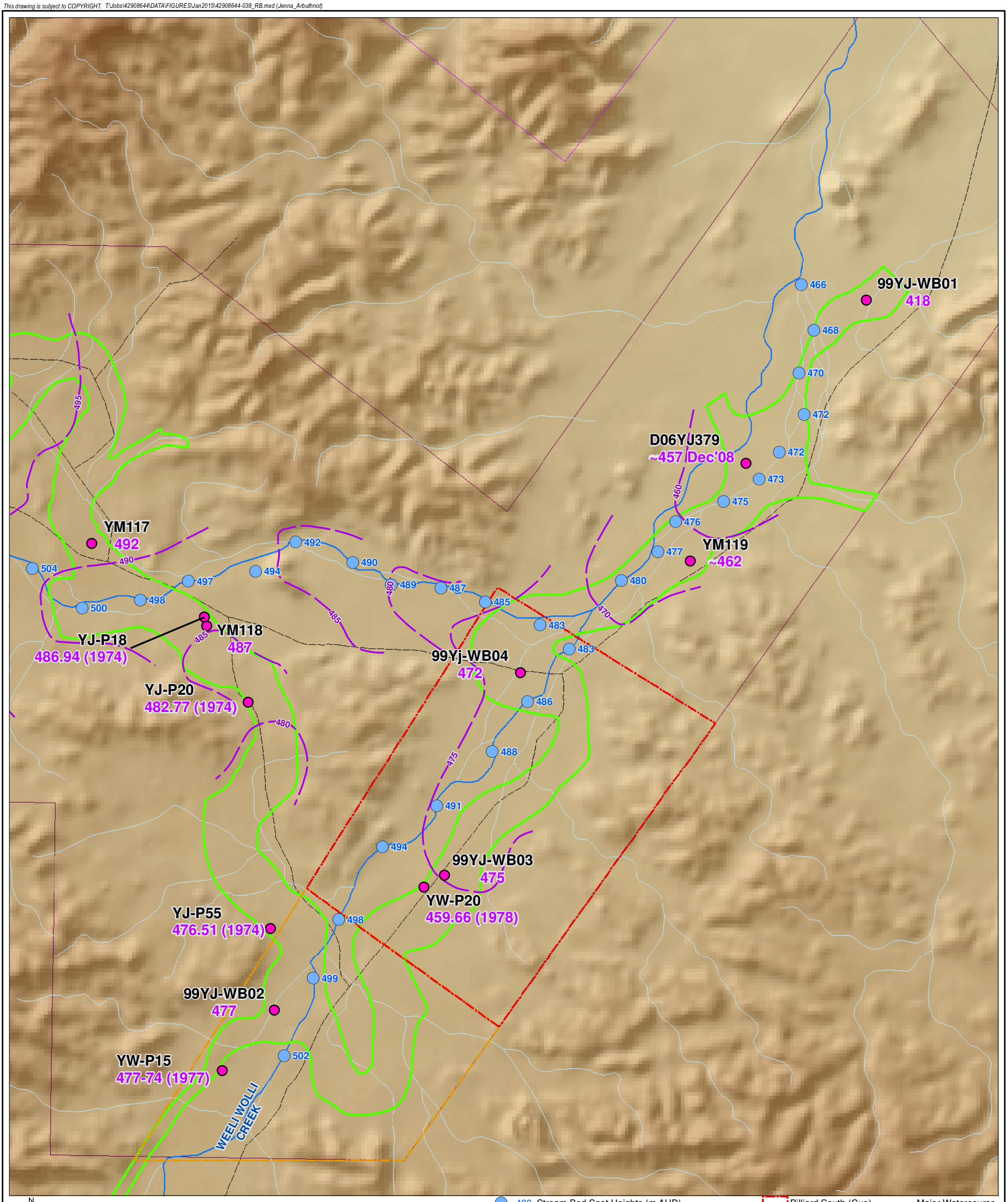

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

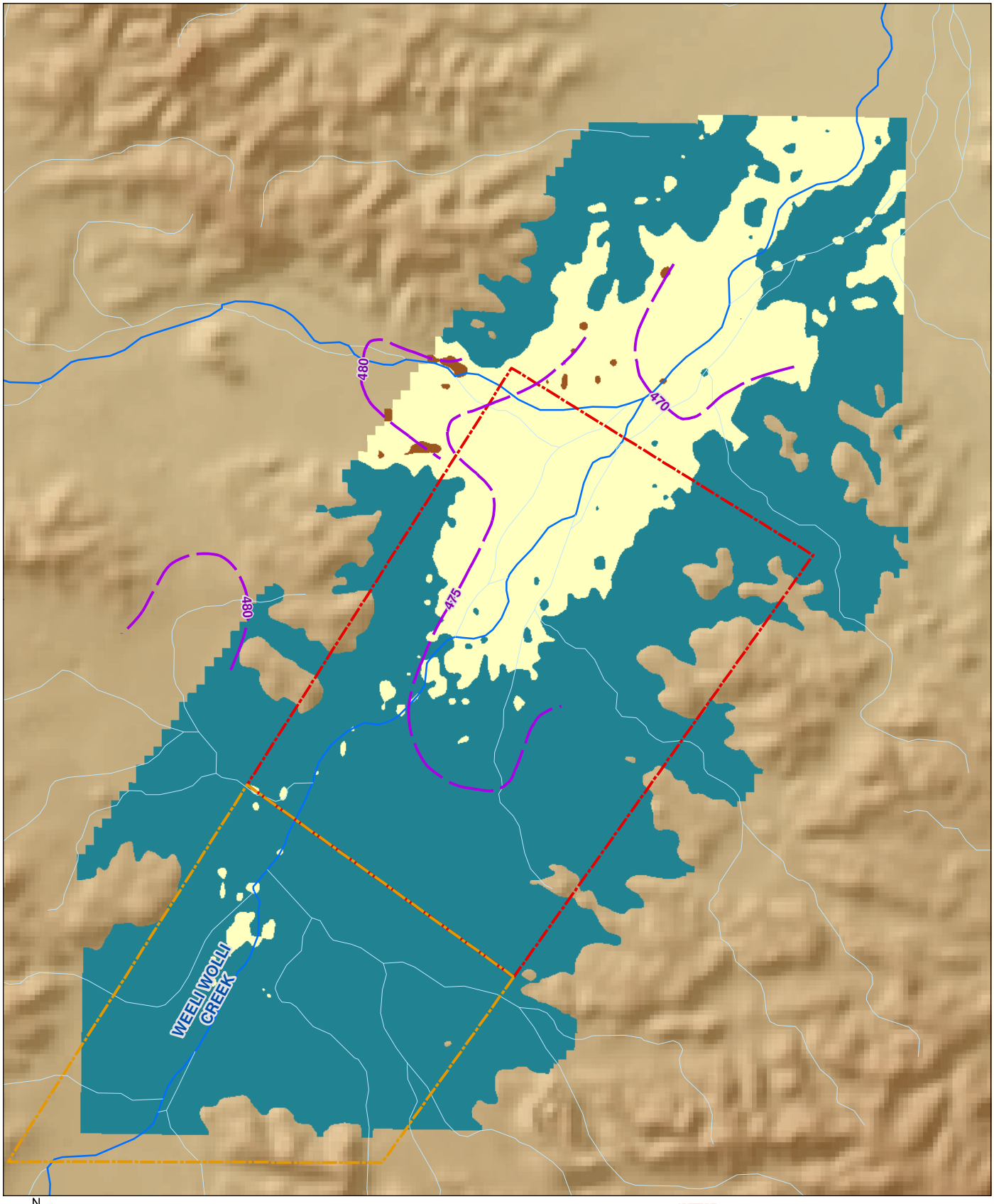
SNAPSHOT OF BASELINE WATER TABLE ELEVATIONS (EARLY-1995)

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **4-2**

File No:**42908644-038_RB.mxd** Drawn: **RNM\JA** Approved:**IGB** Date: **1/05/2015** Rev. **A** A3



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

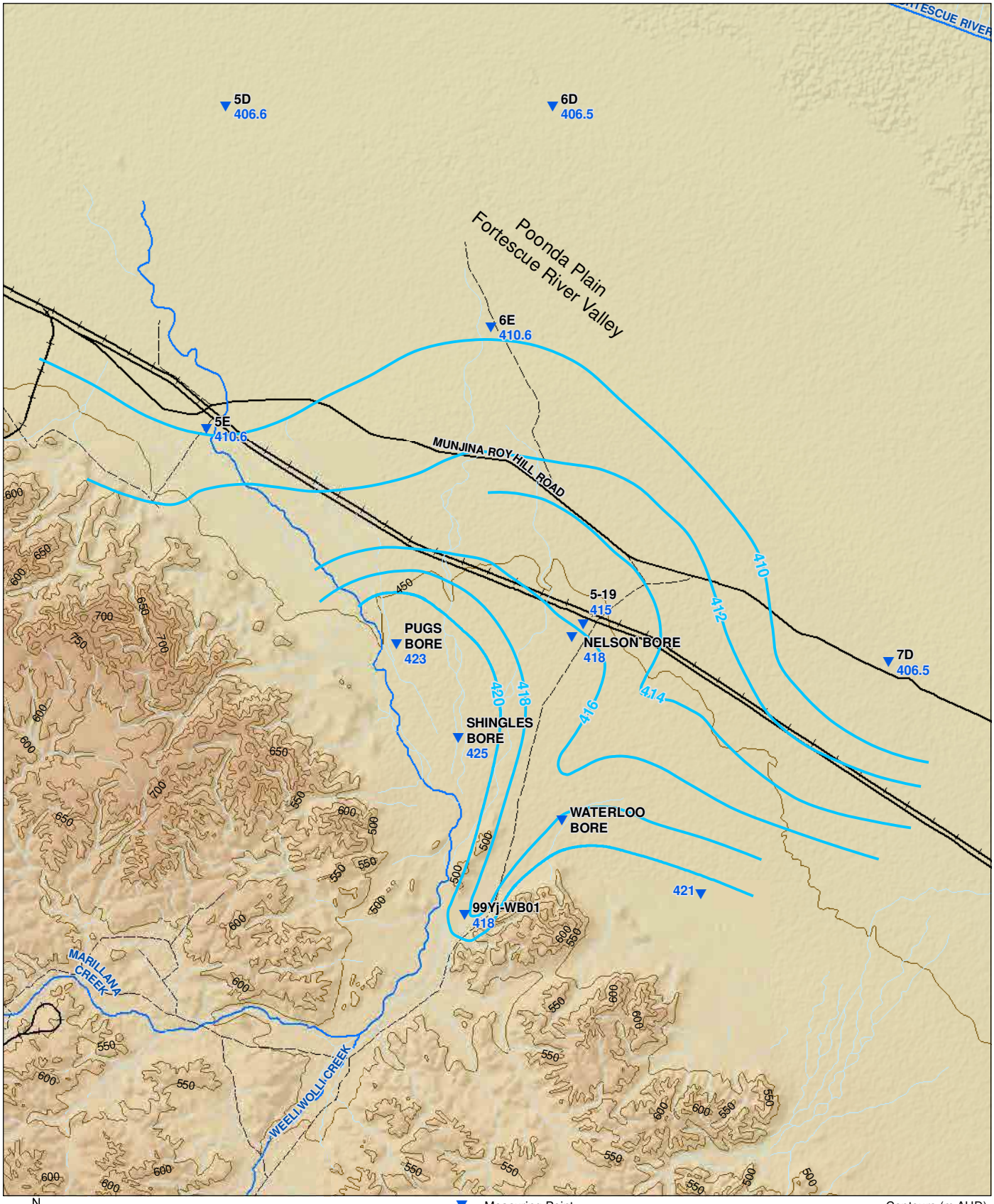
BASELINE DEPTH TO WATER TABLE (EARLY - 1995)

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 4-3

File No: 42908644-006_RC.mxd | Drawn: XX | Approved: XX | Date: 1/05/2015 | Rev. A | A4



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Scale: 1:200,000

0 2 4 6 8 km

Measuring Point

386 Groundwater Levels (m AHD; Late-2009/Early-2010 & Late 2012)

412 Groundwater Level Contours (m AHD; Mid-2009)

Contours (m AHD)
Major Watercourse
Minor Watercourse
Minor Road
Secondary Road
Track
Railways

Coordinate System: GDA 1994 MGA Zone 50

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Aquaterra (2010) and McLean and Sanderson, RTIO; 2012 in draft

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

INTERPRETED WATER TABLE ELEVATIONS BENEATH POONDA PLAIN (EARLY-2010)

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 4-4

File No: 42908644-044_RB.mxd Drawn: RNM Approved: IGB Date: 1/05/2015 Rev. A A4

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Report

Environmental Risk Assessment for Riparian Zones on Weeli Wolli Creek

AUSTRALIA

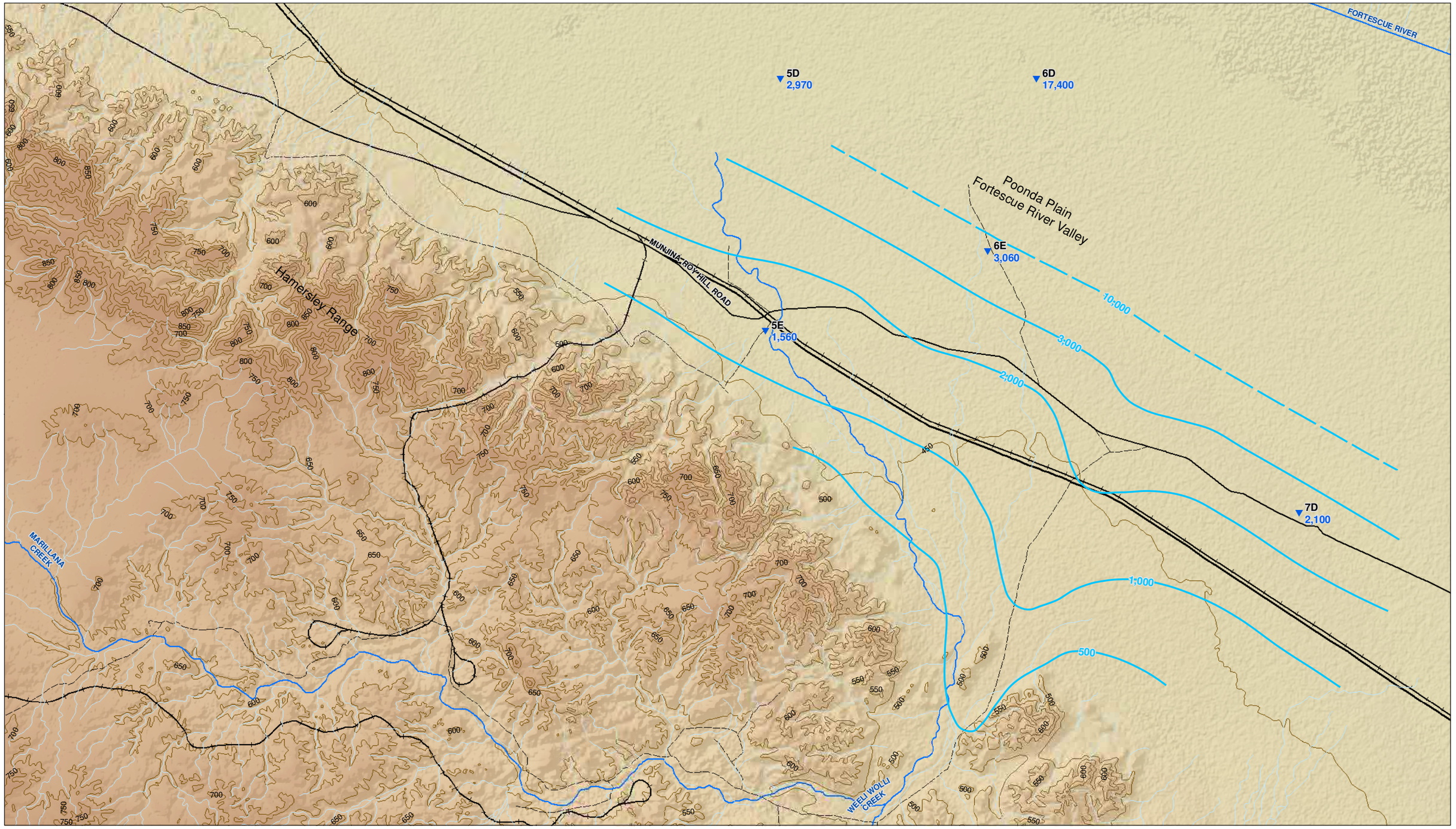
Part 3 - Figures

Riparian Zones Environmental Risk Assessment

30 June 2015
42908644/WY/IGB-Wat-0124/PSM/2

Prepared for:
Rio Tinto Iron Ore Pty Ltd

Prepared by URS Australia Pty Ltd



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

SHALLOW GROUNDWATER SALINITY BENEATH POONDA PLAIN (2009 to 2013)

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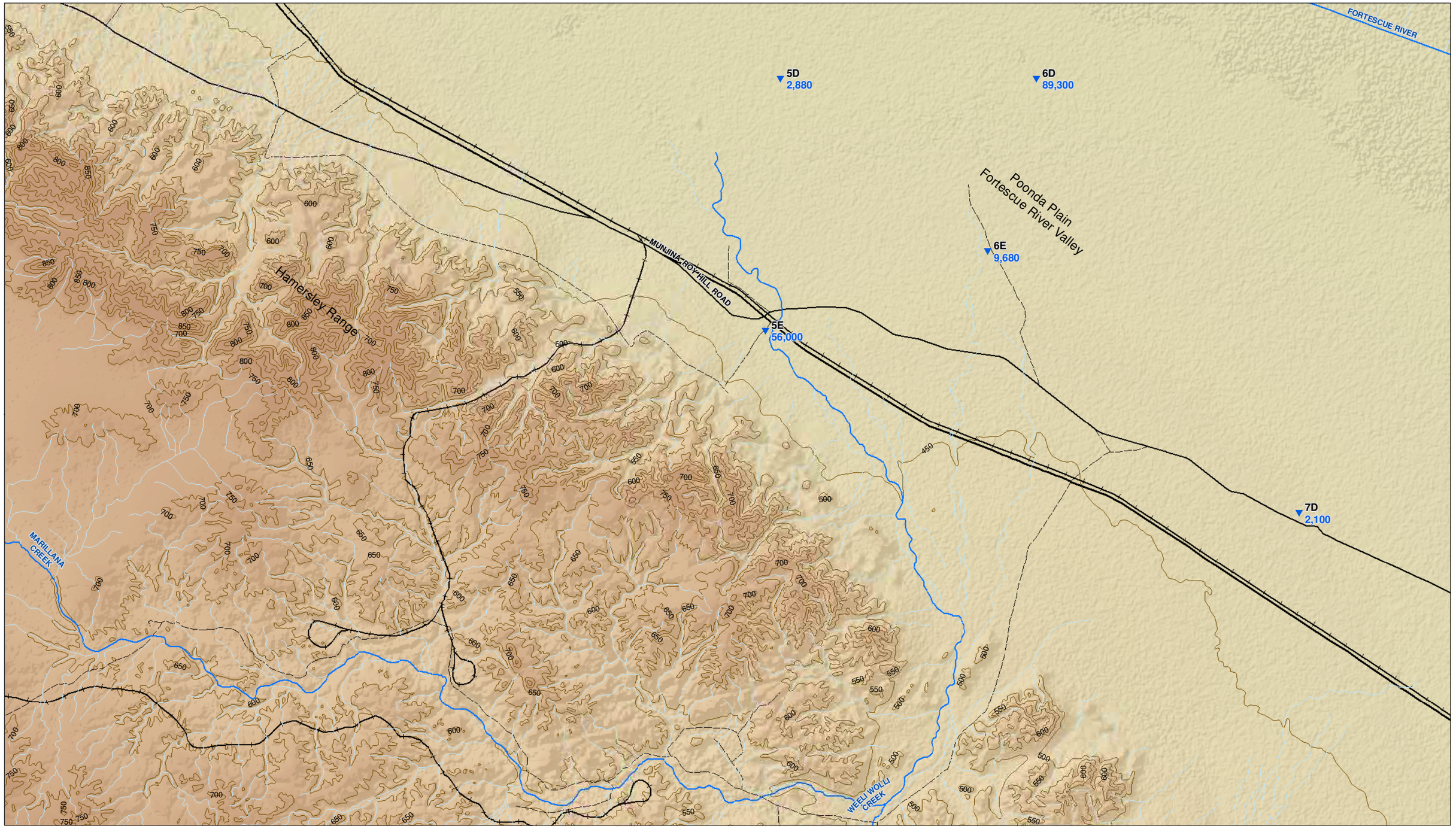
THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **4-5**

File No: **42908644-047_RB.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A3



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

GROUNDWATER SALINITY IN HAMERSLEY GROUP (2009 to 2013)

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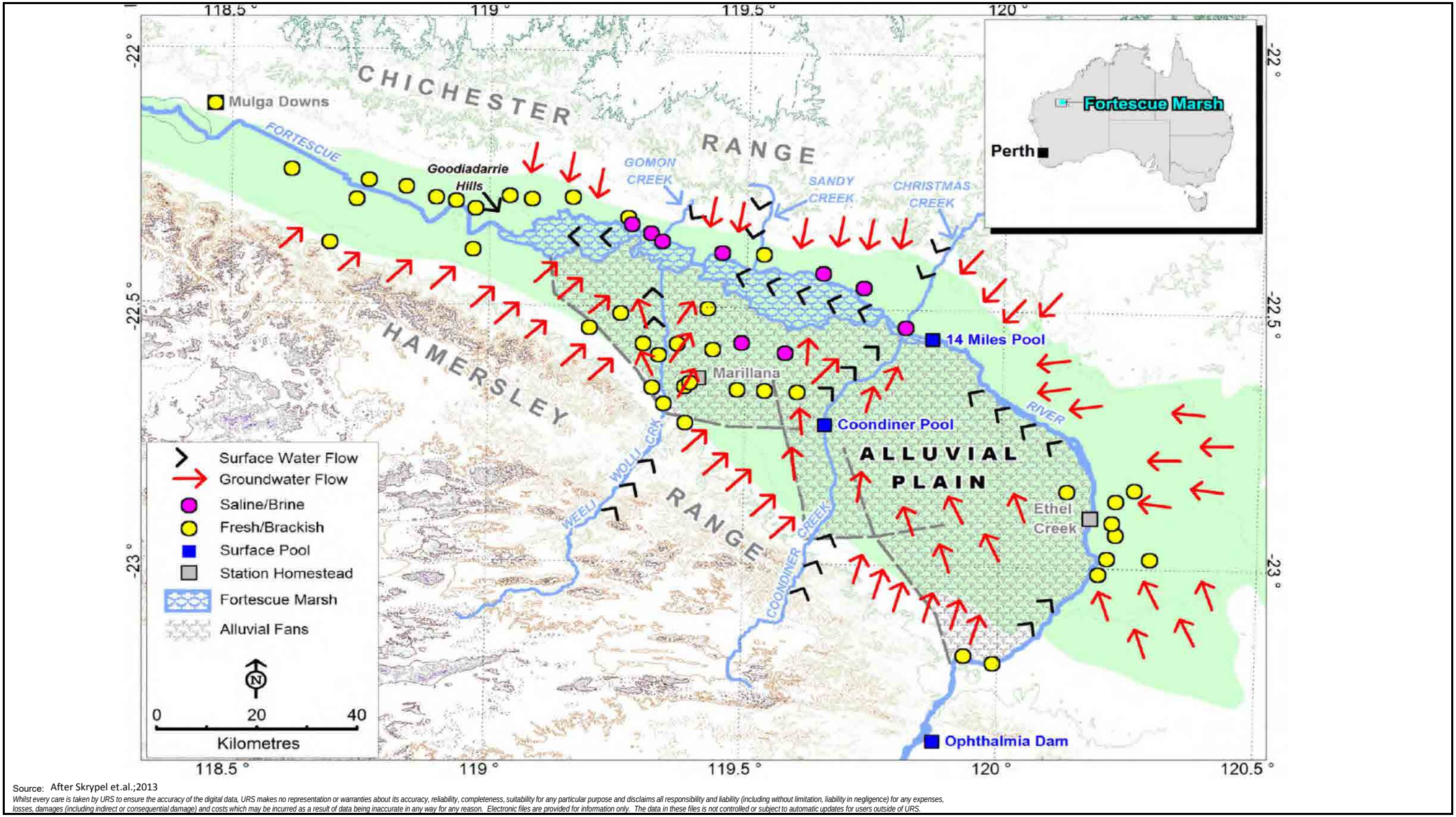
THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **4-6**

File No: **42908644-048_RB.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A3



Source: After Skrypel et.al.;2013

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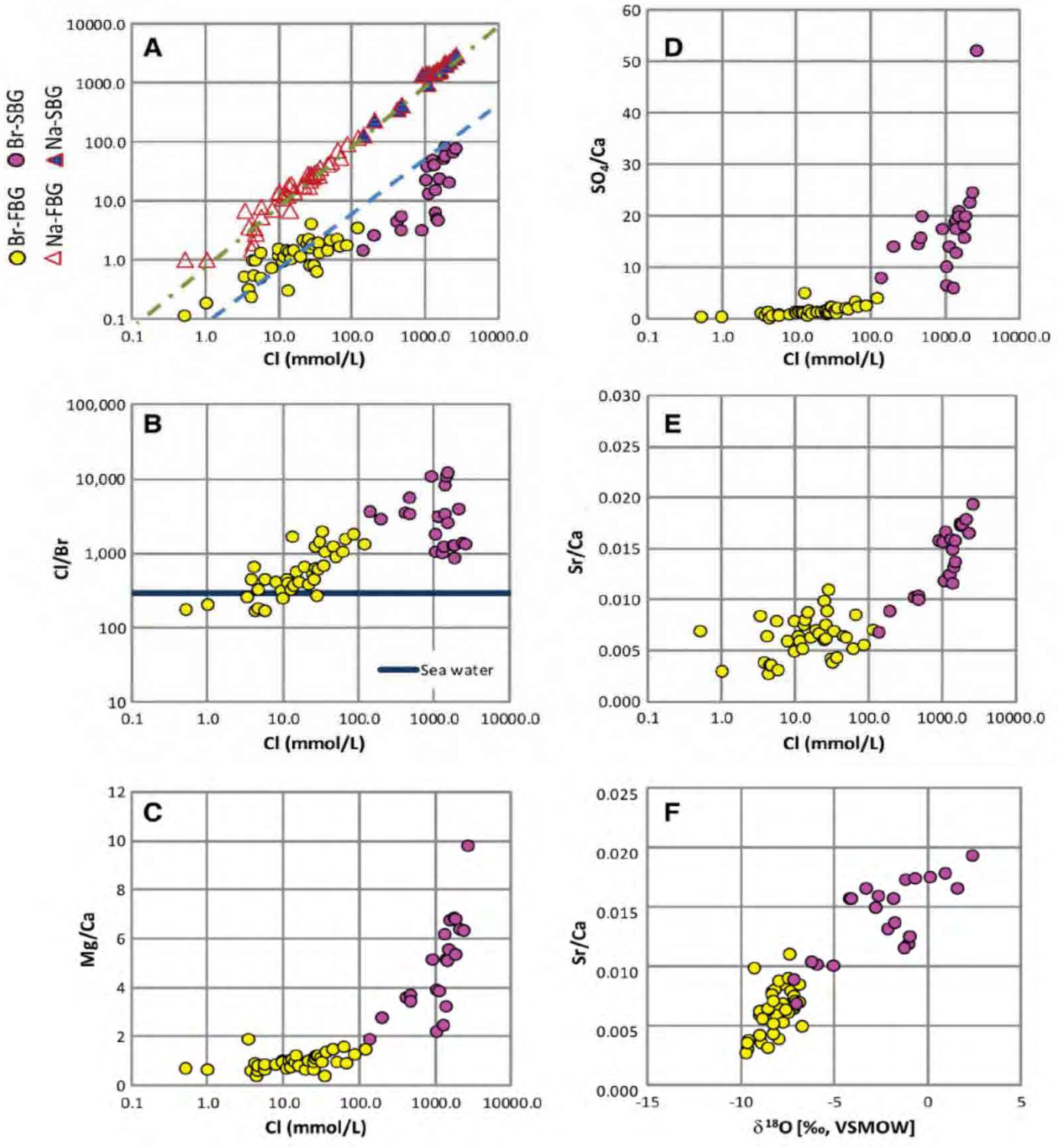
48 GROUNDWATER SAMPLING LOCATIONS UPPER FORTESCUE RIVER VALLEY

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **4-7**

File No: 42908644-058_RB.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: **A** A4



Source: (after Skrzypek et.al.;2013)

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

CHLORIDE AND $\delta_{18}O$ RELATIONSHIPS WITH SELECTED IONS

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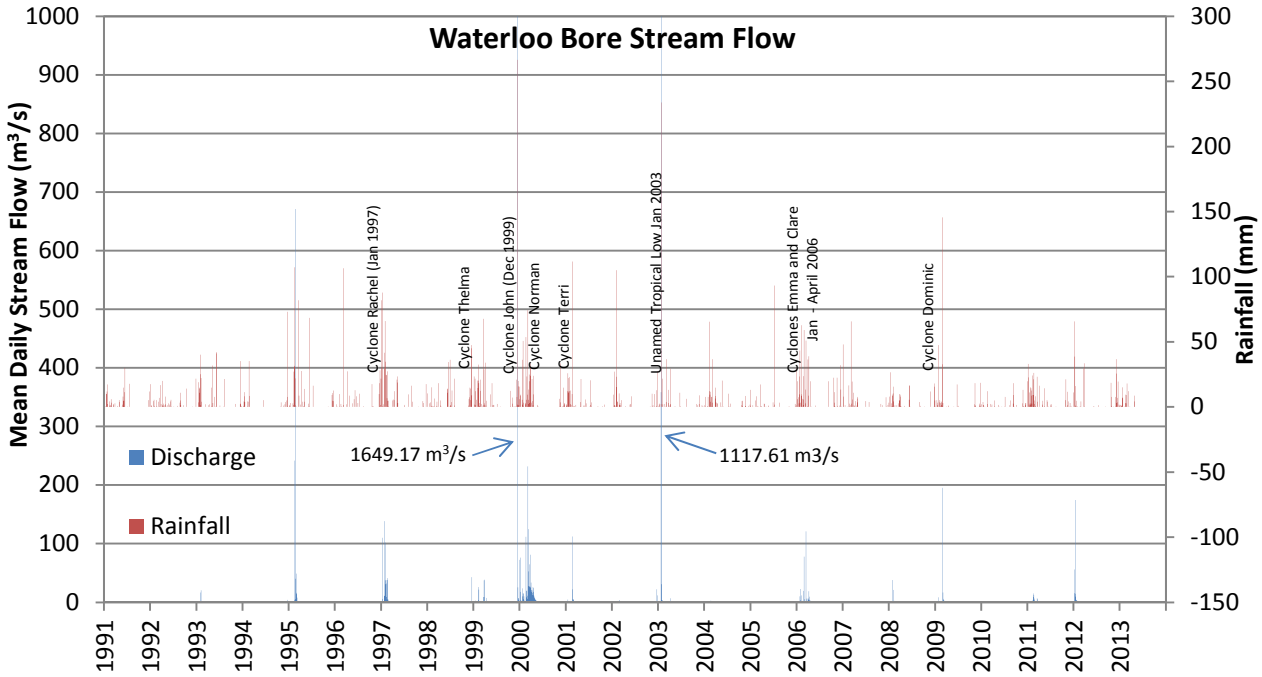
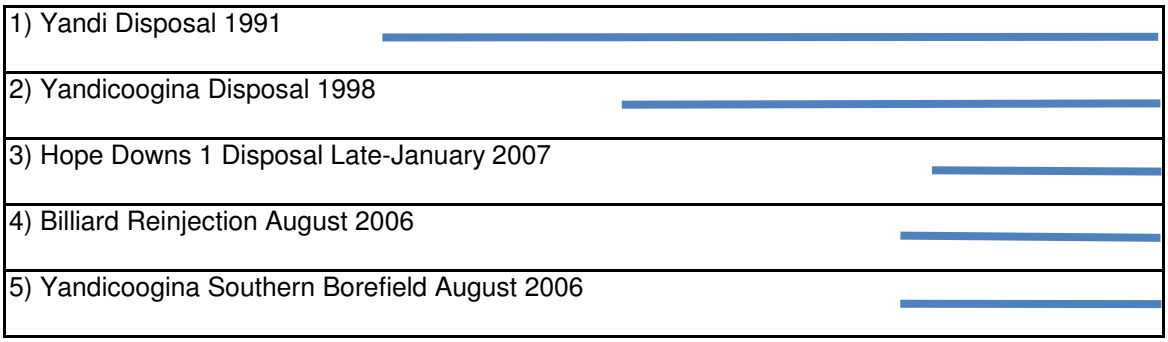
THE POCKET AND BILLIARD SOUTH PROJECT

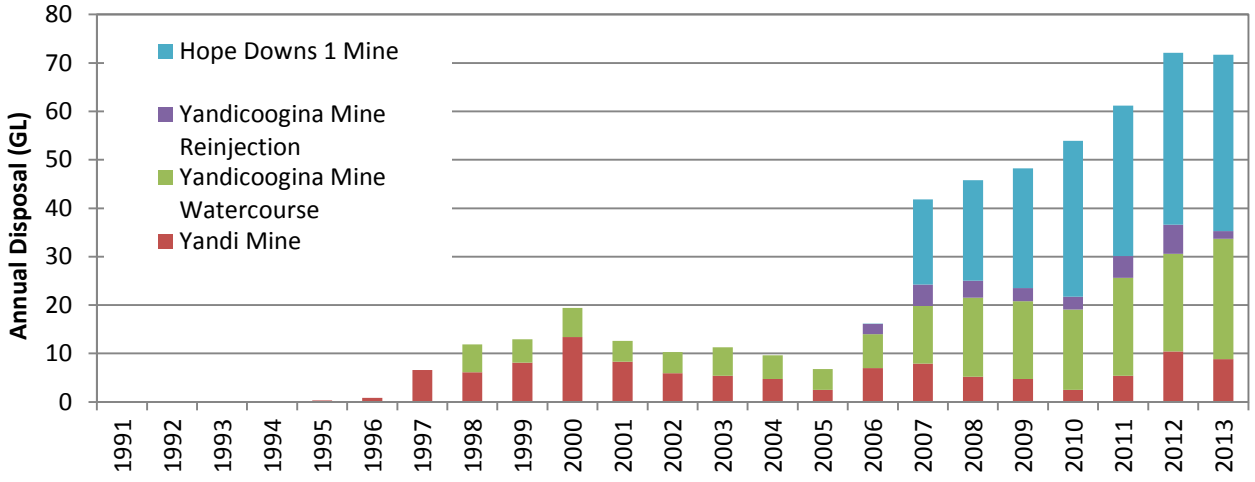
Figure: **4-8**

File No: 42908644-060_RB.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev. **A** A4



Key Dates and Annual Surplus Groundwater Disposal Volumes





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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TRANSIENT SURPLUS WATER DISCHARGE (1991 to 2013)

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THE POCKET AND BILLIARD SOUTH PROJECT

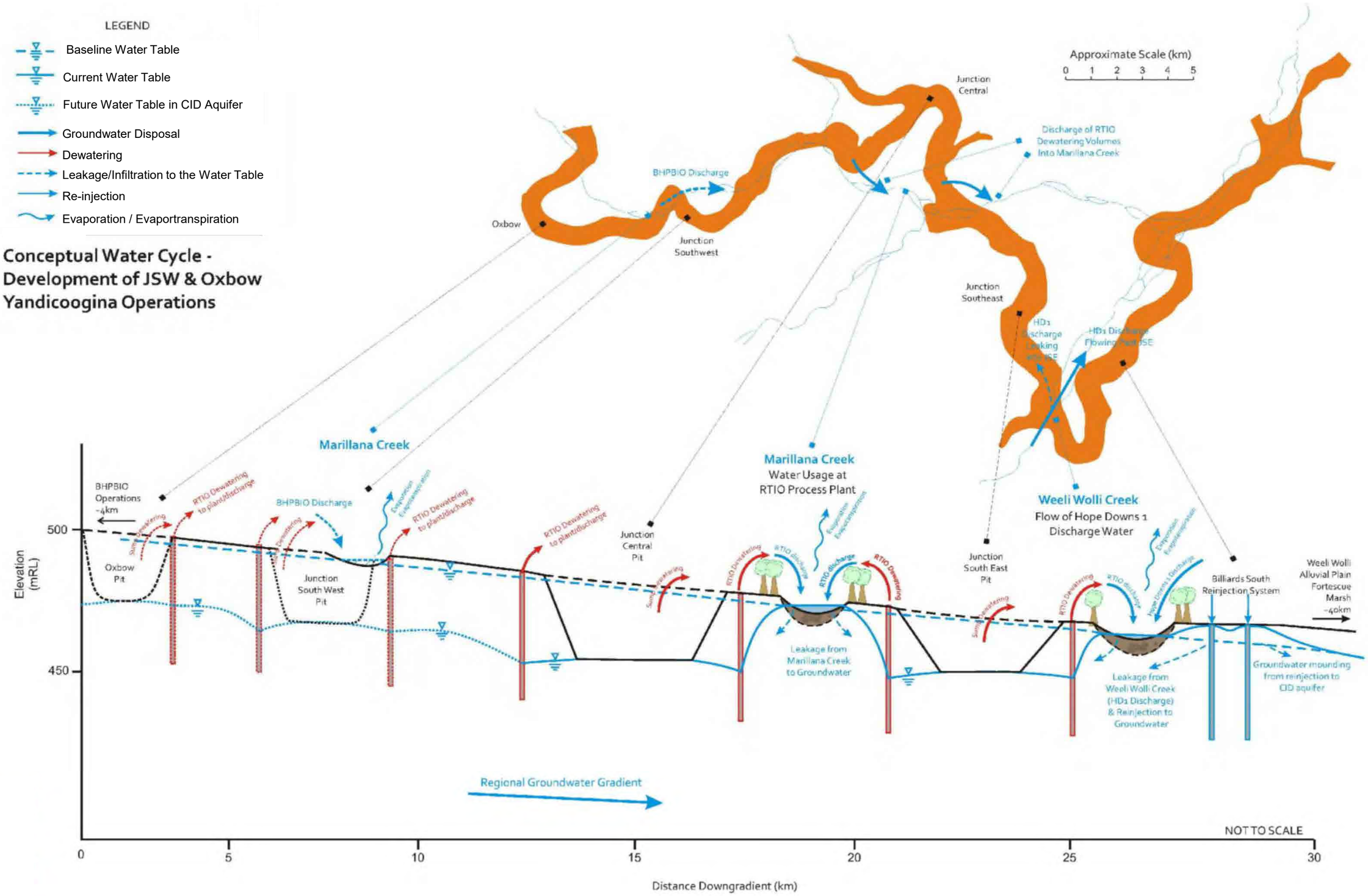
Figure: **5-1**

File No: 42908766-087.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev. **A** A4

LEGEND

- Baseline Water Table
- Current Water Table
- Future Water Table in CID Aquifer
- Groundwater Disposal
- Dewatering
- Leakage/Infiltration to the Water Table
- Re-injection
- Evaporation / Evaportranspiration

Conceptual Water Cycle - Development of JSW & Oxbow Yandicoogina Operations



Source: After Rio Tinto, September 2011 (Public Environmental Review: Yandicoogina Junction South West and Oxbow Iron Ore Project).

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

CONCEPTUAL CROSS-SECTION OF CURRENT DRAWDOWN (2014)

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Figure: 5-2

File No: 42908644-042.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015

Rev. A A3

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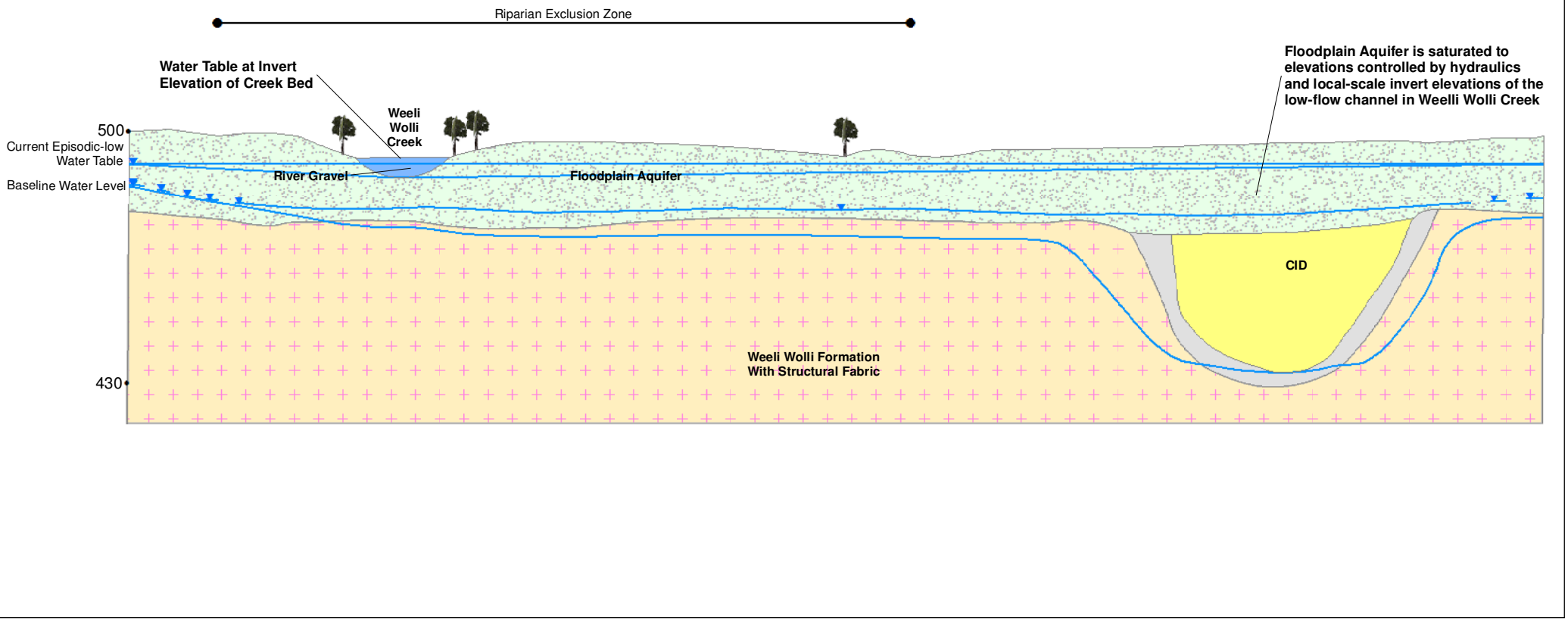

Alluvial/Insitu Weathered Bedrock
Basal Clay Conglomerate
CID
River Gravel
Weeli Wolli Creek
Weeli Wolli Formation

Not To Scale

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010). Public Environmental Review: Yandicoogina Junction South West and Oxbow Iron Ore Project (RTIO,September 2011)

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

COMPARISON OF BASELINE AND CURRENT WATER TABLE SETTINGS BENEATH WEELLI WOLLI CREEK

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 5-3

File No: 42908644-053.mxd Drawn: RNM Approved: IGB Date: 1/05/2015 Rev. A A4

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99YJ-WB01
7/02/2009
D08YJ165
2010
6/08/2008
Aug 2008
16/12/2007
D08YJ216
05/2011
21/10/2007
MARILLANA CREEK
2010
05/2011
YM119
D08YJ126
99YJ-WB04
99YJ-WB03
99YJ-WB02
WEELI WOLLI CREEK

N
W E
S

Scale: 1:50,000
0 500 1,000 1,500 2,000 Meters

Coordinate System: GDA 1994 MGA Zone 50

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05/2011 Observed Surface Water Wetting Front and Date of Measurement
CID Monitoring Bores
CID Boundary

Billiard South (Cue)
Billiard South (Pocket)
BHP Billiton Tenement
RTIO Tenement

Major Watercourse
Minor Watercourse
Track

RIO TINTO IRON ORE PTY LTD

RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

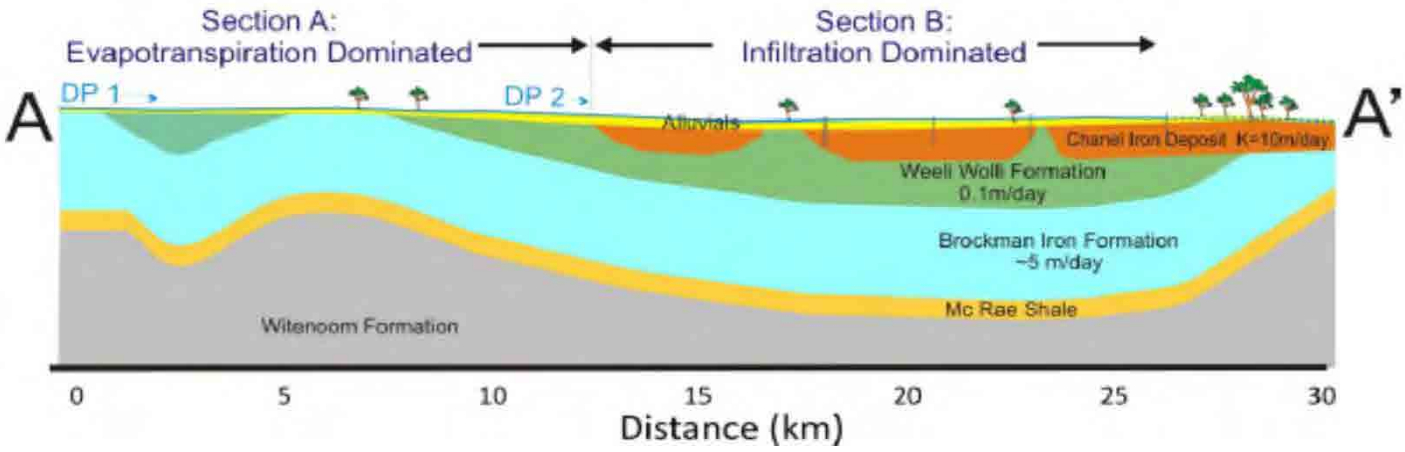
SNAPSHOTS OF SURFACE WATER WETTING FRONTS (2007 TO 2011)

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-4**

File No: **42908644-037_RB.mxd** Drawn: **RNM\JA** Approved: **IGB** Date: **1/05/2015** Rev. **A** A3



Source: Dogramaci et. al., January 2015.

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T:\Jobs\42908644\DATA\FIGURES\Jan2015\[42908644-059.xls]A4L1

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

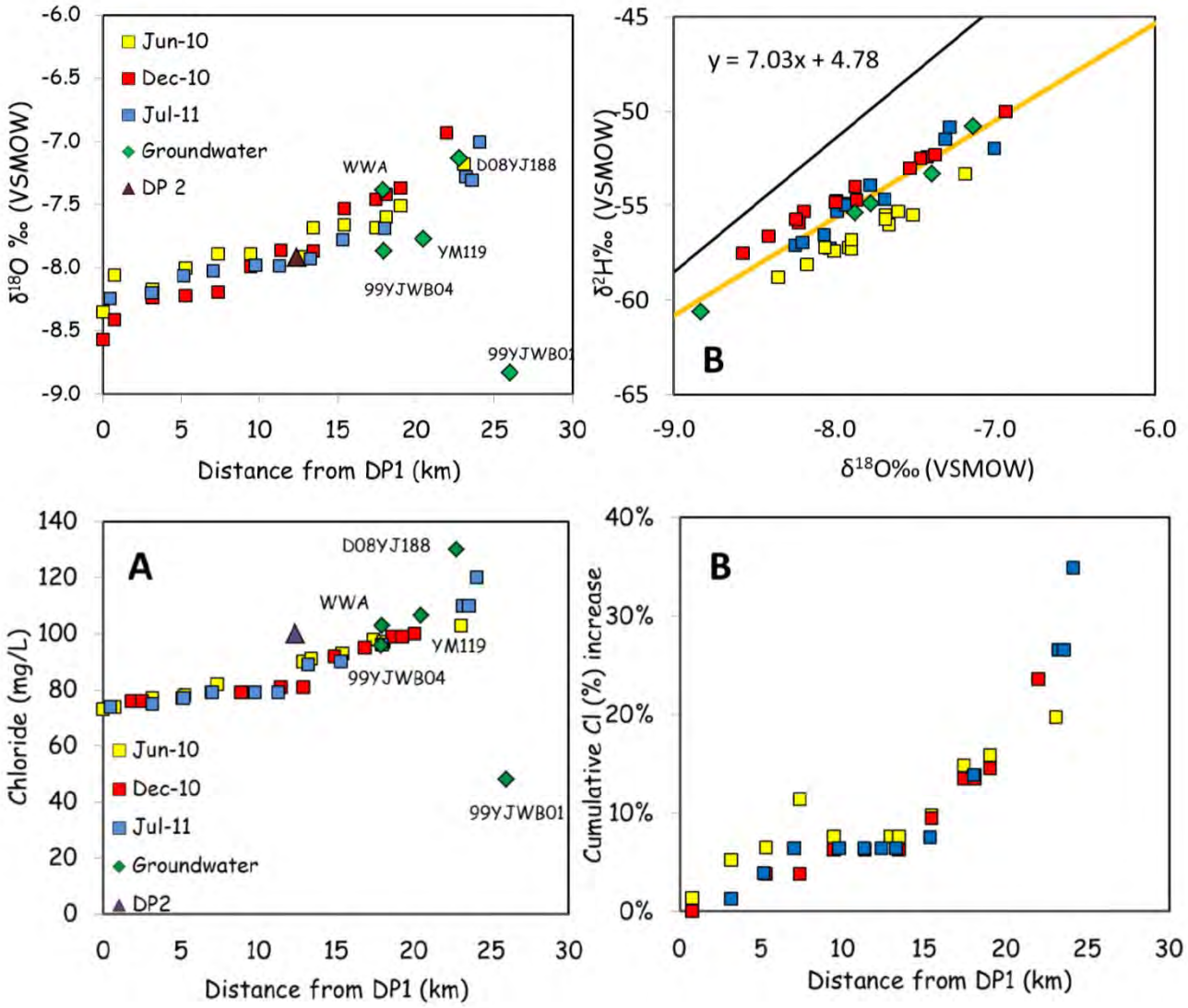
CHLORIDE, $\delta^{18}O$ AND $\delta^{2}H$ SAMPLE SITES

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 5-5

File No: 42908644-059.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev. A A4



Source: Dogramaci et. al., January 2015.

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

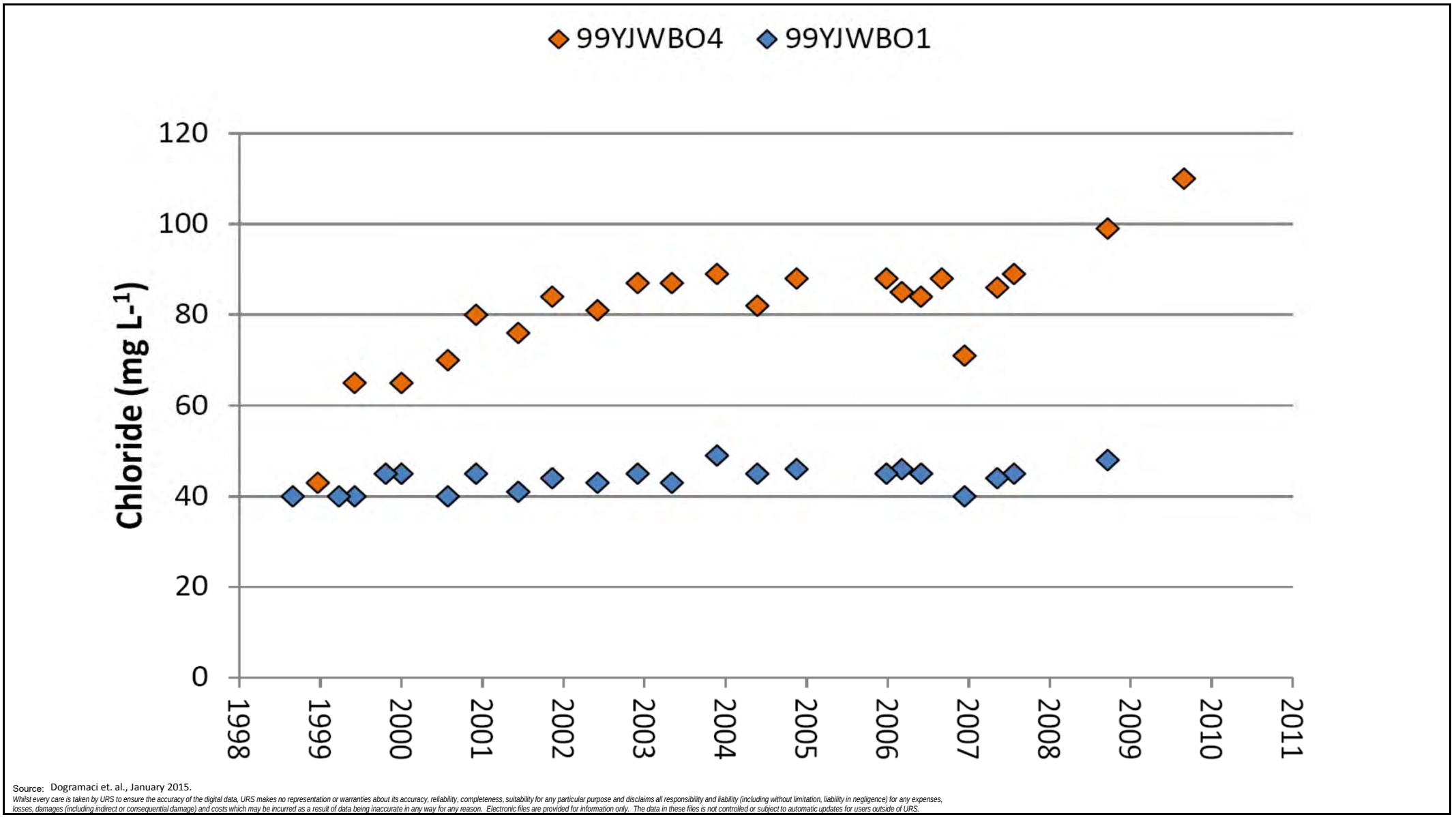
ANALYTICAL DATA ON CHLORIDE, $\delta^{18}O$ AND $\delta^{2}H$ CONCENTRATIONS AND, DISTANCE FROM DP1

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-6**

File No: 42908644-057.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: **A** A4



Source: Dogramaci et. al., January 2015.

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TRANSIENT GROUNDWATER CHLORIDE CONCENTRATIONS 99YJWB01 and 99YJWB04

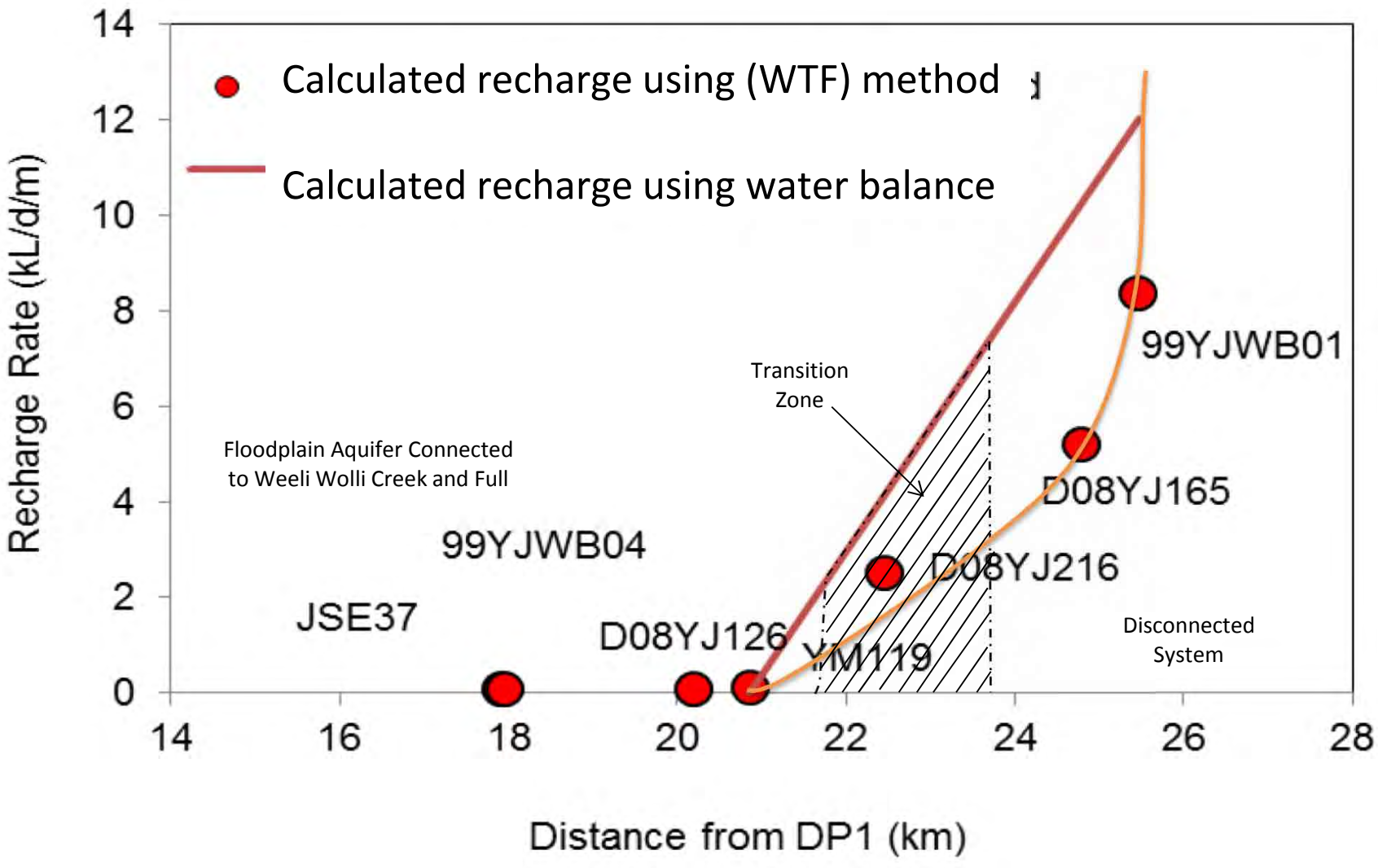
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-7**

File No: 42908644-055.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015

Rev: **A** A4



Source: Dogramaci et. al., January 2015.

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

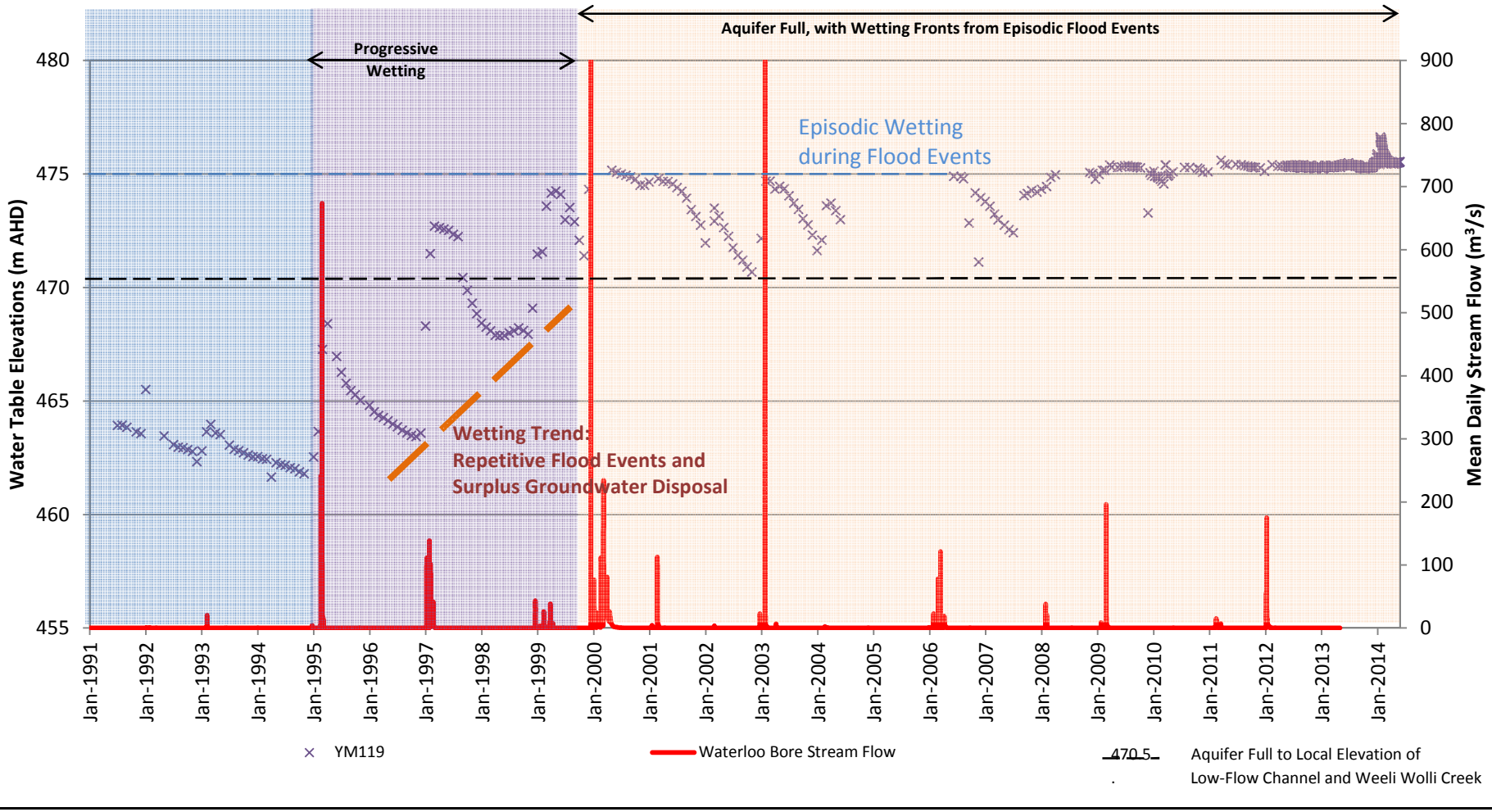
CALCULATED RECHARGE RATES FOR SECTION B WEELI WOLLI CREEK

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 5-8

File No: 42908644-056.xlsx Drawn: RNM Approved: IGB Date: 01/05/2015 Rev: A A4



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\May 2015\[42908644-088.xlsx]Fig 5-9

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

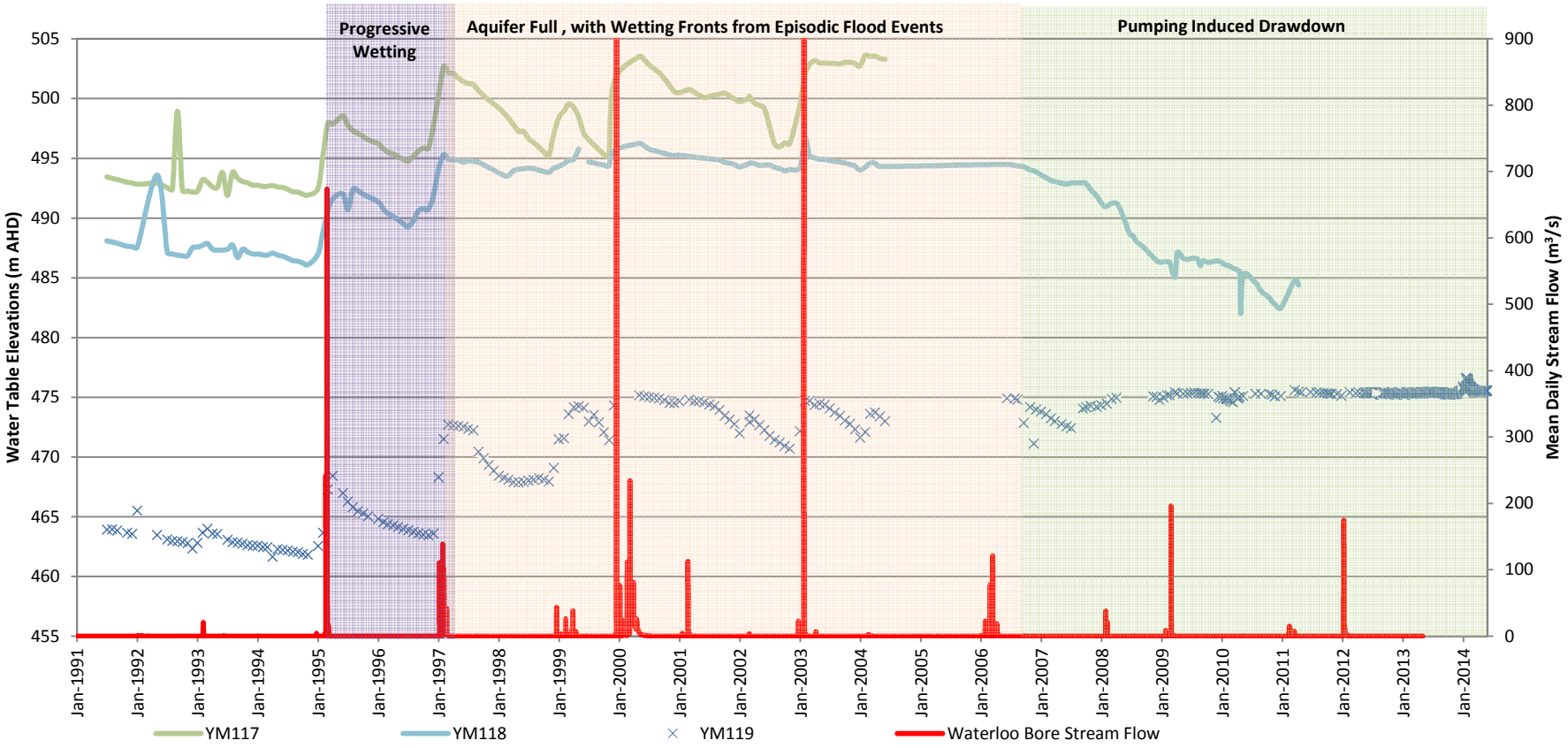
GROUNDWATER WETTING FRONTS - YM119 TEMPLATE

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-9**

File No: 42908644-088.xlsx Drawn: JA Approved: IGB Date: 20/04/2015 Rev: **A** A4



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\May 2015\[42908644-089.xlsx]Fig 5-10

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

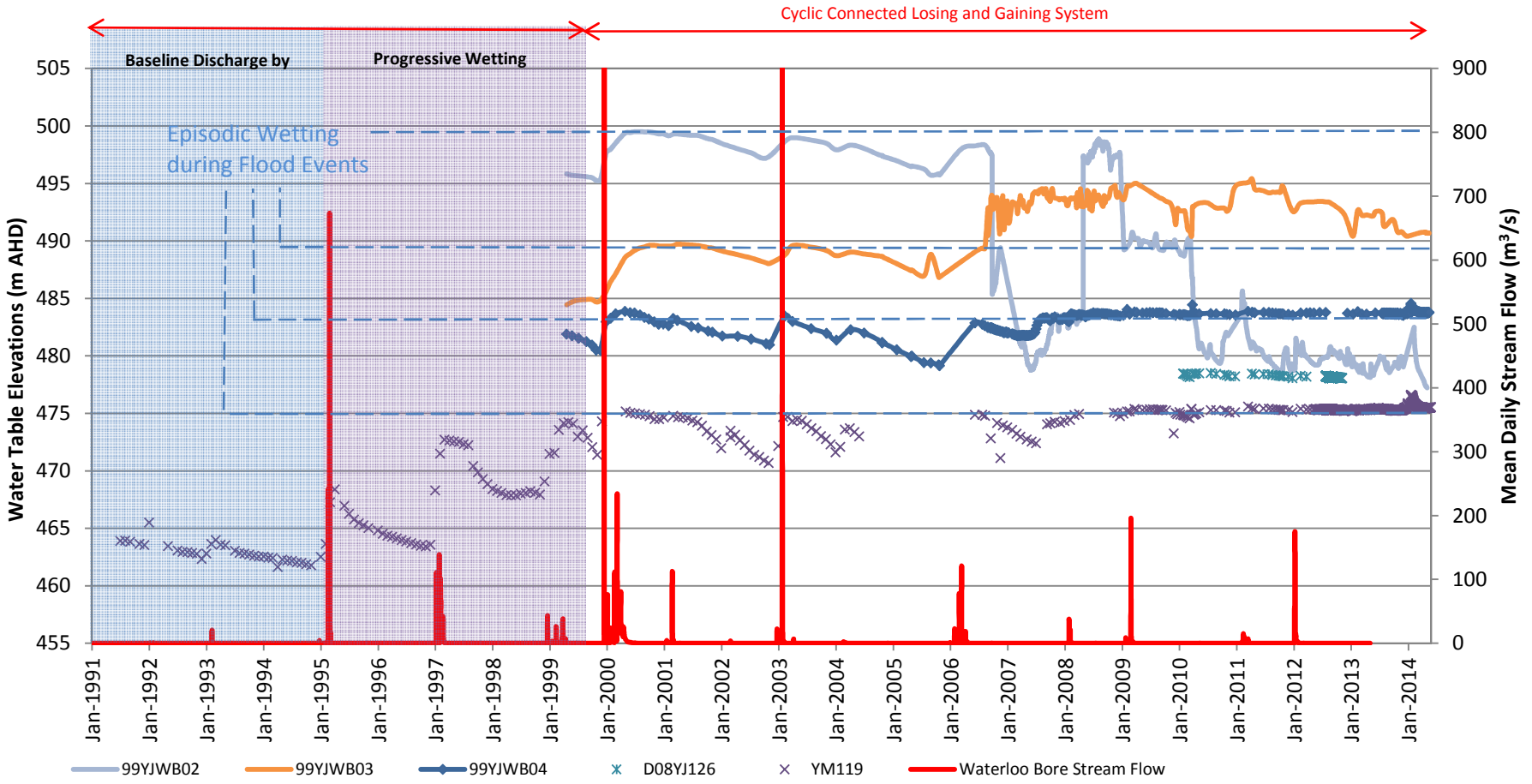
GROUNDWATER WETTING FRONTS - MARILLANA CREEK SETTINGS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-10**

File No: 42908644-089.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\May 2015\[42908644-090.xlsx]Fig 5-11

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

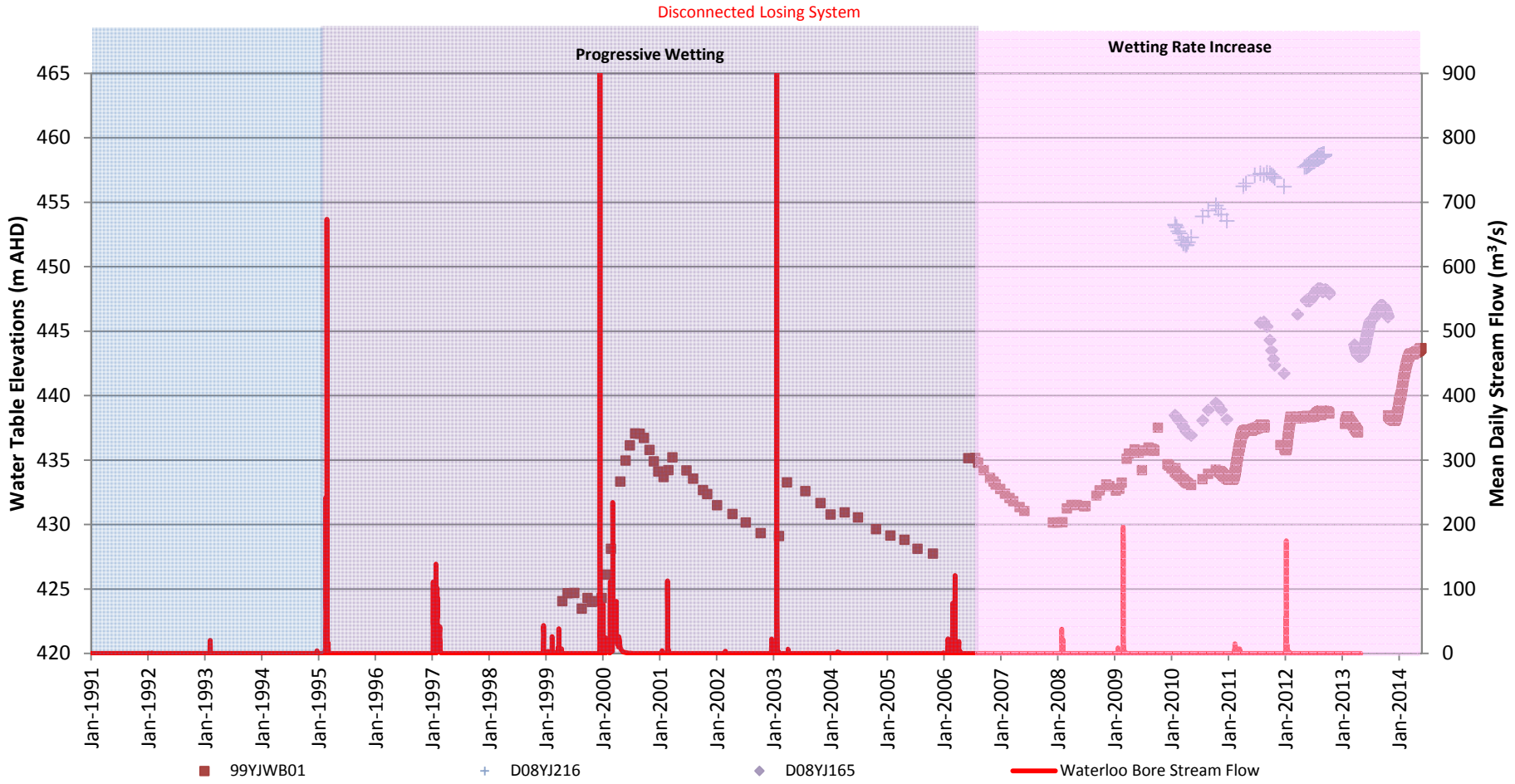
GROUNDWATER WETTING FRONTS - UPPER WEELI WOLLI CREEK SETTINGS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-11**

File No: 42908644-090.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\Jan2015\[42908644-091.xls]Fig 5-12

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

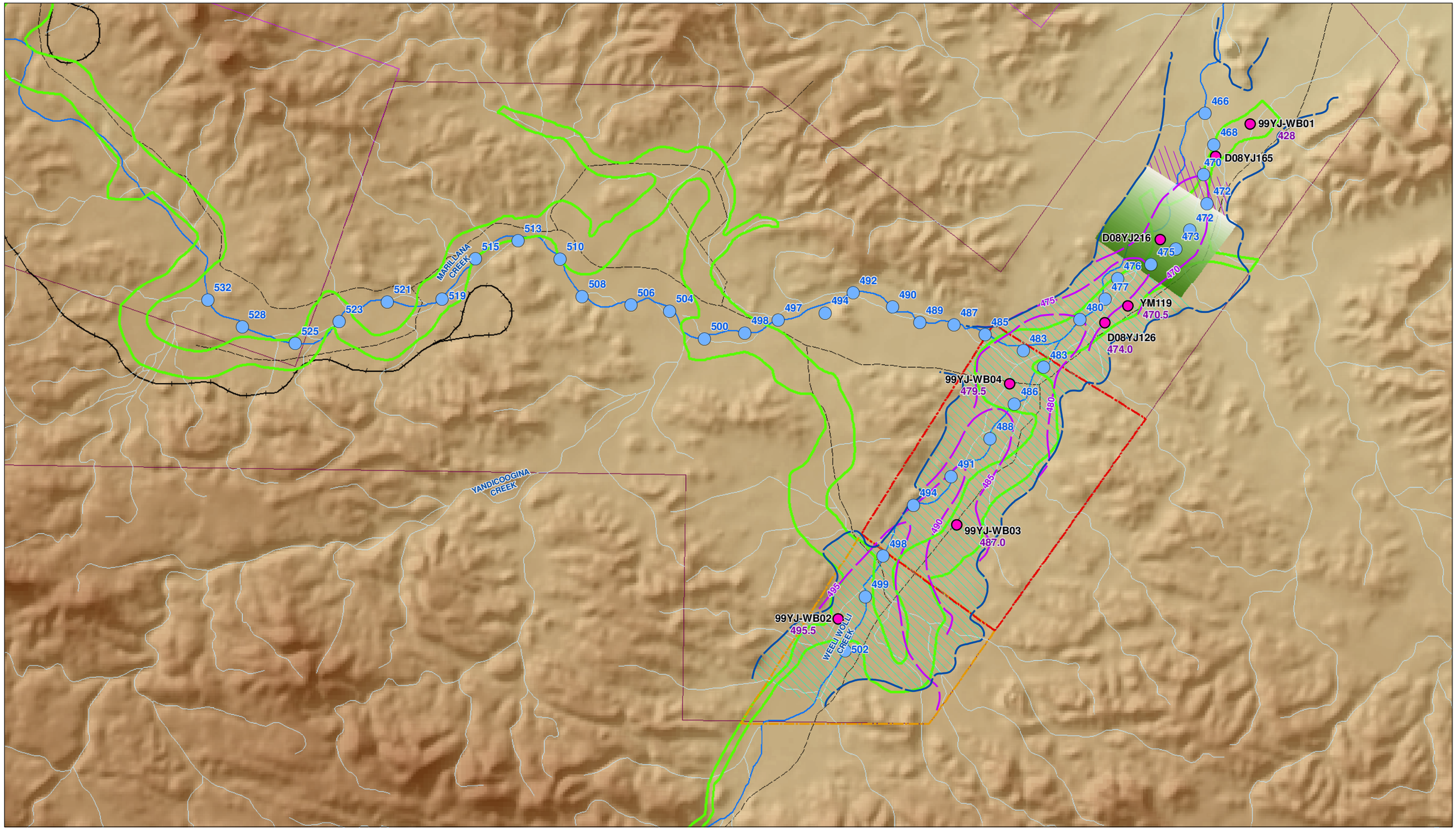
GROUNDWATER WETTING FRONTS - LOWER WEELI WOLLI CREEK SETTINGS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-12**

File No: 42908644-091.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

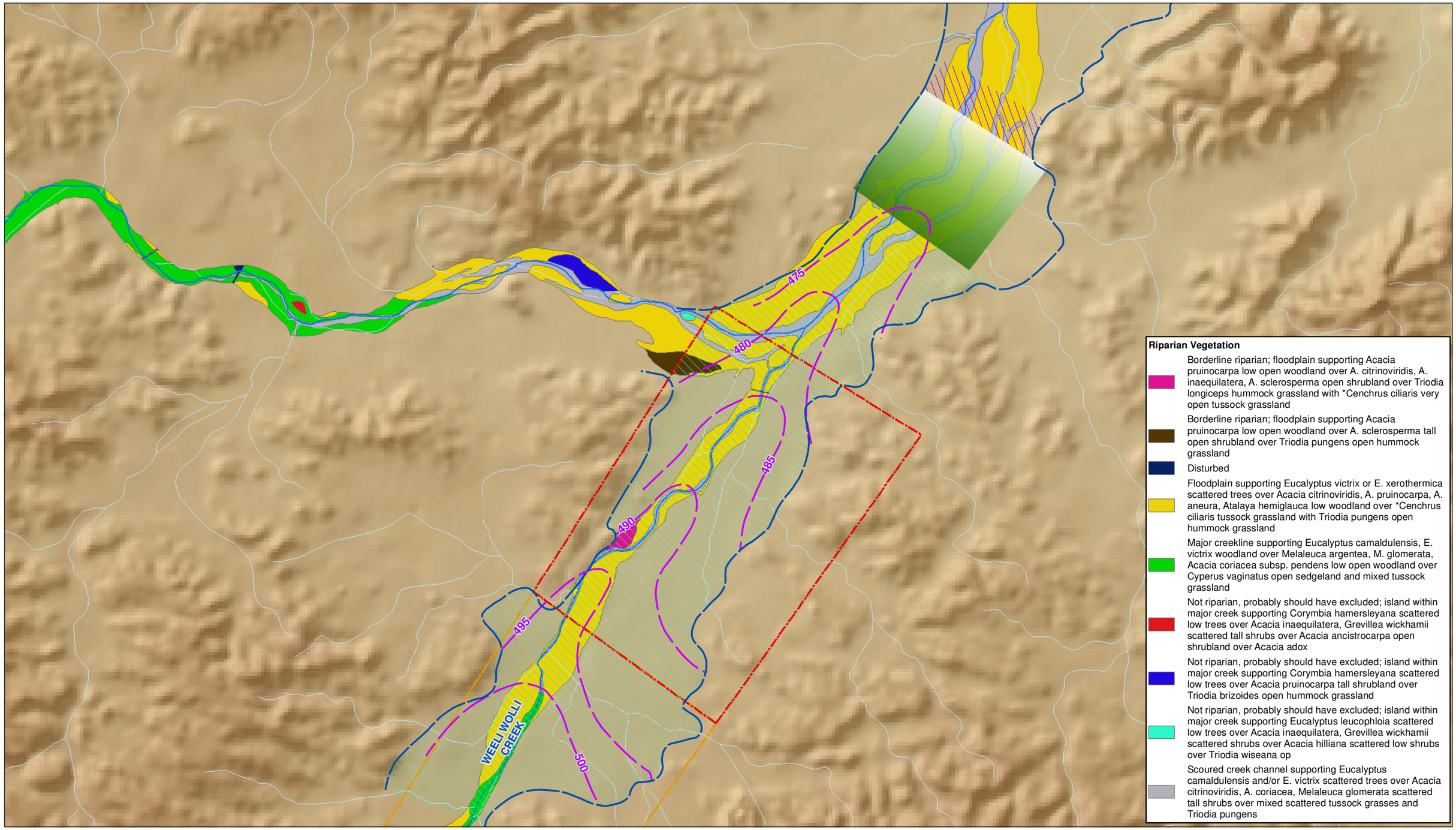
FLOODPLAIN AQUIFER FULLY SATURATED - CYCLIC LOW WATER TABLE ELEVATIONS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-13**

File No: **42908644-040.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A3



Riparian Vegetation

- Borderline riparian; floodplain supporting Acacia pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera, A. sclerosperma open shrubland over Triodia longiceps hummock grassland with *Cenchrus ciliaris very open tussock grassland
- Borderline riparian; floodplain supporting Acacia pruinocarpa low open woodland over A. sclerosperma tall open shrubland over Triodia pungens open hummock grassland
- Disturbed
- Floodplain supporting Eucalyptus victrix or E. xerothermica scattered trees over Acacia citrinoviridis, A. pruinocarpa, A. aneura, Atalaya hemiglauca low woodland over *Cenchrus ciliaris tussock grassland with Triodia pungens open hummock grassland
- Major creekline supporting Eucalyptus camaldulensis, E. victrix woodland over Melaleuca argentea, M. glomerata, Acacia coriacea subsp. pendens low open woodland over Cyperus vaginatus open sedgeland and mixed tussock grassland
- Not riparian, probably should have excluded; island within major creek supporting Corymbia hamersleyana scattered low trees over Acacia inaequilatera, Grevillea wickhamii scattered tall shrubs over Acacia ancistrocarpa open shrubland over Acacia adox
- Not riparian, probably should have excluded; island within major creek supporting Corymbia hamersleyana scattered low trees over Acacia pruinocarpa tall shrubland over Triodia brizoides open hummock grassland
- Not riparian, probably should have excluded; island within major creek supporting Eucalyptus leucophloia scattered low trees over Acacia inaequilatera, Grevillea wickhamii scattered shrubs over Acacia hilliana scattered low shrubs over Triodia wiseana op
- Scoured creek channel supporting Eucalyptus camaldulensis and/or E. victrix scattered trees over Acacia citrinoviridis, A. coriacea, Melaleuca glomerata scattered tall shrubs over mixed scattered tussock grasses and Triodia pungens

-480- Episodic High Water Table Elevations (mid-2006)

Nominal Extent of Floodplain

Floodplain Aquifer Full With Recent Episodic Recharge From Cyclones Claire and Emma

Bedrock Shelf: A Zone of Limited CID Thickness

Transition Zone: Floodplain Aquifer Transition From a Full Condition to a Disconnected Losing System

Billiard South (Cue)

Billiard South (Pocket)

Major Watercourse

Minor Watercourse

N
W E
S

Scale: 1:55,000

0 0.5 1 1.5 2 Km

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

FLOODPLAIN AQUIFER FULLY SATURATED - EPISODIC-HIGH WATER TABLE ELVATIONS

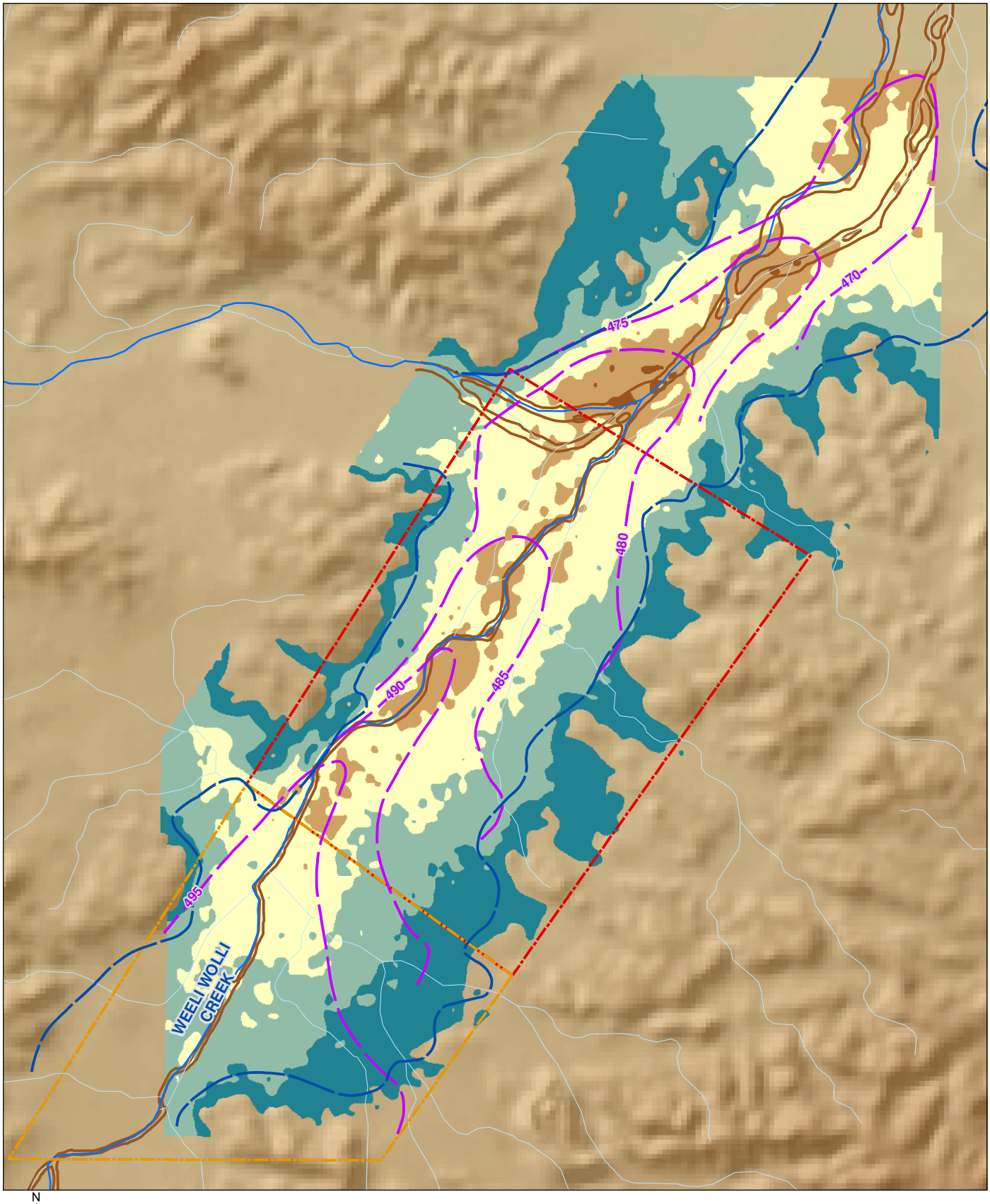
URS

THE POCKET AND BILLIARD SOUTH PROJECT

File No: **42908644-010.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015**

Figure: **5-14**

Rev. **A** A3



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

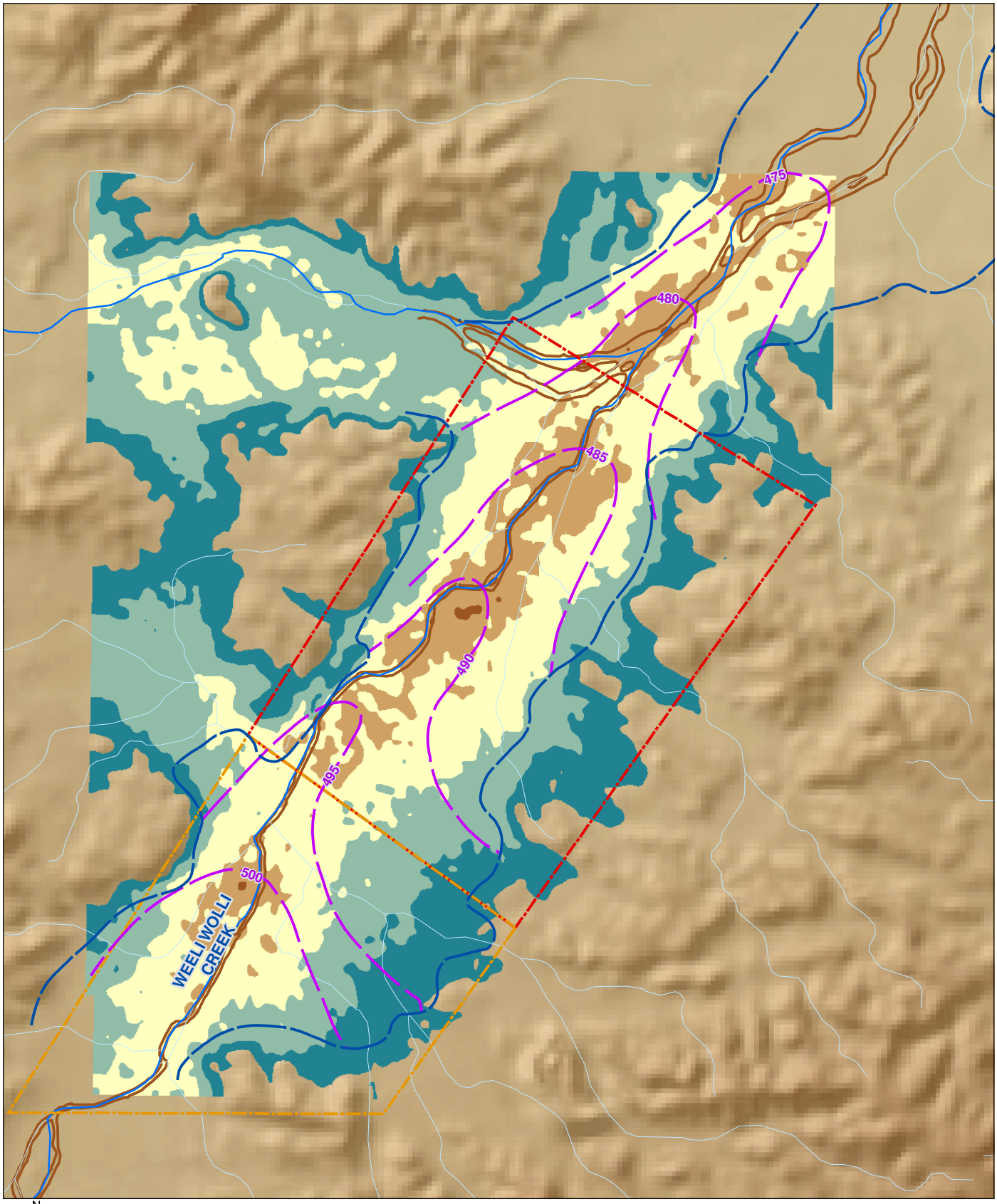
DEPTH TO WATER TABLE - CYCLIC-LOW SNAPSHOT

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 5-15

File No: 42908644-007_RC.mxd Drawn: RNM Approved: IGB Date: 1/05/2015 Rev. A A4



Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

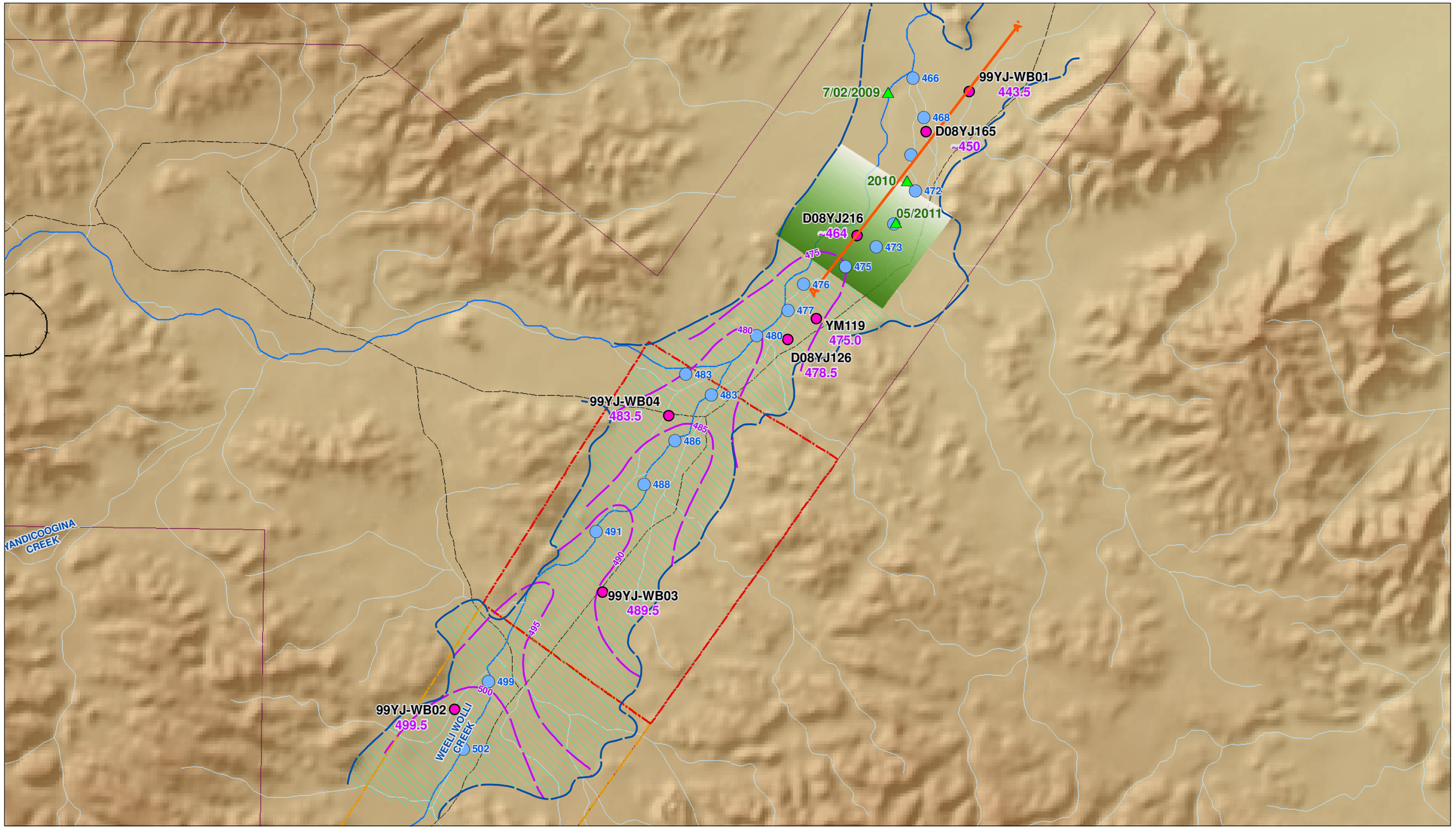
DEPTH TO WATER TABLE - EPISODIC-HIGH SNAPSHOT

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-16**

File No: **42908644-005_RC.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015** Rev. **A** A4



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

WETTING FRONT CONCEPTUALISATION - SETTINGS ON WEELI WOLLI CREEK

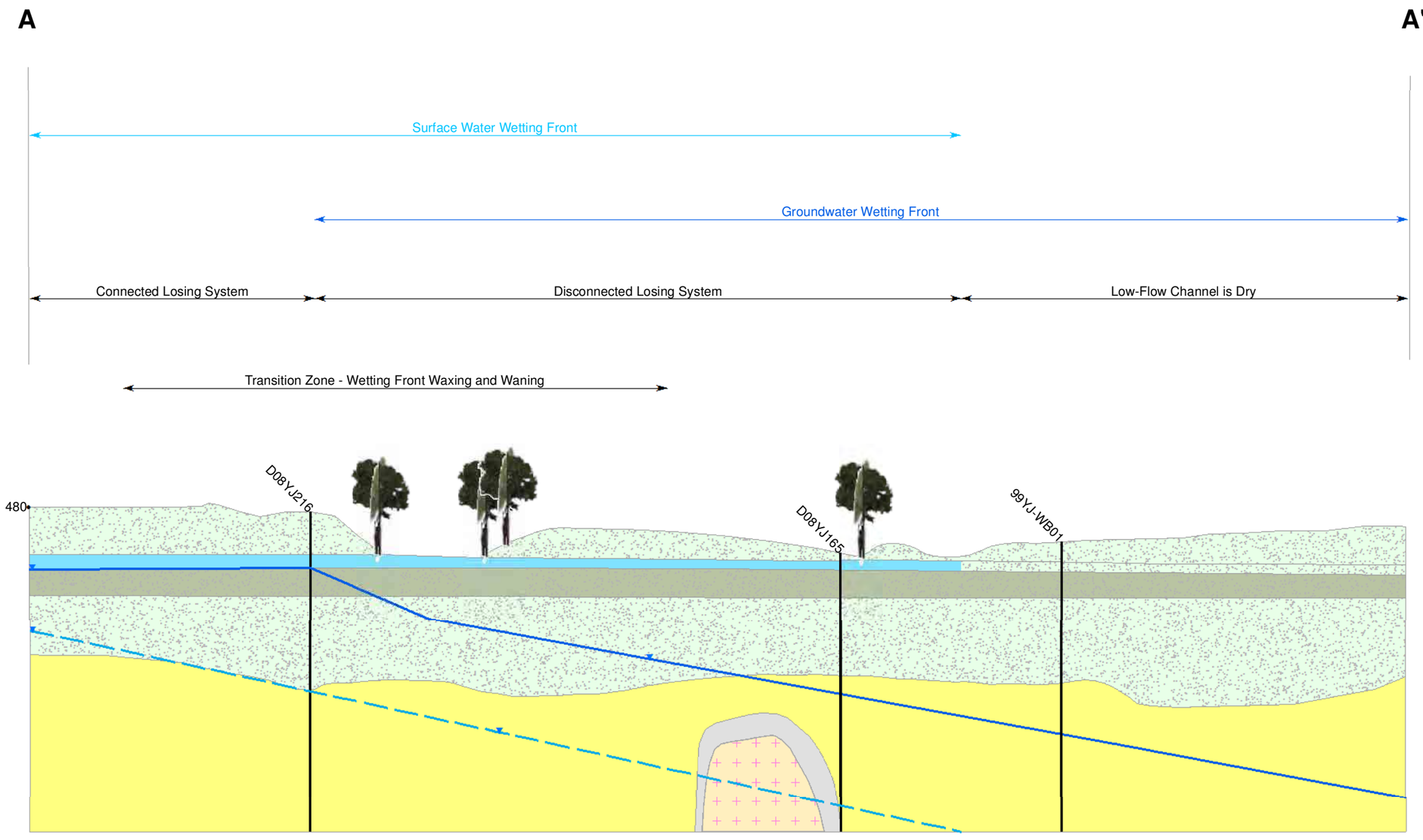
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-17**

File No: **42908644-017_RB.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015**

Rev. **A** A3



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

WETTING FRONTS CONCEPTUALISATION - CROSS-SECTION VIEW

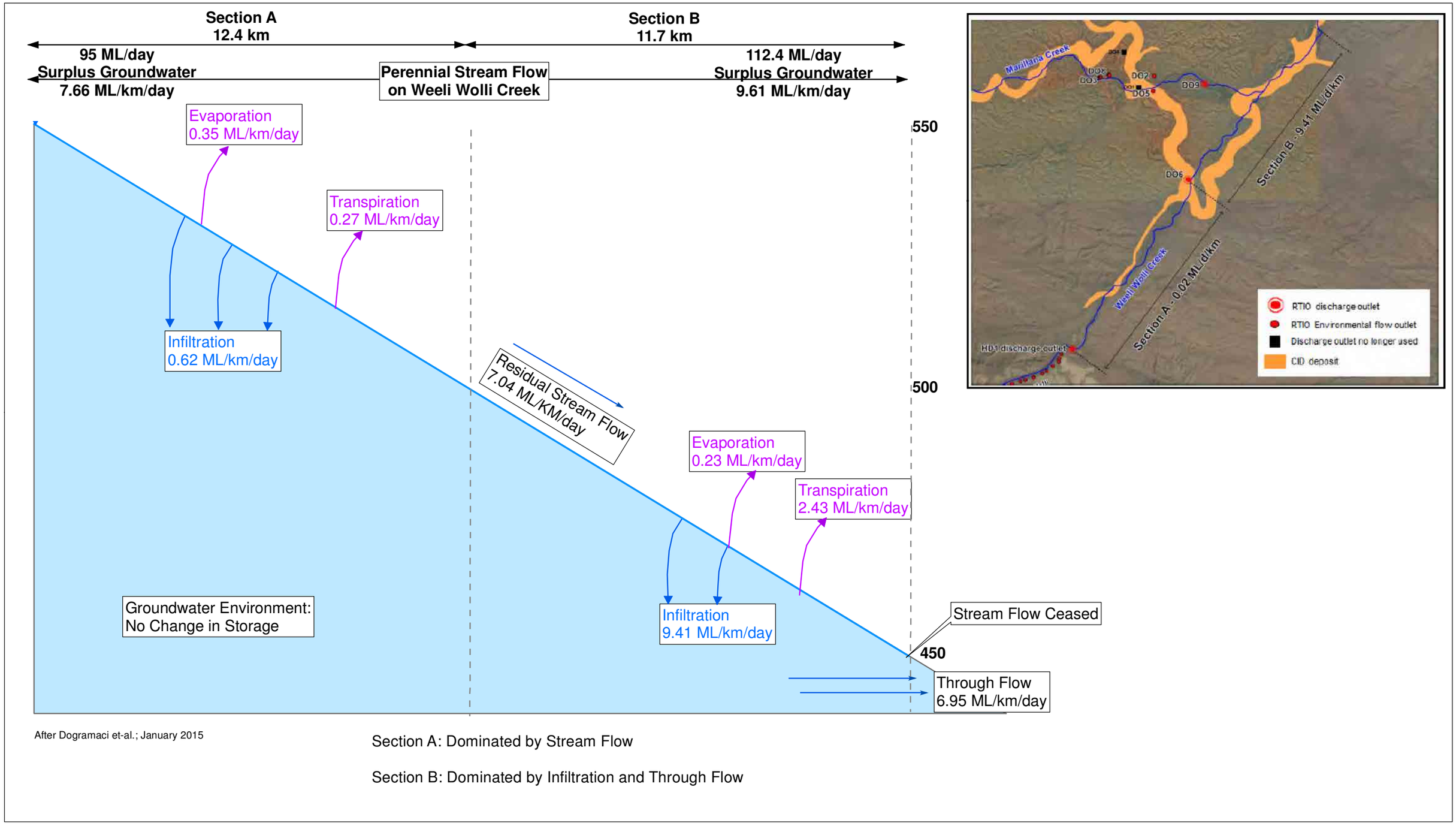
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-18**

File No: **42908644-023_RB.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015**

Rev. **A** A3



After Dogramaci et-al.; January 2015

Section A: Dominated by Stream Flow

Section B: Dominated by Infiltration and Through Flow

Legend

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

CONCEPTUAL MODEL FOR SURFACE WATER TO GROUNDWATER INTERACTION

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **5-19**

File No: **42908644-084.mxd** Drawn: **RNM** Approved: **IGB** Date: **1/05/2015**

Rev. **A** A3

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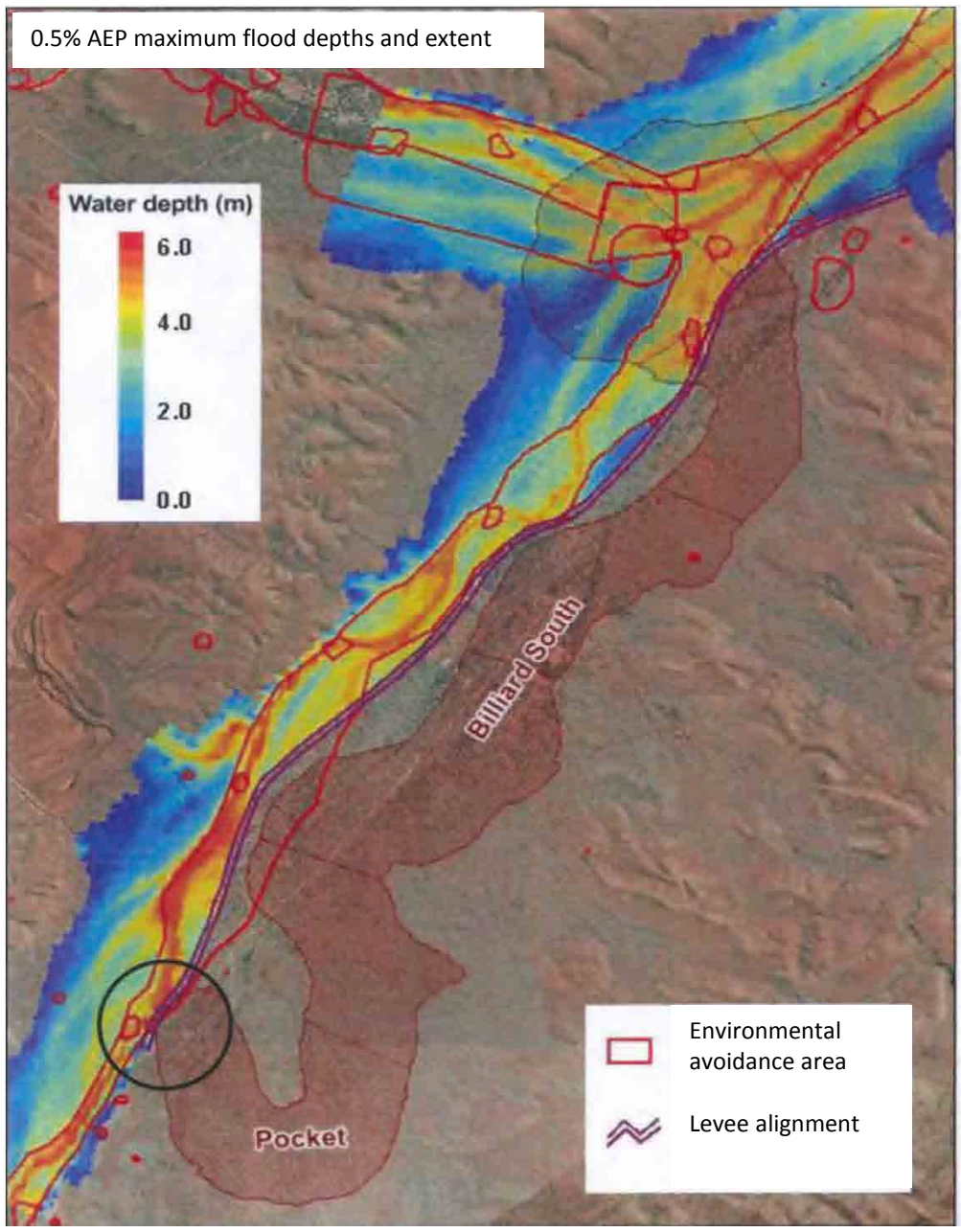
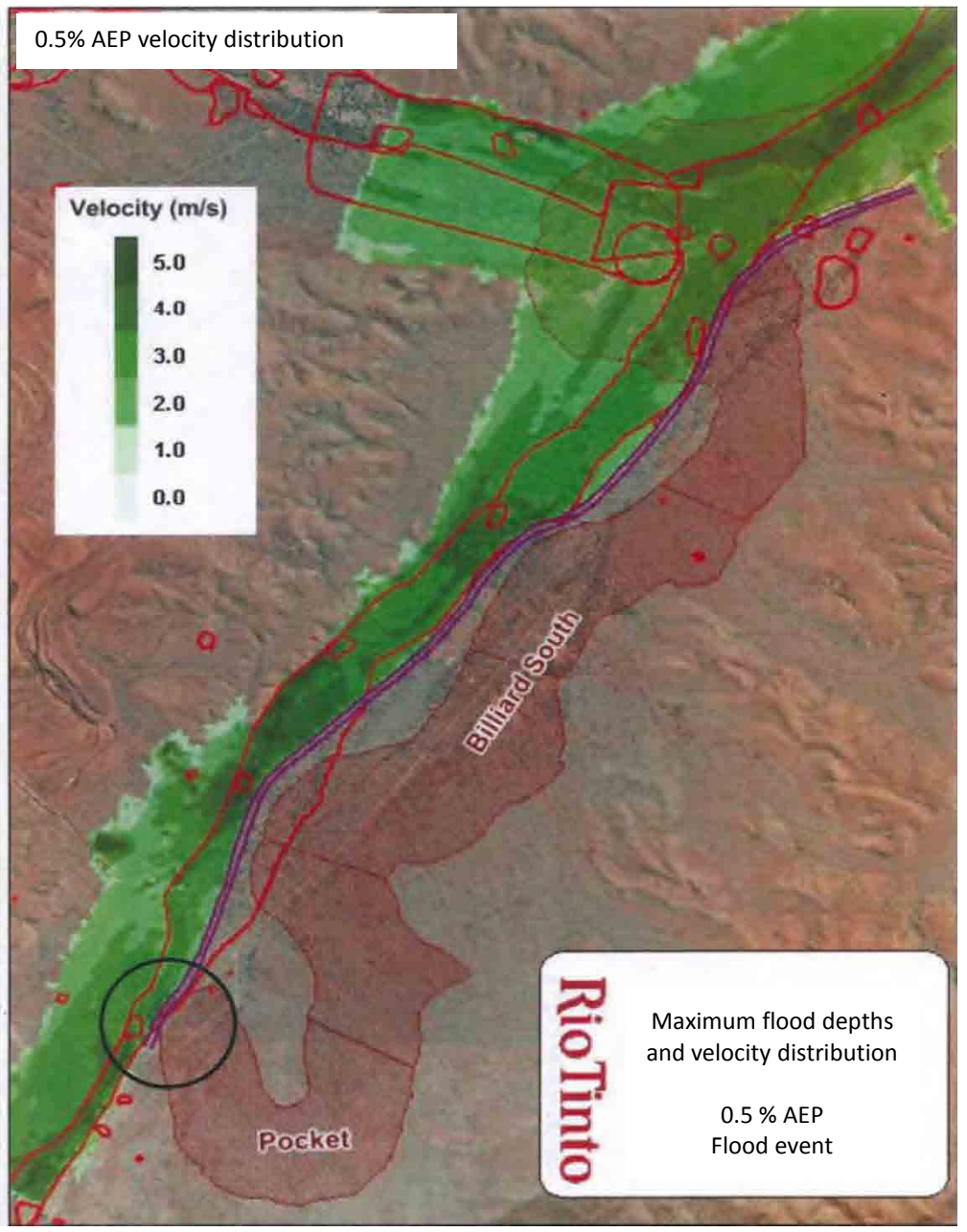
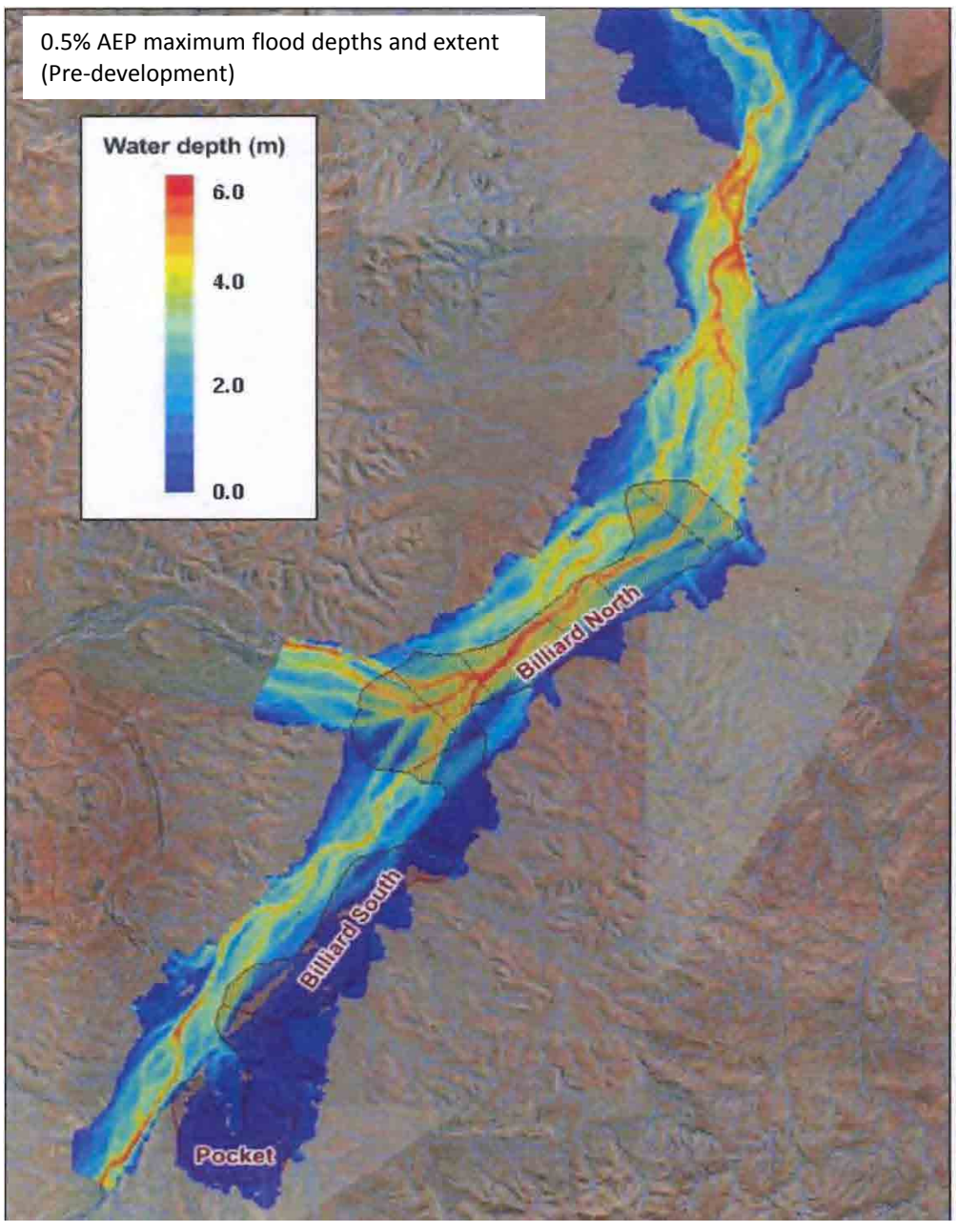
0.5% AEP maximum flood depths and extent



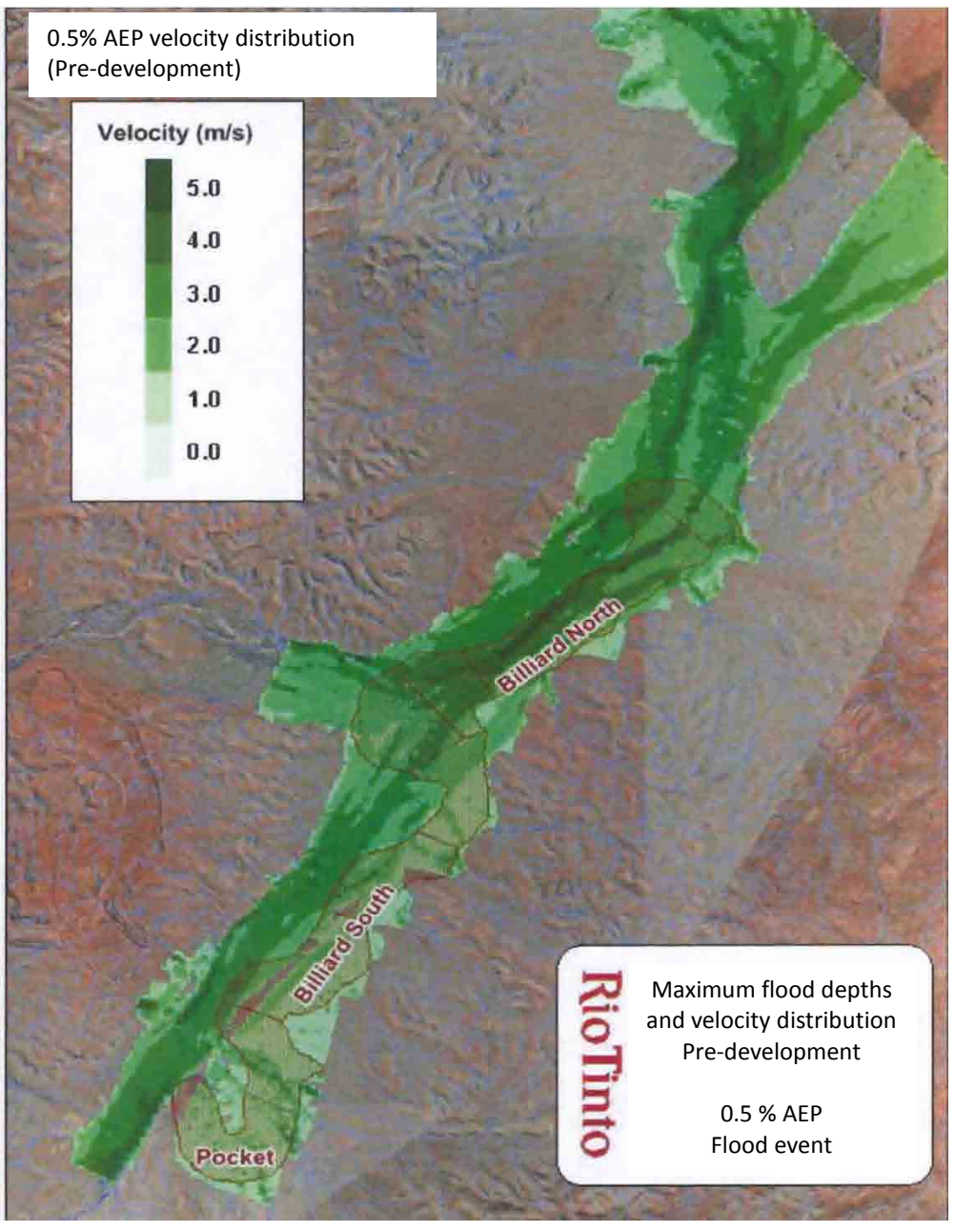
0.5% AEP velocity distribution



0.5% AEP maximum flood depths and extent (Pre-development)



0.5% AEP velocity distribution (Pre-development)



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Source: Rio Tinto Iron Ore Pty Ltd 2013

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

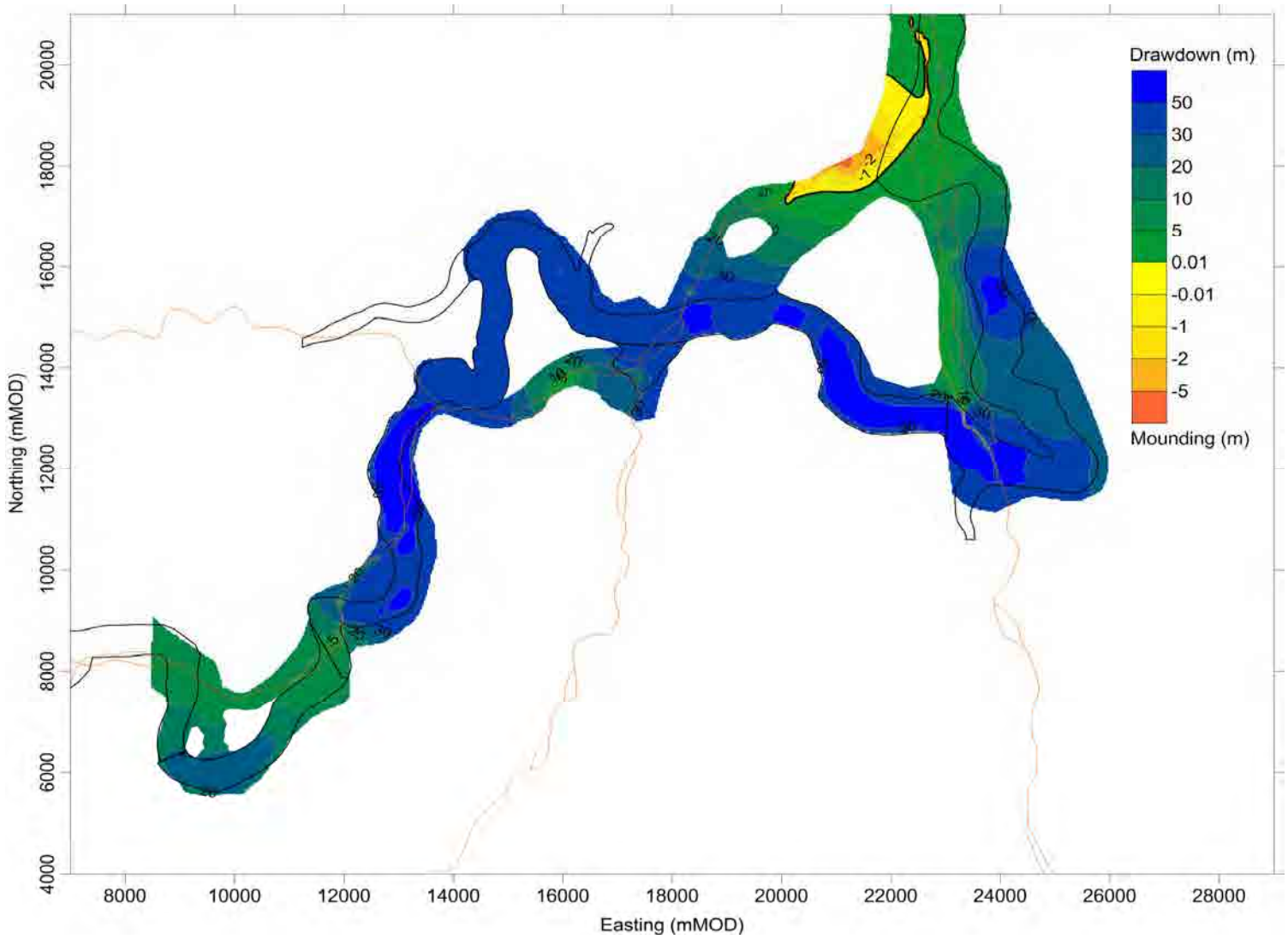
200 - YEAR FLOOD FOOTPRINTS FOR BASELINE AND PROPOSED BILLARD SOUTH SETTINGS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-1**

File No: 42908644-092.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A3



Source: RTIO-Yandicoogina-Pocket and Billiards South Model Setup....

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

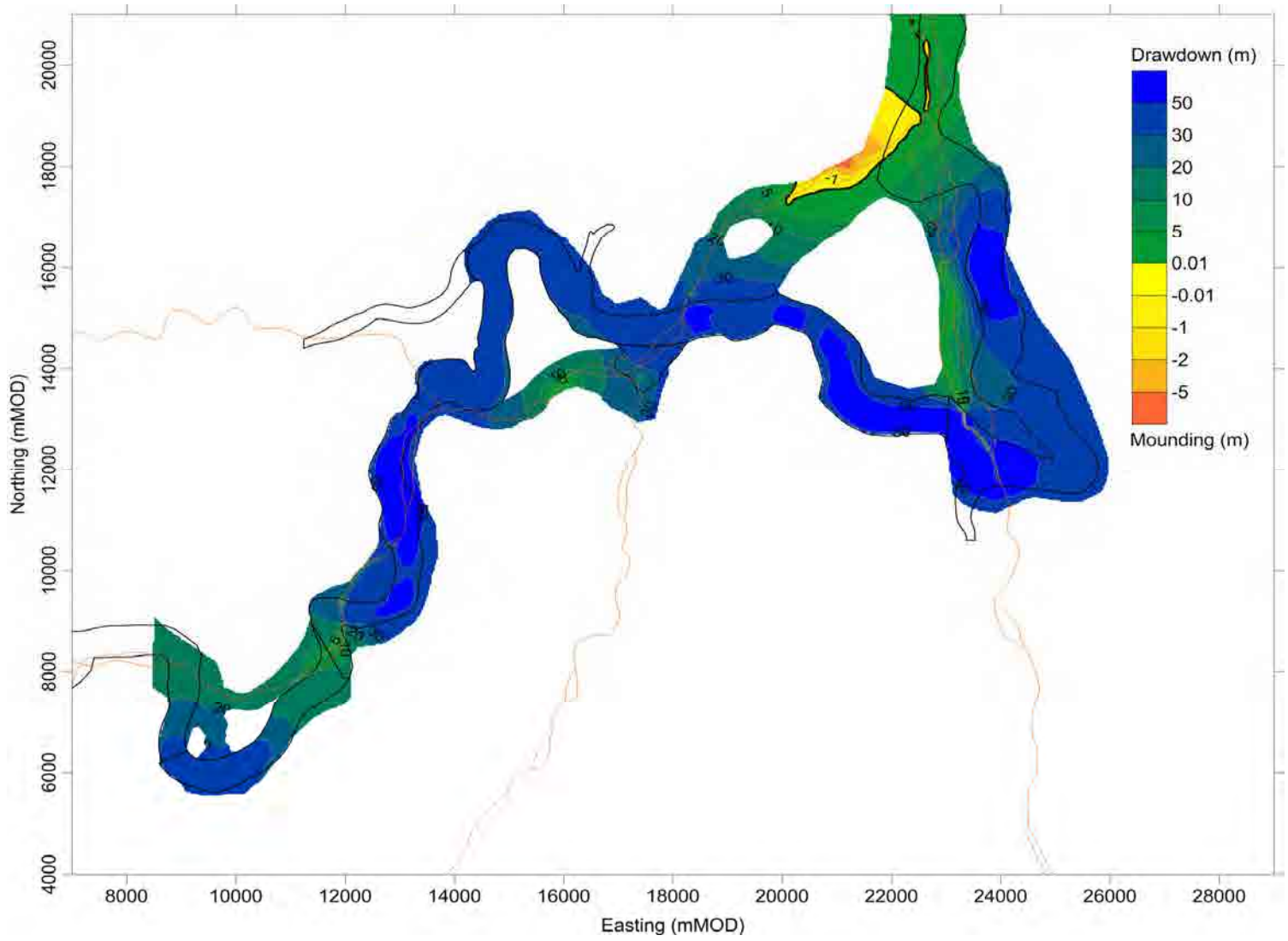
PREDICTED DRAWDOWN IN DECEMBER 2017

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-2**

File No: 42908644-018_RC.xlsx Drawn: RNM Approved: IGB Date: 27/05/2015 Rev: **C** A4



Source: RTIO-Yandicoogina-Pocket and Billiards South Model Setup....

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

PREDICTED DRAWDOWN IN DECEMBER 2019

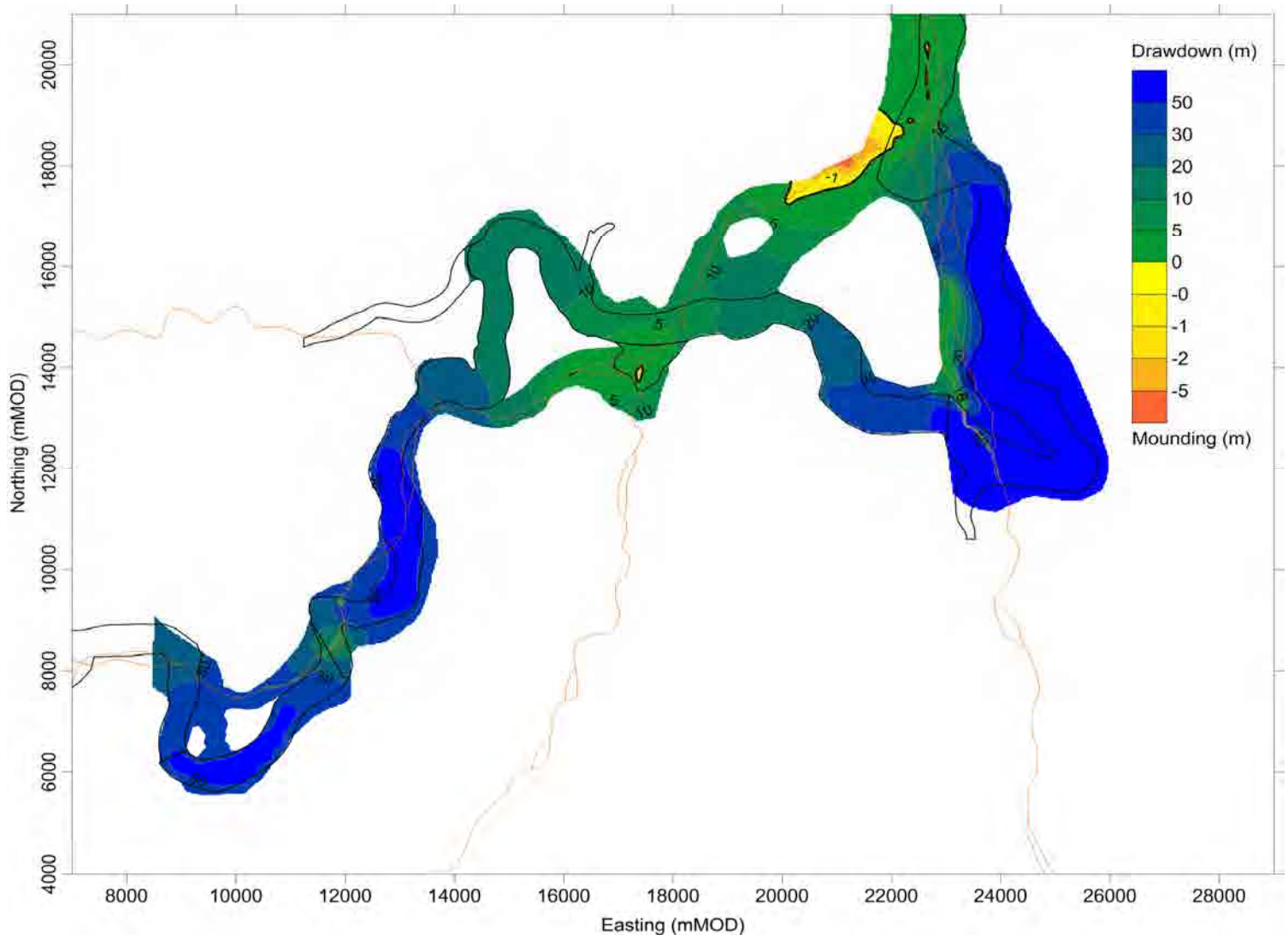
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-3**

File No: 42908644-019_RC.xlsx Drawn: RNM Approved: IGB Date: 27/05/2015

Rev: **C** A4



Source: RTIO-Yandicoogina-Pocket and Billiards South Model Setup....

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

PREDICTED DRAWDOWN IN DECEMBER 2023

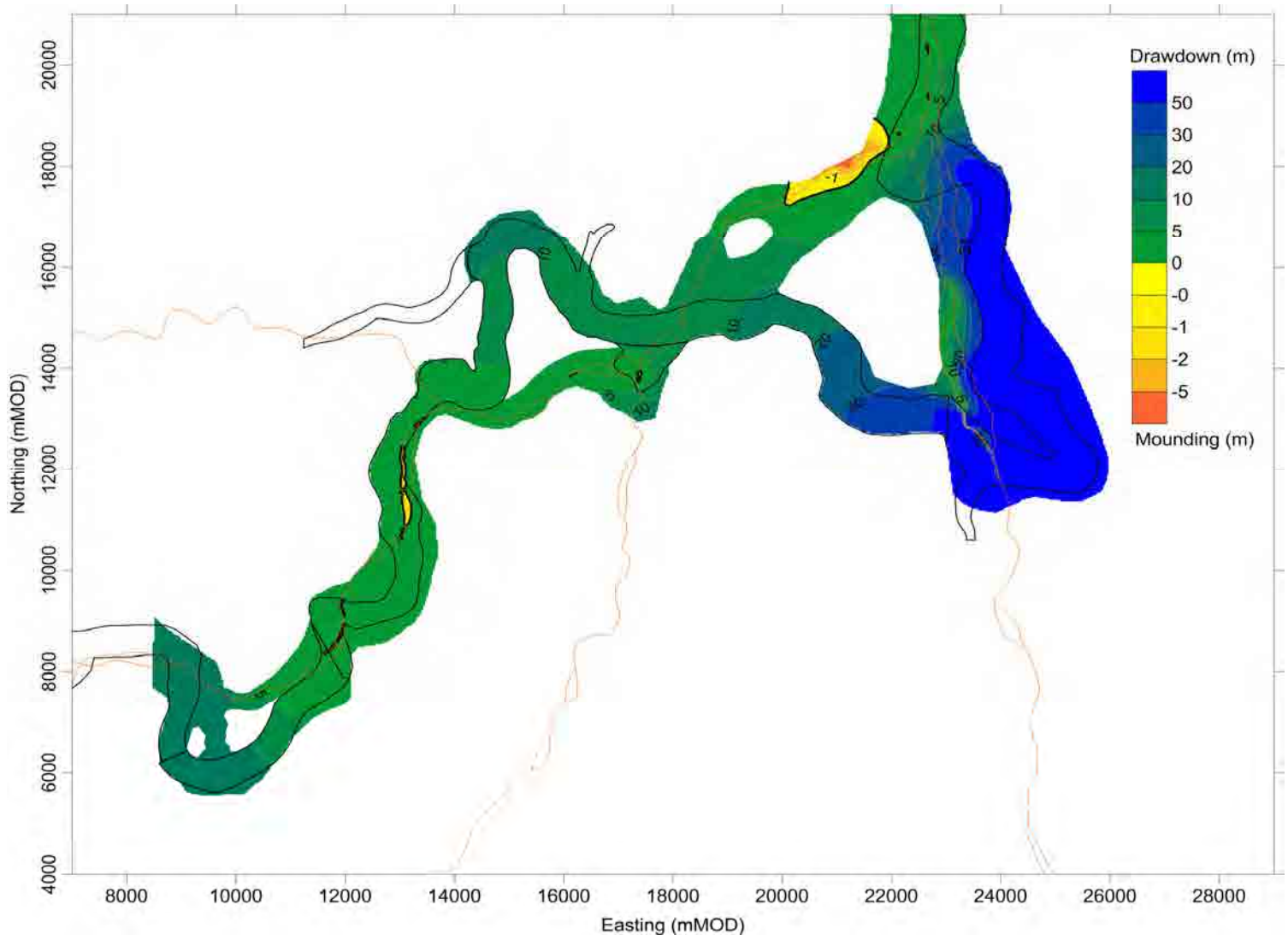
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-4**

File No: 42908644-020_RC.xlsx Drawn: RNM Approved: IGB Date: 27/05/2015

Rev: **C** A4



Source: RTIO-Yandicoogina-Pocket and Billiards South Model Setup....

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

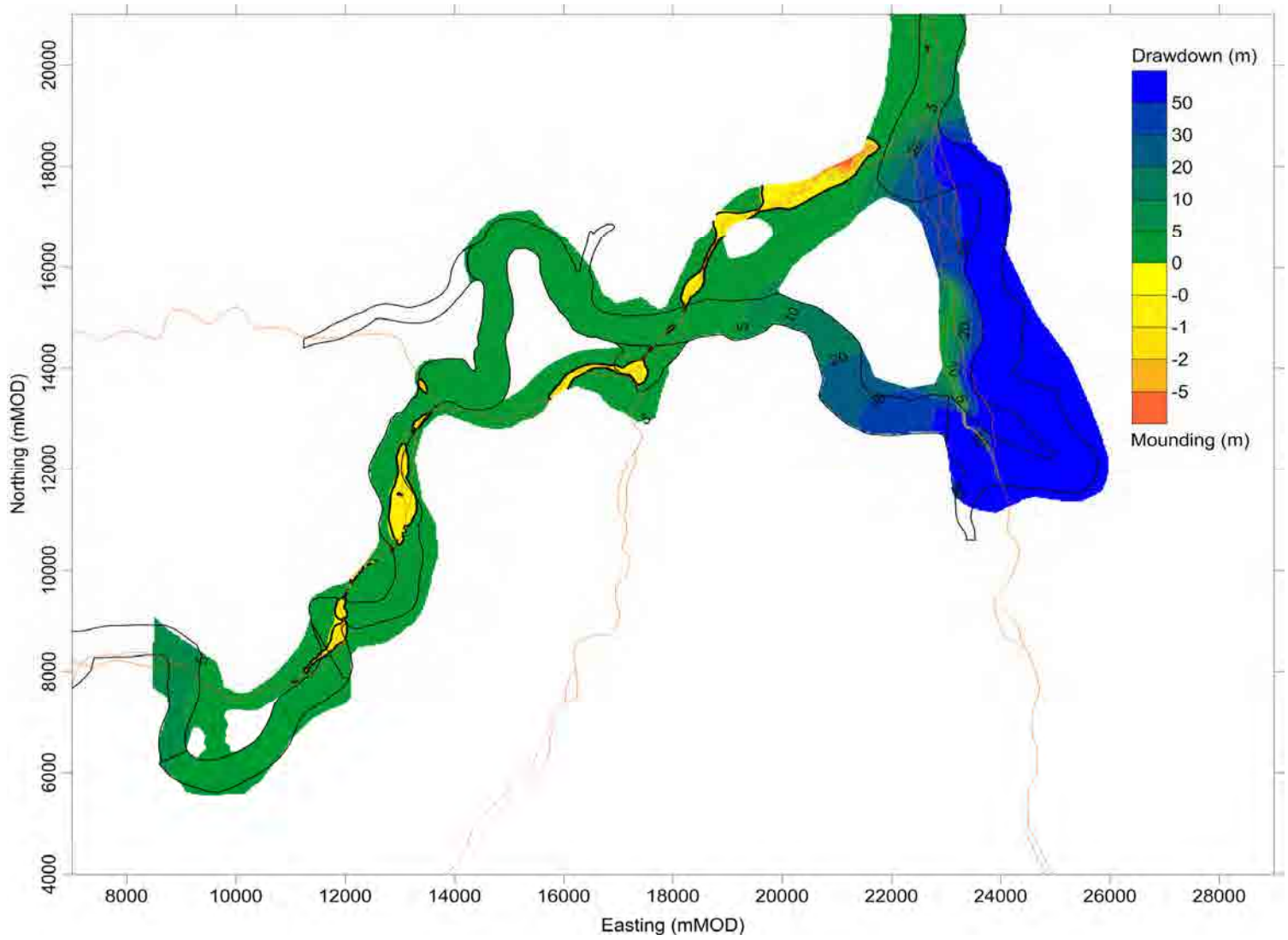
PREDICTED DRAWDOWN IN DECEMBER 2027

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-5**

File No: 42908644-021_RC.xlsx Drawn: RNM Approved: IGB Date: 27/05/2015 Rev: **C** A4



Source: RTIO-Yandicoogina-Pocket and Billiards South Model Setup....

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

PREDICTED DRAWDOWN IN DECEMBER 2032

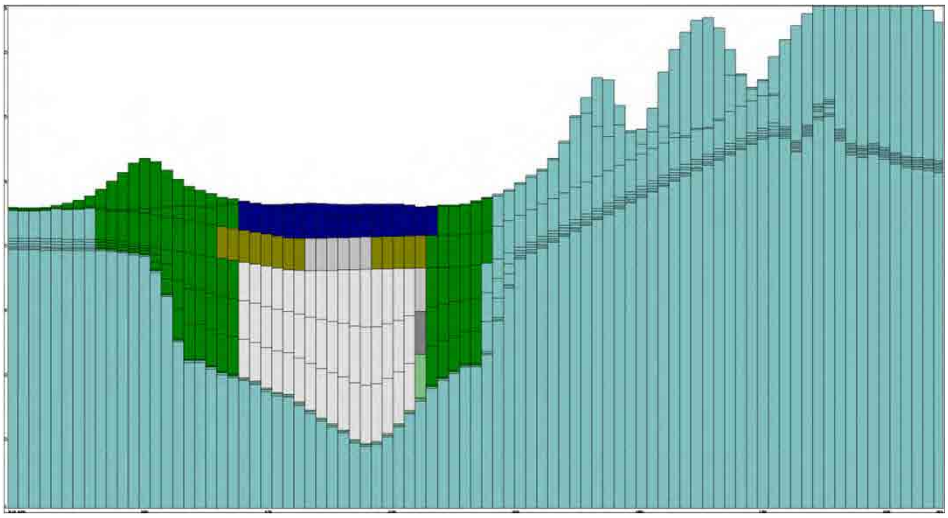
URS

THE POCKET AND BILLIARD SOUTH PROJECT

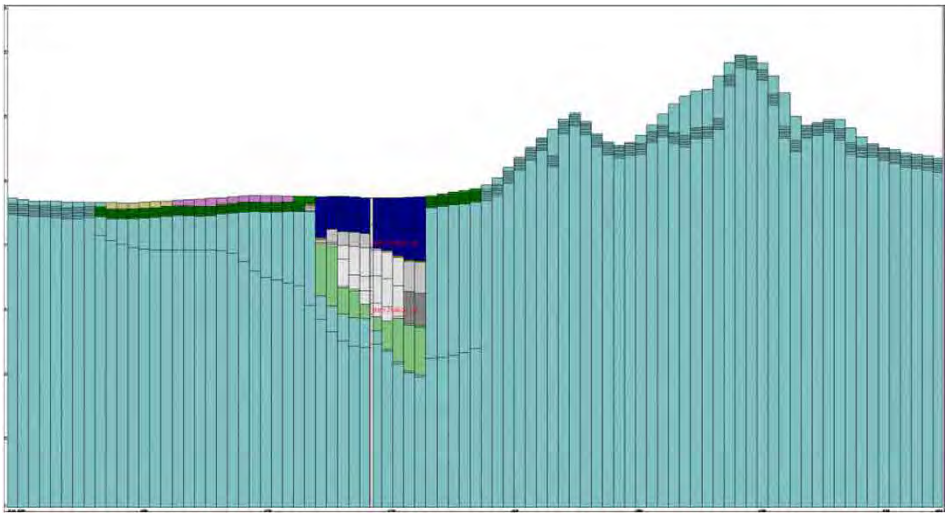
Figure: **6-6**

File No: 42908644-022_RC.xlsx Drawn: RNM Approved: IGB Date: 27/05/2015

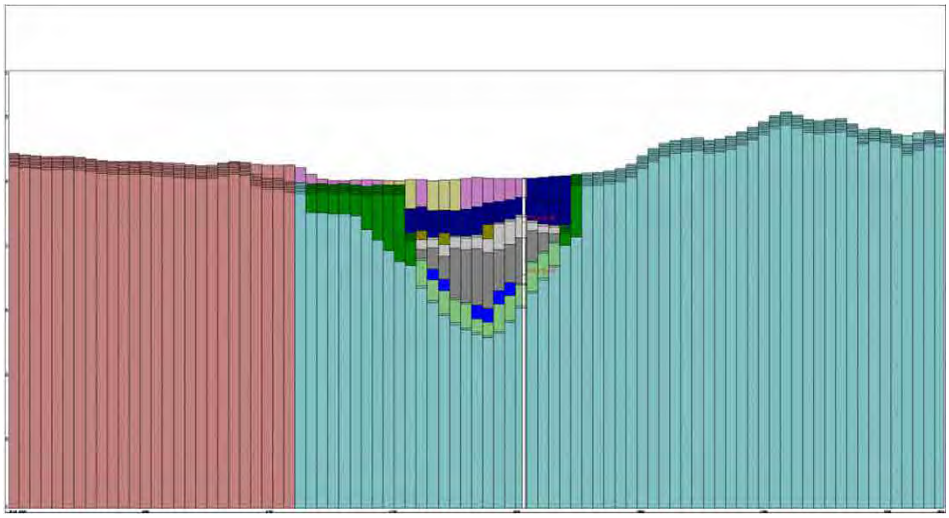
Rev: **C** A4



North Section



Section Across 99YJWB01



Section Across YM119

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

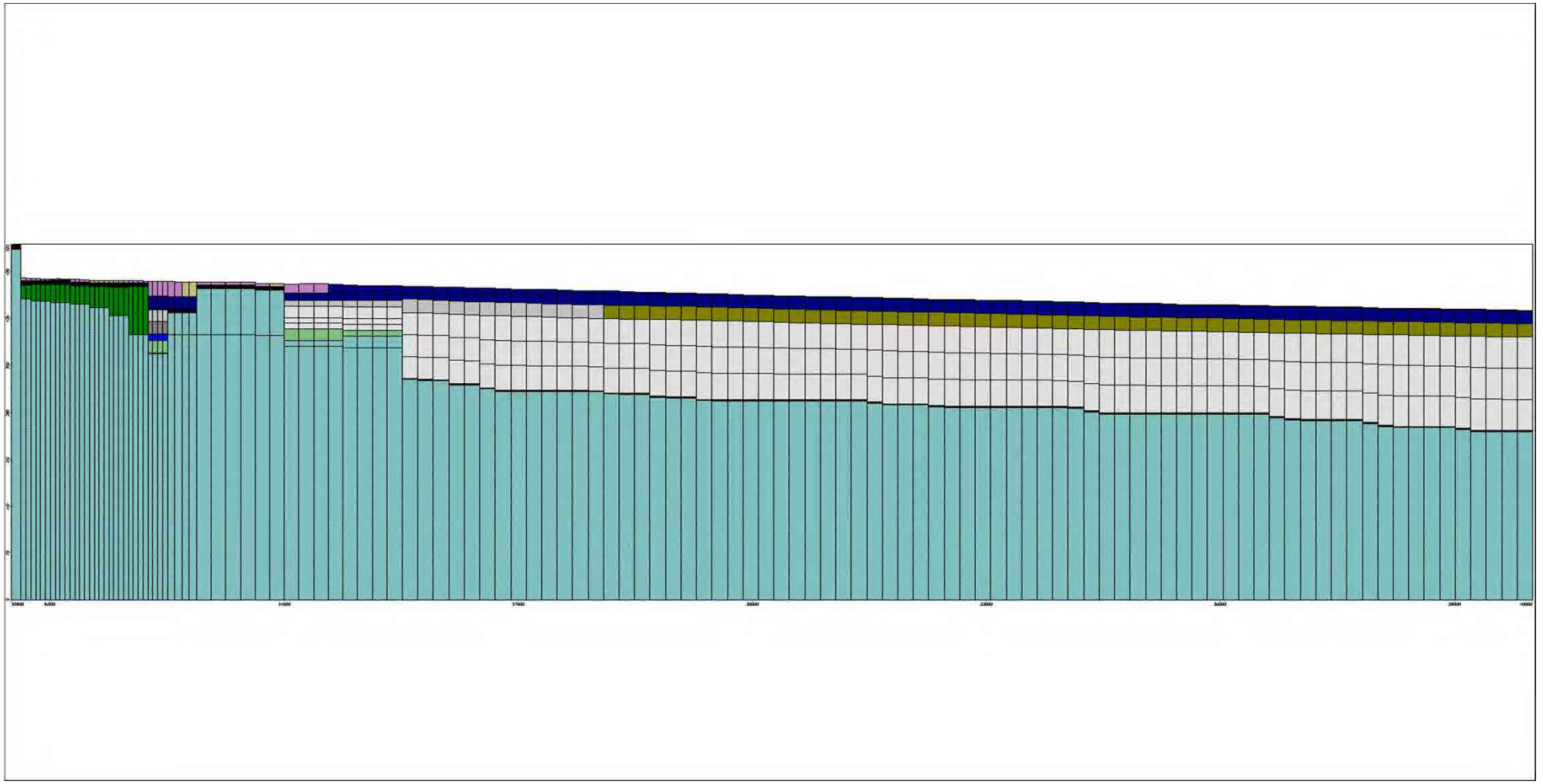
WEST TO EAST CROSS-SECTIONS OF THE WEELI WOLLI CREEK PALAEOVALLEY

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-7**

File No: 42908766-074.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev. **A** A4



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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

SOUTH TO NORTH CROSS-SECTIONS OF THE WEELI WOLLI CREEK PALAEOVALLEY

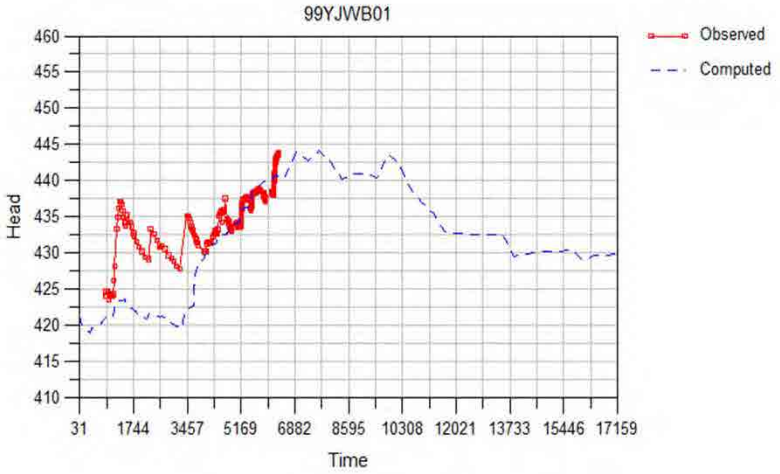
URS

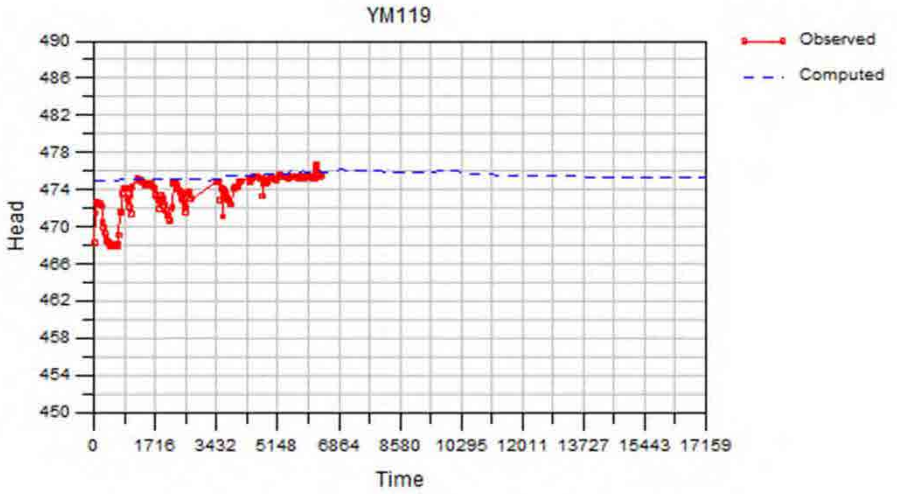
THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-8**

File No: 42908644-075.xlsx Drawn: JA Approved: IGB Date: 01/05/2015

Rev: **A** A4





T:\Jobs\42908644\DATA\FIGURES\arc2015\[42908644-076.xlsx]A4L1

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

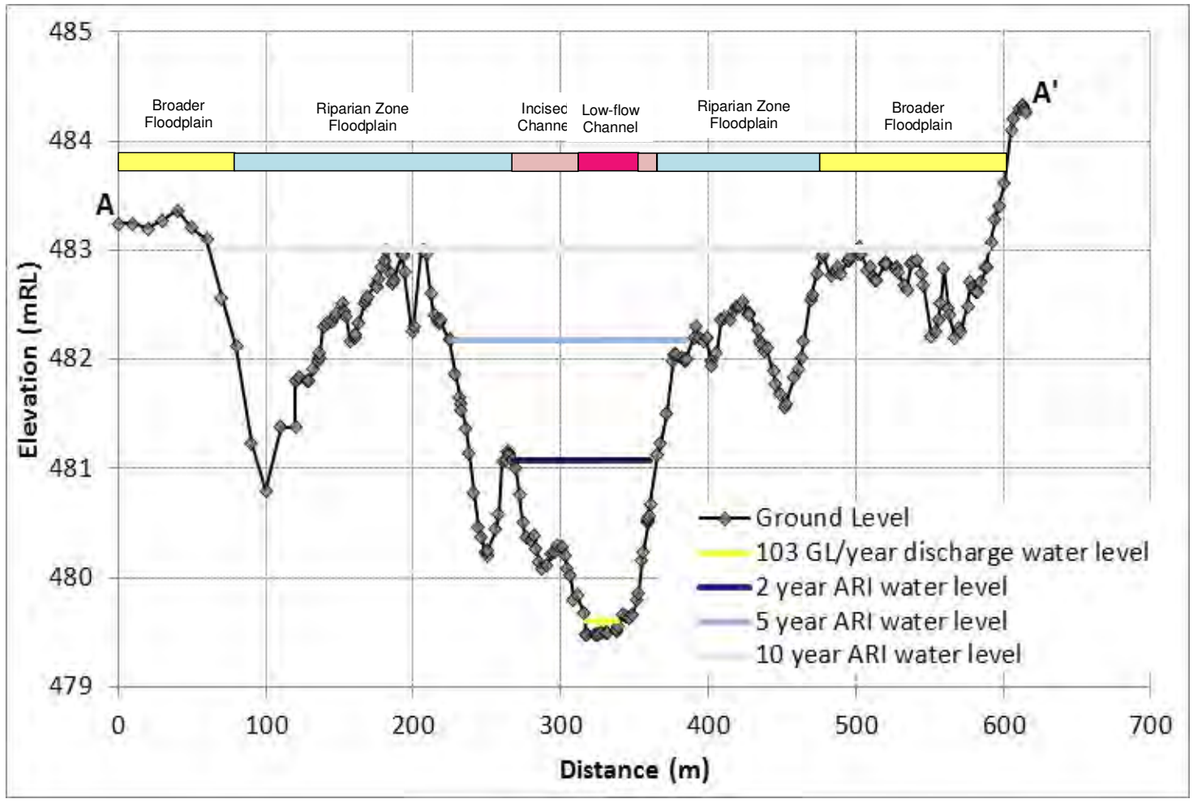
SIMULATED HYDROGRAPHS - TRANSIENT CALIBRATION

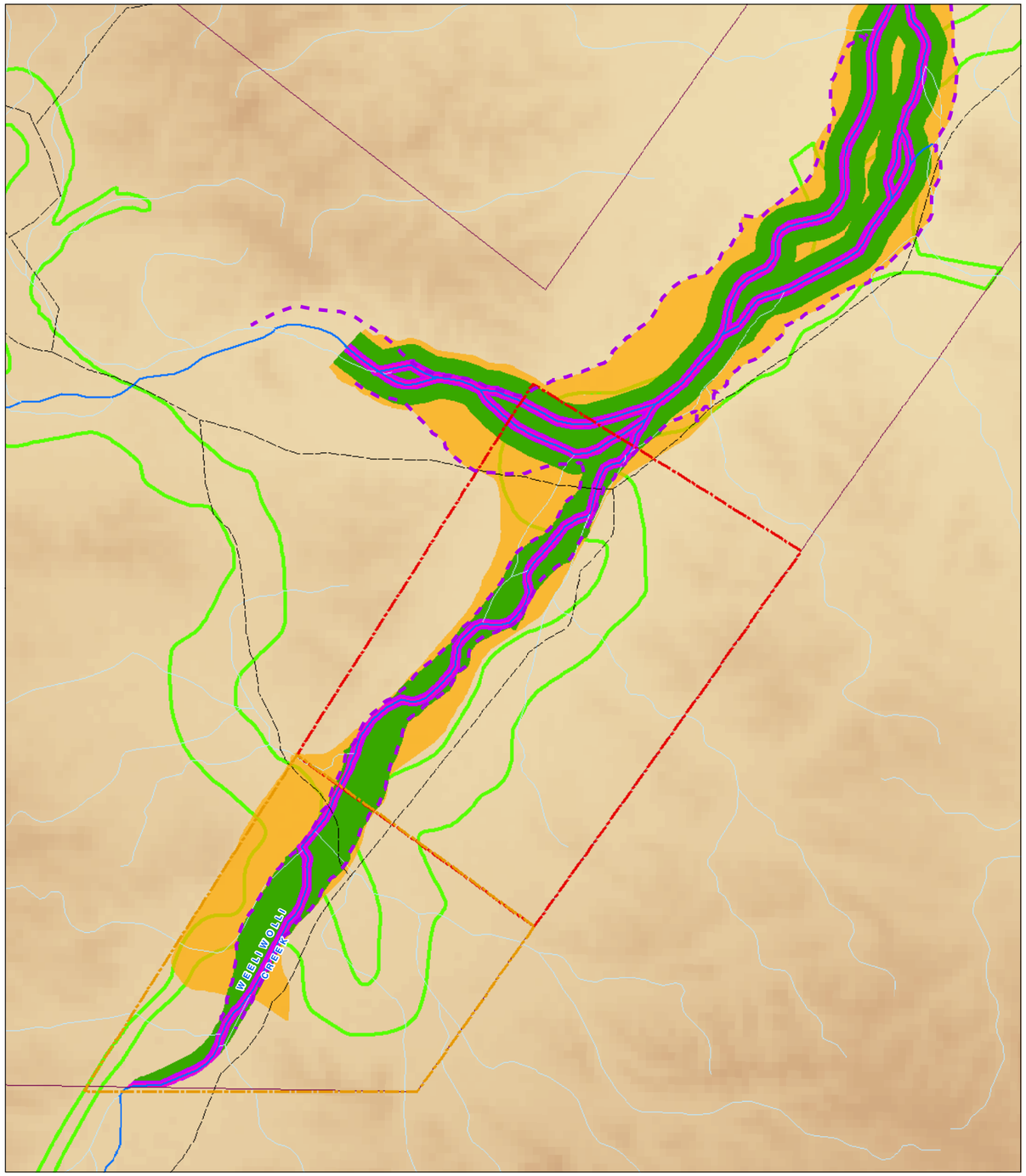
URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **6-9**

File No: 42908644-076.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4





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Scale: 1:60,000
0 200 400 600 800
Meters

Coordinate System: GDA 1994 MGA Zone 50

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010).
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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

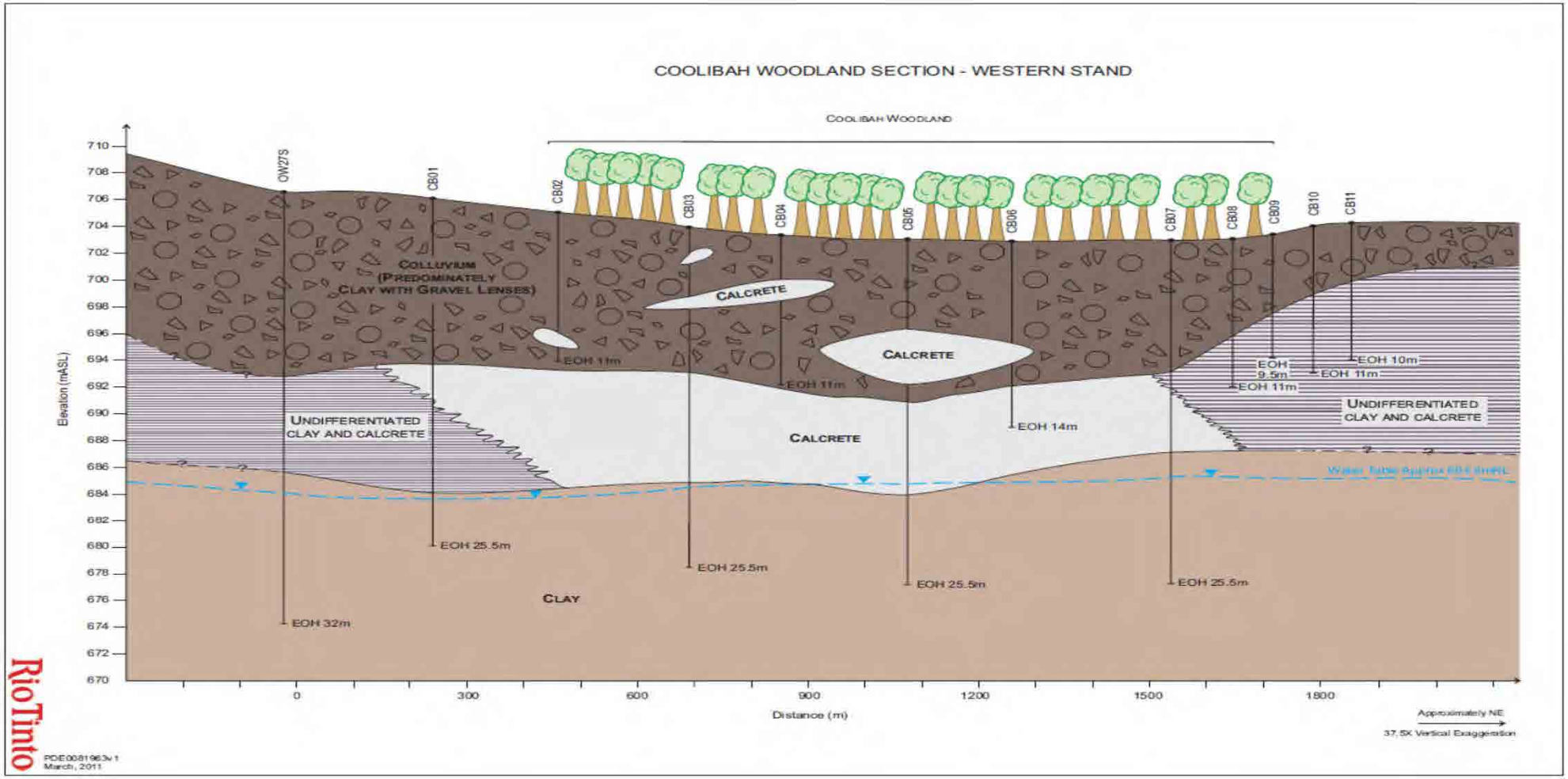
DISCRETISATION OF RIPARIAN ZONES

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-1**

File No: **42908644-086.mxd** Drawn: **RNM** Approved: **IGB** Date: **2/06/2015** Rev. **A** A3



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\Jan2015\[42908644-093.xls]Fig 7-2

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

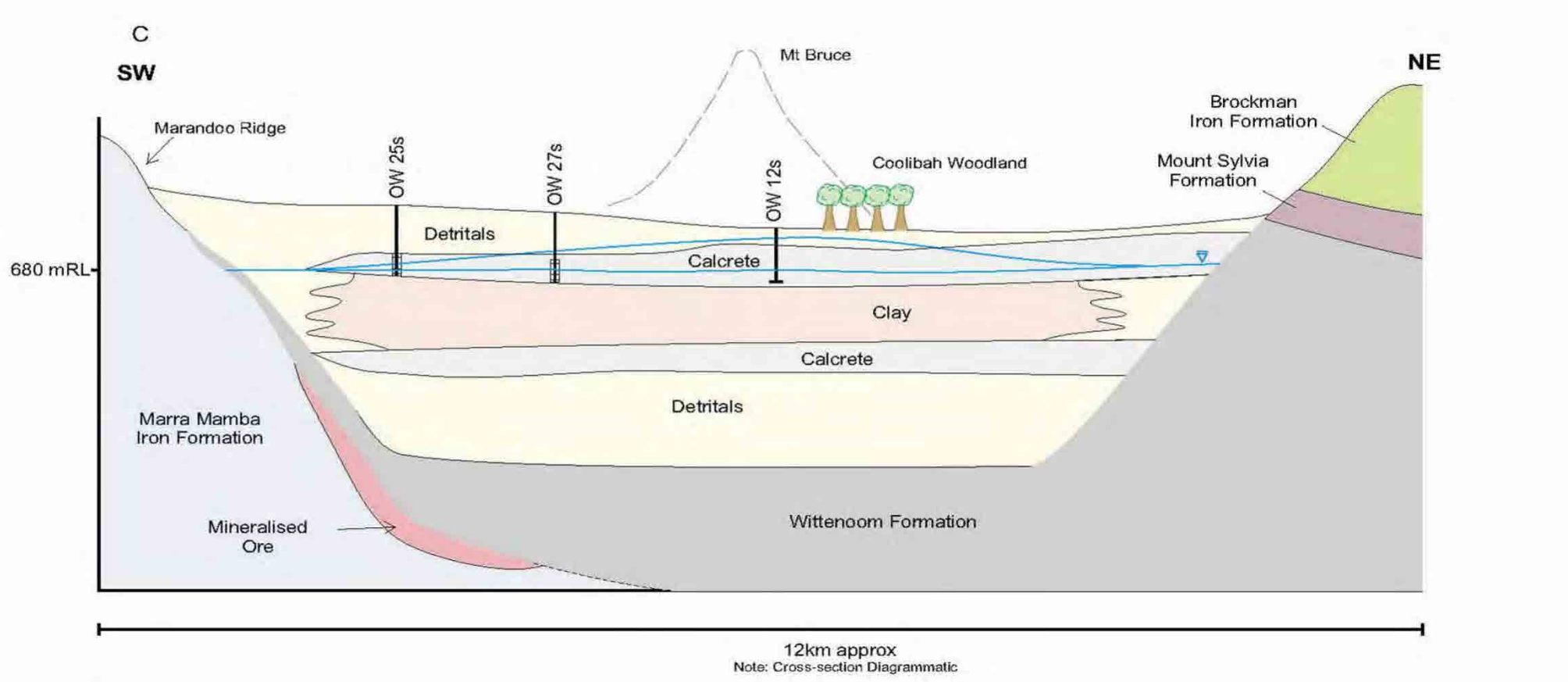
SETTING OF MOUNT BRUCE COOLIBAH WOODLANDS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-2**

File No: 42908644-093.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4



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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\Jan2015\[42908644-094.xlsx]Fig 7-3

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

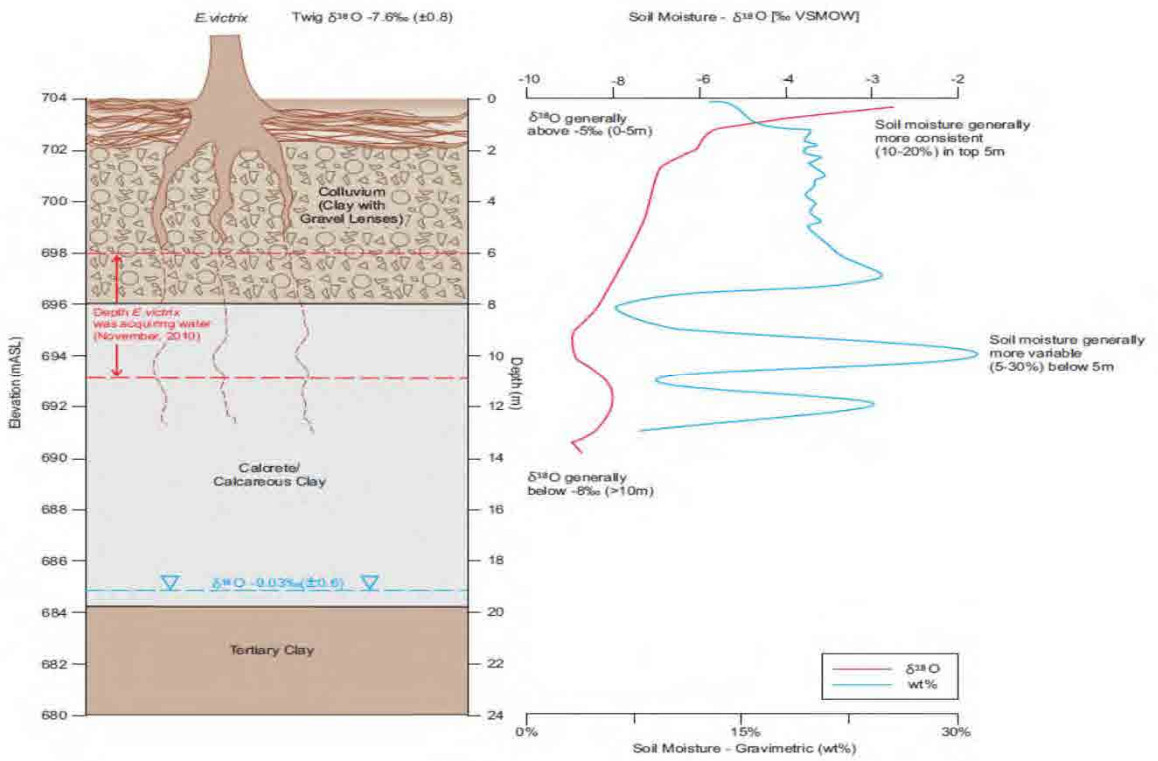
CONCEPTUAL WATER TABLE MOUNDING AFTER EPOSODIC FLOOD EVENT

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-3**

File No: 42908644-094.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4



Conceptual schematic of E. victrix water use, showing δ^{18}O of twig samples, soil moisture, and groundwater inside the Coolibah Woodland (adapted from Batini, 2009).

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Source: Rio Tinto Iron Ore Pty Ltd and BoM 2014

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T:\Jobs\42908644\DATA\FIGURES\Jan2015\[42908644-095.xlsx]Fig 7-4

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

GRAVIMETRIC AND d18O SOIL MOISTURE INDICATIONS

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-4**

File No: 42908644-095.xlsx Drawn: JA Approved: IGB Date: 01/05/2015 Rev: **A** A4

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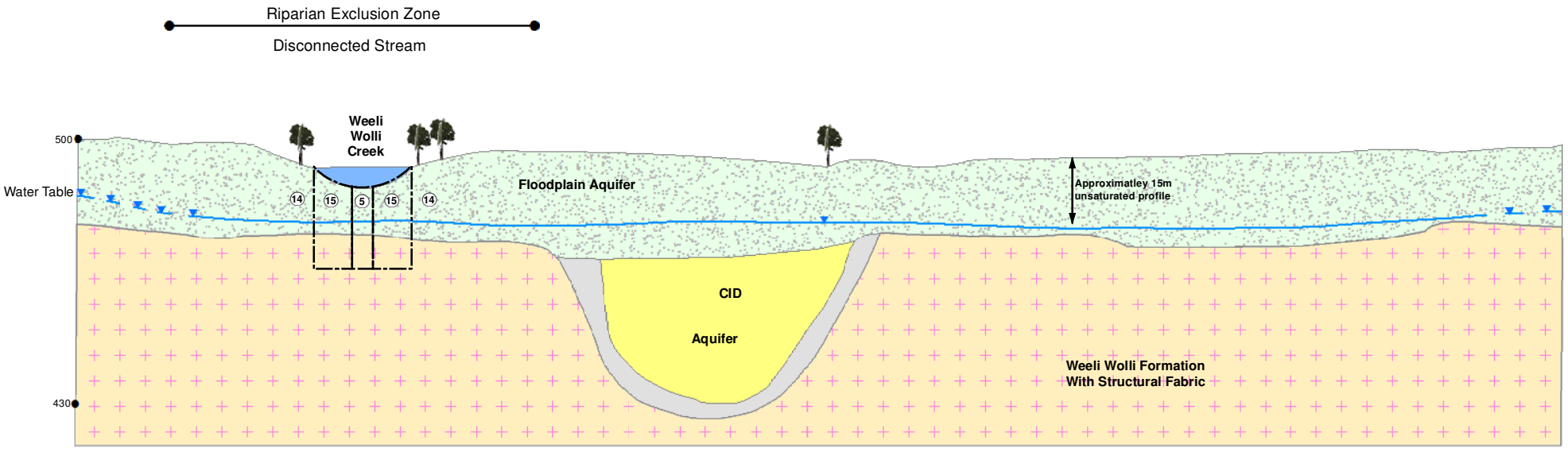
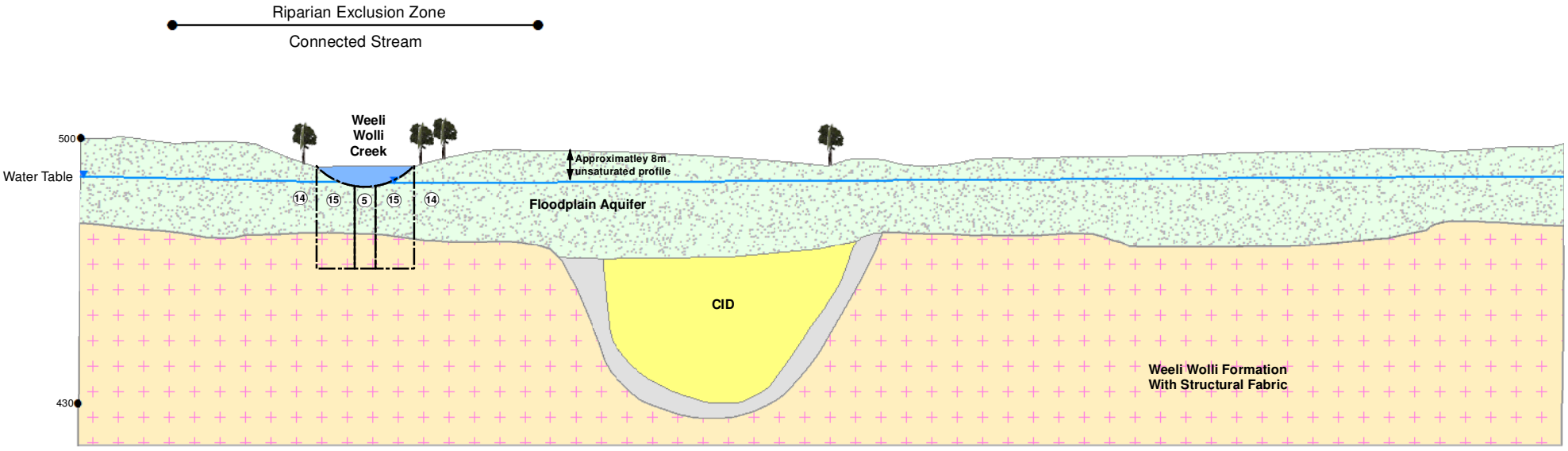
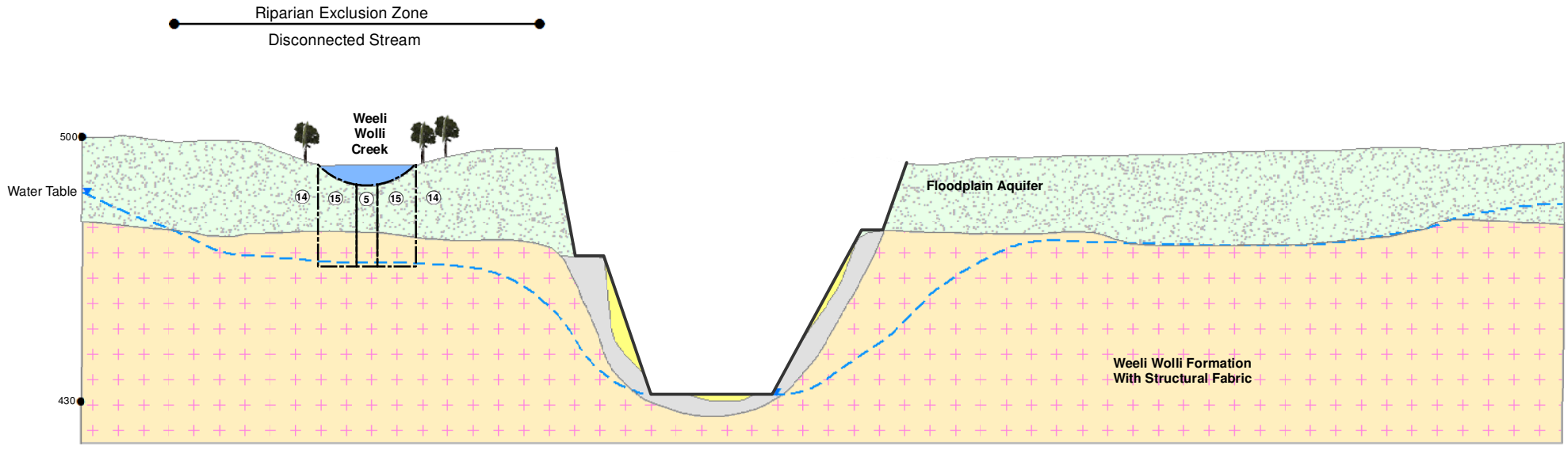
Baseline



Current



Mining



⑥ Zone Budgets
Alluvial/Insitu Weathered Bedrock
Basal Clay Conglomerate
CID
Weeli Wolli Creek
Weeli Wolli Formation

Not To Scale

Source: After Kirkpatrick and Dogramaci, RTIO; 2010

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010).
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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TRANSIENT WATER TABLE SETTINGS - POCKET SCHEMATIC

URS

THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-5**

File No:**42908644-002.mxd** Drawn: **RNM** Approved:**IGB** Date: **1/05/2015** Rev. **A** A3

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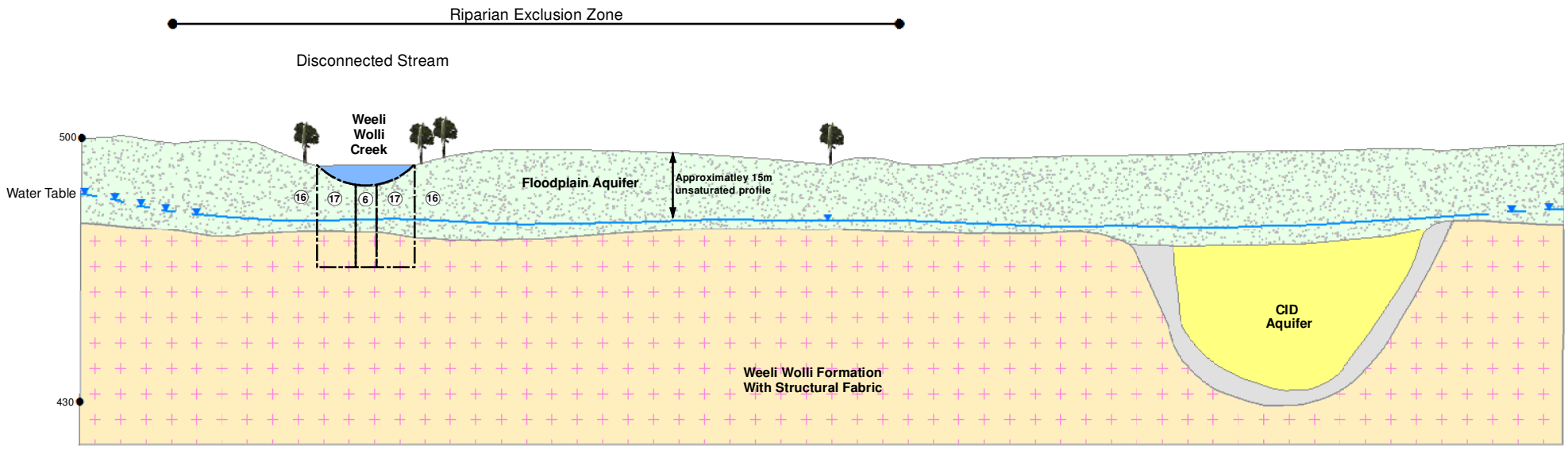
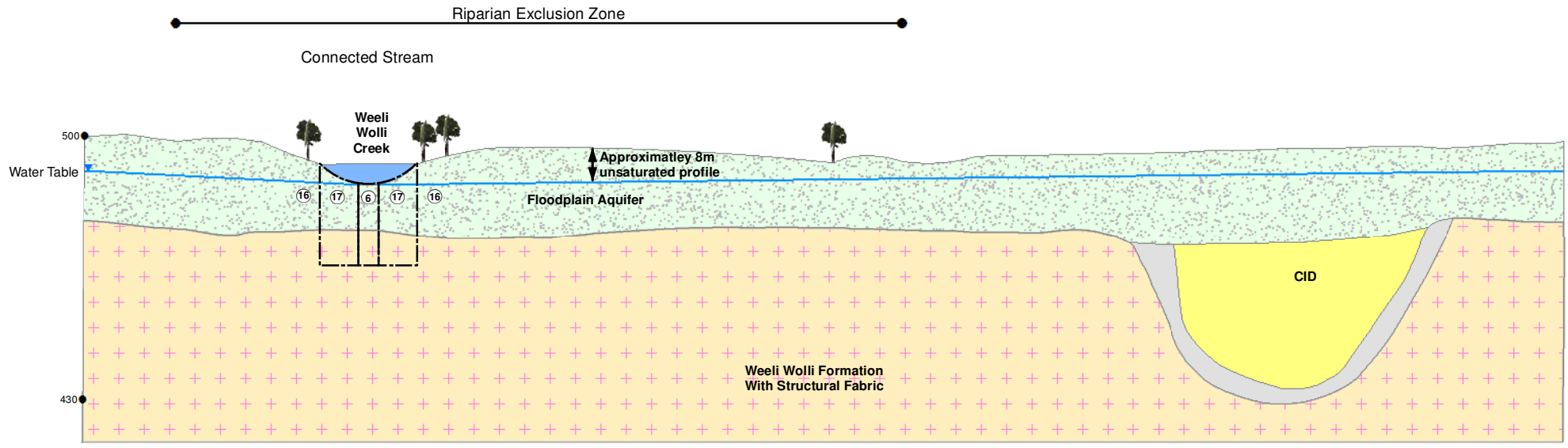
Baseline



Current



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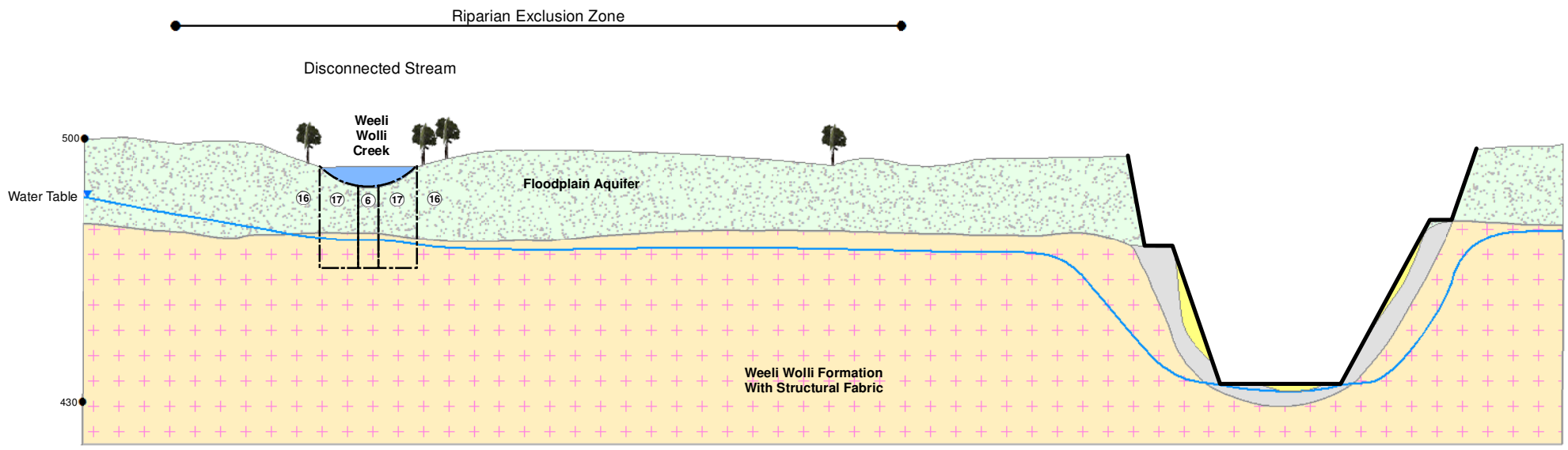

⑥ Zone Budgets
Alluvial/Insitu Weathered Bedrock
Basal Clay Conglomerate
CID
Weeli Wolli Creek
Weeli Wolli Formation

Not To Scale

Source: After Kirkpatrick and Dogramaci, RTIO; 2010

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TRANSIENT WATER TABLE SETTINGS - CUE SCHEMATIC

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-6**

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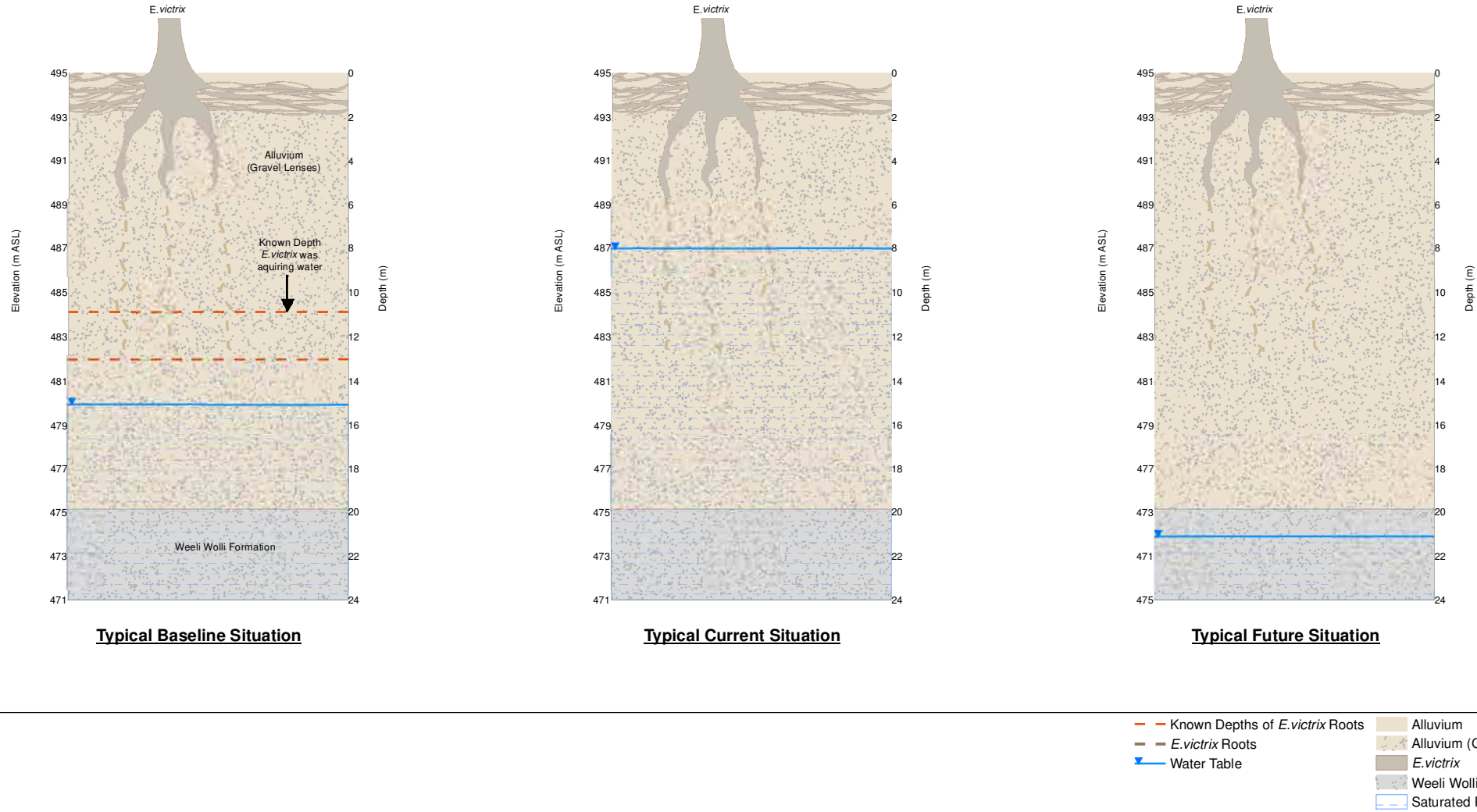

Not To Scale

Source: After Rio Tinto Iron Ore Pty Ltd (June 2011)

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SCHEMATIC OF ROOT DEPTHS AND CHANGES IN WATER TABLE PROFILES

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: 7-7

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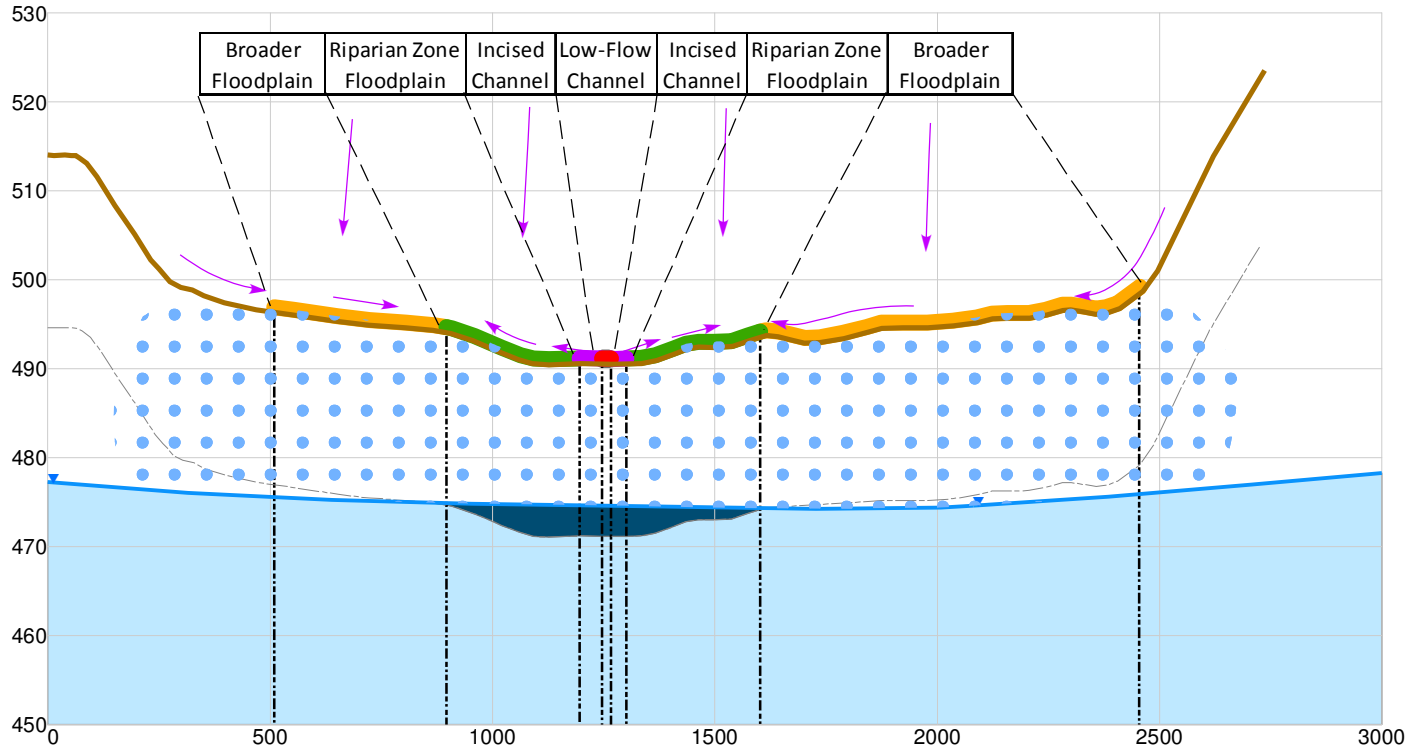
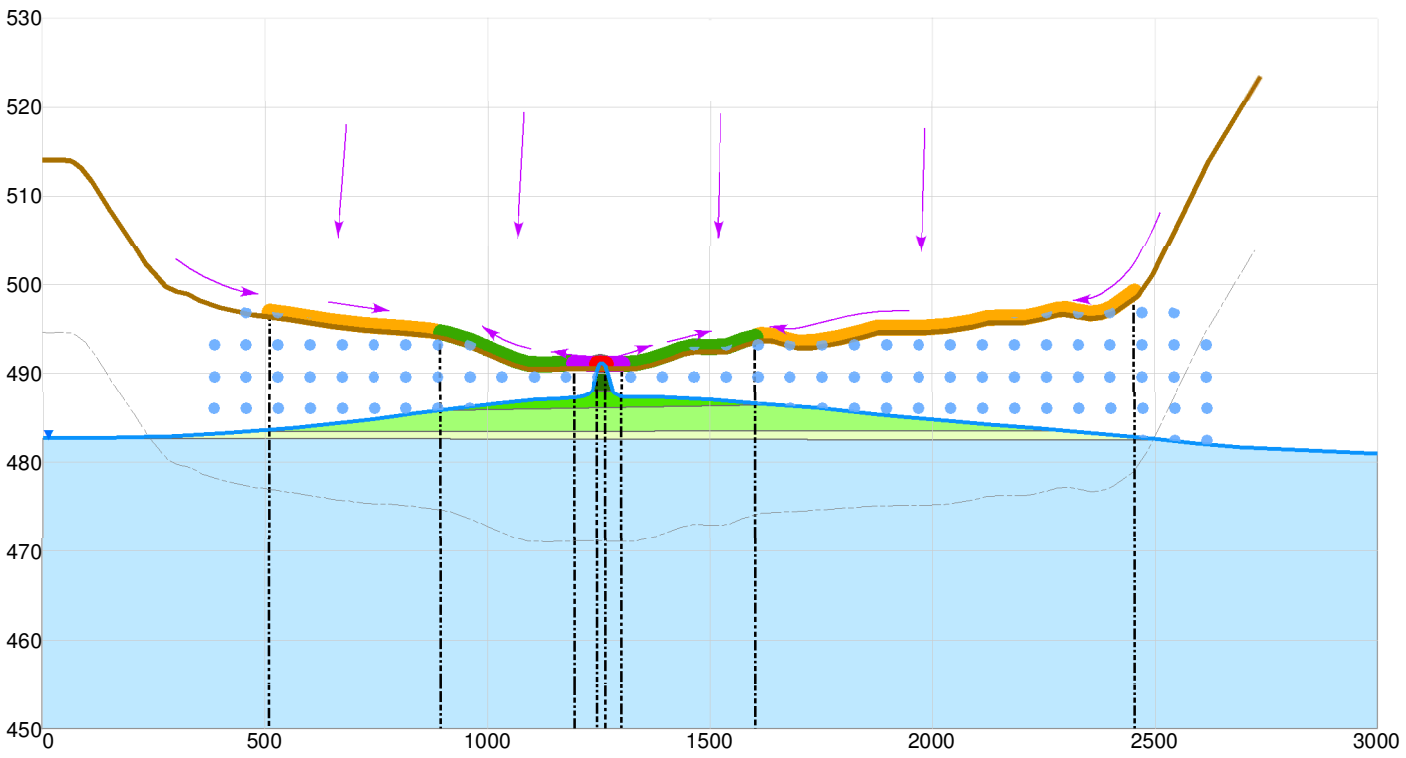
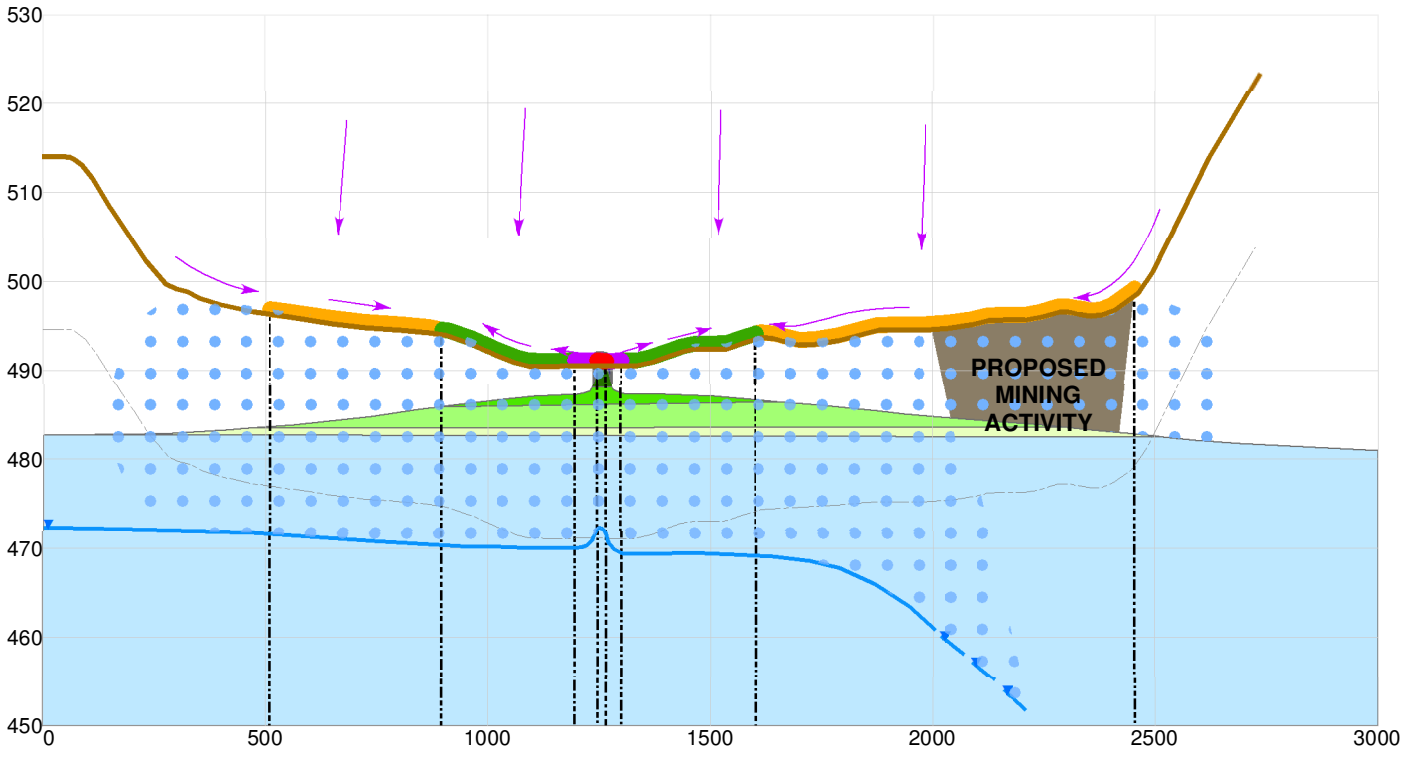
BASELINE CONCEPTUAL MODEL - DISCONNECTED LOSING SYSTEM



CURRENT CONCEPTUAL MODEL - CONNECTED LOSING SYSTEM



MINING SITUATION CONCEPTUAL MODEL - DISCONNECTED LOSING SYSTEM



- Natural Ground
- 46 m Width Weeli Wolli Creek Low-Flow Channel. Episodic Stream Flow and Flooding Each Year.
- 100 m Width Incised Channel. Episodic Stream Flow and 2-Year ARI Flooding.
- 450 m Width Riparian Zone Floodplain. Episodic Flooding 5-Year ARI.
- 1,800 m Width Broader Floodplain. Episodic Flooding 10-Year ARI.
- Wetting Front from Infiltration of Stream Flow
- Pore Water Derived from Surface Water to Groundwater Interaction, including Infiltration from Perennial Stream Flow.
- Water Table Zone. Permanent Groundwater Availability.
- 6 m Low-Flow Channel with Perenial Stream Flow.
- Zones of Potential Groundwater Dependency - Depths to the Water Table 12 to 20 m.
- Depth to Water Table 0 to 2 m : 85 per cent Dependency
- Depth to Water Table 2 to 6 m : 60 per cent Dependency
- Depth to Water Table 6 to 12 m : 30 per cent Dependency
- Depth to Water Table 12 to 20 m : 10 per cent Dependency
- Proposed Mining Activity

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

TEMPLATES FOR CONCEPTUALISATION OF WATER AVAILABILITY ON WEELI WOLLI CREEK

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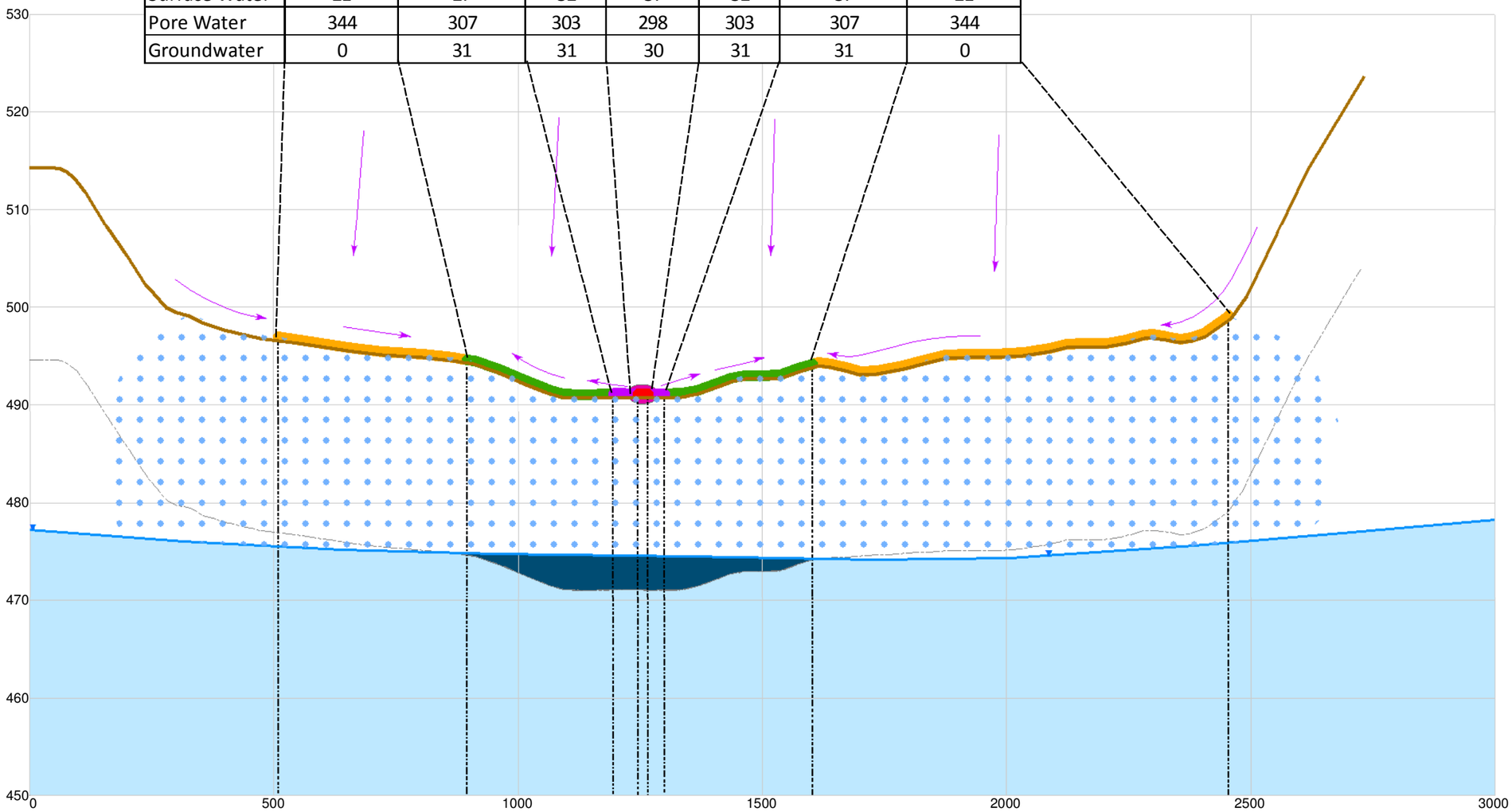
Figure: **7-8** Rev. **A** A3

Interpreted Baseline Annual Water Dependency of the Riparian Zones (Days)

Source	Broader Floodplain	Riparian Zone Floodplain	Incised Channel	Low-Flow Channel	Incised Channel	Riparian Zone Floodplain	Broader Floodplain
Surface Water	21	27	32	37	32	37	21
Pore Water	344	307	303	298	303	307	344
Groundwater	0	31	31	30	31	31	0



i. Depth to Water Table 0 to 2 m: 85 per cent Dependency; High Groundwater Dependency.
ii. Depth to Water Table 2 to 6 m: 60 per cent Dependency; High – Medium Groundwater Dependency.
iii. Depth to Water Table 6 to 12 m: 30 per cent Dependency; Medium Groundwater Dependency.
iv. Depth to Water Table 12 to 20 m: 10 per cent Dependency; Low Groundwater Dependency.
v. Depth to Water Table >20 m: Limited if Any Groundwater Dependency

- Surface Water - Direct Rainfall, Overland Flow, Episodic Stream Flow and Flood Waters
- 6 m Low-Flow Channel with Episodic Stream Flow
- Pore Water Derived from Surface Water to Groundwater Interaction.
- Water Table
- Water Table Zone. Permanent Groundwater Availability.
- Zones of Potential Groundwater Dependency - Depths to the Water Table 12 to 20 m.
- Natural Ground
- 46 m Width Weeli Wolli Creek Low-Flow Channel. Episodic Stream Flow and Flooding Each Year.
- 100 m Width Incised Channel. Episodic Stream Flow and 2-Year ARI Flooding.
- 450 m Width Riparian Zone Floodplain. Episodic Flooding 5-Year ARI.
- 1,800 m Width Broader Floodplain. Episodic Flooding 10-Year ARI.

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BASELINE CONCEPTUAL WATER AVAILABILITY MODEL

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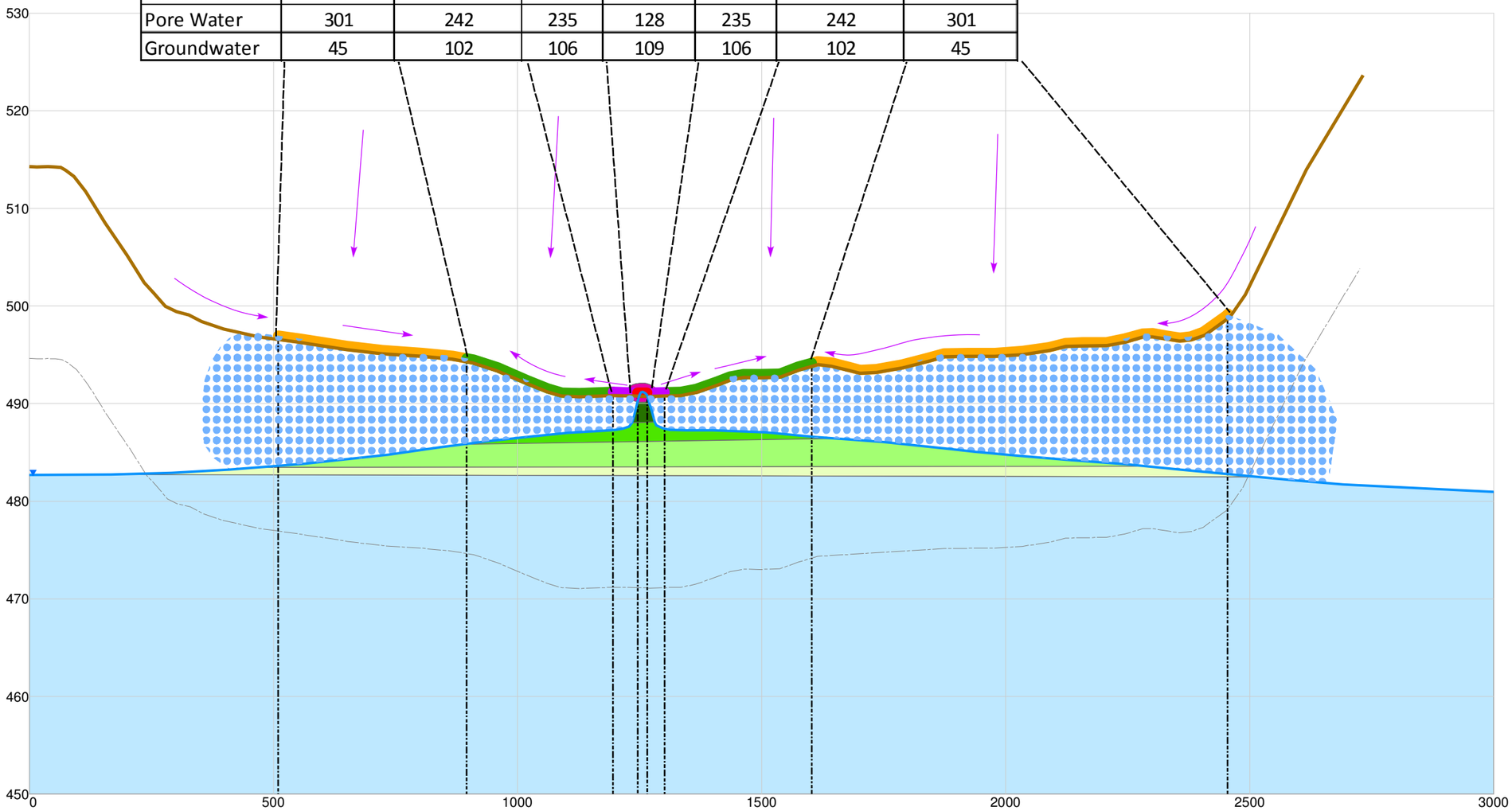
File No: **42908644-070.mxd** Drawn: **RNM** Approved: **IGB** Date: **5/05/2015**

Figure: **7-9** Rev. **A** A3

Interpreted Current Annual Water Dependency of the Riparian Zones (Days)

Source	Broader Floodplain	Riparian Zone Floodplain	Incised Channel	Low-Flow Channel	Incised Channel	Riparian Zone Floodplain	Broader Floodplain
Surface Water	18	21	24	128	24	21	18
Pore Water	301	242	235	128	235	242	301
Groundwater	45	102	106	109	106	102	45



- Surface Water - Direct Rainfall, Overland Flow, Perennial Stream Flow and Episodic Flood Waters
- 6 m Low-Flow Channel with Perennial Stream Flow.
- Pore Water Derived from Surface Water to Groundwater Interaction, including Infiltration from Perenial Stream Flow.
- Water Table
- Water Table Zone. Permanent Groundwater Availability.

Zones of Potential Groundwater Dependency on Available Groundwater

- Depth to Water Table 2 to 6 m : 60 per cent Dependency
- Depth to Water Table 6 to 12 m : 30 per cent Dependency
- Depth to Water Table 12 to 20 m : 10 per cent Dependency
- Depth to Water Table 0 to 2 m : 85 per cent Dependency

- Natural Ground
- 46 m Width Weeli Wolli Creek Low-Flow Channel. Episodic Stream Flow and Flooding Each Year.
- 100 m Width Incised Channel. Episodic Stream Flow and 2-Year ARI Flooding.
- 450 m Width Riparian Zone Floodplain. Episodic Flooding 5-Year ARI.
- 1,800 m Width Broader Floodplain. Episodic Flooding 10-Year ARI.

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CURRENT SITUATION CONCEPTUAL WATER AVAILABILITY MODEL

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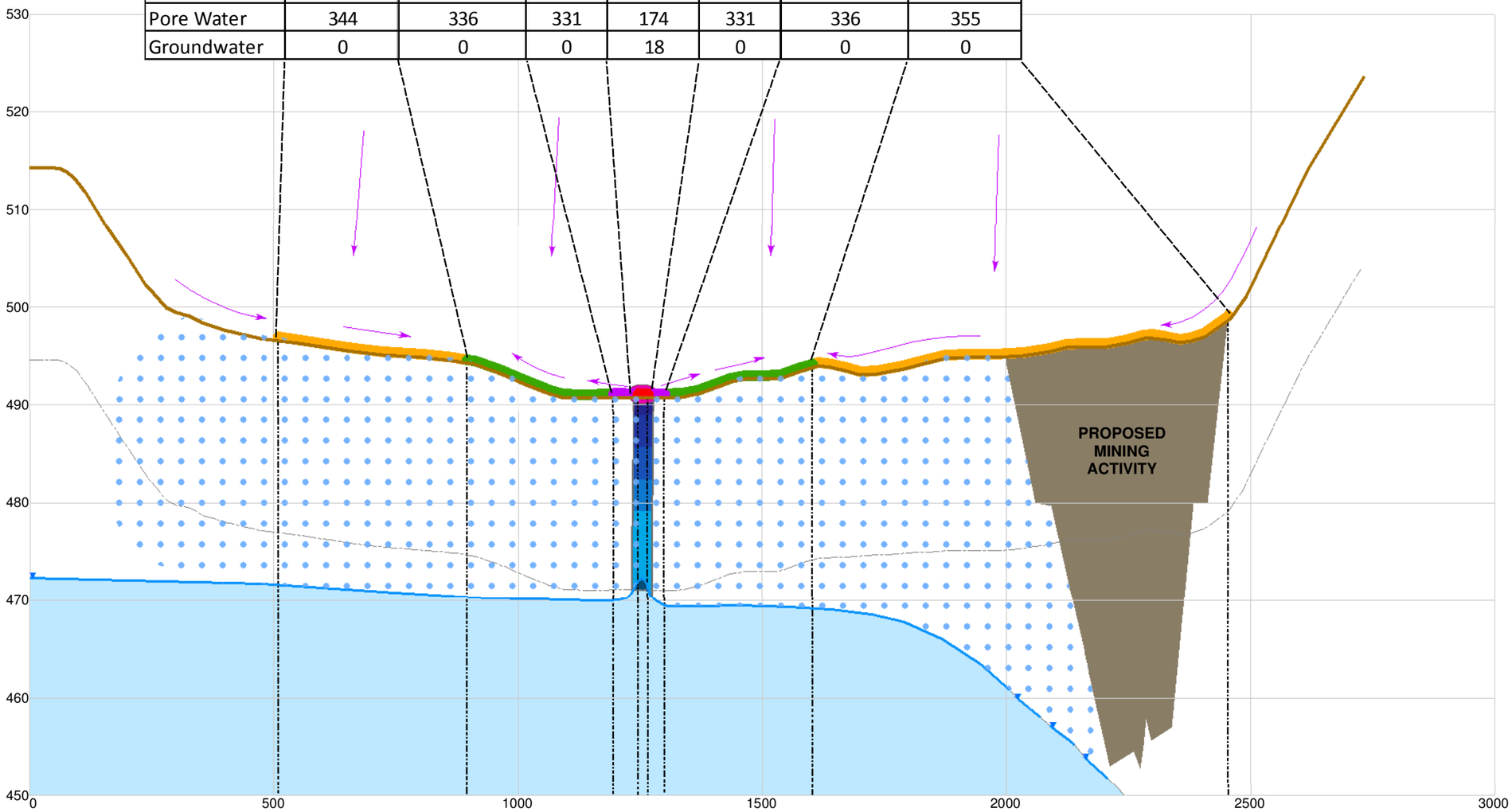
THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-10**

File No: **42908644-071.mxd** Drawn: **RNM** Approved: **IGB** Date: **5/05/2015** Rev. **A** A3

Interpreted Mining Situation Annual Water Dependency of the Riparian Zones (Days)

Source	Broader Floodplain	Riparian Zone Floodplain	Incised Channel	Low-Flow Channel	Incised Channel	Riparian Zone Floodplain	Broader Floodplain
Surface Water	21	29	34	174	34	29	10
Pore Water	344	336	331	174	331	336	355
Groundwater	0	0	0	18	0	0	0



- Surface Water - Direct Rainfall, Overland Flow, Perennial Stream Flow and Episodic Flood Waters
- 6 m Low-Flow Channel with Perennial Stream Flow.
- Pore Water Derived from Surface Water to Groundwater Interaction, including Infiltration from Perennial Stream Flow.
- Water Table
- Water Table Zone. Permanent Groundwater Availability.
- Wetting Front from Infiltration of Stream Flow
- Natural Ground
- 46 m Width Weeli Wolli Creek Low-Flow Channel. Episodic Stream Flow and Flooding Each Year.
- 100 m Width Incised Channel. Episodic Stream Flow and 2-Year ARI Flooding.
- 450 m Width Riparian Zone Floodplain. Episodic Flooding 5-Year ARI.
- 1,800 m Width Broader Floodplain. Episodic Flooding 10-Year ARI.
- Proposed Mining Activity

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MINING SITUATION CONCEPTUAL WATER AVAILABILITY MODEL

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-11**

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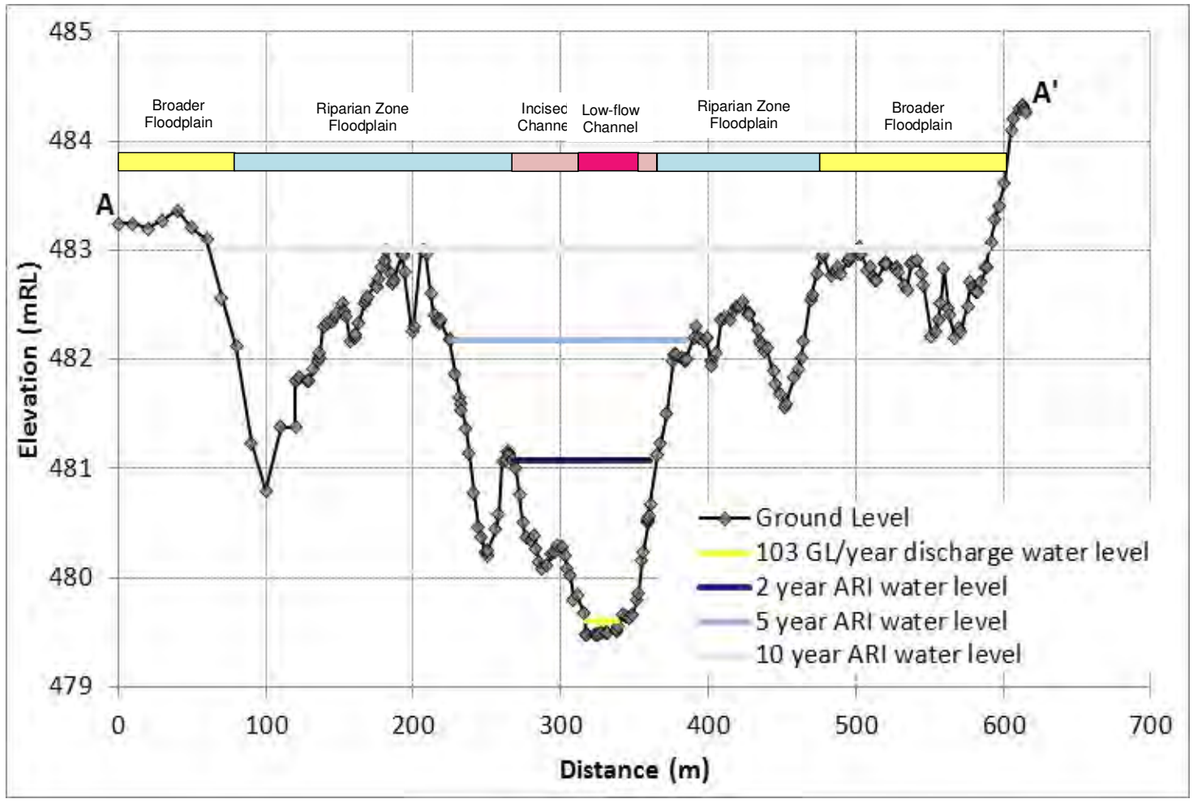

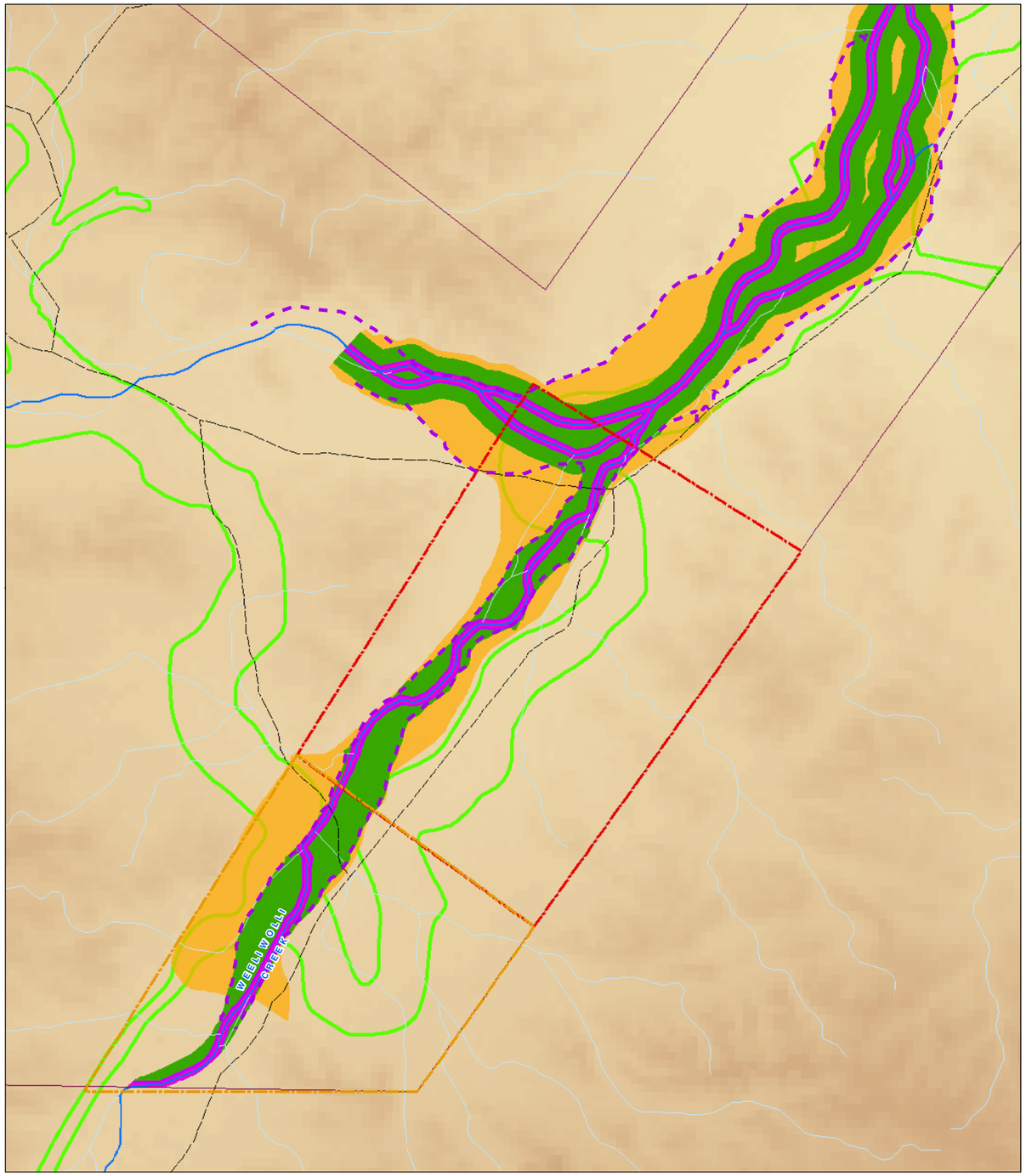

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Scale: 1:60,000
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Meters

Coordinate System: GDA 1994 MGA Zone 50

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

DISCRETISATION OF RIPARIAN ZONES

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **7-1**

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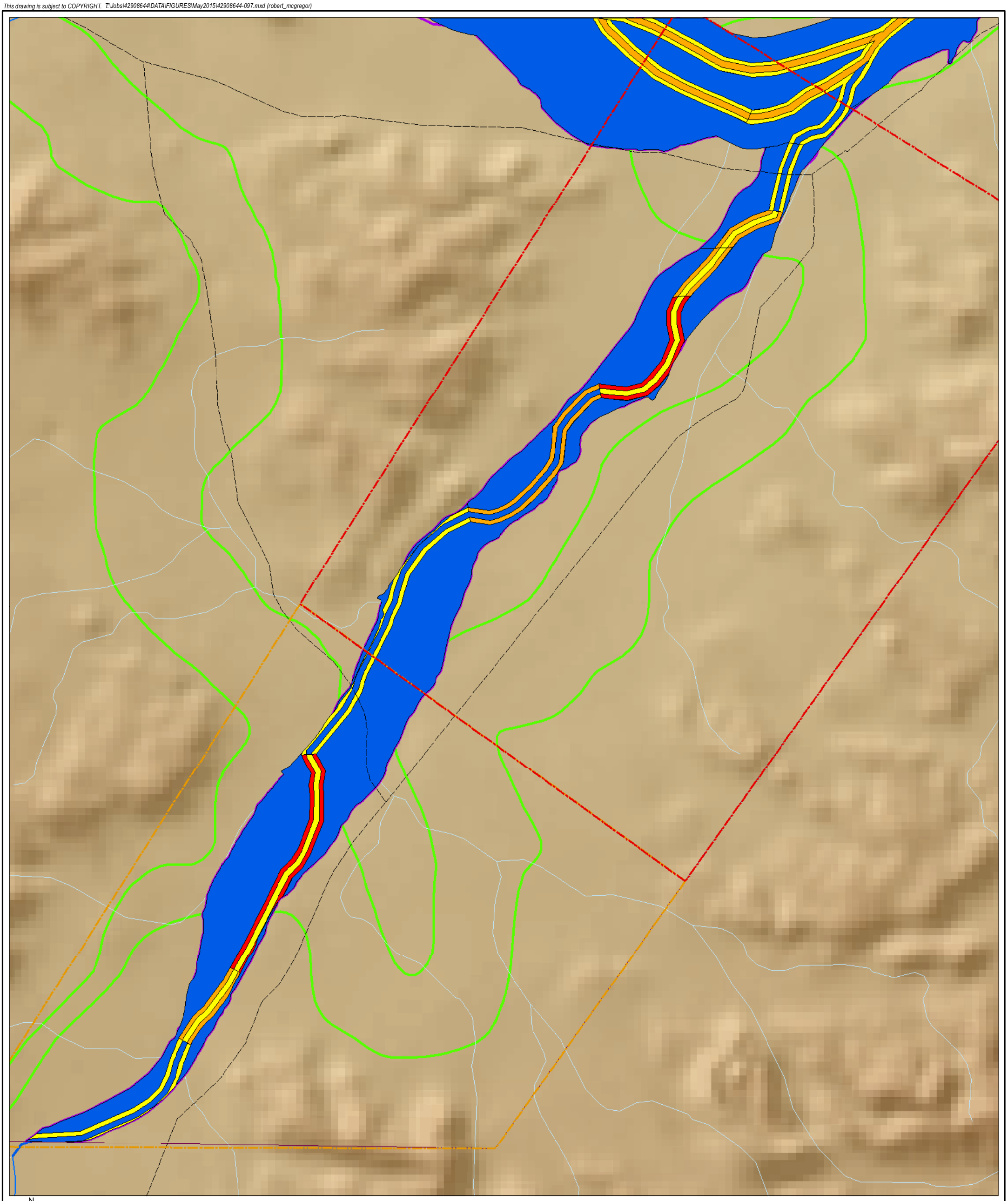

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RIPARIAN ZONES ENVIRONMENTAL RISK ASSESSMENT

WATER AVAILABILITY RISK PROFILE - CURRENT TO PBS SCENARIO

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **8-1**

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Figure 8-2 illustrates the distributions of the mapped vegetation communities (Figure 1-2b) with comparative risk perspectives (listed in order of high to medium risk) that include:
1. *Melaleuca argentea* co-dominated communities – High Risk.
2. *Eucalyptus camaldulensis* co-dominated incised channel zone vegetation and *Eucalyptus victrix* and *Eucalyptus camaldulensis* co-dominated floodplain vegetation – Medium Risk.

N
W E
S

Scale: 1:25,000
0 200 400 600 800
Meters

Coordinate System: GDA 1994 MGA Zone 50

Low Risk
Medium Risk
Medium-High Risk
High Risk

Riparian Exclusion Zone
CID Boundary
Billiard South (Cue)
Billiard South (Pocket)

Major Watercourse
Minor Watercourse
Railway

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RIPARIAN VEGETATION OVERLAY ON THE WATER AVAILABILITY RISK PROFILE

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THE POCKET AND BILLIARD SOUTH PROJECT

Figure: **8-2**

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Rio Tinto

Water Resource Evaluation / Projects & Development

Weeli Wolli Creek Ecohydrology – Yandicoogina Pocket and Billiard South Pre-Feasibility Study

30 April 2015

A study was carried out to identify the likely changes to surface water flow regime and the effects on riparian vegetation along Weeli Wolli Creek as a result of development of the Pocket and Billiard South deposits within the Yandicoogina mine. Mining of the deposits will require construction of flood protection infrastructures, which may alter the existing surface water flow conditions along Weeli Wolli Creek. Hydraulic modelling in 2D was undertaken to define the flow conditions under pre-development and operational catchment conditions when the proposed surface water infrastructures are in place. The degree and extent of change to the flow regime, and the associated impact on the riparian vegetation were determined by comparing the flood elevations and velocities for various events under pre- and post-development conditions.

Based on the model results, it was determined that disruption to the existing surface water flows along Weeli Wolli Creek is small during events of low flows. As the magnitude of the flood increases, changes to the flow regime also increase due to greater constriction and obstruction of flows imposed by the infrastructures along the creek.

Flooding characteristics and creek water supply for riparian vegetation during events of low and medium flows will likely remain unchanged during operation. For larger events, flood level will increase more prominently and the floodplain extends further to the west, thus larger area of vegetation, in particular those fringing the floodplain will be inundated during events of a lower AEP post-development.

Overall, the study demonstrated that the impact to surface water flow regime along Weeli Wolli Creek is confined to the section adjacent to the proposed mine and unlikely to influence the wider creek area during operation. However, it is recommended that appropriate management and monitoring be implemented to minimise long term impacts on the morphology and flow regime of the creek.

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Introduction

1. Overview

The Weeli Wolli Creek riverine environment supports significant stands of riparian vegetation, including *Eucalyptus camaldulensis* (River Red Gum), *E. victrix* (Coolabahs) and low open woodlands of *Melaleuca argentea* (Silver Leaved Paperbark), and the distribution, density and survival of these tree species are most likely related to the water availability and hydrological regime of the creek system. The section of Weeli Wolli Creek, adjacent to the Pocket and Billiard South deposits at Yandicoogina, is categorised as an environment and heritage restriction zone. Development of the deposits will result in direct disturbance of the restriction area and construction of mine and flood protection infrastructure will encroach on the floodplain and modify the existing flow conditions of the creek. Flood levees, designed to the 0.5 % AEP event, will be constructed to protect the pit from Weeli Wolli Creek flood waters and an engineered creek crossing will be required to enable access from the Billiard South operation to the existing Yandicoogina mine. Changes to the existing hydrologic pattern and flood regime, as a result of these infrastructures, may affect riparian vegetation condition within Weeli Wolli Creek. Assessments to investigate the potential impacts to the Weeli Wolli Creek riverine environment as a result of mine development are therefore required to support government approval applications and comply with Rio Tinto standards.

As part of the Pocket and Billiard South Order of Magnitude (OoM) study, hydrologic and hydraulic assessments were undertaken to define the surface water hydrology and flow conditions of Weeli Wolli Creek as well as investigate conceptual flood levee options within the Weeli Wolli Creek floodplain (RTIO, 2013). This study adopts similar modelling approach but focuses on identifying potential environmental impacts as a result of the proposed mine development by comparing the flood regime in Weeli Wolli Creek under pre and operational catchment conditions. This is achieved by:

- Refining the existing (pre-mining) 2D hydraulic model to better capture the flow characteristics, including the flood extents, velocities and shear stresses, of the creek system;
- Development of an operational 2D hydraulic model, which incorporates the designs of the proposed flood and drainage infrastructure, to determine the flow characteristics of Weeli Wolli Creek during mining;
  and
- Describing the possible changes to the existing hydraulic regime of Weeli Wolli Creek during operation and determining the level of impacts and disruption to riparian vegetation within the creek as a result of the development of the Billiard South mine.

2. Terminology

Probability concepts are fundamental to design flood estimation. The terminology used in the communication of these concepts is paramount if it is to be effective for all stakeholders. The term ‘average recurrence interval’ or ‘ARI’ has generally been used within Rio Tinto and by industry professionals to describe the probability of a particular magnitude of flood occurring ie. ‘100 yr ARI’ or ‘1 in 100 year flood’.

Average Recurrence Interval (ARI) - the average period between occurrences equalling or exceeding a given value.

This description of flood events has often been misinterpreted by professionals, community members impacted by floods and other stakeholders as the probability of the chosen event is not explicitly defined. To ensure effective communication of event probabilities alternative terminology will be adopted by the Bureau of Meteorology and other industry bodies. Australian Rainfall and Runoff (ARR) has outlined the proposed terminology to be adopted (Engineers Australia 2013), and this follows.

Annual Exceedance Probability (AEP) - the probability of an event occurring or being exceeded within a year. For example a 1% AEP event has a 1% probability of being equalled or exceeded in any year.

The annual exceedance probability (AEP) expressed as a percentage, will be used to describe flood event probabilities for this study. Additionally, where appropriate, peak flows described as Q_y for the year ARI, will now be described as $Q_{n\%}$ AEP (including the percentage sign). Table 1 gives the AEP equivalent for ARI's commonly in used in flood studies.

Table 1: ARI and equivalent AEP

ARI	AEP (1 in x)	AEP %
1.44	2	50
4.48	5	20
9.49	10	10
20	20	5.0
50	50	2.0
100	100	1.0
200	200	0.50
500	500	0.20
1000	1000	0.10

3. Climate

3.1 Rainfall

The Yandicoogina area is a semi-arid to arid environment characterised by hot summers and warm winters. The region experiences climate extremes, where severe droughts and major floods can follow in close succession.

Rainfall records for Weeli Wolli Creek are available from Department of Water (DoW) gauging stations at Wonmunna (507012) from 1984, Tarina (505040) from 1985 and Waterloo Bore (505041) from 1985; all gauging stations are in operation and their locations are illustrated in Figure 1. Daily gridded rainfall data are also available for the period 1906 – 2011 for the catchment. Detailed analysis of observed rainfall records and gridded data were carried out as part of the OoM study and the long term mean annual rainfall (1906 to 2011) estimated for Billiard South is approximately 309 mm (RTIO, 2014). Rainfall is highly variable between years with the annual recorded rainfall for the region varying from 50 mm to 910 mm but a general increasing trend of 1.4 mm/year is shown in Figure 2. This rising trend has also been observed at other locations within the Pilbara. Rainfall is also highly seasonal with approximately 75 % of the annual total occurring between December and April. It is typically associated with tropical low pressure systems and thunderstorm activity from the monsoonal trough that develops over northern Australia during summer. Winters are typically dry and mild though winter rain events can occur in June and July as a result of tropical cloud bands that intermittently affect the area.

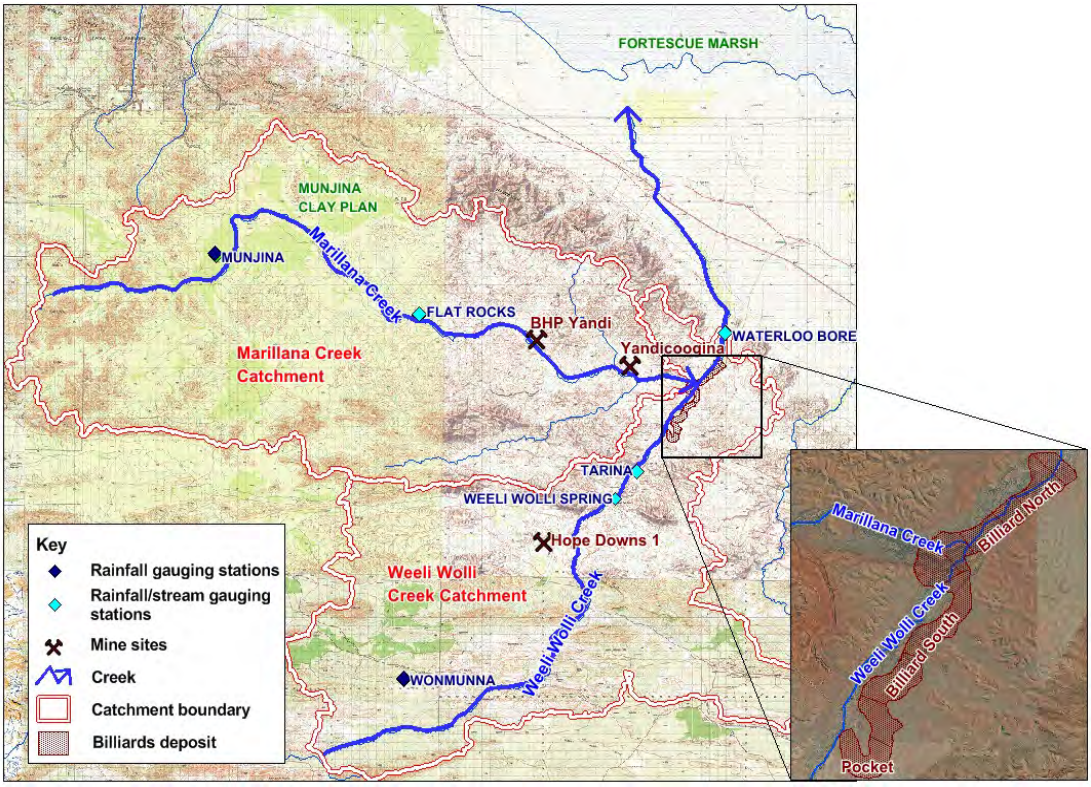


Figure 1: Weeli Wolli Creek regional catchment.

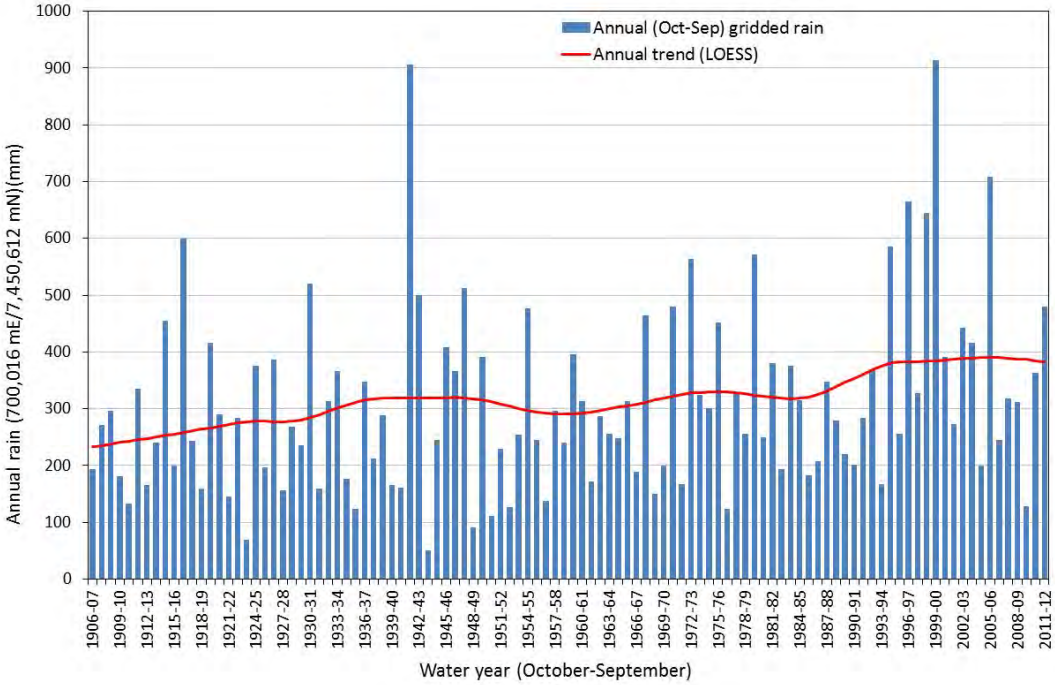


Figure 2: Annual (October-September) gridded rainfall for Billiard South.

A key component governing the hydrology of the Pilbara is the minimum rainfall required to initiate runoff, which can be referred to as the rainfall-runoff threshold. CSIRO has undertaken a detailed analysis of climate characteristics and hydrological catchment responses to define specific parameters and thresholds, including the rainfall-runoff threshold, for major creek systems within the Pilbara (CSIRO, 2013). Preliminary results of the analysis were presented for selected locations including Tarina at Weeli Wolli Creek within the Upper Fortescue River Basin. It was determined that the mean rainfall threshold for runoff commencement at Tarina is 36 mm, which means surface water flows within the Weeli Wolli Creek system will only occur when on average ≥ 36 mm of rainfall is received across the catchment during a single storm event. It is important to note that this value is a mean derived from examining rainfall sequence immediately prior to flow initiation at the gauge; the actual runoff threshold for each flow event will depend on the antecedent moisture conditions of the catchment.

Based on these findings, 30 minute rainfall data (1985 to 2012 water year), at Tarina was reviewed to quantify the occurrence of historical flow events along Weeli Wolli Creek. In the period of 1985 to 2012, 43 storm events of ≥ 36 mm were recorded, and therefore were likely to have generated surface flow in the catchment. Hence there is a probability that two flow generating rainfall events will occur every year on average. The remaining rainfall events were generally less than 10 mm, as illustrated in Figure 3, and therefore unlikely to trigger surface water flows in the system.

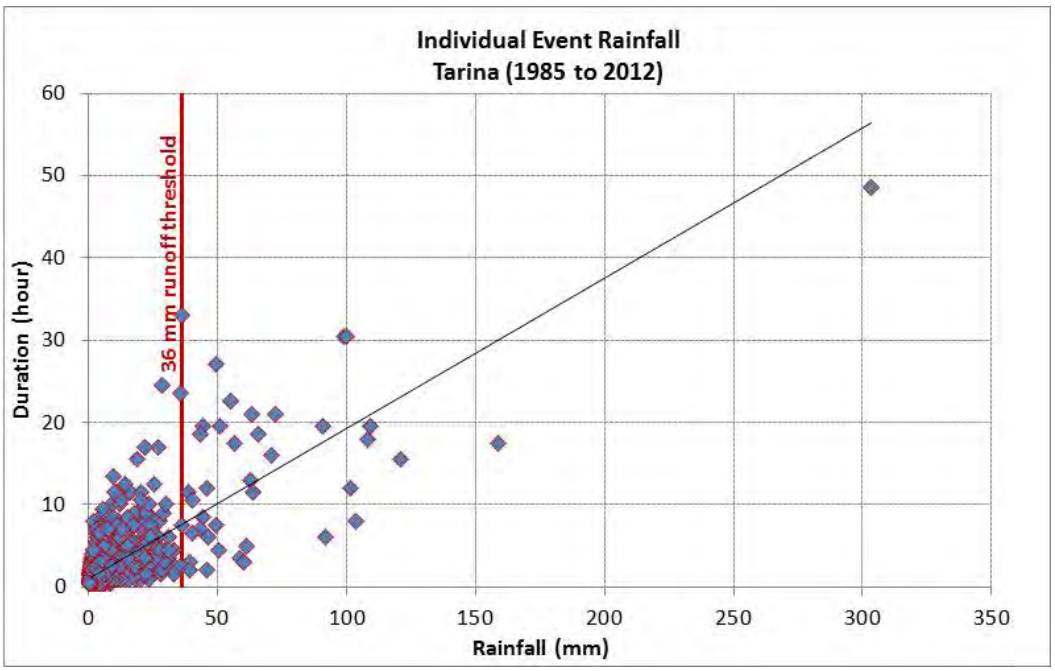


Figure 3: Individual event rainfall at Tarina 1985 to 2012. Majority of the rainfall events were less than 10 mm. During the 28 year period of record, 43 rainfall events were recorded to equal or exceed 36 mm (the runoff threshold established by CSIRO).

3.2 Evaporation

The mean annual Class A pan evaporation estimated for the region (from BoM gridded data, 1975 to 2000) is approximately 3,283 mm. The mean annual evaporation rate (sheltered free water surface) recorded at Yandi mine site weather station, between April 2004 and March 2009, is 1,898 mm/year, which exceeds the mean annual rainfall keeping the landscape typically arid. The conversion from Class A pan evaporation to sheltered free water surface, i.e. dam, conditions is 0.63 (Luke et al. 1987). Monthly evaporation rates are listed in Table 2.

The average point potential evapotranspiration (ET) rate estimated for the region by Bureau of Meteorology (BoM) is approximately 3,024 mm/year. Point potential ET is the ET that would take place, under the conditions of unlimited water supply, from an area so small that the local ET effects do not alter local air mass properties. Based on the information provided by BoM, point potential ET may be taken as a preliminary estimate of evaporation from small water bodies such as shallow water storages, which may include surface water pools within a creek system. The BoM annual actual aerial ET rate, for limited water supply replicating the natural environment rate, is approximately 346 mm/year.

Table 2: Evaporation rates estimated for the regional Weeli Wolli Creek catchment. Daily sheltered evaporation derived from Yandi site weather station (April 2004 to March 2009 sampling interval); Monthly Class A pan evaporation, Point potential and areal actual evapotranspiration obtained from BoM gridded data (1975 to 2005) and Class A pan evaporation conversion factor of 0.63 used to estimate sheltered monthly evaporation.

Month	Yandi sheltered evaporation (mm/day)				Class A pan	Point potential ET	Areal actual ET	Sheltered evaporation
	Min	Max	Mean	Std dev	(mm)	(mm)	(mm)	(mm)
January	0.0	14.9	5.6	3.1	382	389	61	241
February	0.5	17.3	6.6	3.5	294	287	76	185
March	0.3	17.7	5.7	3.1	301	287	52	190
April	0.5	17.1	5.5	2.4	239	204	24	150
May	0.0	6.7	4.0	1.4	175	133	25	110
June	0.2	5.3	3.2	1.1	132	92	28	83
July	0.1	5.0	3.0	1.1	147	110	14	92
August	0.0	7.9	4.6	1.5	190	155	12	120
September	0.0	9.2	5.7	2.2	261	229	12	165
October	0.3	16.3	5.6	2.6	355	333	7	224
November	0.3	14.6	6.0	2.9	387	377	12	244
December	1.0	16.3	6.2	3.4	411	404	31	259
Annual					3283	3024	346	2068

4. Hydrology

Weeli Wolli Creek is currently gauged at two locations: Tarina (708013) approximately 8 km upstream of Billiard South and Waterloo Bore (708014) 11 km downstream. Detailed analyses of observed streamflow records at the gauging stations were carried out, as part of the OoM study, to define the existing hydrological regime of the creek system (RTIO 2013). Figure 4 and Figure 5 illustrate the flow duration curves (FDC) produced for Tarina and Waterloo Bore. The FDCs were generated for each complete water year on record in order to describe the hydrological regime of the section of Weeli Wolli Creek between the two gauges. The grey lines represent the FDC for individual water years, while the thicker black line describes the flow regime for the entire length of record.

The effects of surplus water discharge, from the Hope Downs 1 operation approximately 5 km upstream, on the existing flow regime at Tarina are clearly illustrated in the annual FDCs (Figure 4). Continuous flows are recorded at the gauge since 2007, an occurrence that is outside the natural envelope of existing flow based on available streamflow records at the gauge. The FDCs therefore demonstrate that the flow regime at Tarina has shifted from intermittent to perennial since artificial discharge from Hope Downs 1 begins in 2007.

For Waterloo Bore the wettest year, in terms of sustained flows, on record was 1999-2000, where positive flow was measured nearly 60 % of the time. The next wettest year experienced flows only 22 % of the time, in addition over 90 % of the daily flow record at Waterloo Bore is equal to zero. This suggests significant losses occur in the reaches upstream of the gauging station and that flows at Waterloo Bore will only occur during

severe/high intensity storms. This observation is consistent with the findings of the study conducted by Dogramaci et al, which evaluates the potential recharge along Weeli Wolli Creek based on a combination of numerical modelling and hydrochemistry measurements (Dogramaci et al., 2014). They have differentiated Weeli Wolli Creek into two sections (Figure 6 and Figure 7): Section A, which incorporates a 12 km section of the creek from Weeli Wolli Spring to the start of the Billiard South deposit, is underlain by impermeable Weeli Wolli Formation; this section contrasts to the lower part of Weeli Wolli Creek (Section B), which extends from Billiard South to Waterloo Bore and is underlain by a palaeochannel iron deposit (CID) aquifer that is characterised by a relatively high hydraulic conductivity (K = ~10 m/d). The study determined that groundwater is directly connected to the creek for the upper Section A, suggesting recharge is negligible along this reach of Weeli Wolli Creek. As the creek flows from Section A to Section B, the depth of the unsaturated zone increases and the hydrologic regime transitions from a connected to a disconnected creek, thus allowing recharge to occur (Dogramaci et al., 2014). The rate of recharge, i.e. the loss rate via infiltration, is estimated to increase substantially downstream as the depth to groundwater table increases from 0 m below ground level at Weeli Wolli Spring to 29 m near Waterloo Bore.

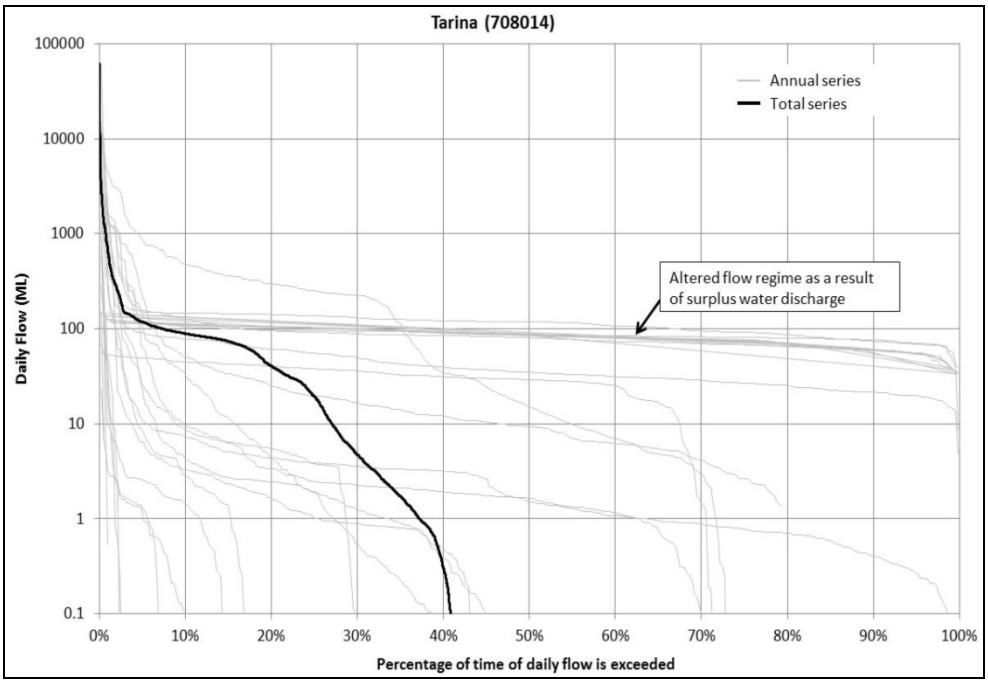


Figure 4: Flow duration curves at Tarina gauging station (708014) on Weeli Wolli Creek

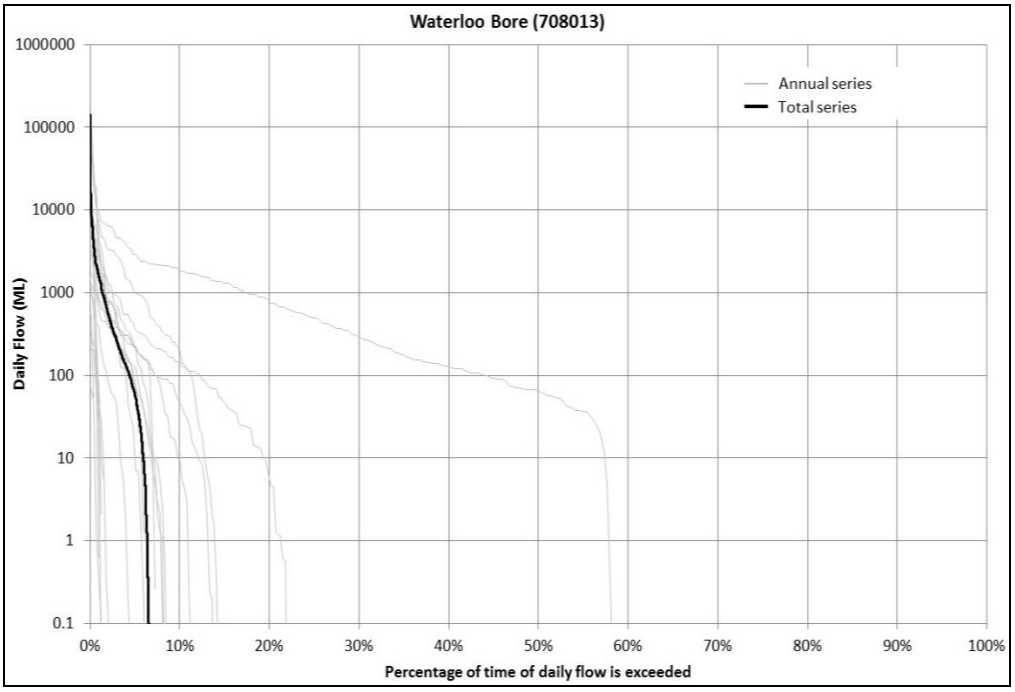


Figure 5: Flow duration curves at Waterloo Bore gauging station (708013) on Weeli Wolli Creek

Figure 6: Upper (Section A) and lower (Section B) Weeli Wolli Creek, including locations of groundwater bores and CID (Dogramaci et al., 2014).

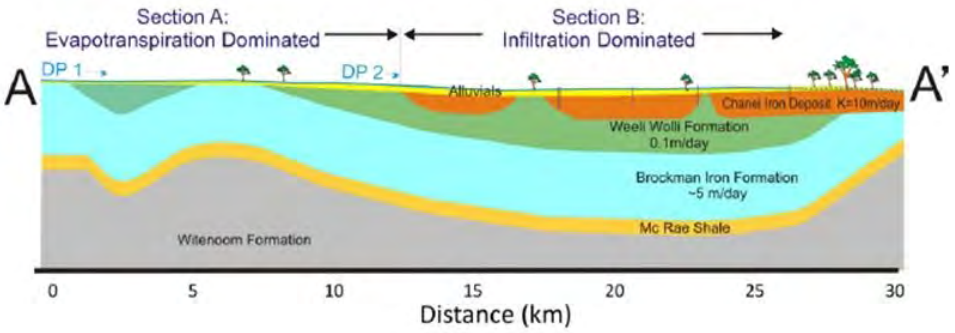


Figure 7: Long section A-A' showing the variation in geology below the creek (Dogramaci et al., 2014).

4.1 Cyclone Heidi

The most recent cyclone to generate significant flows along Weeli Wolli Creek is TC Heidi, which impacted the Pilbara region between 9 and 12 January 2012. The total rainfall recorded between 8 and 13 January at Tarina and Waterloo Bore are 225 mm and 166 mm, respectively. Maximum discharge was recorded on 13 January with flood peaks reaching 240 m^3/s at Tarina and 430 m^3/s at Waterloo Bore. A comparison of creek flows and rainfall volumes measured at the gauging stations are provided in Figure 8 and Figure 9.

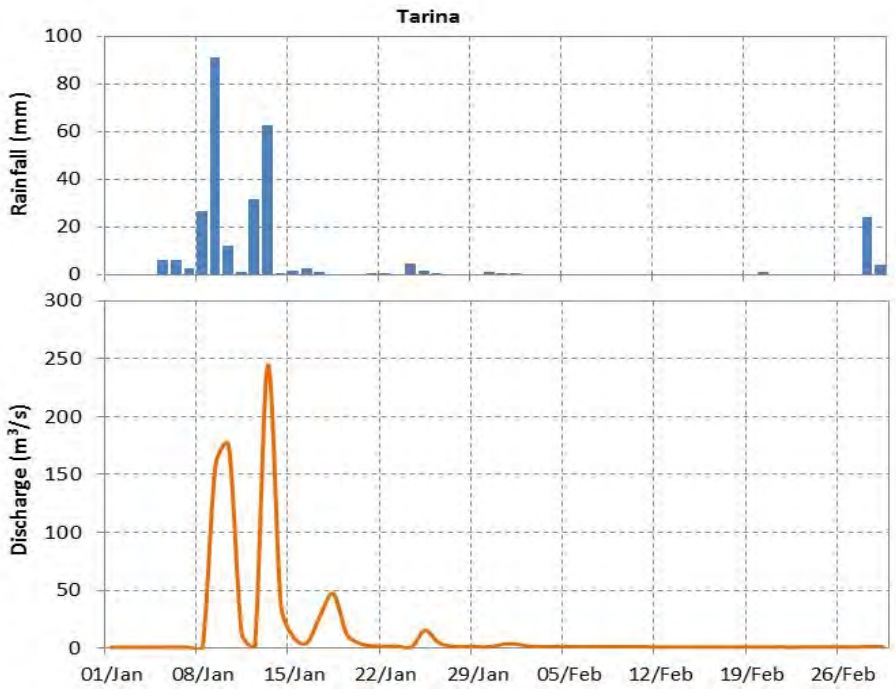


Figure 8: A comparison of rainfall depths and measured creek flows at Tarina gauging station during the period January to February 2012.

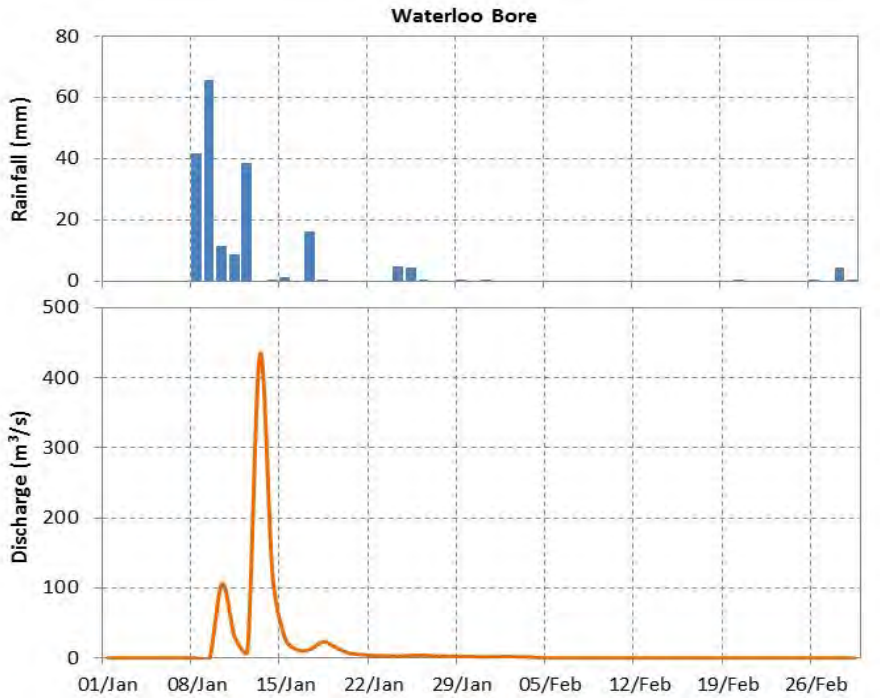


Figure 9: A comparison of rainfall depths and measured creek flows at Waterloo Bore gauging station during the period January to February 2012.

An attempt was made to evaluate the rate of recharge along Weeli Wolli Creek (Section B) in response to Cyclone Heidi by estimating the fluctuation in groundwater table at bores along the CID (Dogramaci et al., 2014). It was estimated that recharge increases downstream from < 1 mm/d at bore 99YJWB04 to approximately 20 mm/d at bore 99YJWB01 (bore locations are illustrated in Figure 6). Subsequently the recharge volumes per unit length calculated by the changes in groundwater levels range from < 0.1 m3/d/m at the confluence with Marillana Creek to 8.4 m3/d/m near Waterloo Bore (Figure x). This finding indicates that infiltration from flow events increases substantially downstream, due to the increase in storage capacity of the underlying aquifer system, thus likely explains the predominant zero flow recorded at Waterloo Bore.

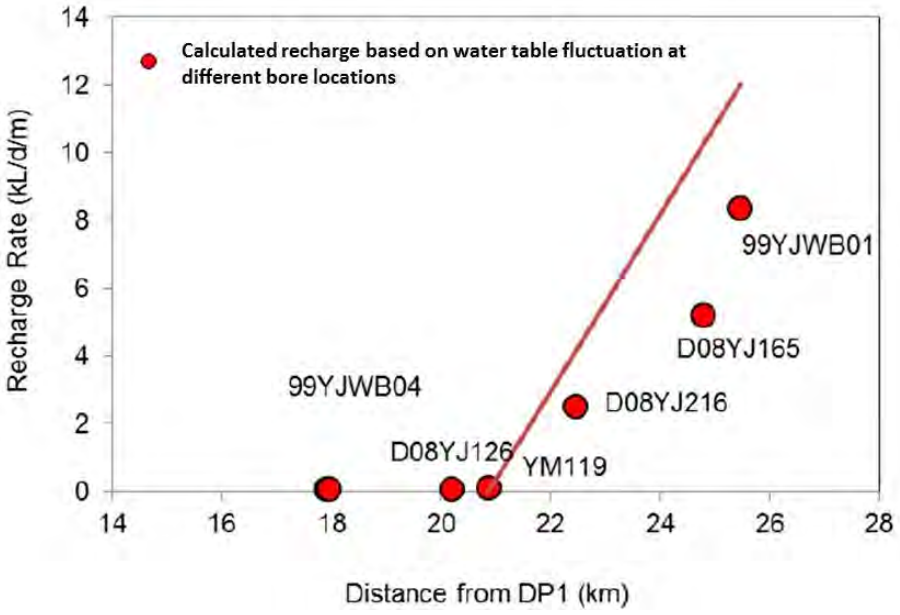


Figure 10: Calculated recharge rates downstream for Section B of Weeli Wolli Creek using the water table fluctuation method (Dogramaci et al., 2014)

4.2 Rainfall-runoff modelling

In order to determine the design flood peaks and hydrographs as required for the design of flood protection infrastructure at Billiard South, a rainfall-runoff routing model for the regional Weeli Wolli Creek catchment, which incorporates the catchment of Marillana Creek, was developed during the OoM (RTIO 2013). The model was calibrated to observed streamflow data at the gauging stations (Flat Rocks on Marillana Creek; Tarina and Waterloo Bore on Weeli Wolli Creek) within the catchment. The peak flow rates, at selected locations along Weeli Wolli Creek, for the 50 to 0.5 % AEP design events are listed in Table 3.

Table 3: Flood peaks produced from RORB model for the Weeli Wolli Creek catchment.

			Peak flow rates (m^3/s)			
AEP (%)	ARI (year)	Critical Duration (hr)	Weeli Wolli Creek at Tarina	Weeli Wolli Creek at Billiard South	Weeli Wolli Creek after Marillana inflow	Weeli Wolli Creek at Waterloo Bore
50	2	9	79	76	111	110
20	5	12	250	240	440	440
10	10	12	510	490	1160	1190
5	20	24	930	950	2660	2720
2	50	24	1960	2200	6600	6950
1	100	24	3700	4070	9810	10240
0.5	200	24	4630	4900	11090	11260

5. Hydraulic conditions

Design flood hydrographs produced from the rainfall-runoff modelling were inputted into a two dimensional (2D) hydraulic model, developed in TUFLOW, to determine the flood levels, velocities and floodplain extents for Weeli Wolli Creek at Billiard South (RTIO 2013). The original model is relatively coarse, incorporating a 2D grid comprised of 40 m by 40 m cells. This resolution is considered insufficient to capture the flow characteristics and resultant changes proposed by the flood levees, in particular along the low flow channel of the creek. Hence the model was refined, by reducing the cell size to 5 m by 5 m, to better capture the hydraulic conditions in the creek.

Flow conditions for the 50 to 0.5 % AEP design events were simulated in TUFLOW. Model results (maximum flood depths and velocity profiles) for the 50 %, 10 % and 1 % AEP events, representing the low, medium and high flow situations in Weeli Wolli Creek, are illustrated in Figure 11, Figure 12 and Figure 13, respectively. The velocity distribution is developed based on categories of permissible velocity, which is the velocity at which particles of a specified mean size begin to be mobilised and can be used as an indication of when channel erosion would occur. The categories of permissible velocity used in the assessment is summarised in Table 4. Cross sections at selected locations along Weeli Wolli Creek, adjacent to Billiards South, were also plotted (Table 5) to illustrate the changes in flood levels for different flow frequencies.

Table 4: Categories of permissible velocity and thresholds for sediment mobilisation

	Velocity (m/s)	Category
	0.0-0.5	OK for most areas
	0.5-1.0	Threshold for silts, fine sands and fine gravels
	1.0-1.5	Threshold for clays and gravels up to 25mm
	1.5-2.0	Threshold for gravels up to 50mm
	2.0-2.5	Threshold for gravels up to 150mm
	2.5-3.0	
	3.0-3.5	Threshold for riprap with d50 = 150-225mm
	3.5-4.0	Threshold for gravels and riprap with d50 = 300mm
	4.0-4.5	Threshold for gravels and riprap with d50 = 450mm
	4.5-5.0	Threshold for gravels and riprap with d50 = 450mm
	5.0-5.5	Threshold for riprap with d50 = 600mm, gabions and concrete
	5.5-6.0	Threshold for riprap with d50 = 600mm, gabions and concrete
	>6.0	High velocity for most areas

As shown in Figure 11, Weeli Wolli Creek is defined by an incised low flow channel that meanders within the floodplain of the creek system. Majority of the flows during the 50 % AEP are contained within the low flow channel with same minor break outs in the secondary channels, in particular downstream of XS4, signifying the transition from a more uniform to a braided system towards and downstream of the confluence with Marillana Creek. The maximum flood depth for the 50 % AEP event reaches 2 m along with the deepest section marked by XS3 where the low flow channel is most incised. Maximum velocity along the channel approaches 2 m/s for the 50 % AEP event, a velocity that is capable of mobilising gravels up to 50 mm along the creek bed.

During the 10 % AEP event, a proportion of the floodplain is activated, including several high flow channels in particular at locations marked by XS3 and XS5 (Figure 12). The maximum flood depth for the event reaches 4 m along the low flow channel with the floodplain inundated with water less than 1.5 m deep. There are isolated areas along the low flow channel where velocities exceed 3 m/s during the 10 % AEP flood. Those areas are areas where significant scour may occur and where pools may potentially form. Conversely, flow velocities along the floodplain and high flow channels are generally below 2 m/s during the event.

Outputs from the hydraulic model indicate that the floodplain of Weeli Wolli Creek is fully engaged in the 1 % AEP flood. As shown in Figure 13, flows are multidirectional and severely bifurcated, particularly at and downstream of the confluence with Marillana Creek. Water depths vary from less than 0.5 m along the perimeter of the flood extent to exceeding 6 m along the main channel. The low flow channel experiences extremely high flow velocities during the 1 % AEP flood with velocities at sections between XS1 and XS3, and at XS6 approaching 5 m/s. These velocities can uproot and transport large trees along the creek. Large woody materials, which appear to have been transported during large flow events, have been observed in the main channel as well as on the floodplain during the site visit of the geomorphological assessment.

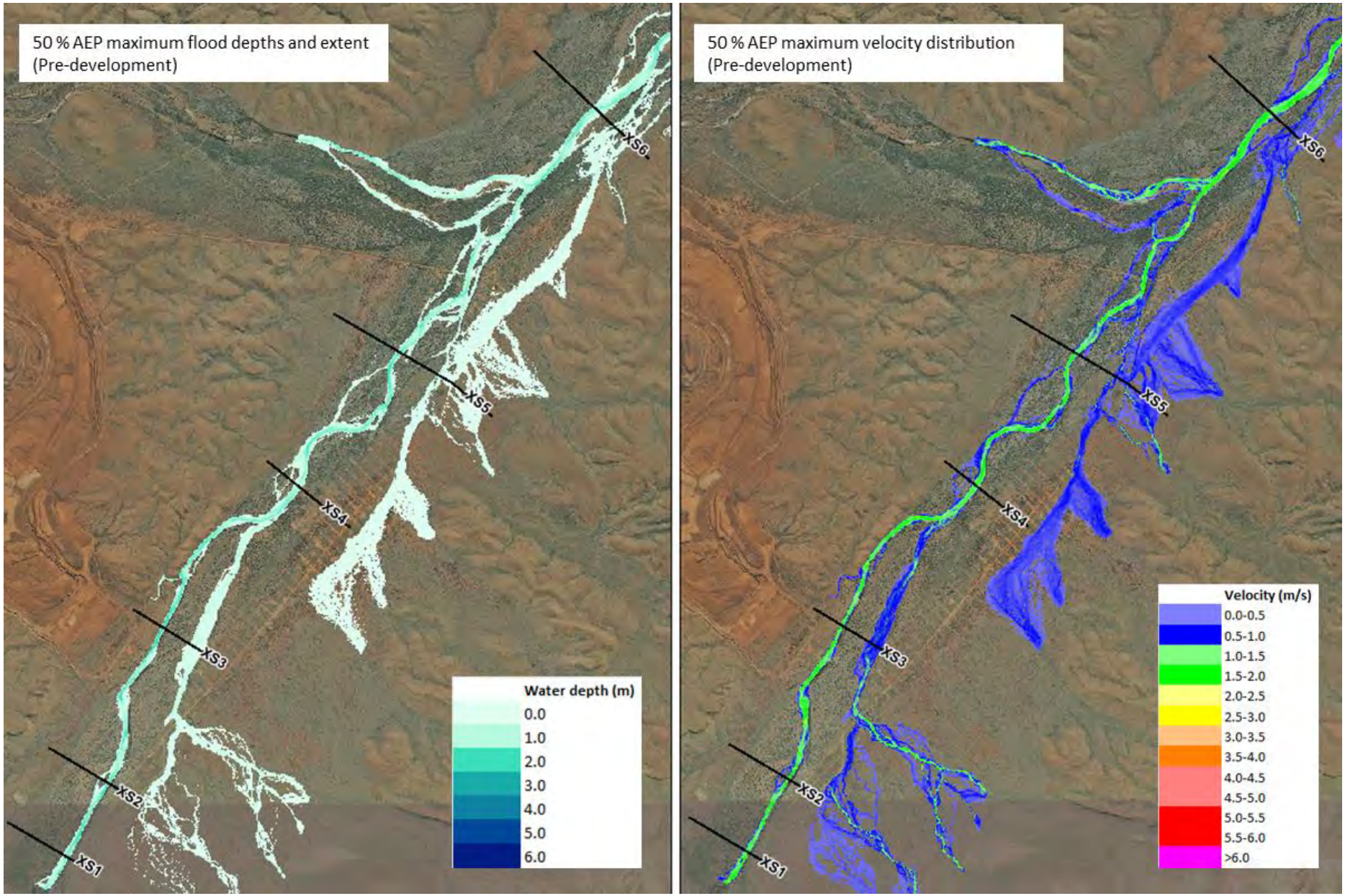


Figure 11: Maximum flood depths and velocity distribution for Weeli Wolli Creek during the 50 % AEP event under pre-development catchment conditions.

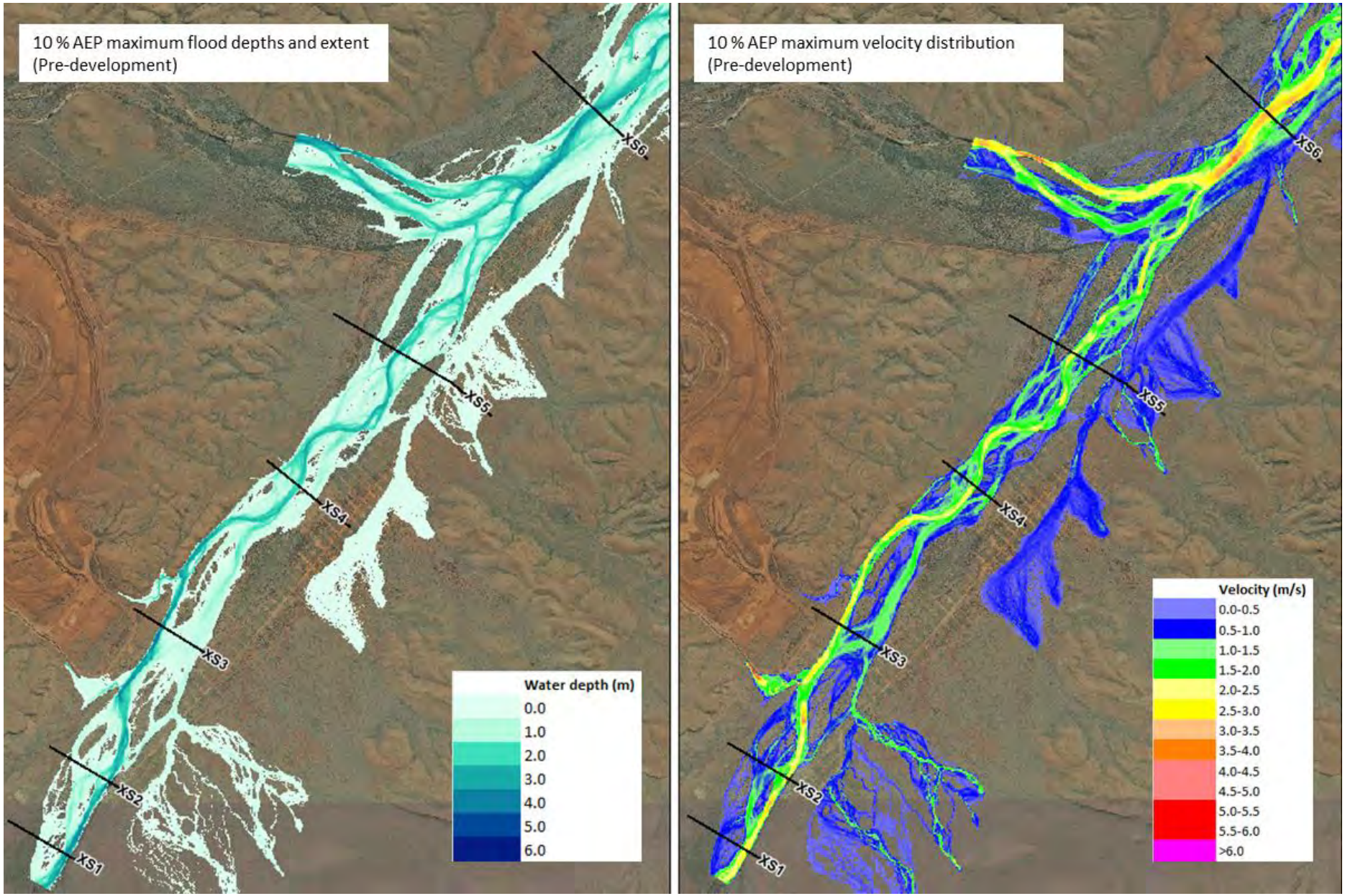


Figure 12: Maximum flood depths and velocity distribution for Weeli Wolli Creek during the 10 % AEP event under pre-development catchment conditions.

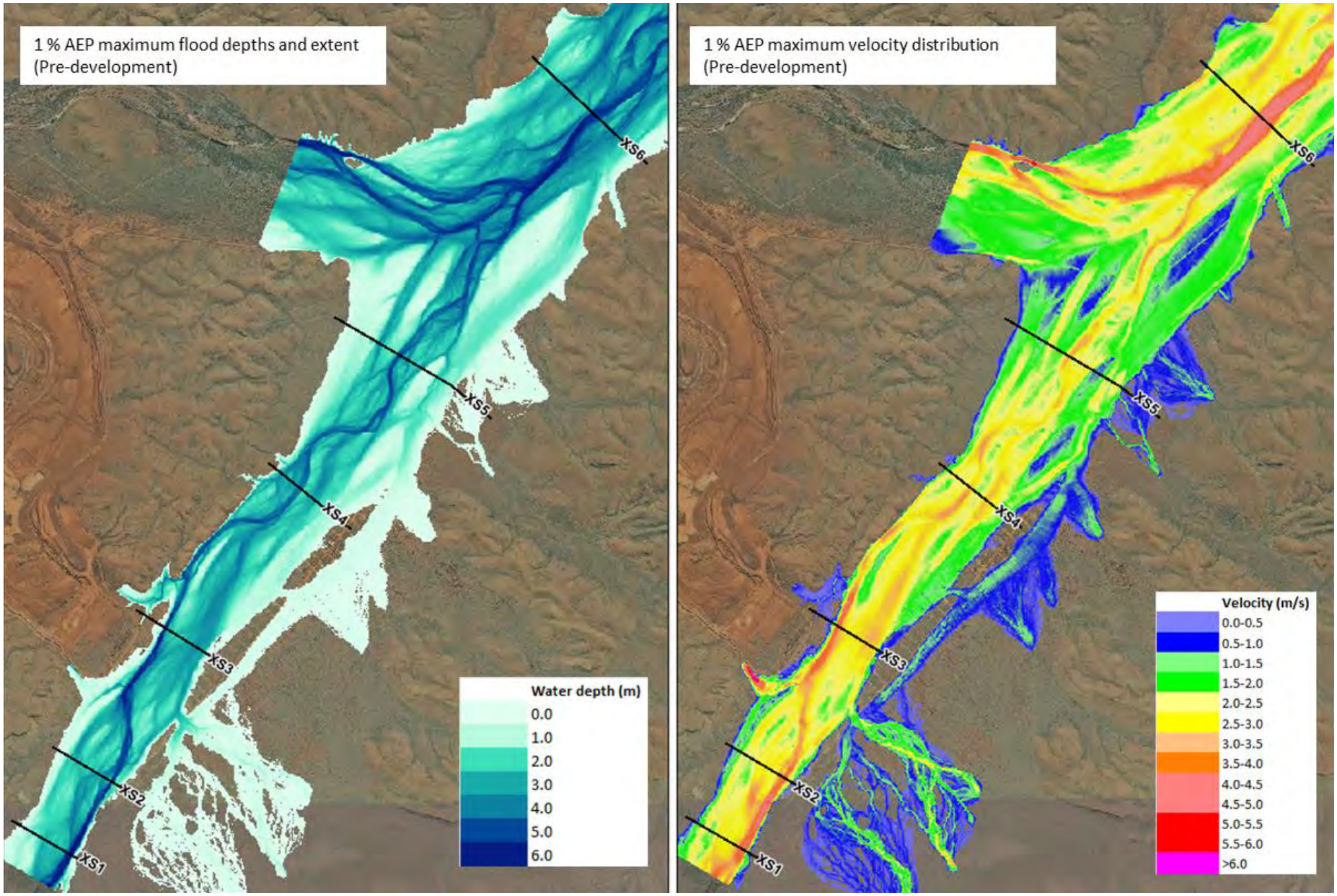


Figure 13: Maximum flood depths and velocity distribution for Weeli Wolli Creek during the 1 % AEP event under pre-development catchment conditions.

6. Sediment characteristics and regime

Detailed assessment has been carried out to identify the geomorphological conditions of Weeli Wolli Creek, adjacent to the Pocket and Billiard South deposits, to support government approval applications (MWH, 2014). Findings of the assessment indicate that the bed materials are predominately gravel, with the presence of large gravel bars in the low flow channel and the more active secondary or high flow channels where velocities are high during larger flow events. On the other hand, finer silty materials are found on the floodplain indicating lower velocities for sediment transport. Observations during the site visit indicate that the bed materials are more angular in the upstream part of the study area, suggesting fresh supply from a local source, while sediments are predominately more rounded further downstream. The increase in sphericity of the bed materials is indicative of greater fluvial reworking, which is supported by the outcomes of the hydraulic modelling where flows are shown to increasingly bifurcate further downstream.

Hydraulic loadings along the creek are episodic, occurring during larger events, and will vary longitudinally and laterally within the creek, reflecting variations in hydraulic conditions. Areas with high erosion potential are areas characterised by high velocity, while deposition will occur in areas when velocity drops. It was observed that the rate of surplus water discharge is too small to mobilise and transport bedload (MWH, 2014), indicating the release of surplus water has minimal effect on the existing geomorphological regime of the creek.

7. Vegetation

Vegetation type, distribution and density can be directly related to the water availability and hydrological regime of a creek system. Numerous vegetation and flora surveys have been carried out in the Yandicoogina region since 1994 and the latest, which incorporates the Billiards area along Weeli Wolli Creek, was conducted by Biota in July 2014. In addition, riparian vegetation monitoring is currently undertaken by Mattiske Consulting at 26 locations along Weeli Wolli Creek to assess the changes in flora and vegetation conditions within the creek as a result of dewatering and surplus discharge from the adjacent Hope Downs 1 and Yandicoogina mines.

Riparian vegetation in Weeli Wolli Creek is dominated by woodlands of *Eucalyptus victrix* (Coolibah) and *Acacia citrinovirdis* (Black Mulga). Patches of *E. camaldulensis* (River Red Gum) and *Melaleuca argentea* (Silver Cadjeput) are also found but they predominately occur in areas upstream of the Junction South East (JSE) operation and downstream of the Marillana Creek confluence. The tree species *E. camaldulensis, E. victrix* and *M. argentea* are common phreatophytic species[1] within riparian systems of the Pilbara bioregion and the presence of these species is often used to infer the existence of a groundwater dependent ecosystem (RTIO 2012). *M. argentea* is a groundwater dependent species, which primarily draws water from the saturated zone below the water table, hence its existence is indicative of permanently inundated pools and springs or where the water table is permanently close to surface. *E. camaldulensis* obtains its water from groundwater and river flooding, with mature trees more reliant on groundwater than young. Stands of River Red Gum are intimately associated with the surface flooding regime of the watercourses and related groundwater flow (CSIRO 2004). *E. victrix* has been shown to access groundwater in areas where the water table is shallow. However in non-riparian habitats or in areas that lack a permanently saturated regolith, the species will exploit shallow soil water to meet its transpiration needs following wet-season rains

[1] Plant species that draw water from the saturated zone or capillary fringe of the water table

(RTIO 2012). Vegetation types along Weeli Wolli Creek are shown at selected locations (XS1 to XS6) in Table 5. Classification of species is based on that established by Biota in their most recent survey in July 2014.

Artificial discharge of groundwater along ephemeral creeks and rivers may influence the growth and conditions of riparian vegetation by changing the hydrologic regime from intermittent to perennial. Monitoring carried out by Mattiske indicates that there have been some localised stress and loss of riparian eucalypts (E. *victrix* and E. *camaldulensis*) in sections subject to inundation, while in other areas the cover/abundance of saplings of M. *argentea* and riparian eucalypts have increased (RTIO 2012). However to date, the extent of change is considered relatively minor and insignificant when compared with regional trends in tree responses to seasonal conditions. Natural flooding in creeks can cause rapid and marked shifts in the understory species and sapling numbers within the creek channel and floodplain. The high flow velocities during these flood events can cause rapid losses in vegetation but the supply of water can also increase the cover/abundance of tree saplings within the creek system. Furthermore, the scouring effect of these events can create suitable habitat (e.g. pools) for tree growth in areas where such habitat did not exist previously (RTIO 2012). Monitoring results in Weeli Wolli Creek, upstream of the confluence with Marillana Creek, for the period 2007 to 2011 is illustrated in Figure 14; monthly rainfall for the same period is shown in Figure 15. There is a general increase in foliage cover when surplus discharge from Hope Downs 1 began in 2007. Changes in foliage cover subsequently stabilised and varied only in response to seasonal conditions between 2008 and 2010. However there was a notable drop in foliage cover from October 2010 to March 2011, potentially a reaction to the extremely low wet season rainfall for the 2009 water year where total rainfall was less than 150 mm from November 2009 to April 2010. This was followed by a general trend of increasing foliage cover from June 2011 as a result of the higher wet season rain for the 2010 water year. As shown in Figure 14, tree responses to artificial discharge varied spatially between the different monitoring sites and also temporally where some sites responded quicker than others. On the other hand, their reactions to notable changes in seasonal rainfall were more unanimous suggesting impacts caused by natural events are more significant than that caused by anthropogenic disturbances.

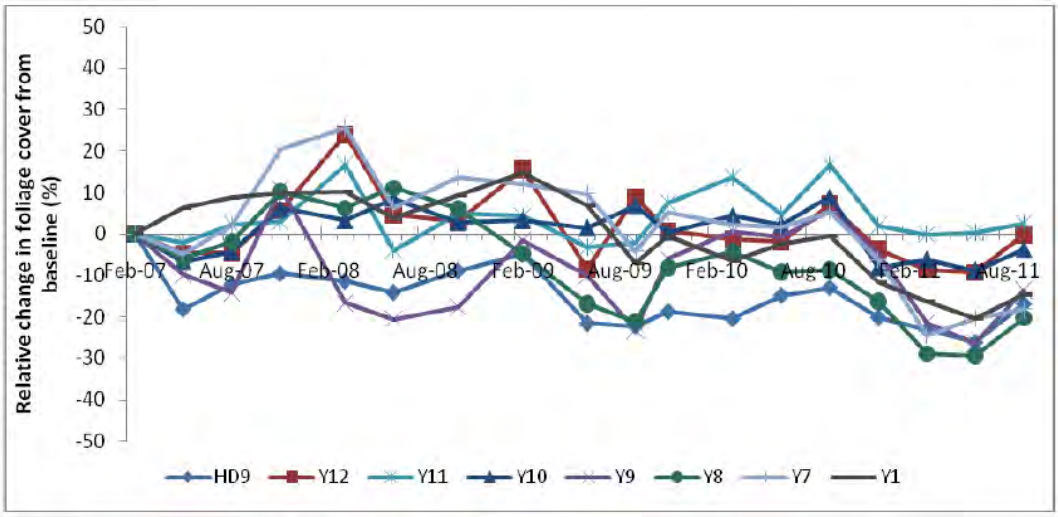


Figure 14: Changes in foliage cover through time at monitoring sites in Weeli Wolli Creek, upstream of Marillana Creek confluence (RTIO 2012).

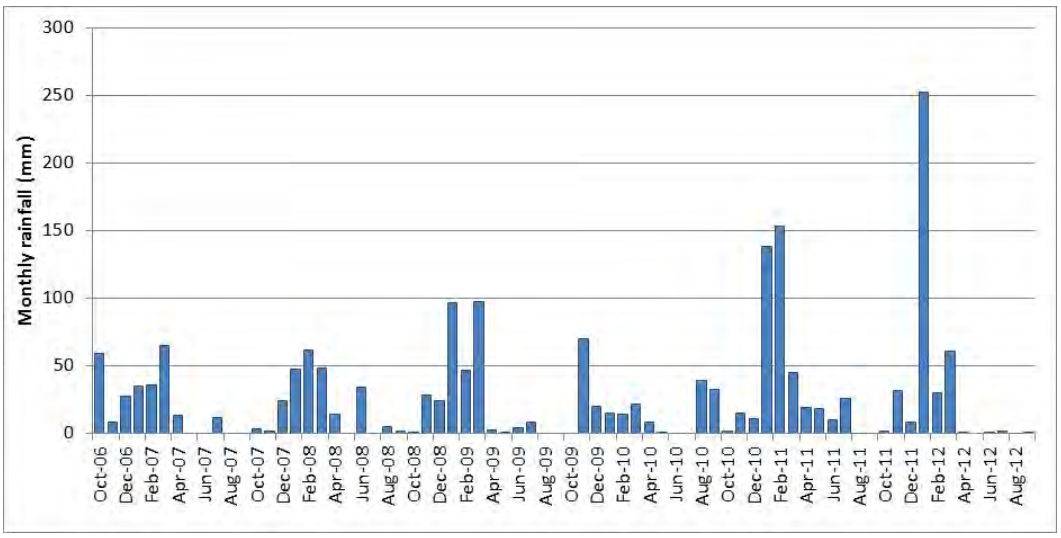
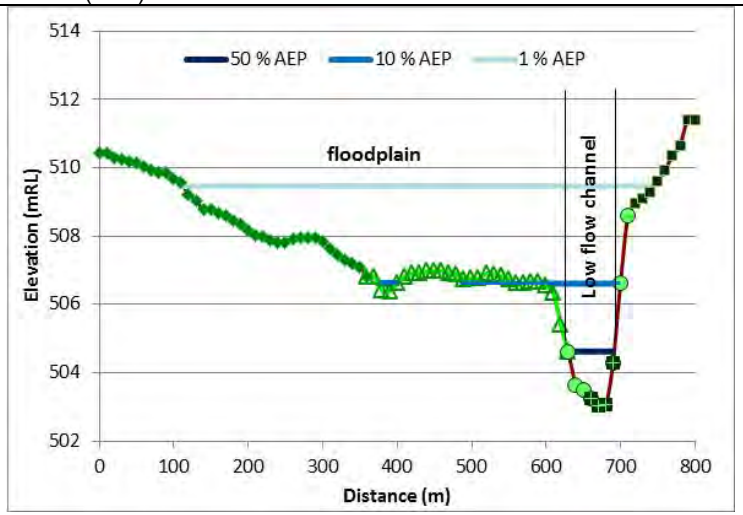


Figure 15: Monthly rainfall recorded at Tarina gauging station (2006 to 2011water year).

Table 5: Chosen cross section locations along Weeli Wolli Creek showing typical riparian vegetation and flood levels for the 50 %, 10 % and 1 % AEP events under pre-development catchment.

Cross section 1 (XS1)

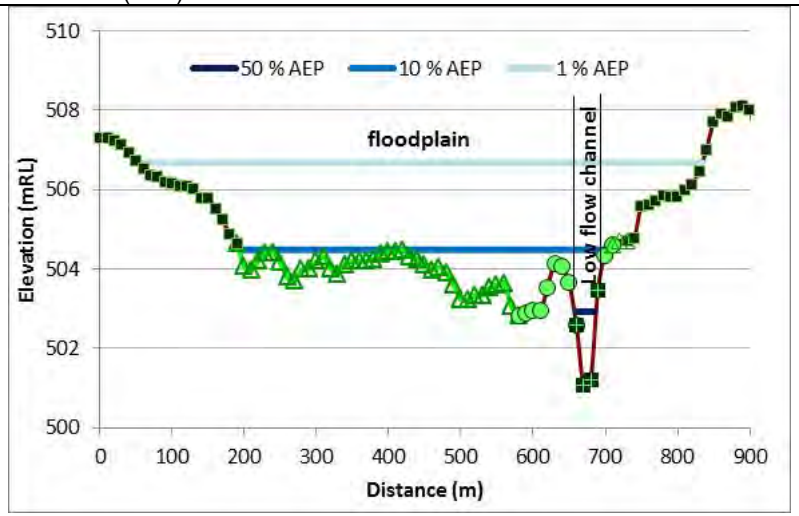


(F2)	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland
(C4)	*Eucalyptus victrix* open woodland over *A. citrinoviridis*
(C1)	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(P4)	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland

Weeli Wolli Creek at XS1 is characterised by a relatively stable low flow channel with well-defined banks. This section of the creek is likely to experience high flow velocities during floods. Potential scouring and increased sediment loading may be expected along this section. Flows during the 50 % AEP event are contained within the low flow channel and further modelling indicates that the 20 % AEP flows are also confined within the main channel. Activation of the floodplain will likely occur during the 10 % AEP or greater events.

Tree species found along and lining the banks of the low flow channel include both of the riparian eucalypts as well as *Melaleuca argentea.* The presence of *M. argentea* indicates permanent water, which is likely a result of continuous discharge from the Hope Downs 1 mine. Under natural conditions, phreatophytic species within and along the low flow channel would receive water fairly frequently from the creek during low flow situations, while vegetation (type C4) along the left floodplain would only be flooded during a 10 % AEP or greater event. Flooding of vegetation (F2 and P4) within the floodplain would only occur during significant events in excess of 5 % AEP, signifying these species prefer unsaturated soil conditions with periods of drought broken by recharge from direct infiltration of rainfall and/or surface flows.

Cross section 2 (XS2)

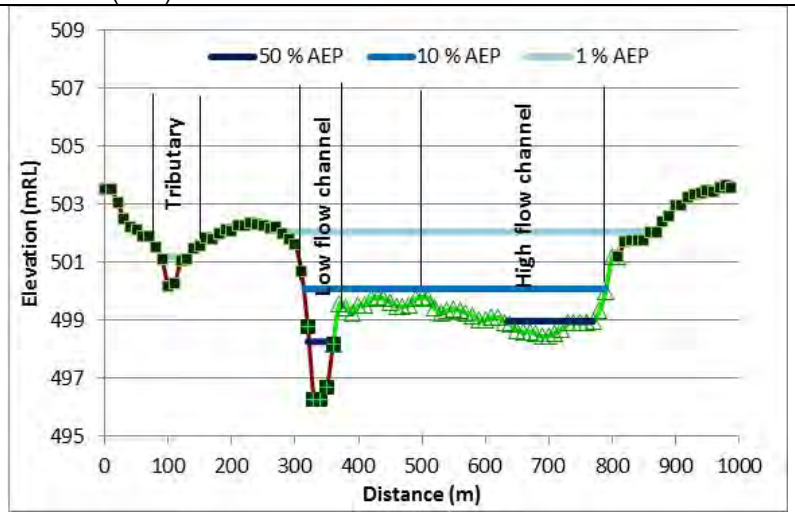


(C4)	*Eucalyptus victrix* open woodland over *A. citrinoviridis*
(C1)	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(P4)	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland

XS2 marked the location of a semi-permanent pool in Weeli Wolli Creek. The low flow channel is narrower and more incised at this location. Based on the channel geometry and results from the hydraulic modelling, it is evident that flow velocities would be very high during floods and the scouring effects of the rapidly flowing water would likely have created the current morphology allowing the pool to form. Flows for more frequent events of 50 % AEP or less would contain within the low flow channel, while activation of the floodplain would occur during the 5 % AEP or larger events.

There is an abundance of type C1 vegetation adjacent to the low flow channel due to the presence of the pool, which is sustained by surplus discharge. These tree species would be flooded by the creek in a 20 % AEP event. Under natural conditions, stands of *E. victrix* that dominate the left floodplain would be inundated during the 10 % AEP flood. On the other hand, the type P4 vegetation that occurs along the boundary of the floodplain would only receive water from the creek during large events in excess of 5 % AEP.

Cross section 3 (XS3)

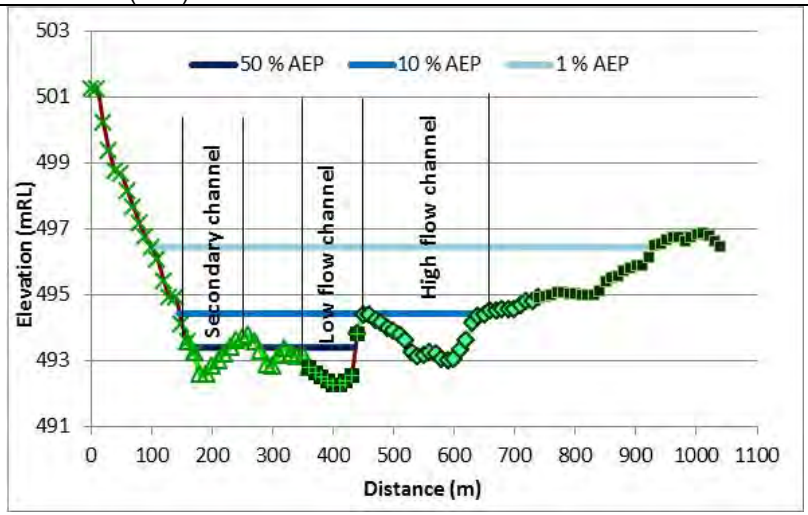


(P4) ■	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland
(C3) ▪	*E. victrix* scattered trees over *A. citrinoviridis*
(C4) △	*E. victrix* open woodland over *A. citrinoviridis*

XS3 is located immediately downstream of the JSE mine. Once again it represents a section of the creek that is characterised by an incised low flow channel, which will experience high flow velocity during a flood. Hydraulic modelling indicates that the high flow channel on the right would only receive surface water runoff from local catchments during the 50 % AEP event but activation by Weeli Wolli Creek would occur in a 20 % AEP or greater event. The tributary on the left is not explicitly modelled in TUFLOW hence water received in the channel is generated by backwater from Weeli Wolli Creek during a flood.

Vegetation mapping indicates the lack of *Eucalyptus camaldulensis* and *Melaleuca argentea* but the abundance of *E. victrix* in this area, suggesting a possible change in water source or availability along this section of the creek. Woodland of *E. victrix* on the right floodplain and within the high flow channel will receive water from Weeli Wolli Creek during a 20 % AEP or greater event. Flooding and inundation of vegetation (type P4) on the island between the tributary and the low flow channel would not occur until the 0.5 % AEP flood. Hence it is unlikely that this type of vegetation would rely on creek flows for water supply on an annual basis.

Cross section 4 (XS4)

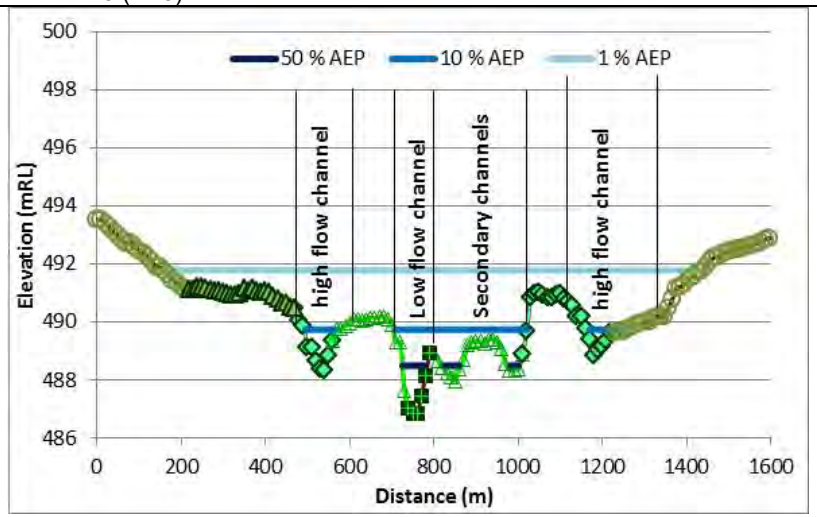


(H1) ×	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera*
(C4) △	*E. victrix* open woodland over *A. citrinoviridis*
(C3) ▪	*E. victrix* scattered trees over *A. citrinoviridis*
(P3) ◆	*A. pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera*
(P4) ■	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland

Weeli Wolli Creek transitions from a more uniform to a braided system downstream of XS4. The low flow channel is less incised at this location and the 50 % AEP event would likely activate the minor secondary channels on the left. The high flow channel on the right would be engaged during the 20 % AEP event and the wider floodplain would be inundated during the 5 % AEP storm.

Among the common phreatophytes found within Weeli Wolli Creek, only *Eucalyptus victrix* exists along this section of the creek. The extent of the 50 % AEP flood marks the occurrence of this species, indicating these trees would likely receive water from creek flows at a regular basis. Acacia species dominate the right-hand floodplain of the creek, with the type P3 found within the high flow channel; this vegetation type would be flooded during a 20 % AEP or greater storm. Type P4 vegetation occurs along the wider floodplain and would only receive water from the creek during larger events in excess of the 2 % AEP. Type H1 vegetation fringes the left-hand floodplain and extends towards the slope of the ridge. However, only the lower portion of this vegetation group will receive water from creek flows.

Cross section 5 (XS5)

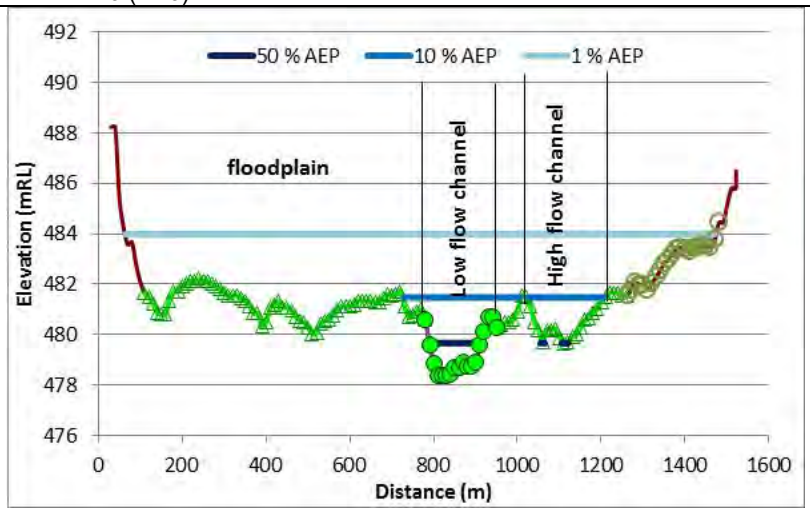


(P5) ○	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland
(P6) ▲	*A. aptaneura* low open forest over *Eremophila forrestii* open shrubland
(P3) ◆	*A. pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera*
(C4) △	*E. victrix* open woodland over *A. citrinoviridis*
(C3) ■	*E. victrix* scattered trees over *A. citrinoviridis*

XS5 is located upstream of the Weeli Wolli and Marillana Creek intersection. The floodplain widens at this location with notable bifurcations activated by varying level of flows. Modelling results indicate that creek flows for more frequent events of 50 % AEP or smaller would confine within the low flow channel, while engagement of the high flow channels would occur during the 10 % AEP storm. Flood flows for events greater than the 2 % AEP would activate the wider floodplain at this location.

Once again, the frequency of flows dictates the types and occurrences of vegetation within the creek. Larger trees of *Eucalyptus victrix* are found in sections more frequently inundated; while Acacia species occur in abundance on the floodplain receiving water only occasionally from creek flows. Scattered trees of *E. leucophloia* and *E. gamophylla* in type P5 vegetation are found along the edges of the floodplain. This species will not receive water from the creek until the 2 % AEP flood.

Cross section 6 (XS6)



(C4) △	*Eucalyptus victrix* open woodland over *Acacia. citrinoviridis*
(C1) ●	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(P5) ○	*E. leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *A. bivenosa, A. ancistrocarpa* open shrubland

XS6 illustrates the section of Weeli Wolli Creek immediately downstream of the confluence. This section is characterised by a braided, meandering creek system within a wide floodplain that stretches hundreds of metres across. Smaller flows of 50 % AEP or less would likely contain within the low flow channel but the 20 % AEP flood would activate the high flow channel on the right. Engagement of the floodplain to the left would occur in a 5 % AEP or greater event.

Riparian vegetation density increases substantially at and downstream of the confluence. Type C1 vegetation, which includes *Eucalyptus camaldulensis* and *Melaleuca argentea*, reappears at this location within the low flow channel and would likely sustain by creek flows at a regular basis. Woodland of *E. victrix* and *Acacia citrinoviridis* dominates the floodplain and these trees would be inundated during rarer events in excess of 5 % AEP.

8. Surface water infrastructure

Surface water infrastructures are required for the management of flood risks at Pocket and Billiard South. These include flood protection levees, local diversions and appropriate protection at road crossing along Weeli Wolli Creek. Locations and designs of these infrastructures are detailed as follow.

8.1 Weeli Wolli Creek flood protection

The Pocket and Billiard South deposits are positioned adjacent to and within Weeli Wolli Creek. Development of the deposits will encroach on the floodplain of the creek, and mining will be constrained by the natural flood extent unless mitigation measures are in place. It is proposed that flood levees be constructed along the deposits to prevent flooding from Weeli Wolli Creek. Two levee alignments are investigated: first the main levee, which offers protection for the Billiard South mine on the eastern side of the creek, its position maximises ore recovery but encroaches into the environmental restriction area within Weeli Wolli Creek, and second the pillar levee, which is located around the JSE mine in the east to allow expansion towards Weeli Wolli Creek. The proposed structures will be designed to accommodate the 0.5 % AEP flood level with a 0.5 m freeboard.

8.2 Weeli Wolli Creek crossing

A heavy vehicle road for Pocket and Billiard South is required to cross Weeli Wolli Creek in order to gain access to the services area as well as the processing plant within the existing Yandicoogina mine. The design of the road crossing is being carried out by MWH and Calibre, and it is proposed that the road be constructed as a floodway with culverts or bridge openings to accommodate low flows to a maximum of 125 m^3/s, while activation of the floodway will occur for all greater events (MWH, 2015). The proposed location and design of the floodway on the west bank require some minor excavations of the creek, upstream and downstream of the infrastructure, to prevent obstruction to flood flows. The current areas of excavation encroach into the Weeli Wolli Creek riparian zone but further work on the crossing will be carried out during the feasibility stage of the study to better determine the requirement for excavation and the area to be excavated.

Two crossing options have been investigated and they are summarised as follow:

- **Pipe culverts crossing** – this design positions eight 3.6 m diameter pipe culverts within the low flow channel and a floodway in the west to allow larger flows in excess of the capacity of the culverts to spill over the road. The crossing ties in with the Billiard South levee in the east and the pillar levee in the west..
- **Box culvert bridge crossing** – this design positions a 22 m wide, 3.6m tall box culvert bridge within the low flow channel. A floodway is located in the west to allow larger flows in excess of the bridge opening to spill over the road. The crossing ties in with the Billiard South levee in the east and the pillar levee in the west.

8.3 Local diversions

Deposits and associated mine infrastructure at Pocket and Billiard South are exposed to surface water runoff sourced from local catchments east of Weeli Wolli Creek. The ‘diversion’ surface water management is recommended to direct these runoffs away from

active areas of mining. Two diversion drains are proposed and each is designed to provide protection up to the 2 % AEP storm:

- **Southern diversion** is designed to capture runoff generated from local catchments above Pocket. Surface water flows from the drain will be diverted around Pocket and released into Weeli Wolli Creek, upstream of the operation.
- **Main diversion**, which runs parallel to the entire length of the Billiard South deposit, is designed to convey runoff sourced from the eastern catchments. Surface water flows captured by the drain will be discharged north back to Weeli Wolli Creek, downstream of the operation.

Unlike the flood levees and creek crossings, the diversions are not explicitly modelled in TUFLOW. However, surface water flows likely to be captured and discharged from the drains to Weeli Wolli Creek for each AEP event up to the 2 % AEP are modelled to represent the activation of the diversions by local runoff during a storm event.

9. Model results

Two operational TUFLOW models were developed to simulate the flow characteristics of Weeli Wolli Creek under the pipe culverts and box culvert bridge crossing options with the proposed Billiard South and pillar levee alignments. The position of the local diversions remained unchanged for both crossing options; hence the position of the outlets and the volume of local surface water runoff entering Weeli Wolli Creek remained the same for both models.

Operational flow conditions for the 50 to 0.5 % AEP design events were simulated and model results for the 50 %, 10 % and 1 % AEP storms are presented in this report to illustrate the low, medium and high flow situations in Weeli Wolli Creek during mining.

9.1 Peak flow rates and total flow volumes

Runoff hydrographs for each of the modelled AEP events were outputted at XS6, downstream of the operation, to determine the changes in flow rates and volumes through Weeli Wolli Creek under pre-development and operational catchment conditions. A comparison of the runoff hydrographs for the 50 %, 10 % and 1 % AEP storms are illustrated in Figure 16, Figure 17 and Figure 18, respectively.

Model results indicate minor increases in peak flow rates downstream of the operation during mining. Flood peaks are increased by no more than 16 % for all the modelled AEP events and the percentage difference in peaks decreases progressively with AEP, where less than 1 % change in flood peak is observed for the 0.5 % AEP storm. The increase in peak discharges, immediately downstream of the operation, could be resulted from the point source release of surface water from local diversion (North drain) to Weeli Wolli Creek. Surface water runoffs captured and transported by North drain will contribute quicker to Weeli Wolli Creek at XS6 than what can be expected under existing conditions, thus temporarily raising the flood peak at this location. However, as the magnitude of the storm/flood event increases, the influence of runoff contributing from the diversion decreases in comparison to surface water flows contributing from Weeli Wolli Creek, hence the impact to the overall flood regime, downstream of the operation, diminishes with AEP.

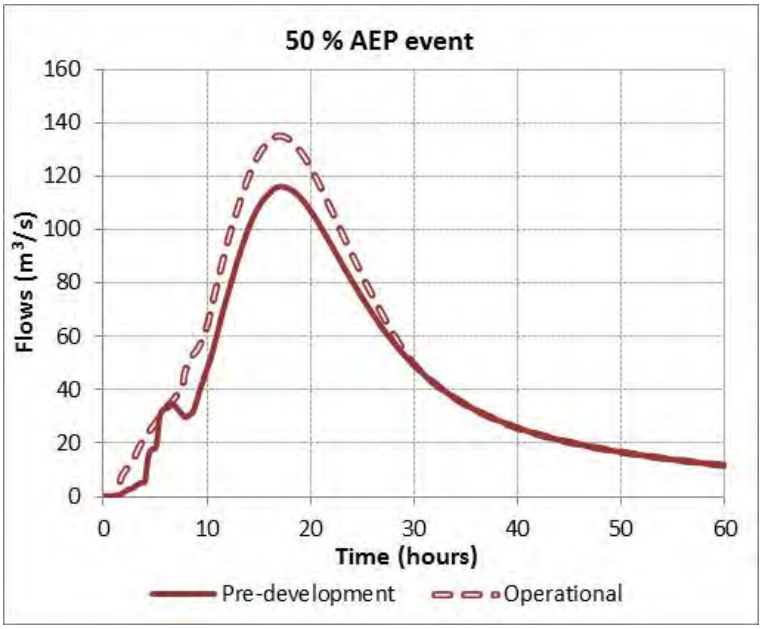


Figure 16: A comparison of the runoff hydrographs for the 50 % AEP event under pre-development and operational catchment conditions.

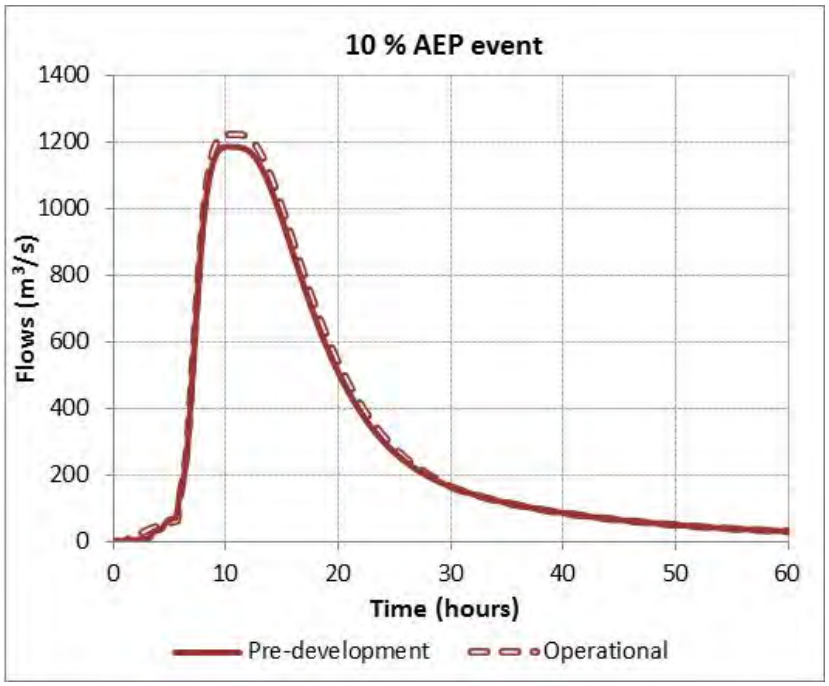


Figure 17: A comparison of the runoff hydrographs for the 10 % AEP event under pre-development and operational catchment conditions.

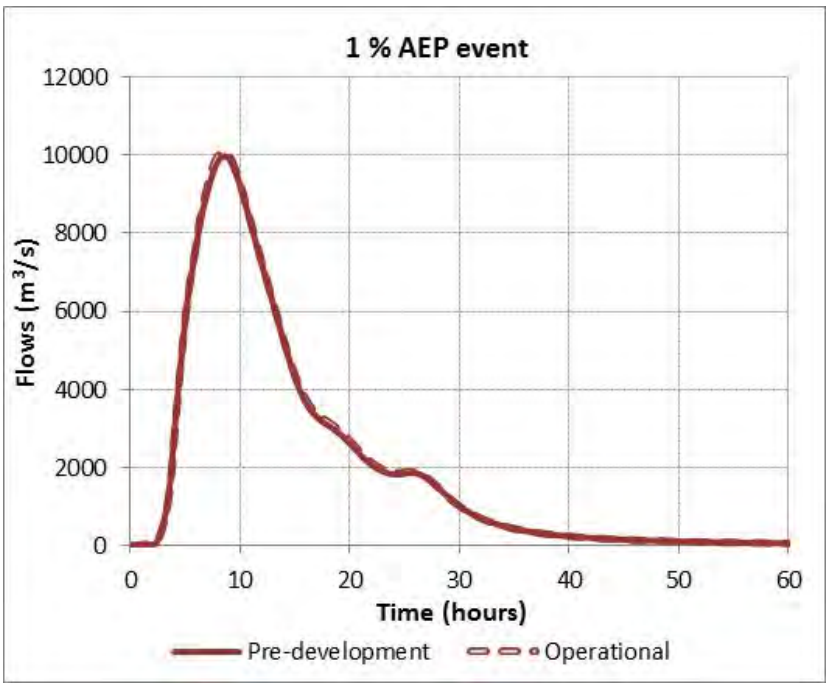


Figure 18: A comparison of the runoff hydrographs for the 1 % AEP event under pre-development and operational catchment conditions.

9.2 Flood levels and extents

Changes to the flood level and extent are to be expected due to flow constrictions and re-directions proposed by the levees and/or crossings along Weeli Wolli Creek. This modification to the flood regime may affect riparian vegetation, whose existence is likely linked to surface flooding characteristics and the frequency of over bank flow conditions during flood events. Increase or decrease in flood level will result in more or less water being available for flood dependent regeneration of riparian ecosystems and may over time alter the creek ecology and potentially the biodiversity of riparian environments. The degree and extent of change to the flood regime, and the associated impact on the riparian vegetation were assessed by comparing the flood elevations and extents for the 50 %, 10 % and 1 % AEP storms under pre-development and operational catchment conditions. Model results are presented in the form of flood difference maps and are plotted in XS1 to XS6 to illustrate the change in flood levels and the subsequent influence on riparian vegetation at selected locations along Weeli Wolli Creek.

TUFLOW simulations were carried out to determine the potential flood regime change along Weeli Wolli Creek under the pipe culverts and the box culvert bridge crossings with the Billiard South and pillar levees in place. A comparison of the model results (Appendix A) indicates minimal changes in flow regime for the two crossing designs, where less than ± 1 % change in flood level is observed at the selected cross sections (XS1 to XS6) along Weeli Wolli Creek. This suggests the two crossings behave or function similarly during a flood and therefore have similar influence on the flow regime of Weeli Wolli Creek during mining. For this reason, only results for the pipe culverts crossing are presented below.

Model results (maximum flood depths and flood depth differences) for the 50 %, 10 % and 1 % AEP storms are illustrated in Figure 21, Figure 22 and Figure 23, respectively. The flood difference maps identify changes in water elevations between the existing and developed catchment conditions. The differences are presented in three shades of

colour: the yellow shade indicates less than ± 0.25 m change in flood level; the orange shade indicates an increase in flood level (> 0.25 m increase); and the green shade shows a decrease (> 0.25 m decrease).

As shown in Figure 21, surface water flows along Weeli Wolli Creek during the 50 % AEP event do not interact with the levee hence disturbance to the regime for low flows is likely to be small during operation. However, a minor increase in water level is observed in vicinity of the crossing due to flow constrictions through the culverts causing flood level to rise temporarily near the infrastructure. A more significant change in flow regime is triggered not by disruption to surface water flows along Weeli Wolli Creek but by modification to local runoff from the eastern catchments causing water level to decrease or increase along the creek. A reduction in flood level is observed along the creek section between XS3 and XS4 due to re-direction of the local runoff upstream and downstream of the operation, terminating surface water flows that would naturally activate the high flow channel during the 50 % AEP event. Conversely, all surface water runoffs contributing to Billiard South are captured by the main diversion and released into Weeli Wolli Creek at XS6. This resulted in an increase in flood peak (as described in Section 9.1), which translated to an increase in flood level as shown in Figure 21. However, these impacts are likely to decrease with AEP when the influence of flows contributing from Weeli Wolli Creek exceeds those from the eastern catchments.

The 10 % AEP event (Figure 22), which has a flood peak of approximately 490 m^3/s at Billiard South, generates flows that exceed the capacity of the culverts and therefore activate the floodway of the road crossing. As expected, the greatest change in flow regime occurs in vicinity of the crossing where significant impoundment of flows is observed immediately upstream of the road. Water elevation is raised by approximately 1 m above the pre-development level and the effects of backwater propagated 300 m upstream due to flow constriction caused by the levee as well as the crossing where conveyance is restricted to the small opening through the culverts and the floodway in the west (Figure 19). Conversely, water level is reduced by more than 0.25 m along a short section of the creek between XS3 and XS4, possibly due to termination of runoff from the east but also a result of flow obstruction caused by the crossing further upstream. Again, water level is shown to increase immediately downstream of the main diversion where majority of the captured runoffs are released.

As the magnitude of the flood event increases, the impact proposed by the infrastructures also increases due to greater obstruction and constriction of flows through the creek. Significant flood level change is observed along the creek between XS2 and XS4 (approximately 4 km in length) during the 1 % AEP flood (Figure 23). The road crossing is completely submerged during this event and water level in vicinity of the crossing is increased by 3 m above the pre-development level, with the effects of backwater propagated approximately 2 km upstream (Figure *20*). Constriction of the floodplain caused by the levee also raises the water level, and at the same time pushes the flood extent further to the west. However, it is important to note that the extent of impact is restricted to the creek section between XS2 and XS4 and does not propagate beyond, where the change in depth is less than 0.25 m and therefore negligible. Model results suggest a decrease in water level at the outlet of main diversion drain. This is because the diversion is designed to accommodate up to the 2 % AEP storm hence any flows in excess of the design event will likely spill into the pit and not be diverted to Weeli Wolli Creek, thus causes a localised decrease in water level during the 1 % AEP storm.

Based on the modelling results, it can be seen that flood regime change caused by infrastructures, whether during events of high, medium or low magnitudes, is confined to the creek section adjacent to the proposed mine. Beyond the area of influence, modifications to flood levels and extents along the creek are likely to be small. The effects on riparian vegetation as a result of flood level change are illustrated in Table 6.

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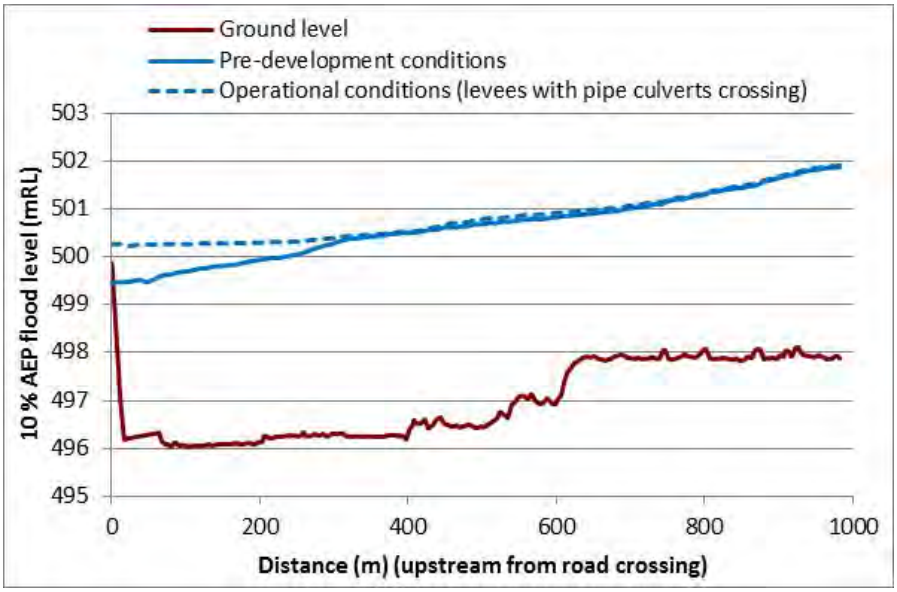


Figure 19: A comparison of the flood level for the 10 % AEP event, immediately upstream of the creek crossing, under pre-development and operational catchment conditions.

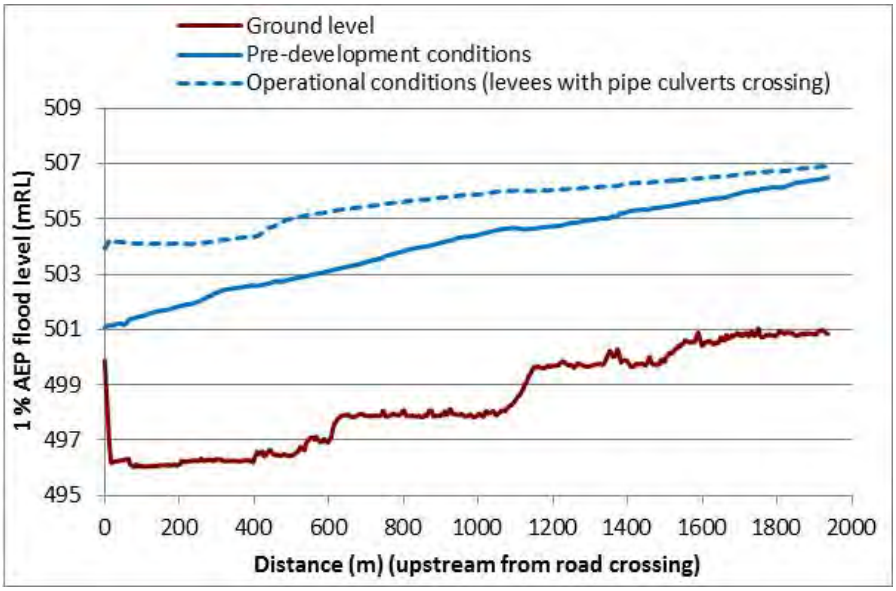


Figure 20: A comparison of the flood level for the 1 % AEP event, immediately upstream of the creek crossing, under pre-development and operational catchment conditions.

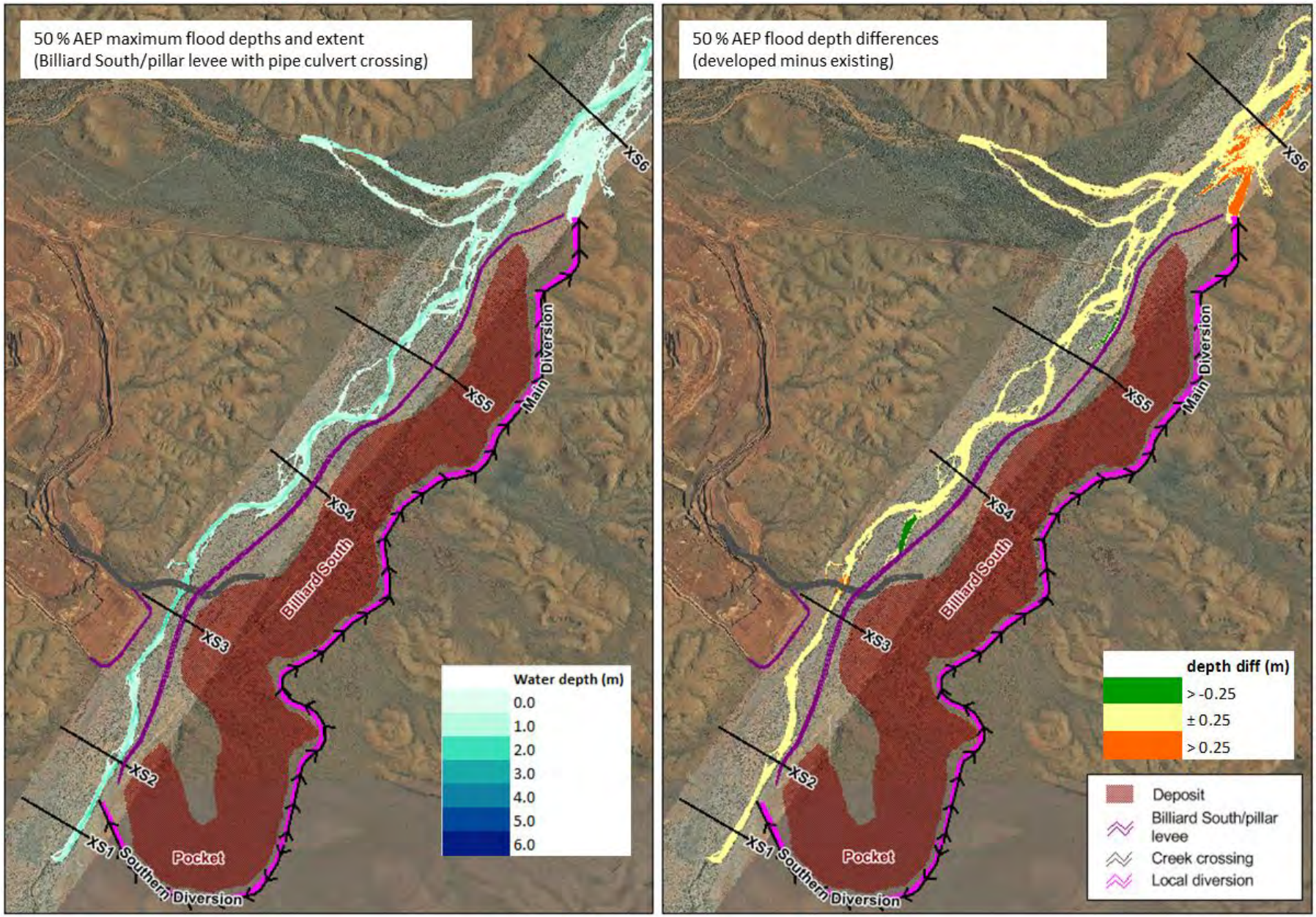


Figure 21: Maximum flood depths and flood depth differences for the 50 % AEP event.

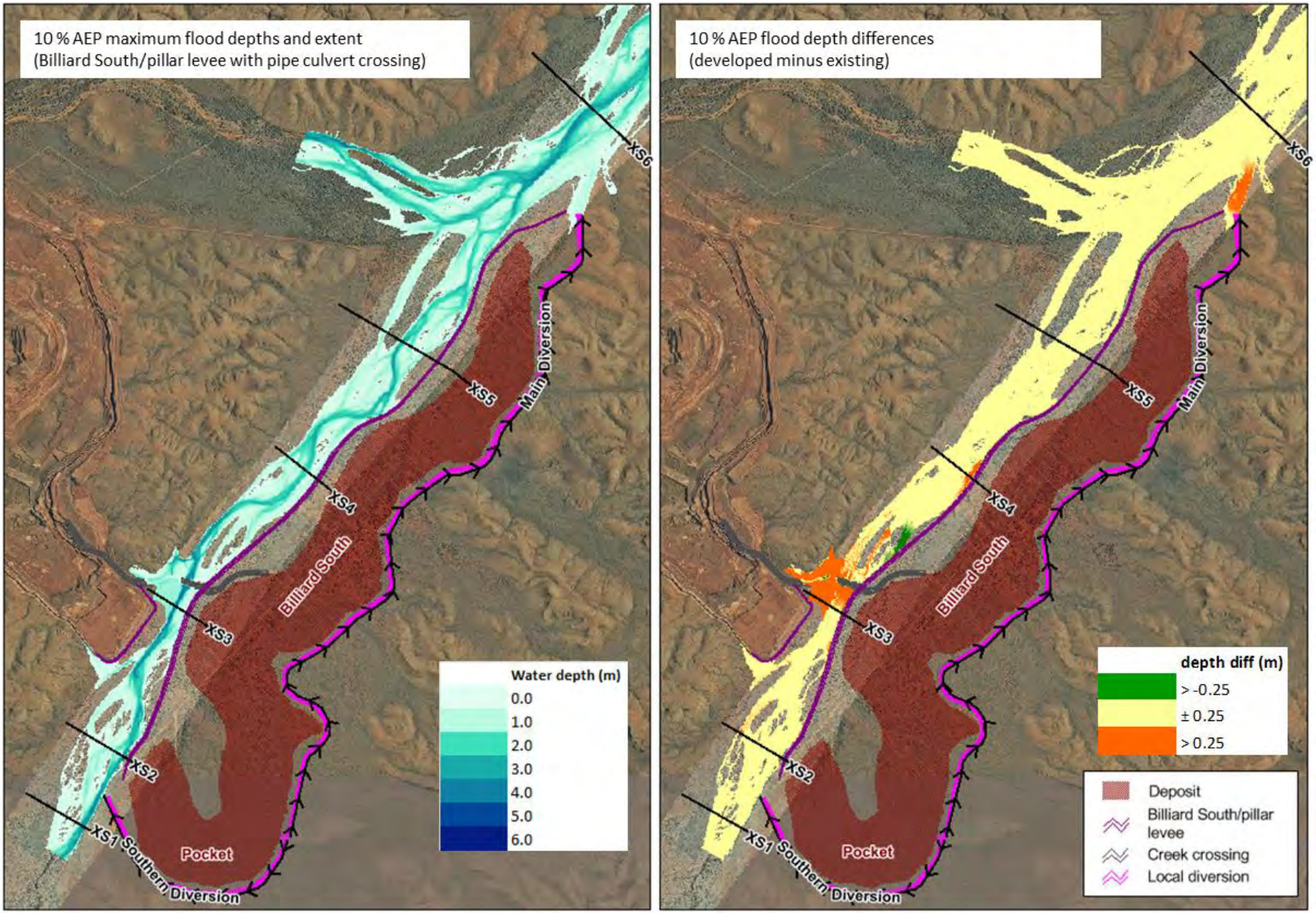


Figure 22: Maximum flood depths and flood depth differences for the 10 % AEP event.

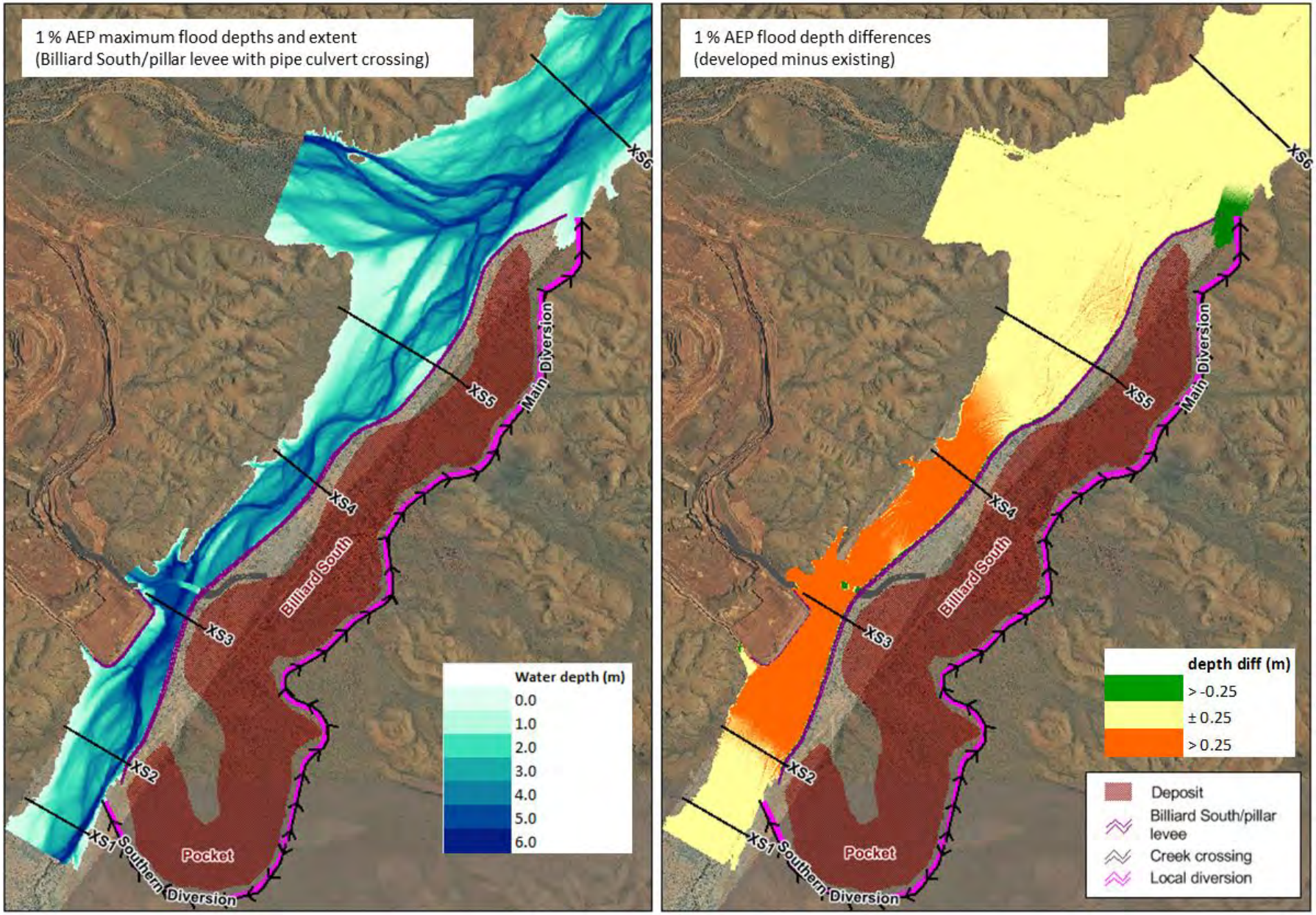
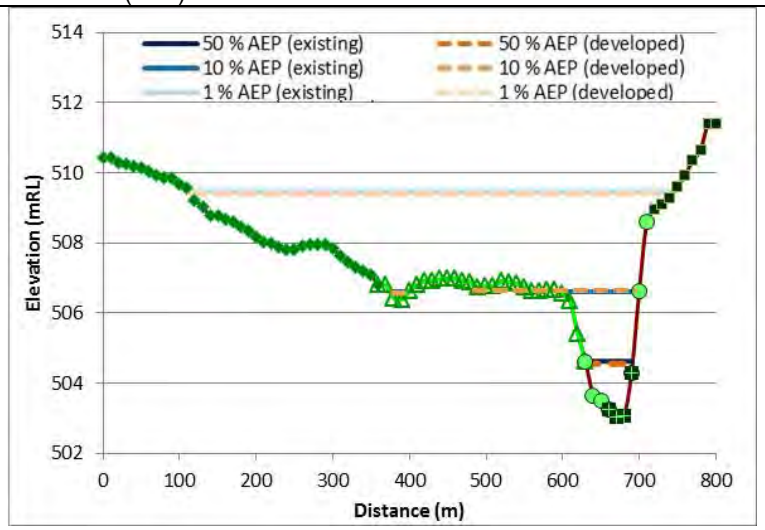


Figure 23: Maximum flood depths and flood depth differences for the 1 % AEP event.

Table 6: Chosen cross section locations along Weeli Wolli Creek showing typical riparian vegetation and flood level differences for the 50 %, 10 % and 1 % AEP events between the existing and developed catchment conditions.

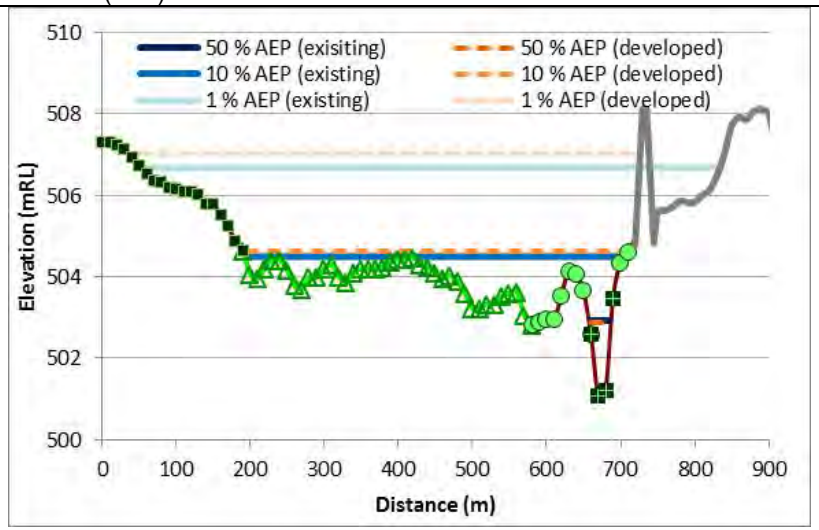
Cross section 1 (XS1)



(F2)	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland
(C4)	*Eucalyptus victrix* open woodland over *A. citrinoviridis*
(C1)	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(P4)	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland

A comparison of the flood elevations for the 50 %, 10 % and 1 % AEP events under existing and developed catchment conditions indicates flood regime change at XS1 is negligible. Flood level is altered by no more than 10 cm, for both the pipe culverts and box culvert bridge crossings, at this location post-development. This suggests the flooding characteristics and flood water supply for riparian vegetation along this section of the creek will likely remain unchanged during operation.

Cross section 2 (XS2)



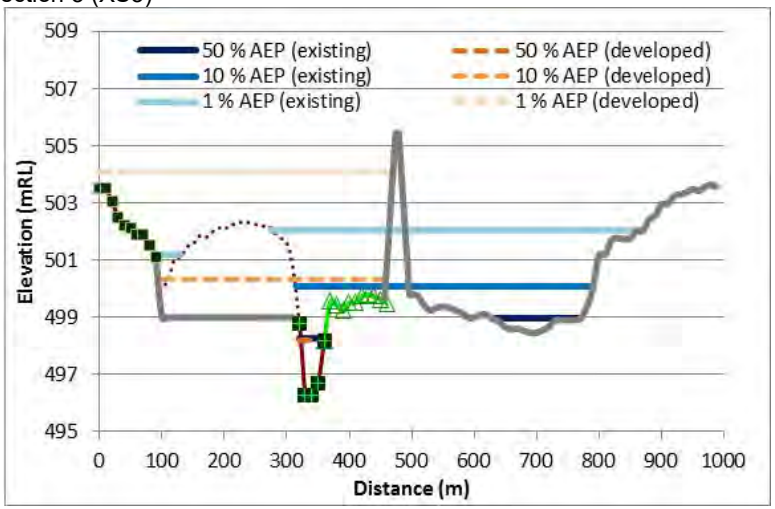
(C4)	*Eucalyptus victrix* open woodland over *A. citrinoviridis*
(C1)	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(P4)	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland
	Potential disturbed areas

XS2 identifies the upstream end of the Billiard South levee, which alignment, as shown in grey in the cross section, is positioned on the right-hand bank of the creek.

Hydraulic modelling indicates the 50 % AEP flow along the low flow channel of the creek will remain more or less unchanged under this option thus creek water supply for the type C3 vegetation, which occurs along the low flow channel, will likely be unaffected during mining. A minor increase in water level is observed for the 10 % AEP event but changes, based on the model results, are less than 4 % for both crossing options and therefore unlikely to cause significant impacts on riparian vegetation, in particular the type C4 species, at this location. It is expected that the woodland of *E. victrix* on the left floodplain be flooded during the 10 % AEP event under natural conditions; this flooding regime will likely remain unchanged post-development.

A greater change in flood regime is observed for the 1 % AEP event, where the developed water level is raised 0.3 to 0.4 m higher than the pre-development level. This may result in more of the type P4 vegetation being inundated during this event.

Cross section 3 (XS3)



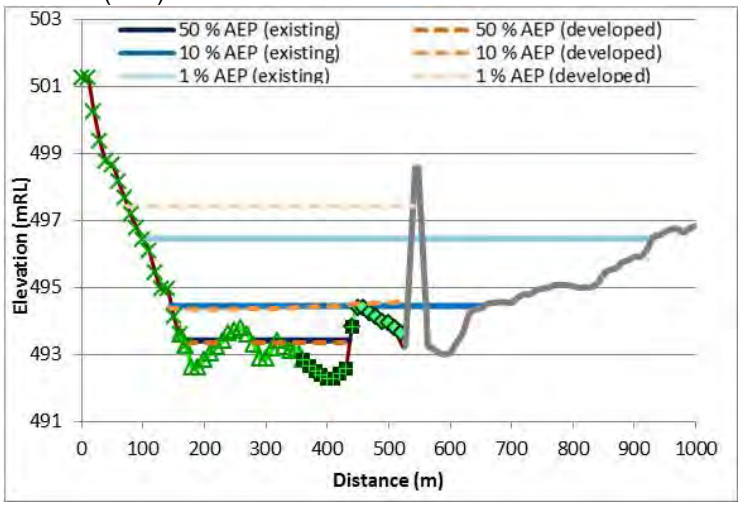
(P4)	*A. pruinocarpa low open woodland over Triodia wiseana* open hummock grassland
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(C4)	*E. victrix* open woodland over *A. citrinoviridis*
	Potential disturbed areas

XS3 marked the location where the creek will be most significantly affected during mining. Potential disturbed areas, as identified in grey in the cross section, include the levee and the pit beyond in the east and the excavated area immediately upstream of the crossing in the west. The floodplain is also most constricted at this location, whereby the area of conveyance is reduced by half under this levee option.

Low flow conditions along the creek will likely be unaffected during mining under this option hence water supply by creek flows for riparian vegetation that occurs within or aligns the bank of the low flow channel will remain unchanged post-development.

Model results suggest small increase in flood level (less than 0.25 m) for the 10 % AEP event while flood elevation is raised by more than 2 m during the 1 % AEP storm for both the pipe culverts and box culvert bridge crossing options. This is a result of severe flow constriction and obstruction caused by the levee and road crossing immediately downstream. Consequently, all the type P4 vegetation that fringes the left-hand floodplain will be inundated during the 1 % AEP event instead of the 0.5 % AEP flood during operation.

Cross section 4 (XS4)



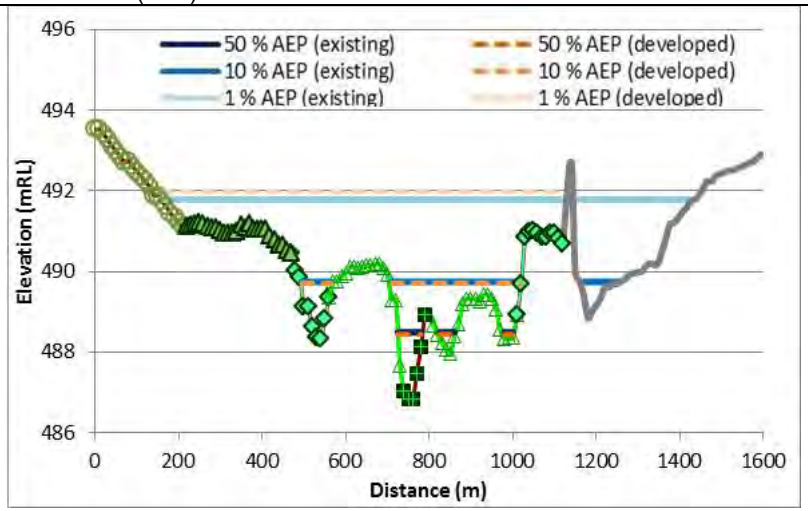
(H1)	*Eucalyptus leucophloia* scattered low trees over *Hakea chordophylla*, *Acacia inaequilatera*
(C4)	*E. victrix* open woodland over *A. citrinoviridis*
(C3)	*E. victrix* scattered trees over *A. citrinoviridis*
(P3)	*A. pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera*
	Potential disturbed areas

Similarly the greyed out area in XS4 illustrates the position of the proposed levee and pit on the eastern floodplain of the creek.

As shown in the plot above, the levee does not interfere with the 50 % AEP flood extent hence regime change for these smaller events is likely to be minimal during operation. Similarly, model results indicate impacts to flows for the 10 % AEP event is small. This suggests vegetation species (mainly type C3 and C4) that would normally receive water from creek flows during these events pre-development will likely be unaffected under developed conditions.

Flood level is shown to increase by approximately 1 m at this location during the 1 % AEP storm, which exceeds the pre-development flood level for the 0.5 % AEP event. As shown above, the 1 % AEP flood extent is extended further to the west, causing vegetation that will only receive water during rarer events of 0.5 % AEP or greater pre-development be flooded during the 1 % AEP storm under developed conditions.

Cross section 5 (XS5)

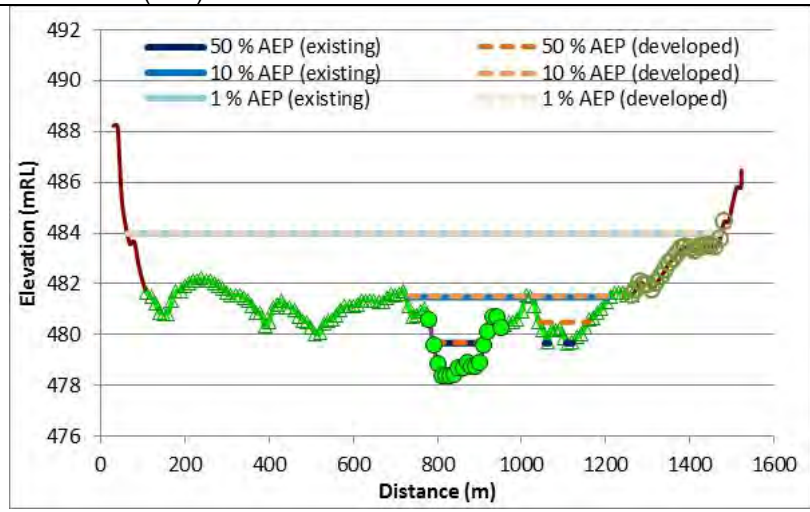


(P5) ○	*Eucalyptus leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland
(P6) △	*A. aptaneura* low open forest over *Eremophila forrestii* open shrubland
(P3) ◇	*A. pruinocarpa low open woodland over A. citrinoviridis, A. inaequilatera*
(C4) △	*E. victrix* open woodland over *A. citrinoviridis*
(C3) ▦	*E. victrix* scattered trees over *A. citrinoviridis*
∿	Potential disturbed areas

Similar to XS4, the levee at this location does not interact with the 50 % AEP flood along Weeli Wolli Creek hence changes to flow characteristics for these smaller events are likely to be small during mining. Flood level change for the 10 % AEP event is also negligible, where water level is altered by no more than several centimetres for both the pipe culverts and box culvert bridge crossing options. This suggests the flooding characteristics and creek water supply for riparian vegetation at this location will likely remain unchanged post-development during events of low and medium magnitudes.

Model results indicate a minor increase in flood level, approximately 0.2 m, for the 1 % AEP event under developed conditions. This may result in a greater portion of the type P5 vegetation being inundated during this event, but impacts, as shown in the plot above, are likely to be minor.

Cross section 6 (XS6)



(C4) △	*Eucalyptus victrix* open woodland over *Acacia. citrinoviridis*
(C1) ●	*E. camaldulensis, E. victrix* woodland over *Melaleuca argentea*
(P5) ○	*E. leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *A. bivenosa, A. ancistrocarpa* open shrubland

XS6 illustrates the section of Weeli Wolli Creek immediately downstream of the operation. Hydraulic modelling indicates flood regime change caused by the proposed surface water infrastructures along Weeli Wolli Creek is unlikely to propagate downstream beyond the vicinity of the operation. However surface water runoff contributing to the high flow channel in the east may increase during smaller events of 50 % AEP or less due to increased contribution of runoff from the main diversion, temporarily raising the water level at this location. This means a larger extent of the C4 vegetation on the floodplain will be inundated during low flows if the diversion is activated by local catchment runoff from the east. However, changes to the flood regime is expected to decrease with AEP when the high flow channel is activated by Weeli Wolli Creek and when the influence of creek flows exceeds that of runoff contributing from the drain.

Based on the model results, it can be seen that the overall impacts on the flooding regime and creek water supply for riparian vegetation at XS6 and beyond are small during operation.

9.3 Flow velocities

Modifications to flow velocities are also a consequence of flow constrictions and obstructions caused by the levees and/or crossings along Weeli Wolli Creek. This change to the regime may affect the geomorphological conditions of the creek by increasing the erosion potential of sections where velocity increases or encouraging sediment deposition where ponding occurs and velocity drops. This shift in velocity distribution may also alter areas of vegetation growth where sections of increased velocity may experience increased vegetation loss while ponding areas, in particular behind the road crossing, may become suitable habitat for tree growth.

The degree and extent of change to the flow velocity were assessed by comparing the velocity distribution during the 50 %, 10 % and 1 % AEP floods under pre-development and operational catchment conditions. Model results are presented in the form of velocity difference maps, which illustrate the changes in three shades of colour: the yellow shade indicates less than ± 0.5 m/s change in velocity; the red shade indicates an increase in velocity (> 0.5 m/s increase); and the blue shade shows a decrease (> 0.5 m/s decrease). If changes are within 0.5 m/s, there are unlikely significant changes to the mobilisation of sediments specific to that velocity range (Table 4). However, if changes are more than ± 0.5 m/s, there is the potential for an increase or decrease in sediment mobilisation, which signifies a more noticeable change in geomorphological characteristics of the creek.

Model results (maximum velocity distribution and velocity differences) for the 50 %, 10 % and 1 % AEP storms are illustrated in Figure 24, Figure 25 and Figure 26.

As shown in Figure 24, changes to velocity along the main channel of Weeli Wolli Creek are minimal during the 50 % AEP event. Maximum velocity remained at approximately 2 m/s, the pre-development level for the same event. However, velocity is shown to decrease between XS3 and XS4 along the high flow channel due to termination of runoff from the east while increases at XS6 as a result of increased contribution of runoff from the main diversion. Flows exiting the diversion drain will have higher velocities than natural, but, based on the model results, not exceeding 1.5 m/s for the 50 % AEP event hence unlikely to cause significant erosion or scour along the creek bed. It is important to note that velocities at the outlets of the diversions will increase with AEP thus energy dissipation structures are required to minimise scour along the creek immediately downstream. Overall, it can be concluded that the flood infrastructures have minor impacts on the velocity distribution and subsequently the sediment conditions along Weeli Wolli Creek during events of low flows.

For the 10 % AEP event (Figure 25), notable changes are observed around the creek crossing where velocities are increased over the floodway and decreased when ponding occurs upstream of the road embankment. These changes are to be expected as the road disrupts surface water flows along the creek and potential changes to the existing geomorphological regime may occur in vicinity of the crossing. However, based on the model results, these changes are localised and unlikely to extend 1 km upstream and downstream of the road, thus impacts to the wider creek area are likely to be small. Velocity is shown to increase, against the levee, immediately downstream of XS4 where the floodplain is most constricted. This area will experience increased erosion during a flood and the impacted area will expand as the magnitude of the storm increases.

Severe changes to the flow velocities and as a result the geomorphological characteristics of the creek can be observed upstream and downstream of the creek crossing during the 1 % AEP flood (Figure 26). The impact zone, as shown in the difference map, extends approximately 1.7 km upstream and 850 m downstream of the road. Velocities generally increase as a result of flow constriction and obstruction caused by the levee and crossing but the critical location is along the low flow channel adjacent to the outcrop where velocity approaches 6 m/s. If a flood event of this magnitude occurs, the morphology of the creek will change along this section if no management is in place to control the velocities. Furthermore, some heavy rock armouring will be required along the road crossing to minimise the risk of failure, which would result in a severe consequence to the riverine environment of Weeli Wolli Creek. Velocity is shown to increase across the whole breadth of the creek, downstream of XS4. Pre-development flow velocity ranges from 2 to 3 m/s along this section of the creek, which is increased to 3 to 4 m/s under developed conditions. Increased erosion and scour is expected along this section, which may result in higher vegetation loss during events of this magnitude.

Overall, significant changes to flow velocities and sediment conditions along the creek are confined to section adjacent to the operation. However, appropriate erosion protections around major infrastructures are required to minimise long term impacts on the morphology and sediment characteristics of the creek.

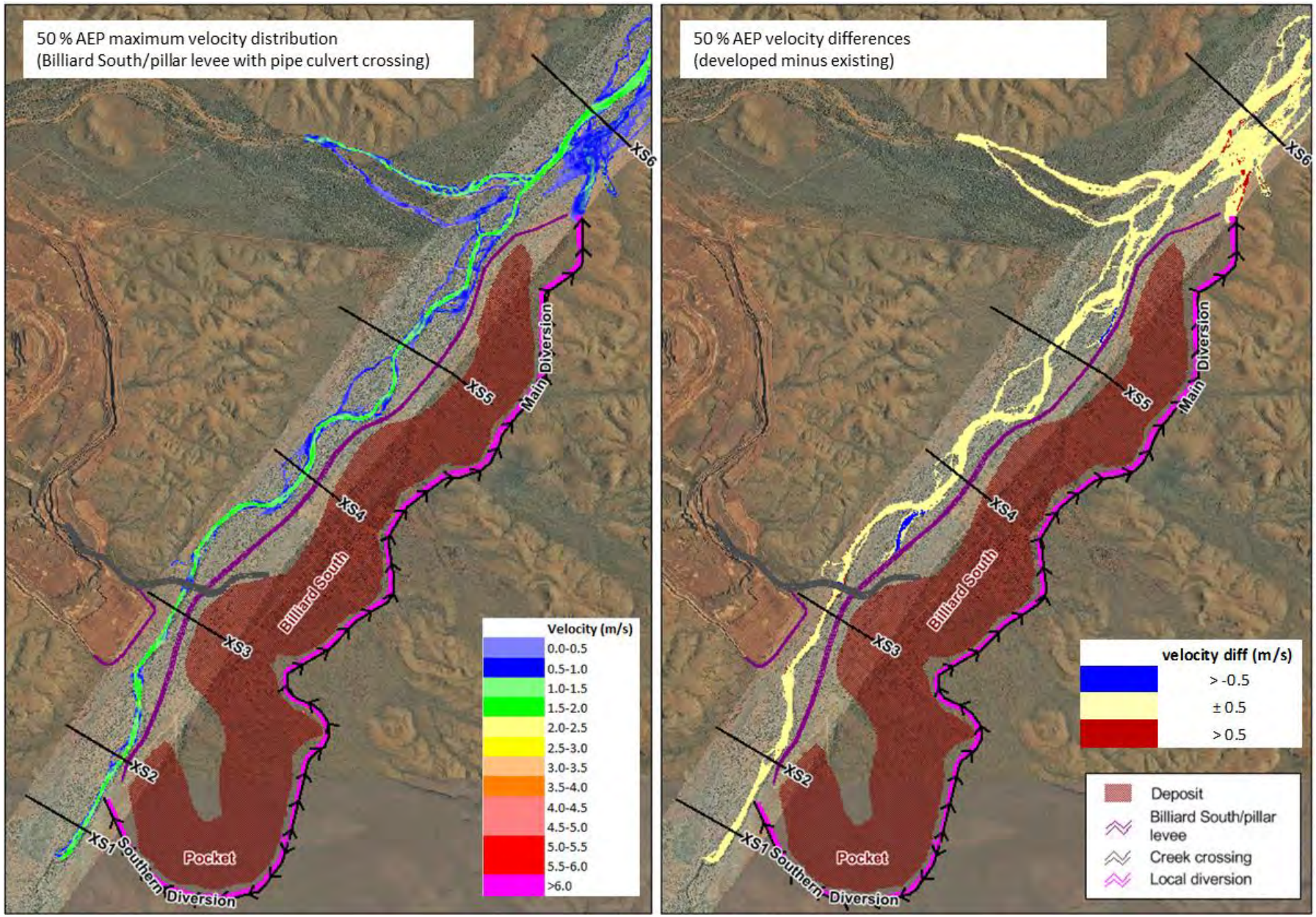


Figure 24: Maximum velocity distribution and velocity differences for the 50 % AEP event.

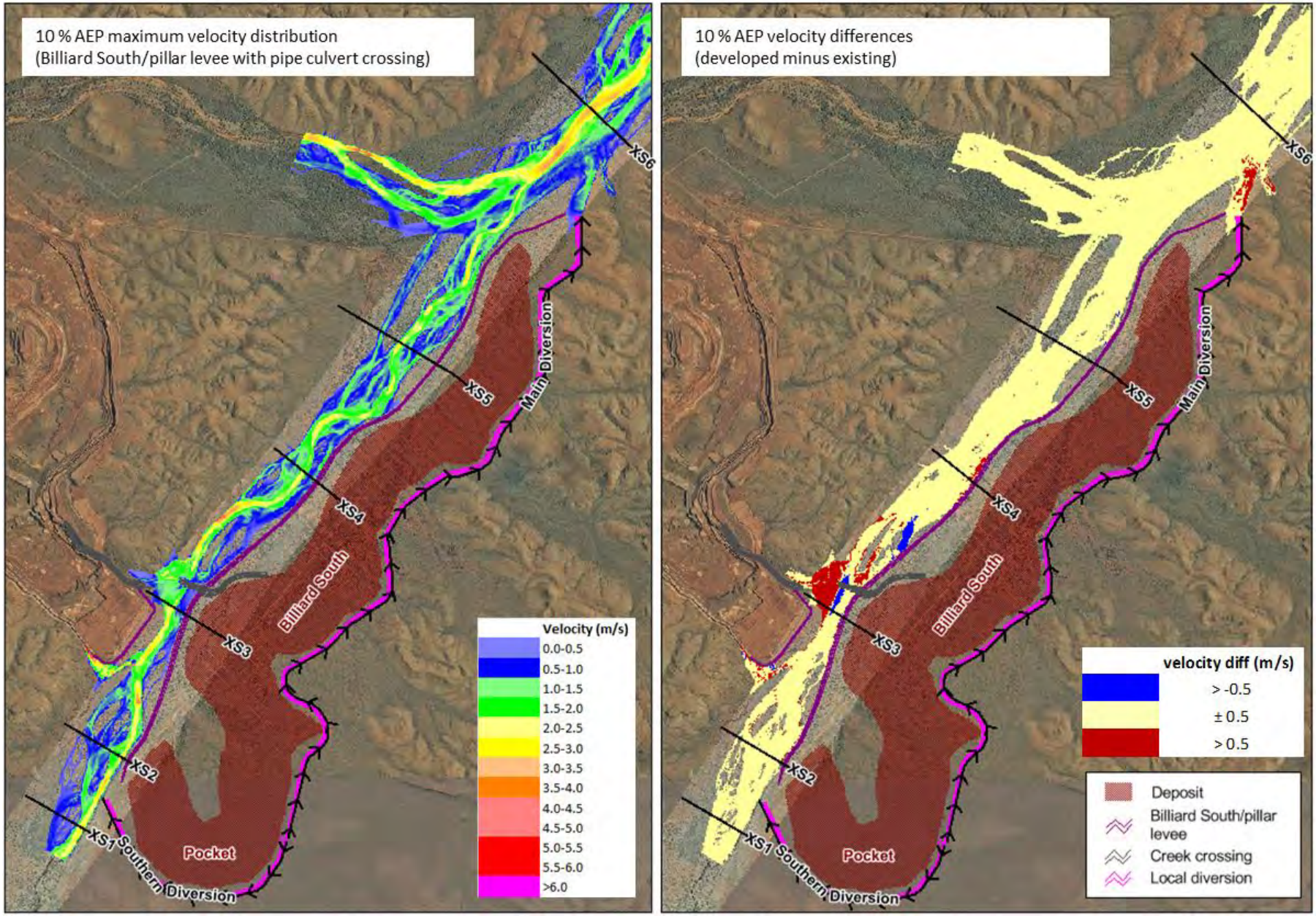


Figure 25: Maximum velocity distribution and velocity differences for the 10 % AEP event.

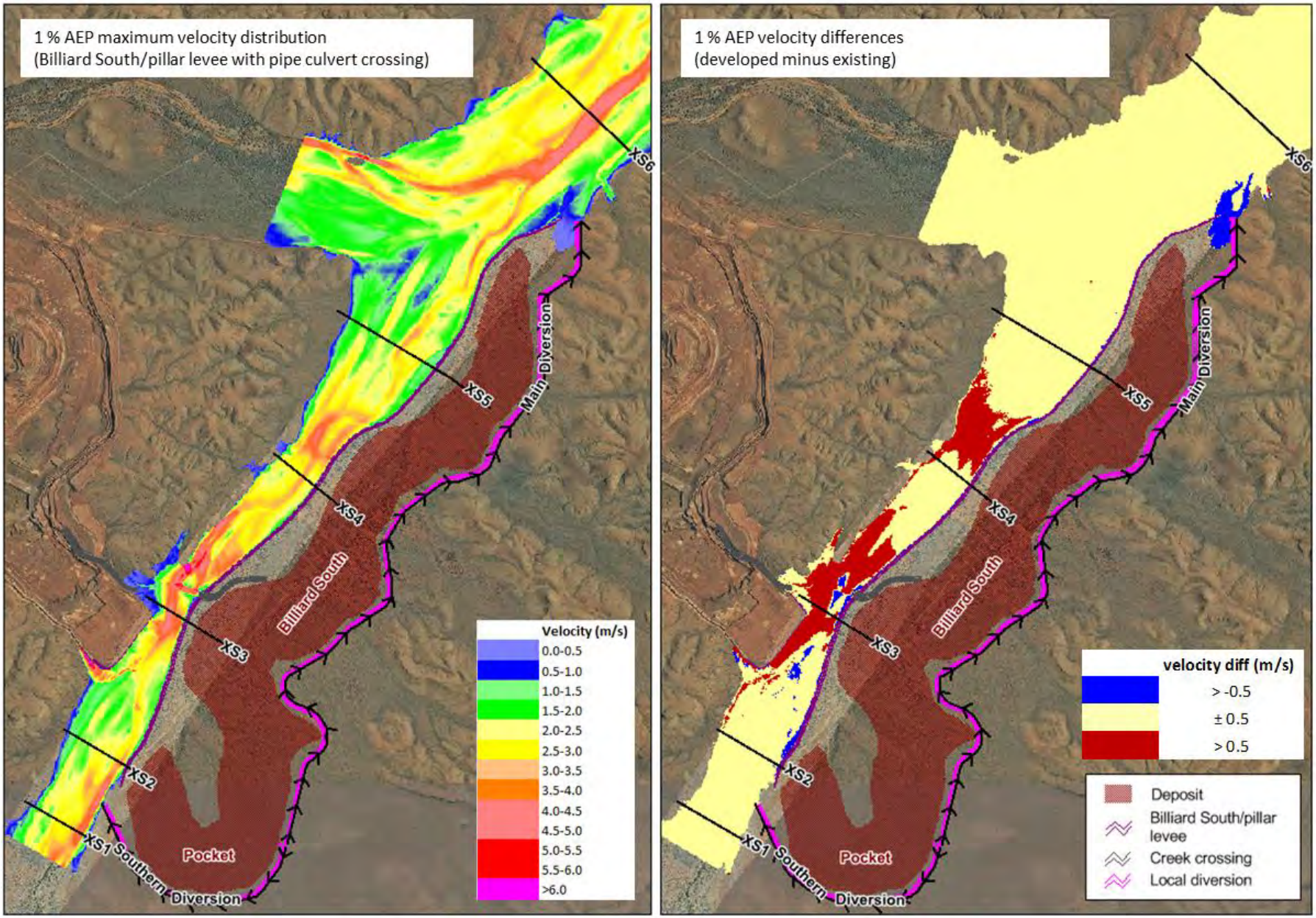


Figure 26: Maximum velocity distribution and velocity differences for the 1 % AEP event.

Conclusion

An ecohydrological assessment was carried out to identify the likely changes to surface water flow regime of Weeli Wolli Creek and the subsequent impacts on riparian vegetation as a result of development of Pocket and Billiard South within the Yandicoogina mine. Mining of these deposits will require rigorous approach of surface water management, which includes the construction of flood protection levees, local diversions and road crossing along Weeli Wolli Creek. These infrastructures will constrict and impede surface water flows and consequently alter the surface water flow conditions, such as the flood level and velocities, along the creek.

2D hydraulic modelling was carried out to determine the likely flow characteristics of Weeli Wolli Creek during mining when these infrastructures are in place. It can be concluded that:

- Minor increases in peak flow rates may be expected downstream of the operation during mining due to concentrated runoff contribution from the main diversion drain. However, impacts to the overall flood regime will decrease with AEP as the influence of surface water flows from Weeli Wolli Creek exceeds that from the diversion.
- Disruption to the existing surface water flows (water level and velocity) along Weeli Wolli Creek is small during events of low flows. A greater change, however, may be triggered by modification to local runoff from the eastern catchments causing water level/velocity to decrease or increase along the creek.
- Notable changes in flood level occur along the section of the creek between XS3 and XS4, in particular around the creek crossing, during the 10 % AEP event. Water elevation is raised by approximately 1 m behind the road, with the effects of backwater propagated 300 m upstream. Beyond the area of influence, changes are minimal.
- Impacts caused by infrastructures during the 1 % AEP flood are more significant due to greater constriction and obstruction of flows, in particular along the section between JSE and Billiard South. Greater effects of backwater are generated by the crossing, with the water level increased by 3 m above the pre-development level and the backwater propagated 2 km upstream. However the changes are confined to the creek section adjacent to the proposed operation and unlikely to extend beyond the impact zone.
- Significant changes in flow velocities occur in vicinity of the creek crossing where velocities are increased over the floodway and decreased when ponding occurs upstream of the road embankment. Flow velocities also increase along the creek section where the floodplain is most constricted. Changes are significant during the 1 % AEP event, with velocity reaching 6 m/s along the low flow channel immediately downstream of the crossing.
- Flooding characteristics and creek water supply for riparian vegetation during events of low and medium flows will likely remain unchanged during operation. For larger events, flood level will increase more prominently and the floodplain extends further to the west, thus larger area of vegetation, in particular those fringing the floodplain will be inundated during events of a lower AEP post-development.
- Changes to the flow velocities will likely influence the geomorphological conditions of the creek, especially in vicinity of the crossing. Increased erosion is expected in

areas where velocity increases and higher rate of sediment deposition will take place in areas where ponding occurs.

Based on the study outcomes, it was determined that the overall impact to surface water flow regime along Weeli Wolli Creek is restricted to the section adjacent to the proposed mine, while impact to the wider creek area is small during operation. However, appropriate management and monitoring are recommended to minimise long term impacts on the morphology and flow regime of the creek.

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Appendix

10. Appendix A – A comparison of the model results for the pipe culverts and the box culvert bridge crossing designs.

Maximum flood depth (m)										difference between the crossing designs	
Cross section location	AEP (%)	Pre-developmen	Billiard South/pillar levees with pipe	depth diff (m)	% diff	Pre-developmen	Billiard South/pillar levees with box crossing	depth diff (m)	% diff	depth diff (m)	% diff
XS1	50	1.597	1.531	-0.066	-4.14%	1.597	1.531	-0.066	-4.14%	0.000	0.00%
	10	3.589	3.520	-0.069	-1.92%	3.589	3.520	-0.069	-1.92%	0.000	0.00%
	1	6.444	6.378	-0.066	-1.02%	6.444	6.378	-0.066	-1.02%	0.000	0.00%
XS2	50	1.854	1.806	-0.048	-2.57%	1.854	1.806	-0.048	-2.57%	0.000	0.00%
	10	3.422	3.558	0.136	3.97%	3.422	3.558	0.136	3.97%	0.000	0.00%
	1	5.605	5.962	0.357	6.37%	5.605	5.962	0.357	6.37%	0.000	-0.01%
XS3	50	1.976	1.919	-0.058	-2.92%	1.976	1.917	-0.060	-3.02%	-0.002	-0.11%
	10	3.801	4.046	0.245	6.44%	3.801	4.029	0.228	6.00%	-0.017	-0.42%
	1	5.768	7.818	2.050	35.54%	5.768	7.807	2.039	35.34%	-0.011	-0.15%
XS4	50	1.151	1.089	-0.062	-5.37%	1.151	1.089	-0.062	-5.37%	0.000	0.00%
	10	2.175	2.173	-0.002	-0.09%	2.175	2.173	-0.002	-0.09%	0.000	0.00%
	1	4.191	5.167	0.976	23.29%	4.191	5.167	0.976	23.29%	0.000	0.00%
XS5	50	1.670	1.614	-0.056	-3.35%	1.670	1.614	-0.056	-3.35%	0.000	0.00%
	10	2.922	2.888	-0.034	-1.17%	2.922	2.888	-0.034	-1.17%	0.000	0.00%
	1	4.965	5.151	0.187	3.76%	4.965	5.154	0.190	3.82%	0.003	0.06%
XS6	50	1.280	1.302	0.021	1.67%	1.280	1.302	0.021	1.67%	0.000	0.00%
	10	3.092	3.127	0.035	1.14%	3.092	3.127	0.035	1.14%	0.000	0.00%
	1	5.594	5.608	0.014	0.25%	5.594	5.608	0.014	0.25%	0.000	0.00%

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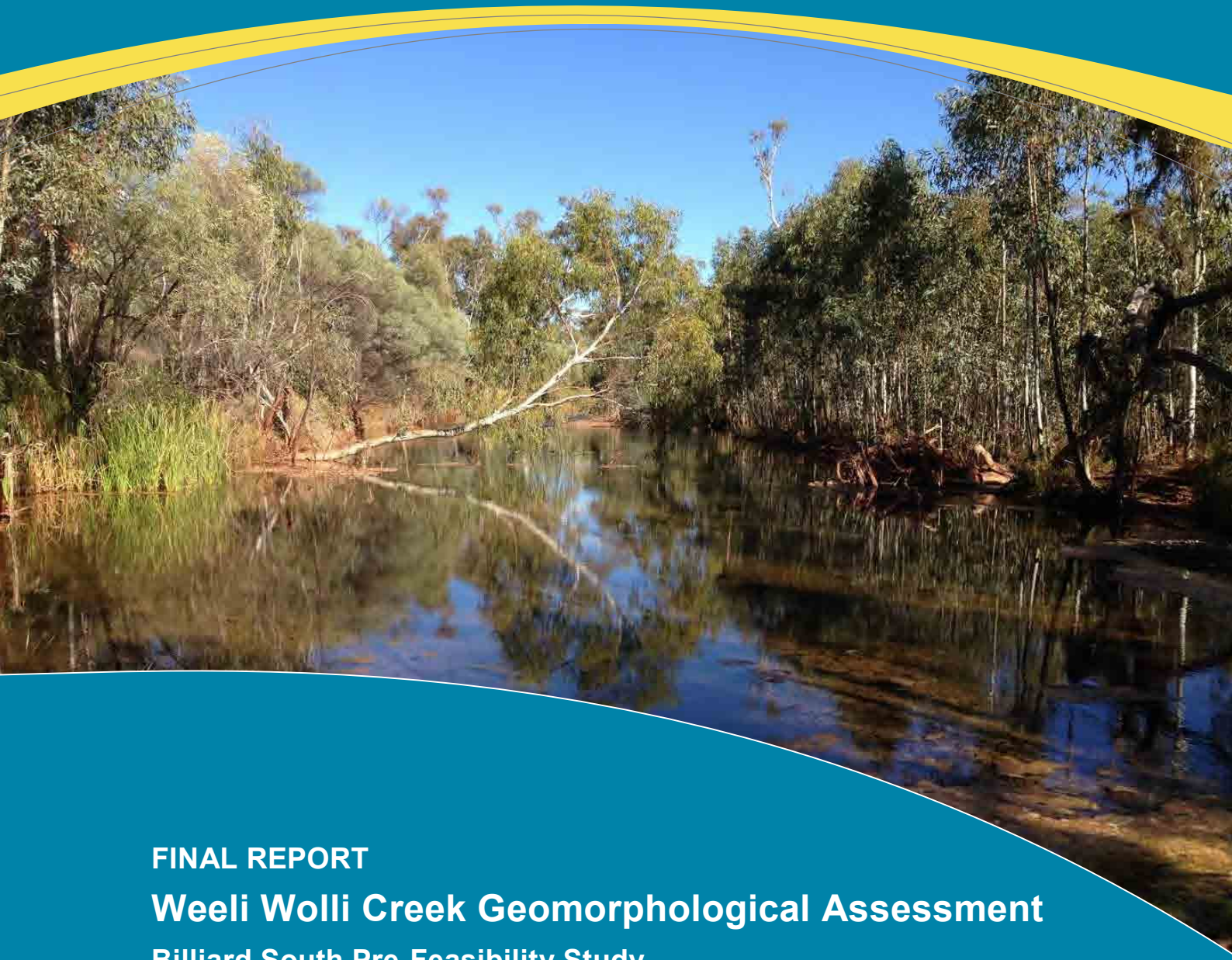

FINAL REPORT

Weeli Wolli Creek Geomorphological Assessment

Billiard South Pre-Feasibility Study

Prepared for Rio Tinto Iron Ore

October 2015

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Executive Summary

Development of the Billiard South iron ore deposit, located within Rio Tinto's Yandicoogina operation upstream of the confluence of Marillana Creek and Weeli Wolli Creek, will encroach on the existing floodplain. Mining will be constrained by the natural flood extent unless flood protection levees are constructed. A conceptual flood protection levee alignment has been proposed to permit safe mining of the Billiard South deposit.

Weeli Wolli Creek is a significant Pilbara creek system subject to large, infrequent flood events. These large floods are significant events for the geomorphology of the creek. An understanding of the fluvial processes in Weeli Wolli Creek is important for managing potential impacts of the proposed development. This geomorphological study report is intended to increase understanding in support of Rio Tinto's environmental approval process.

This report covers the following items:

- Description of the existing geomorphological regime of Weeli Wolli Creek in the study area;
- Assessment of the potential impact of the proposed levee associated with development of the Billiard South iron ore deposits on the existing geomorphological regime of Weeli Wolli Creek; and
- Identification of key geomorphological issues for Weeli Wolli Creek related to haul road design, potential development of iron ore deposits at Billiard North, and Yandicoogina mine closure plans.

The current flow regime of Weeli Wolli Creek has been altered from the naturally ephemeral, pre-mining regime due to sustained discharges from upstream dewatering activities. Weeli Wolli Creek primarily has a single, sinuous low-flow channel situated within a high-flow channel characterised by gravel bars and connected to an anabranching system of flood runners activated by larger flows. The floodplain has multiple levels that are engaged at varying flow frequencies. The lowest levels are the most active area, and are associated with gravelly deposits, whereas the higher, less frequently engaged levels are characterised by silty surface sediment deposits and are vegetated with spinifex. Comparisons of historical aerial photographs show that the low-flow channel has become more pronounced due to flow supplementation but there is little evidence of change in channel location over the past four decades. Some localised migration has occurred by processes of lateral erosion and accretion, with this seen as within the normal bounds of the natural processes.

In the Billiard South levee scenario, the proposed levee would encroach on part of the existing floodplain and anabranch system. The constrictions created by the proposed levee encroachment on the floodplain has significant hydraulic effects and geomorphological implications. In broad terms, the levee would lead to additional sedimentation in the backwater zone upstream of the constriction, an increase in sediment mobilisation through the constriction, and deposition of scoured material downstream of the constriction as the stream power returns to its natural level. Key issues include risk of levee failure (particularly at pressure points where the creek or floodplain flows impinge against the levee), potential destabilisation of the creek channel and floodplain in the project area, vegetation loss, increased debris loads, risk of headward erosion extending upstream of the study area and increased sediment export to downstream reaches.

Local tributaries from the catchment area to the east of the South Billiard deposits will be routed around the levee and join Weeli Wolli Creek further downstream. This is not expected to significantly impact on the geomorphology of Weeli Wolli Creek, as these local tributaries drain a small proportion of the total catchment area and would be relatively minor contributors of flow and sediment.

The hydraulic modelling of the levee scenario does not include the impacts of a haul road across the floodplain and channel. Assessment of preliminary haul road designs indicates significant risk of exacerbating the hydraulic and geomorphological impacts of the levee, which need to be addressed by careful haul road design assessed to the same hydraulic and geomorphological standards as the levee scenario.

Although this study focuses on Billiard South, mine planning for the Junction South East (JSE) and Billiard North deposits is relevant to the closure design for Billiard South. JSE is outside of the Weeli Wolli Creek floodplain and is not further considered here. The Billiard North deposit extensively overlaps the Weeli Wolli Creek floodplain and its development may potentially have significant geomorphological impacts upstream and downstream as well as within the project area. These risks have not been assessed quantitatively in this report.

Rio Tinto has recognised that closure challenges for Yandicoogina are largely associated with water management. Although this report focuses on the Billiard South Deposit during operations, closure scenarios are also relevant and are addressed briefly in this report. The currently preferred closure scenarios involve the creation of permanent pit lakes that will impact the downstream flow frequency, floodplain connectivity and sediment transport regime. In the Billiard South area, a key risk for the rehabilitated landforms will be the avulsion of Weeli Wolli Creek into the former mine. It will be important to ensure that the rehabilitated landforms and surface water management features are designed to minimise this risk.

Rio Tinto Iron Ore

Weeli Wolli Creek Geomorphological Assessment

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1 Introduction

1.1 Scope and objectives

Weeli Wolli Creek drains the Hamersley Range in the Eastern Pilbara region of Western Australia. It is a tributary stream in the Fortescue River catchment and discharges into the Fortescue Marshes. This report discusses the geomorphology of Weeli Wolli Creek in the vicinity of the Billiard South iron ore deposit near Yandicoogina. The study area is situated in the vicinity and upstream of the confluence of Weeli Wolli Creek and Marillana Creek (Figure 1-1).

The objectives of this report are to:

- Describe the existing geomorphological regime of Weeli Wolli Creek in the study area;
- Assess the potential impact of the proposed levee alignment associated with development of the Billiard South iron ore deposits on the existing geomorphological regime of Weeli Wolli Creek; and
- Identify key geomorphological issues for Weeli Wolli Creek related to a haul road crossing, potential development of iron ore deposits at Billiard North, and Yandicoogina mine closure plans.

The existing geomorphological regime of Weeli Wolli Creek differs from the natural regime primarily because of flow supplementation with mine water discharged from Hope Downs and Yandicoogina's Junction South East (JSE), resulting in the presence of permanent water in this formerly ephemeral reach. Further details are described in Chapter 2.

The potential impact of the Billiard South development has been assessed by comparing the existing condition to a levee scenario defined by Rio Tinto Iron Ore (RTIO) that encroaches onto the floodplain of Weeli Wolli Creek. Further information about the existing and levee scenarios is provided in Chapter 3.

1.2 Methodology and data sources

This report is based on a site inspection of Weeli Wolli Creek and a review of existing reports and data. The site inspection was undertaken on 24-25 June 2014 by Mark Pearcey (RTIO), Scott Seymour (Aquatic Systems Management) and Krey Price (MWH). Appendix A presents the field notes and site visit route (Figures A-1 and A-2).

The description of the current geomorphology of Weeli Wolli Creek and the assessment of operational and closure scenarios are based on the site inspections and the following key reports and data sources:

- Aerial photographs (1970, 1994, annual from 2003 to 2014);
- Published 1:250,000 geological mapping (SF 50-12 Roy Hill);
- Digital Elevation Model (DEM) and floodplain cross-sections based on LiDAR data surveyed in December 2011;
- RTIO (2013) Weeli Wolli Creek Hydrology & Floodplain Assessment - Yandicoogina Billiard South Order of Magnitude Study, December 2013 (RTIO-PDE-0117748);
- RTIO (2014) Yandicoogina Closure Plan (RTIO-HSE-0208486);
- Two-dimensional TUFLOW hydraulic modelling outputs for the existing condition (2% AEP flow, 1% AEP flow and 0.5% AEP flow); and
- Stream flow data for GS 708013 Weeli Wolli Creek at Waterloo Bore and GS 708014 Weeli Wolli Creek at Tarina (http://kumina.water.wa.gov.au/waterinformation/telem/stage.cfm).

The assessment of potential impacts of the Billiard South development is based on scenarios outlined by RTIO (2013) and two-dimensional TUFLOW hydraulic modelling outputs provided by RTIO:

- 2% AEP flow – existing condition and levee condition;
- 1% AEP flow – existing condition and levee condition; and
- 0.5% AEP flow – existing condition only (levee condition not provided).

Potential implications of a haul road and bridge crossing were examined based on:

- Preliminary designs for bridge and haul road, (RTIO Plans BILL-PRJ-SKE-Y-0004_A and BILL-PRJ-SKE-Y-0005_A); and

- RTIO Water Resource Evaluation (2014) Billiard South bridge crossings – design review, July 2014 (RTIO Internal Memo).

Discussion of geomorphological issues associated with the development of the Billiard North iron ore deposits and Yandicoogina mine closure is based on:

- RTIO (2013) Weeli Wolli Creek Hydrology & Floodplain Assessment - Yandicoogina Billiard South Order of Magnitude Study, December 2013 (RTIO-PDE-0117748); and
- RTIO (2014) Yandicoogina Closure Plan (RTIO-HSE-0208486).

1.3 Report outline

The existing geomorphological regime of Weeli Wolli Creek is discussed in Chapter 2. The geological and topographic settings are outlined in Section 2.1 and key hydrologic influences are discussed in Section 2.2. Section 2.3 examines creek channel characteristics and behaviour with reference to channel/floodplain interactions (Section 2.3.1), the creek bed and banks (Section 2.3.2), sediment characteristics and regime (Section 2.3.3), and vegetation cover (Section 2.3.4).

The Billiard South development scenarios are examined in Chapter 3. The scenarios and assumptions are outlined in Section 3.1. The levee scenario is discussed in Section 3.2.

Chapter 4 discusses other related proposals, including the potential implications of a haul road crossing that links Billiard South to the existing Yandicoogina Mine (Section 4.1), key issues for the geomorphology of Weeli Wolli Creek relating to the potential development of the Billiard North iron ore deposits (Section 4.2), and Yandicoogina mine closure plans (Section 4.3).

Appendices include notes, findings, and background details from the site visit (Appendix A), results of the historical aerial photo analysis (Appendix B), hydraulic modelling results (Appendix C), and a discussion of hydraulic design implications (Appendix D).

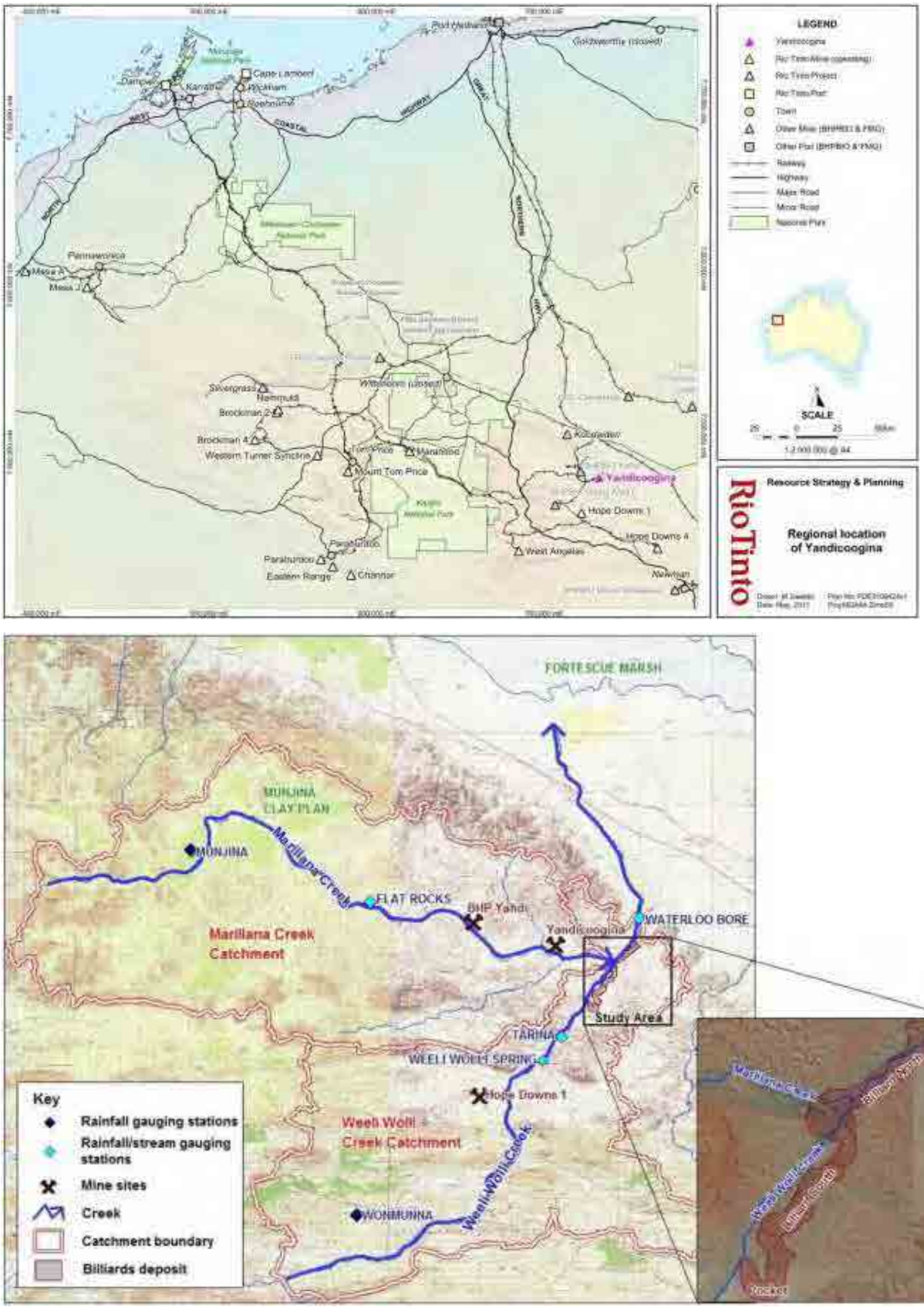

Figure 1-1: Yandicoogina Vicinity (RTIO 2014b) and Weeli Wolli Creek catchment (RTIO 2013)

2 Existing regime of Weeli Wolli Creek

This chapter describes the existing and pre-mining geomorphology of Weeli Wolli Creek in the Billiard South project area. Whilst mining operations have been ongoing in the Weeli Wolli Creek catchment for several decades, the primary differences between natural and existing regimes in the immediate project area relate to flow supplementation from JSE (adjacent to the project reach) and Hope Downs (upstream of the study area).

2.1 Geology and topography

Figure 2-1 shows a shaded digital elevation model of the study area as an overlay on the 2014 aerial photo. The relief shows the network of channels comprising Marillana Creek and Weeli Wolli Creek.

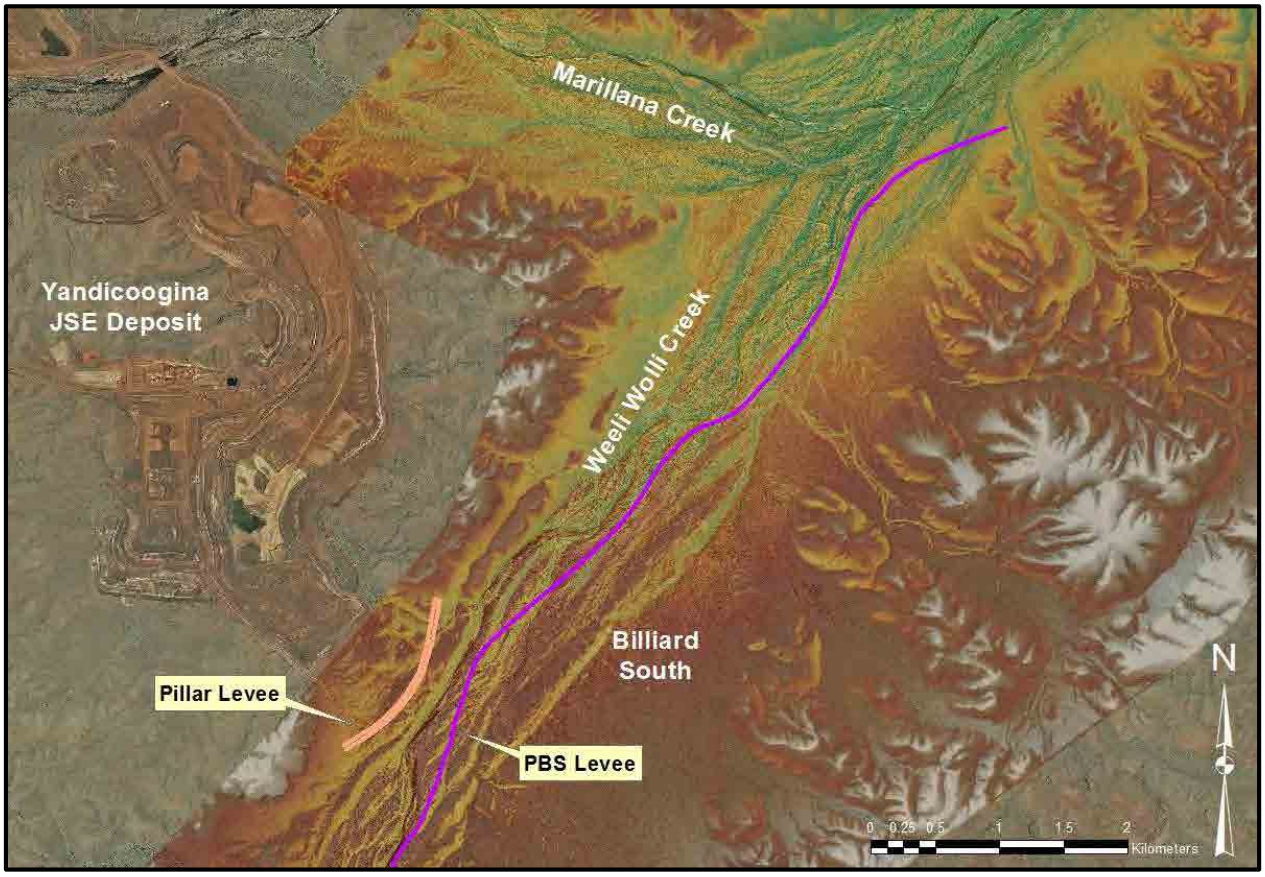

Figure 2-1: Digital Elevation Model of Study Area showing Levee Alignments

The Roy Hill 1:250,000 geological map shows that Weeli Wolli Creek in the study area flows in a generally NNE direction along a valley cut into ancient Proterozoic rocks of the Hamersley Group's Weeli Wolli Formation, consisting of banded iron-formation (commonly jaspilitic) pelite and metadolerite sills. The valley contains Cainozoic sediment deposits, including Cainozoic colluvium (partly consolidated quartz and rock fragments in silt and sand matrix; old valley fill deposits) and Cainozoic calcrete (sheet carbonate; found along major drainage lines) as well as a floodplain consisting of Quaternary alluvium. At the downstream end of the study area, Weeli Wolli Creek is joined by Marillana Creek, its largest tributary[1]. The floodplain of Weeli Wolli Creek widens at the Marillana Creek confluence.

Within the study area and throughout the catchment, there are minor localised impacts from trampling by introduced grazing animals, particularly cattle.

[1] Note: In some mapping sources, Marillana Creek is considered to be a tributary to Yandicoogina Creek; this report presents Yandicoogina Creek as a tributary entering Marillana Creek upstream of the Weeli Wolli Creek confluence.

Upstream of the study area, the various upper catchment tributaries of Weeli Wolli Creek converge in a broad basin containing Cainozoic sedimentary deposits. The creek then flows through a narrow valley carved through Proterozoic bedrock, which includes Weeli Wolli Springs and the Tarina stream flow gauging station (GS No. 708014). Weeli Wolli Creek emerges from this confined valley a few kilometres upstream of the study area

Immediately downstream of the study area, the geological and topographic setting is similar to the study area, but with a broader floodplain. Further downstream, Weeli Wolli Creek discharges onto a broad, flat deposition zone containing extensive deposits of Quaternary and Cainozoic sediments. Weeli Wolli Creek fans out into multiple distributaries as it enters this depositional basin, although a clearly defined main channel is evident. About 10 km downstream of the study area, the main valley passes through a narrower constriction confined by Proterozoic bedrock ranges on both sides, but higher level floodplain deposits diverge from the main valley upstream of this constriction to follow an alternative course toward Fortescue Marsh. Hydraulic modelling information provided by Rio Tinto indicates that this alternative course is only active in large floods. Floodplain flows cross the Mt Newman Railway in a series of culverts and bridges. The main Weeli Wolli Creek channel crosses the railway under a trestle located approximately 20 km downstream of the alluvial fan apex. Weeli Wolli Creek terminates at the Fortescue Marsh approximately 15 km downstream of the railway crossing.

2.2 Hydrology

Stream flow records for the Tarina gauging station (GS No. 708014), which is situated in the narrow valley upstream of the study area, show that the natural flow regime of Weeli Wolli Creek is summer-dominant. There is a high degree of annual variability in flows, with cyclones bringing major episodic flooding. A decadal trend in rainfall and streamflow has been noted, with 1985-1993 and 2006-present being drier than average, while 1994-2005 was wetter than average with five major cyclones passing in the vicinity of the Weeli Wolli Creek catchment (RTIO 2013).

The flow regime of Weeli Wolli Creek is naturally ephemeral; however, since 2007, flows in Weeli Wolli Creek have been supplemented by the discharge of surplus mine water (approximately 110 ML/d) from Hope Downs (RTIO 2013). There are also pumped inflows to Weeli Wolli Creek from the Yandicoogina mine of approximately 38 ML/d. Supplementation has increased total flows in the creek, reduced the degree of annual variability, and changed the flow regime from ephemeral to having a sustained base flow and permanent pools. The wetting front extends beyond the downstream end of the study area, generally occurring between 4 and 5 km downstream of the confluence of Weeli Wolli Creek and Marillana Creek (RTIO 2013) before all surface flows have drained into the deeper gravel lenses in the floodplain alluvium.

There is a high degree of natural connectivity between surface water and groundwater in Weeli Wolli Creek. Weeli Wolli and Marillana Creeks are important sources of groundwater (Inverarity et al 2012[2]). Water is retained in alluvial aquifers when the creeks cease to flow, supporting riparian vegetation (Inverarity et al 2012). In the case of Weeli Wolli Creek, the supplemented flow persists as a sustained surface base flow through the study area, but further downstream the creek reverts to its natural ephemeral character as the supplemented base flow is lost from the creek due to seepage into the alluvium and gravel seams. The older trees along Weeli Wolli Creek and its anabranches are using this shallow groundwater as their main water source.

The Marillana Creek catchment receives a slightly higher average annual rainfall than the Weeli Wolli Creek catchment (408 mm/a compared with 382 mm/a) (RTIO 2013). Rainfall and streamflow are spatially variable, and the proportional contribution of Weeli Wolli Creek and Marillana Creek to any given flood event is also variable. For example, in the flood of February 1995, the flood flows originated primarily from Marillana Creek catchment rather than Weeli Wolli catchment, whereas in other floods there has been a more significant contribution from Weeli Wolli Creek (RTIO 2013). The flood peaks in both streams, even if similar in magnitude, are generally not simultaneous; for example, a cyclone or tropical low may cross the Marillana Creek catchment well before reaching the upper Weeli Wolli Creek catchment. This hydrological variability creates complex and variable hydraulic conditions, which are reflected in the complex geomorphology of the confluence zone. The design floods used by RTIO in the TUFLOW modelling are based on uniform application of the design rainfall across the entire Marillana and Weeli Wolli catchments (RTIO 2013).

[2] Inverarity, N., Dogramaci, S. and Rea, I. (2012) Combined numerical and analytical modelling as a means to assess closure options for open-pit mines, Pilbara Region. International Mine Water Association Annual Conference, 2012.

2.3 Channel characteristics and behaviour

2.3.1 Channel / Floodplain interaction

Weeli Wolli Creek primarily has a single main river channel under low flow conditions. The channel pattern is generally sinuous. The main stream channel consists of a high flow channel characterised by gravel bars, with a smaller low flow channel situated within it (Figure 2-2).

The low flow channel is connected to an anabranching system of flood runners, which are activated by larger flows (Figure 2-3), and the floodplain is also engaged in large floods (Figure 2-4). The floodplain has multiple levels, associated with varying flow frequencies. The lowest levels are the most active area, and are associated with gravelly deposits, whereas the higher, less frequently engaged levels are characterised by silty surface sediments.

Comparisons of aerial photographs taken in 1970 and 2014 show a wet and clearly defined low flow channel in 2014, compared with an anabranching system of dry channels in 1970. The 2014 low flow channel generally follows the alignment of the 1970 channel system, with some localised migration by processes of lateral erosion and accretion (Appendix B). However, it cannot be conclusively determined whether the same channel was dominant in its entirety in 1970 as in 2014.

Hydraulic conditions in Weeli Wolli Creek and floodplain have been simulated by RTIO in a two-dimensional TUFLOW hydraulic model. Flow conditions for the 2%, 1% and 0.5% AEP were provided. Outputs from these model runs (Appendix C) show that the floodplain is extensively engaged in the 2% AEP flow, but some of the higher benches are only inundated in larger events. Hydraulic loadings (as indicated by flow velocities and shear stress) are highest along the main channel and are also high along parts of the major anabranches.

Figure 2-2: Narrow low flow channel bordered by wide gravel bars

Note: The gravel bars at this site include well-worn river gravels as well as some more angular material that appears to have been more recently won from bank erosion impinging on adjacent foothills.

Figure 2-3: Example of a mid-level anabranch of Weeli Wolli Creek

Note: The lower level anabranches display evidence of more active fluvial processes, with exposed gravel and pebble deposits in the bed.

Figure 2-4: Weeli Wolli Creek floodplain

Note: The surface sediments consist of silty material with extensive growth of spinifex.

2.3.2 Bed and banks

The low flow channel has pools (Figure 2-5) separated by gravel-bar controls (Figure 2-6). Gravel bars provide riffle-run habitat. Under low flow conditions, part of the Weeli Wolli Creek flow appears to seep through the controls. Historical aerial photographs from 1970, prior to flow supplementation, show a dry bed with no permanent pools.

Field observations indicate that the material exposed in the creek banks consists largely of alluvium, and is subject to erosion by natural meander processes. As noted in Section 2.3.1, comparison of historical (1970) and recent (2014) aerial photographs shows only a few localised shifts in channel position, indicating slow overall meander migration rates over this period. The two-dimensional hydraulic modelling outputs show areas of locally high velocity and shear stress occur in the creek channel during large floods. The limited degree of meander migration over the past 44 years reflects episodic meander migration processes and the infrequent incidence of large floods associated with significant channel change, as is common in arid and semi-arid zone streams, rather than a stable channel. Weeli Wolli Creek remains at risk of significant erosion in major floods.

Localised outcrops of calcrete were observed during the site inspection, particularly at Site 4 and Site 14, (Figure A-2) which abut areas of Cainozoic calcrete mapped on the 1:250,000 Roy Hill geological sheet (e.g. Figure 2-7). However, no evidence was observed of any widespread calcrete or hard bedrock controls, i.e. large or extensive outcrops that would significantly limit bed or bank erosion. This means that in a major flood, particularly if hydraulic loadings are increased (for example, due to confinement by the levees), bed and bank scour would occur at rates governed by the erodibility of the bed and bank sediments, rather than being constrained by hard bedrock or calcrete outcrops. Hence, Weeli Wolli Creek is susceptible to significant geomorphological change in response to change or disturbance.

Figure 2-5: Example of a pool, a key element in the characteristic pool and gravel bar morphology of Weeli Wolli Creek

Note: Under natural conditions, prior to flow supplementation, the pools were generally dry, although the same bedforms would have been present.

Figure 2-6: Example of a gravel-bar control, which provides riffle-run habitat

Figure 2-7: Calcrete outcrop (arrowed) at Site 14 (downstream of Grey's Crossing)

Note: This area coincides with the edge the of Cainozoic calcrete deposit mapped on the Roy Hill 1:250,000 geological map.

2.3.3 Sediment characteristics and regime

Weeli Wolli Creek is a gravel-bed stream. A general feature is the presence of large gravel bars in the main channel (Figure 2-2) and the more active anabranches (Figure 2-8), with finer material, particularly silt, in the less active anabranches (Figure 2-3), and on the floodplain benches where velocities are lower (Figure 2-4).

Figure 2-8: Gravel bars in an anabranch near Site 7

The predominant Wentworth size class on the gravel bars is pebble/gravel size (2 mm to 64 mm), with some larger particles up to cobble size (64 mm to 256 mm), as well as sand-sized material (62.5 µm to 2 mm) (Figure 2-9). There is considerable variability in sediment size within the creek channel, reflecting local variations in hydraulic conditions.

In the upstream part of the study area, the bed sediments include a mixture of materials that are angular with sharp edges, suggesting fresh supply from a proximal local source, as well as more rounded (i.e. less sharp) materials, indicative of a greater degree of fluvial reworking. Further downstream the bed materials are predominantly well-rounded. The rock particles generally have low sphericity (i.e. particles tend to be oblong or flat rather than spherical), reflecting the properties of the rock formations from which they were sourced.

Sediment transport processes are episodic, with most bedload transport occurring during flood events, when significant scour and fill may occur, particularly in the vicinity of localised flow obstructions such as trees (Figure 2-10). Given the channel configuration, the velocity and stream power associated with the supplemented baseflow (approximately 150 ML/d) are below the entrainment thresholds required to mobilise and transport bedload in Weeli Wolli Creek. No bedload transport was observed during the June 2014 site inspection, when flows of 169-189 ML/d were recorded at the Tarina gauging station.

Figure 2-9: Typical gravel bar in Weeli Wolli Creek

Figure 2-10: Exposure of tree roots on gravel bars provides evidence of scour-and-fill processes

2.3.4 Vegetation cover

There is a dense band of riparian trees and shrubs along the low flow channel of Weeli Wolli Creek, with scattered trees and shrubs across the high flow channel and floodplain. There is bare gravel within the high flow channel and in major flood runners. On the floodplain surface, there is finer sediment with extensive groundcover of spinifex, reflecting more benign hydraulic conditions.

A key feature of Weeli Wolli Creek is the strong recruitment of river red gums along the edge of the low flow channel over the past 7 years of supplemented flows (Figure 2-11), with at least 3 distinct age class cohorts of saplings evident. The persistently wet substrate resulting from supplemented flows into which the new trees could recruit has created favourable conditions for the establishment of the young red gums, possibly working in combination with wet seasons flows setting off seeding behaviour. The absence of major floods over this period (as indicated by the streamflow sequence shown in Figure 6.2 of RTIO 2013) would also have contributed by minimising the disturbance of the seedlings by scour. These new trees increase the flow resistance (hydraulic roughness) and decrease the erodibility of the areas they vegetate.

Patchy growths of Typha species were observed in some pools (Figure 2-12), but otherwise little aquatic macrophyte cover was observed in the low flow channel, despite the persistent flows and extensive pools. The presence of typha appeared to be associated with a lack of shading and the presence of permanent water. Typha is unlikely to have been present in this reach of Weeli Wolli Creek in its natural ephemeral condition, although suitable habitat would have been present further upstream at Weeli Wolli Springs.

Extensive growths of algae were observed to present in the pool areas within the study area.

Some large woody material is present in Weeli Wolli Creek, including the main channel, anabranches and floodplain (Figure 2-13). The large woody material appears to have been transported downstream during flood events. This is supported by hydraulic modelling results supplied by RTIO, which indicate deep and locally fast flows during large flood events.

Figure 2-11: Young cohort of red gum saplings

Note: Saplings have colonised the margins of the low flow channel in apparent response to the supplemented flows.

Figure 2-12: Typha sp. colonisation of sediments in large pool at Site 11

Figure 2-13: Large woody material in Weeli Wolli Creek channel and floodplain, Site 2

3 Billiard South development scenarios

3.1 Scenario descriptions and assumptions

The Billiard South iron ore deposit runs parallel to Weeli Wolli Creek and intersects the Weeli Wolli Creek floodplain (Figure 1-1 inset). The operational scenario is examined as a basis for assessing the potential implications of the Billiard South development on the geomorphology of Weeli Wolli Creek. The operational scenario allows for the development of the Billiard South iron ore deposit. In this scenario, mining operations extend onto the Weeli Wolli Creek floodplain, with a flood levee and minimum buffer separating the Billiard South mine from Weeli Wolli Creek and its flood flows.

Local drainage from the catchment area to the east of the Billiard South deposits and outside the levee will be routed around the levee and join Weeli Wolli Creek further downstream. This will affect the timing of some of the contributing flow; however, relative to the main channel flow, the overall flow frequency and floodplain connectivity downstream of the proposed levee is not anticipated to be significantly affected during operations. These local tributaries drain a small proportion of the total catchment area and would be relatively minor contributors of flow and sediment.

Heavy and light vehicle roads would be required to connect the Billiard South development to the service area and processing plant within the existing Yandicoogina mine. At least one crossing of Weeli Wolli Creek and its floodplain would be required. No provision for a road crossing is simulated in the 2D hydraulic modelling that was reviewed for this report; therefore, the road crossing is not incorporated in the geomorphological analysis of the Billiard South development scenarios in Sections 3.2 and 3.3; however, a general discussion of geomorphological considerations relating to such a road crossing is included in Section 4.1, because such a crossing could potentially have significant geomorphological impacts.

The geotechnical properties below the levee alignment are currently unknown. RTIO (2013) noted this as a knowledge gap and recommended that geotechnical investigations be carried out to characterise geotechnical properties of the foundation soil profile and provide baseline information for slope stability and seepage analysis of the levee structure. Similarly, no information was reviewed covering implications of groundwater drawdown from mine dewatering or effects related to the shallow alluvial aquifers that interact with surface flows and support riparian vegetation. The assessment of geomorphological implications of the Billiard South development scenarios in this report (Sections 3.2 and 3.3) has been undertaken primarily based on hydraulic considerations, coupled with analysis of geomorphological conditions and processes outlined above.

To distinguish between other proposed levees in report figures, the levee along the east bank of Weeli Wolli Creek that is the focus of this report is referred to as the Pocket and Billiard South (PBS) Levee, In addition to the PBS Levee, RTIO (2013) discusses two other levee proposals for the Weeli Wolli Creek floodplain: the Pillar Levee and Fortescue Metals Group (FMG) levees. The Pillar Levee option entails the construction of a new levee to protect expansion of the JSE mine, which would be situated immediately opposite the Pocket and PBS levee, further confining the Weeli Wolli Creek floodplain (RTIO 2013). The Pillar Levee would further constrict the flow and further increase hydraulic loadings (RTIO 2013), which would be expected to generally increase geomorphological impacts; however, geomorphological assessment of the Pillar Levee option is beyond the scope of this report.

The FMG levees would be situated approximately 10 km downstream of the study area. RTIO (2013) simulated these levees in the 2D TUFLOW hydraulic model. The results show significant local increases in flood inundation depth in the vicinity of FMG levees; however, the impacts of the FMG levees do not extend as far upstream as the Billiard South project area. Hence, the FMG levees are not considered further in this report.

The assessment of the geomorphological implications of the Billiard South development options was undertaken for the operating life of the mine, with the levees remaining in place and separating the mine from the creek and floodplain. Mine closure scenarios are discussed in broad terms in Section 4.3.

3.2 PBS Levee

The PBS levee leads to a significant reduction in the width of the Weeli Wolli Creek floodplain, particularly in the middle section of the study area. This leads to the direct loss of a substantial part of the floodplain and the truncation of several anabranches, including a major anabranch system (Figure 3-1). Appendix C shows hydraulic output for the existing condition and the levee scenario. Figures C-1 to

C-20 show the entire extent of the proposed levees, while Figures C-21 to C-30 focus on the area with the maximum constriction near the JSE Deposit.

The compression of the floodplain leads to increased hydraulic loadings, as indicated by increases in velocity and shear, particularly in the more confined parts of the floodplain (Figures C-13 and C-14). Geomorphological implications of these hydraulic changes include:

- Potential destabilisation of the creek channel, including increased bank erosion, increased rates of meander migration, increased mobility of bed sediment, channel widening, bend cut-offs and bed deepening (including erosion of bed controls). Figure 3-3 and Figure 3-4 show that velocity and shear will be highest in the middle section of the study area, putting this part of the creek at highest risk of destabilisation.
- Increased rates of meander migration that could lead to the migration of pressure points where the creek channel impinges against the levee (Figure 3-2), extending the length of the area requiring protective reinforcement.
- Erosion of bed controls (which from the site inspection appear to be gravel controls that are not visibly underpinned by calcrete or bedrock) that could lead to the upstream transmission of an erosion head for several kilometres until stopped by a bedrock control.
- A change in channel morphology towards a wider, more braided channel form within and downstream of the study area resulting from increased sediment load due to increased local erosion within the study area and potentially increased sediment inputs from upstream sources if headward erosion occurs.
- Increased hydraulic loadings on the remaining floodplain (significant parts will be cut off by the levee) are indicated by the hydraulic modelling (Figure 3-3 and Figure 3-4), particularly in the middle section of the study area. This is likely to lead to more dynamic geomorphological processes, including floodplain scour and stripping, sand and gravel splay deposition (i.e. deposition of fan-like lobes of coarse sediments onto the floodplain), and increased risk of shifts in channel position by meander cutoffs and avulsion.
- Increased sediment export to downstream reaches.
- Vegetation loss, including old mature trees, would be expected in the area of increased energy, due to direct hydraulic loadings as well as undermining by bank erosion and scour of adjacent soil and sediments. Vegetation loss due to direct hydraulic loadings could be expected in areas where shear exceed 50 n/m^2; however, local turbulence and indirect effects via scour of banks and substrate could result in vegetation loss in areas with lower shear. The middle section of the study area where hydraulic loadings will be largest (Figure 3-3 and Figure 3-4) will be at greatest risk. Debris loads of large woody material would increase.

The hydraulic effects of the levee result in a significant risk of levee failure, particularly at pressure points where the creek or floodplain flows impinge against the levee (Figure 3-2). Levee failure would have major consequences for the Billiard South mining operation. Although the levee design and armour rock sizing is beyond the scope of this study, the geomorphic implications of levee failure warrant some discussion of armour requirements. RTIO (2013) recognised this risk and noted the need for protective reinforcement works along the levee. The current levee alignment is conceptual and armour design has not been completed; however, it is assumed that levee armouring and toe scour control will be required to a sufficient height above and depth below the toe of the levee. Bed control in the form of structures such as cross-channel bed armouring may also be required. Consideration should also be given to the installation of structures (e.g. groynes) to deflect fast, deep, and turbulent flows away from the toe of the levee.

Although the 2D hydraulic model scenario for the levee scenario did not include a haul road, the model results indicate severe hydraulic conditions that are likely to destabilise a haul road and any foundations for structural elements placed within the constricted reach. RTIO's (2014) review of the preliminary design for a haul road shows significant stability problems even at the 2% AEP flow, which is considerable smaller than the 0.5 % AEP design flow for the levee (see Section 4.1).

Backwater effects at the upstream end of the study area (upstream of the confined section), may lead to an undersized levee and locally reduced hydraulic loadings (Figures C-13 and C-14). This may promote

increased deposition, unless the creek is destabilised by headward erosion originating in the area of high hydraulic loadings.

If constructed in conjunction with the proposed haul road crossing, the geomorphological impacts of the crossing (described in Section 4.1) would apply to this scenario.

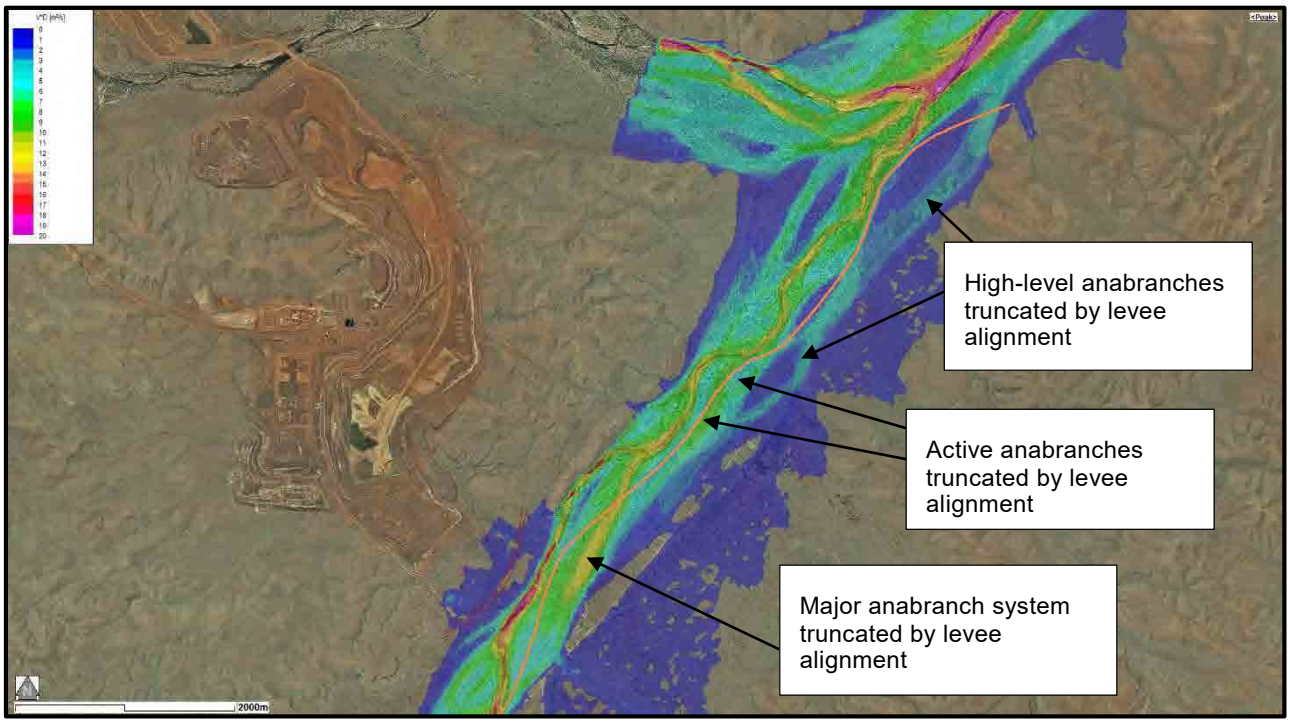

Figure 3-1: Map of flow depth times velocity for the 0.5% AEP flow

Note: Flow areas to the east of the levee will be disconnected from Weeli Wolli Creek by the levee.

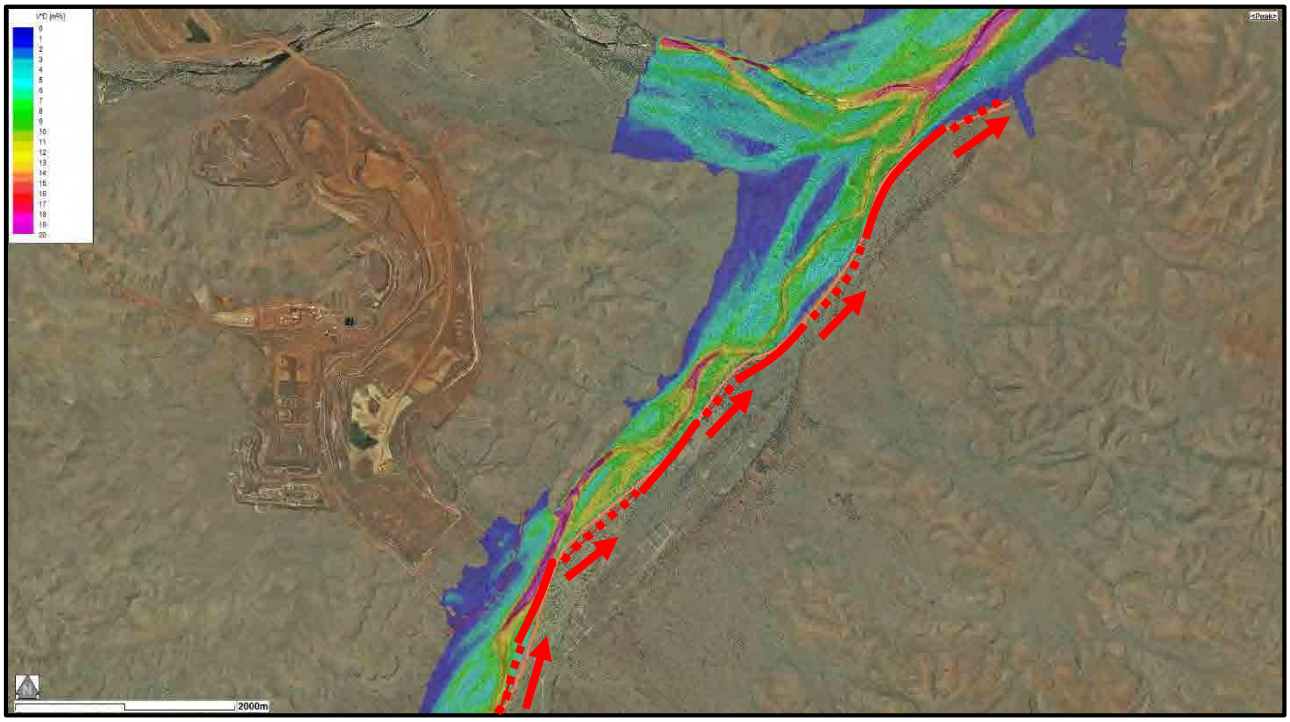

Figure 3-2: Map of flow depth times velocity for the 1% AEP flow levee scenario

Note: Key pressure points at risk from bank erosion from the main channel are indicated by solid red lines, and areas at risk from anabranch or floodplain flows are highlighted by dashed red lines. Arrows indicate the likely downstream migration of pressure points where the main channel impinges on the levee.

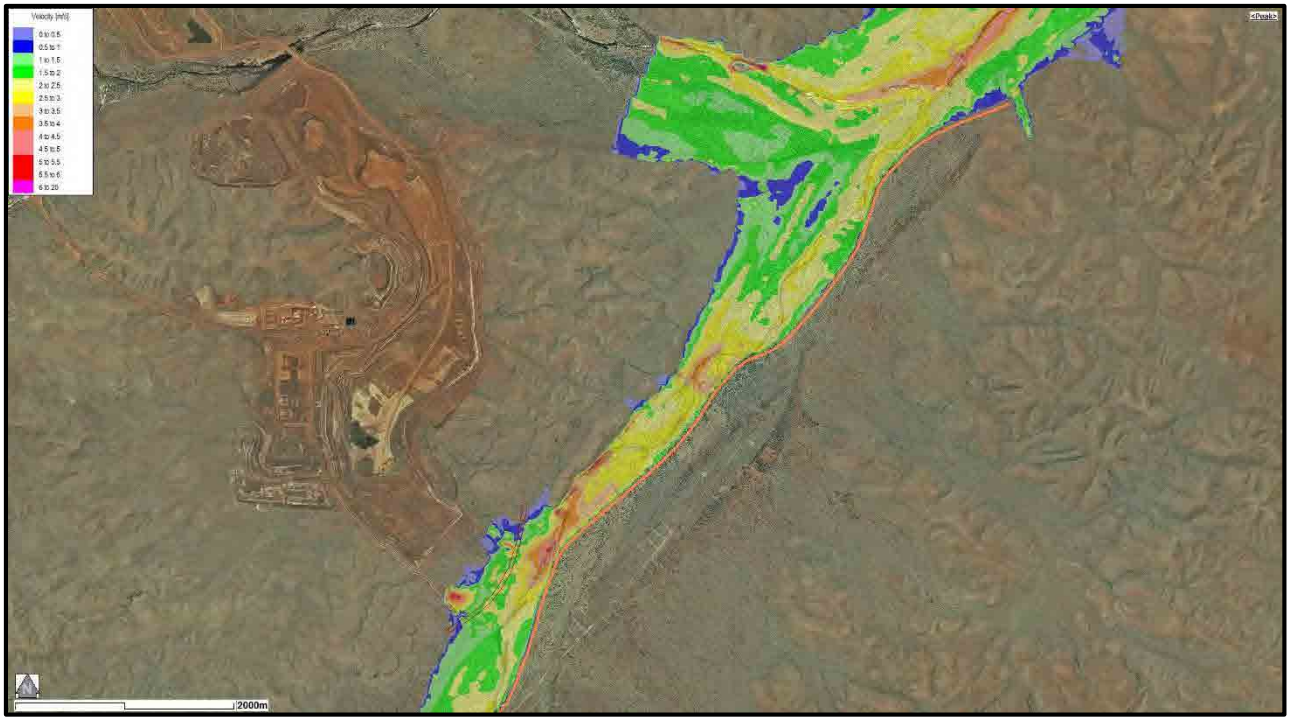

Figure 3-3: Map of velocity for the 1% AEP flow levee scenario

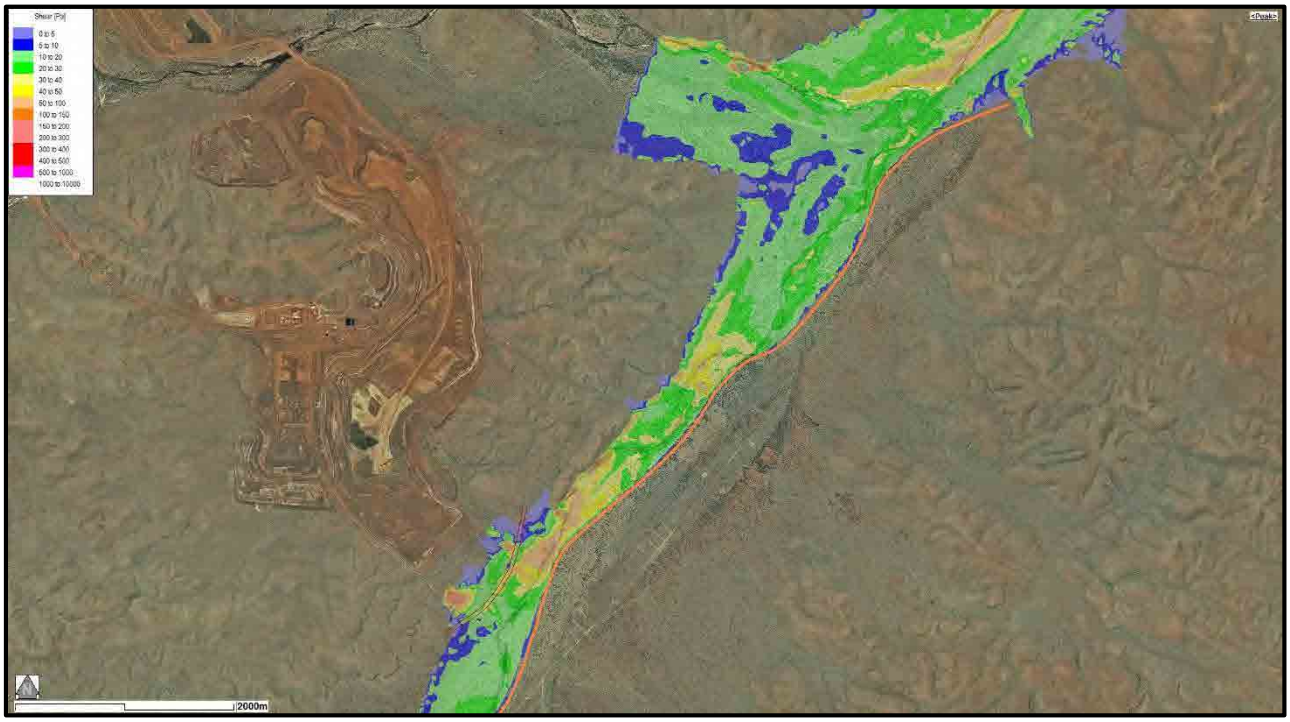

Figure 3-4: Map of shear for the 1% AEP flow levee scenario

Appendix D includes typical thresholds for various bank stabilisation materials. RTIO has incorporated guidance from U.S. Army Corps of Engineers (Fischenich, 2001) into a standard palette that is shown in the figure legends for velocity and shear (Figures C-11 to C-30). A description of the categories corresponding to each velocity and shear range is shown in Table D-1. As indicated by the hydraulic results in the constricted area (Figure C-29), localised velocities approach the threshold for 600mm D_{50} armour rock. The rock must be properly graded (i.e. D_{10} = 250mm, D_{50} = 600mm, D_{90} = 900mm) to ensure interlocking, and the rock armouring would need to be at least 2 x D_{50} deep.

Appendix D also includes Main Roads WA guidance (Tables D-2 and D-3) for armour rock sizing. As shown in the tables, Main Roads WA recommends a velocity-based approach. The ability of hydraulic forces to mobilise a particular rock size is also highly dependent on the depth, however, shear stress is a more reliable predictor of erosive potential. Velocity times depth is also commonly used to assess erosive potential or flood hazard. Figure D-1 shows the standard flood hazard mapping categories using the classification system embedded in WaterRide software. Areas of high depth times velocity indicate stronger, deeper flows; as shown in Figure D-1, the main channel is entirely in the extreme hazard classification.

Figures D-2 through D-6 show an indicative comparison of channel hydraulics for the existing condition and levee scenario in profile and section view. These figures are based on 1-dimensional modelling and should be viewed to interpret general trends rather than reflecting the results at specific cross sections.

4 Additional scenarios

Whilst this study focuses on the levee scenario, additional considerations are presented related to the proposed haul road crossing, the development of Billiard North, and Yandicoogina mine closure scenarios.

4.1 Haul road crossing

The construction of a haul road crossing across Weeli Wolli Creek and its floodplain to connect Billiard South to the existing mine at Yandicoogina has potentially significant hydraulic and geomorphological implications. The preliminary haul road alignment is shown in Figure 4-1.

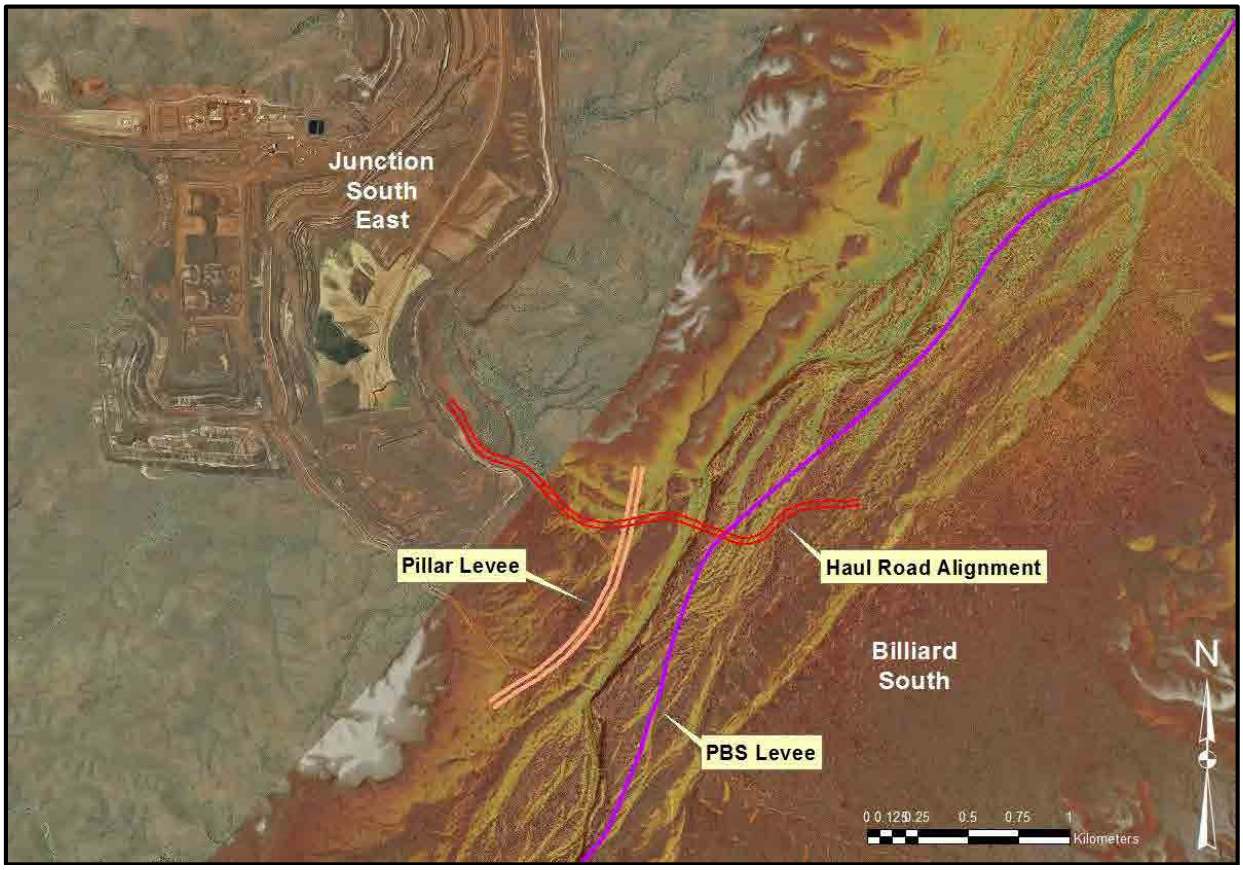

Figure 4-1: Haul Road Alignment (RTIO 2014b)

An internal RTIO hydraulic review indicated that the initial design had inadequate hydraulic capacity (RTIO 2014). Furthermore, the original design was found to be problematic in terms of hydraulic and environmental impacts (RTIO 2014). Further refinement to the design is ongoing; hence the discussion of geomorphological issues relating to a haul road crossing here are general in nature rather than referring to a specific crossing design. RTIO reported localised velocities in excess of 5 m/s for preliminary designs, which exceeds the bounds of many rip rap sizing charts and requires structural protection methods (such as those intended for spillway designs) that can accommodate supercritical flows and resist cavitation with concrete lining designs or energy dissipation structures that create a hydraulic jump.

The issues identified in this assessment relate to the geomorphological character of Weeli Wolli Creek. The creek and its flood runners consist of a gravel and cobble bed stream with large gravel bar deposits. These deposits, which are lightly vegetated with grasses, are fairly loose and subject to surficial reworking under most events into new banks and mounds. Finer fractions are subject to winnowing from the deposits and will be moved further. The floodplain surface is silty and vegetated with spinifex.

Debris load – Weeli Wolli Creek carries a debris load that includes natural timber from fallen trees. Increased vegetation growth in response to flow supplementation has increased the availability of organic material to contribute to flood debris. In addition, increased erosion in the development scenarios would generate further debris. This makes it highly likely that a culvert-type crossing as shown

in the preliminary designs would easily become partially or fully blocked during a flood. Therefore, it is important that blockage analysis be incorporated into the hydraulic assessment of the haul road design, especially for a culvert-type crossing. Debris traps, transitional inlet designs, or other design features may reduce the amount of debris build-up.

Crossing location – The confinement of flow by the PBS and Pillar Levees will lead to severe hydraulic conditions where the flow confinement is greatest, as shown by the 2D hydraulic modelling output. RTIO (2014) noted this problem in regard to the crossing location, where severe hydraulic conditions make any crossing problematic. Further hydraulic assessment would be necessary to determine the performance of the design under larger flows with potential sedimentation, scour, and culvert blockages.

Flow impedance and confinement – The degree of flow impedance and confinement by the crossing should be minimised. Both of the preliminary crossing designs indicate significant impedance of flows, resulting from filling of the floodplain and confinement of flows into a culvert-style crossing at the creek and a secondary higher level floodway. This can be expected to lead to ponding, increased flood heights and reduced velocities upstream of the crossing (promoting increased deposition) and increased velocities across the formation and downstream of the crossing (promoting scour, including the formation of scour holes in the creek bed or floodplain surface, and potentially under the culverts). There is high potential for bed foundation failure of the main opening /culverts through scouring. If hydraulic forces across the road or floodway are high and reach critical or supercritical conditions, the road or floodway embankment are most likely to fail. Energy dissipation structures may be warranted for this case but as a standalone measure are unlikely to mitigate failure. Hydraulic loadings would be exacerbated if energy gradient is steepened by downstream scour, or if the culvert crossing is blocked by debris, diverting additional flow over the formation. Sudden failure of the floodway or embankment could lead to significant floodplain scour and potentially to channel avulsion. There is also potential for the hydraulic impacts resulting from flow impedance and confinement by the crossing to threaten the integrity of the levee (via elevated flood levels, increased velocities and turbulence from flow eddies), potentially resulting in levee failure.

The following design criteria would help minimise impedance and confinement of flow:

- Minimum loss of floodplain cross section and flood channel;
- Establish the haul road at the floodplain surface;
- Open spans rather than culverts over the main channel and large openings on flood runners;
- No further compression of floodplain with haul road ramps over levees.

Foundations – Weeli Wolli Creek in the study area flows through unconsolidated gravelly alluvium. The depth to bedrock or other consolidated material that would provide a stable foundation is unknown. Geotechnical investigations should be undertaken to determine suitable foundations for the structural components of the proposed crossing.

The hydraulic standard for designing the haul road should be the same as for the levee, namely the 0.5% AEP flow. This is due to the potential for hydraulic changes resulting from the haul road to destabilise the creek channel and the levee, including the risk of levee failure. If the crossing is designed to meet the above criteria, it may become submerged at or above the bankfull discharge stage (of the primary channel).

4.2 Billiard North development

Although this study focuses on Billiard South, mine planning for the JSE and Billiard North deposits is relevant to the closure design for Billiard South. Under the current mine plan, overburden waste from Billiard South will be used to backfill the JSE pits, and waste from Billiard North will potentially be used to backfill Billiard South. Mining of the Billiard North Deposit is not expected to commence until around 2027, and any proposed use of material from Billiard North is subject to further environmental approvals for applications that may be submitted in the meantime.

JSE is outside of the Weeli Wolli Creek floodplain and is not further considered here.

The Billiard North deposit extensively overlaps the Weeli Wolli Creek floodplain. Development of this deposit is likely to require substantial constriction or diversion of Weeli Wolli Creek and disconnection of large areas of floodplain. The Marillana Creek confluence area may potentially require relocation as well and may involve a series of diversions implemented at various stages of the mine plan. Such extensive changes bring many significant geomorphological risks, including loss of channel and floodplain habitat; channel, floodplain and infrastructure stability issues associated with floodplain compression (as

discussed above for Billiard South in Chapter 3 and Section 4.1); scour and sedimentation issues that extend beyond tenement boundaries; and risks associated with failure of stream diversions (including habitat and stability issues).

As well as affecting the project area, there may be upstream and downstream impacts. Flow constriction in the Billiard North project area may have upstream backwater effects that result in additional deposition upstream. Erosion originating in the Billiard North project area could migrate upstream by headward processes, leading to extensive destabilisation of the creek system near Greys Crossing.

Channelising the creek to enable Billiard North establishment and operation may result in a higher energy environment than the natural system. If the diversion channel is designed to remain stable and prevent scour or aggradation, the reach would act as a pass-through for sediment transport, and material that might otherwise have deposited in this reach will be transported further downstream than under the existing conditions. The discharge of the confined flow could lead to a zone of instability downstream of the confined or diverted channel, where the creek adjusts to the downstream change in hydraulic conditions (similar to an alluvial fan). Increased sediment mobilisation within and upstream of the project area could result in increased sediment export to downstream reaches.

Overall, the potential development of the Billiard North deposits appears to have high geomorphological risks; a separate detailed evaluation beyond the scope of this study is recommended.

4.3 Closure scenarios

The stated goals of the April 2014 Yandicoogina Closure Plan related to surface water include:

- maintenance of the Weeli Wolli Creek system;
- creating stable landforms;
- ensuring rehabilitated landforms are stable and designed to manage floodwater appropriately;
- ensuring water systems support existing riparian vegetation and are compatible with the natural system dynamics;
- establishing ecosystems with similar biodiversity and cultural heritage values as surrounding reference sites;
- maintaining environmental and cultural heritage values associated with creek flows and function;
- retaining environmental values of Fortescue Marsh;
- ensure water quality within pit lakes support natural ecosystems and are appropriate for use;
- minimise impacts to surface water flow paths, volumes and levels.

Appendix D of the Yandicoogina Closure Plan (RTIO 2014) outlines six options for closure:

1. No backfill (all voids become lakes);
2. Backfill to pre-mining water table (material would be mined from adjacent hills to achieve this scenario);
3. Maintaining creek flows (with lakes, including a large on-stream lake on Weeli Wolli Creek extending downstream from the Marillana Creek confluence);
4. Multiple small, deep lakes (Weeli Wolli Creek captured);
5. One permanent lake (large lake captures Weeli Wolli Creek); and
6. Continuous channel (large lake in palaeo valley, all creeks captured).

At present, Option #3 is preferred by RTIO as representing the optimal balance of known constraints. Figure 4-2 shows the final post-closure landforms.

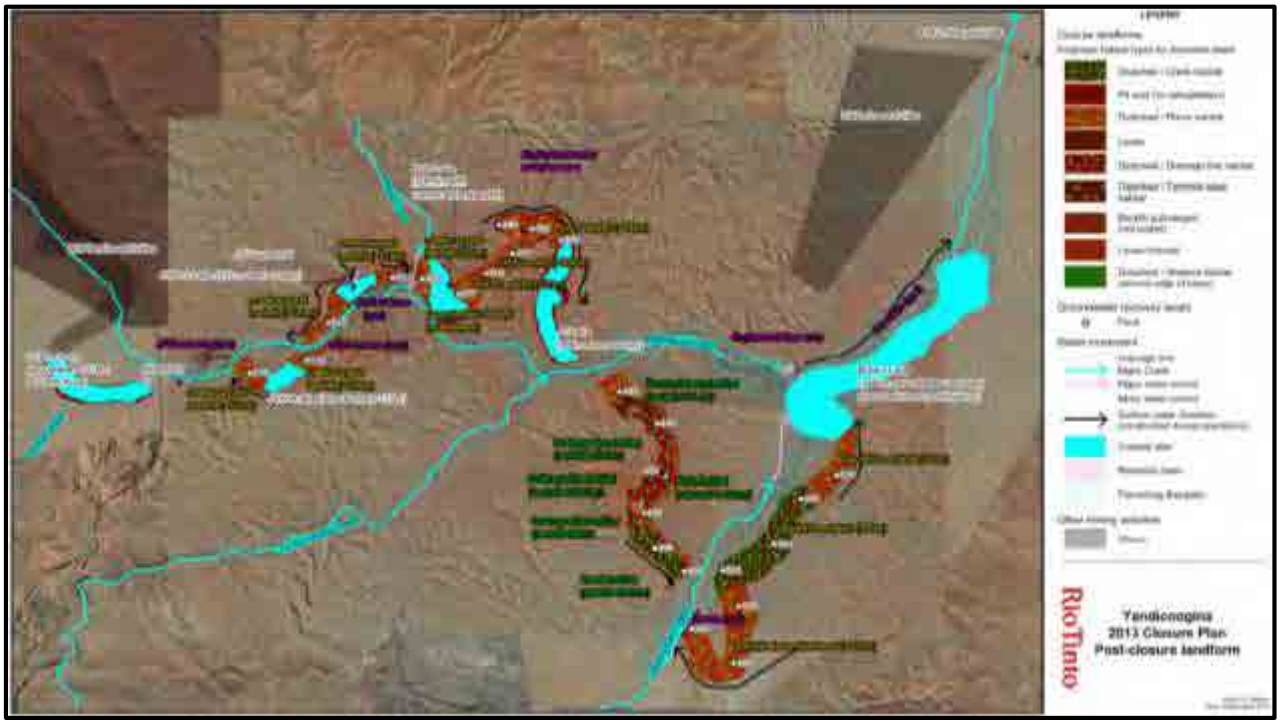

Figure 4-2: Post-closure landforms (RTIO 2014a)

An additional scenario is being considered in the event that the development of the Billiard North Deposit is not approved. This scenario includes a permanent lake or series of lakes within the Billiard South Deposit area rather than the Billiard North lake shown in Figure 4.2. It is recognised that both scenarios (approval and non-approval) must be considered until the outcome of the Billiard North approval is known.

Although Marillana Creek is shown as being diverted around the permanent lake in Figure 4-2, levee functionality is highly dependent on regular maintenance, and any engineered structure that is abandoned without maintenance will thus have a finite design life. Levee failure can result from cracking, animal burrowing or undermining, overtopping, vegetation growth (decomposition or overturning), localised erosion, geotechnical failure, or a number of other mechanisms. A single failure point will cause an entire levee to be ineffective. As such, closure scenarios that leave a pit within a floodplain should account for the potential of creek capture. Any engineered structures left in place or constructed at closure will provide additional protection but are not expected to be permanent structures that remain functional in perpetuity. Ongoing monitoring and maintenance would be required to ensure the continued integrity of the structures.

If utilised as part of the diversion plan, critical components of future levee design phases include assessment of durability, predicted long-term performance without maintenance, and erodibility if overtopped. For flow that is re-established across backfill, critical features of the pit backfill design include the infiltration rate relative to the pre-mining condition, re-establishment of drainage paths and active channel migration over the backfill, erodibility of the backfill material when inundated by floodplain flows, and settlement that might result in permanent standing water.

As shown in Figure 4-2, a permanent lake would be established in the Billiard North area. This scenario would have long-term impacts on the sediment and surface water conveyed to the downstream reach. Extreme flood flows may fill the lake and create through-flow conditions; however, the entire bed load would be retained in the void, increasing the erosive potential of the exiting flows. Downstream flow frequency and floodplain connectivity would be significantly affected as peak flows are attenuated by the storage capacity available in the void. Further studies will be required to predict environmental impacts to downstream receptors, particularly in terms of surface water delivery to the Fortescue Marsh.

From a geomorphological viewpoint, a key risk for the rehabilitated landforms at Billiard South will be the avulsion of Weeli Wolli Creek into the former mine. This risk would apply if the mine is filled and revegetated to recreate habitat that functions similarly to the pre-mining areas (as is proposed if the Billiard North development proceeds, providing material for backfill of the Billiard South mine). This risk would also apply if Billiard South is rehabilitated to one or more off-stream lakes. The risk of avulsion

could be mitigated through careful design incorporating rigorous hydraulic and geomorphological requirements. It will be important to ensure that ground surface levels and hydraulic conditions in the rehabilitated landforms are designed to minimise this risk.

If Billiard South is rehabilitated to an in-stream lake (as may occur if Billiard North does not proceed), there would be impacts resulting from disruption of sediment transport, as discussed above for Option 3.

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Appendix A Site Visit Notes

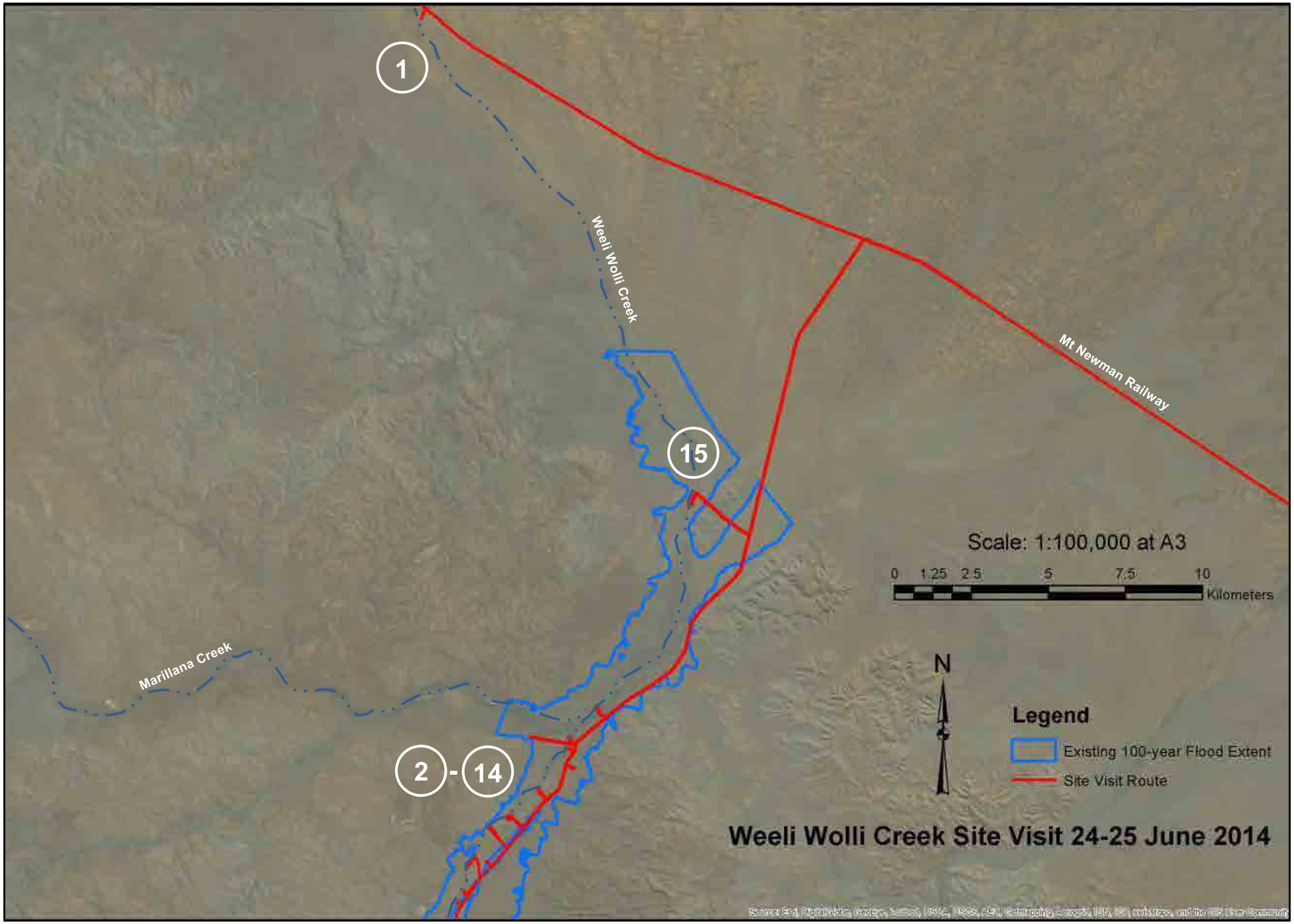


Figure A-1 Overview of Site Visit Route

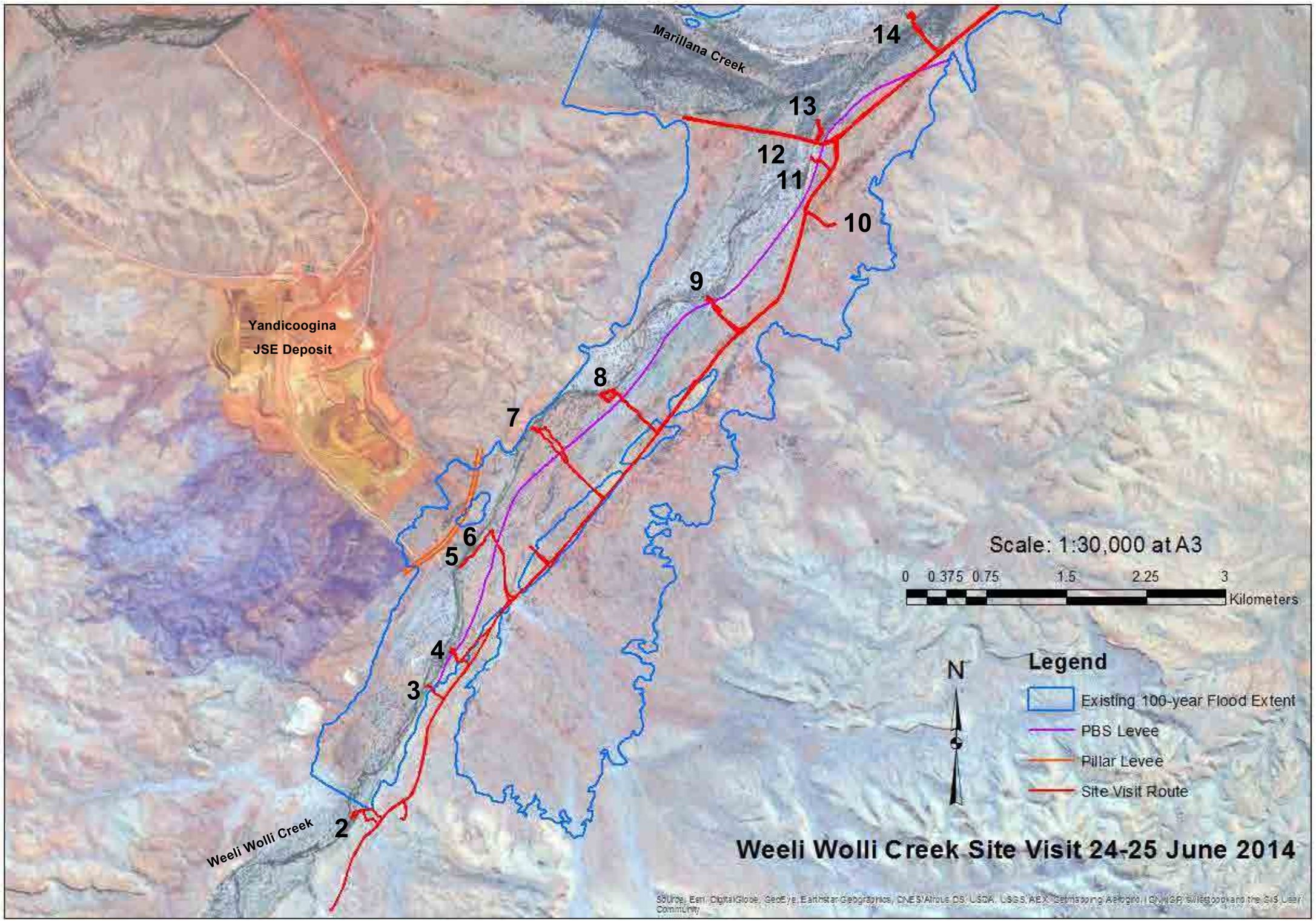


Figure A-2 Site Visit Creek Access Locations

Table A-1: Site Visit Notes

Weeli Wolli Creek Geomorphic Condition Assessment				
Sites Inspected	**27/28 June 2014**			
General notes	Conditions dry - no antecedent rain - base flow from Hope Downs and Yandi JSE evident			Weeli Wolli Creek is flows in a generally NNE direction through the Hamersley Range in a series of valleys carved into ancient bedrock. In the study area, it has a gravel, sand and cobble bed. Generally ephemeral but base flows have been supplemented by mine dewatering from Hope Downs and Yandi JSE downstream to North east of the Marillana Creek Junction. A feature of the immediate wetted perimeter in the supplemented reach was the strong recruitment of river red gums with 3 distinct year age classes over the last 7-8 years – possibly due to wet seasons setting off seeding behaviours and also a wet substrate into which the new trees could recruit. These new trees increase the roughness coefficient. A general feature was the presence of large gravel banks in the low flow channel plus multiple flood runners and gravel banks and active high flow channels, with finer material up on the floodplain benches above, where velocities were lower amongst the spinifex

Site number	Site description	Lat	Long	Conditions description
1	Lower Weeli Wolli near head of marshes U/s Railway and east of Munjina - Roy Hill Road	731514	7500912	Large deeply incised channel 45m wide by 8m deep - well rounded gravel and cobble beds with wave bedforms - up to 2 m down edges of toe of banks - with deep fine to coarse silt overlays - silt drapes on banks. No silt levees on upper bank - indicating limited overtopping - some tree losses on banks - no instream macrophytes. Highly dynamic - ephemeral - subject to major flood flows only. Gravels and cobbles reworked from banks ?? limited d/s transport of gravels, pebbles and cobbles - Next channel east not active - good vegetation cover - shrubs & small trees - 2nd east is active - 40 m wide and fine to medium silt over gravels and small rock - dryland
2	Upper end of study reach upstream of proposed levee system for Billiard Sth	731 984	747 1089	Confined stream section - primary channel 15-20 m 5m deep. Floodplain 210 m wide - Multiple flood runners - some with gravels and coarse sands - tree damage by floods - shifting gravel beds with cobbles up to 180mm - well rounded and worked but freshly won and fractured material evident from bank winning against foothills. Large trash load - small tree and Phragmites debris. Multiple gravel dumps in main active channel - steep batters - Manning's 0.065?? Base flow 110ML/day with pools held by gravel bars and small runs

3	Near start of levees and compression point - ref section 11514.42	732 724	747 2283	Floodplain 600 m wide - mainly on left bank (LB) - multiple channels on right bank (RB).
3a	major channel deviation ref section 9396	732 802	747 2479	Large outcrop of calcrete in RB deflecting flow to LB side at water level and above - wide floodplain on LB with 2 major flood runners - rock sizing from med sand to 150 mm cobbles - 20 – 100 mm dominant
4	Us/ Pillar (ref section 8769)	732 921	747 2645	Straight angle section from calcrete redirection - long pool u/s. Multiple channels RB - step off from prior floodplain with active runner in RB - steep LB – reduced limited floodplain
5	Near Pillar Levee (U/s ref section 8308)	732 986	747 3498	Large RB silt/gravel levee - prior floodplain to RB - old runners on LB - (prior floodplain). Main channel well formed with pools and gravel bar controls. Rock sizing - coarse sand to 150 mm cobbles
6	Junction of inputs from JC - us of proposed haul road (ref section 8308) - HIGH conflict zone	733 561	747 4470	Confined section stream over against LB in well-defined channel - Strong levee /gravel dump RB with old flood runner on RB side - An old prior floodplain - Rock sizing 20 – 100 mm - with small gravel and coarse sand - a lot of broken rock fragments – newly won material from left bank
7	Straight section up against hill 1300 m D/s haul Road u/s of section 6901	733 727	747 4692	Large active floodplain RB with runners but fine silts - Prior floodplain step to active floodplain - multiple runners to main channel against the RB - main channel 20 m only a lot of veg damage - lots of recruitment of new trees - rock sizing small. Gravel dumps to 3 m high. Pools all gravel bar controlled
7a	u/s bend d/s end from straight against LB hill (u/s ref section 6901)	733 680	747 4725	Pools with Gravel Bar controls - semi imbrication on channel runners - large RB floodplain - only one runner - Prior floodplain step - lots of fine silt on upper floodplain
8	Start of meandering section u/s of section 6184	734 326	747 5049	First meander bend d/s of confined valley - broad shallow channel - multiple runners with lots of gravel - Multiple gravel mounds - grain size coarse sand to large cobbles to 150 mm. - Floodplain 400 m wide - silt levee RB - with prior floodplain behind - fine silts

9	levee conflict zone	735 325	747 5952	Channel on RB with only one runner to prior FP?? - Large sed/gravel levee adj to main channel - main channel section 200 m wide - lots of gravel banks and pools - 5m deep. Other flood runners on LB - rock sizing variable less fines - 20 - 120 mm. Meander active against RB – increased levels of Typha- less shading?
10	Looking for potential break away to RB around old sand island Ref section 6901u/s	735 655	7475562	LB minor catchment's floodway breaks to main channel over road - high subject to some minor break away on 0.001% event?? - road up on ancient silt mound - drops away to west. Broad overland flow path recrosses track prior to silt Island DS [no photos]
11	U/s of Grey Crossing	736 292	747 7258	Large pools with typha - little sign of large sediment transfer d/s - one main channel 40 m wide by 3 m deep - but multiple channels in FP to LB with gravel bars to 2 m high. Also wide higher level terrace to LB - 500 m wide – with old inactive channels - full of veg - Large regeneration of recruiting trees due to continual wetness in main active channels. Gravel banks d/s 2 m high. Step up from active floodplain 3-4 m river terrace
12	Greys Crossing Main floodplain and channel u/s Yandi Road Crossing	736 292	747 7429	Large pools with Typha - little sign of active large particulate sediment transfer d/s - one main channel 40 m w by 3 m deep - but multiple channel in FP to LB with gravel bars to 2 m high - channel. Also wide higher level terrace to LB - <500 m wide - old inactive channels - full of veg - Large regeneration of recruiting trees due to continual wetness in active channel . Gravel banks d/s 2 m high. Step up from active floodplain 3-4 m to higher River terrace
13	D/s Greys Crossing - large pools drying - dead algae	736 351	747 7621	Wide gravel bed stream within shallow Floodplain - many flood runners - fine sediments. 2m +high gravel banks and lots of debris. Lower water levels ?? Due to losses to deeper gravel beds - flows low. Calcrete in RB - LB 3 m high vs. 1.5 in RB - hence runners in LB FP Gravel/pebble/Cobble size 20- 120 mm - some large rocks at crossing – bought in for crossing construction- high LWD debris and vegetative trash loads
14	d/s Marillana Junction	737 265	747 8580	Very wide gravel bed stream with large shallow pools within broad shallow active channel - many flood runners - fine sediments on RB. 2m +high Gravel banks and lots of debris. Lower water levels ?? Due to losses to deeper gravel beds - flows low. Calcrete in RB - LB 3 m high vs. 1.5 in RB - hence runners in LB FP Cobble size 20- 120 mm - some large rocks - high debris loads. Overall floodplain nearly 950 m wide with an older terrace step on LB

15	At Valley choke 9.2km d/s of Greys Crossing	740 295	748 5191	Broad deep cobble bed - limited fines - all 20 mm upwards to flat cobbles 150 diameter -- areas of imbrication - some gravel beds 2- 3 m high - dramatic photo of dynamic shifts - roots in tree up 1.8 m above the bed - Floodplain and stream 340 m wide - main channel incised 2 m - multiple runners separated by gravel banks - some steep bow fronts indicating cascading movement - of 20- 50 mm size material - a lot of winnowing going on indicated by size sorting and a general lack of finer material

Appendix B Historical Aerial Photo Analysis

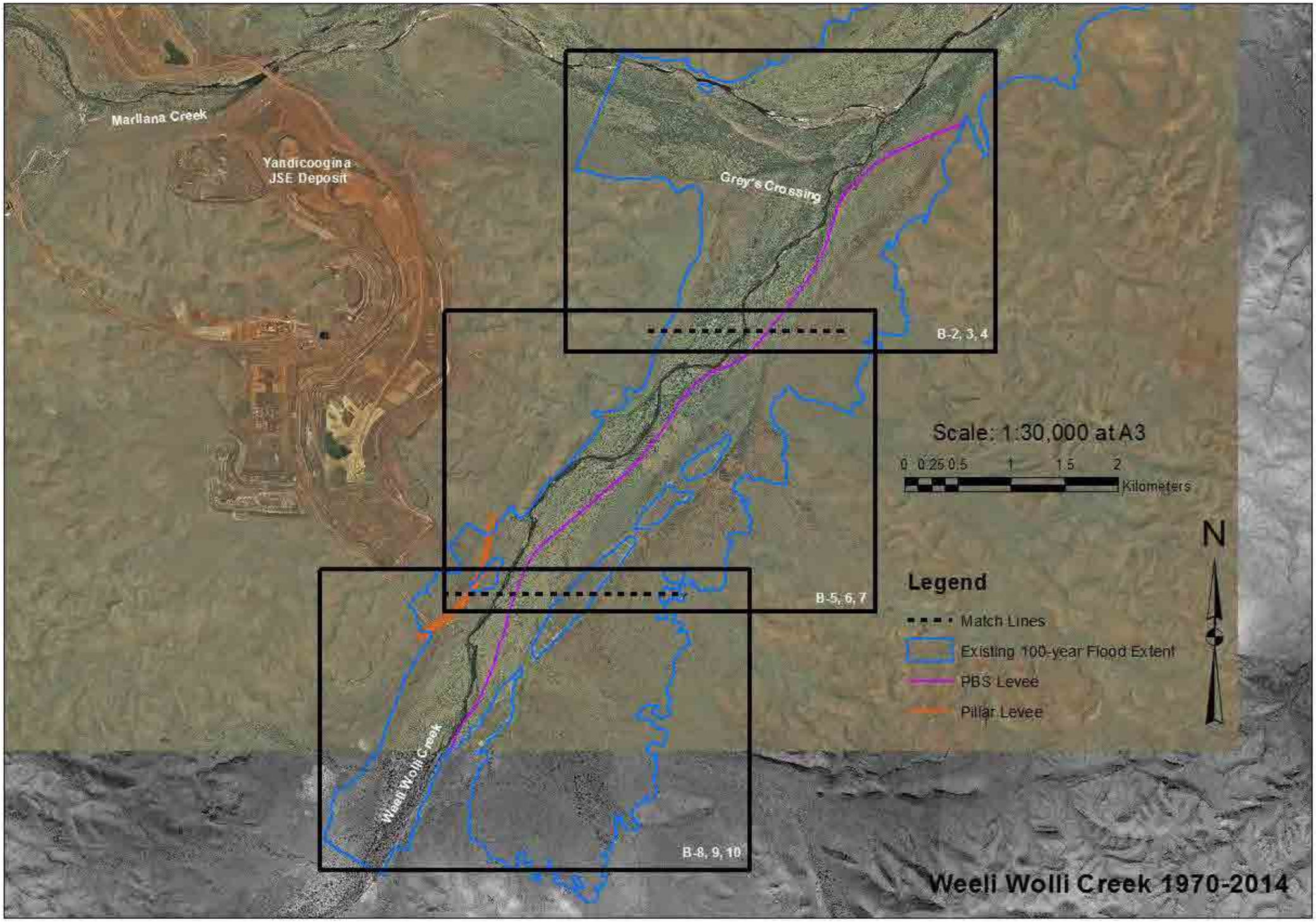


Figure B-1 Overview

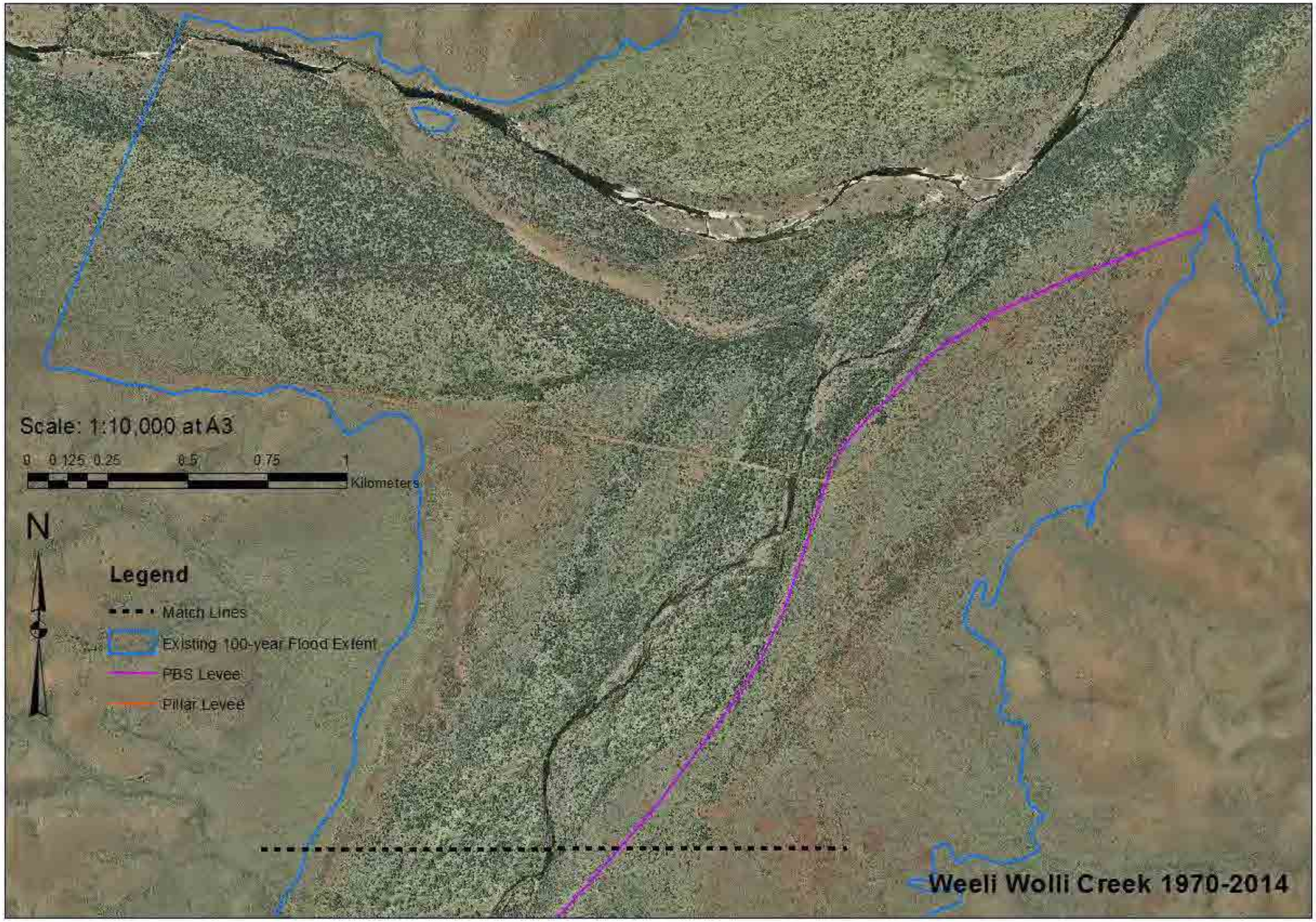


Figure B-2 Downstream Reach with 2014 Aerial

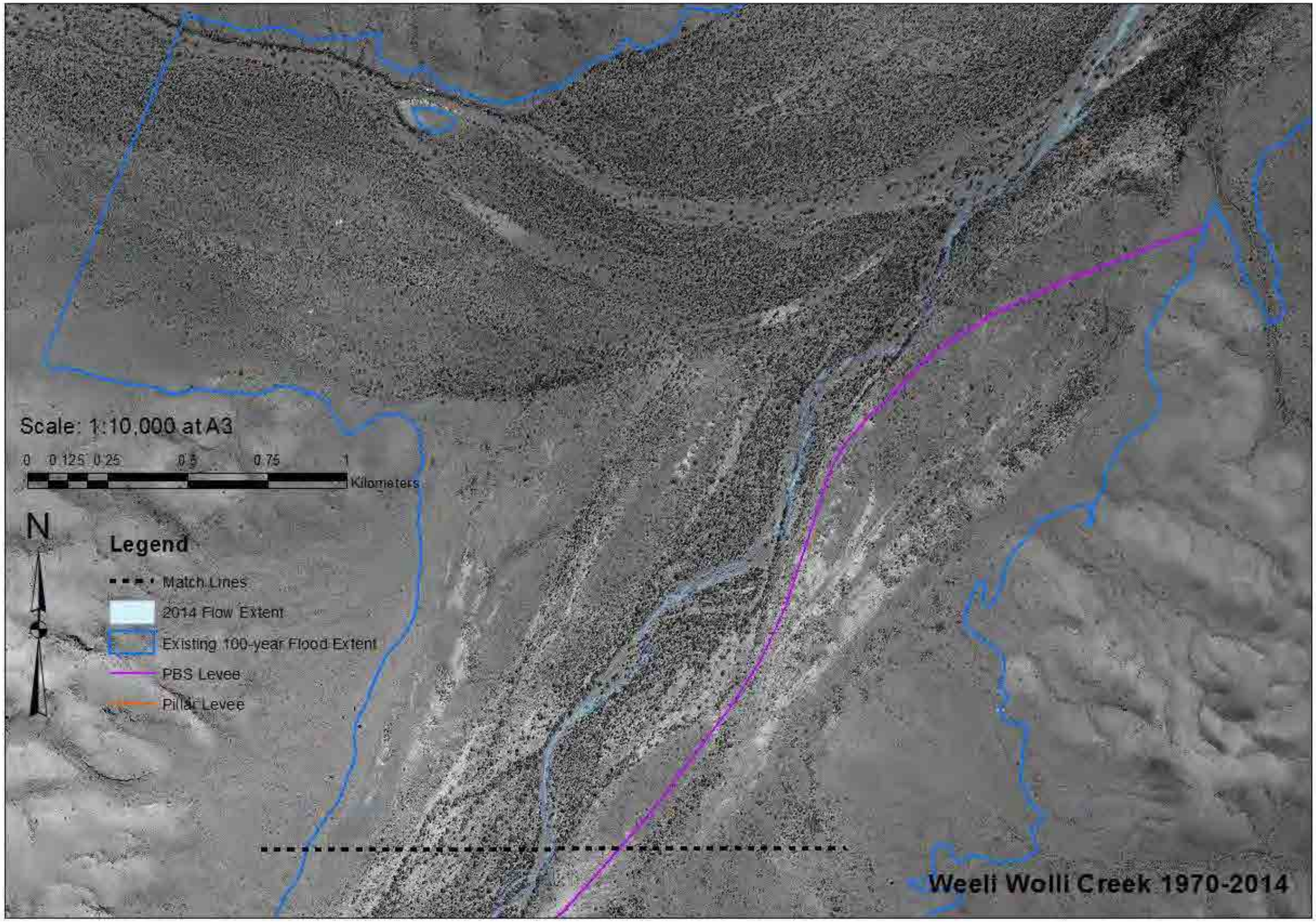


Figure B-3 Downstream Reach with 1970 Aerial and 2014 Flow Extent

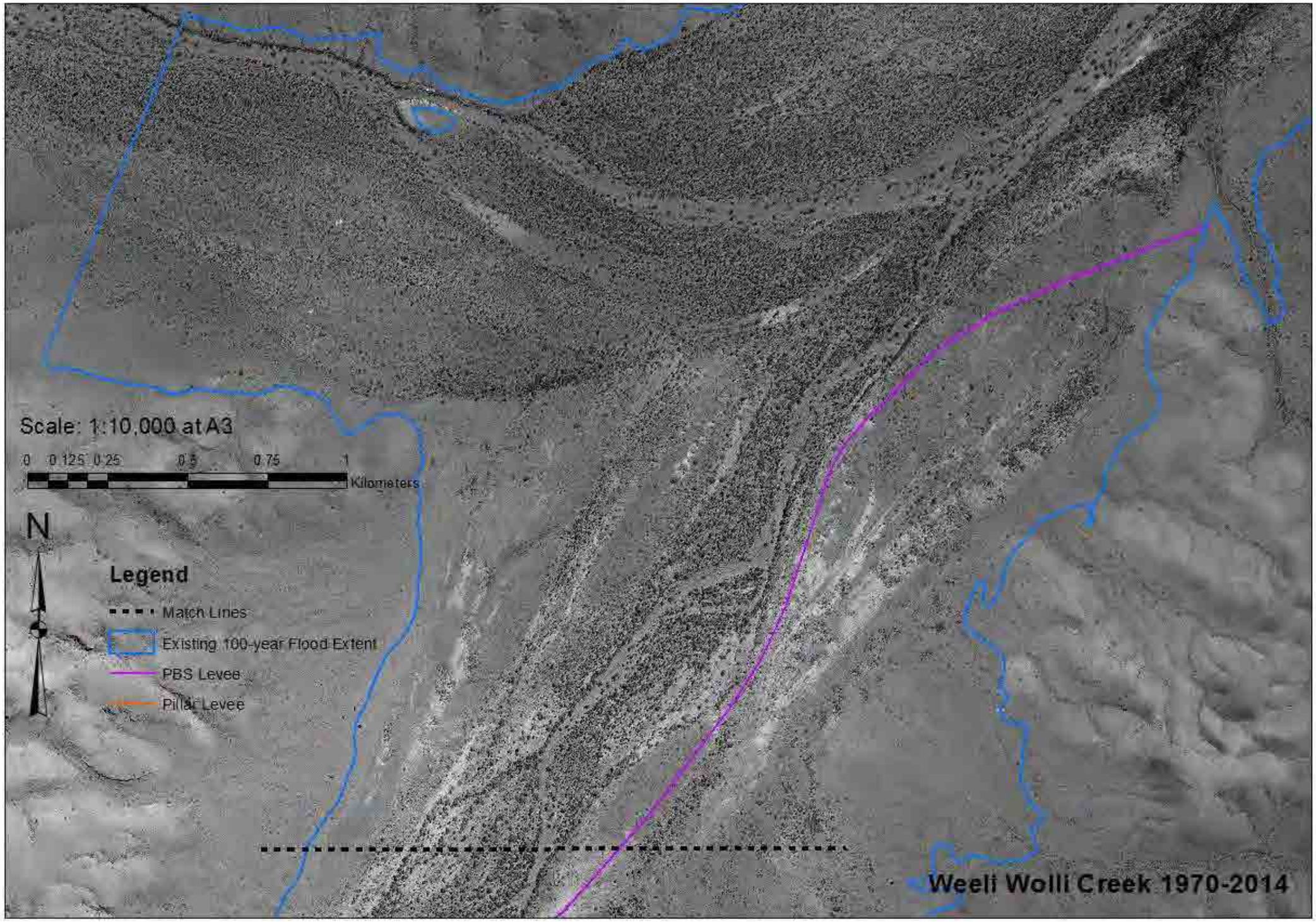


Figure B-4 Downstream Reach with 1970 Aerial Background

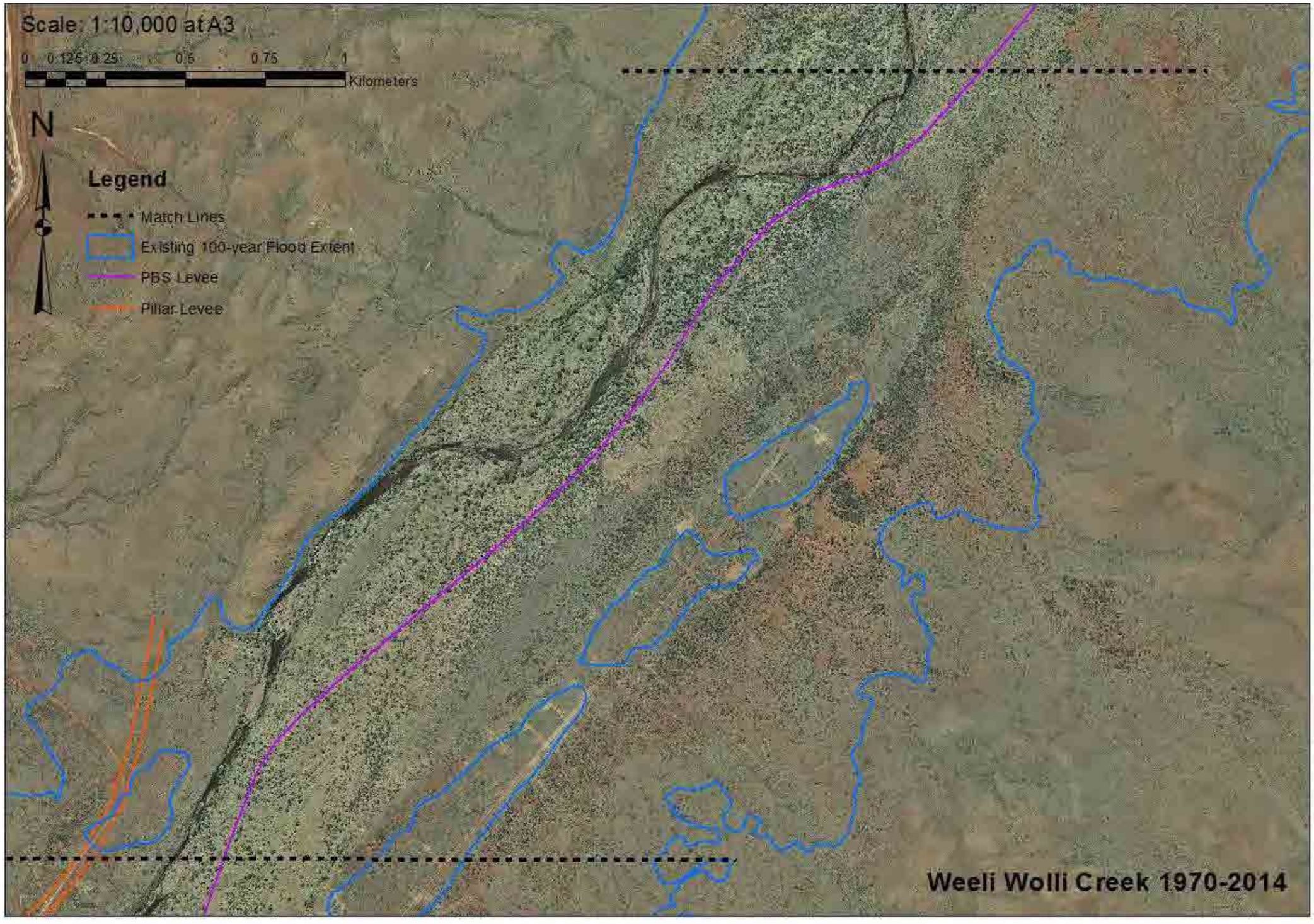


Figure B-5 Middle Reach with 2014 Aerial Background

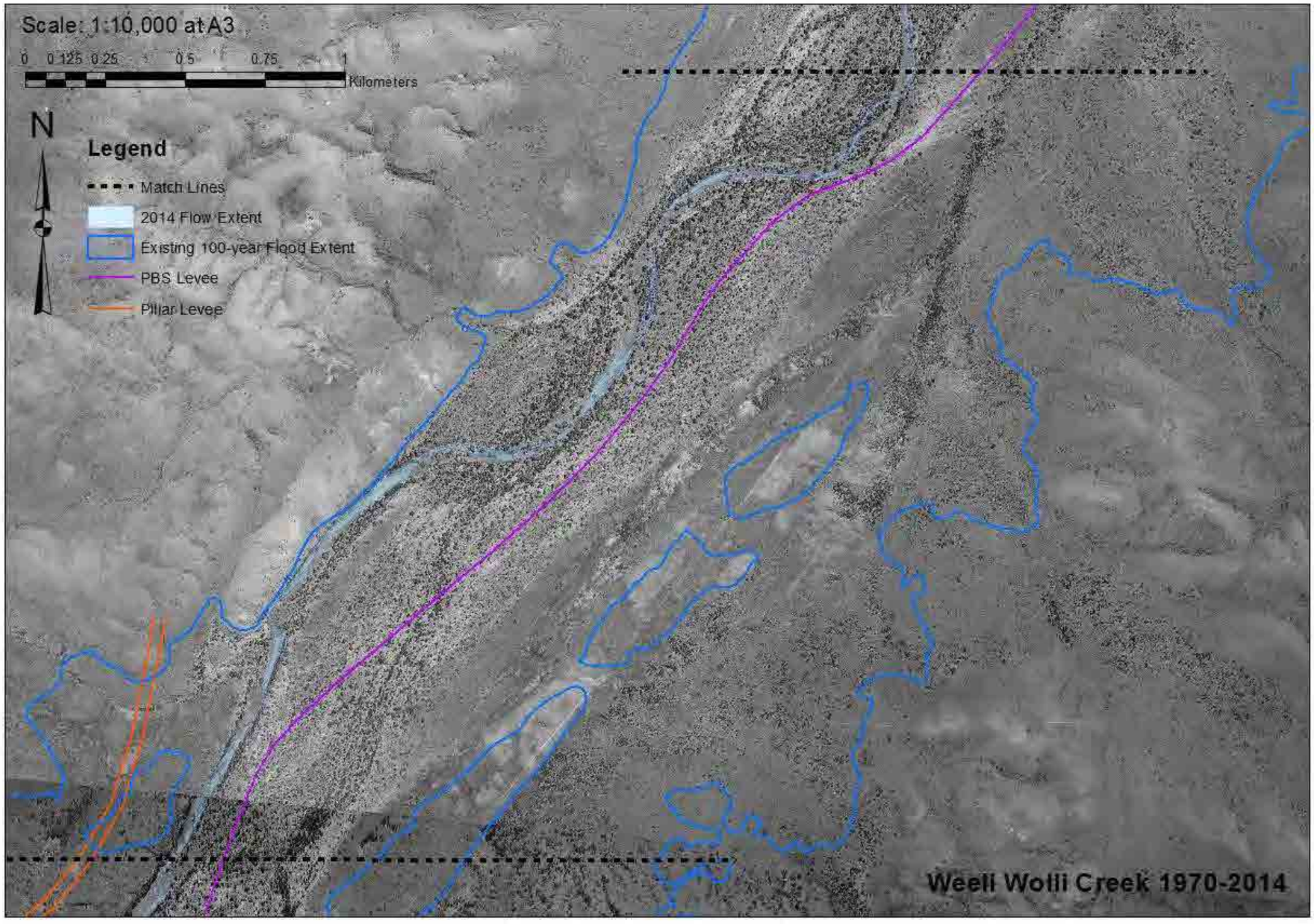


Figure B-6 Middle Reach with 1970 Aerial Background and 2014 Flow Extent

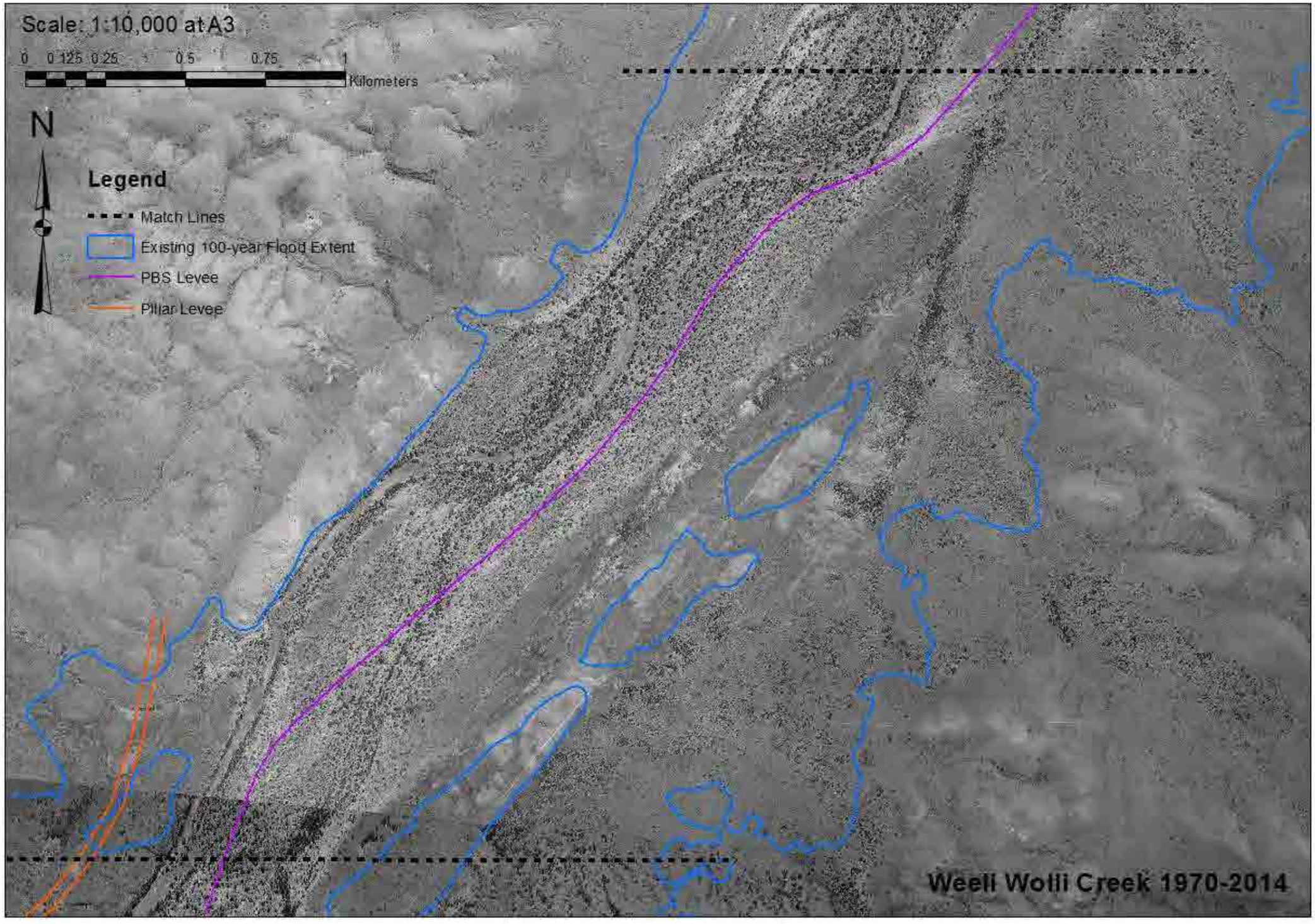


Figure B-7 Middle Reach with 1970 Aerial Background

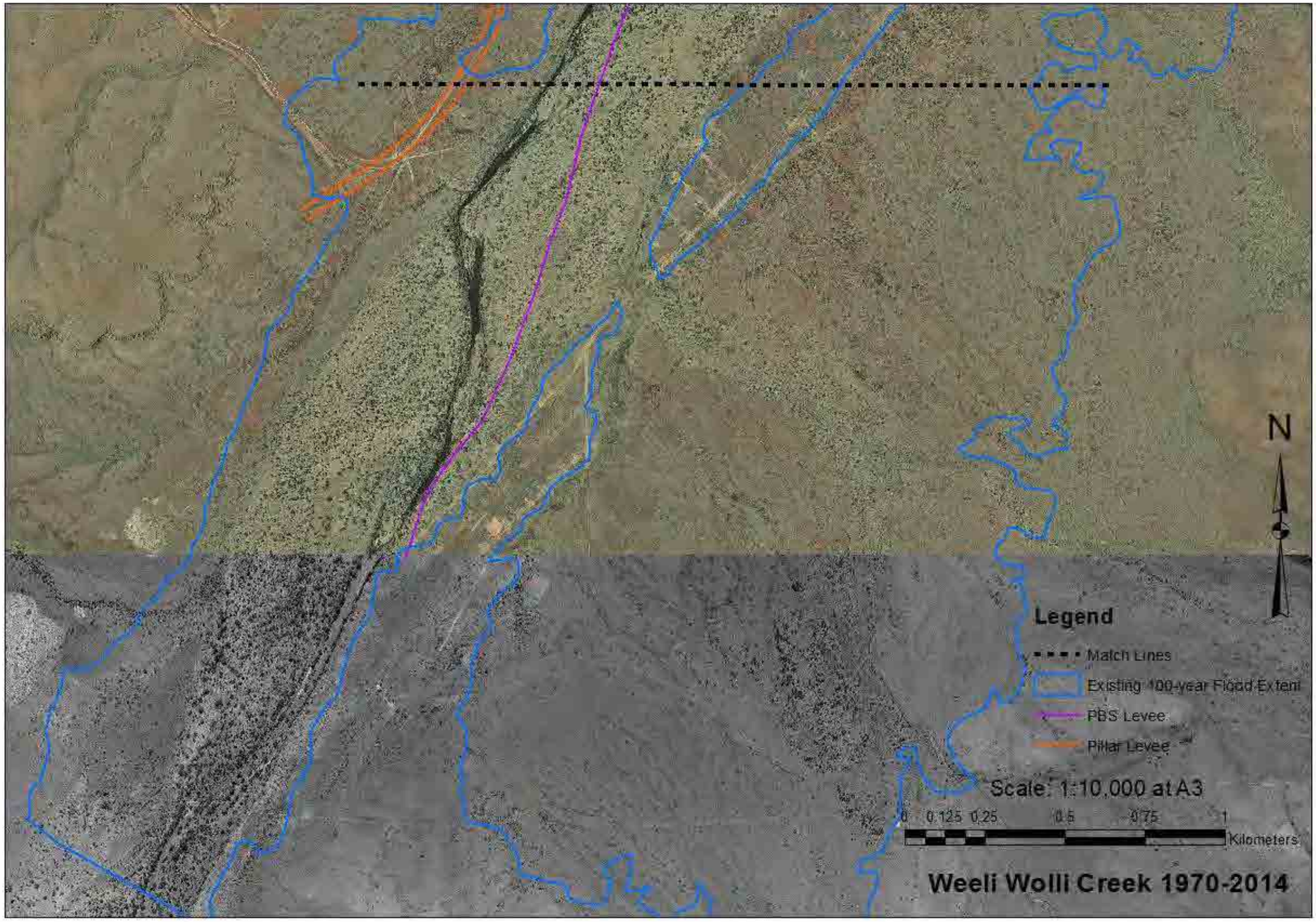


Figure B-8 Upstream Reach with 2014 Aerial Background

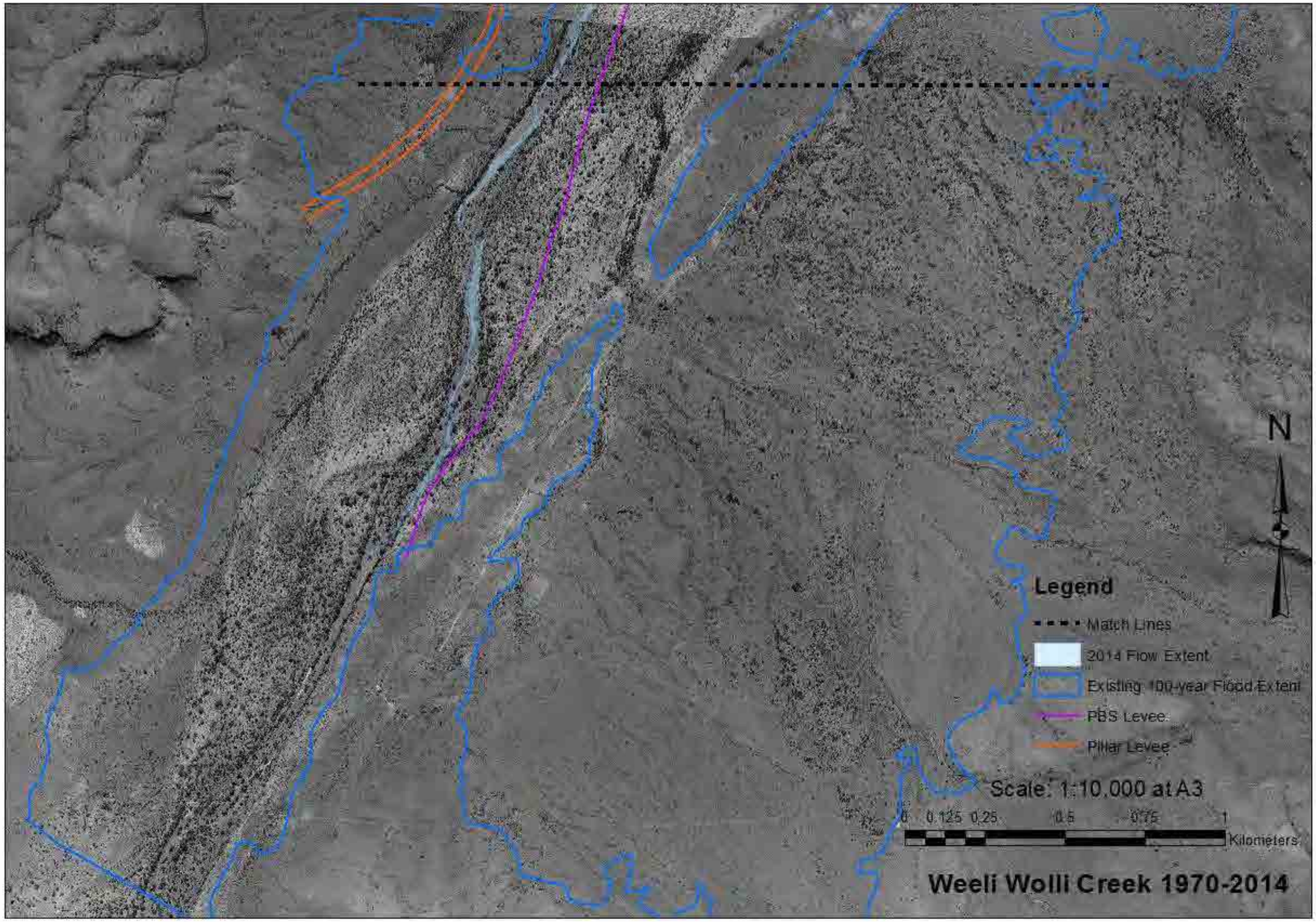


Figure B-9 Upstream Reach with 1970 Aerial Background and 2014 Flow Extent

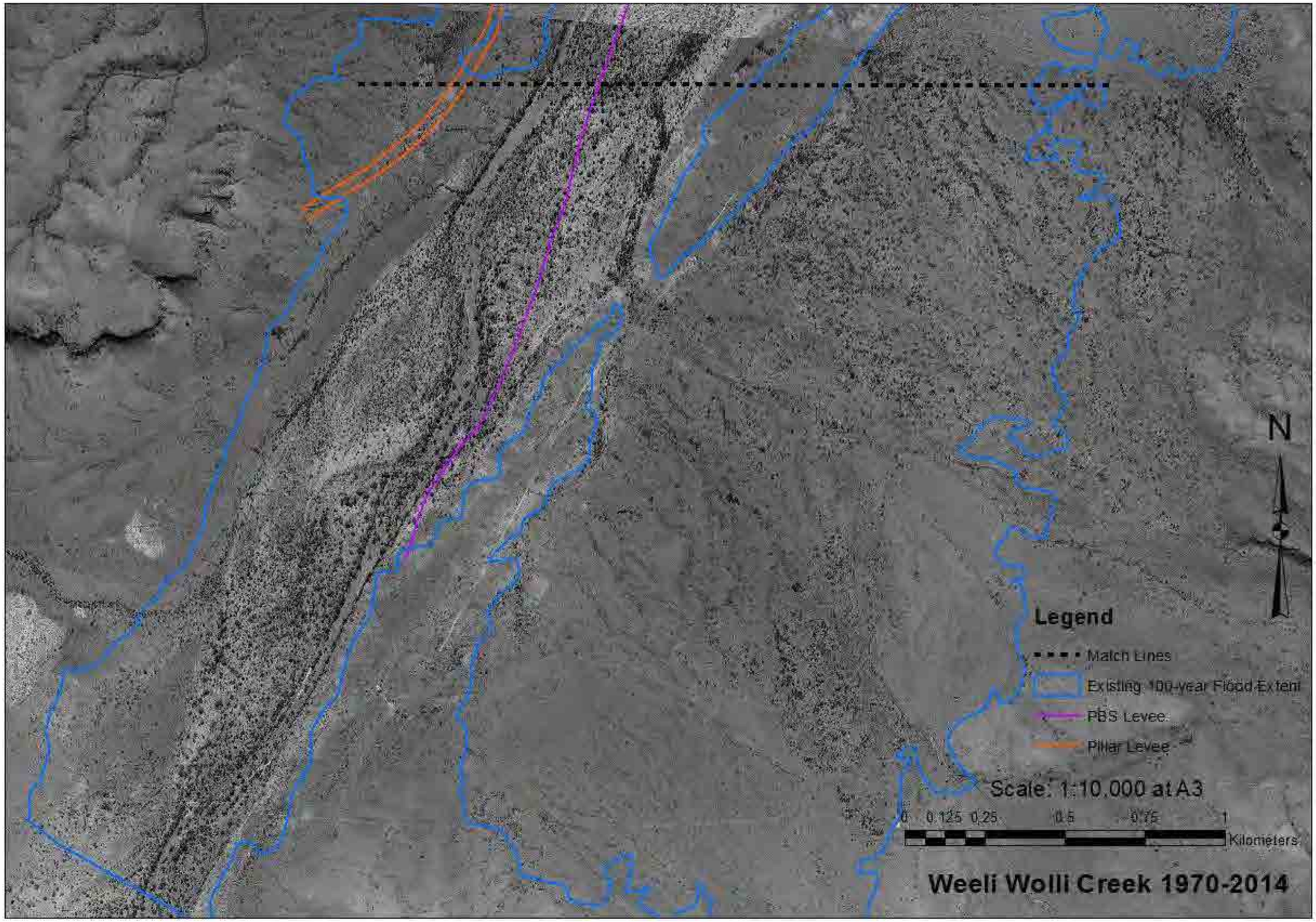


Figure B-10 Upstream Reach with 1970 Aerial Background

Appendix C 2-Dimensional Hydraulic Results

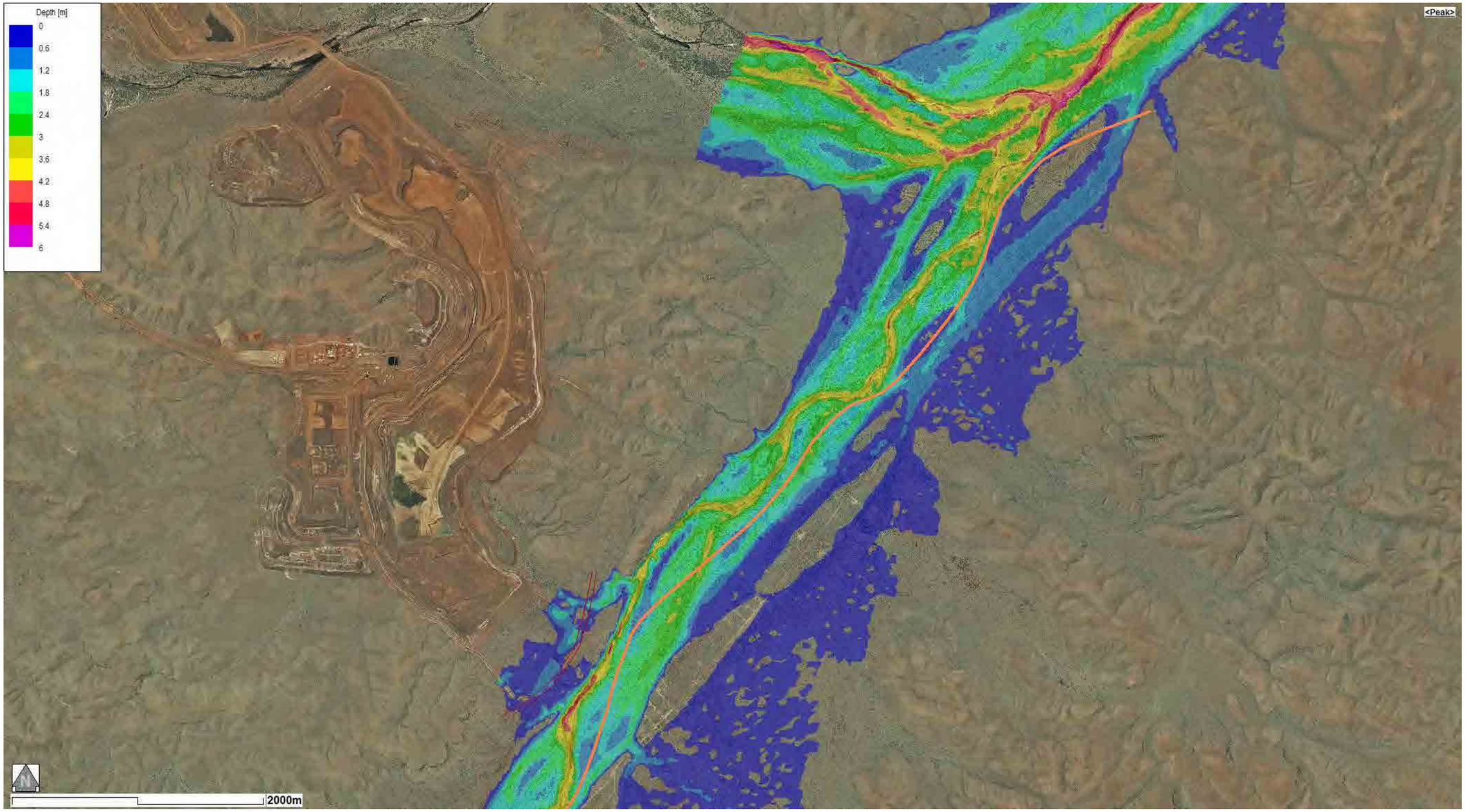


Figure C-1 2% AEP Existing Condition Depth

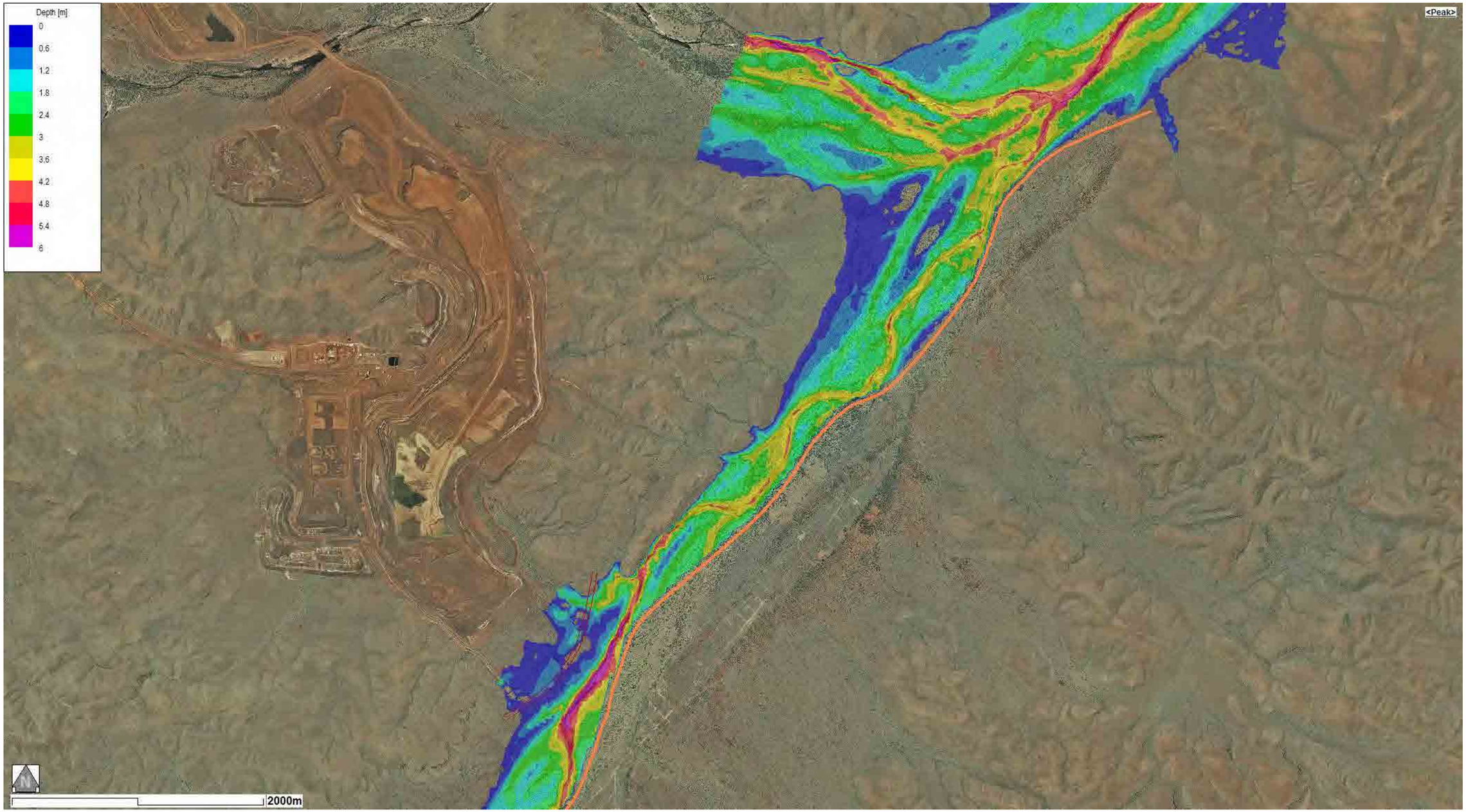


Figure C-2 2% AEP Levee Scenario Depth

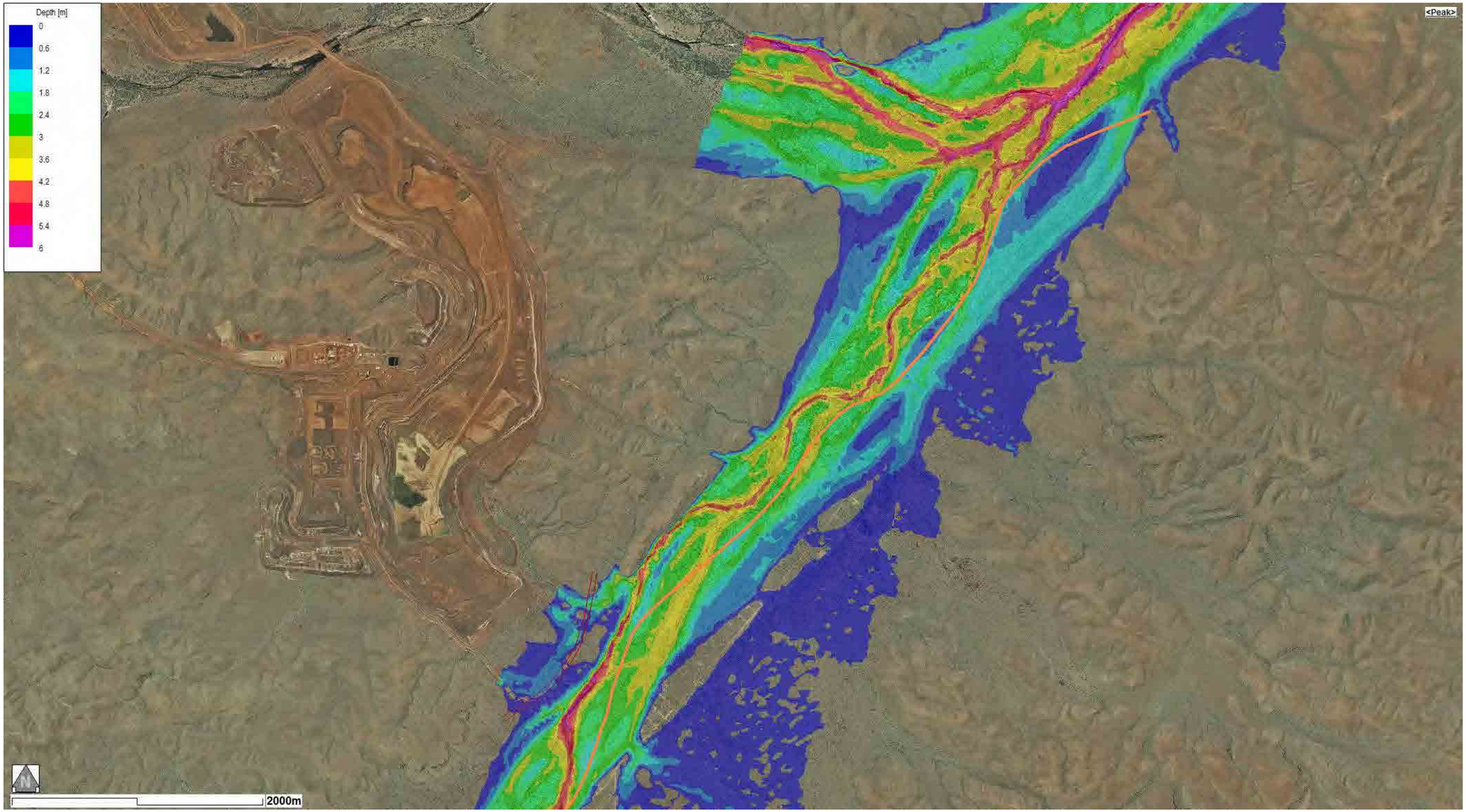
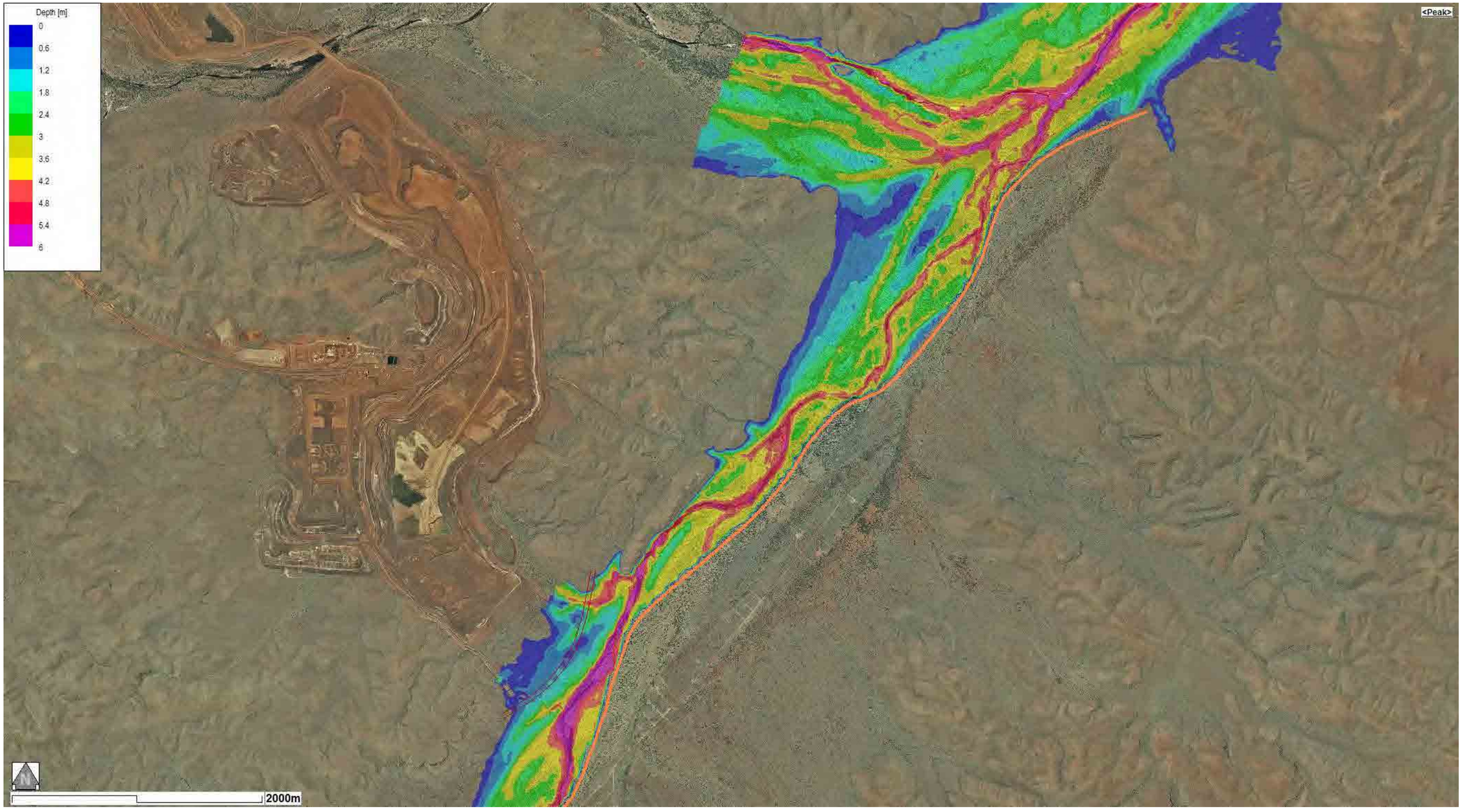


Figure C-3 1% AEP Existing Condition Depth



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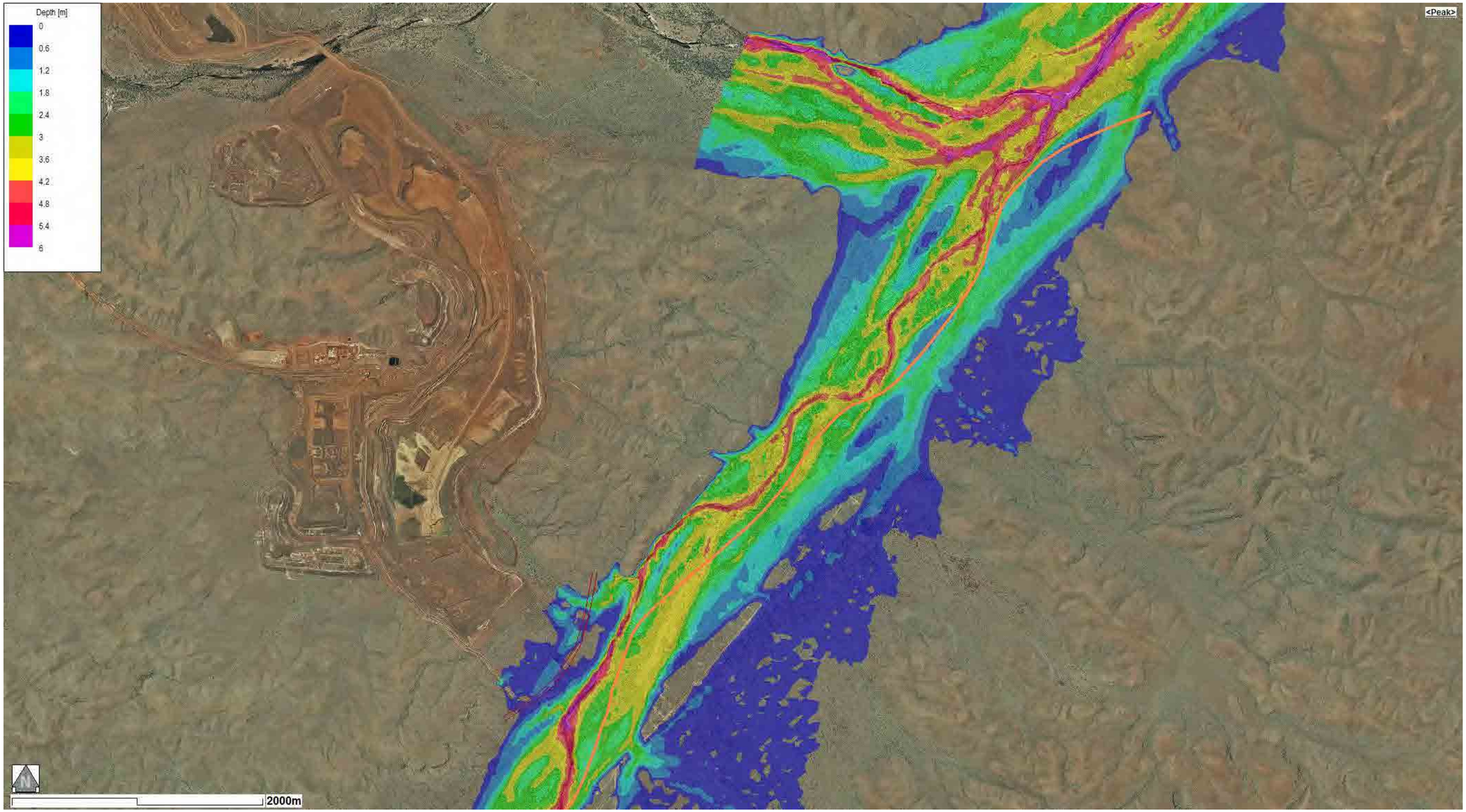


Figure C-5 0.5% AEP Existing Condition Depth

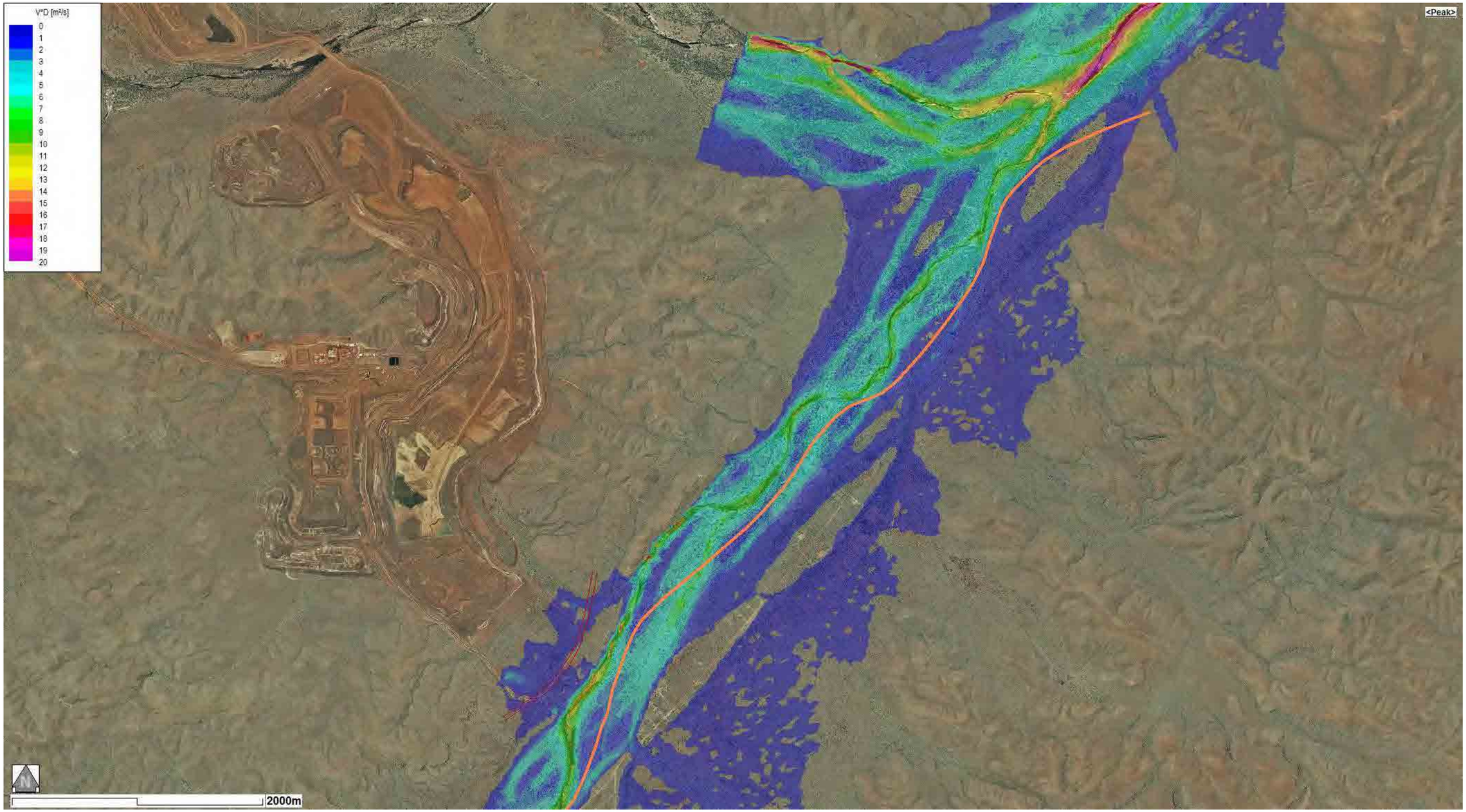


Figure C-6 2% AEP Existing Condition Velocity Times Depth

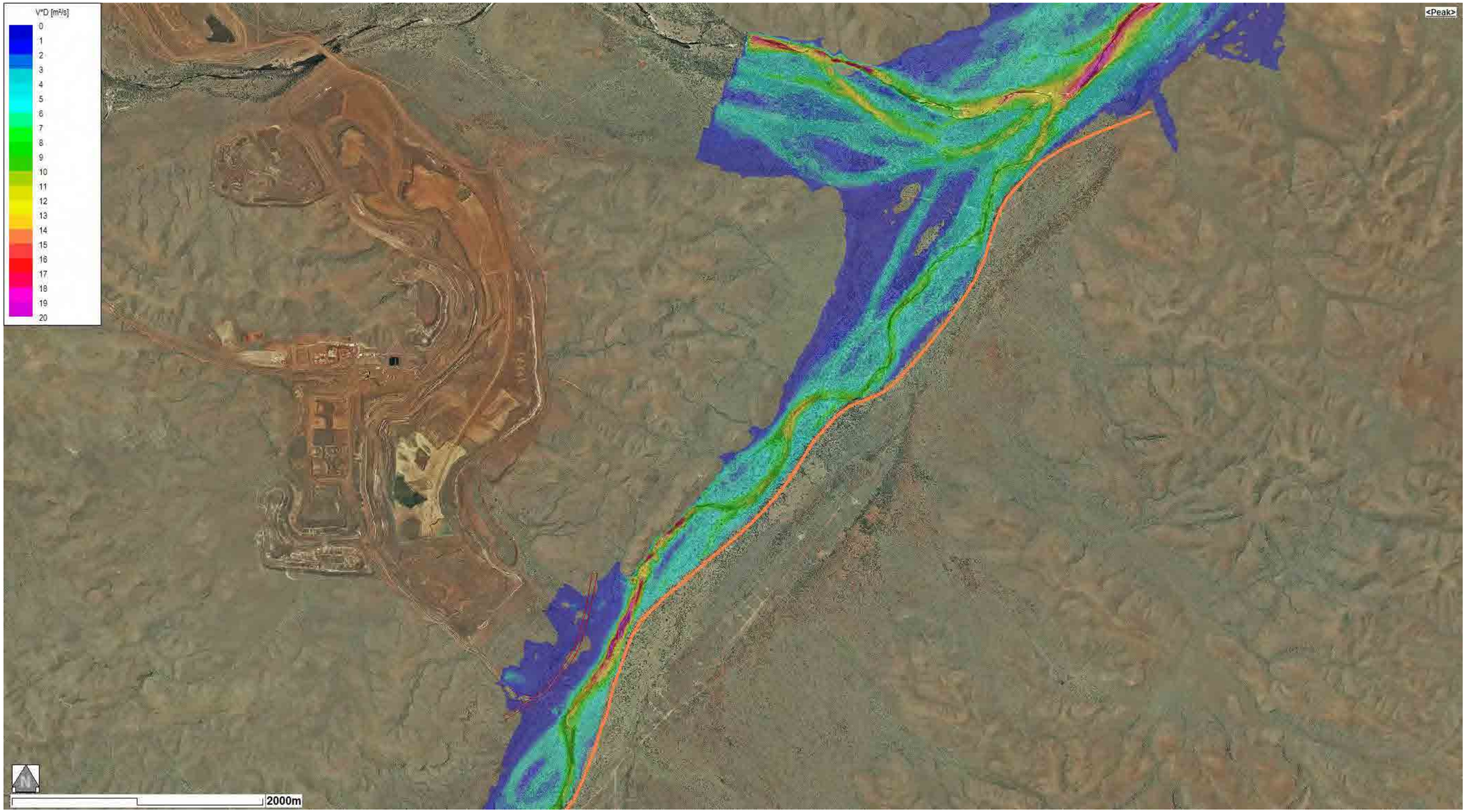


Figure C-7 2% AEP Levee Scenario Velocity Times Depth

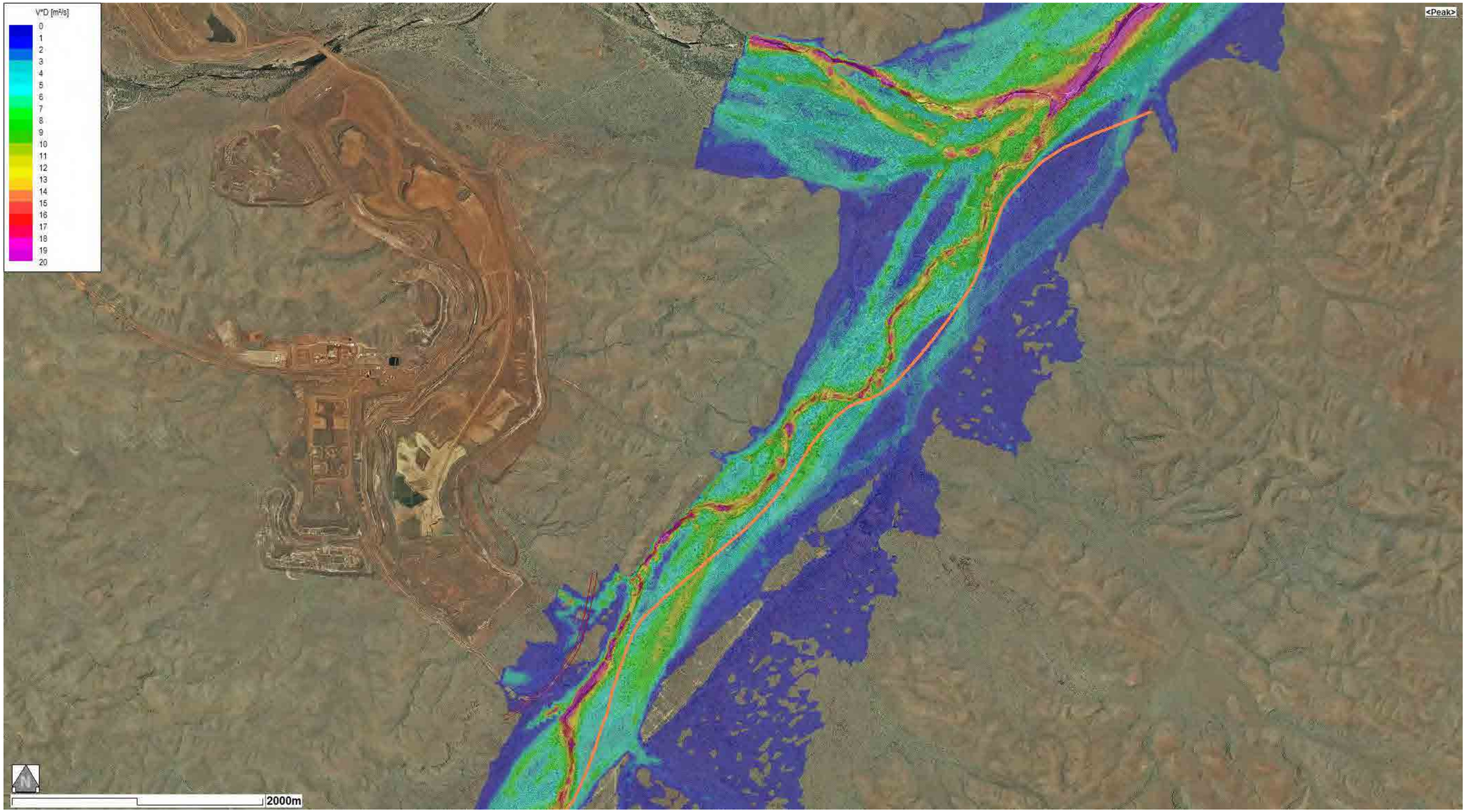


Figure C-8 1% AEP Existing Condition Velocity Times Depth

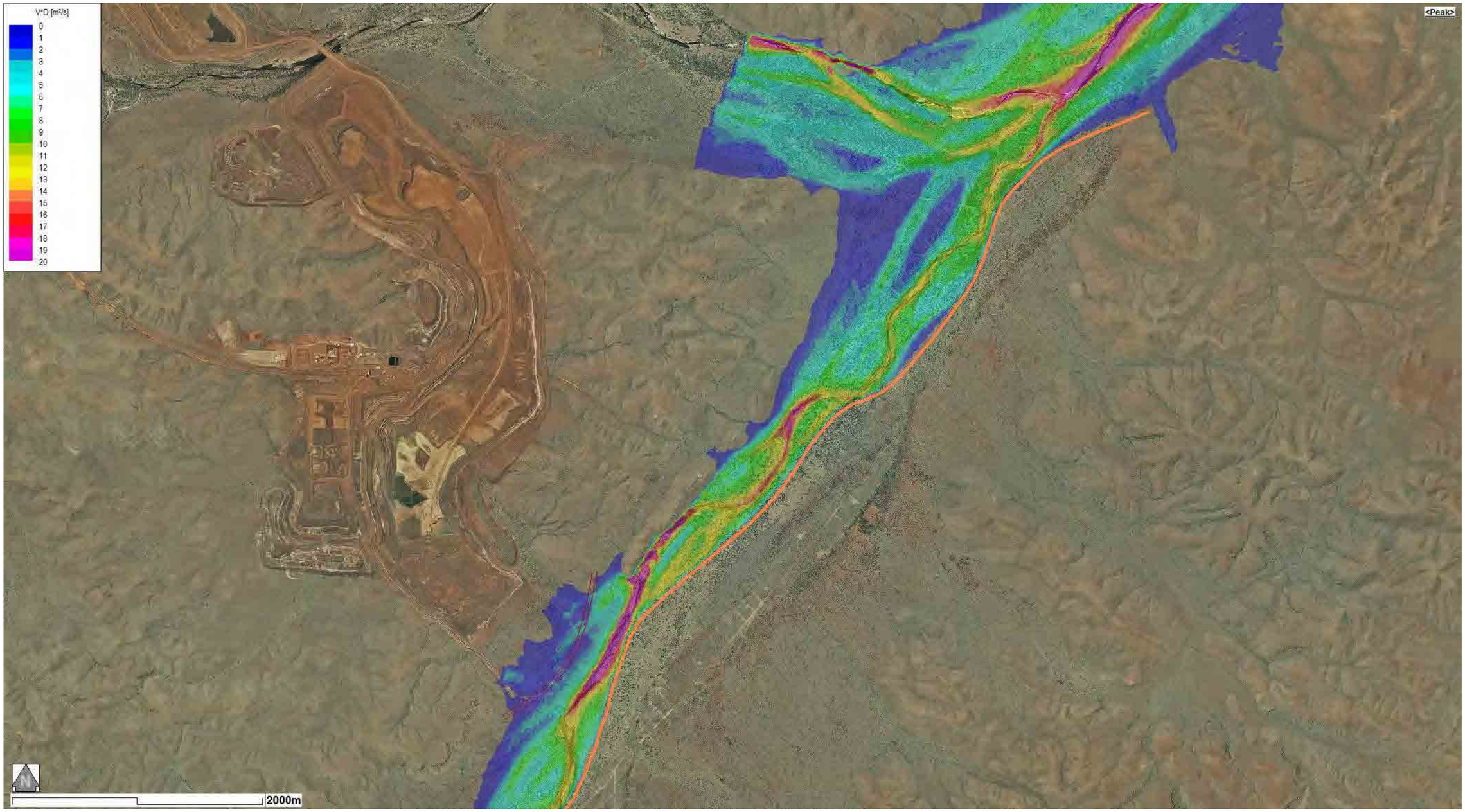


Figure C-9 1% AEP Levee Scenario Velocity Times Depth

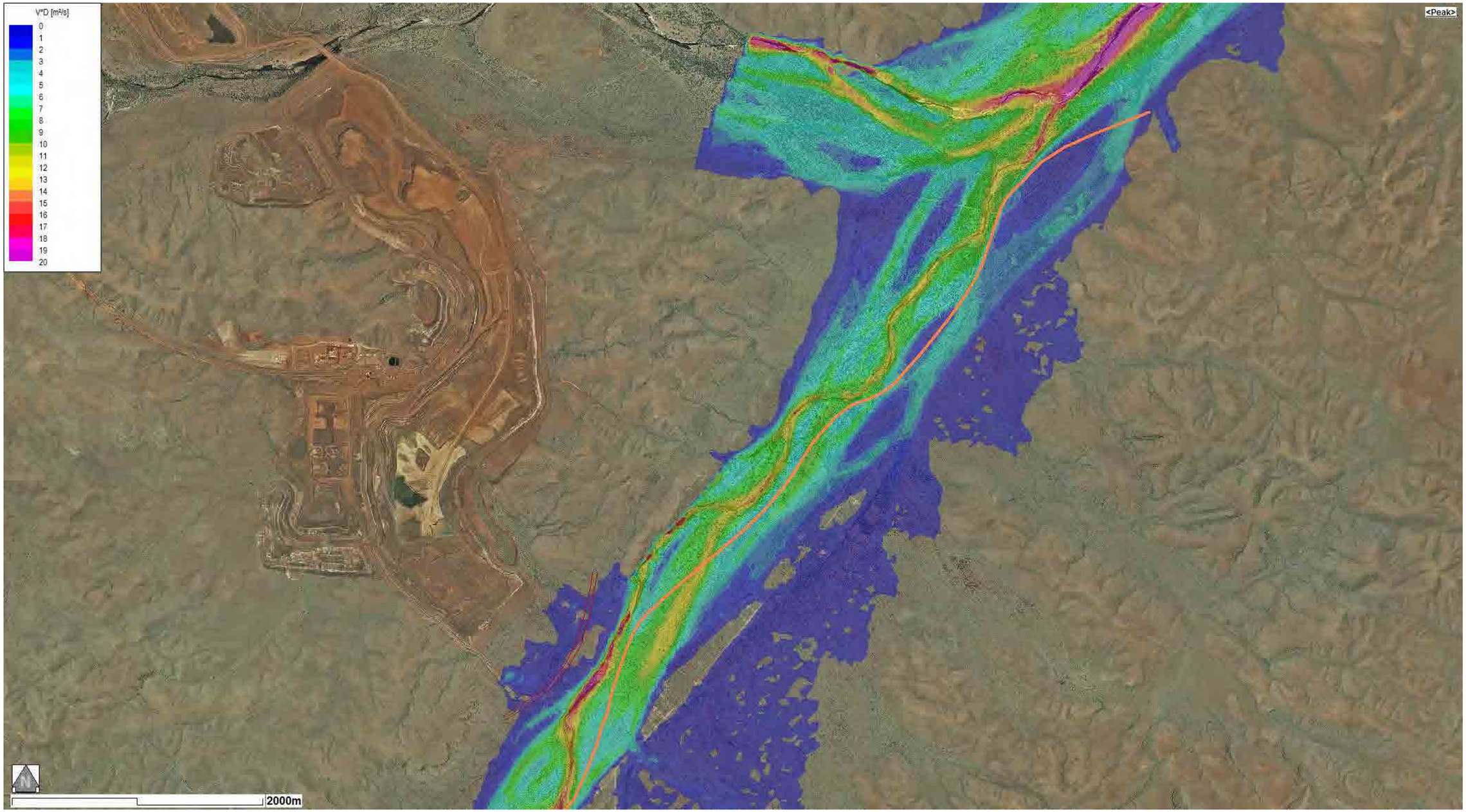


Figure C-10 0.5% AEP Existing Condition Velocity Times Depth

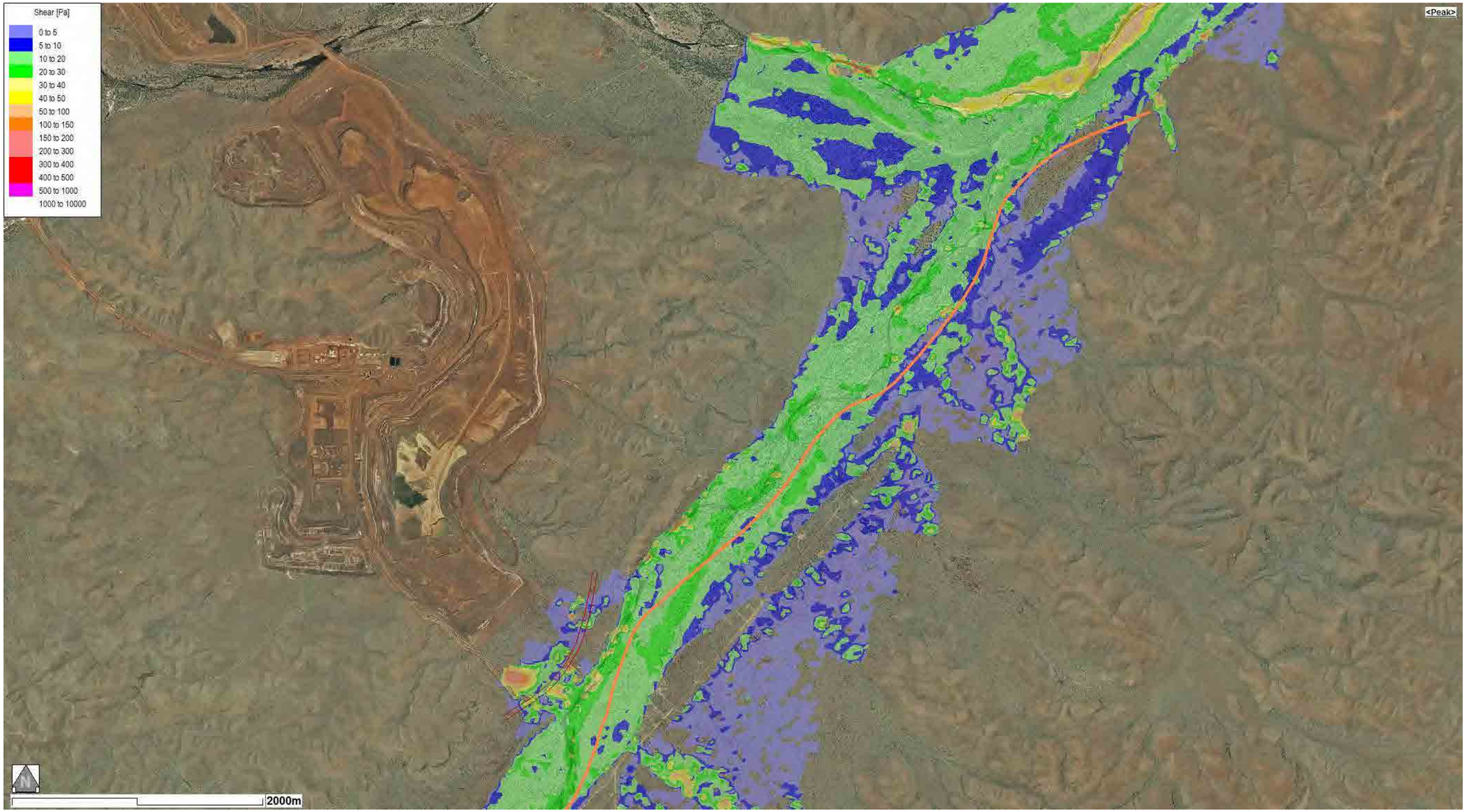


Figure C-11 2% AEP Existing Condition Shear

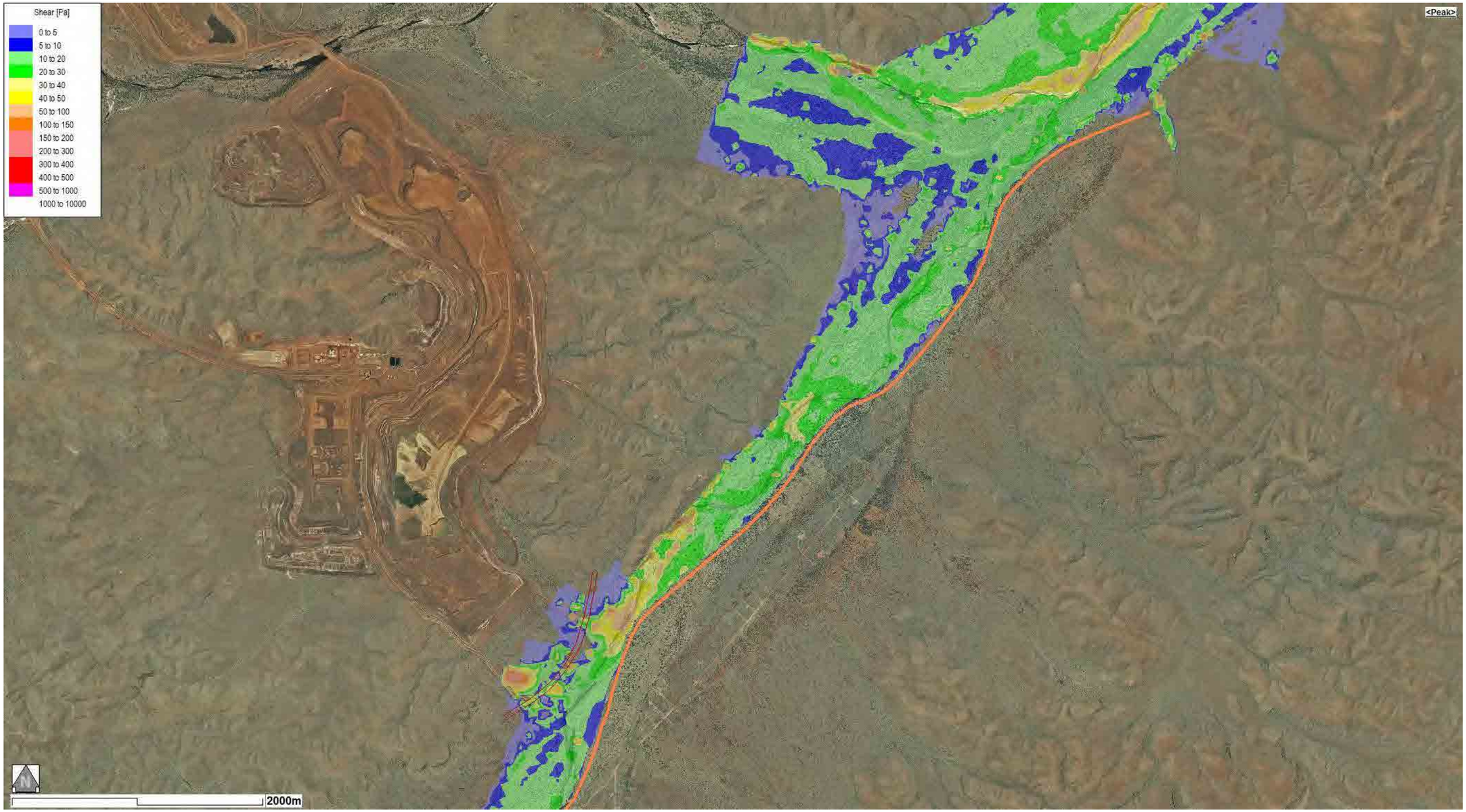


Figure C-12 2% AEP Levee Scenario Shear

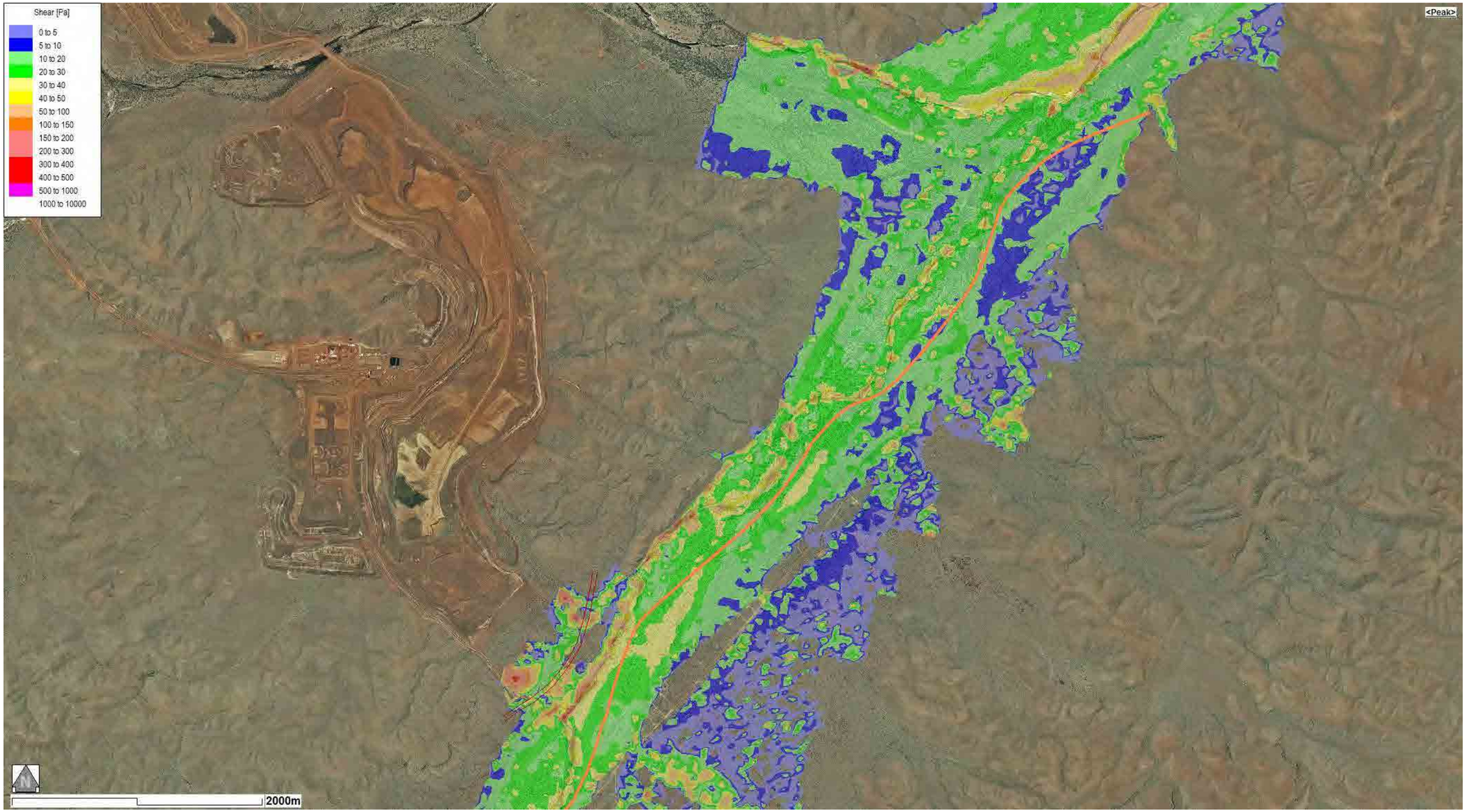


Figure C-13 1% AEP Existing Condition Shear

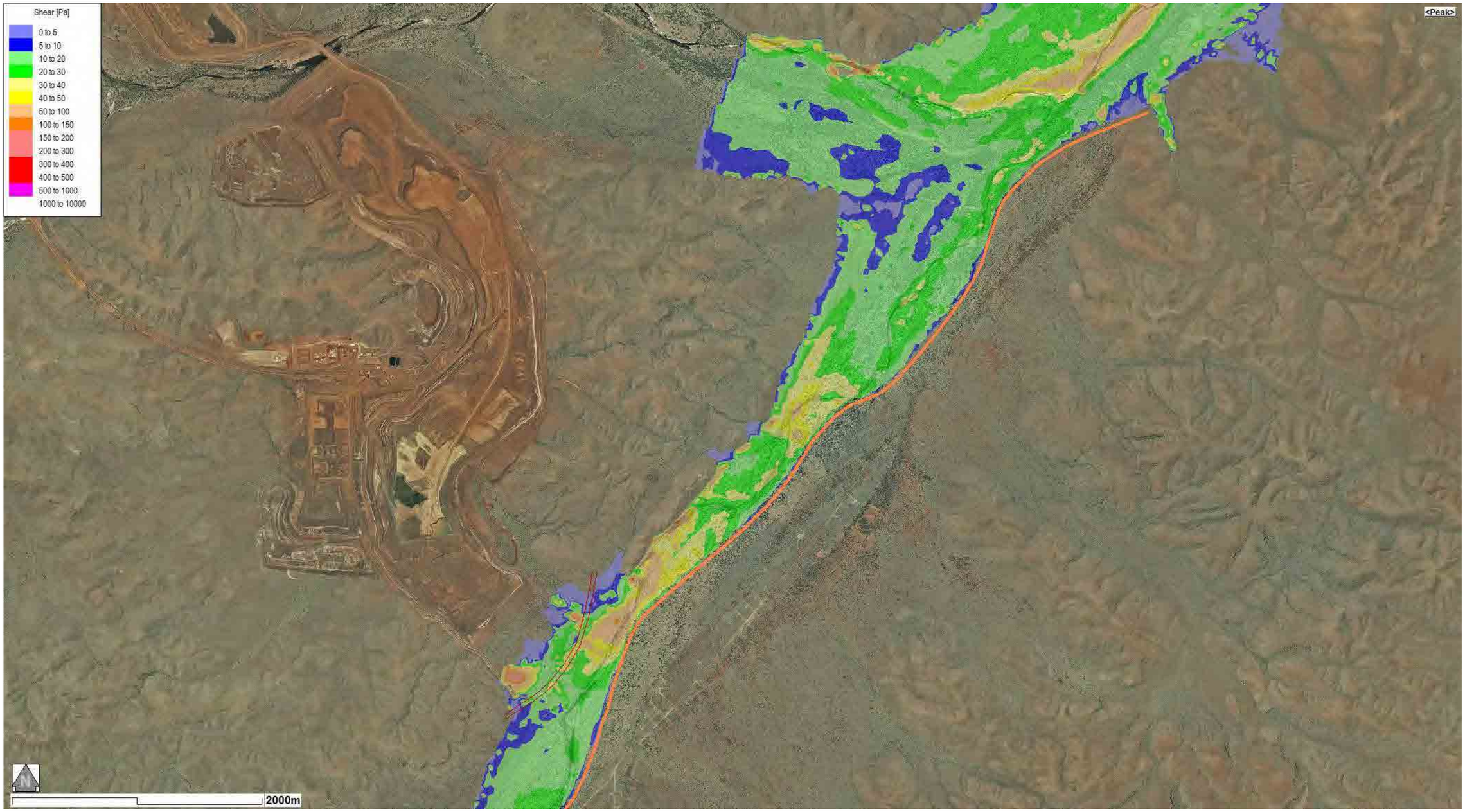


Figure C-14 1% AEP Levee Scenario Shear

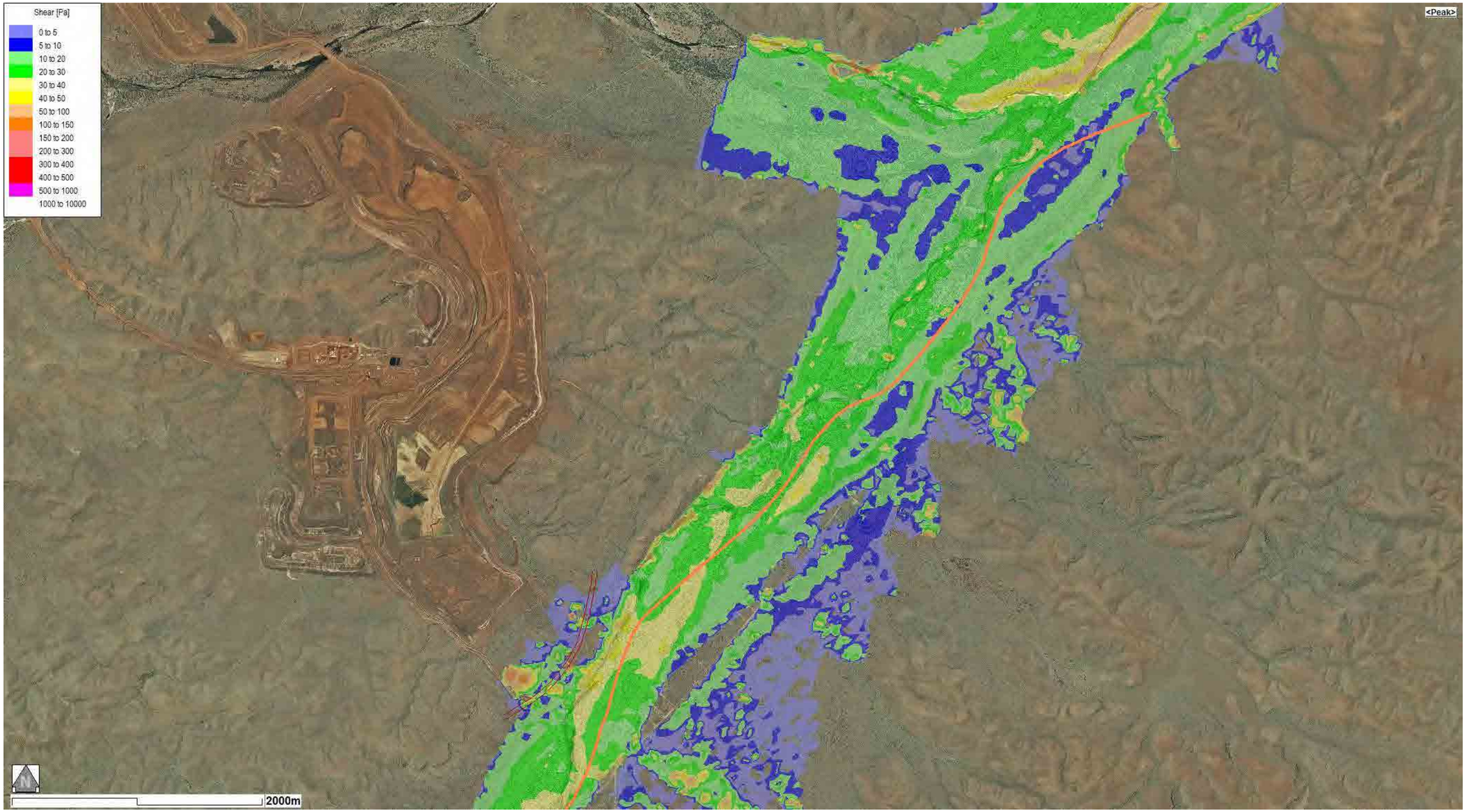


Figure C-15 0.5% AEP Existing Condition Shear

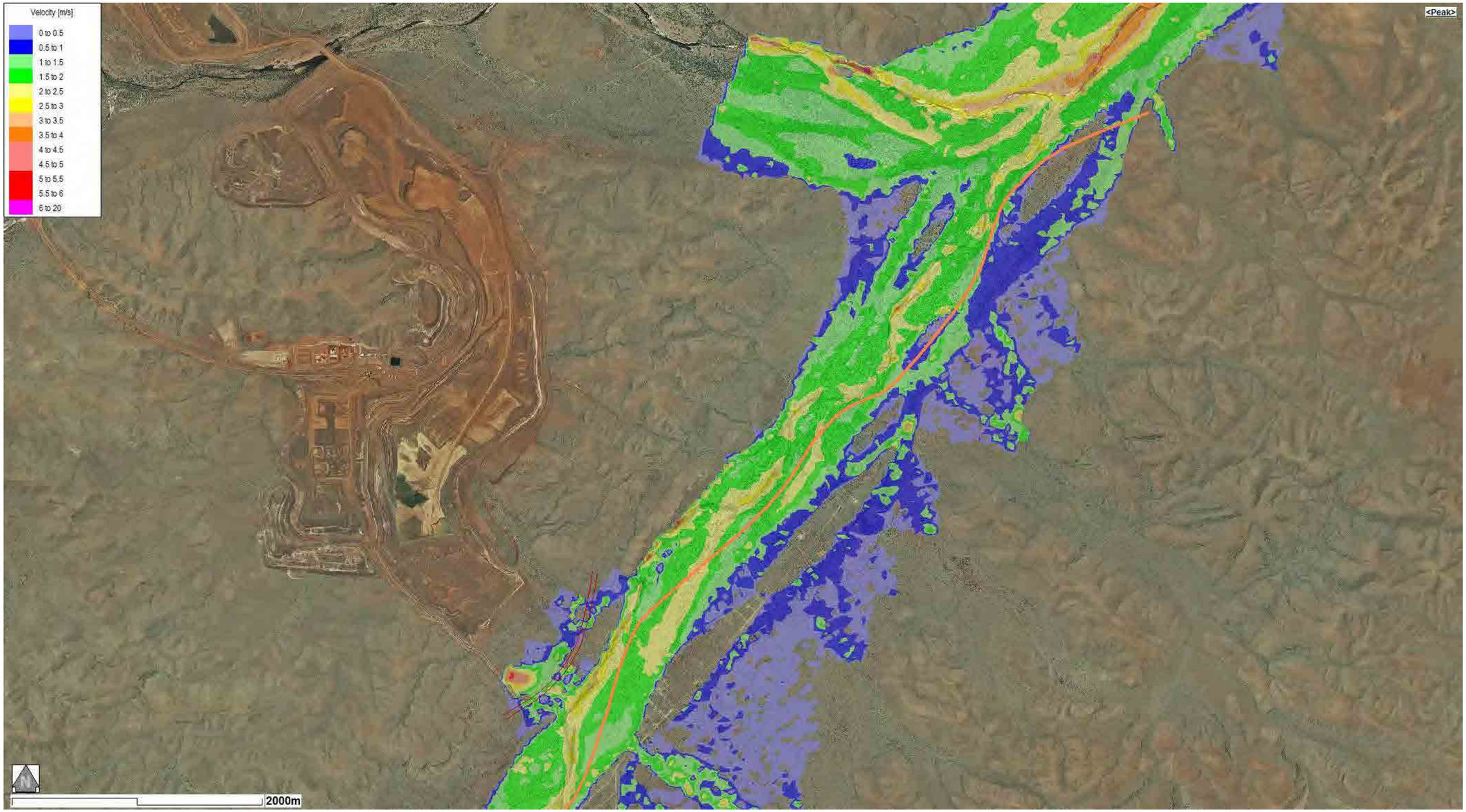


Figure C-16 2% AEP Existing Condition Velocity

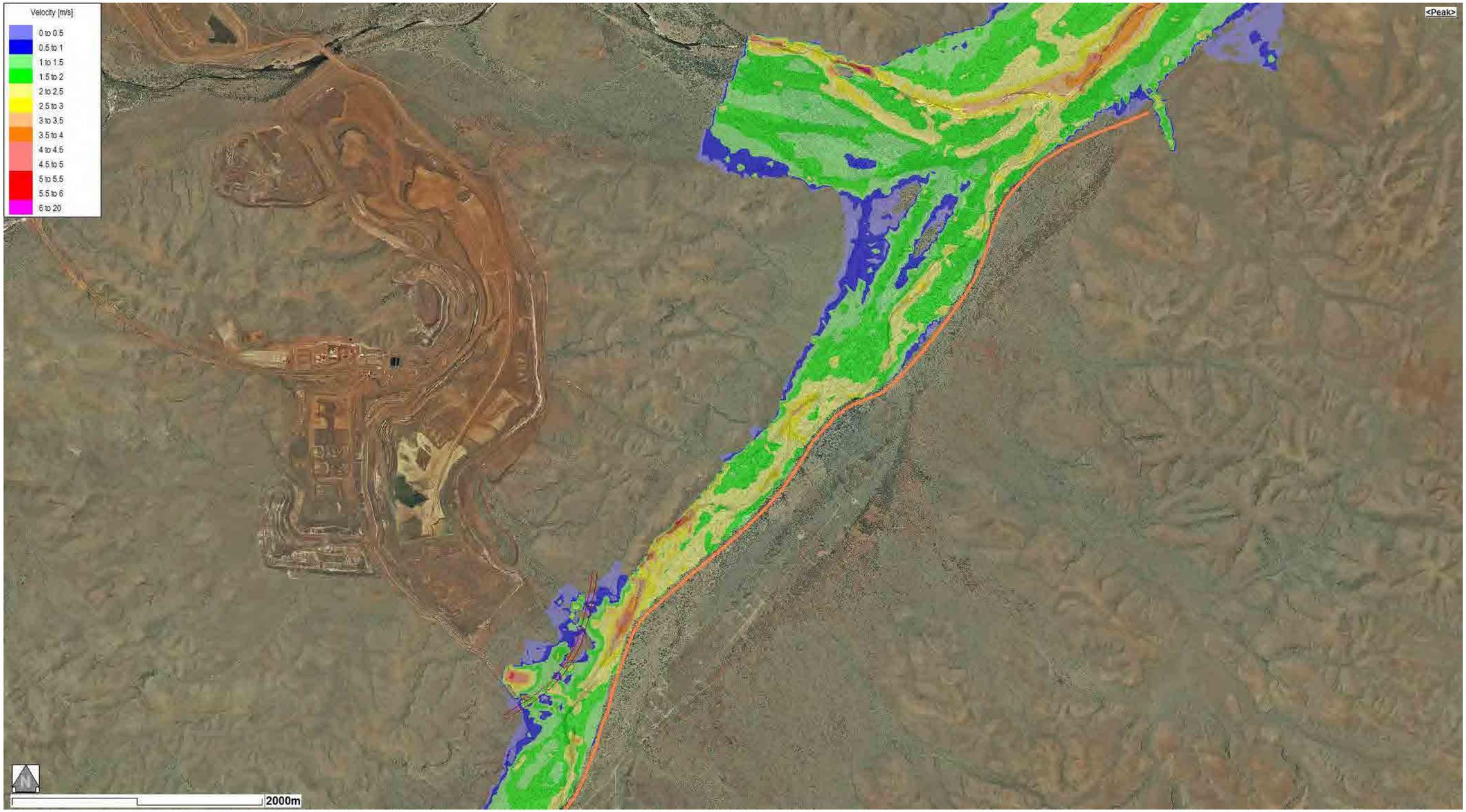


Figure C-17 2% AEP Levee Scenario Velocity

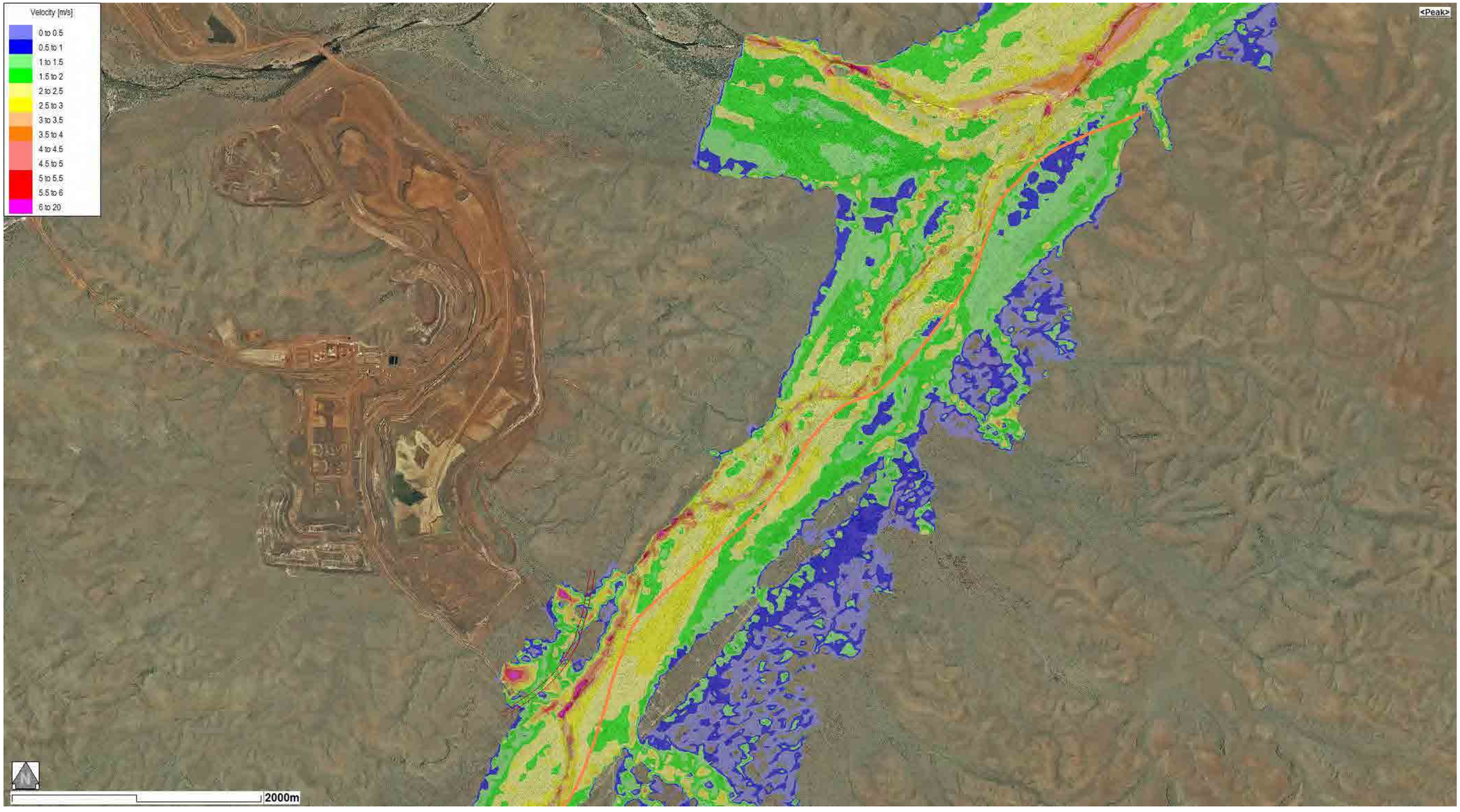


Figure C-18 1% AEP Existing Condition Velocity

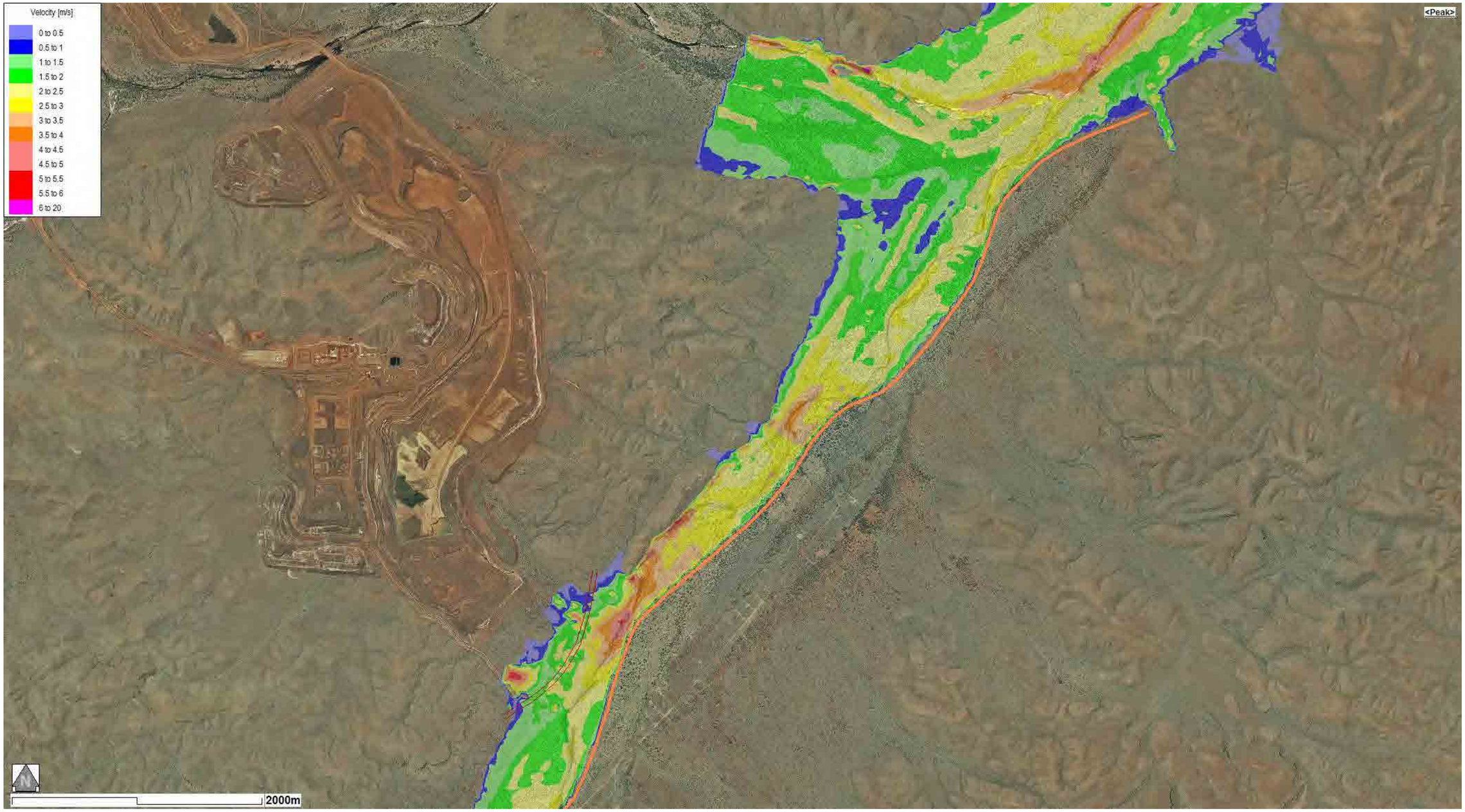


Figure C-19 1% AEP Levee Scenario Velocity

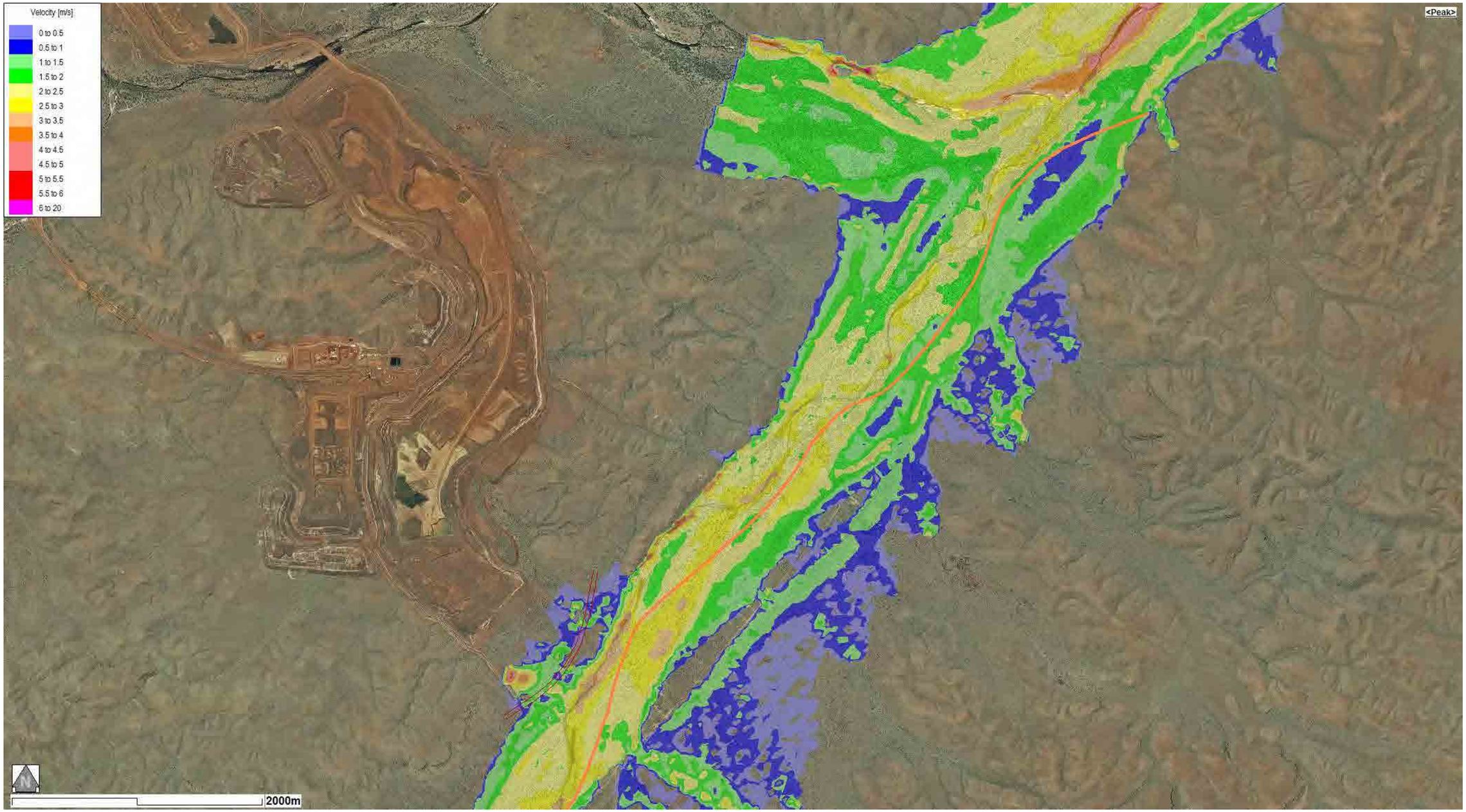


Figure C-20 0.5% AEP Existing Condition Velocity

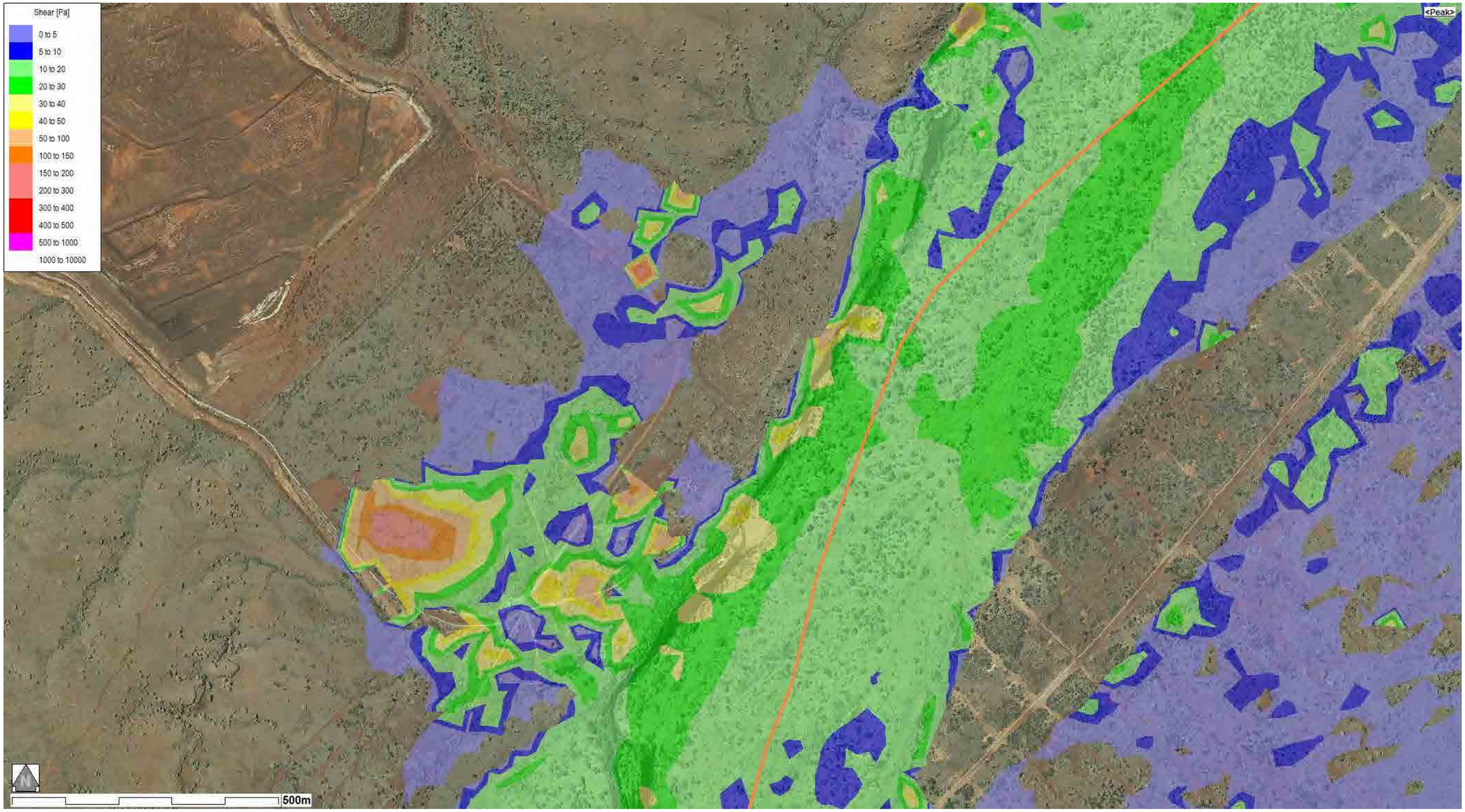


Figure C-21 2% AEP Existing Condition Shear, Constricted Reach

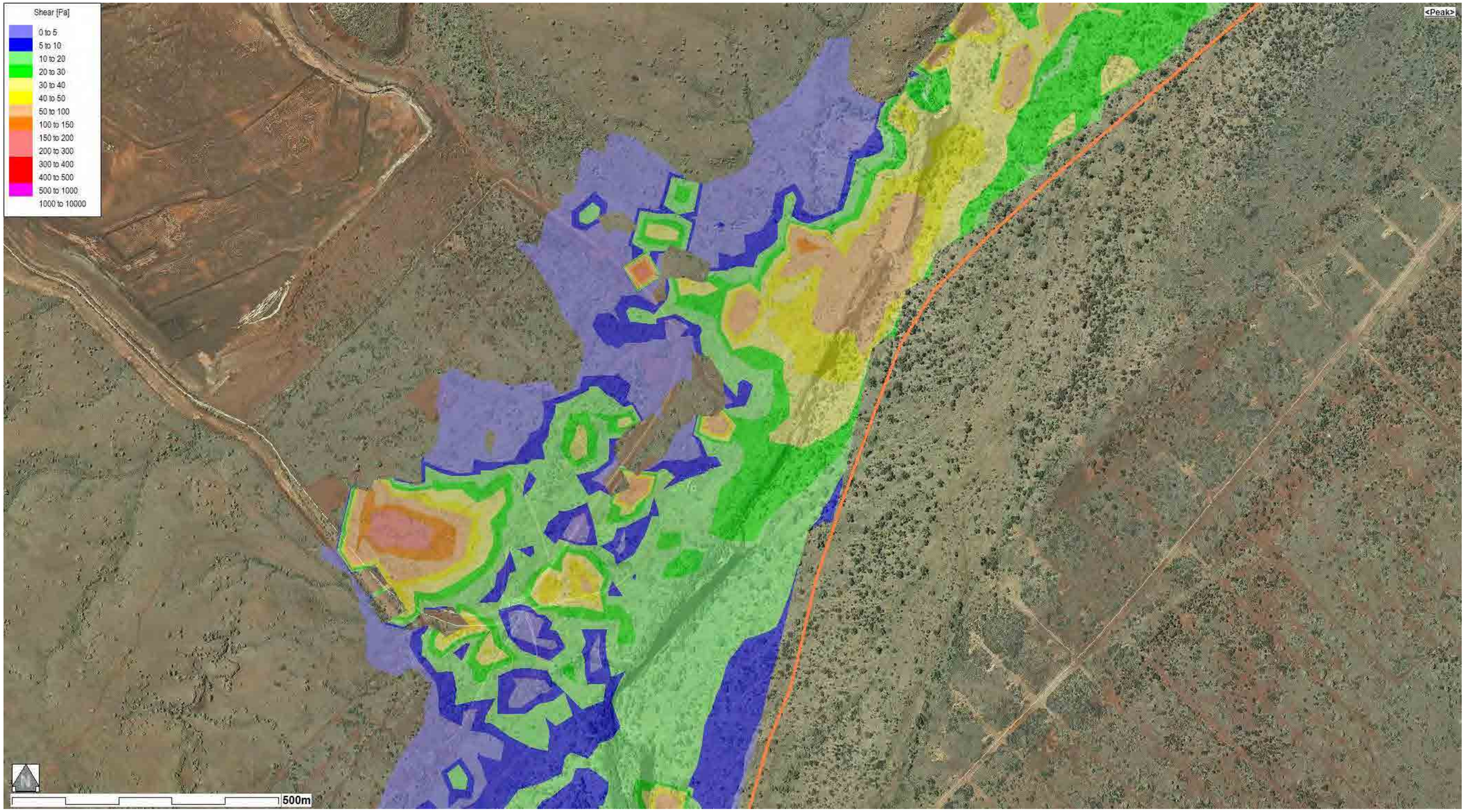


Figure C-22 2% AEP Levee Scenario Shear, Constricted Reach

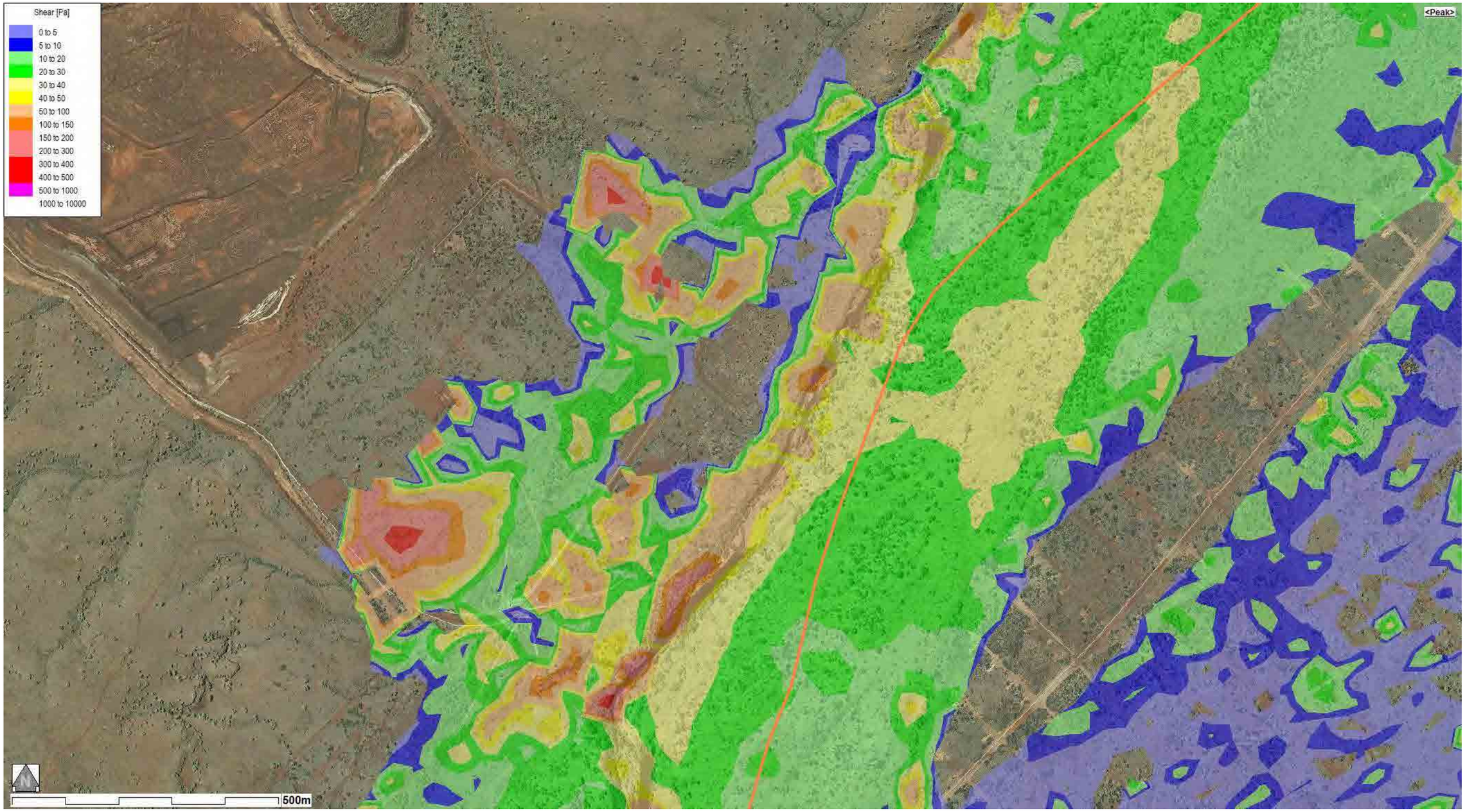


Figure C-23 1% AEP Existing Condition Shear, Constricted Reach

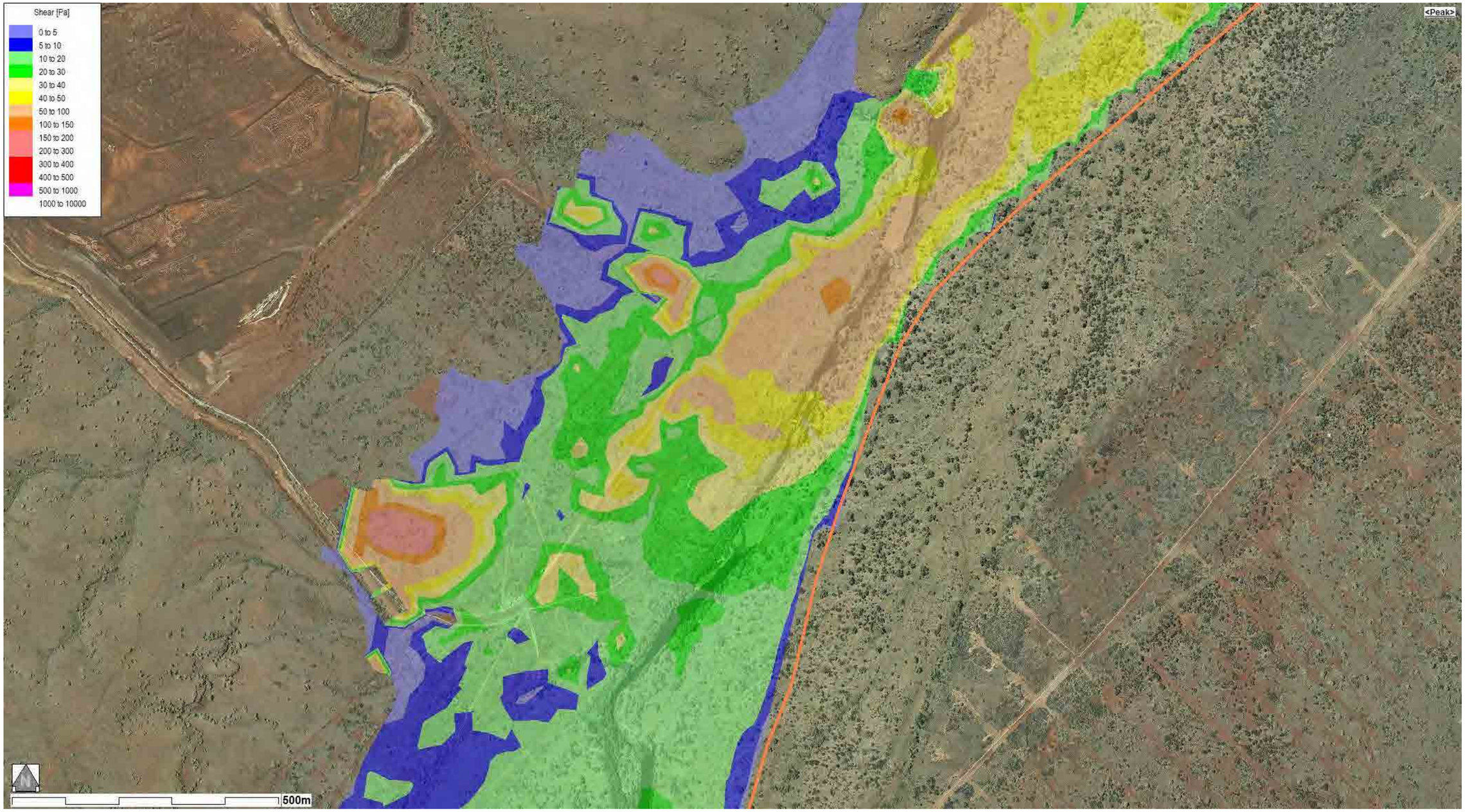


Figure C-24 1% AEP Levee Scenario Shear, Constricted Reach

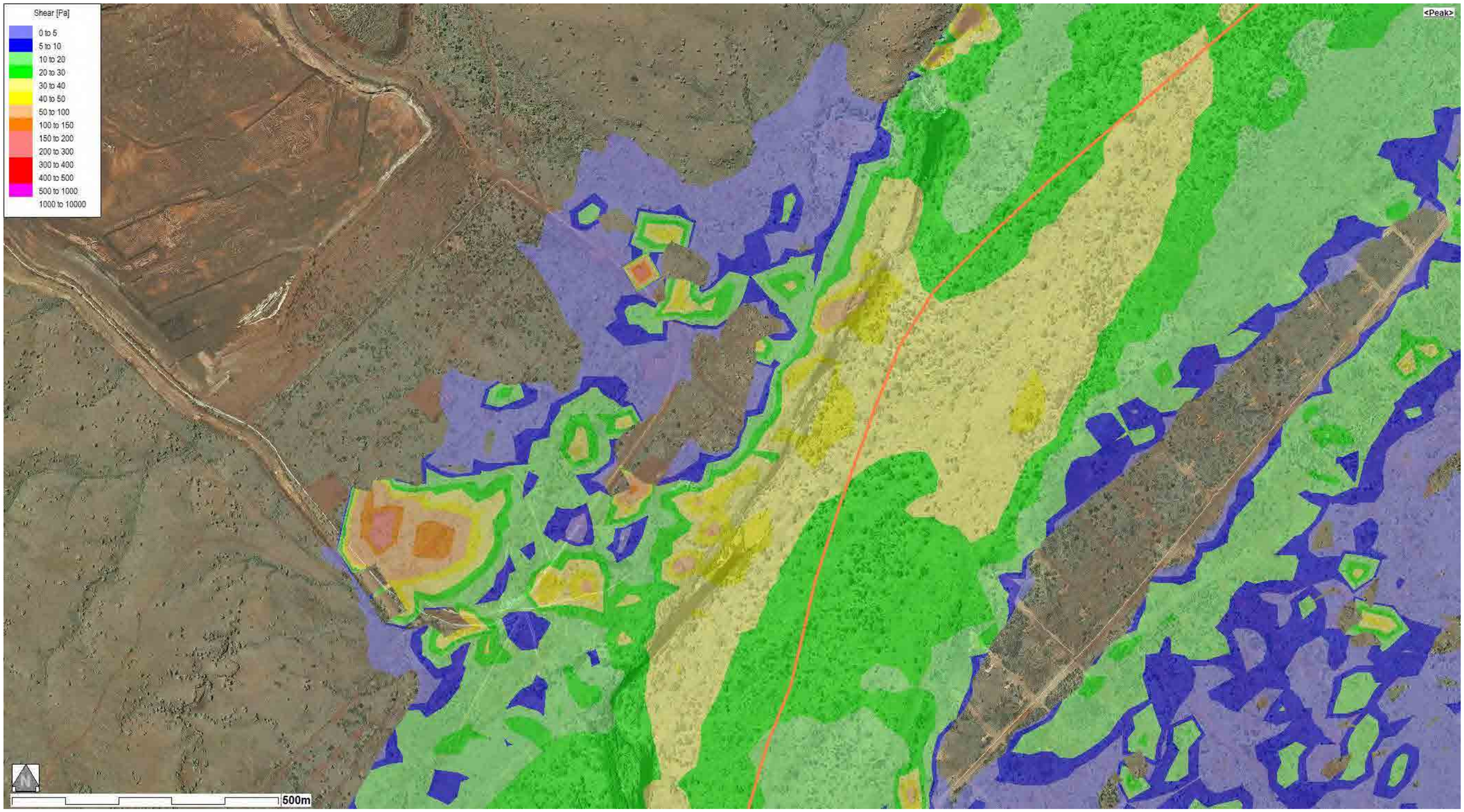


Figure C-25 0.5% AEP Existing Condition Shear, Constricted Reach

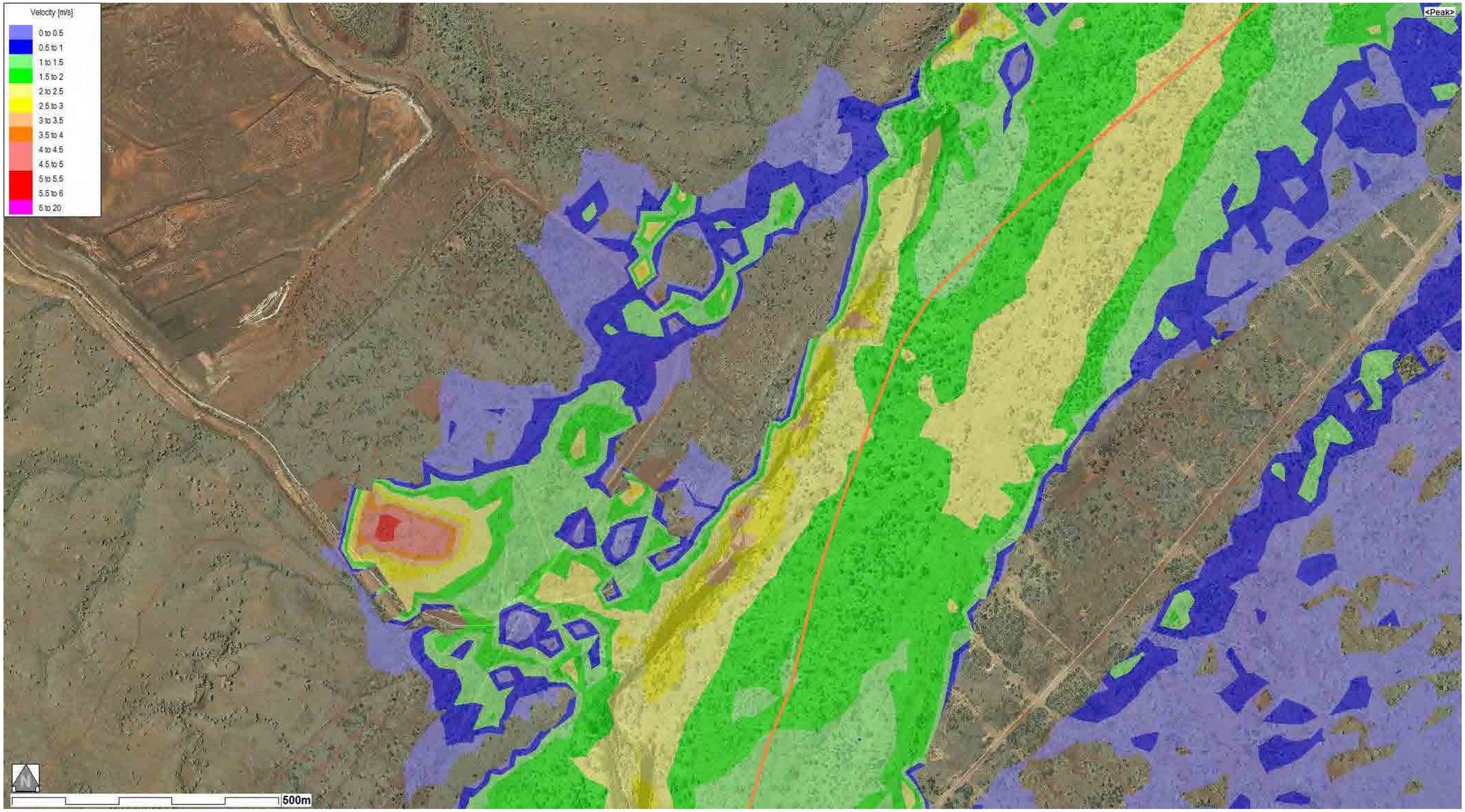


Figure C-26 2% AEP Existing Condition Velocity, Constricted Reach

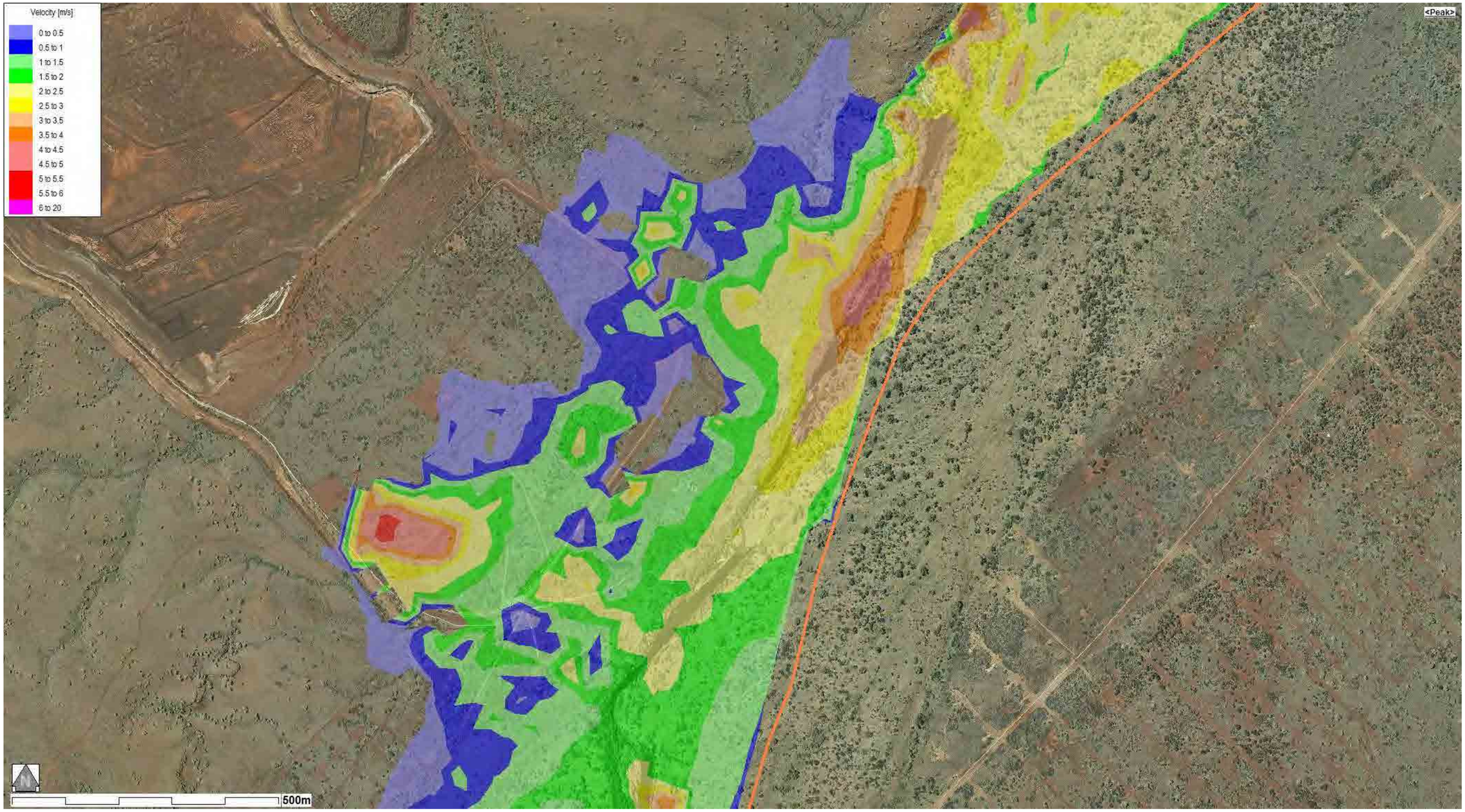


Figure C-27 2% AEP Levee Scenario Velocity, Constricted Reach

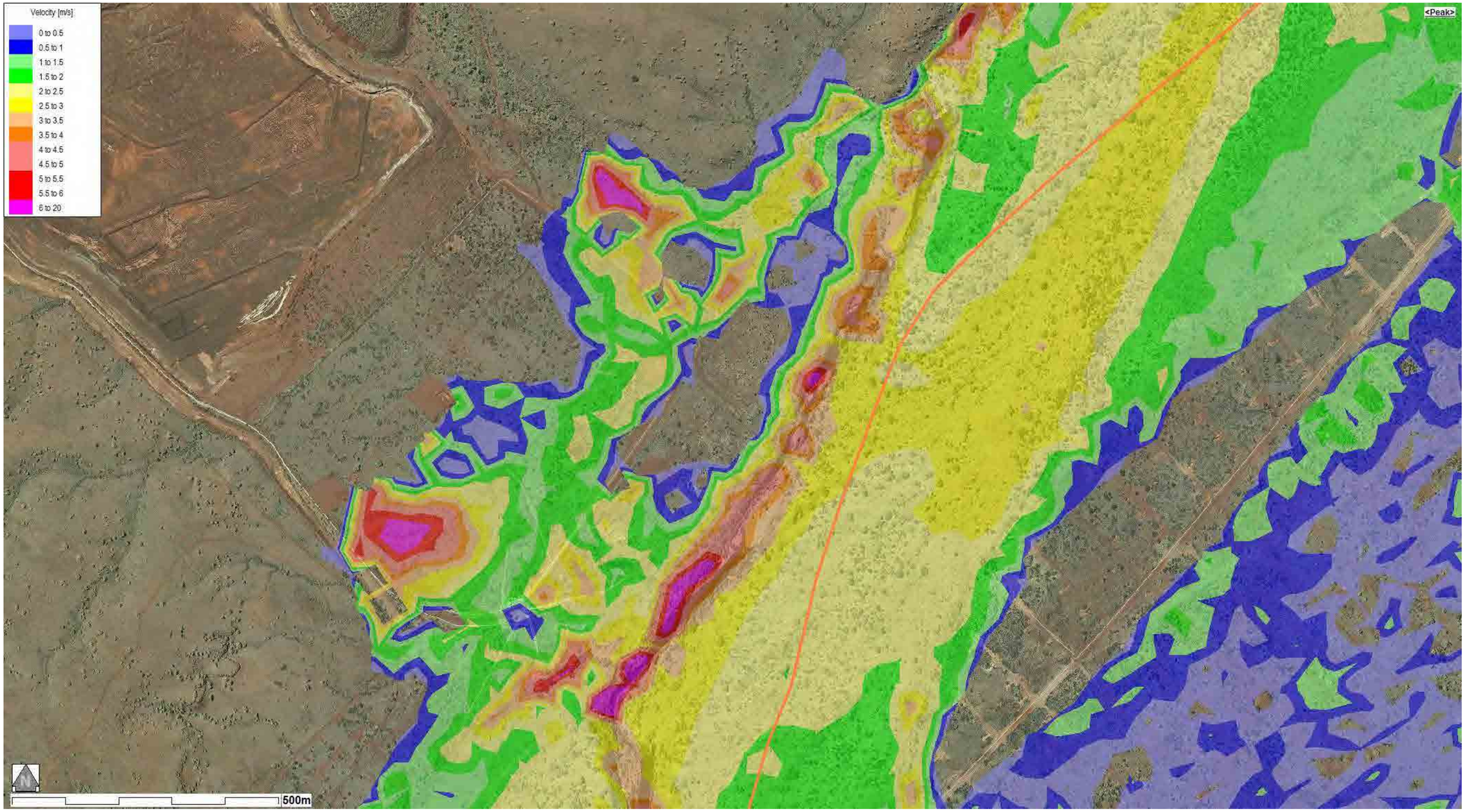


Figure C-28 1% AEP Existing Condition Velocity, Constricted Reach

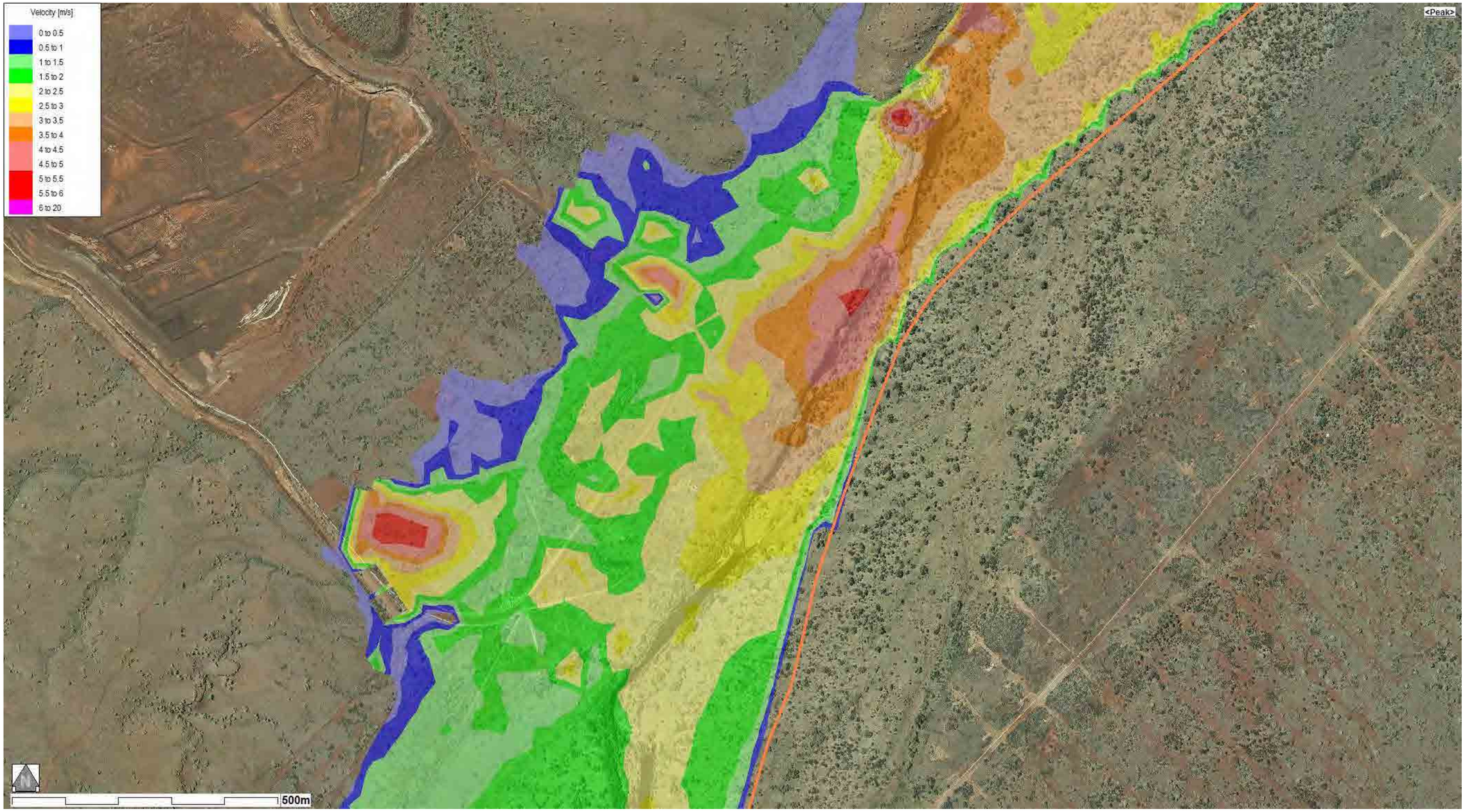


Figure C-29 1% AEP Levee Scenario Velocity, Constricted Reach

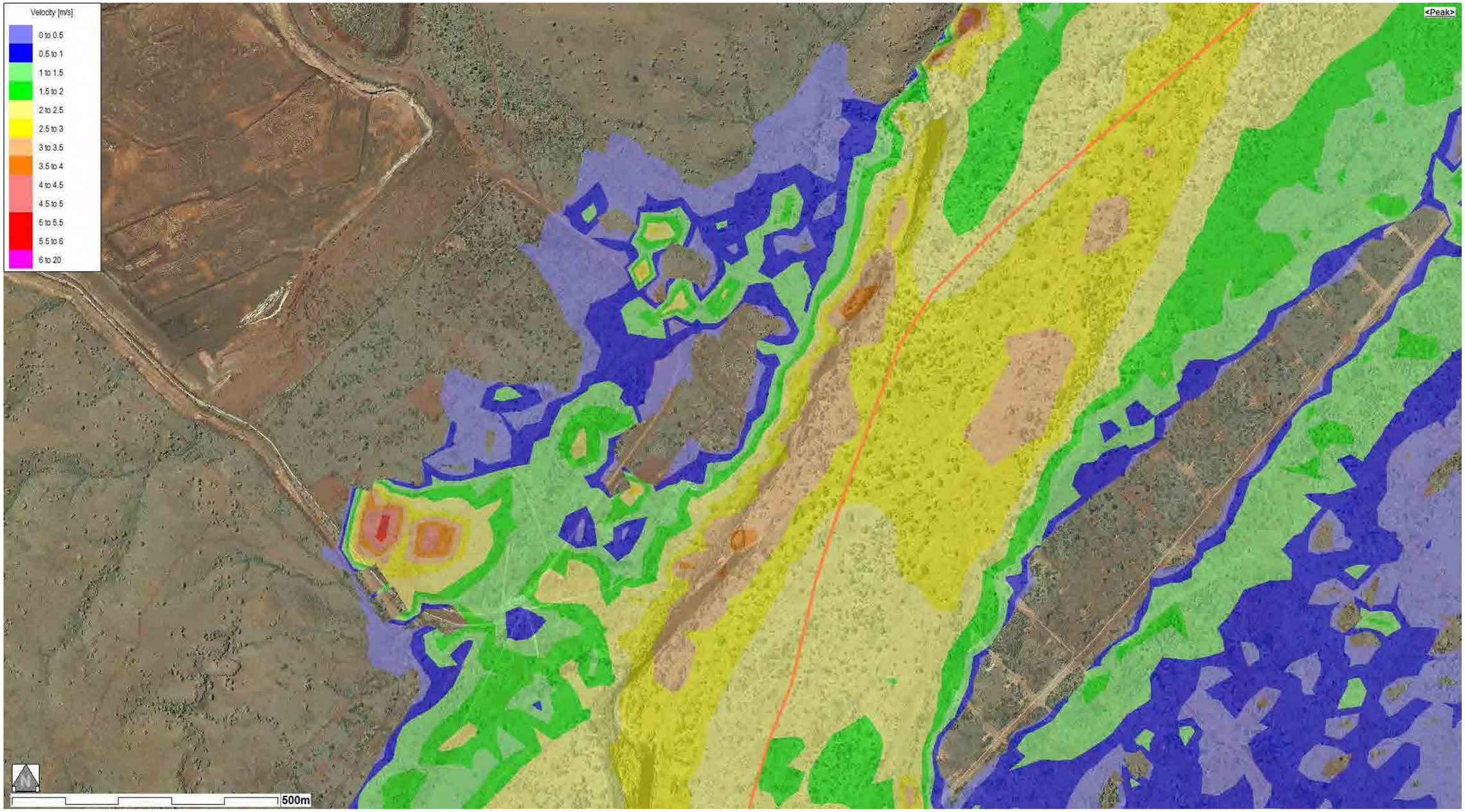


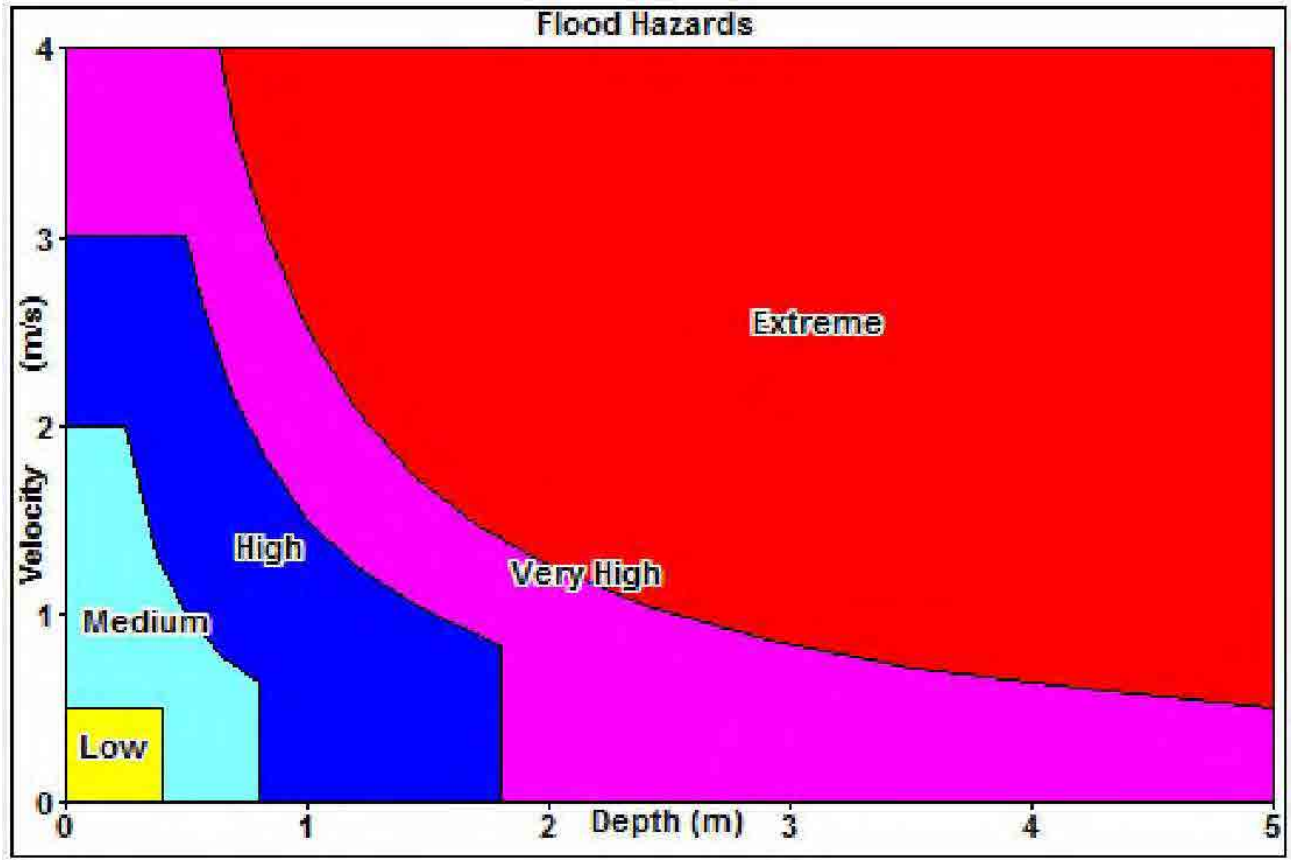
Figure C-30 0.5% AEP Existing Condition Velocity, Constricted Reach

Appendix D Hydraulic Design Implications

Table D-1 Equivalent material thresholds corresponding to hydraulic results figure legend

Legend Colour	Shear stress (Pa)	Category
	0-5	Threshold for silts and fine sands
	5-10	Threshold for loams, clays and fine gravels
	10-20	Threshold for gravels up to 25mm
	20-30	Threshold for gravels up to 50mm
	30-40	Threshold for gravels with d50 = 50mm, shale and short native grass
	40-50	Threshold for long native grass
	50-100	Threshold for riprap/gravels with d50 ~100mm
	100-150	Threshold for riprap/gravels with d50 = 150mm
	150-200	Threshold for riprap/gravels with d50 = 225mm
	200-300	Threshold for riprap with d50 = 300mm
	300-400	Threshold for riprap with d50 = 450mm
	400-500	Threshold for gabions and riprap with d50 = 600mm
	500-1000	Threshold for concrete

Legend Colour	Shear stress (Pa)	Category
	0.0-0.5	Acceptable for most areas
	0.5-1.0	Threshold for silts, fine sands and fine gravels
	1.0-1.5	Threshold for clays and gravels up to 25mm
	1.5-2.0	Threshold for gravels up to 50mm
	2.0-2.5	Threshold for gravels up to 150mm
	2.5-3.0	Threshold for light riprap
	3.0-3.5	Threshold for riprap with d50 = 150-225mm
	3.5-4.0	Threshold for gravels and riprap with d50 = 300mm
	4.0-5.0	Threshold for gravels and riprap with d50 = 450mm
	5.0-6.0	Threshold for riprap with d50 = 600mm, gabions and concrete
	>6.0	Exceeds most material thresholds



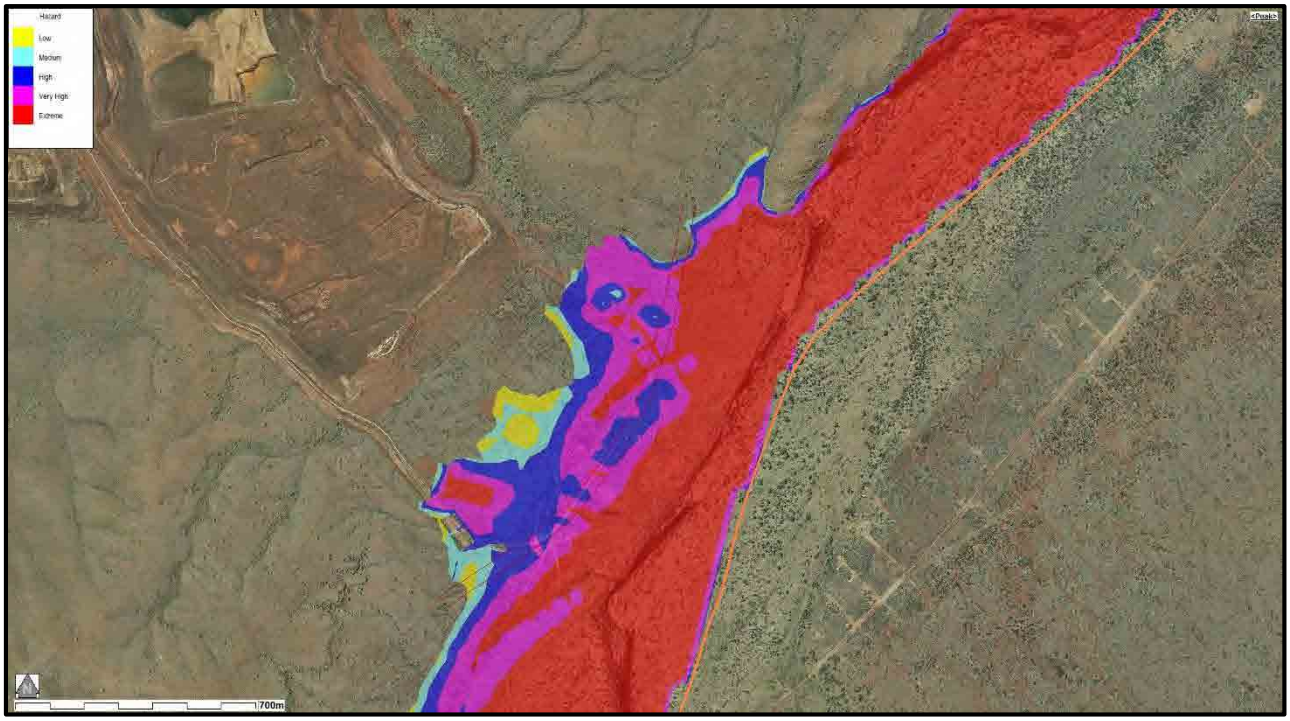


Figure D-1 WaterRide Hazard Mapping for constricted reach (1% AEP)

General rock sizing notes for levee armour and grade control rock:

Average channel velocities along the proposed levee are generally between 1.5 and 2.5 metres per second. According to Main Roads armour rock guidance (Tables D-2 and D-3), these velocities can be accommodated with Facing Rock, provided the rock is placed to sufficient depth with a properly engineered bedding layer. However, monitoring and maintenance would be required to ensure that scour does cause impinging localised flows with higher velocities to be directed toward the levee. Maximum velocities are generally at least 50% greater than average channel velocities, and the presence of bends can force higher energy flow directly against the levee.

In accordance with Main Roads WA guidelines, levees and abutments generally require armouring to resist shear stresses and other hydraulic forces where channel velocities exceed 2 m/s, with size and thickness of rock protection determined based on AustRoads Waterway Design, 2013 (p51). Main Roads design criteria are based on velocity only and do not account for the depth of flow, which affects the actual shear stress required to mobilise a particular particle size. A conservative approach may be warranted if the impacts of failure are deemed to be critical. In general, floods peaks in the Weeli Wolli Creek system are of relatively short duration, and sustained water depths against the levee are not likely; however, a seepage barrier (geosynthetic clay, for example) can extend the life of the structure. A key trench would increase the flow path length and prevent piping along the interface between levee fill and insitu materials.

Where levees terminate, armour rock should be keyed in to prevent erosion as flows spread out. Additional rock placement may be specified to account for loss and wastage. Rock armouring should be keyed in to the predicted scour depth below existing ground surface. Rock should meet minimum specific gravity requirements. Rock strength should typically meet “very high” or “extremely high” strength as defined in AS1726. Any stone placed as armour rock protection may break down over time. Some overdesign may be warranted to account for rock degradation, particularly if hardness, strength, and durability parameters are below standard recommendations. Tables D-2 and D-3 summarise the rock sizing requirements as presented in AustRoads design guides (2013). Strength requirements are shown in Table D-4.

Table D-2 Permissible velocities for standard rock classes (AustRoads 2013, MRWA 2006)

Velocity (m/s)	Class of rock protection (tonne)	Section thickness, *T* (m)
< 2	None	–
2.0–2.6	Facing	0.50
2.6–2.9	Light	0.75
2.9–3.9	¼	1.00
3.9–4.5	½	1.25
4.5–5.1	1.0	1.60
5.1–5.7	2.0	2.00
5.7–6.4	4.0	2.50
> 6.4	Special	–

Table D-3 Rock Protection Requirements (Table 3.12, AustRoads 2013)

Rock Class	Rock Size Diameter (m) *	Approximate Rock Mass (kg)	Minimum Percentage of Rock Larger than Rock Size in the Second Column	Typical Use (Examples Only)
Type A	0.20 0.10 0.075		0 50 90	Catchpit Surrounds
Type B1	0.30 0.20 0.10		0 50 90	Culvert Outlets
Type B (Facing)	0.40 0.30 0.15	100 35 2.5	0 50 90	Culvert Outlets
Light	0.55 0.40 0.20	250 100 10	0 50 90	Floodway Batters
Quarter Tonne	0.75 0.55 0.30	500 250 35	0 50 90	Floodway Batters
Half Tonne	0.90 0.70 0.40	1000 450 100	0 50 90	Floodway Batters
One Tonne	1.15 0.90 0.55	2000 1000 250	0 50 90	Floodway Batters
Two Tonne	1.45 1.15 0.75	4000 2000 500	0 50 90	Floodway Batters
Rock Pitching	0.40 x 0.40 x 0.20 0.15 x 0.15 x 0.15		60 100	Landscaped Slopes

Table D-4 Rock Strength Requirements (Table A8, AS1726)

STRENGTH OF ROCK MATERIAL

Term	Letter symbol	Point load index (MPa) I_s50	Field guide to strength
Very high	VH	>3 ≤10	Hand specimen breaks with pick after more than one blow; rock rings under hammer
Extremely high	EH	>10	Specimen requires many blows with geological pick to break through intact material; rock rings under hammer

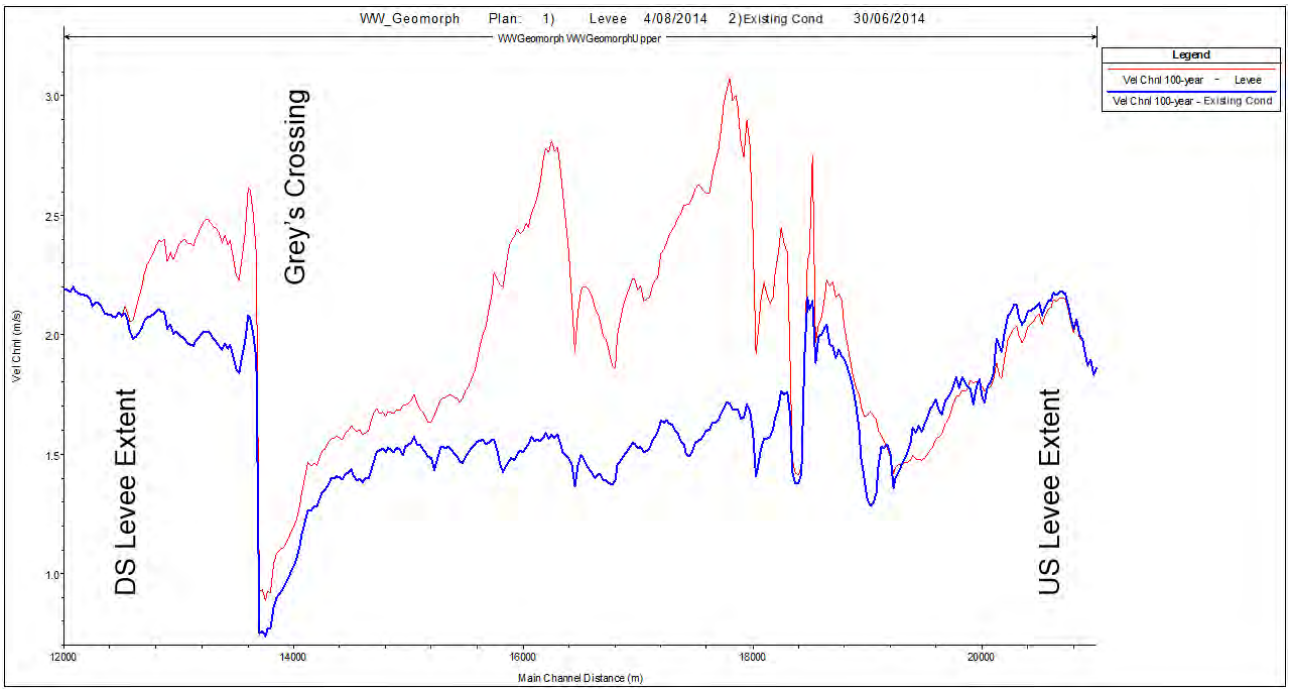


Figure D-2 1% AEP Channel Velocity, Existing vs Levee

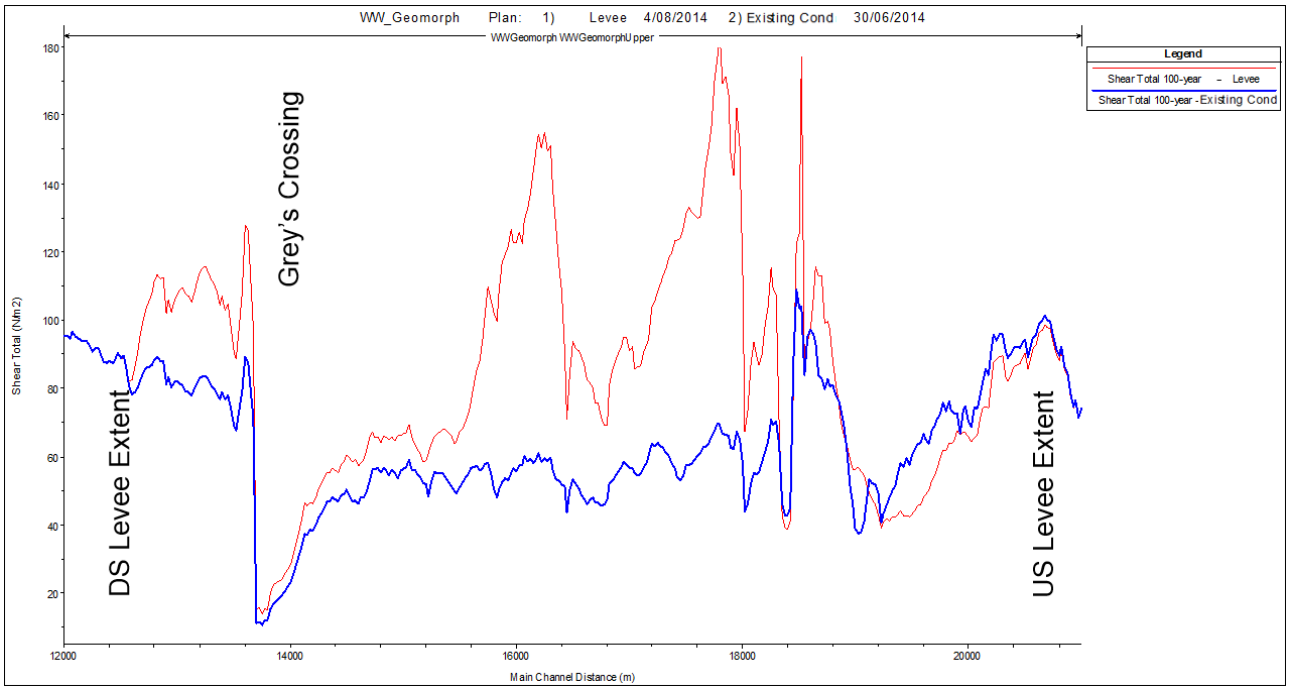


Figure D-3 1% AEP Total Shear, Existing vs Levee

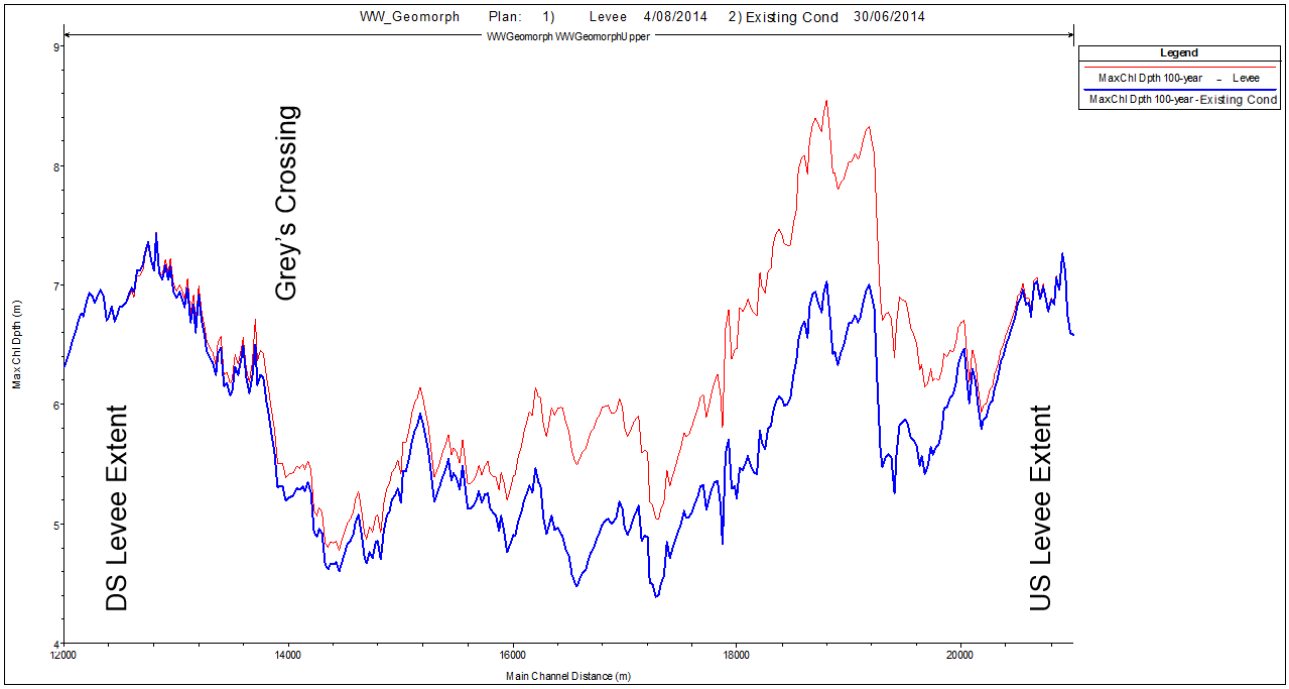


Figure D-4 1% AEP Maximum Depth, Existing vs Levee

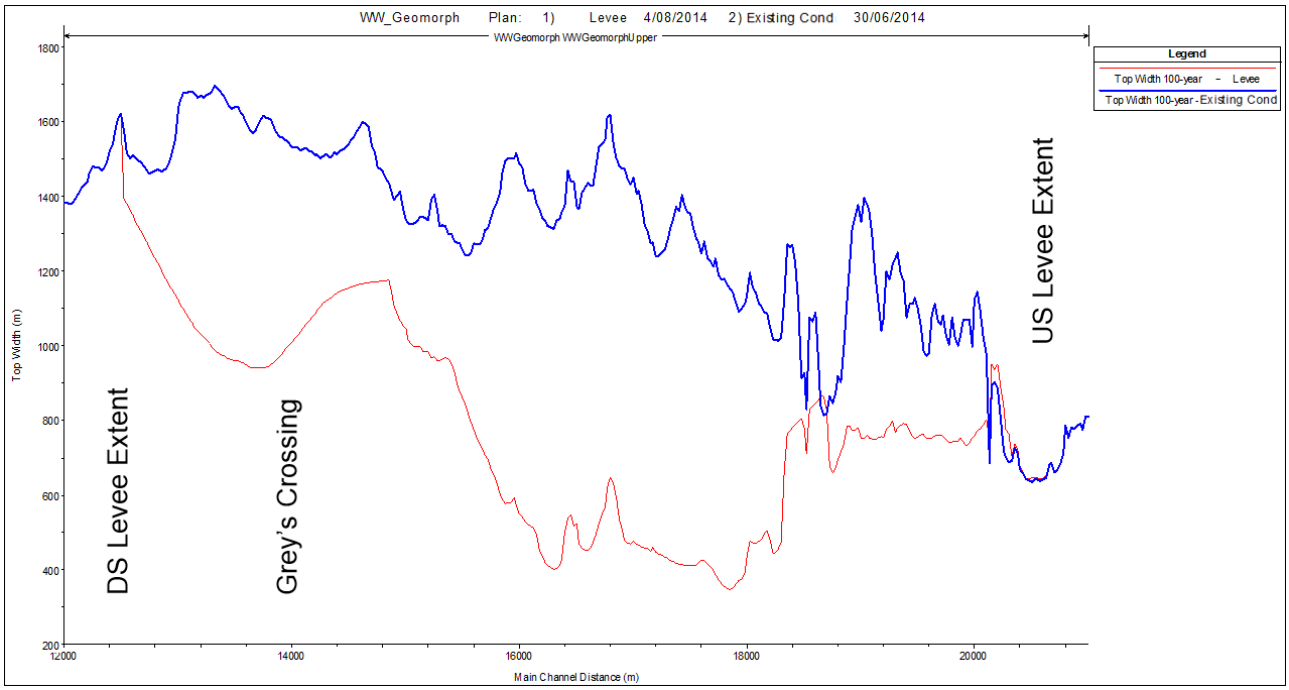


Figure D-5 1% AEP Top Width, Existing vs Levee

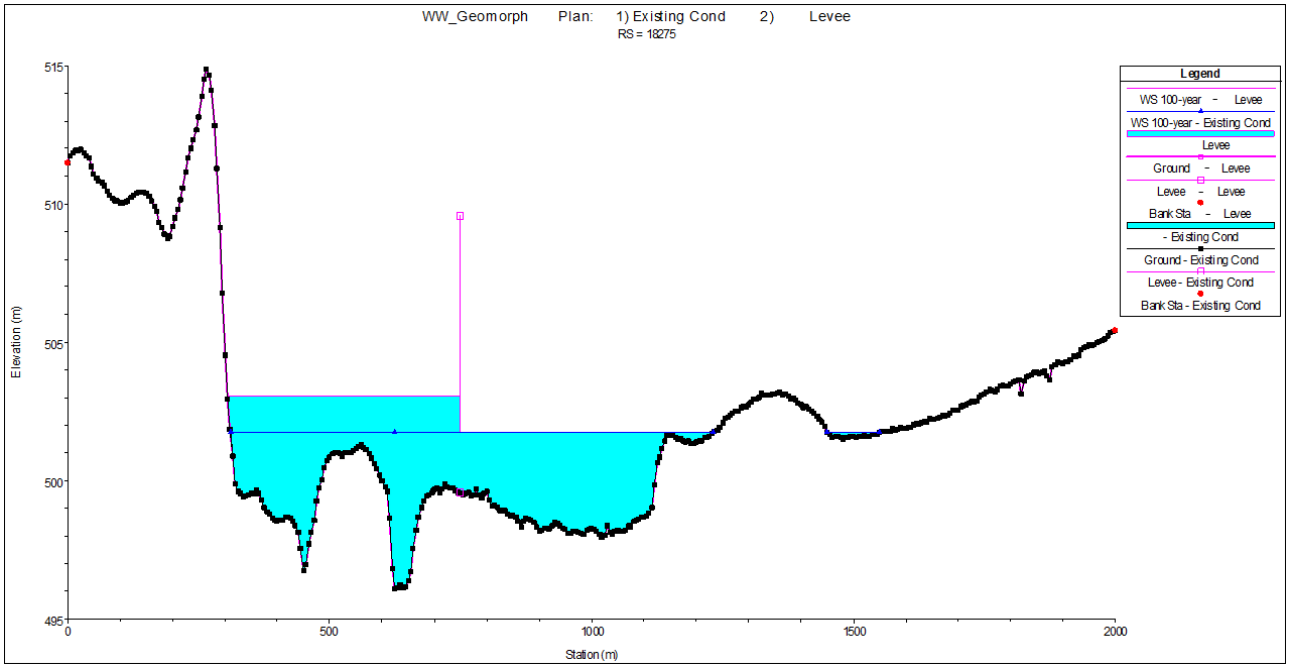


Figure D-6 1% AEP water surface cross section in area most constricted by levee

Biota Environmental Sciences

Yandi Billiards Vegetation and Flora Survey – Phase 1 and Phase 2

Prepared for Rio Tinto Pty Ltd

October 2014

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Yandi Billiards Vegetation and Flora Survey – Phase 1 and Phase 2

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1.0 Summary

Rio Tinto Pty Ltd's (Rio Tinto) Yandicoogina (Yandi) iron ore project is located approximately 75 km northwest of Newman, in the Pilbara region of Western Australia. Rio Tinto is currently undertaking a 'Pre-feasibility Study' for development of two channel-iron deposits at Yandi Billiards, called Pocket and Billiards South. Numerous biological surveys have been completed in the Yandi locality, and although some of these overlap Yandi Billiards, they do not provide full coverage of this area.

Biota Environmental Sciences (Biota) was commissioned in 2014 to undertake a vegetation and flora survey at Yandi Billiards (hereafter referred to as the study area) in order to address gaps in knowledge and expand the existing dataset for flora and vegetation. This survey was conducted over two seasons to comply with the requirements of a Level 2 vegetation and flora assessment. This report documents the combined results of both field surveys (Phase 1, completed in March 2014; and Phase 2, completed in July 2014).

A desktop review of biological information relevant to the study area was undertaken prior to the survey. A total of 121 quadrats and 28 relevés have been sampled in the study area to date. Of these, 46 quadrats and eight relevés were established during the Phase 1 survey and three quadrats were established during the Phase 2 survey in order to sample previously unsurveyed areas and to provide replicated sampling for particular vegetation types. Resampling of established quadrats was also undertaken during both the Phase 1 and Phase 2 surveys. Overall, 68 quadrats in the study area have been resampled over two seasons (with at least one phase of sampling in favourable conditions for plant growth). Mapping of dominant vegetation types was also undertaken in previously unsurveyed areas and in areas of broad-scale historical mapping. The field survey also included targeted searches for the Threatened species, *Lepidium catapycnon*, and for Priority flora that were identified by the desktop review as having the potential to occur in the study area.

A total of 23 vegetation types have been described for the study area. These vegetation types were associated with four broad landscape categories: major creeklines and tributaries; minor creeklines, floodplains and valleys; hills, ridges and breakaways; and plains. Most of the vegetation was in Good to Very Good condition, however the creekline and floodplain vegetation ranged from Good to Very Poor condition due to weed invasion and disturbance from cattle.

None of the vegetation types observed in the study area represent Threatened Ecological Communities (TECs) or Priority Ecological Communities (PECs). Vegetation similar to that recorded for the study area is well represented in the broader locality. One vegetation type (C1) is considered to represent an ecosystem at risk, and two other vegetation types (C2 and C3) represent good condition riparian vegetation. These vegetation types are all associated with Marillana Creek and Weeli Wolli Creek, which are two of the major ephemeral creek systems of the locality.

A total of 455 native vascular flora taxa from 147 genera and 47 families have been recorded from the study area to date. This species richness is high but still within the range expected for an area of this size in this locality.

One Threatened flora species, *Lepidium catapycnon*, was recorded from two locations in the study area during previous field surveys (Hamersley Iron 2006, Biota 2009a). These populations were not found during the Phase 1 survey, nor were any additional populations located during targeted searches. Further searches were undertaken during the Phase 2 field survey, and *L. catapycnon* was recorded from 26 locations separated into three distinct populations: the existing population originally located by Biota (2009a) and two new populations. The location of the historical record made by Hamersley Iron (2006) was searched in both Phase 1 and Phase 2, however no plants were observed. A total of 777 individuals were counted in the study area during Phase 2. Two of the

L. catapycnon populations are partly located within the preliminary proposed waste dump locations, with a total of 389 individuals (50% of the individuals recorded in 2014) located within the current project footprint.

Additional habitat suitable for *Lepidium catapycnon* occurs in the study area, not all of which has been searched. All hills and slopes of the study area could comprise suitable habitat for *L. catapycnon*, especially areas that have been burnt recently or have rocky ironstone shale slopes, however vegetation type H1 remains the most prospective unit for this species. While it is possible that additional populations of *L. catapycnon* occur in the study area, there is a low likelihood of new populations being located in areas where targeted searches have been undertaken.

Two Priority flora species were recorded in the study area:

- The Priority 3 *Sida* sp. Barlee Range (S. van Leeuwen 1642) was recorded from a free face supporting vegetation type H5 at two locations in close proximity: three individuals were recorded from the southern boundary of the study area, while two individuals were recorded approximately 10 m south of the study area. Both of these records are outside the proposed project footprint.
- The Priority 4 *Goodenia nuda* was recorded from nine locations within vegetation types P6, P2 and P3, comprising 76 individuals. Four of these locations occur in the proposed project footprint. Given that *Goodenia nuda* is a small herb, and that additional suitable habitat is present in the study area, additional populations of this species may occur.

Based on the results of the field survey, as well as the known distribution of conservation significant species and the types of habitats present in the study area, a further three Priority flora species may potentially occur in the study area:

- *Stylidium weeliwolli* (Priority 2) is a small annual herb that could occur in Weeli Wolli Creek or Marillana Creek.
- *Rostellularia adscendens* var. *latifolia (*Priority 3) is also a herb and has a wide range of habitat preferences, although it is most commonly recorded in drainage areas.
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) is a tussock grass that could occur as scattered individuals, particularly on the floodplains surrounding the major creeks.

Eighteen introduced flora species (weeds) were recorded from the study area. **Argemone ochroleuca* (Mexican Poppy) is the only species listed as a Declared Pest for WA. **Cenchrus ciliaris* (Buffel Grass) was the most prolific weed observed in the study area. This species formed dense populations along sections of creek banks and floodplains, frequently in association with **Cenchrus setiger* (Birdwood Grass). Both **Cenchrus* species are serious environmental weeds.

2.0 Introduction

2.1 Project Background

Rio Tinto currently operates the Yandi iron ore mine as part of its Pilbara Iron operations. Yandi is located approximately 75 km northwest of Newman in the Pilbara region of Western Australia (Figure 2.1). The original Yandi mine, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999. The Yandi operations are approved under Ministerial Statement 914 (MS914).

Rio Tinto is currently undertaking a 'Pre-feasibility Study' for development of two channel-iron deposits at Yandi Billiards, called Pocket and Billiards South (PBS), located approximately 7 km east of the existing Yandi mine.

It is anticipated that the future development of Yandi Billiards may be formally assessed under the WA *Environmental Protection (EP) Act 1986* and potentially the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Numerous biological surveys have been completed in the Yandi locality, and although some of these overlap Yandi Billiards, they do not provide full coverage of this area (as defined in MS914; see Figure 2.1).

A desktop review of the surveys completed in the Yandi Billiards area was recently conducted (Biota 2013) to determine any further work required to bring the level of information for the area to a level suitable for environmental impact assessment (EIA) under Part IV of the WA *EP Act 1986*. Biota was subsequently commissioned to undertake a vegetation and flora survey in the Yandi Billiards area to address the recommendations of this report. The Yandi Billiards survey area is approximately 8,640 ha in size and is hereafter referred to as the 'study area'.

2.2 Scope and Objectives of this Study

The objective of this study was to conduct a Level 2 seasonal vegetation and flora survey in the study area, based on the recommendations of the desktop review (Biota 2013), in order to expand the existing flora and vegetation dataset for the area. This vegetation and flora assessment was undertaken in accordance with:

- the Environmental Protection Authority (EPA) Position Statement No. 3 "Terrestrial Biological Surveys as an Element of Biodiversity Protection" (EPA 2002); and
- the EPA Guidance Statement No. 51 "Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia"(EPA 2004).

This report details the combined methods, results and key findings of the first phase (Phase 1: 'wet season') and second phase (Phase 2: 'dry season') vegetation and flora surveys undertaken in the study area in March and July 2014, respectively. The results of the first phase of sampling in the study area were previously presented in an interim report (Biota 2014a). Information presented in the current report has been reviewed and updated as necessary, based on the combined results of the two field surveys.

As part of the Phase 1 survey, the following tasks were required to be completed:

- review and discuss the existing information for the study area, including a summary of the relevant findings of the desktop review (Biota 2013);
- describe, photograph and map the dominant vegetation types in previously unsurveyed areas of the study area, and revise and refine the existing broad-scale historical vegetation mapping as necessary;
- establish floristic survey quadrats in previously unsurveyed areas and areas of existing broad-scale historical mapping;

- establish additional floristic survey quadrats in previously mapped areas for vegetation types that required additional sampling replication to meet Level 2 requirements;
- resample approximately 60% of the existing historical quadrats in the study area;
- identify any vegetation types of conservation significance, including TECs and PECs (see Appendix 1);
- conduct targeted searches for the Threatened flora species, *Lepidium catapycnon,* and Priority flora species that may occur in the study area (see Appendix 1);
- record any introduced (weed) species and conduct vegetation condition mapping for the study area; and
- combine the Phase 1 survey results with existing data to compile a list of vascular flora species for the study area.

As part of the Phase 2 survey, the following tasks were required to be completed:

- resample approximately 60% of the floristic survey quadrats established during the first phase of sampling;
- establish any additional floristic survey quadrats in previously mapped areas for vegetation types that required additional sampling replication to meet Level 2 requirements;
- refine and update the vegetation boundaries and descriptions, where necessary;
- conduct additional searches for the Threatened flora species, *Lepidium catapycnon,* and Priority flora species that may occur in the study area;
- record any additional introduced (weed) species and update vegetation condition mapping where necessary; and
- combine existing data and results from the current survey to compile a vascular flora species inventory for the study area.

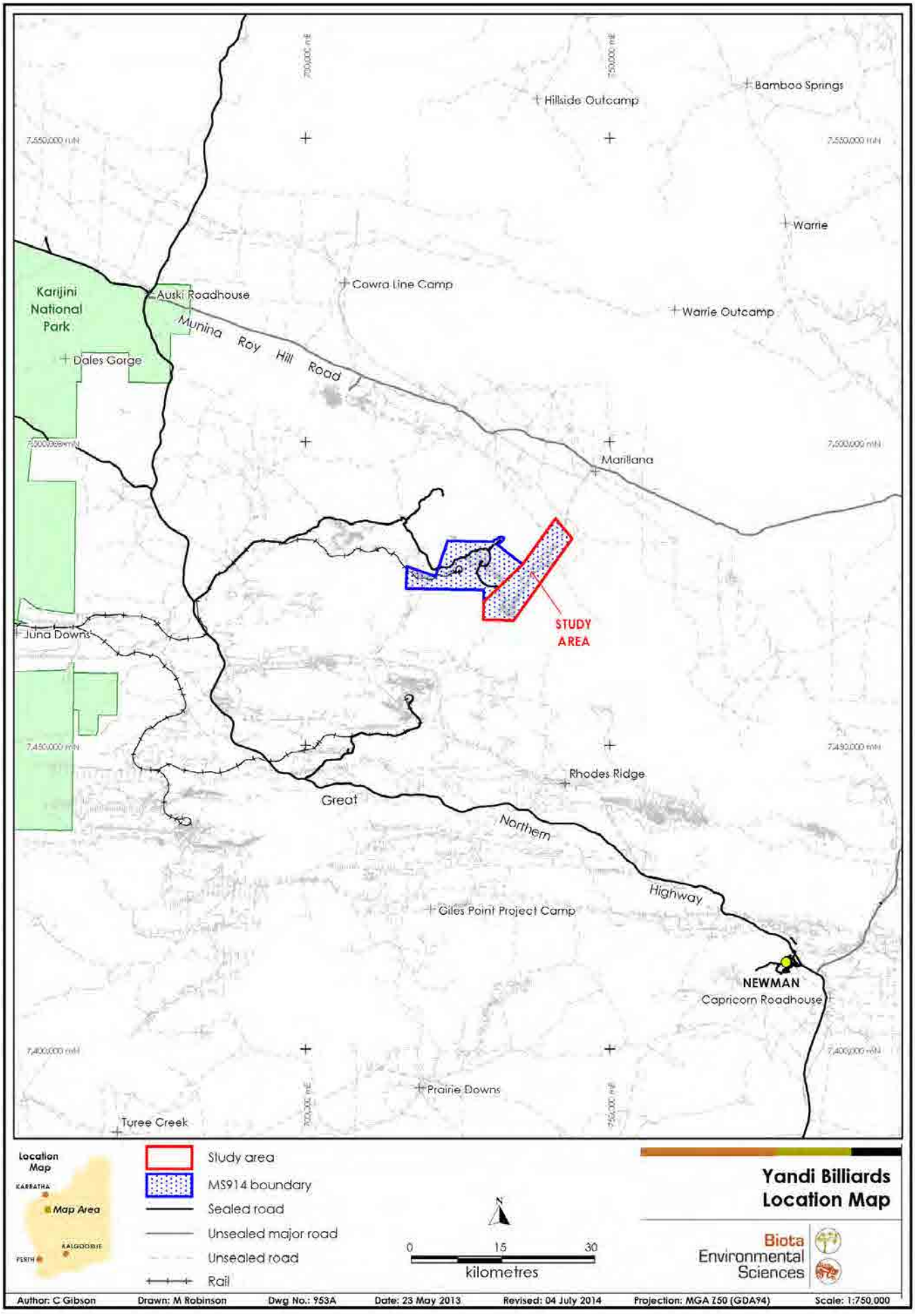

Figure 2.1: Location of the study area and the MS914 boundary.

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3.0 Methodology

To meet the objectives of the study and provide an assessment of the biological values of the study area, a desktop review was completed (see Section 3.1), followed by a field survey (see Section 3.2).

3.1 Desktop Review

Prior to the field survey, Biota was commissioned to undertake a desktop review of the study area with the specific aim of assessing the survey effort completed to date, identifying data gaps, and providing recommendations on additional biological surveys required to support a formal EIA of the study area. This review considered regional information, previous biological surveys in the locality, and the results of various database searches, as discussed in the sections below. The results of the desktop review were used to identify gaps in knowledge (see Section 4.10), which were then addressed in the design of the current field survey.

3.1.1 Literature Review

Published and unpublished reports relevant to the study area were examined. Several regional-scale reports and datasets were reviewed, including the summary of bioregional data (Kendrick 2003a), land systems mapping (Van Vreeswyk et al. 2004) and vegetation description and mapping by Beard (1975a, 1975b).

Additionally, a number of vegetation and flora surveys undertaken previously in the vicinity of the study area were reviewed (see Section 4.7).

3.1.2 Database Searches

Three databases were searched for records of flora and vegetation of conservation significance[1] that had been previously recorded or could potentially occur within or in the vicinity of the study area:

- The NatureMap[2] database: NatureMap is a joint project of the Western Australian Museum (WAM) and the WA Department of Parks and Wildlife (DPaW), which was formerly known as the Department of Environment and Conservation (DEC). This database represents the most comprehensive source of information on the distribution of Western Australia's flora and fauna, comprising records from DPaW's Fauna Survey Returns Database, Threatened Fauna Database Threatened Flora database and the WA Herbarium Specimen Database; the WAM Specimen Database; and BirdLife Australia's Atlas of Australian Birds.
- The Commonwealth *EPBC Act 1999* Protected Matters database.
- The Atlas of Living Australia[3], which is a joint project between academic collecting institutions, private individual collectors and community groups. The atlas contains occurrence records, environmental data, images and the conservation status of species throughout Australia.

The NatureMap and *EPBC Act 1999* Protected Matters database searches were based on an approximate central point of the study area (22° 47' 31"S, 119° 18' 26"E) surrounded by a 25 km buffer. The Atlas of Living Australia search was centred around the same coordinate (22° 47' 31"S, 119° 18' 26"E), using a 10 km buffer. All database searches were conducted on 22nd May 2013. In addition, outputs from Rio Tinto's and Biota's internal databases of rare flora records from previous surveys in the vicinity were also examined.

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1 The framework for conservation significance ranking of communities and species in Western Australia is presented in Appendix 1.

2 http://NatureMap.dpaw.wa.gov.au

3 http://www.ala.org.au/

3.1.3 Ranking of Conservation Significant Flora

All results from the literature review and database searches were used to compile a list of conservation significant flora species that had previously been recorded from the broader locality. The likelihood that each species would occur in the study area was then assessed using the rankings and criteria provided in Table 3.1. Two rankings have been provided:

1. An initial assessment was made during the desktop review (see Section 4.9 and Appendix 2). This was based on consideration of the overall distribution of the species, the proximity of the study area to known populations and, if the species was known to be linked to particular habitats, whether suitable habitat was present in the study area based on inspection of aerial photography and/or existing information. In the case of the current study area, major and minor creeklines, stony hills and plains were apparent on aerial imagery.
2. The likelihood rankings were subsequently revised as necessary based on the findings of the field survey (see Section 6.4 and Appendix 2). Where the initial and final likelihood rankings were different, the reason was provided.

Table 3.1: Ranking system used to assign the likelihood that a species would occur in the study area.

Rank	Example Criteria
Recorded	1. The species has been previously recorded in the study area.
Likely	1. There are existing records of the species in close proximity to the study area, or from the locality; and • the species is strongly linked to a specific habitat, which is present in the study area; or • the species has more general habitat preferences, and suitable habitat is present.
May potentially occur	1. There are existing records of the species from the locality, however • the species is strongly linked to a specific habitat, of which only a small amount is present in the study area; or • the species has more general habitat preferences, but only some suitable habitat is present. 2. There is suitable habitat in the study area, but the species is recorded infrequently in the region.
Unlikely	1. The species is linked to a specific habitat, which is absent from the study area; or 2. Suitable habitat is present, however there are no existing records of the species from the locality despite reasonable previous search effort in suitable habitat; or 3. There is some suitable habitat in the study area, however the species is very infrequently recorded in the region.
Would not occur	1. The species is strongly linked to a specific habitat, which is absent from the study area; and/or 2. The species' range is very restricted and would not include the study area.

3.2 Field Survey

3.2.1 Survey Team

A two-phase survey was carried out in the study area, with the first phase timed to follow the expected period of highest rainfall in the Pilbara bioregion (i.e. after summer) and the second phase timed to follow winter rain. The timing of the two-phase field survey was selected to provide optimal conditions for the detection of all species present in the study area (see Section 3.2.2). Both phases of the field survey were undertaken by Biota botanists who have extensive experience in flora and vegetation surveys in the Pilbara, including large-scale Level 2 surveys.

Phase 1 of the field survey was undertaken between the 8th and 20th of March 2014 by five botanists (Rachel Butler, Chloe Flaherty, Pierre-Louis de Kock, Dr Shadila Venkatasamy and Scott Werner). Chloe Flaherty completed the mapping traverses during this survey, while the remaining personnel conducted the quadrat sampling. Excluding travel days, a total of 57.5 person days

were spent on this phase of sampling (no sampling occurred on the 8th of March and a half day of sampling was completed on the 20th of March).

Phase 2 of the field survey was undertaken largely between the 7th and 11th of July 2014 by four botanists (Prue Anderson, Pierre-Louis de Kock, Chloe Flaherty and Scott Werner), who all completed quadrat sampling. Additional traverses through the study area were also completed on the 14th of July. Excluding travel days, a total of 20 person days were spent on this phase of sampling.

3.2.2 Survey Timing and Conditions

The weather conditions (particularly rainfall) leading up to a field survey are important factors influencing the number and type of flora species that are recorded from an area. To indicate rainfall leading up to this survey, monthly rainfall data from the Yandi mine weather station for the months preceding the field surveys are shown in Figure 3.1. The monthly rainfall totals were compared to the long-term median monthly rainfall for the area. The latter data were sourced from the Bureau of Meteorology (BOM) Marillana weather station (number 5009), which is the closest recording station to the study area (approximately 20 km away) with long-term rainfall data (BoM 2014).

The data showed that rainfall received at Yandi during the wet season (December 2013 to February 2014) preceding the Phase 1 field survey was more than twice the median rainfall for this period (334.4 mm compared to 118.3 mm). Several large rainfall events occurred in December 2013-January 2014, and the last rainfall event prior to the Phase 1 survey occurred over the 10th-12th February (23 days before the Phase 1 survey, when 6.4 mm of rain was received). Given this, the Phase 1 survey timing was considered optimal for the collection of annual and cryptic perennial flora species.

In the three months preceding the Phase 2 survey (April-June 2014), 45 mm of rainfall was received at Yandi, which is 1.6 times the median for this period (28 mm). The last rainfall event preceding this survey was over the 24th–25th of June (12 days before the Phase 2 survey, when 4.6 mm of rain was received). The Phase 2 survey timing was therefore considered favourable for the collection of perennial flora. However, despite the above average rainfall preceding the Phase 2 survey, July is still a typically dry time of year for the Pilbara and it is possible that some annual and cryptic perennial species may not have been present.

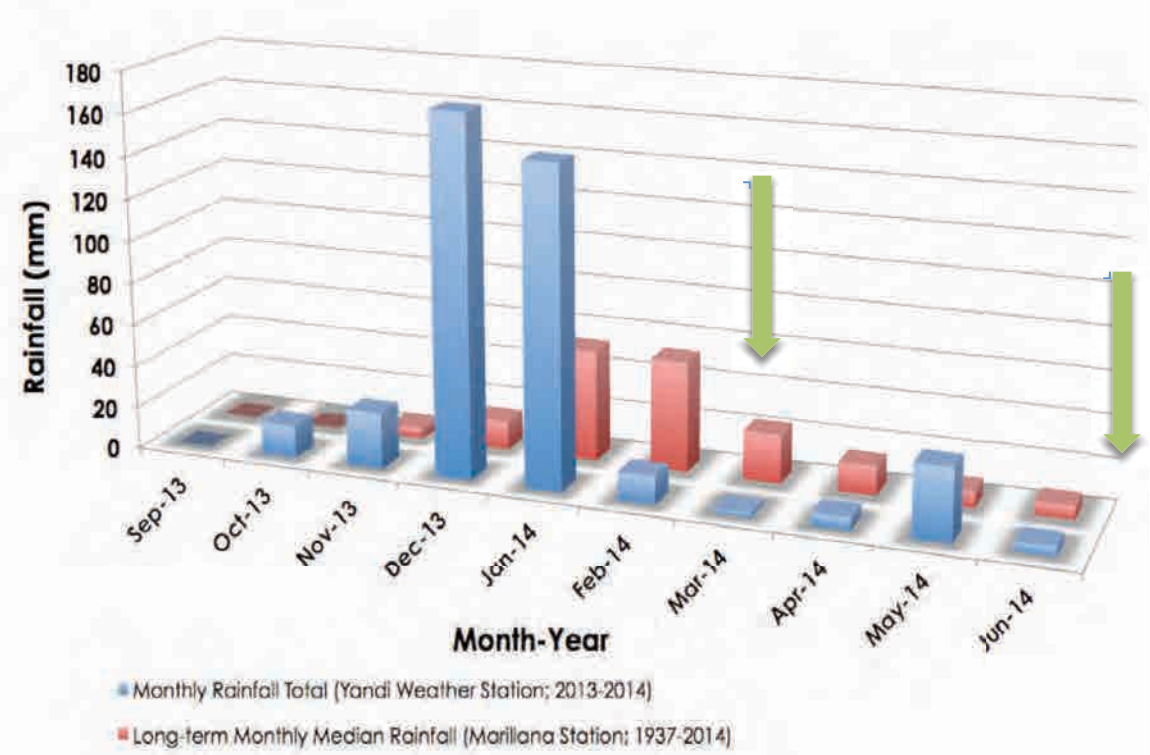

Figure 3.1: Monthly rainfall at the Yandi mine weather station for September 2013-June 2014, compared to the long-term monthly median rainfall from the Marillana recording station (BoM 2014). Arrows indicate timing of field surveys.

3.2.3 Establishment and Assessment of Flora Quadrats and Relevés

Indicative quadrat locations were selected prior to the field survey. The study area boundaries, aerial photography and previous vegetation mapping were viewed using Geographical Information System (GIS) software (QGIS). Quadrat sites were then selected such that there was replication of sampling (a minimum of two quadrats) within each mapped vegetation type, taking into account the broad habitats and vegetation types apparent from the aerial imagery. Some additional quadrats were established in previously mapped areas to improve sampling replication. Once in the field, the actual locations of the quadrats were adjusted as necessary (e.g. to be placed in an area more representative of the broader vegetation type).

Permanently marked quadrats (flora sampling sites of a fixed area) were used wherever possible. Most quadrats established were 50 m x 50 m in size, or an equivalent area (2,500 m^2). This area is recognised as providing an adequate sample of species presence for the Pilbara vegetation and is the standard quadrat size for botanical survey work in the region (Clarke 2009). Where a square quadrat was unsuitable for capturing the vegetation type (e.g. along narrow creeklines), a rectangular quadrat of equivalent area (e.g. 25 m x 100 m) was established instead. The quadrats were permanently marked using steel fence droppers on at least three corners. An optical square and measuring tapes were used to accurately position the quadrat boundaries.

In cases where quadrats could not be established (e.g. due to the small size or irregular shape of the habitat), these locations were instead surveyed as relevés, or mapping notes were taken (see Section 3.2.4). A relevé is an unbounded flora sampling site with a similar area to a standard quadrat; essentially the same information is recorded as for a quadrat, however the sampling of flora is typically not as thorough. Relevé sampling is usually undertaken if the vegetation type has a narrow linear or irregular shape (e.g. minor flowlines, narrow ridgelines, areas of cracking clay, etc.) or comprises only a small area (e.g. on rockpiles), making establishment of a standard quadrat in a single vegetation type difficult.

A total of 121 quadrats and 28 relevés have been sampled in the study area to date (Table 3.2 and Figure 3.2). These include 46 quadrats and eight relevés established during Phase 1 of the current survey, and three additional quadrats established during Phase 2.

Resampling of established quadrats was also undertaken in Phase 1 and Phase 2 of the current study. Overall, 68 quadrats in the study area have been resampled over two seasons to date (with at least one phase of sampling in favourable conditions for plant growth). These include:

- 32 existing quadrats that were established within the study area as part of other surveys in the locality, which were resampled during the Phase 1 survey;
- 30 quadrats that were established in Phase 1, which were resampled during the Phase 2 survey; and
- six quadrats that had been both established and resampled during a previous survey (Biota 2009b).

Eleven quadrats out of the 36 sampled by Biota (2009b) were established at a time when conditions for plant growth were unfavourable, and were resampled during a typically dry time of year (although the conditions during this latter survey were relatively favourable for this season). These quadrats have not been considered as being effectively resampled, as it is likely that some species may not have been present or identifiable at the time of both phases of surveys (e.g. annual daisies that would germinate mostly after late winter rains, annual grasses, etc.).

Fourteen quadrats that were sampled in the study area have since been cleared for expansion of the mine or the establishment of roads or drill tracks (see Table 3.2).

Table 3.2: Number of quadrats and relevés sampled in the study area.

Survey (Reference)	Survey Timing (Conditions for Plant Growth)	Number of Quadrats Established	Number of Quadrats Resampled	Number of Relevés Recorded	Other Comments
Yandi Billiards Vegetation and Flora Survey – Phase 2 (current survey)	July 2014 (favourable for this time of year)	3	30	0	
Yandi Billiards Vegetation and Flora Survey – Phase 1 (current survey)	March 2014 (optimal)	46	32	8	
Yandi Additional Areas Level 2 Flora and Vegetation Survey (Biota 2014b)	June 2012 (favourable for this time of year)	11	0	5	1 quadrat has subsequently been cleared.
Vegetation and Flora Survey of the Billiards Deposit, near Yandi (Biota 2009b)	June 2007 (unfavourable)	29	0	14	2 quadrats have subsequently been cleared.
	July/August 2008 (favourable for this time of year)	7	11	0	Quadrats were both established and resampled under unfavourable conditions, and are therefore not included in the overall resample total.
	June 2009 (favourable for this time of year)	0	6	0	
Flora and Vegetation Survey of the Yandi Expansion Area (Biota 2004a)	August/September 2004 (unfavourable)	13	0	1	6 quadrats have subsequently been cleared.
Flora and Vegetation Survey of the Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b)	April 2003 (favourable)	9	0	0	4 quadrats have subsequently been cleared.
Vegetation and Flora of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002)	April/May 2001 (favourable)	2	0	0	1 quadrat has subsequently been cleared.
Hope Downs Rail Corridor Biological Surveys (Halpern Glick Maunsell 2000)	November/ December 1999 (unfavourable)	1	0	0	
	Total	121	68	28	

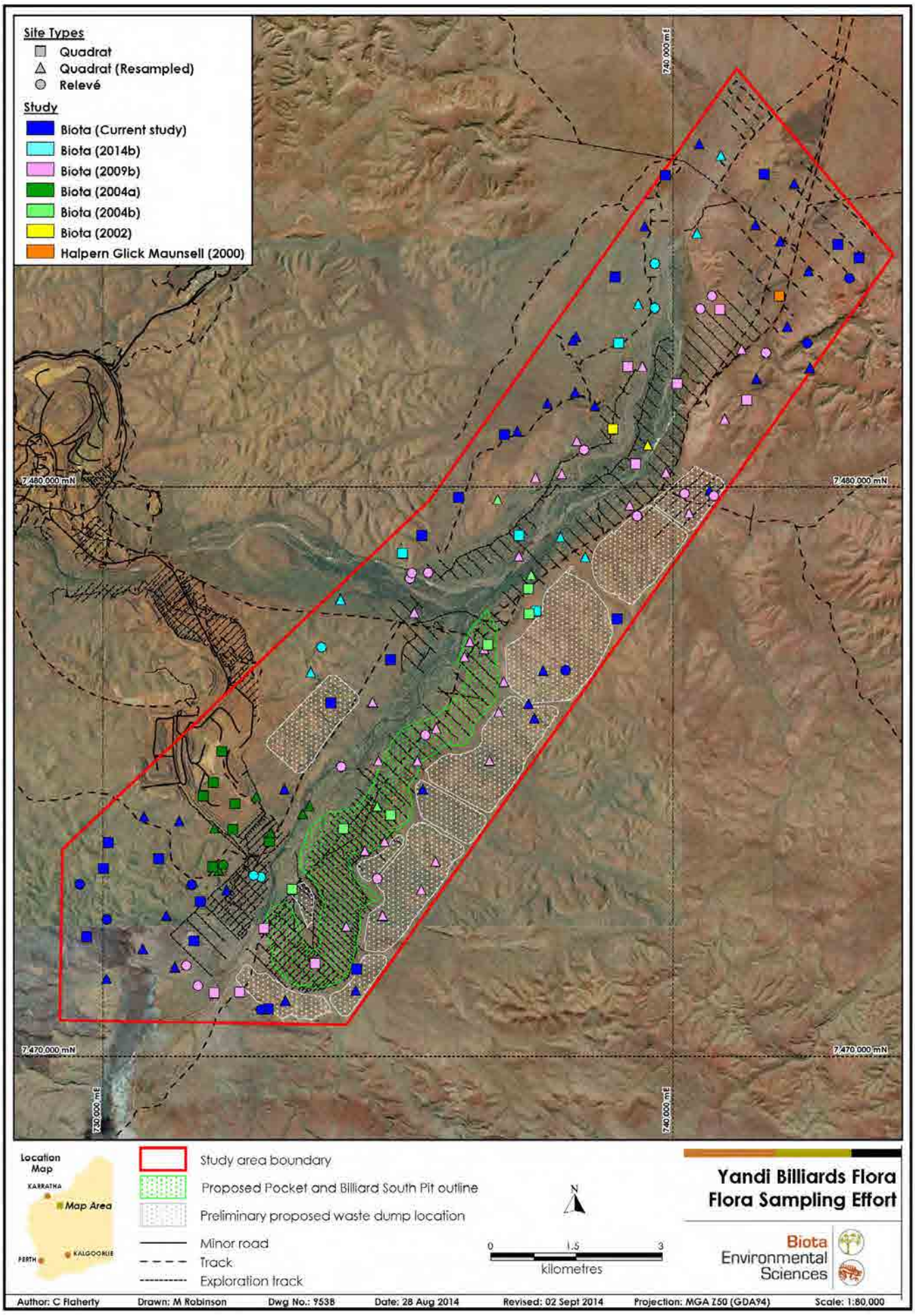

Figure 3.2: Quadrat and relevé locations in the study area.

The following information was recorded for each quadrat and relevé:

- location co-ordinates (±5 m), recorded with a hand-held Global Positioning System (GPS) using the WGS84 datum; all coordinates in this report are displayed in MGA Zone 50;
- a colour photograph of each site (usually taken from the northwest corner of the quadrat, looking southeast);
- habitat description;
- broad soil type;
- fire history (approximate time since last fire, where applicable);
- vegetation description based on the height and estimated cover value of dominant species (Aplin 1979; see Appendix 3);
- vegetation condition ranking (Trudgen 1988; see Appendix 3); and
- the estimated percent foliar cover of each flora species present within the quadrat, or in the vicinity (within a ~30 m radius) of the centre point of the relevé.

Quadrat and relevé locations are shown on the vegetation mapping in Appendix 4. Vegetation condition mapping and weed locations are provided in Appendix 5. All raw data from the sampling sites are presented in Appendix 6.

3.2.4 Vegetation Description and Mapping

Vegetation mapping was undertaken in the study area in previously unsurveyed areas and areas of broader historical mapping (see Figure 4.5), which extended over an area of 3,395 ha (39% of the study area).

Vegetation types identified from aerial photography were ground-truthed during foot traverses in the study area. The boundaries of the study area were loaded onto hand-held GPS units to ensure that the correct areas were traversed. Vegetation descriptions for each vegetation type observed in the field were recorded at all quadrats and relevés (see Section 3.2.3), and also in a series of mapping notes. Mapping notes are sampling sites conducted over an area of smaller scale than a quadrat or relevé; these notes are typically brief, with only dominant and commonly associated species being recorded. Mapping notes are taken primarily during foot traverses of an area, with the objective of detecting boundaries and changes in vegetation types. Typical information recorded at a mapping note location includes notes on the habitat, landscape and vegetation type, usually with a representative photograph and often with opportunistic specimen collections to supplement the species list. Mapping note locations are presented in Appendix 7.

Vegetation descriptions were based on the height and estimated cover value of dominant species using Aplin's (1979) modification of the vegetation classification of Specht (1970). The previous detailed vegetation mapping of the study area (Biota 2014b) was used as a guide to inform the mapping of the unsurveyed areas. Vegetation was mapped to a similar scale and, where possible, vegetation types used in previous surveys were extended or repeated.

The vegetation types were described at the sub-association level (level VI as per the National Vegetation Information System)[4]. The sub-association level includes information about the dominant growth form, height and cover for up to five species in all layers/sub-strata observed (e.g. *Eucalyptus xerothermica* scattered low trees over *Acacia citrinoviridis, Stylobasium spathulatum* tall shrubland over *Ptilotus obovatus* var*. obovatus* scattered shrubs over *Themeda triandra, Chrysopogon fallax, *Cenchrus ciliaris* very open tussock grassland).

Similar vegetation descriptions were grouped to establish the vegetation types for the study area. Vegetation descriptions that shared a suite of perennial species with a similar range of cover values were considered to be alike.

[4] http://www.environment.gov.au/erin/nvis/publications/avam/section-2-1.html

Two coding systems are presented in this report to refer to the individual vegetation types:

1. An alphabetic code was assigned to represent the dominant flora species from the tallest stratum to the lowest stratum. Each dominant species was given a unique code by using an abbreviation of the genus to capital letter(s) followed by an abbreviation of the species to lower case letter(s) (e.g. EvAciAcMgCEc denotes a vegetation type dominated by *Eucalyptus victrix, Acacia citrinoviridis, Acacia coriacea* subsp*. pendens, Melaleuca glomerata and *Cenchrus ciliaris*). This coding enables vegetation types from different studies to be quickly compared, although it can sometimes result in long and unwieldy codes.
2. To aid interpretation, each vegetation type was also assigned an alpha-numeric code as a unique precursor to the species-driven code (e.g. C3: EvAciAcMgCEc for the third creekline sub-association). This short code is used to refer more simply to the individual vegetation types.

Although some of the vegetation types were first drafted in the field, the majority of the vegetation mapping was completed in the office after the fieldwork was completed. Field data and aerial imagery were studied to determine boundaries of vegetation types, which were then mapped to an appropriate scale. The maps were created and consolidated using GIS software (QGIS and MapInfo), and point locations of sampling sites, conservation significant flora and weeds were added. All maps in this report were produced using the MapInfo package (version 11).

3.2.5 Searches for Flora of Conservation Significance and Weeds

Targeted searches were undertaken in suitable habitats for the conservation significant flora[5] that were identified through the desktop review as having the potential to occur in the study area (see Section 4.9). A map of all foot traverses conducted through the study area during Phase 1 and Phase 2 is provided in Appendix 7 as an indication of the degree of survey effort for conservation significant flora.

The Threatened species *Lepidium catapycnon* was a key search focus for the field survey, given that it is known to occur in the Yandi locality and was previously recorded from two locations in the study area (Hamersley Iron 2006, Biota 2009a). The locations of the previously recorded populations of *L. catapycnon* were checked in Phase 1 and Phase 2 of the field survey so that the populations could be confirmed and number of individuals re-counted (see Section 6.4.1). Additional targeted searches for *L. catapycnon* were undertaken in habitat determined likely to support this species, with a focus on searching potential habitat within the main project footprint. Based on known records of this species and its habitat preferences (see Section 4.9.1), areas of rocky hills and slopes in the study area were identified as potentially suitable habitat within the study area and these areas were the focus of the targeted searches. Searches for *L. catapycnon* and other conservation significant flora were also conducted during the extensive foot traverses that were required to validate the vegetation mapping, while traveling on foot between sites, and also while completing quadrats and relevés.

The locations of flora of conservation significance, unknown flora and introduced species (weeds) were recorded using a hand-held GPS (WGS84 datum, Zone 50). Where conservation significant flora species were encountered, estimates of the density or number of individuals were made in the area (in an approximate 20 m radius) and a description of the habitat and associated flora were recorded. A continuous list of vascular flora species was also recorded during the traverses, which contributed to the overall species list for the study area (see Appendix 8).

All records of conservation significant flora are provided in Section 6.4 and are displayed on the vegetation mapping in Appendix 4. All records of introduced flora are provided in Appendix 5.

[5] The framework for conservation significance ranking of species in Western Australia is provided in Appendix 1.

3.3 Specimen Identification, Nomenclature and Data Entry

Common species that were well known to the survey botanists were identified in the field. Voucher specimens of all other species were collected and assigned a unique number to facilitate tracking of data. These were pressed in the field and dried using heaters.

Specimens were identified using flora keys, consulting appropriate publications, checking voucher reference collections, and comparing the specimens to the collections held at the WA Herbarium. Biota botanists (Cassie Adam, Prue Anderson, Rachel Butler, Pierre-Louis de Kock and Chloe Flaherty) identified most specimens, the majority of which were confirmed by Biota's principal botanist (Michi Maier). A Pilbara flora expert, Malcolm Trudgen (of M.E. Trudgen and Associates), was consulted for some complex plant identifications, including but not limited to *Abutilon* and *Corchorus* species. Ryonen Butcher (WA Herbarium taxonomist) was consulted for assistance with the genus *Tephrosia*. Andrew Perkins (WA Herbarium taxonomist) provided confirmation for conservation significant specimens and some atypical specimens collected from the study area (*Corchorus tectus, Heliotropium glabellum* and *Swainsona maccullochiana*).

Nomenclature was checked against the current listing of scientific names recognised by the WA Herbarium and updated as necessary. All data were entered into a Microsoft Access Vegetation Database structure held internally at Biota. The database model employed by Biota was developed by Ted Griffin (private consultant) at the request of Malcolm Trudgen (M.E. Trudgen and Associates).

Data from sites located in the current study area that were sampled during previous surveys were reviewed, and specimen identifications were checked and amended as necessary to reflect recent taxonomic changes.

Provided material is of adequate condition and not already vouchered for the locality, specimens will be lodged with the WA Herbarium for all taxa representing flora of conservation significance, range extensions, undescribed or poorly collected taxa. Threatened and Priority Flora Report Forms will be submitted to DPaW for all Threatened and Priority flora species recorded from the study area.

3.4 Floristic Analysis

In order to examine the relationships between the floristic composition of the sampling sites in the study area compared to a selection of sites from the broader locality, cluster analyses were carried out using the PRIMER software package. The dataset comprised 212 quadrats and 17 detailed relevés from the locality, comprising:

- 81 quadrats and seven relevés assessed within the study area during Phase 1 and/or Phase 2 of the current survey;
- another 39 quadrats and five relevés from the study area that had been sampled previously (Halpern Glick Maunsell 2000, Biota 2004a, 2009b, 2010, 2014b, 2014c); and
- 92 quadrats and five relevés in the broader Yandi locality (sampled previously by Biota 2004a, 2009b, 2010, 2014b, 2014c).

A full list of the sites and their source studies is provided in Appendix 9, with each site attributed with its alpha-numeric vegetation code and broad habitat (see Section 3.2.4). Seven vegetation types that were not mapped within the study area were present within the data set. Although these are not discussed in the report, each has been assigned a vegetation code as follows to assist with data presentation:

- Ca (vegetation code C3 of Biota 2014b): *Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland in a minor creekline;

- Ha (vegetation code H8 of Biota 2014b): *Acacia inaequilatera* scattered tall shrubs over *Eremophila fraseri* subsp. *fraseri* scattered shrubs over *Triodia pungens* very open hummock grassland on a hill;
- Hb (vegetation code H5 of Biota 2014c): *Grevillea pyramidalis, Eremophila fraseri* tall open shrubland over *Triodia pungens* hummock grassland on a hill slope;
- Hc (vegetation code H7 of Biota 2014c): *Corymbia hamersleyana* scattered low trees over *Gossypium robinsonii, Androcalva luteiflora, Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* shrubland over *Themeda triandra, Cymbopogon ambiguus* open tussock grassland in a gorge;
- Hd (vegetation code H3 of Biota 2014c): *Eucalyptus leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland on hills;
- He (vegetation code H4 of Biota 2014c): *Eucalyptus leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana, T. pungens* open hummock grassland on hills; and
- Hf (vegetation code H6 of Biota 2014c): *Acacia monticola* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* closed hummock grassland on a hill slope.

A combined species list was created from all of the sites and reviewed for errors or inconsistencies in nomenclature. Both annual and perennial vascular flora species were included. Fungi were removed, as were all weeds other than **Cenchrus ciliaris* and **C. setiger*, which were combined and treated as "**Cenchrus* spp.". Where multiple taxa were considered likely to represent the same species, these were all referred to a single taxon identification code in the dataset, and thus treated as a single entity in the subsequent analyses. Where a taxon name could refer to more than one entity across different projects (e.g. "*Euphorbia* sp."), it was excluded. Finally, singleton species (those occurring in only one site) were removed to reduce noise in the dataset, unless they were characteristic of a particular habitat (e.g. *Astrotricha hamptonii*).

Site data from multiple phases were merged to create a single set of data for each site; where cover values differed between phases, the highest cover value was accepted.

For the resulting list of species, two matrices were then generated:

- percentage foliar cover of each species at each site; and
- presence / absence of each species at each site.

Two additional matrices were generated from the above by removing annual species, which would only be recorded under optimal sampling conditions. These matrices were used to investigate potential bias in the dataset caused by sampling during different seasonal conditions for different projects.

Four analyses were subsequently performed based on:

1. Percentage foliar cover data for all species (perennials and annuals);
2. Percentage foliar cover data for perennial species only;
3. Presence / absence data for all species (perennials and annuals); and
4. Presence / absence data for perennial species only.

Percentage foliar cover values were transformed using a square root transformation. The Bray-Curtis coefficient was used to produce a similarity matrix. The cluster analysis used the group average method. The clusters were tested for significance using the similarity profile permutation test (SIMPROF). The similarity percentage test (SIMPER) was used to determine which species contributed most to the similarities between groups.

Following initial review of the floristic groups identified by these analyses, further analyses were performed with the addition of some other sites from the locality (specifically three sites in *Triodia*

schinzii hummock grasslands, and numerous sites in *Triodia longiceps* hummock grasslands) to test whether particular floristic groups were restricted to the study area.

Representative outputs are presented as both floristic dendrograms and non-metric, multi-dimensional scaling (MDS) ordination plots in Section 5.4 and Appendix 9. Due to the size of the dataset it is not provided within this document.

3.5 Limitations of this Study

Limitations of this study that should be considered are as follows:

- Whilst targeted searches for conservation significant flora were undertaken and opportunistic taxa were recorded during representative traverses through all habitats in the study area, the entire study area was not systematically searched. The list of vascular flora documented from the study area is therefore not exhaustive.
- The Phase 1 survey was undertaken in March 2014 and was optimally timed for the collection of annual flora. The Phase 2 survey was undertaken in July, which is typically a dry time of year in the Pilbara, however above average rainfall was received prior to this survey. Given the favourable rainfall conditions, most species should have been present during the field surveys, however it is possible that some annual or cryptic perennial species would have been absent during the Phase 2 survey due to the seasonal timing (see Section 3.2.2).
- Consistent with the accepted level of effort for a survey of this type and scale, fungi and non-vascular flora (algae, mosses and liverworts) were not sampled.
- One vegetation type (H5; see Section 5.0) was described from relevés rather than quadrats. Quadrats could not be established in this vegetation type due to the narrow dimensions of the habitat and the steep, rocky terrain.
- The existing disturbance footprint for the study area was the most current version available (December 2013), however clearing is ongoing for earthworks which are not part of this proposal (drill pads, drill tracks, etc.). Some areas of recent clearing within the study area were therefore not mapped.
- Quadrat data for the Pilbara region is typically patchily distributed and concentrated in development areas, and not all vegetation associations are equally well sampled. The results of the floristic analysis presented in this report reflect the dataset utilised, and analysis using different or additional sites may result in a somewhat different interpretation.

4.0 Desktop Review

4.1 IBRA Bioregion and Subregion

The study area lies within the Pilbara bioregion, one of 89 bioregions defined by the Interim Biogeographic Regionalisation for Australia (IBRA) (Department of Environment 2013). The study area occurs at the boundary between two subregions of the Pilbara:

- Hamersley (PIL3): mountainous area of Proterozoic ranges and plateaus with low Mulga (*Acacia aneura*) woodland over bunch grasses on fine textured soils, and Snappy Gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on the skeletal sandy soils of the ranges (Kendrick 2003a); and
- Fortescue Plains (PIL2): alluvial plains and river frontages with salt marsh, Mulga-bunch grass and short grass communities on alluvial plains and River Gum (*Eucalyptus camaldulensis*) woodlands fringing drainage lines (Kendrick 2003b).

4.2 Conservation Reserves in the Locality of the Study Area

The IBRA provides a national system for assessing the condition of native ecosystems and their level of protection in the National Reserve System (NRS). The NRS is Australia's network of protected areas, including national parks and other Government reserves, indigenous lands, and reserves run by non-profit conservation organisations. At the time of the regional biodiversity audit conducted by the then Department of Conservation and Land Management, the Pilbara bioregion was considered to be under-represented by the NRS, with less than 10% of the bioregion protected (Kendrick 2003a, 2003b). Of the four subregions within the Pilbara bioregion, the Hamersley subregion had the highest percentage of area under some form of protection, while the Fortescue Plains subregion had the lowest (Kendrick 2003a, 2003b).

Karijini National Park (Karijini) is the closest conservation reserve to the study area. The nearest boundary of Karijini to the study area is approximately 64 km to the west. Areas surrounding the Fortescue Marsh, approximately 30 km north of the study area, are also proposed to be excluded from the Marillana Station pastoral lease in 2015 to assist with management of this important ephemeral wetland.

4.3 Surface Geology

The study area encompasses eight geological units mapped by the Geological Survey of Western Australia (1984). These units are described in Table 4.1 and displayed in Figure 4.1.

Table 4.1: Geological units occurring within the study area (Geological Survey of Western Australia 1984).

Unit Code	Geological Description	Area (ha)	Percentage of Study Area
Czc	Colluvium: partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits.	2,337	27.0%
Czk	Calcrete-sheet carbonate; found along major drainage lines.	341	3.9%
Czp	Robe Pisolite: pisolitic limonite deposits developed along river channels.	4	0.05%
PLHb	Brockman Iron Formation: banded iron-formation, chert, and pelite.	637	7.4%
PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite and numerous metadolerite sills.	2,350	27.2%
Qa	Alluvium: unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains.	2,413	27.9%
Qs	Eolian deposit-sand; in sheets and longitudinal dunes.	1	0.01%
Qw	Alluvium and colluvium: red-brown sandy and clayey soil; on low slopes and sheetwash areas.	557	6.4%

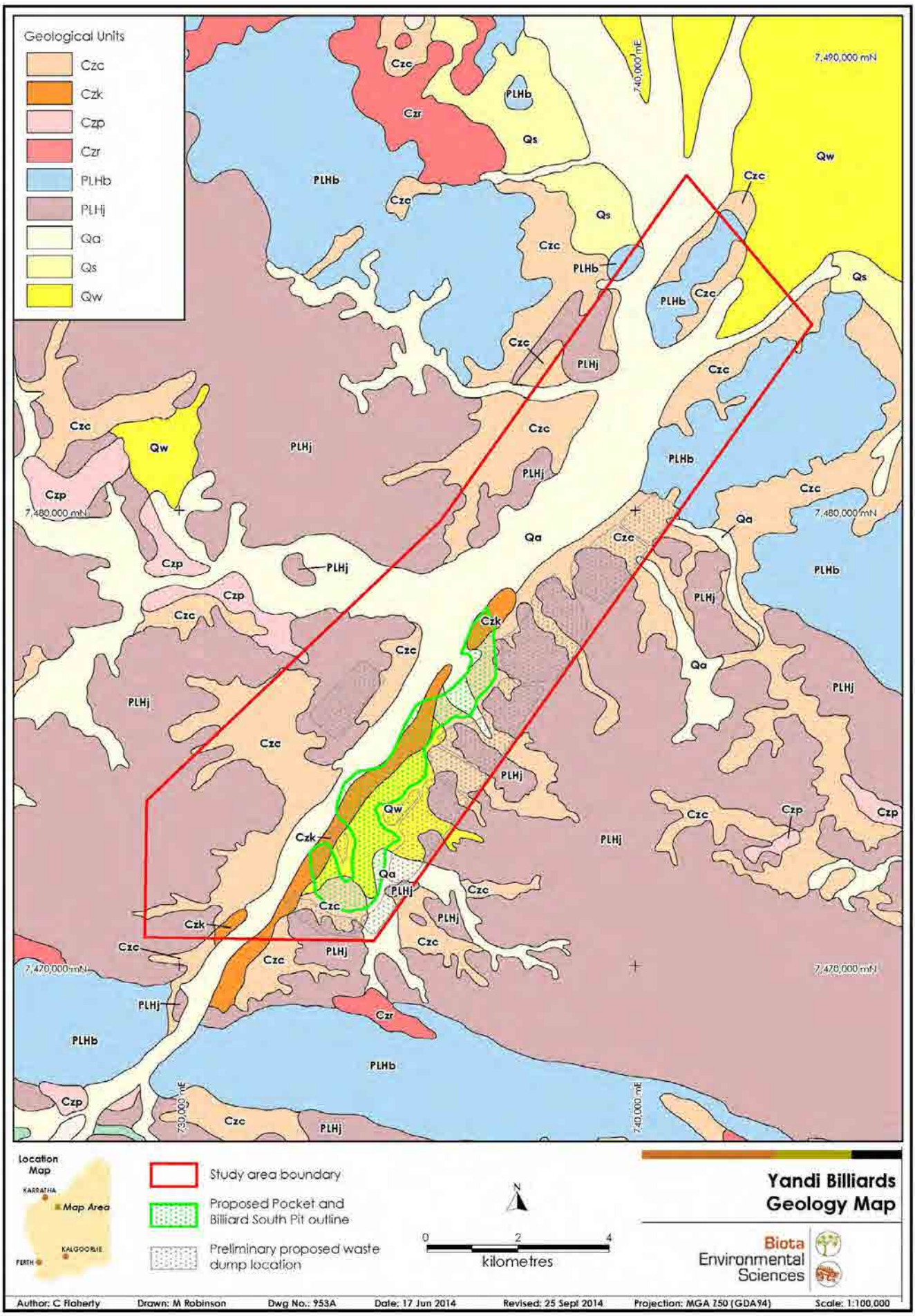

Figure 4.1: Geological units mapped in the vicinity of the study area (Geological Survey of Western Australia 1984).

4.4 Land Systems

Western Australian Rangelands Surveys have been conducted for various parts of the State as part of a program of rangeland classification, mapping and resource evaluation (Waddell et al. 2010). These surveys have been conducted in Western Australia since the 1950s, when they were commenced by the Commonwealth Scientific and Industrial Research Organisation (Speck et al. 1960), and more recently have been conducted as a collaboration between the Department of Agriculture and Food WA and Landgate. The land system approach to mapping different country types has been used in all of the regional rangeland surveys in Western Australia.

The concept of land systems was first used by Christian and Stewart (1953). They defined a land system as 'an area with a recurring pattern of topography, soils and vegetation'. These recurring patterns can be mapped using 1:50,000 scale aerial photography or other remotely sensed images (Waddell et al. 2010). It is assumed areas with a similar pattern represent the same land system. The land systems are then ground-truthed during fieldwork.

A total of 105 land systems have been identified and mapped in the Pilbara bioregion[6], with 63 land systems occurring in the Hamersley subregion and 54 occurring in the Fortescue Plains subregion. Land systems mapping covering the study area has been prepared by van Vreeswyk et al. (2004).

The study area intersects five land systems, which are summarised in Table 4.2. These land systems are widespread and extensive in terms of their area within the Pilbara bioregion. Their location in relation to the study area is shown in Figure 4.2.

4.5 Landforms and Surface Hydrology

Aerial imagery and available information indicate that the study area encompasses the northern portion of the Weeli Wolli Creek valley, where this widens from a shallow gorge to form a true valley, and its associated floodplains and hillslopes.

Drainage within the study area is dominated by Weeli Wolli Creek, which flows in a northeast direction through the Hamersley Range and ends in an alluvial fan. The alluvial fan stretches from the footslopes of the Hamersley Range scarp, across the pediment slope to the edge of the Fortescue Marsh. The confluence of Weeli Wolli Creek and Marillana Creek occurs in the centre of the study area, just behind the scarp of the Hamersley Range. There are numerous floodout areas adjacent to the creeks, and islands in the anabranching creek beds of both creek systems.

Low crests and hillslopes define the edge of the creek valley. Numerous short minor drainage lines dissect the hills, forming shallow gorges and narrow floodplains before they flow into Weeli Wolli Creek. In an area near the southern end of the eastern boundary of the study area, the creek valley widens considerably and several minor drainage lines flow through a narrow pediment zone before entering the Weeli Wolli Creek floodplain.

[6] This information was obtained by merging the Ashburton land system mapping (Payne et al. 1988) and Pilbara land system mapping (Van Vreeswyk et al. 2004) and intersecting this with the Pilbara bioregion (Environment Australia 2000) in ArcView (v. 3.2).

Table 4.2: Extent of land systems in the study area and the percentage this represents of their total extent in the Pilbara bioregion.

Land System	Description (Van Vreeswyk et al. 2004)	Total Area of Land System within the Study Area	Percentage of Study Area	Total Area of Land System in the Pilbara	Percentage of Total Land System in Study Area
Boolgeeda	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands. Component landforms include low hills and rises (4%), stony slopes and upper plains (20%), stony lower plains (65%), groves (1%), and narrow drainage and channels (10%). Not susceptible to degradation or soil erosion.	2,221 ha	25.8%	961,637 ha	0.2%
McKay	Hills, ridges, plateaus and breakaways of meta-sedimentary rocks supporting hard spinifex grasslands. Component landforms include hills, ridges ad plateaus remnants (60%), breakaways (2%), lower foot slopes (10%), stony plains (20%), and drainage floors (8%). Not susceptible to degradation or soil erosion.	1,455 ha	16.8%	426,145 ha	0.3%
Newman	Rugged jaspilite plateaus, ridges and mountains supporting hard spinifex grasslands. Component landforms include plateaus, ridges, mountains and hills (70%), lower slopes (20%), stony plains (5%), and narrow drainage floors with channels (5%). Not susceptible to degradation or soil erosion.	2,326 ha	26.9%	1,993,745 ha	0.1%
River	Active floodplains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands. Component landforms include sandy levees and sand sheets (15%), upper terraces (5%), floodplains and lower terraces (50%), stony plains (10%), and minor and major channels (20%). Susceptibility to erosion is high or very high if vegetation is removed.	2,142 ha	24.8%	497,421 ha	0.4%
Urandy	Stony plains, alluvial plains an drainage lines supporting shrubby soft spinifex grasslands. Component landforms include stony plains (58%), alluvial plains (35%), and drainage zones and channels (7%). Most of the system is not susceptible to degradation or soil erosion.	496 ha	5.7%	131,975 ha	0.4%

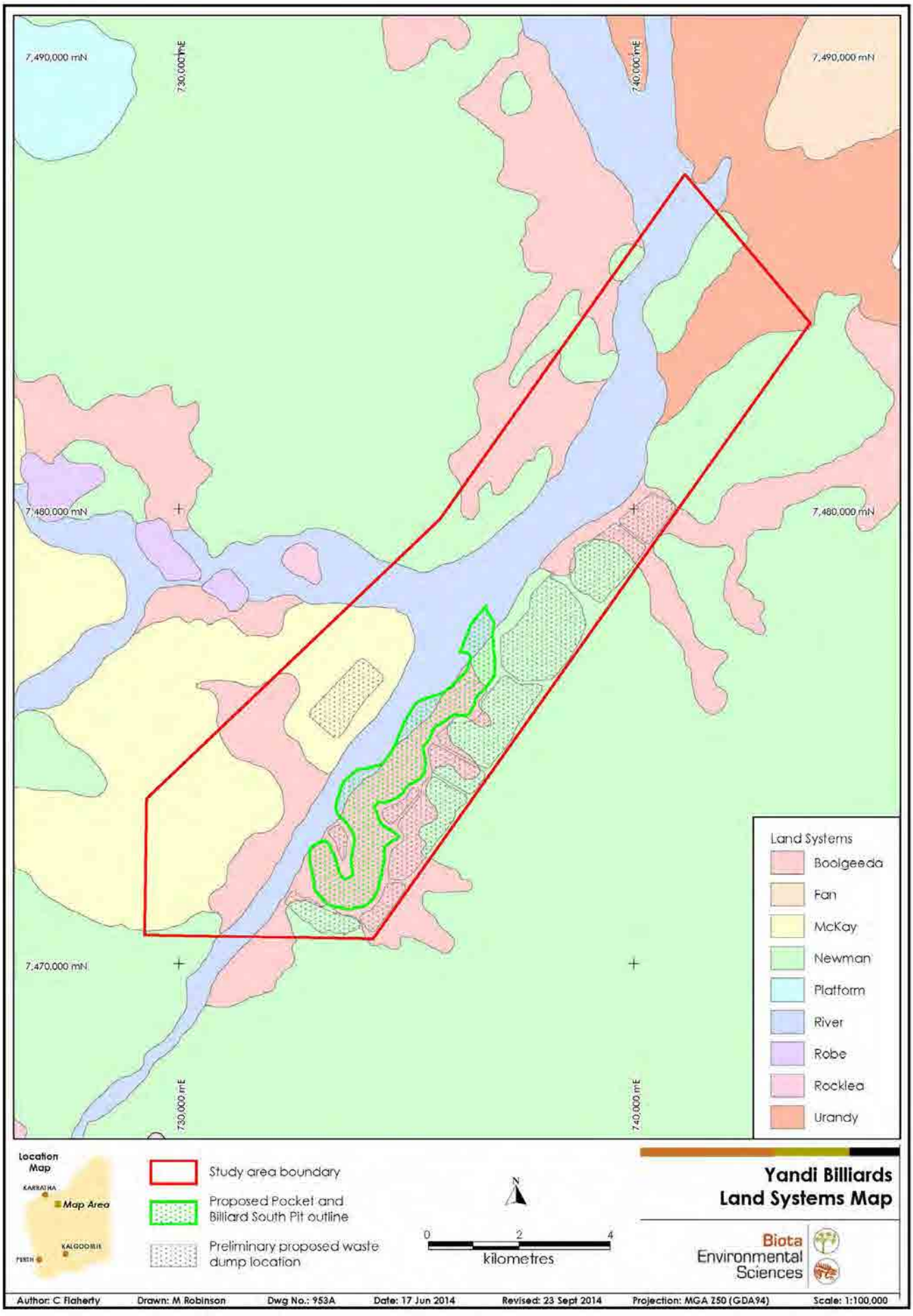

Figure 4.2: Land systems of the locality including the study area.

4.6 Beard's Vegetation Mapping

Beard (1975a, 1975b) described and mapped the vegetation of the Pilbara at a scale of 1:1,000,000. The study area is located on the Hamersley Plateau, which is within the Fortescue Botanical District of the Eremaean Botanical Province as defined by Beard. The vegetation of this province is typically open, and frequently dominated by spinifex, wattles and occasional eucalypts.

Three vegetation units mapped by Beard (1975b) occur within the study area (see Figure 4.4), two of which are essentially the same vegetation type:

- Fortescue Valley 29: Sparse low woodland; Mulga (*Acacia aneura* sens. lat.), discontinuous in scattered groups; and
- Fortescue Valley 82 and Hamersley 82: Hummock grasslands, low tree steppe; Snappy Gum (*Eucalyptus leucophloia*) over Limestone Spinifex (*Triodia wiseana*).

These vegetation units are relatively widespread in the Pilbara bioregion and largely uncleared (see Table 4.3). Given the broad nature of Beard's mapping, these units are only broadly applicable to the vegetation of the study area (see Section 5.0 for a more detailed description of the vegetation).

Table 4.3: Beard's (1975b) mapping units that occur in the study area and their extent in the Pilbara bioregion (data from Government of Western Australia 2013).

Beard's Vegetation Mapping Unit	Pre-European Extent in the Hamersley or Fortescue Subregion (as relevant)	Current Extent in the Hamersley or Fortescue Subregion (% Remaining)	Extent within the Study Area (% of Current Mapped Extent in the Hamersley or Fortescue Subregion)
Fortescue Valley 29	893,395 ha	893,222 ha (>99.9%)	4,512.1 ha (0.5%)
Fortescue Valley 82	24,192 ha	24,192 ha (>99.9%)	1,021.8 ha (4.2%)
Hamersley 82	2,177,574 ha	2,165,235 ha (99.4%)	3,105.2 ha (0.1%)

4.7 Previous Biological Surveys in the Locality

Numerous botanical surveys have been undertaken in the Yandi locality. In order to provide regional context, 12 previous botanical surveys completed in the vicinity of the study area were reviewed (see Table 4.4). In particular, the review aimed to identify species and communities of conservation significance that may occur in the study area (see Section 4.9 and Appendix 2). Eight of these surveys overlap the study area (Figure 4.3), and the key findings from these are summarised in Table 4.5.

Table 4.4: Previous flora and vegetation surveys in the Yandi locality that have been reviewed.

Survey	Reference
Flora and vegetation survey of the Northern Transport Corridor associated with the Yandicoogina Junction Project Area	Mattiske (1995a)
Flora and vegetation survey of the Southern Transport Corridor associated with the Yandicoogina Junction Project Area	Mattiske (1995b)
Hope Downs Rail Corridors biological surveys	Halpern Glick Maunsell (2000)
Tom Price – Yandi Power Line review of botanical surveys	Biota (2000)
Vegetation and flora survey of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek	Biota (2002)
Flora and vegetation survey of the Yandi Expansion area	Biota (2004a)
Flora and vegetation survey of the Hope Downs Rail Corridor Extension through the Hamersley Range	Biota (2004b)
Yandicoogina waste dumps, topsoil stockpiles and haulroads native vegetation clearing permit report	Biota (2009a)
A flora and vegetation survey of the Billiards Deposit, near Yandi	Biota (2009b)
Vegetation and flora surveys of the Oxbow and Junction South West (JSW) Deposits, near Yandicoogina	Biota (2010)
Yandi Additional Areas Level 2 vegetation and flora assessment	Biota (2014b)
Yandi JSW and Oxbow vegetation and flora integration report	Biota (2014c)

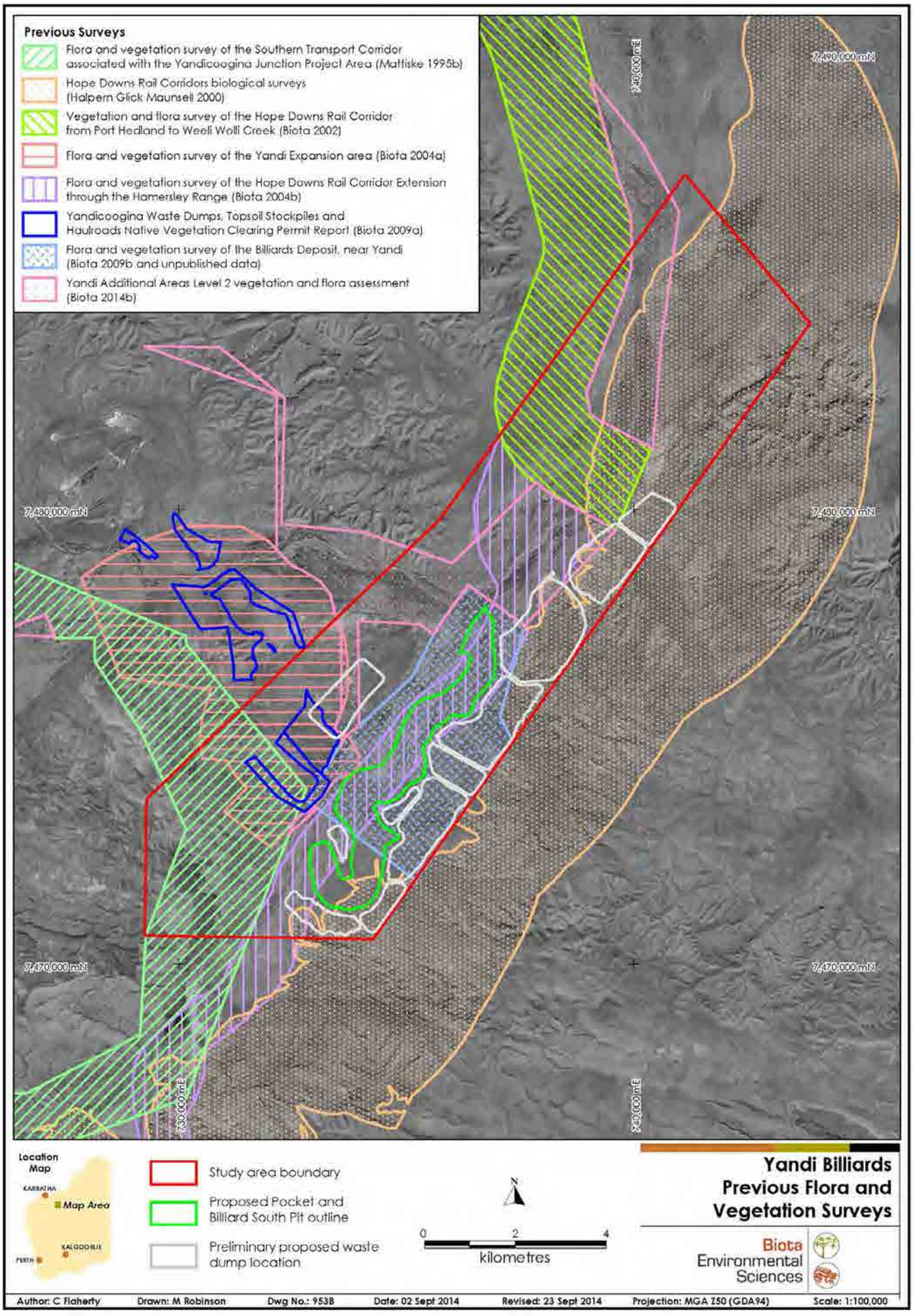

Figure 4.3: Previous flora and vegetation surveys conducted in the vicinity of the study area.

Table 4.5: Summary of previous vegetation and flora surveys that overlap the study area.

Survey (Reference)	Survey Dates	Location in Relation to Study Area	No. of Sites Recorded	No. of Flora Species Recorded		Communities and Species of Conservation Significance Identified for the Overall Survey Area	Survey / Report Limitations
				Native Vascular Flora	Introduced Flora		
Flora and vegetation survey of the Southern Transport Corridor associated with the Yandicoogina Junction Project Area (Mattiske 1995b)	January and March 1994 February 1995	Covers 1,061.4 ha of the study area.	116	392	7	• No TECs or PECs. • Three communities of local significance and four communities of regional significance. • No Threatened flora. • Five Priority flora species recorded (no longer listed). Two species of significance noted, which are currently listed as Priority flora species: *Stylidium weeliwolli* (Priority 2) and *Rhagodia* sp. Hamersley (M. Trudgen 17794) (Priority 3).	• Vegetation mapping was completed at a very broad scale. • No quadrat data was provided to support the mapping. • Climatic data for Marillana Station (the closest recording station to the study area) is not available for the survey dates. Thus, the suitability of the conditions for plant growth prior to the surveys is unknown. • Plant identifications were completed 17 years ago, over which time there have been many taxonomic changes for Pilbara flora.
Hope Downs Rail Corridors biological surveys (Halpern Glick Maunsell 2000)	16-23 October 1998 25 November - 3 December 1999	Covers 1,903.8 ha of the study area.	75	354	8	• No TECs or PECs. • Three communities of conservation significance. • No Threatened flora. • Six Priority flora species recorded (five are no longer listed; the remaining species was not recorded near Yandi and is not considered further).	• Vegetation mapping was completed at a broad scale. • Quadrats were widely spaced along the corridor. • Plant identifications were completed 13 years ago, over which time there have been many taxonomic changes for Pilbara flora.

Survey (Reference)	Survey Dates	Location in Relation to Study Area	No. of Sites Recorded	No. of Flora Species Recorded		Communities and Species of Conservation Significance Identified for the Overall Survey Area	Survey / Report Limitations
				Native Vascular Flora	Introduced Flora		
Vegetation and flora survey of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002)	25 April – 14 May 2001 29 May – 10 June 2001 July 2001	Covers 448.5 ha of the study area.	286	752	8	• No TECs or PECs. • Eight vegetation types of high conservation significance. • No Threatened flora. • 14 Priority flora recorded (seven are no longer listed; three were not recorded near Yandi). The remaining species are *Indigofera ixocarpa* (Priority 2), *Gymnanthera cunninghamii* (Priority 3), *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) and *Goodenia nuda* (Priority 4).	• Vegetation mapping was completed at a broad scale • Quadrats were widely spaced along the corridor.
Flora and vegetation survey of the Yandi Expansion area (Biota 2004a)	30 August – 5 September 2004	Covers 884.1 ha of the study area.	39	319	13	• No TECs or PECs. • No Threatened flora. • Five Priority flora species recorded (three are no longer listed). The remaining species are *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) and *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3).	• Unfavourable climatic conditions during the survey for the identification of annual and cryptic flora species. • Quadrats were sampled once only.
Flora and vegetation survey of the Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b)	April 2003	Covers 1,183.1 ha of the study area.	25	361	10	• No TECs or PECs. • Four vegetation types of high conservation significance. • No Threatened flora. • Seven Priority flora (six no longer listed): the remaining species is *Goodenia* sp. East Pilbara (A.A. Mitchell PRP 727) (Priority 3).	• Vegetation mapping was completed at a broad scale. • Quadrats were widely spaced along the corridor.
Yandicoogina Waste Dumps, Topsoil Stockpiles and Haulroads Native Vegetation Clearing Permit Report (Biota 2009a)	4 – 7 September 2008	Covers 175.7 ha of the study area	NA	211	11	• No TECs or PECs. • One Threatened flora species: *Lepidium catapycnon*. • No Priority flora.	• Unfavourable climatic conditions during the survey for the identification of annual and cryptic flora species

Survey (Reference)	Survey Dates	Location in Relation to Study Area	No. of Sites Recorded	No. of Flora Species Recorded		Communities and Species of Conservation Significance Identified for the Overall Survey Area	Survey / Report Limitations
				Native Vascular Flora	Introduced Flora		
Flora and vegetation survey of the Billiards Deposit, near Yandi (Biota 2009b and unpublished data)	11 – 20 June 2007 27 July – 6 August 2008 3 – 9 June 2009	Covers 1,510.0 ha of the study area.	50	247	7	• No TECs or PECs. • One vegetation type of high conservation significance. • No Threatened flora. • No Priority flora.	• Unfavourable climatic conditions during the 2007 and 2008 surveys for the identification of annual and cryptic flora species. • Only some quadrats were resampled.
Yandi Additional Areas Level 2 vegetation and flora assessment (Biota 2014b)	12 – 18 June 2012	Covers 1,518.7 ha of the study area.	34	313	14	• No TECs or PECs. • Ecosystems at risk were identified (Weeli Wolli Creek and Marillana Creek). • No Threatened flora. • One Priority 4 flora species: *Goodenia nuda.* • One species of interest: *Eulalia* sp. (Three Rivers Station, B. Forsyth AQ6789133).	• Quadrats sampled once only.

4.8 Communities of Conservation Significance Known from the Locality

The following section describes vegetation of conservation significance known from the Yandi locality. The framework for ranking communities of conservation significance in Western Australia is presented in Appendix 1.

4.8.1 Threatened Ecological Communities

TECs are described by DPaW as "biological (flora or fauna) assemblages occurring in a particular habitat, which are under threat of modification or destruction from various processes" (DEC 2010a). TECs listed by DPaW are significant at the State level and are protected as Environmentally Sensitive Areas (ESAs) under the WA *Environmental Protection Act 1986*.

Two TECs are listed for the Pilbara bioregion: the '*Themeda* grasslands on cracking clays (Hamersley Station, Pilbara)' and the 'Ethel Gorge aquifer stygobiont community' (DPaW 2014a). Twenty-three of the 69 TECs listed in Western Australia are also nationally recognised and listed under the Commonwealth *EPBC Act 1999.* These do not include either of the two TECs listed for the Pilbara bioregion.

The Ethel Gorge stygobiont TEC is approximately 77 km southeast of the study area, while the nearest area of the *Themeda* grasslands TEC is approximately 140 km northwest. Neither TEC is therefore relevant to the study area.

4.8.2 Priority Ecological Communities

PECs include possible TECs that do not meet survey criteria or are not adequately defined (DEC 2010a). These are added to DPaW's PEC list under Priorities 1 (highest priority), 2 and 3. Ecological Communities that are: 1) adequately known; 2) are rare but not threatened, or meet criteria for Near Threatened; or 3) have been recently removed from the threatened list, are placed in Priority 4. Conservation dependent ecological communities are placed in Priority 5.

Thirty PECs are listed for the Pilbara bioregion (DPaW 2014b). No PECs are known to occur in the study area. The nearest PECs to the study area are the Priority 1 'Weeli Wolli Spring community', located approximately 7 km to the south; and two of the Priority 3 'Fortescue Valley Sand Dunes', one located approximately 5 km to the east and the other 5 km to the northwest of the study area. The Priority 1 'Fortescue Marsh' PEC is also located in the vicinity of the study area; the marsh itself is located approximately 27 km north of the study area, and is surrounded by fringing vegetation. None of these mapped occurrences of PECs would be expected to be impacted by the proposed works.

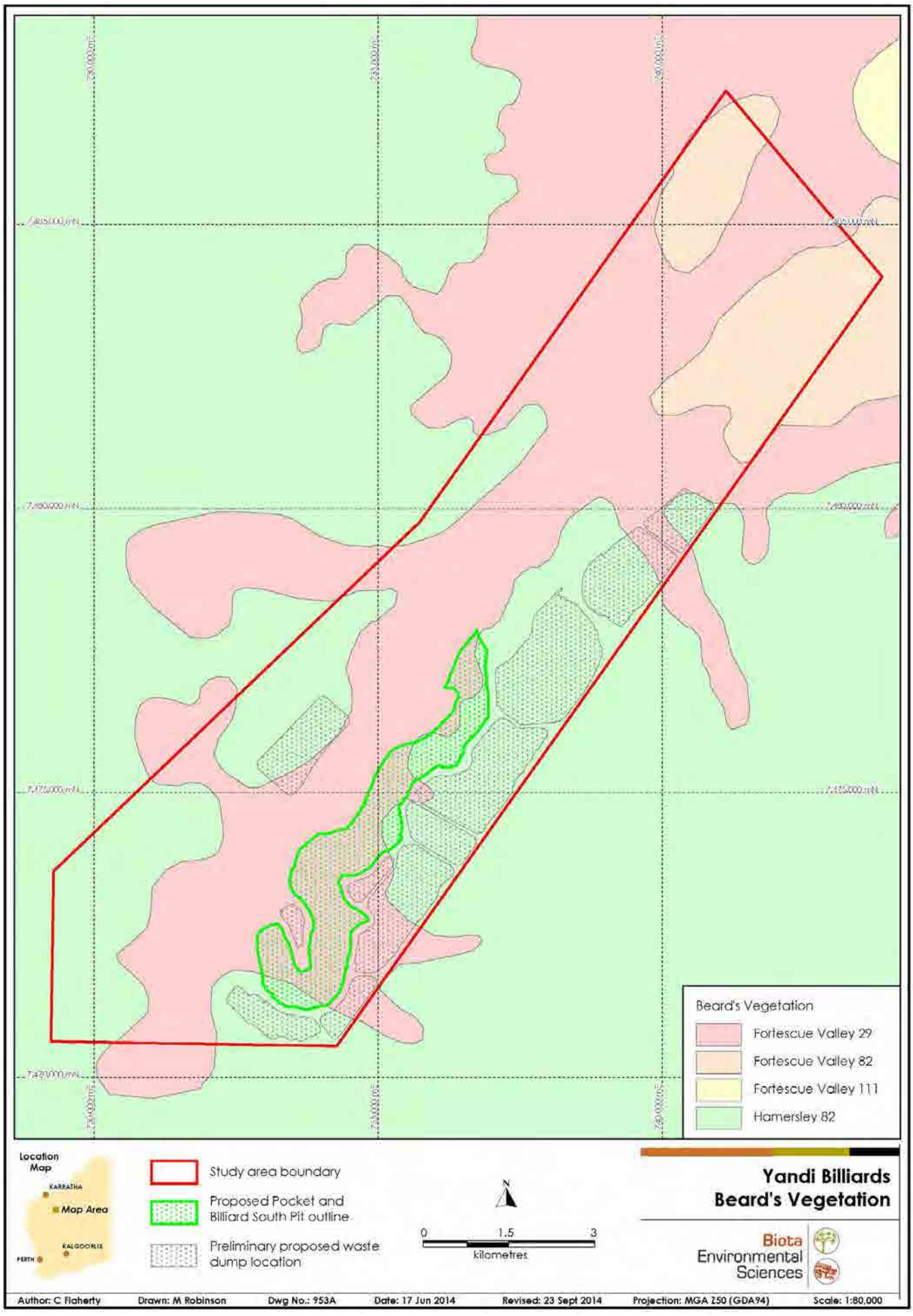

Figure 4.4: Beard's vegetation mapping for the locality including the study area.

4.9 Conservation Significant Flora Known from the Locality

4.9.1 Threatened Flora

Three Threatened flora species (*Aluta quadrata, Lepidium catapycnon* and *Thryptomene wittweri*) are known from the Pilbara bioregion. *Lepidium catapycnon* and *Thryptomene wittweri* are listed as Threatened flora under the Commonwealth *EPBC Act 1999* as well as the WA *Wildlife Conservation Act 1950*. *Aluta quadrata* has only recently been listed (State of Western Australia 2012) and is currently only recognised as Threatened under the *Wildlife Conservation Act 1950.* Each species is described briefly below:

- *Aluta quadrata* is a perennial shrub occurring mainly in rocky gullies, although it sometimes extends down along the creeklines draining the gullies, or out onto the adjacent ridge slopes and crests. This species is currently thought to be restricted to the southern flanks of the range of hills surrounding Paraburdoo, where it occurs over an east-west range of approximately 40 km. *Aluta quadrata* has not been previously recorded within 40 km of the study area. Given the restricted distribution of this species, it would not occur in the study area.
- *Lepidium catapycnon* (Hamersley Lepidium) is a woody perennial herb or low shrub occurring mainly on hillsides in skeletal soils. It typically occurs in hummock grasslands on low stony hills and occasionally stony plains, particularly in association with the Newman land system (see Section 4.4). This relatively short-lived shrub species is often recorded from areas that have been recently disturbed, apparently persisting for only a few years. *Lepidium catapycnon* has a range that extends broadly from Tom Price to Newman. It is now known from over 30 locations in the Hamersley Range, including one population in the conservation estate of the Karijini National Park (DPaW 2014c). Some of these populations comprise hundreds to over a thousand individuals (M. Maier, Biota, pers. obs.).

  Lepidium catapycnon has been previously recorded from two locations in the study area (Hamersley Iron 2006, Biota 2009a) and additional suitable habitat for this species is present. *Lepidium catapycnon* may therefore occur at other locations within the study area.

  Table 4.6: Locations of the Threatened flora species, *Lepidium catapycnon*, in the study area.

Species	Source	Number of individuals	Easting	Northing
Lepidium catapycnon	Biota (2009a)	171	733172	7475074
Lepidium catapycnon	Hamersley Iron (2006)	not provided	732596	7470785

- *Thryptomene wittweri* (Mountain Thryptomene) is a spreading, perennial shrub occurring in skeletal stony soils on breakaways and in drainage channels, typically high in the landscape on mountains of greater than 1,000 m elevation. All Pilbara records are restricted to the Mt Meharry area. *Thryptomene wittweri* would not occur in the study area as suitable habitat is not present, and its distribution does not include the study area.

4.9.2 Priority Flora

Based on the results of the database searches and literature reviews conducted for this study, a total of 12 Priority taxa and two species of interest have been recorded within 25 km of the study area. A brief description of these taxa along with an assessment of the likelihood of occurrence for each taxon in the study area is provided in Appendix 2.

Prior to the current survey, no Priority flora were known from the study area. Based on the known distributions of the Priority flora species, and comparison of their habitat preferences with the habitats that appeared to be present in the study area, five of the 12 Priority flora taxa were identified through the desktop review as:

- Likely to occur:
  - one Priority 4 taxon: *Goodenia nuda*.
- May potentially occur:
  - one Priority 2 taxon: *Stylidium weeliwolli; and*

– three Priority 3 taxa: *Rostellularia adscendens* var. *latifolia, Sida* sp. Barlee Range (S. van Leeuwen 1642) and *Themeda* sp. Hamersley Station (M.E. Trudgen 11431).

With regards to the species considered likely to occur in the study area:

- *Goodenia nuda* (Priority 4)
  Goodenia nuda is an erect to ascending, slender herb growing to 50 cm in height, with yellow flowers and narrow, pale green glaucous leaves (DPaW 2014c). This species is typically found growing near creeklines and in wet areas. It has a broad distribution; most records occur over a range of approximately 450 km through the Pilbara bioregion, with populations known from Karijini and Millstream-Chichester National Parks. There is also an outlying record from the Canning Stock Route in the Gascoyne bioregion. *Goodenia nuda* has been recorded 7.2 km northwest of the study area, next to Marillana Creek (Biota 2010). This species has also been recorded during several other surveys in the Yandi locality (Biota 2000, 2002, 2014b, 2014c), predominantly from floodplains associated with Marillana Creek (or tributaries of Marillana Creek). This species would be likely to occur in the study area, particularly in association with minor flowlines or floodplains.

With regards to the species considered to have the potential to occur in the study area:

- *Stylidium weeliwolli* (Priority 2)
  This annual herb grows to 25 cm and produces pink flowers between August and September. This species has a relatively broad range through the Pilbara and Gascoyne bioregions, extending over more than 330 km, but is only infrequently recorded. This is probably partly due to its small and delicate stature, and also a reflection of the habitats in which it occurs (seasonally damp or wet areas including root mats of *Melaleuca*, on floodplains and in seepages around granite rocks). In the Pilbara, this species occurs mainly along major watercourses. There are two records of this species from the Yandi locality: from Weeli Wolli Creek, in the vicinity of Weeli Wolli Springs (the closest record is approximately 6 km upstream of the study area); as well as from a tributary of Marillana Creek (approximately 23 km upstream of the study area). It is possible that this species occurs along the sections of Marillana Creek and Weeli Wolli Creek within the study area.

- *Rostellularia adscendens* var. *latifolia* (Priority 3)
  Rostellularia adscendens var. *latifolia* is a small herb to low shrub that occurs in a broad range of habitats, but is most frequently recorded in drainage areas and on plains (DPaW 2014c). This taxon has a broad distribution across the Pilbara (over 400 km, extending from the Brockman locality to the Oakover River), with five populations known from Karijini National Park. There is suitable habitat for this species in the study area and it has been recorded from a location 7.6 km to the northwest (Biota 2014c).

- *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3)
  This spreading shrub grows to 0.5 m tall and produces yellow flowers in August. It typically occurs on steep slopes with red skeletal soils and exposed rock, often in gorges and gullies. This species has been recorded from rocky habitat along Marillana Creek, approximately 2.3 km northwest of the study area (Biota 2004a); the number of individuals in this population was not recorded. It is possible that this species could occur in rocky habitats within the study area.

- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3)
  This tussock grass grows to 1.8 m tall and occurs on red clay pans and grass plains. It differs from the more common and widespread *Themeda triandra* by its larger size, sturdier culms and pale bluish colouring (*T. triandra* has yellowish colouring). There is a record of this species from 2.8 km northwest of the study area (Biota 2004a), which is the only record within 30 km. This species could potentially occur in the study area, particularly along the floodplains associated with Marillana or Weeli Wolli Creek.

4.9.3 Other Species of Interest

Two taxa of interest have been recorded near Yandi and may occur in the study area (see Appendix 2). These are:

- *Eulalia* sp. (Three Rivers Station, B. Forsyth AQ6789133)
  This currently undescribed species of *Eulalia* has been recorded from one location on a plain on the southern side of Marillana Creek (Biota 2014b), 900 m west of the current study area. Dr. Ken Tinley first collected this species in 2008 on Three Rivers Homestead (approximately 290 km south of the Yandi project) and the phrase name *Eulalia* sp. (Three Rivers Station) was applied (Bryan Simon, Queensland Herbarium, pers. comm. 2012). *Eulalia* sp. (Three Rivers Station) differs from the common *Eulalia* species occurring in the Pilbara (*E. aurea*) by its broader leaves, elongated rhizomes and the inflorescences remaining closed at maturity (Simon and Alfonso 2012). It is likely that this taxon has been under-collected given its similarity to *Eulalia aurea*. Currently, the phrase name is not recognised on FloraBase or Australia's Virtual Herbarium. A formal description of *Eulalia* sp. (Three Rivers Station) is being progressed by Rachel Butler (Biota) and Mr. Malcolm Trudgen (M.E. Trudgen and Associates).

- *Glycine* sp. aff. *arenaria*
  This creeper with apparent affinities to *Glycine arenaria* was collected from a single site in Marillana Creek (Biota 2014c), approximately 11 km upstream of the current study area. This taxon was identified by Malcolm Trudgen (M.E. Trudgen and Associates), who described it as uncommon in the Pilbara. To date, no specimens of *G. arenaria* have been vouchered from outside the Northern Kimberley. The voucher specimen collected by Biota (2012a) was submitted to the WA Herbarium for lodgement in February 2013, but is believed to be awaiting incorporation to the collection. Additional collections of *Glycine* have recently been made from this area; none are currently considered likely to represent *G. arenaria,* however the identifications are pending confirmation by Andrew Perkins (taxonomist at the WA Herbarium). These specimens will be submitted for lodgement if required.

4.10 Knowledge Gaps Identified for the Study Area

The following section summarises the flora and vegetation findings based on the results of the 2013 desktop review of the study area (Biota 2013).

While a comprehensive dataset existed for the Yandi Billiards study area and there was considerable data from the locality to provide context, some additional biological survey work was considered to be required to raise the level of information for the study area to a level suitable for EIA under Part IV of the *Environment Protection Act 1986*.

Key flora and vegetation knowledge gaps identified in 2013 for the Yandi Billiards study area included:

1. Approximately 9% (or 784 ha) of the study area had not been subject to vegetation mapping or flora quadrat sampling (Figure 4.5). A further 30% (or 2,611 ha) had only been subject to broad historical vegetation mapping, which required refinement and additional flora quadrat sampling (Figure 4.5). Approximately 39% of the area thus required vegetation mapping to current standards.
2. Six vegetation types from recent vegetation mapping (Biota 2004a, 2009b, 2014b), totalling 376 ha, required additional flora quadrat sampling to meet current regulator expectations (Figure 4.5).
3. A total of 49 of the 72 flora quadrats previously established in the study area were sampled during unfavourable climatic conditions for plant growth. These required resampling to meet Level 2 survey standards.
4. Targeted systematic searches for the Threatened flora species, *Lepidium catapycnon,* had not been conducted in all suitable habitats.

5. A total of 32 flora taxa recorded previously within the study area were required to be reviewed to address advances in taxonomy since their original identification.

These points are discussed in more detail in the Yandi Billiards Terrestrial Fauna, Flora and Vegetation Desktop Assessment (Biota 2013).

The current study (this report) addresses these five points to bring the baseline surveys for the study area up to a Level 2 standard.

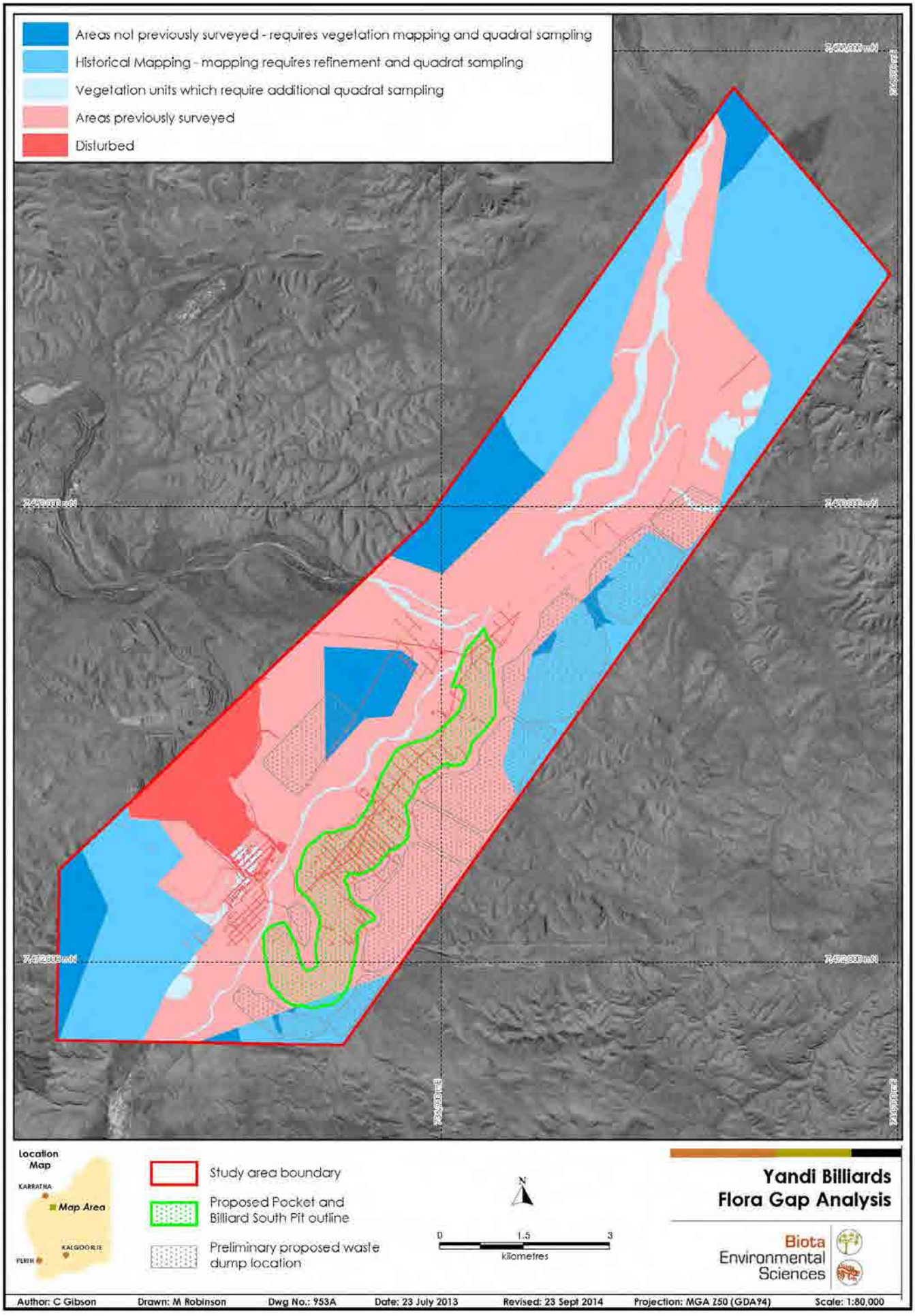

Figure 4.5: Gaps in vegetation mapping and quadrat sampling of the study area that were identified by Biota (2013).

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5.0 Vegetation of the Study Area

5.1 Overview

A total of 495 ha (5.7%) of the study area had been cleared and was mapped as "Disturbed". Twenty-three vegetation types have been described for the study area, as summarised in Section 5.2.

These vegetation types were broadly associated with the following landforms:

- major creeklines and tributaries;
- minor creeklines, floodplains and valleys;
- hills, ridges and breakaways; and
- plains.

Soils in the study area were generally described as red-brown loams, clay loams or sandy clay loams and were covered with a loose surface layer of stones and pebbles. Soils were stonier at the margins of the valley and on the associated footslopes. Heavier soils were found in the lower parts of the valley and in the flood-out areas. Some small areas of light clay supported Mulga woodland on the plains. Soils of the creek beds were a coarse sand-pebble mix.

Table 5.1: Area of each unit mapped in the study area.

Mapping Unit Code	Area Mapped in Study Area (ha)	Percent of Study Area
Vegetation of Major Creeklines and Tributaries		
C1: EcEvMaMgAc	73.1	0.8
C2: EvChAtuGwTErCYpERItTHt	22.6	0.3
C3: EvAciAcMgCEc	269.3	3.1
C4: EvAciAprAThCEc	1,059.2	12.3
Vegetation of Minor Creeklines, Floodplains and Valleys		
F1: ChAtuGwTp	95.2	1.1
F2: AprAciCEc	314.7	3.6
F3: ElChAtuAaAbGwTspp	93.6	1.1
F4: ChAtuAaPcAtenBONeARhPAmTp	41.7	0.5
F5: ChAciAaAiSENsppTp	31.4	0.4
Vegetation of Hills, Ridges and Breakaways		
H1: ElHcAiGwTsps	1,325.7	15.3
H2: ElAiTwTsps	1,345.8	15.6
H3: ElGwAarTsps	210.4	2.4
H4: ChAarTspsTw	74.3	0.9
H5: ElCfERImTHspp	11.8	0.1
Vegetation of Plains		
P1: ElEgAprAbAaAdTwTpTsps	43.4	0.5
P2: ChAprAiAsclApaTp	563.5	6.5
P3: AprAciAiAsclTlo	177.9	2.1
P4: AprAsyAiTw	352.8	4.1
P5: ElEgAbAaTb	1,446.7	16.7
P6: AapERfoERI/g	144.1	1.7
P7: ERf/g	35.6	0.4
P8: EgAiTs	32.4	0.4
P9: ChEgAiAaAprPcTb	380.3	4.4
Other Units		
Disturbed	495.2	5.7
Total	8,640.6	100.0

5.2 Description of the Vegetation Types

5.2.1 Vegetation of Major Creeklines and Tributaries

C1: EcEvMaMgAc	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
Distribution and Comments	This riparian vegetation type occurred in the bed of Weeli Wolli Creek and Marillana Creek (Plate 5.1). Cadjeputs (*Melaleuca argentea*) occurred in patches along the creek. In wetter areas, an open sedgeland of *Cyperus vaginatus* was present, sometimes with patches of Native Bulrush (*Typha domingensis*). In drier areas, a tussock grassland stratum was typically present; this was dominated by a combination of *Eriachne tenuiculmis, Eulalia aurea* and *Themeda triandra.*
Associated Species	Trees/Tall Shrubs: *Acacia citrinoviridis, A. pyrifolia* var. *pyrifolia, Atalaya hemiglauca* and *Gossypium robinsonii.* Low Shrubs: *Corchorus crozophorifolius, Heliotropium pachyphyllum, Hybanthus aurantiacus, Indigofera monophylla, Sesbania cannabina, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) and *Waltheria indica.* Herbs and Grasses: *Amaranthus undulatus, *Argemone ochroleuca* subsp. *ochroleuca, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Euphorbia alsiniflora, E. biconvexa, Evolvulus alsinoides* var. *villosicalyx, *Flaveria trinervia, Gomphrena cunninghamii, Ipomoea muelleri, *Malvastrum americanum, Phyllanthus maderaspatensis, Pluchea dentex, P. rubelliflora, Polycarpaea longiflora, Rhynchosia minima, *Solanum nigrum, *Sonchus oleraceus, Stemodia grossa, Trachymene oleracea* subsp. *oleracea, Typha domingensis* and *Wahlenbergia tumidifructa.*
Vegetation Condition	Good; several weed species have been recorded, however none were abundant; they typically occurred only as scattered individuals. There was some evidence of disturbance by cattle, which are widespread in the Yandi area.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI30S^ and YBI23 (Biota 2009b).
Other Notes	Quadrat YBI23 was not resampled during the current survey as the creek was inundated (Plate 5.2).

Plate 5.1: Vegetation type C1 (YBI30S).

Plate 5.2: Quadrat YBI23 inundated in 2014.

C2: EvChAtuGwTErCYpERItTHt	*Eucalyptus victrix, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland
Distribution and Comments	This vegetation occurred in the study area in three moderate-sized creeklines (tributaries feeding into Weeli Wolli Creek; Plate 5.3). Patches of the tall shrub *Androcalva luteiflora* were present in places, and *Triodia pungens* sometimes occurred as a very open hummock grassland. **Cenchrus ciliaris* and **C. setiger* were present as an open tussock grassland in some places.
Associated Species	Tall Shrubs: *Acacia pyrifolia* var. *pyrifolia, Atalaya hemiglauca* and *Gossypium robinsonii.* Shrubs: *Corchorus crozophorifolius, Eremophila longifolia, Gossypium australe, Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* and *Sida* sp. spiciform panicles (E. Leyland s.n. 14/8/90). Low Shrubs: *Crotalaria medicaginea* var. *neglecta, Hybanthus aurantiacus, Indigofera georgei, Ptilotus astrolasius* and *Waltheria indica.* Herbs and Grasses: *Amaranthus undulatus*, *Aristida holathera* var. *holathera*, *Boerhavia coccinea, *Cenchrus ciliaris*, **C. setiger, Enneapogon polyphyllus, Gomphrena cunninghamii, Goodenia stobbsiana, Paraneurachne muelleri, Polycarpaea longifolia* and *Triodia pungens.*
Vegetation Condition	Good; **Cenchrus ciliaris* and **C. setiger* often occurred as scattered tussock grasses to an open tussock grassland, and scattered individuals of **Setaria verticillata* were also recorded. Several standing dead trees, which could not be distinguished as *E. victrix* or *C. hamersleyana*, were noted in quadrat BIL31; the cause of these deaths was not apparent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL02^ and BIL31^ (current survey).
Other Notes	This vegetation was originally mapped as EvAtuGwTErCYpERItTHt (Biota 2014b). The description has been updated with the addition of *Corymbia hamersleyana* in the low tree stratum; this species occurred as a co-dominant with *Eucalyptus victrix* in some creeklines in the study area.

Plate 5.3: Vegetation type C2 (BIL02).

C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
Distribution and Comments	This was the predominant vegetation of the creek beds of Marillana and Weeli Wolli Creek (Plate 5.4). It was observed in scoured channels that occurred in a braided pattern through the broader creekline vegetation.
Associated Species	Tall Shrubs: *Acacia pyrifolia* var. *pyrifolia* and *Atalaya hemiglauca*. Shrubs: *Corchorus crozophorifolius, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) and *Waltheria indica*. Low Shrubs: *Crotalaria medicaginea* var. *neglecta* and *Indigofera monophylla.* Herbs and Grasses: **Argemone ochroleuca* subsp. *ochroleuca*, *Amaranthus undulatus*, *Boerhavia coccinea, Cleome viscosa, Cymbopogon procerus, Enneapogon lindleyanus, Eriachne tenuiculmis, Eulalia aurea, Gomphrena cunninghamii, Goodenia lamprosperma, Phyllanthus maderaspatensis, Pluchea rubelliflora* and *Polycarpaea longiflora.*
Vegetation Condition	Very Good; scattered individuals of several weed species were recorded, along with minor disturbance from cattle (scats and low levels of grazing).
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI01^ (Biota 2009b) and BIL30^ (current survey).
Relevés in the Study Area	YBI-RRWB (Biota 2009b).

Plate 5.4: Vegetation type C3 (BIL03).

C4: EvAciAprAThCEc	*Eucalyptus victrix* open *woodland* over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
Distribution and Comments	This vegetation type occurred on the broad floodplains of Marillana and Weeli Wolli Creeks (Plate 5.5). It was also recorded from two moderate-sized creeklines (tributaries of Weeli Wolli Creek) at the southern end of the study area. **Cenchrus ciliaris* formed a closed tussock grassland in some sites situated on floodplains. Scattered *Triodia pungens* was often present in the understorey.
Associated Species	Trees/Tall Shrubs: *Acacia coriacea* subsp. *pendens, A. pyrifolia* var. *pyrifolia, A. sclerosperma* subsp. *sclerosperma, Corymbia hamersleyana, Gossypium robinsonii, Hakea lorea* subsp. *lorea and Stylobasium spathulatum.* Shrubs: *Corchorus crozophorifolius, Gossypium sturtianum, Ptilotus obovatus* var. *obovatus, Rhagodia eremaea, Senna artemisioides* subsp. *helmsii, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) and *Waltheria indica.* Low Shrubs: *Hybanthus aurantiacus, Indigofera monophylla, Melhania oblongifolia* and *Ptilotus astrolasius.* Herbs, Grasses and Sedges: **Bidens bipinnata, *Cenchrus setiger, Cymbopogon procerus, Cyperus vaginatus, Dicladanthera forrestii, Enneapogon lindleyanus, E. robustissimus, Eulalia aurea, Evolvulus alsinoides* var. *decumbens, Evolvulus alsinoides* var. *villosicalyx, *Malvastrum americanum, Notoleptopus decaisnei* var. *decaisnei, Phyllanthus maderaspatensis, *Setaria verticillata, Themeda triandra* and *Triodia pungens.*
Vegetation Condition	Good to Very Poor: much of this vegetation type was extensively invaded by **Cenchrus ciliaris* (often with **C. setiger* as a co-dominant). Several other weed species were present as scattered individuals and disturbance from cattle was also recorded. Historical (mostly overgrown) drill lines were also noted in this vegetation type.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	H051 and H050^ (Biota 2002); HDA09^ (Biota 2004b); YBI02, YBI03, YBI04 and YBI08^ (Biota 2009b); YAQ12^ and YAQ21 (Biota 2014b); and YEX02^ (Biota 2004a).
Relevés in the Study Area	YBI-RBMK, YBI-RPHB and YBI-RPHA (Biota 2009b); and YAQ-CSRA (Biota 2014b).
Other Notes	Quadrat H051 has been cleared.

Plate 5.5: Vegetation type C4 (YAQ12).

5.2.2 Vegetation of Minor Creeklines, Floodplains and Valleys

F1: ChAtuGwTp	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland
Distribution and Comments	This vegetation type occurred throughout the study area in minor creeklines on plains and in between low hills (Plate 5.6). It was also found in a broad valley in the northern end of the study area, where the vegetation was regenerating after being recently burnt (less than 3 years ago).
Associated Species	Trees: *Eucalyptus gamophylla*. Tall Shrubs: *Acacia ancistrocarpa, A. bivenosa, A. dictyophleba, A. pyrifolia* var. *pyrifolia, Androcalva luteiflora* and *Gossypium robinsonii.* Shrubs: *Gossypium australe, Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla, S. artemisioides* subsp. *oligophylla x* subsp. *helmsii* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186). Low Shrubs: *Corchorus lasiocarpus* subsp. *lasiocarpus, C. tectus, Hybanthus aurantiacus* and *Waltheria indica.* Herbs and Grasses: *Aristida holathera* var. *holathera, Bothriochloa ewartiana, *Cenchrus ciliaris, Cymbopogon ambiguus, Digitaria brownii, Eriachne mucronata, Goodenia muelleriana, Hibiscus sturtii* var. *platychlamys, Pterocaulon sphacelatum, Rhynchosia minima, Sida cardiophylla, Stemodia grossa, Themeda triandra* and *Trichodesma zeylanicum* var. *zeylanicum*.
Vegetation Condition	Very Good to Good: scattered weed species were present at some sites. **Cenchrus ciliaris* formed a very open tussock grassland in some areas.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI20^, YBI25 and YBI35S^ (Biota 2009b); BIL16^ (current survey).
Relevés in the Study Area	YBI-RBME (Biota 2009b); BIL-RCFC and BIL-RSWA (current survey).

Plate 5.6: Vegetation type F1 (BIL16).

F2: AprAciCEc	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland
Distribution and Comments	This vegetation type occurred on broad floodplains fringing Weeli Wolli Creek in the north of the study area, and in broad tributaries of Weeli Wolli Creek at the southern end of the study area (Plate 5.7). *Corymbia hamersleyana* and *Eucalyptus victrix* trees were occasionally scattered in areas close to the creekline. **Cenchrus ciliaris* formed a continuous tussock grassland in the understorey, however occasional *Triodia pungens* hummocks were also present.
Associated Species	Trees: *Corymbia hamersleyana* and *Eucalyptus victrix.* Tall Shrubs: *Acacia bivenosa, A. pyrifolia* var. *pyrifolia, A. synchronicia, A. tumida* var. *pilbarensis, Androcalva luteiflora, Atalaya hemiglauca, Gossypium robinsonii* and *Hakea lorea* subsp. *lorea.* Shrubs: *Ptilotus obovatus* var. *obovatus* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186). Low Shrubs: *Abutilon lepidum, Corchorus lasiocarpus* subsp. *lasiocarpus, Crotalaria medicaginea* var. *neglecta* and *Hybanthus aurantiacus.* Herbs and Grasses: *Bothriochloa ewartiana, Chrysopogon fallax, Enneapogon polyphyllus, Eulalia aurea, *Flaveria trinervia, Duperreya commixta, *Malvastrum americanum, Streptoglossa decurrens* and *Themeda triandra.*
Vegetation Condition	Poor; extensively invaded by **Cenchrus ciliaris* (sometimes with **C. setiger*), and scattered other weeds of various species were also present; some disturbance from cattle (grazing and scats).
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YEX38^ (Biota 2004a); YAQ30^ (Biota 2014b); BIL23^ and BIL24^ (current survey).
Relevés in the Study Area	YBI-RBMF and YBI-RBMH (Biota 2009b); YAQ-CSRC and YAQ-CSRD (Biota 2014b).

Plate 5.7: Vegetation type F2 (BIL24).

F3: ElChAtuAaAbGwTspp	*Eucalyptus leucophloia, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland
Distribution and Comments	This vegetation type occurred in numerous minor creeklines amongst low hills in the south of the study area near the Junction South East (JSE) mine (Plate 5.8). These creeklines had a defined rocky bed and narrow banks. Most of the creeklines were too narrow to establish a standard flora quadrat (50 x 50 m). The composition of the shrub stratum was variable but was typically dominated by a combination of the species listed above. The dominant spinifex varied with location and usually reflected the species present in the surrounding plains; *Triodia pungens, T. basedowii* and *T. wiseana* were typical dominant species.
Associated Species	Trees: *Eucalyptus victrix* and *E. xerothermica*. Tall Shrubs: *Acacia coriacea* subsp. *pendens, A. dictyophleba, Androcalva luteiflora, Atalaya hemiglauca, Eremophila longifolia* and *Gossypium robinsonii.* Shrubs: *Acacia tenuissima, Jasminum didymum* subsp. *lineare, Ptilotus obovatus* var. *obovatus, Santalum lanceolatum, Senna artemisioides* subsp. *helmsii* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186). Low Shrubs: *Crotalaria medicaginea* var. *neglecta, Indigofera monophylla, Melhania oblongifolia* and *Waltheria indica.* Herbs and Grasses: *Aristida holathera* var. *holathera, Boerhavia coccinea, Bonamia erecta, *Cenchrus ciliaris, Enneapogon robustissimus, Eriachne mucronata, Eulalia aurea, Evolvulus alsinoides* var. *villosicalyx, Goodenia microptera, G. muelleriana, Indigofera colutea, Polycarpaea longiflora* and *Setaria verticillata.*
Vegetation Condition	Good; **Cenchrus ciliaris* was the dominant weed species, forming a very open tussock grassland in some creeklines. Several other weed species were present as scattered individuals.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YEX07, YEX08^ (Biota 2004a); BIL35^ and BIL36^ (current survey).
Relevés in the Study Area	YAQ-RPLA, established in the Yandi Additional Areas survey (Biota 2014b).
Other Notes	Quadrat YEX07 has been cleared.

Plate 5.8: Vegetation type F3 (BIL35).

F4: ChAtuAaPcAtenBONeARhPAmTp	*Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland.
Distribution and Comments	This vegetation type occurred on a floodout located on a plain and fed by minor creeklines that flowed through low hills to the east (Plate 5.9).
Associated Species	Trees: *Eucalyptus gamophylla*. Tall Shrubs: *Acacia citrinoviridis, A. dictyophleba, A. inaequilatera, A. pruinocarpa* and *Gossypium robinsonii*. Shrubs: *Acacia pyrifolia* var. *pyrifolia, Gossypium australe, Senna artemisioides* subsp. *oligophylla* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186). Low Shrubs: *Corchorus tectus, Dicrastylis cordifolia, Hibiscus sturtii* var. *platychlamys, Hybanthus aurantiacus, Indigofera georgei, Ptilotus astrolasius* and *Sida cardiophylla*. Herbs and Grasses: *Boerhavia coccinea, *Cenchrus ciliaris, Eriachne aristidea, Gomphrena cunninghamii, Polymeria ambigua, Themeda triandra* and *Triodia basedowii.*
Vegetation Condition	Very Good; some scattered individuals of **Cenchrus ciliaris* and **Setaria verticillata*; minor disturbance from cattle.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL11^, BIL14 and BIL46^ (current survey).

Plate 5.9: Vegetation type F4 (BIL46).

F5: ChAciAaAiSENsppTp	*Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland.
Distribution and Comments	This vegetation type occurred on a small area of floodplains and floodouts in the southernmost part of the study area (Plate 5.10). The shrub stratum consisted of a mixture of *Senna* spp. including *Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* and *S. glutinosa* subsp. x *luerssenii.*
Associated Species	Trees: *Acacia aptaneura*. Tall Shrubs: *Acacia bivenosa, A. pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis, Atalaya hemiglauca, Eremophila longifolia, Gossypium robinsonii, Grevillea wickhamii, Hakea chordophylla, H. lorea* subsp. *lorea* and *Santalum lanceolatum.* Shrubs: *Corchorus crozophorifolius*, *Indigofera monophylla*, *Tephrosia* sp. Fortescue (A.A. Mitchell 606) and *Waltheria indica*. Low Shrubs: *Corchorus lasiocarpus* subsp. *lasiocarpus, C. tectus, Hybanthus aurantiacus, Isotropis atropurpurea, Pluchea ferdinandi-muelleri* and *Waltheria indica*. Herbs and Grasses: *Aristida inaequiglumis*, **Cenchrus ciliaris, Cleome viscosa, Digitaria ctenantha, Enneapogon polyphyllus, Paraneurachne muelleri, Polycarpaea corymbosa, Sida* sp. verrucose glands (F.H. Mollemans 2423), *Streptoglossa decurrens* and *Themeda triandra.*
Vegetation Condition	Good; **Cenchrus ciliaris* occurred as a very open tussock grassland in some areas, and there was some evidence of grazing by cattle.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL21^, BIL47 (current survey).

Plate 5.10: Vegetation type F5 (BIL21).

5.2.3 Vegetation of Hills, Ridges and Breakaways

H1: ElHcAiGwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
Distribution and Comments	This vegetation type occurred throughout the study area on the crests and slopes of low stony hills (Plate 5.11). Scattered individuals of *Triodia wiseana* were also recorded at some sites and *T. brizoides* was present on some of the steeper slopes. Some areas of this vegetation type also had *Acacia adoxa* var. *adoxa* and/or *Acacia hilliana* present as scattered low shrubs to a low open shrubland. Parts of this vegetation type along the southern and eastern boundaries of the study area had been recently burnt (approximately 2 years prior; Plate 5.12). This vegetation type supported the populations of the Threatened species *Lepidium catapycnon* that were recorded from the study area (see Section 6.4.1).
Associated Species	Tall Shrubs: *Acacia bivenosa* and *A. pruinocarpa*. Shrubs: *Ptilotus rotundifolius, Senna artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *glutinosa, S. glutinosa* subsp. *x luerssenii* and *S. glutinosa* subsp. *pruinosa.* Low Shrubs: *Acacia spondylophylla, Corchorus lasiocarpus* subsp. *lasiocarpus, Lepidium catapycnon* (Threatened), *Ptilotus astrolasius, Sida echinocarpa, Sida* sp. Pilbara (A.A. Mitchell PRP 1543), *Solanum lasiophyllum* and *Tribulus suberosus.* Herbs, Grasses and Sedges: *Amphipogon sericeus, Aristida holathera* var. *holathera, Eriachne mucronata, Fimbristylis dichotoma, F. simulans, Goodenia stobbsiana, G. triodiophila, Ptilotus calostachyus* and *Schizachyrium fragile.*
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI31S^ and YBI33S^ (Biota 2009b); YEX01^, YEX06^ and YEX37 (Biota 2004a); YAQ14^, YAQ25^ and YAQ27^ (Biota 2014b); BIL05, BIL17^, BIL19, BIL20^, BIL28, BIL34^, BIL37 and BIL43.

Plate 5.11: Vegetation type H1 (BIL20).

Plate 5.12: Burnt hillslopes supporting vegetation type H1.

H2: ElAiTwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
Distribution and Comments	This vegetation type occurred throughout the study area on the crests and slopes of low to moderate-sized stony hills (Plate 5.13). Although the dominant spinifex species in this vegetation type was *Triodia wiseana, Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) was co-dominant in some places. Scattered low shrubs to a low open shrubland of *Indigofera rugosa* and/or *Acacia adoxa* var. *adoxa* was sometimes present. Minor drainage lines (too small to map) dissected this vegetation type and consisted of *Gossypium australe, Acacia pyrifolia* and *A. maitlandii* open shrublands over mixed tussock grasslands. A small area of this vegetation type along the eastern edge of the study area had been recently burnt (approximately 2 years prior; Plate 5.14).
Associated Species	Tall Shrubs: *Acacia bivenosa, A. pruinocarpa, Grevillea wickhamii* and *Hakea lorea* subsp. *lorea*. Shrubs: *Senna artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *glutinosa, S. glutinosa* subsp. *x luerssenii, S. glutinosa* subsp. *pruinosa*. Low Shrubs: *Calytrix carinata, Dampiera candicans, Indigofera monophylla, Ptilotus rotundifolius, Solanum lasiophyllum, Tephrosia* sp. Fortescue (A.A. Mitchell 606) and *Tribulus suberosus.* Herbs, Grasses and Sedges: *Aristida holathera* var. *holathera, Boerhavia gardneri, Bonamia* sp. Dampier (A.A. Mitchell PRP 217), *Bulbostylis barbata, Enneapogon polyphyllus, Eriachne aristidea, Fimbristylis dichotoma, Goodenia muelleriana, G. stobbsiana, G. triodiophila, Mollugo molluginea, Ptilotus calostachyus, P. nobilis* subsp. *nobilis* and *Tephrosia* sp. NW Eremaean (S. van Leeuwen et al. PBS 0356).
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	HDA16, HDA24^ (Biota 2004b); YBI05^, YBI36^, YBI32S^ (Biota 2009b); YAQ19, YAQ18 (Biota 2014b); BIL03, BIL15^, BIL26, BIL27, BIL29, BIL39^, BIL40, BIL44 (current survey).
Relevés in the Study Area	BIL-RCFA (current survey).

Plate 5.13: Vegetation type H2 (BIL40).

Plate 5.14: Burnt hills supporting vegetation type H2.

H3: ElGwAarTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland
Distribution and Comments	This vegetation type occurred on the crests and slopes of low rocky hills in the northeast of the study area (Plate 5.15). The northern half of this vegetation type had been recently burnt at the time of the survey (within the last 2 years; Plate 5.16).
Associated Species	Tall Shrubs: *Acacia bivenosa* (wispy/weeping form) and *A. inaequilatera.* Shrubs: *Senna artemisioides* subsp. *oligophylla* and *S. glutinosa* subsp. *glutinosa* x subsp. *pruinosa.* Low Shrubs: *Acacia adoxa* var. *adoxa* and *Ptilotus astrolasius.* Herbs, Grasses and Sedges: *Eriachne lanata, E. pulchella, Fimbristylis dichotoma, F. simulans, Goodenia stobbsiana, Ptilotus calostachyus* and *Triodia pungens.*
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL01^ and BIL06^ (current survey).
Relevés in the Study Area	BIL-RPCA (current survey).

Plate 5.15: Vegetation type H3 (BIL06).

Plate 5.16: Burnt hillslopes supporting vegetation type H3.

H4: ChAarTspsTw	*Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland
Distribution and Comments	This vegetation type occurred on the crests and upper slopes of two low stony hills in the northeast of the study area (Plate 5.17).
Associated Species	Tall Shrubs: *Acacia inaequilatera, Grevillea wickhamii* and *Hakea chordophylla.* Shrubs: *Acacia pachyacra, Senna artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *glutinosa, S. glutinosa* subsp. *x luerssenii* and *S. glutinosa* subsp. *pruinosa.* Low Shrubs: *Acacia adoxa* var. *adoxa, Calytrix carinata, Dampiera candicans, Ptilotus astrolasius, P. rotundifolius* and *Solanum lasiophyllum.* Herbs, Grasses and Sedges: *Amphipogon sericeus, Aristida holathera* var. *holathera, Cymbopogon obtectus, Eriachne pulchella, Fimbristylis simulans, Goodenia stobbsiana, Pterocaulon sphacelatum, Ptilotus calostachyus* and *Schizachyrium fragile.*
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI24^ (Biota 2009b) and BIL04^ (current survey).

Plate 5.17: Vegetation type H4 (YBI24).

H5: ElCfERImTHspp	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis, Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade (M.E. Trudgen 2471), *T. triandra* open tussock grassland
Distribution and Comments	This vegetation type occurred on several narrow ridgelines with rocky free face and breakaway slopes, located in the southern half of the study area (Plate 5.18 and Plate 5.19). This vegetation type was characterised by very steep (often vertical) rocky slopes. The soil was skeletal and often occurred in pockets amongst exposed rock outcrops. This vegetation supported two populations of the Priority 3 *Sida* sp. Barlee Range (S. van Leeuwen 1642).
Associated Species	Tall Shrubs: *Clerodendrum floribundum* var. *angustifolium* and *Grevillea wickhamii*. Shrubs: *Dodonaea coriacea, Ptilotus obovatus* var. *obovatus, Rhagodia eremaea, Senna glutinosa* subsp. *glutinosa, S. glutinosa* subsp. *x luerssenii* and *Sida* sp. spiciform panicles (E. Leyland s.n. 14/8/90). Low Shrubs: *Abutilon lepidum, Maireana planifolia, Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3), *S.* sp. Excedentifolia (J.L. Egan 1925), *Hibiscus* sp. Mt Robinson (G. Byrne 3537) and *Solanum lasiophyllum.* Herbs and Grasses: *Aristida holathera* var. *holathera, Enneapogon polyphyllus, Goodenia microptera, G. muelleriana, G. stobbsiana* and *Triodia pungens.*
Vegetation Condition	Typically Excellent; one individual of **Cenchrus ciliaris* was recorded on one ridgeline.
Relevés in the Study Area	YEX-J (Biota 2004a); BIL-RCFB and BIL-RCFD (current survey).
Other Notes	As this vegetation type was too narrow for quadrat sampling, only relevés were completed.

Plate 5.18: Vegetation type H5 (BIL-RCFB).

Plate 5.19: A free face slope of vegetation type H5.

5.2.4 Vegetation of Plains

P1: ElEgAprAbAaAdTwTpTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
Distribution and Comments	This vegetation type occurred over undulating, colluvial stony plains near the JSE mine, located between Weeli Wolli Creek and a range of low hills to the west (Plate 5.20). The proportion of the dominant spinifex varied considerably with location, with *Triodia wiseana* and/or *T. pungens* dominating the majority of the lower-lying areas and *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) tending to dominate the more elevated areas.
Associated Species	Tall Shrubs: *Acacia inaequilatera, A. pachyacra, A. synchronicia, Codonocarpus cotinifolius* and *Hakea chordophylla.* Shrubs: *Acacia hilliana, Eremophila fraseri* subsp. *fraseri, Senna glutinosa* subsp. *x luerssenii* and *S. glutinosa* subsp. *pruinosa.* Low Shrubs: *Acacia adoxa* var. *adoxa, Bonamia erecta, Corchorus lasiocarpus* subsp. *lasiocarpus, Hybanthus aurantiacus, Sida arenicola, S. echinocarpa* and *Solanum lasiophyllum.* Herbs and Grasses: *Aristida contorta, Cymbopogon obtectus, Goodenia microptera, G. stobbsiana, Paraneurachne muelleri, Ptilotus nobilis* subsp. *nobilis, Tephrosia* sp. NW Eremaean (S. van Leeuwen et al. PBS 0356) and *Themeda triandra.*
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YEX05 (Biota 2004a); BIL38^, BIL49 (current survey).
Other Notes	Quadrat YEX05 has been cleared.

Plate 5.20: Vegetation type P1 (BIL38).

P2: ChAprAiAsclApaTp	*Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland
Distribution and Comments	This vegetation type occurred broadly over plains between low hills in the north of the study area, as well as on plains fringing the floodplains of both Marillana and Weeli Wolli Creeks (Plate 5.21). Shrub species varied with location; the typical dominant species are listed in the description above, however *Acacia dictyophleba* was also abundant in some places. Shrub cover tended to be higher in areas closer to the major creeks. *Triodia pungens* was the dominant spinifex species, however occasional hummocks of *T. basedowii* were also recorded.
Associated Species	Tall Shrubs: *Acacia ancistrocarpa, A. citrinoviridis, A. pyrifolia* var. *pyrifolia, Atalaya hemiglauca* and *Hakea chordophylla.* Shrubs: *Eremophila longifolia, Gossypium australe, Ptilotus obovatus* var. *obovatus, Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *x luerssenii* and *S. glutinosa* subsp. *pruinosa.* Low Shrubs: *Corchorus sidoides* subsp. *sidoides, Dicrastylis cordifolia, Dodonaea coriacea, Hibiscus sturtii* var. *platychlamys, Indigofera monophylla, Sida arsiniata, S. cardiophylla, S.* sp. verrucose glands (F.H. Mollemans 2423), *Solanum lasiophyllum* and *Tephrosia supina.* Herbs, Grasses and Sedges: *Boerhavia coccinea, Bulbostylis barbata, *Cenchrus ciliaris, Enneapogon polyphyllus, Eragrostis eriopoda, Eriachne pulchella, Mollugo molluginea, Paraneurachne muelleri* and *Tribulus astrocarpus.*
Vegetation Condition	Good; scattered individuals to a very open tussock grassland of **Cenchrus ciliaris* in places, along with scattered individuals of several other weed species.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	YBI10^ and YBI26 (Biota 2009b); YAQ16^, YAQ29 (Biota 2014b); BIL07^, BIL08, BIL09, BIL10^ (current survey).
Relevés in the Study Area	YBI-RBMC and YBI-RBMD (Biota 2009b).
Other Notes	YBI26 and YAQ29 have since been cleared.

Plate 5.21: Vegetation type P2 (BIL10).

P3: AprAciAiAsclTlo	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland
Distribution and Comments	This vegetation type occurred on plains fringing the floodplains on either side of Weeli Wolli Creek in the central section of the study area (Plate 5.22).
Associated Species	Trees: *Acacia aptaneura, A. coriacea* subsp. *pendens* and *Corymbia hamersleyana.* Tall Shrubs: *Acacia bivenosa, A. dictyophleba, A. pyrifolia* var. *pyrifolia, A. tenuissima, Atalaya hemiglauca, Eremophila longifolia, Hakea lorea* subsp. *lorea, Stylobasium spathulatum.* Shrubs: *Corchorus crozophorifolius, C. lasiocarpus* subsp. *lasiocarpus, Gossypium sturtianum, Ptilotus obovatus* var. *obovatus, Senna artemisioides* subsp. *helmsii* and *S. artemisioides* subsp. *oligophylla.* Low Shrubs: *Abutilon lepidum, Corchorus sidoides* subsp. *sidoides, Sida* sp. verrucose glands (F.H. Mollemans 2423) and *Solanum lasiophyllum.* Herbs and Grasses: *Abutilon otocarpum, Aristida holathera* var. *holathera, Boerhavia coccinea, *Cenchrus ciliaris, Cymbopogon ambiguus, Enneapogon caerulescens, Goodenia microptera, Pterocaulon sphacelatum, Sclerolaena cornishiana, Themeda triandra* and *Triodia basedowii.*
Vegetation Condition	Typically Very Good (occasionally Poor, depending on the level of weed invasion). The cover of **Cenchrus ciliaris* ranged from scattered individuals to a very open tussock grassland. One site (YBI17) was rated as Poor: a **Malvastrum americanum* open herbland was present, and several other weed species occurred there as scattered individuals.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	HDA14 (Biota 2004b); YBI11^ and YBI17^ (Biota 2009b).
Relevés in the Study Area	YBI-RBMJ (Biota 2009b).
Other Notes	HDA14 has been cleared.

Plate 5.22: Vegetation type P3 (YBI11).

P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
Distribution and Comments	This vegetation type occurred on the plains at the southernmost end of the study area, fringing the floodplain on both sides of Weeli Wolli Creek (Plate 5.23).
Associated Species	Trees: *Acacia aptaneura, A. sibirica, Corymbia hamersleyana* and *Eucalyptus xerothermica.* Tall Shrubs: *Acacia bivenosa, A. pachyacra* and *A. sericophylla*. Shrubs: *Capparis spinosa* var. *nummularia, Corchorus lasiocarpus* subsp. *lasiocarpus, Eremophila forrestii* subsp. *forrestii, Gossypium australe, Ptilotus obovatus* var. *obovatus, Senna artemisioides* subsp. *helmsii, S. glutinosa* subsp. *glutinosa* and *S. glutinosa* subsp. *x luerssenii.* Low Shrubs: *Indigofera monophylla, Maireana planifolia* and *Ptilotus astrolasius.* Herbs and Grasses: *Abutilon otocarpum, *Cenchrus ciliaris, Chrysopogon fallax, Enneapogon polyphyllus, Eragrostis cumingii, E. eriopoda, Hibiscus burtonii, Sida* sp. verrucose glands (F.H. Mollemans 2423), *Paraneurachne muelleri, Polymeria ambigua, Pterocaulon sphacelatum, Streptoglossa decurrens* and *Themeda triandra.*
Vegetation Condition	Very Good to Good; scattered **Cenchrus ciliaris* were common, and some sites had other weedy herbs present as scattered individuals.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	HDA07, HDA15 (Biota 2004b); YBI19 (Biota 2009b); YEX03, YEX04^, YEX32 (Biota 2004a).
Relevés in the Study Area	YAQ-CSRB (Biota 2014b).
Other Notes	Quadrats HDA07, HDA15, YEX03, YEX32 and YBI19 have been cleared.

Plate 5.23: Vegetation type P4 (YEX04).

P5: ElEgAbAaTb	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
Distribution and Comments	This vegetation type occurred on plains throughout the study area (Plate 5.24). It was particularly common on the eastern side of Weeli Wolli Creek. *Triodia basedowii* was the dominant spinifex species in this vegetation type, however occasional *T. pungens* hummocks were also recorded. (Note that *T. basedowii* was identified as *T. lanigera* in previous reporting.) A small area of this vegetation had been recently burnt (approximately 2-3 years prior to the survey).
Associated Species	Trees: *Acacia aptaneura* and *Corymbia hamersleyana*. Tall Shrubs: *Acacia dictyophleba, A. inaequilatera, A. pachyacra, A. tumida* var. *pilbarensis, Eremophila longifolia, Gossypium robinsonii, Grevillea wickhamii* subsp. *hispidula* and *Hakea chordophylla.* Shrubs: *Acacia adsurgens, Indigofera monophylla, Ptilotus obovatus* var. *obovatus, Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* and *S. artemisioides* subsp. *oligophylla x* subsp. *helmsii.* Low Shrubs: *Abutilon lepidum, Bonamia erecta, Corchorus sidoides* subsp. *sidoides, C. tectus, Dicrastylis cordifolia, Ptilotus astrolasius, Scaevola parvifolia* subsp. *pilbarae, Sida cardiophylla* and *Solanum phlomoides.* Herbs, Grasses and Sedges: *Abutilon otocarpum, Aristida contorta, A. holathera* var. *holathera, Bulbostylis barbata, Cymbopogon obtectus, Enneapogon polyphyllus, Eragrostis eriopoda, Eriachne aristidea, Perotis rara, Ptilotus calostachyus, Themeda triandra, Tribulus macrocarpus, Trichodesma zeylanicum* var. *zeylanicum* and *Yakirra australiensis* var. *australiensis.*
Vegetation Condition	Excellent to Good; scattered weeds were present at some sites. **Cenchrus ciliaris* was the most common weed species and formed a very open tussock grassland in some areas. Historical drill lines (mostly overgrown) were found in this vegetation type.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	WW30 (Halpern Glick Maunsell 2000); HDA12 (Biota 2004b); YEX33 (Biota 2004a); YBI06^, YBI07^, YBI09^, YBI14, YBI16, YBI21, YBI22, YBI27^, YBI28, YBI29 and YBI34S^ (Biota 2009b); YAQ23^ (Biota 2014b); BIL18 and BIL33^ (current survey).
Relevés in the Study Area	YBI-RBMB, YBI-RBMA and YBI-RROA (Biota 2009b).
Other Notes	Quadrats HDA12 and YEX33 have been cleared.

Plate 5.24: Vegetation type P5 (BIL18).

Plate 5.25: Burnt vegetation type P5 (YAQ23).

P6: AapERfoERI/g	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
Distribution and Comments	This vegetation type occurred in narrow stands adjacent to the floodplains along either side of Weeli Wolli Creek (Plate 5.26). Several small patches of this vegetation also occurred on plains and hill crests in the study area. Tussock grasses typically dominated the understorey, however scattered hummock grasses were often present. This vegetation type supported the Priority 4 species, *Goodenia nuda*.
Associated Species	Trees: *Acacia ayersiana, A. catenulata, A. pruinocarpa* and *Corymbia candida*. Tall Shrubs: *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Atalaya hemiglauca* and *Hakea lorea* subsp. *lorea.* Shrubs: *Gossypium australe, Ptilotus obovatus* var. *obovatus, Rhagodia eremaea, Senna artemisioides* subsp. *helmsii* and *S. artemisioides* subsp. *oligophylla.* Low Shrubs: *Abutilon fraseri, A. lepidum, A. macrum, Corchorus sidoides* subsp. *sidoides, Hybanthus aurantiacus, Maireana planifolia, M. villosa, Sida platycalyx* and *Waltheria indica.* Herbs and Grasses: *Abutilon otocarpum, Bothriochloa ewartiana, *Cenchrus ciliaris, *C. setiger, Chrysopogon fallax, Cleome viscosa, Cymbopogon ambiguus, Dactyloctenium radulans, Dichanthium sericeum* subsp. *humilius, Digitaria brownii, D. ctenantha, Dipteracanthus australasicus* subsp. *australasicus, Dysphania melanocarpa, D. rhadinostachya* subsp. *rhadinostachya, Enteropogon ramosus, Eragrostis cumingii, Evolvulus alsinoides* var. *villosicalyx, Goodenia nuda* (Priority 4), *G. prostrata, Indigofera linifolia, *Malvastrum americanum, Pterocaulon sphacelatum, Sida* sp. verrucose glands (F.H. Mollemans 2423), *Sporobolus australasicus, Trianthema pilosum, Triodia basedowii, T. longiceps, T. pungens* and *T. wiseana.*
Vegetation Condition	Good; minor disturbance from cattle (scats and grazing); presence of several weed species as scattered individuals. Existing drill lines dissected much of this vegetation type.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	HDA08^, HDA13 (Biota 2004b); YEX09 (Biota 2004a); YBI12^, YBI13, YBI15^ (Biota 2009b); BIL32^ (current survey).
Relevés in the Study Area	YBI-RBMI (Biota 2009b); BIL-RSPA (current survey).
Other Notes	Quadrat YEX09 has been cleared.

Plate 5.26: Vegetation type P6 (BIL32).

P7: ERf/g	*Eremophila fraseri* subsp. *fraseri* open shrubland over mixed very open grassland
Distribution and Comments	This vegetation type was recorded from three small areas of plain with a calcrete substrate in the south of the study area (Plate 5.27). The understorey was variable, consisting of either a mixed tussock grassland (with the dominant species comprising *Aristida contorta, Enneapogon polyphyllus, Eragrostis eriopoda, Paraneurachne muelleri*) or a *Triodia wiseana* hummock grassland.
Associated Species	Tall Shrubs: *Acacia bivenosa, A. citrinoviridis, A. synchronicia* and *Hakea lorea* subsp. *lorea.* *Shrubs:* *Corchorus lasiocarpus* subsp. *lasiocarpus, Gossypium australe, Rhagodia eremaea* and *Senna artemisioides* subsp. *helmsii.* Low Shrubs: *Abutilon lepidum, Melhania oblongifolia, Scaevola spinescens, Sclerolaena cornishiana, Sida echinocarpa* and *Solanum lasiophyllum* Herbs and Grasses: *Abutilon otocarpum, Aristida contorta, A. holathera* var. *holathera, Chrysopogon fallax, Enneapogon polyphyllus, Eragrostis eriopoda, Indigofera colutea, Paraneurachne muelleri, Sida fibulifera* sens. lat. and *S.* sp. verrucose glands (F.H. Mollemans 2423).
Vegetation Condition	Good; scattered **Cenchrus ciliaris*; signs of cattle.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL25^, BIL48 (current survey).
Relevés in the Study Area	YBI-RBMG (Biota 2009b).

Plate 5.27: Vegetation type P7 (BIL25).

P8: EgAiTs	*Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland
Distribution and Comments	This vegetation type was recorded from loamy sands on gently sloping pediment slopes and colluvial plains at the base of a range of low hills in the northern section of the study area (Plate 5.28).
Associated Species	Tall Shrubs: *Acacia bivenosa* and *A. pruinocarpa*. Shrubs: *Acacia dictyophleba, A. pachyacra, A. trudgeniana*, *Santalum lanceolatum* and *Senna artemisioides* subsp. *oligophylla*. Low Shrubs: *Bonamia erecta, Corchorus tectus, Dicrastylis cordifolia, Scaevola parvifolia* subsp. *pilbarae, Senna notabilis* and *Sida cardiophylla*. Herbs and Grasses: *Abutilon otocarpum, Aristida holathera* var. *holathera, Chrysopogon fallax, Eragrostis eriopoda, Trianthema pilosum* and *Trichodesma zeylanicum* subsp. *zeylanicum*.
Vegetation Condition	Excellent.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL22^ and BIL42^ (current survey).

Plate 5.28: Vegetation type (BIL22).

P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland
Distribution and Comments	This vegetation type (Plate 5.29) occurs broadly over the plains on the western side of Weeli Wolli Creek, north of Marillana Creek. While the dominant spinifex species was *Triodia basedowii*, occasional hummocks of *T. pungens* were sometimes found in this vegetation type. (Note that *Triodia basedowii* was identified as *T. lanigera* in previous reporting.)
Associated Species	Tall Shrubs: *Acacia bivenosa, A. citrinoviridis, A. dictyophleba, A. pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis, Gossypium robinsonii, Grevillea wickhamii, Hakea chordophylla* and *H. lorea* subsp. *lorea.* Shrubs: *Gossypium australe, Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* and *S. glutinosa* subsp. *glutinosa.* Low Shrubs: *Corchorus lasiocarpus* subsp. *lasiocarpus, C. tectus, Dicrastylis cordifolia, Dodonaea coriacea, Hybanthus aurantiacus, Indigofera monophylla, Ptilotus astrolasius, Sida cardiophylla* and *S. echinocarpa.* Herbs and Grasses: *Aristida holathera* var. *holathera, Cleome viscosa, Cymbopogon obtectus, Eragrostis eriopoda, Gomphrena cunninghamii, Goodenia microptera, Mollugo molluginea, Paraneurachne muelleri* and *Triodia pungens.*
Vegetation Condition	Very Good; scattered **Cenchrus ciliaris* present. Occasional areas had a **Cenchrus ciliaris* and **C. setiger* open tussock grassland.
Quadrats in the Study Area (^ denotes the quadrat has been seasonally sampled)	BIL12^, BIL13, BIL41^ and BIL45^ (current survey).

Plate 5.29: Vegetation type P9 (BIL41).

5.3 Vegetation Condition

Vegetation condition mapping for the study area is presented in Appendix 4. The vegetation condition ranking was based on the degree of weed presence, human impact, feral animals and livestock activities, and the perceived structural integrity of the vegetation as a whole, given the impact of these disturbance factors. Appendix 3 presents the vegetation condition scale, developed by Trudgen (1988), that was used in determining the vegetation condition rankings.

A total of 5.7% of the study area was mapped as Disturbed, which is equivalent to a Completely Degraded vegetation condition (Trudgen 1988). These areas comprised current vehicle tracks, drill lines, drill pads and the JSE main mine pit. The extents of these areas were based on Rio Tinto's December 2013 disturbance footprint layer.

At the time of the field survey, additional drill lines were being cleared on the eastern side of Weeli Wolli Creek, south of the confluence with Marillana Creek. These new drill lines were not mapped as disturbed areas, as they were too new to be visible on aerial photography or captured in the Rio Tinto December 2013 disturbance footprint layer.

Fourteen quadrats that were previously sampled in the study area (between 2001 and 2012) were found to have been cleared prior to the current field survey (Table 5.2).

Table 5.2: Quadrats in the study area that have been cleared.

Vegetation Type	Quadrats that Have Been Cleared	
	Total Number	Site Name and Reference
C4: EvAciAprAThCEc	1	H051 (Biota 2002).
F3: ElChAtuAaAbGwTspp	1	YEX07 (Biota 2004a).
P1: ElEgAprAbAaAdTwTpTsps	1	YEX05 (Biota 2004a).
P2: ChAprAiAsclApaTp	2	YBI26 (Biota 2009b); YAQ29 (Biota 2014b).
P3: AprAciAiAsclTlo	1	HDA14 (Biota 2004b).
P4: AprAsyAiTw	5	HDA07, HDA15 (Biota 2004b); YEX03, YEX32 (Biota 2004a); YBI19 (Biota 2009b).
P5: ElEgAbAaTb	2	HDA12 (Biota 2004b); YEX33 (Biota 2004a).
P6: AapERfoERl/g	1	YEX09 (Biota 2004a).

The intact vegetation of the study area ranged from Excellent to Very Poor condition. The main disturbance factors in the study area were weed invasion and disturbance from livestock (cattle) including grazing, tracks, trampled vegetation and scats.

Dense weed infestations and high cattle activity were generally restricted to the creeklines and floodplains of the study area (Sections 5.2.1 and 5.2.2). **Cenchrus ciliaris* (Plate 5.30) was the most prolific weed in these habitats, sometimes occurring together with **Cenchrus setiger*. **Cenchrus* species were present as a continuous population along the edges of Weeli Wolli and Marillana Creeks and on adjacent floodplains. Where the **Cenchrus* formed a closed tussock grassland, a low number of native species was observed in the understorey.

Parts of the study area appear to have shown an increase in the infestation of **C. ciliaris* over time. In some cases this could be attributed to differing estimates of the proportion of **Cenchrus ciliaris* and **C. setiger;* the two species are indistinguishable without flowering material, which is less abundant during dry conditions. For example, an apparent increase in **C. ciliaris* at quadrat HDA09 was mirrored by a decrease in **C. setiger*, with the overall cover remaining stable. In other cases, the increase may be partly explained by variation in seasonal conditions between the two sampling phases. For example, although quadrats YEX08 and YBI10 both showed a large increase (approximately 25%) in the cover of **C. ciliaris* since they were first sampled, the first survey was undertaken during dry conditions, while the second survey was undertaken following substantial rainfall.

Given the aggressively invasive nature of these grasses, it is however probable that the abundance of **Cenchrus* species will increase over time in areas of suitable habitat, and populations may also spread to surrounding areas. Dispersal may be aided by factors such as flowing water, cattle activity, and clearing for tracks and other infrastructure; all of which are present in the study area.

Several other weed species were found in the creeklines of the study area, but these were usually present as scattered individuals only (see Section 6.6 for more information on the weeds in the study area). While most creekline and floodplain vegetation types were rated as being in Good condition, some areas were rated as Very Poor due to the high weed cover (greater than 70% cover) and evidence of extensive grazing and trampling by cattle (Plate 5.31).

Plate 5.30: **Cenchrus ciliaris*, the most prolific weed species in the study area.

Plate 5.31: Creekline vegetation in the study area with a dense **Cenchrus ciliaris* understorey grazed by cattle.

The plains of the study area (Section 5.2.4) also contained some weed species, although they were usually only present as scattered individuals. Occasionally a very open tussock grassland of **Cenchrus ciliaris* was present, usually on plains adjacent to creeklines or floodplains. Evidence of cattle was also occasionally noted on the plains. The vegetation condition of the plains therefore ranged from Good to Excellent.

The hills, ridges and breakaways of the study area (Section 5.2.3) were in Excellent condition and were mostly free from any form of disturbance. Some of the hills and slopes of the study area had been recently burnt (within 2-3 years; see Section 5.2.3). Fire is a natural process in the Pilbara region, and natural fire regimes need not affect the overall condition of vegetation (see Appendix 3).

There was a small amount of older historical clearing in the study area. Some parts of the study area contained old drill pads and tracks that were mostly overgrown (and therefore not mapped as disturbed). These areas were visible on aerial photography (2011 imagery) in vegetation types P5 and C4 (Section 5.2). As these areas were in the latter stages of regeneration, they were not mapped as Disturbed and they had only a small impact on the overall vegetation condition of these vegetation types.

5.4 Results of the Floristic Clustering Analysis

At the broadest level, sites located on stony hills (vegetation codes with an “H” prefix) tended to cluster separately on the basis of their floristic composition from sites in drainage lines (vegetation codes with a “C” prefix; see Figure 5.1). Sites on stony plains (vegetation codes with a “P” prefix) and in minor drainages and on floodplains (vegetation codes with an “F” prefix) were more variable floristically, being distributed between these two broad groupings (Figure 5.1). This is as expected, given that the topographic position of the plains landform is intermediate between the hills and drainages; and that water availability, which strongly influences the species present, declines markedly along this gradient.

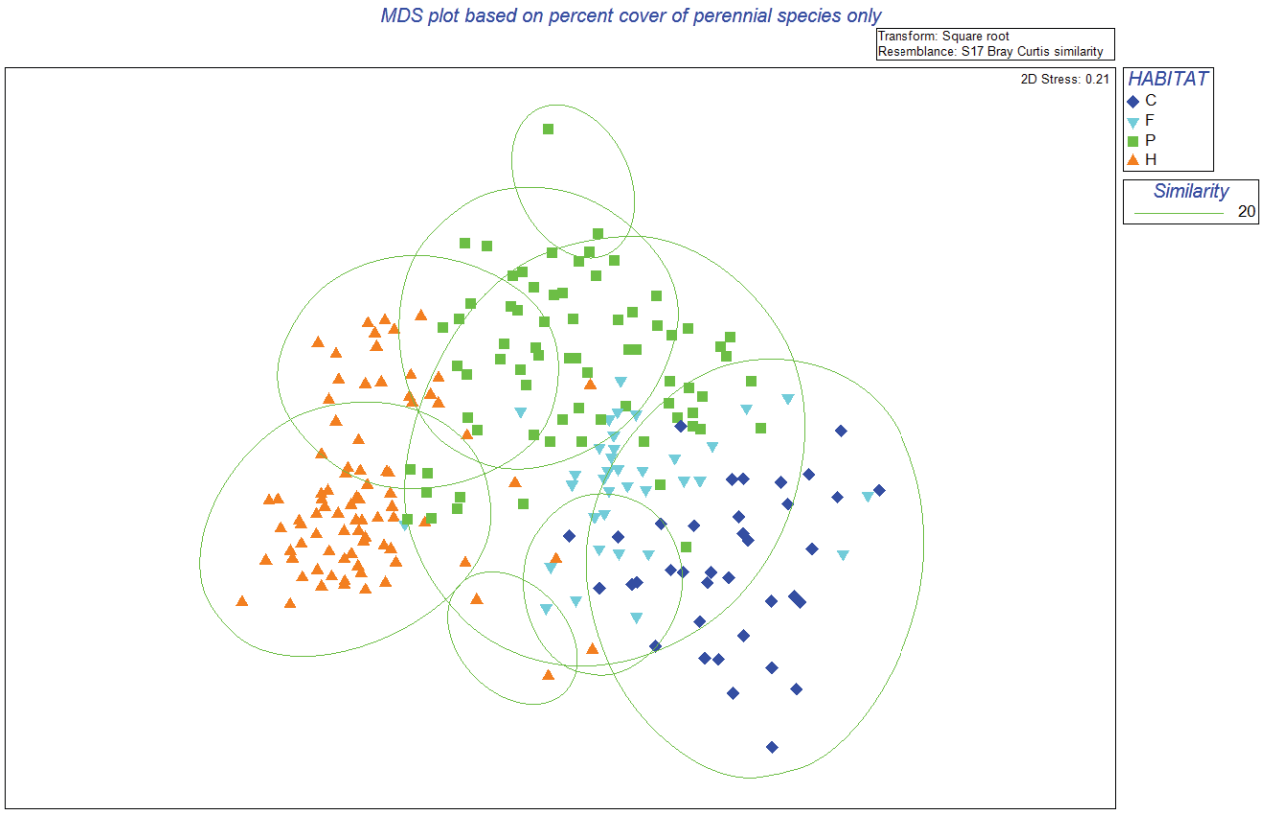

Figure 5.1: MDS plot based on percent cover data for perennial species for sites from the Yandi locality, with sites coded by broad habitat grouping.
(C = major creeklines and tributaries; F = minor creeklines, floodplains and valleys; P = plains; H = hills, ridges and breakaways.)

Sites within the study area generally grouped together with other sites that had been sampled in the locality (Figure 5.2), however some of the floristic groups identified by the analysis only contained sites from the study area. These are discussed further below.

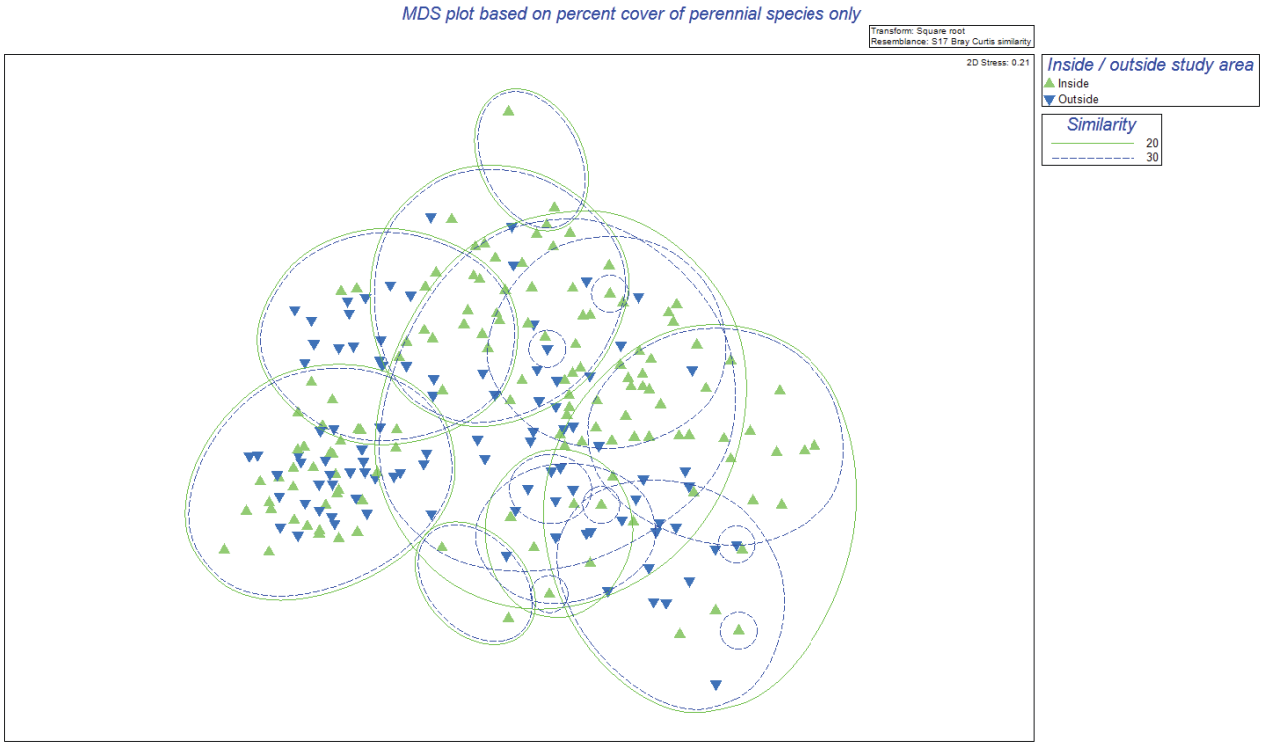

Figure 5.2: MDS plot based on percent cover data for perennial species for sites from the Yandi locality, with sites coded by their location inside or outside the study area.

The floristic analyses based on only the perennial species resulted in the closest match to the described vegetation sub-associations, as would be expected given that the latter were defined primarily on the abundance of the dominant species, which tended to be perennials. The analyses including annual species resulted in 50 floristic groups based on cover and 79 groups based on presence/absence data, including 11 and 29 groups respectively that contained only one site. Although there was still some reasonable correspondence between floristic composition and vegetation type, the groupings were less distinct, and the analyses using only the perennial species have therefore been discussed in the following section.

There was a reasonable correspondence between the floristic groups identified through the PRIMER analyses and the vegetation types described for the study, although these were not exact (see Figure 5.3). This is as expected, given that floristic composition of vegetation varies along a continuum, while the classification of sample sites into vegetation types is an attempt to impose distinct groups incorporating vegetation structure.

The analyses based on only perennial species identified 35 floristic groups from the 229 sites in the dataset when percent cover data were used, and 41 groups when presence/absence data were used (Appendix 9, Figures 1 and 2). Six floristic groups in each analysis comprised singletons (i.e. contained only one sampling site), however there was no correspondence in the particular sites that occurred as singletons in the two analyses. The analysis based on percent cover provided the most consistent interpretation, and is the primary analysis discussed further.

While there are clearly significant floristic differences between sites at lower level, the following summarised description of the floristic communities is based on a nominal 30% similarity as identified by the SIMPROF test. At this level, 16 floristic groups were identified within the data (see Figure 5.3 and Table 5.3). These groups had clear associations with the vegetation types identified for the study area, although sites from individual vegetation types were sometimes spread across more than one floristic group.

Most of the floristic groups included sites from both inside and outside the study area, and for those that did not, the pattern was typically no longer apparent when presence / absence data only were considered (compare Figures 1 and 2 in Appendix 9). However, two of the floristic groups at the 30% similarity level contained sites from the study area only (i.e. FG4, which contained the two sites sampled in vegetation type P8; and FG13, which contained sites from various vegetation types including all sites sampled in vegetation type P6). This was considered likely to be a function of the limitations of the data set, rather than an indication of a genuinely restricted distribution. To confirm this, further analyses were conducted using additional sites. Figure 3 in Appendix 9 confirms that additional sites have been sampled outside the study area in vegetation type P8. Similarly, the addition of additional sites with *Triodia longiceps* to the data set resulted in splitting apart of the original FG13 sites into three separate floristic groups at the 30% similarity level, however each of these groups now contained sites from outside the study area (Figure 4 in Appendix 9). None of the broad floristic groups identified at the 30% similarity level are therefore considered to be restricted to the study area.

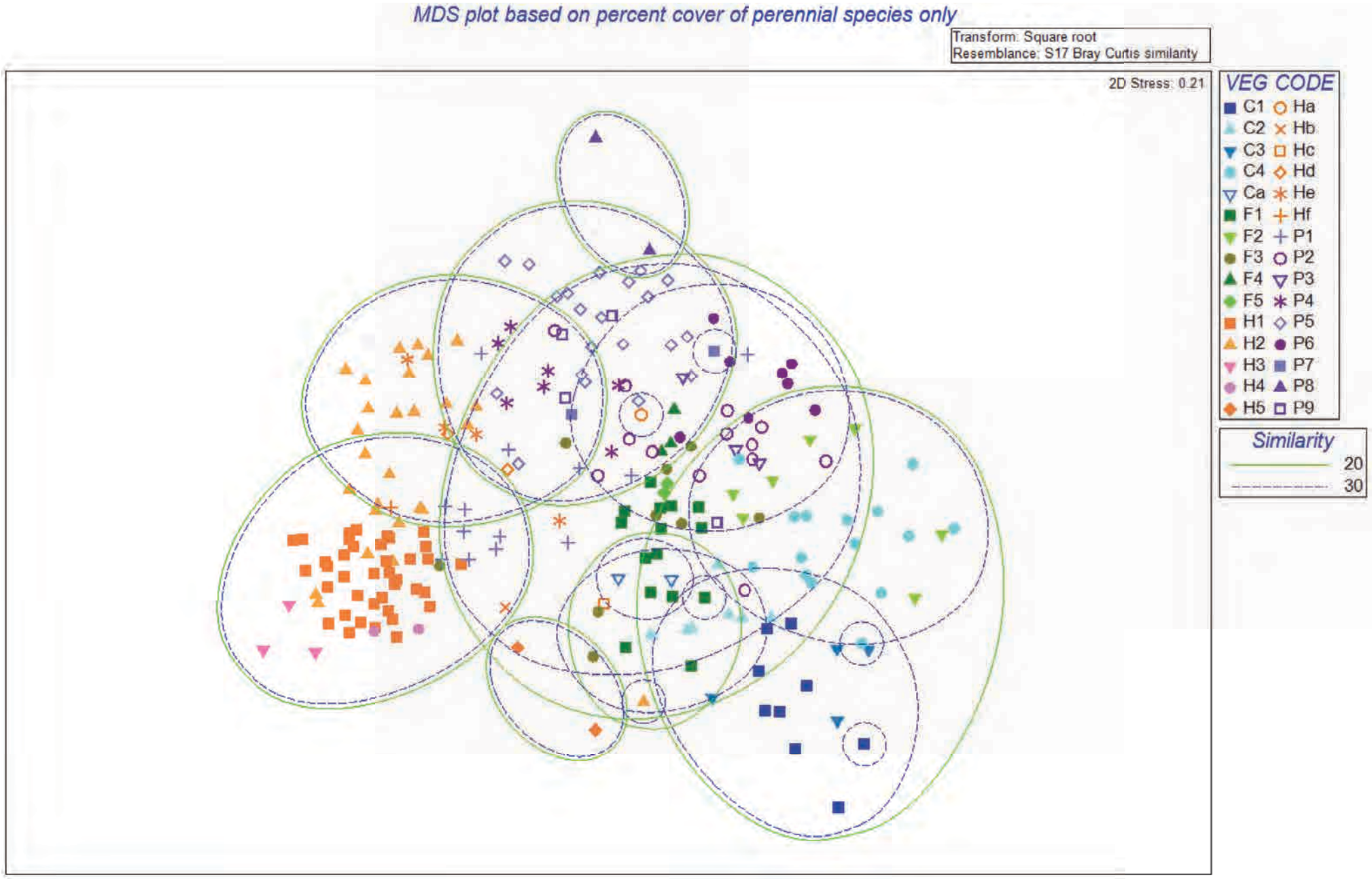

Figure 5.3: MDS plot based on percent cover of perennial species for sites from the immediate Yandi locality.

Table 5.3: Summary details for the 16 floristic groups identified at the 30% similarity level by the SIMPROF test for sites in the Yandi locality (analysis based on percent cover of perennial species only).

Floristic Group (No. of Sites in Group)	Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group † (Sites within Current Study Area)	Summarised Habitat and Vegetation
FG1 (n=2)	*Eriachne mucronata* (23.68%) *Corymbia ferriticola* (13.67%) *Cymbopogon ambiguus* (13.67%) *Eucalyptus leucophloia* subsp. *leucophloia* (13.67%)	H5 (BIL-RCFB, BIL-RCFD)	Vegetation of gullies.
FG2 (n=64)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (55.74%) *Eucalyptus leucophloia* subsp. *leucophloia* (5.81%) *Acacia hilliana* (4.24%) *Grevillea wickhamii* (3.79%)	F3 (nil) H1 (BIL05, BIL17, BIL20, BIL28, BIL34, BIL37, BIL43, YAQ14, YAQ19, YAQ25, YAQ27, YBI31S, YBI33S, YEX01, YEX06, YEX37) H2 (BIL03, BIL15, BIL19, BIL29, BIL39, HDA16, HDA24, YAQ18, YBI32S, YBI36) H3 (BIL01, BIL06, BIL-RPCA) H4 (BIL04, YBI24) Hf † P1 (BIL49, BIL38, YEX05)	Stony hills and plains dominated by *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grasslands.
FG3 (n=27)	*Triodia wiseana* (67.74%) *Acacia inaequilatera* (6.33%) *Paraneurachne muelleri* (1.87%) *Solanum lasiophyllum* (1.78%)	H2 (BIL26, BIL27, BIL40, BIL44, YBI05) Hd, He † P1 (nil) P4 (HDA07, HDA15, YAQ-CSRB, YBI19, YEX03) P7 (BIL43)	Stony hills and plains dominated by *Triodia wiseana* hummock grasslands.
FG4 (n=2)	*Triodia schinzii* (59.47%) *Eucalyptus gamophylla* (16.89%) *Acacia dictyophleba* (3.38%) *Acacia pachyacra* (3.38%)	P8 (BIL22, BIL42)	Plains with *Eucalyptus gamophylla* mallees over *Triodia schinzii* hummock grasslands.
FG5 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG14 and FG15 due to the particularly high cover of *Eucalyptus victrix* (65%) and also *Cyperus vaginatus* (25%)	C1 (YBI23)	Major creek channel supporting *Eucalyptus victrix* (Coolibahs) open forest over *Melaleuca argentea* (Cadjeputs), *Acacia citrinoviridis* and *A. coriacea* subsp. pendens over *Cyperus vaginatus* open sedgeland.
FG6 (n=15)	*Eucalyptus victrix* (14.48%) *Eucalyptus camaldulensis* subsp. *refulgens* (9.28%) *Acacia coriacea* subsp. *pendens* (6.33%) *Corchorus crozophorifolius* (6.10%)	C1 (YBI30S) C2 (nil) C3 (BIL30, YBI01)	Major creeklines supporting riparian vegetation of *Eucalyptus victrix* and *E. camaldulensis* subsp. *refulgens* (River Red Gums) over *Acacia citrinoviridis*.
FG7 (n=20)	**Cenchrus* spp. (47.93%) *Acacia citrinoviridis* (21.68%) *Eucalyptus victrix* (4.58%) *Atalaya hemiglauca* (3.99%)	C4 (H050, H051, HDA09, YAQ12, YAQ21, YAQ-CSRA, YBI02, YBI03, YBI04, YEX02) F2 (BIL23, BIL24, YAQ30, YAQ-CSRC, YAQ-CSRD) P9 (BIL12)	Moderate to major creeklines and associated floodplains supporting riparian vegetation of *Eucalyptus victrix* over *Acacia citrinoviridis*, usually with **Cenchrus* spp. in the understorey.

Floristic Group (No. of Sites in Group)	Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group † (Sites within Current Study Area)	Summarised Habitat and Vegetation
FG8 (n=23)	*Triodia basedowii* (47.61%) *Acacia ancistrocarpa* (3.47%) *Paraneurachne muelleri* (3.24%) *Acacia pruinocarpa* (2.84%)	P5 (BIL08, BIL18, BIL33, YAQ23, YBI06, YBI07, YBI09, YBI14, YBI16, YBI21, YBI22, YBI27, YBI28, YBI29, YBI34S, YEX33) P9 (BIL13, BIL41, BIL45)	Plains dominated by *Triodia basedowii* hummock grasslands.
FG9 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG22 and FG23 due to the relatively high cover of *Senna artemisioides* subsp. *oligophylla* (15%) and *Triodia epactia* (5%).	F1 (BIL-RSWA)	Valley supporting *Gossypium robinsonii, Senna artemisioides* subsp. *oligophylla, Atalaya hemiglauca* tall shrubland over *Triodia epactia* very open hummock grassland.
FG10 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG22 and FG23 due to the relatively high cover of *Cymbopogon ambiguus* (15%) and *Enneapogon lindleyanus* (10%), and probably the lack of species such as *Acacia aneura* and *A. pruinocarpa.*	H2 (BIL-RCFA)	Minor creek supporting *Senna artemisioides* subsp. *oligophylla, Gossypium australe, Acacia pyrifolia* var. *pyrifolia* open shrubland over open tussock grassland dominated by *Cymbopogon ambiguus* and *Enneapogon lindleyanus*.
FG11 (n=2)	*Acacia bivenosa* (14.94%) *Eucalyptus victrix* (14.94%) *Eriachne tenuiculmis* (9.45%) *Acacia ancistrocarpa* (6.68%)	Ca †	Moderate-sized creeklines with an open forest to low open woodland of *Eucalyptus victrix* over a tall open shrubland dominated by *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* over a mixed tussock grassland dominated by *Eriachne tenuiculmis.*
FG12 (n=1)	Not calculated (only one site in floristic group); the small amount of *Triodia wiseana* (0.1%) appears to separate this site from BIL48 in FG2, leading to clustering with FG25-FG27; FG24 appears to then be separated due to the relatively high cover of *Eremophila fraseri* (20%) and *Eragrostis eriopoda* (7%)	P7 (BIL25)	Plain supporting *Eremophila fraseri* subsp. *fraseri, (Acacia citrinoviridis)* tall shrubland over *Senna artemisioides* subsp. *helmsii* open shrubland over *Eragrostis eriopoda* very open tussock grassland.
FG13 (n=14)	*Acacia aneura* (22.57%) *Acacia pruinocarpa* (9.82%) **Cenchrus* spp. (5.78%) *Triodia longiceps* (4.33%)	F2 (YEX38) P3 (YBI11, YBI17) P4 (YEX04, YEX32) P5 (HDA12) P6 (BIL32, BIL-RSPA, HDA08, HDA13, YBI12, YBI13, YBI15, YEX09)	Alluvial plains supporting Mulga and *Acacia pruinocarpa* low woodlands over open hummock grasslands of mixed species, often dominated by *Triodia longiceps,* with mixed tussock grasses.
FG14 (n=1)	Not calculated (only one site in floristic group); appears to be separated due to the combination of a reasonable cover of *Eremophila fraseri* and *Triodia pungens*, together with negligible cover of *T. wiseana*	Ha †	*Acacia inaequilatera* scattered tall shrubs over *Eremophila fraseri* subsp. *fraseri* scattered shrubs over *Triodia pungens, (T. wiseana)* very open hummock grassland.

Floristic Group (No. of Sites in Group)	Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group † (Sites within Current Study Area)	Summarised Habitat and Vegetation
FG15 (n=9)	*Acacia tumida* var. *pilbarensis* (27.34%) *Triodia pungens* (8.06%) *Corymbia hamersleyana* (5.25%) *Grevillea wickhamii* (4.45%)	F1 (BIL-RCFC, YBI20, YBI25) F3 (YAQ-RPLA) C2 (BIL02)	Creeklines supporting scattered low trees to low open woodlands of *Corymbia hamersleyana* over tall shrublands to tall open scrub usually dominated by *Acacia tumida* var. *pilbarensis* and *Grevillea wickhamii* over a hummock grassland of *Triodia pungens.*
FG16 (n=46)	*Triodia pungens* (33.42%) *Corymbia hamersleyana* (4.99%) **Cenchrus* spp. (3.56%) *Acacia tumida* var. *pilbarensis* (2.74%)	C2 (BIL31) C4 (YBI08) F1 (BIL16, YBI35S) F3 (BIL35, BIL36, YEX07, YEX08) F4 (BIL11, BIL14, BIL46) F5 (BIL21, BIL47) Hb, He † P1 (nil) P2 (BIL07, BIL09, BIL10, YAQ16, YAQ29, YBI10, YBI26) P3 (HDA14) P5 (WW30)	Predominantly floodplains with scattered *Corymbia hamersleyana* trees over a scattered to open tall shrub layer of various *Acacia* spp., usually including *A. tumida* var. *pilbarensis*, over a hummock grassland of *Triodia pungens.*

† Vegetation type not mapped in the current study area.

5.5 Vegetation of Conservation Significance

5.5.1 TECs and PECs

None of the vegetation types represent TECs listed either under the Commonwealth *EPBC Act 1999* or the WA *Environmental Protection Act 1986* (see Section 4.8.1), nor do they represent PECs listed by DPaW (see Section 4.8.2).

5.5.2 Ecosystems At Risk

While not formally listed as TECs or PECs or protected by any legislation, a number of "other ecosystems at risk" are identified for the Hamersley and Fortescue Plains subregions of the Pilbara bioregion (see Kendrick 2003a, 2003b). These are ecosystems of some level of significance that are at risk of degradation from a variety of factors, including development, groundwater drawdown, frequent fires, grazing and weed invasion. One of these is relevant to the study area:

- 'All major ephemeral water courses' in the Hamersley subregion are listed as an ecosystem at risk by Kendrick (2003a). These water courses are described as supporting "*Eucalyptus* forests with a shrubby understorey", which are under threat of degradation from weed invasion and grazing and trampling by feral herbivores (Kendrick 2003a). Groundwater drawdown could also potentially impact such vegetation if it included phreatophytic (groundwater dependent) species such as *Melaleuca argentea* (Cadjeput) or *Eucalyptus camaldulensis* (River Red Gum).

One vegetation type (C1) described for the study area is considered to represent this ecosystem at risk (Table 5.4). This vegetation is associated with Marillana Creek and Weeli Wolli Creek, two of the major ephemeral creek systems for the locality. Two other vegetation types (C2 and C3) comprise riparian vegetation along these same major creek systems, but do not feature dense forests of Eucalypts.

Table 5.4: Vegetation types considered to be "ecosystems at risk" after Kendrick (2003a) and other riparian vegetation of major creeks.

Vegetation Code	Vegetation Description	Area (ha)	Percentage of the Study Area
'All major ephemeral water courses' Ecosystem at Risk			
C1: EcEvMaMgAc	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland	73.1	0.8
Other Riparian Vegetation of Major Creeks			
C2: EvChAtuGwTErCYpERItTHt	*Eucalyptus victrix, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	22.6	0.3
C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	269.3	3.1
	Total	365.0	4.2

Vegetation type C1 is currently in Good condition; although several weed species were recorded, they were generally present in only low numbers. Vegetation type C1 also supported both *Melaleuca argentea* and *Eucalyptus camaldulensis*, two species that could be affected by groundwater drawdown from the adjacent mining operations. Similar vegetation is widespread in major creek systems through the Pilbara, including the Robe River, Hardey River, Caves

Creek/Duck Creek and Marillana Creek/Weeli Wolli Creek systems. This vegetation is therefore considered significant at a local, rather than regional, scale.
Vegetation types C2 and C3 are similarly in Good to Very Good condition, with **Cenchrus* spp. present as only scattered individuals. These vegetation types were dominated by only scattered trees of *Eucalyptus victrix* and did not support the phreatophytic species present in C1, but occurred along the same major creek systems. Similar vegetation assemblages are widespread in major creek systems through the Pilbara including tributaries of the Beasley River, and in the Caves Creek/Duck Creek, Hardey River and Marillana Creek/Weeli Wolli Creek systems. This vegetation is thus again considered significant at a local, rather than regional, scale.

While vegetation type C4 also occurred in the major creeklines of the study area (mainly on the broad floodplains of Weeli Wolli and Marillana Creek), it has been extensively degraded by invasion of **Cenchrus ciliaris* (often together with **C. setiger*) in the understorey. This vegetation has therefore already been substantially impacted by the processes threatening riparian vegetation, and is not of particular conservation significance.

5.5.3 Other Conservation Values

All of the habitats in the study area are widespread in the locality, and none of the vegetation types appear to be restricted in distribution on the basis of their floristic composition (see Section 5.4).

The remaining vegetation types in the study area are considered to be of low conservation significance, being representative of the vegetation occurring in similar habitats throughout the local area. Note that this is not meant to imply that the vegetation in the study area is of no conservation value, as all intact native vegetation is inherently valuable (DEWHA 2010).

6.0 Flora of the Study Area

6.1 Overview

A total of 455 native vascular flora taxa from 154 genera and 47 families have been recorded from the study area, based on all survey effort to date. This includes one Threatened species (discussed in Section 6.4.1) and two Priority flora species (discussed in Section 6.4.2). Eighteen introduced flora species have also been recorded (see Section 6.6).

6.2 Dominant Families and Genera

The dominant families and genera (native taxa only) recorded from the study area are presented in Table 6.1. These are typical of the most well represented families and genera in the Pilbara bioregion.

Table 6.1: Dominant plant families and genera in the study area.

Family	No. of Native Taxa	Genus	No. of Native Taxa
Fabaceae	88	*Acacia*	39
Poaceae	81	*Senna*	20
Malvaceae	52	*Euphorbia*	14
Amaranthaceae	21	*Ptilotus*	13
Asteraceae	19	*Sida*	12

6.3 Species Richness – Regional Context

Species richness tends to vary on a logarithmic scale with the size of the study area. However, the array of habitats (and therefore vegetation types) present also has a large influence on the number and type of species recorded, as different habitats provide a greater variety of ecological niches that can be occupied by a greater number of different species. The shape of the survey area may also influence the number of species recorded, with long linear survey areas tending to intersect a greater variety of habitats and, depending on the length, sometimes different biogeographic regions.

Figure 6.1 shows the species richness of the study area compared to eight other study areas from the locality: Yandi Additional Areas (Biota 2014b), Koodaideri Northern Extension (Biota 2012b), Koodaideri Mining Lease (Biota 2012c), Koodaideri Southern Infrastructure Corridor (Biota 2012d), Junction South West Deposit (Biota 2010), Oxbow Deposit (Biota 2010), Billiards Deposit (Biota 2009b) and Yandi Expansion (Biota 2004a). When compared to these other study areas in the broader locality, all of which have been surveyed in recent years, the total number of native flora taxa recorded from the study area is high but within the range that would be expected for a survey area of this size.

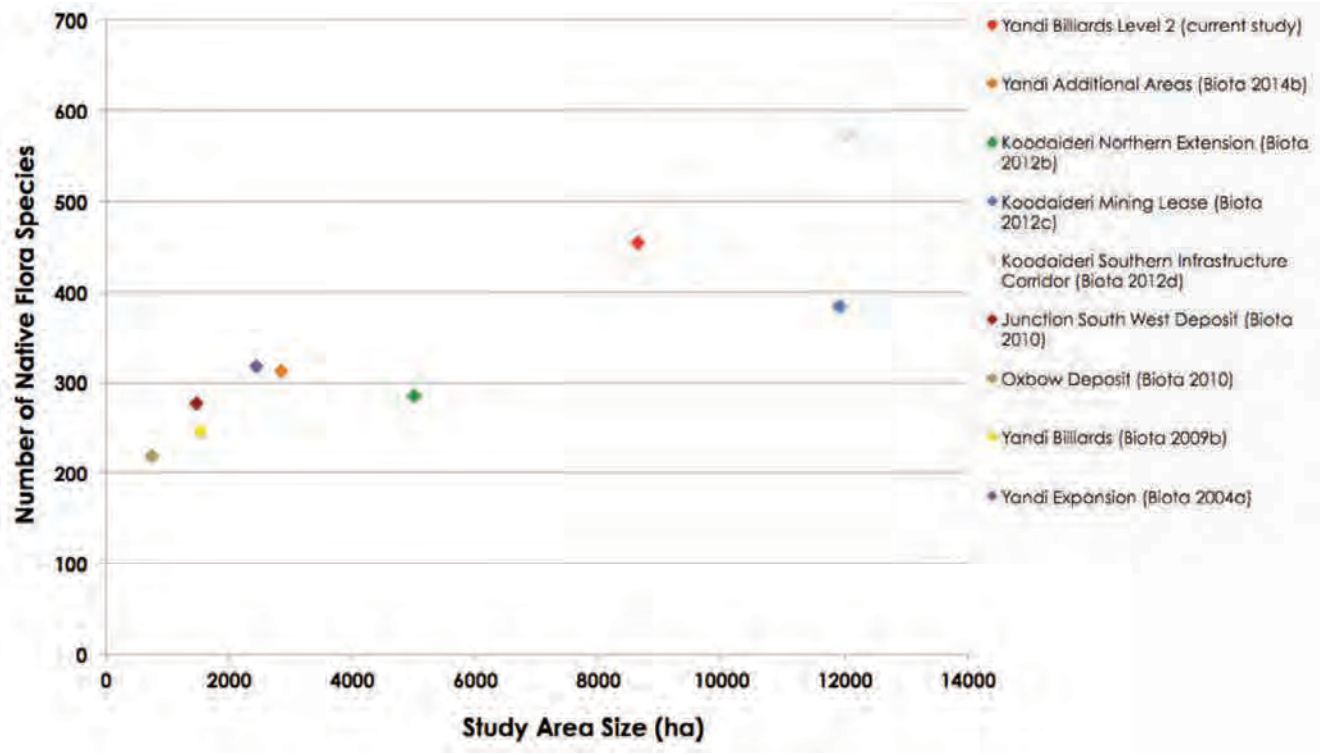

Figure 6.1: The number of native taxa recorded from the study area compared to other recent surveys in the locality.

6.4 Flora of Conservation Significance

6.4.1 Threatened Flora

One Threatened species, *Lepidium catapycnon,* listed under the Commonwealth *EPBC Act 1999* or the WA *Wildlife Conservation Act 1950,* has been recorded from the study area (see Section 4.9.1 for a description of this species).

Lepidium catapycnon was recorded from two locations in the study area during previous surveys (Hamersley Iron 2006, Biota 2009a; see Table 6.2). These are designated Populations 1 and 2 in Table 6.2 and the following text. Searches were undertaken during the Phase 1 survey at the locations of the existing records, as well as targeting areas deemed potentially suitable habitat, however no individuals of *L. catapycnon* were recorded. It was noted at the time that there was additional suitable habitat for this species in the study area and that this species may occur at other locations (Biota 2014a), therefore further targeted searches were undertaken during the Phase 2 survey.

Lepidium catapycnon was subsequently recorded during the Phase 2 survey from 26 locations comprising three separate populations[7]. Two of these represented new populations for the study area (Populations 3 and 4; see Table 6.2 and further text). Following broader searches around the record of Population 1, three individuals were found; the population size was greatly reduced compared to the original record (see below). The remaining historically recorded population, Population 2, was not found. In total, 777 individuals were counted in the study area during Phase 2, which included both mature adult and juvenile plants[8] (Plate 6.1). No individuals were flowering or fruiting at the time of the survey; all plants were in a vegetative state and appeared healthy.

[7] Plants more than 500 m from a known population are considered to be a new population (DEC 2010b).

[8] Mature adult plants are defined as those that have the potential to reproduce, while juvenile plants are defined as immature plants that have lost their cotyledons but not yet flowered (DEC 2010b). As no plants were flowering at the time of the survey, plants less than 10 cm in height were defined as juveniles.

Plate 6.1: A mature plant (left) and juvenile plant (right) of *Lepidium catapycnon* found in the study area.

All records of *Lepidium catapycnon* from the study area are provided in Table 6.2. Additionally, all records are displayed over the proposed project footprint in Figure 6.2 as well as on the vegetation mapping (Maps 4 and 5) in Appendix 4.

Table 6.2: All records of the Threatened species, *Lepidium catapycnon*, located in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	Number of Individuals	Status (2014) †
Population 1	Biota (2009a)	7-Sep-08	733172	7475074	171	Not found.
	Current study (Ph2)	10-Jul-14	733185	7475117	3	3 A.
Population 2	Hamersley Iron (2006)	Not provided	732596	7470785	Not provided	Not found.
Population 3	Current study (Ph2)	8-Jul-14	733334	7470806	50	30 A, 20 J.
		8-Jul-14	733363	7470663	1	1 A.
		8-Jul-14	733370	7470785	23	12 A, 11 J.
		8-Jul-14	733373	7470723	10	10 A.
		8-Jul-14	733373	7470739	3	2 A, 1 J.
		8-Jul-14	733373	7470762	33	18 A, 15 J.
		8-Jul-14	733374	7470867	10	6 A, 4 J.
		8-Jul-14	733390	7470691	20	20 A.
		10-Jul-14	733399	7470826	24	10 A, 14 J.
		10-Jul-14	733776	7470609	17	12 A, 5 J.
		9-Jul-14	733911	7470603	27	22 A, 5 J.
		9-Jul-14	733928	7470625	18	18 A.
		10-Jul-14	733942	7470609	32	10 A, 22 J.
		9-Jul-14	733947	7470645	80	65 A, 15 J.
		9-Jul-14	733947	7470675	50	30 A, 20 J.
		10-Jul-14	733968	7470690	27	17 A, 10 J.
Population 4	Current study (Ph2)	14-Jul-14	735843	7473347	30	30 A.
		14-Jul-14	735870	7473373	5	5 A.
		14-Jul-14	735946	7473354	1	1 A.
		14-Jul-14	735962	7473331	10	10 A.
		14-Jul-14	736005	7473311	85	65 A, 20 J.
		14-Jul-14	736038	7473307	72	60 A, 12 J.
		14-Jul-14	736060	7473302	13	13 A.
		14-Jul-14	736141	7473312	111	103 A, 8 J.
		14-Jul-14	736176	7473323	22	22 A.

† A = adult; J = juvenile.

The *Lepidium catapycnon* populations recorded in the study area (both new and historical records) are described further below:

- Population 1 (see Map 4 in Appendix 4): The 171 individuals of *L. catapycnon* previously recorded by Biota (2009a) were not found during the Phase 1 or Phase 2 surveys, however additional searches undertaken around this location in Phase 2 identified three small adult plants approximately 50 m north of the original record (Plate 6.2). These were observed growing in a shallow drainage gully amongst low undulating rocky hills, in an area mapped as the McKay land system (Van Vreeswyk et al. 2004). The associated vegetation comprised a mature community of *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia wiseana* open hummock grassland, which was more broadly mapped as vegetation type H1 (see Section 5.2.3). Given the mature size of the *Triodia* hummocks, the fire age of this site was estimated to be more than five years. No dead plants were found in the area, nor were there any signs of clearing or obvious disturbance. It appears that the majority of plants in this population recorded by Biota (2009a) have died since the original record was made. It is likely that the number of individuals in this population will increase following a disturbance (particularly following a fire). This population is located adjacent to (approximately 20 m from) a preliminary proposed waste dump location (Figure 6.2).
- Population 2 (see Map 5 in Appendix 4): The site of the *L. catapycnon* record documented by Hamersley Iron (2006) was revisited and searched during both phases of the field survey. A radius of approximately 50-100 m immediately surrounding the location coordinates was searched, however no individuals were found. This area is mapped as the Newman land system (Van Vreeswyk et al. 2004). The habitat appeared to be suitable to support the species, comprising rocky slopes and a small gully below a ridgeline (Plate 6.3), which was more broadly mapped as vegetation type H1 (see Section 5.2.3). There were no obvious signs of clearing or other disturbance at the site. Some of the slopes around this location had been recently burnt (fire age of approximately two years), however there was no sign of recent fire in the small gully. As for Population 1, it appears that these plants have died since the original record was made eight years ago, and that no recruitment has occurred to renew the population. It is likely that Population 2 would re-establish following disturbance (particularly following a fire). This population does not occur within the proposed project footprint (Figure 6.2).
- Population 3 (see Map 5 in Appendix 4): A new population of *L. catapycnon* was found in the southern section of the study area (east of Weeli Wolli Creek), in an area of Newman land system (Van Vreeswyk et al. 2004). This population occurred below a free face on several steep, shale-covered slopes of a range of hills, which comprised moderate-sized rocky flat-topped hills and mesas (Plate 6.4). *Lepidium catapycnon* was recorded at 16 locations in this area[9] during targeted traverses along these slopes. Most of the plants were found growing on the east-facing upper slopes or mid-slopes, with a few records from west-facing or north-facing slopes. The associated vegetation was predominantly *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over mixed *Triodia* spp. very open hummock grassland, with the dominant *Triodia* species varying between *T. brizoides, T.* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* and *T. pungens*. This vegetation was more broadly mapped as H1 (slopes), with some areas of H5 (free faces and breakaways of ridgeline) (see Section 5.2.3). Most of the records from this population occurred in areas that had been recently burnt, with the fire age estimated at approximately two years, however some records occurred on slopes with no sign of recent fire. A total of 425 individuals were recorded from this population, comprising 283 mature plants and 142 juvenile plants. Part of this population (a total of 173 individuals (41%) from eight of the 16 location records) is located within a preliminary proposed waste dump location (Figure 6.2).
- Population 4 (see Map 5 in Appendix 4): Another new population of *L. catapycnon* was found approximately 3 km northeast of Population 3, in an area of Newman land system (Van Vreeswyk et al. 2004). This population extended along the south-facing slope of a moderate-sized rounded hill, which had a loose, ironstone shale surface (Plate 6.5). Individuals were recorded at nine locations, however the population appeared to be continuously distributed along the slope. The vegetation at this site comprised *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia wiseana* open hummock grassland, which was more broadly mapped as vegetation type H1 (see Section 5.2.3). Fire age was estimated to be approximately 4-5 years and there was a considerably higher proportion of mature plants

[9] At each recorded location, all plants were counted in an approximate 20 m radius of the coordinate (see Section 3.2.5).

compared to Population 3. A total of 349 individuals were recorded from this population, comprising 309 mature plants and 40 juvenile plants. A total of 216 individuals (62%), from seven of the nine locations recorded in this population, are located within a preliminary proposed waste dump location (Figure 6.2).

Plate 6.2: *Lepidium catapycnon* Population 1: three individuals found approximately 50 m north of those originally recorded by Biota (2009a).

Plate 6.3: *Lepidium catapycnon* Population 2: habitat at site of record made by Hamersley Iron (2006). No plants were located during the current survey.

Plate 6.4: *Lepidium catapycnon* Population 3: steep, recently burnt slopes below a free face.

Plate 6.5: *Lepidium catapycnon* Population 4: south-facing slope of a moderate-sized hill.

Additional suitable habitat for *Lepidium catapycnon* occurs in the study area, not all of which has been searched. As only a portion of the suitable habitat was searched, it is possible that this species occurs at other locations in the study area. All *Lepidium catapycnon* populations in the study area occurred mainly within vegetation type H1, with some individuals occurring in areas mapped as vegetation type H5. All hills and slopes of the study area (vegetation types H1, H2, H3, H4 and H5, totalling 2,968 ha; see Appendix 4) could comprise suitable habitat for *L. catapycnon*, especially areas that have been burnt recently or have rocky ironstone shale slopes. However, vegetation type H1 (1,326 ha) remains the most prospective unit for this species. While it is possible that additional populations of *Lepidium catapycnon* occur in the study area, there is a low likelihood of new populations being located in areas where targeted searches have been undertaken. A map of the traverses through the study area is provided in Appendix 7 as an indication of the survey effort completed to date.

Lepidium catapycnon occurs over a broad range through the Pilbara, extending from northwest of Tom Price across to Newman. Over 30 populations are known, including one population in the conservation estate of the Karijini National Park, and some of these populations number in the

hundreds to over a thousand individuals (M. Maier, Biota, pers. obs.). The four populations recorded in the study area are located within the known range of the species and a total of 948 individuals have been recorded by all surveys to date (although only 777 individuals were present during the 2014 surveys). Rio Tinto database records show that *Lepidium catapycnon* has been recorded from 45 locations in the Yandi locality. These include over 3,059 individuals recorded from 25 locations within 10 km to the west of the study area, while additional populations are located within 10 km to the south of the study area. The populations within the study area would therefore not be considered to be of regional significance, and would be unlikely to be of local significance.

The preliminary proposed waste dump locations (areas where vegetation clearing would be required) intersect two of the *Lepidium catapycnon* populations (Populations 3 and 4; see above). Of the 777 individuals recorded in the study area during the 2014 surveys, 389 individuals (50%) in Populations 3 and 4 occur within the preliminary proposed waste dumps. The proposed works would therefore directly impact this species unless the preliminary waste dump design is modified to avoid these populations.

6.4.2 Priority Flora

Two Priority flora species, *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) and *Goodenia nuda* (Priority 4), were recorded in the study area during the field survey. Discussion of the populations in the study area is provided below, while a more general description of these species is provided in Section 4.9.2. All Priority flora records are displayed on the vegetation mapping provided in Appendix 4.

- *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3)
  A total of five individuals of *Sida* sp. Barlee Range (S. van Leeuwen 1642) were recorded during the Phase 2 survey from two locations (Table 3). These records were in close proximity (25 m apart). The first record, of three individuals, was located on the southern boundary of the study area in vegetation type H5 (see Map 5 in Appendix 3). The second record, of two individuals, was made in the same vegetation type outside the study area, approximately 10 m south of the southern boundary. At both locations, the plants were found growing out of the side of a free face at the top of a shale-covered steep hillslope (Plate 6.6). All plants were mature, in healthy condition and flowering at the time of the survey. Both of these records occur outside of the proposed project footprint.

  Sida sp. Barlee Range (S. van Leeuwen 1642) is known from a number of locations throughout the Hamersley Range (DPaW 2014c), extending over a range of approximately 250 km from Brockman to Coondiner Creek. There has only been one previous record of this species within 10 km of the study area (Biota 2004a; see Appendix 2), however numerous additional locations have been recorded approximately 30 km northwest at Koodaideri (Biota 2012e) and there is also a record 36 km southeast at Coondiner Creek (DPaW 2014c). There is considerable suitable habitat along the range of hills to the northwest and southeast of the study area, and the lack of records of this species in the intervening areas is considered to be a reflection of a lack of survey effort rather than a genuine indication of the species' distribution. The five individuals recorded from the study area would therefore not be regionally or locally significant.

  It is possible that additional populations of this species occur in the study area but were not located during the current survey. The preferred habitat for *Sida* sp. Barlee Range (S. van Leeuwen 1642) comprises exposed rock in gullies and gorges, and vegetation type H5 (11.8 ha) is considered to represent the most prospective unit to support further populations of this species in the study area.

Table 3: Locations of *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) recorded inside and outside the study area during the current survey.

Location	Record Type	Date	Easting (mE)	Northing (mN)	Number of Individuals
Inside study area	Opportunistic	9-Jul-14	733697	7470558	3
Outside study area	Opportunistic	9-Jul-14	733720	7470548	2

- *Goodenia nuda* (Priority 4)
  A total of 76 individuals of *Goodenia nuda* were recorded from nine locations in the study area during the Phase 1 survey (Table 6.4; Plate 6.7). Seven of the locations were in Mulga woodlands (vegetation type P6; Section 5.2.4) on the eastern side of Weeli Wolli Creek. The two other records were from plains (vegetation types P2 and P3; Section 5.2.4) adjacent to the Marillana Creek and Weeli Wolli Creek floodplains. No additional locations of *G. nuda* were recorded during Phase 2, however the timing of this survey was less suitable to detect this species. Four records (comprising a total of 37 individuals) are located within the footprint of the proposed Pocket and Billiards South pit.

  Goodenia nuda has a broad distribution over a range of 500 km throughout the Pilbara bioregion, from Mardie Station on the coast to the eastern section of the Fortescue Valley (DPaW 2014c). This species has been recorded during several other surveys in the Yandi locality (Halpern Glick Maunsell 2000, Biota 2002, 2010, 2014b, 2014c; see Appendix 2). The records from the study area are therefore not considered to be either regionally or locally significant. Given that several populations of *G. nuda* are known from the study area (as well as from the broader Yandi locality) and that this species is a small, often inconspicuous herb, it is possible that additional populations of this species occur in the study area. Floodplains in the study area would provide the most suitable habitat for this species.

Table 6.4: Locations of *Goodenia nuda* (Priority 4) recorded in the study area.

Record Type	Date	Easting (mE)	Northing (mN)	Number of Individuals
Quadrat (YAQ16)	16-Mar-14	734166	7478025	4
Quadrat (HDA08)	16-Mar-14	734807	7474388	5
Quadrat (YBI12)	17-Mar-14	735517	7475188	1
Opportunistic	15-Mar-14	736668	7477105	8
Quadrat (YBI15)	16-Mar-14	736687	7477149	23
Opportunistic	18-Mar-14	737054	7477706	6
Opportunistic	18-Mar-14	737185	7477540	26
Opportunistic	18-Mar-14	737185	7477606	2
Opportunistic	18-Mar-14	737274	7477733	1

Plate 6.6: *Sida* sp. Barlee Range (S. van Leeuwen 1642) growing out of a rocky free face in the study area.

Plate 6.7: *Goodenia nuda* inflorescence (photo not from the study area).

The three other Priority flora that were identified as having the potential to occur in the study area based on the desktop review (see Section 4.9.2 and Appendix 2) still retain this ranking, as the entire study area has not been blanket searched:

- *Stylidium weeliwolli* (Priority 2) is a small annual herb that may be present within the creek beds of Weeli Wolli and Marillana Creek. Although conditions were favourable for annual species at the time of the Phase 1 field survey, there is a possibility that individuals could have been missed due to the small size of this species. *Stylidium weeliwolli* has a broad range through the

Pilbara and Gascoyne regions (DPaW 2014c), however it is infrequently recorded. There are a number of records of this species in the Yandi locality, with the closest being 6 km upstream in Weeli Wolli Creek and 23 km upstream in a tributary of Marillana Creek (see Section 4.9.2). If *Stylidium weeliwolli* was present in the study area, it is unlikely that populations would be considered either regionally or locally significant.

- *Rostellularia adscendens* var. *latifolia* (Priority 3) is also small in size and there is the possibility that individuals could have been missed during the survey. This species may occur within the study area, particularly in creekline or floodplain habitat. *Rostellularia adscendens* var. *latifolia* is known from a number of locations with a broad distribution through the Pilbara (405 km), ranging from northwest of Tom Price to West Angelas in the south and Warrawagine in the northeast (DPaW 2014c). The study area lies within this range, and this species has been recorded at scattered locations from previous surveys in the Yandi locality (Biota 2010, 2014c). *Rostellularia adscendens* var. *latifolia* typically occurs in low numbers, when recorded. If this species was present in the study area, the populations would not be considered either regionally or locally significant.
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) is typically associated with clayey plains, where it may form dense grasslands, however there are occasional isolated records from creeks and floodplains. This species may potentially occur in the study area, particularly on the floodplains surrounding the major creeks. However, given that it has not been recorded to date from the area, it would occur only as isolated individuals rather than dense grasslands. If this species was present in the study area, the populations would not be considered either regionally or locally significant.

6.4.3 Other Species of Interest

The currently undescribed taxon *Eulalia* sp. (Three Rivers Station, B. Forsyth AQ6789133) was recorded from three locations in the study area in a minor creekline, on a floodplain and on a plain. One of the records of this taxon was from a resampled quadrat, and it is likely that this taxon has been confused with the more common species, *E. aurea,* in past surveys. This species has a broad range extending over approximately 380 km from the Pilbara to the Gascoyne bioregion (see Section 4.9.3), and it has been recorded from other surveys in the locality including at Yandi (Biota 2014b), West Angelas (Biota 2014d) and Koodaideri (Biota 2012e). The populations in the study area are therefore unlikely to be considered either regionally or locally significant.

The taxon *Glycine* sp. aff. *arenaria* was not recorded from the study area, but may potentially occur along the sections of Marillana and Weeli Wolli Creek in the study area. Specimens of *Glycine* were collected in 2014 at the original locality near Oxbow, however none bear the 1-2 seeded pods that should be characteristic of *G. arenaria* (see Section 4.9.3). Further taxonomic work is required to determine whether the taxon from Oxbow represents *G. arenaria* or a separate species, and further resolution of the specimens collected in 2014 is being progressed through Andrew Perkins (WA Herbarium taxonomist). Given that there is currently only one record of *Glycine* sp. aff. *arenaria* from the Pilbara bioregion, if populations were present in the study area they may be considered regionally significant, depending on the outcome of the taxonomic placement. Further surveys in the Yandi locality should include targeted searches for this taxon.

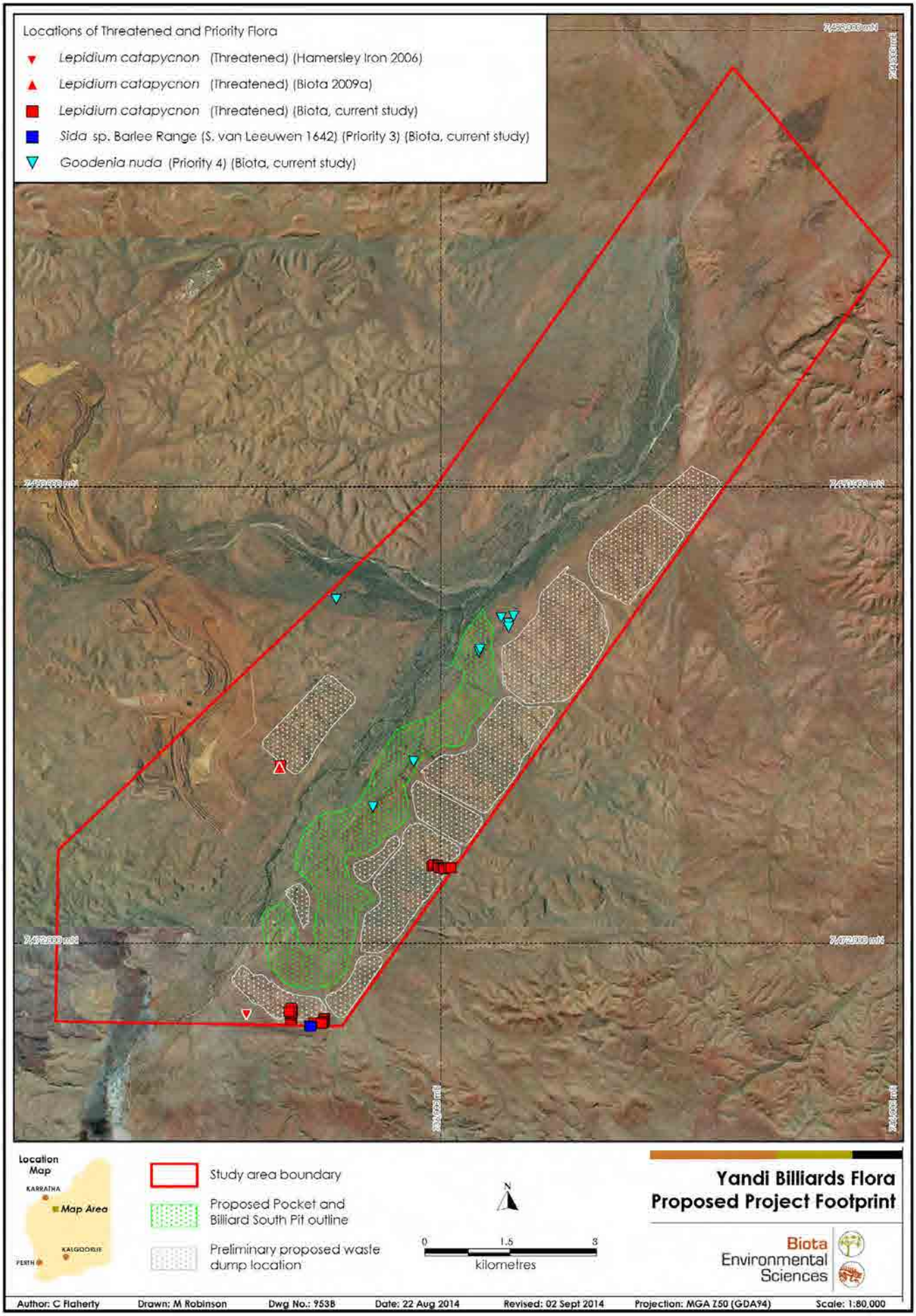

Figure 6.2: Locations of conservation significant flora in the study area shown with the proposed project footprint of the Pocket and Billiard South project.

6.5 Poorly Collected, Variable or Incompletely Resolved Taxa

Some apparent range extensions were recorded, which are considered likely to represent poorly collected taxa (*Euphorbia australis* var. *australis, Heliotropium glabellum* and *Peripleura hispidula* var. *hispidula*; see Appendix 10). In addition, some variable taxa that were distinguished with informal names in previous reporting are referred to as single entities sens. lat. ('in the broad sense') for this document (Appendix 10). One taxon recorded from the study area (*Portulaca oleracea/P. intraterranea*) has not been conclusively resolved due to a lack of taxonomic framework (see Appendix 10). None of these taxa are considered to be of conservation significance.

6.6 Introduced Flora (Weeds)

Eighteen introduced flora (weeds) have been recorded from the study area during the current and previous surveys at Yandi Billiards. Table 6.5 presents the number of records made for each weed species and the total number of locations from which each weed was recorded (the latter was to account for weeds being recorded multiple times at resampled quadrats). Weed locations are mapped and coordinates are provided in Appendix 5. Note that some of these locations have subsequently been cleared.

None of the weeds recorded are listed as Weeds of National Significance (Thorp and Lynch 2000)[10]. However, **Argemone ochroleuca* (Mexican Poppy) is listed under the WA *Biosecurity and Agriculture Management Act 2007 (BAM Act)* as a Declared Pest for the whole of WA in category C3 (management).

The draft Environmental Weed Strategy for WA developed by CALM (1999) ranked weed species according to their invasiveness, distribution and environmental impacts. Under this process **Aerva javanica*, **Acetosa vesicaria*, **Cenchrus ciliaris, *C. setiger, *Typha orientalis* and **Vachellia farnesiana* were ranked as weeds with High ecological impact, while **Datura leichhardtii, *Malvastrum americanum, *Sigesbeckia orientalis, *Sisymbrium orientale, *Solanum nigrum* and **Sonchus oleraceus* were ranked as Moderate. **Argemone ochroleuca* subsp. *ochroleuca* was ranked as Mild, and **Setaria verticillata* was ranked as Low. **Bidens bipinnata*, **Cucumis melo* subsp. *agrestis*, **Flaveria trinervia* and **Tribulus terrestris* were not rated.

DPaW currently applies an alternative ranking system to weed species within each management region, called the Weed Prioritisation Process (DPaW 2013a). None of the weed species recorded in the study area are ranked as Very High or High management priorities for the Pilbara region. However, it should be noted that for some species (e.g. **Cenchrus* spp.), this is a result of their low feasibility of control, rather than a reflection of their perceived invasiveness. **Acetosa vesicaria* is ranked by DPaW (2013a) as a Medium management priority, and all other species recorded in the study area are ranked as Low or Negligible.

[10] For the current listing of Weeds of National Significance, go to http://www.weeds.org.au/WoNS/

Table 6.5: Introduced species recorded from the study area.

Family	Species	Source and Number of Records								Total No. of Records	Total No. of Weed Locations
		Biota (2002)	Biota (2004a)	Biota (2004b)	Biota (2009b)	Biota (2014b)	Current study (Phase 1)	Current study (Phase 2)	Other		
Amaranthaceae	**Aerva javanica*				1	4	11	2		18	16
Asteraceae	**Bidens bipinnata*		1	3	4		16	1		25	20
	**Flaveria trinervia*		1	1	2		3			7	6
	**Sigesbeckia orientalis*			1			1			2	2
	**Sonchus oleraceus*			1	3	1				5	4
Brassicaceae	**Sisymbrium orientale*				1					1	1
Cucurbitaceae	**Cucumis melo* subsp. *agrestis*				1	2				3	3
Fabaceae	**Vachellia farnesiana*			1	1	2	3	1		8	5
Malvaceae	**Malvastrum americanum*		4	5	18	1	19	2	3	52	37
Papaveraceae	**Argemone ochroleuca* subsp. *ochroleuca*				4	1				5	4
Poaceae	**Cenchrus ciliaris*	2	6	6	36	15	88	21	16	190	150
	**Cenchrus setiger*	2		1	14	5	35	9		66	49
	**Setaria verticillata*	2	1	2	12	1	16	3		37	28
Polygonaceae	**Acetosa vesicaria*								3	3	3
Solanaceae	**Datura leichhardtii*		1	2						3	3
	**Solanum nigrum*				1					1	1
Typhaceae	**Typha orientalis*								3	3	3
Zygophyllaceae	**Tribulus terrestris*				1		9	1		11	10

Each weed species recorded in the study area is discussed briefly below:

- **Acetosa vesicaria* (Ruby Dock)
  Ruby Dock is a stout, fleshy-leaved and hollow-stemmed herb that grows up to 1 m in height and has red to pink fruit from winter to spring. It prefers sandy alluvial or ironstone soils and is commonly encountered on roadsides or in disturbed areas. It grows throughout WA with the exception of the Northern province (DPaW 2014c). This species was recorded from a creekline near the JSE mine pit by Pilbara Iron botanists (unpublished data). The remaining two records were made by GHD (2009); both of these locations have been subsequently cleared for the JSE mine footprint.

- **Aerva javanica* (Kapok)
  Kapok is a perennial herb to low shrub that typically grows up to 1.2 m tall, which has white woolly flowers from January to October (DPaW 2014c). Kapok is a widespread weed that occurs through the Pilbara and the Kimberley regions, and can form dense infestations. It is known from a variety of habitats including rocky outcrops, coastal areas, sand-dunes, creeklines and floodplains, along with disturbed areas (Hussey et al. 1997). This species reproduces by seed, which are only produced on the female plants. The small fruit are probably dispersed by animals and wind. They may also be spread by vehicles and in soil, as infestations often first appear along roadsides and near mine sites (The University of Queensland 2011). **Aerva javanica* was recorded from 16 locations in the study area, all from creekline or floodplain habitats.

- **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)
  This annual daisy grows to 1 m tall and has spiny leaves. The white to pale yellow flowers are produced in February to March or July to November, and the resulting seed pods contain vast quantities of very fine seed. This species is commonly found in sandy or clay loam substrates on riverbanks, creek edges or roadsides throughout WA (DPaW 2014c). Mexican Poppy is difficult to control as it produces large quantities of seed and flooding of its habitat can spread the

seed for large distances. This species was recorded from four locations in the study area, all from major creeklines (Weeli Wolli Creek and Marillana Creek).

- **Bidens bipinnata* (Bipinnate Beggartick)
  Bipinnate Beggartick is an annual daisy, which grows to 90 cm tall and produces yellow flowers between March and September (DPaW 2014c). This species is commonly observed in association with Mulga vegetation and creeklines in the Pilbara. **Bidens bipinnata* may occur in high densities within suitable habitats and given appropriate conditions, but on its own does not appear to cause exclusion of native flora species. **Bidens bipinnata* has been recorded from 20 locations in the study area. Large populations (comprising up to 8,000 individuals) were found in Mulga woodlands. Populations were also found in floodplains and minor creeklines.

- **Cenchrus ciliaris* (Buffel Grass)
  Buffel Grass is a perennial grass introduced by pastoralists as a fodder species. It typically grows on white, red or brown sand or stony red loam and can form dense tussock grasslands along creeklines, on floodplains and in sandy, coastal areas (DPaW 2014c). **Cenchrus ciliaris* grows to 1 m tall and flowers for most the year. This species has demonstrated allelopathic capacities, whereby it releases chemicals that inhibit the growth of other plants, and it competes aggressively and effectively with native flora species (Cheam 1984a, 1984b). It reproduces by seed and short rhizomes and is thought to be dispersed primarily by wind and water, but can also be spread through movement of mammals, birds and vehicles (DPaW 2014c). **Cenchrus ciliaris* was the most prolific weed in the study area; it was recorded from 150 locations in the study area and was the dominant grass in two of the vegetation types (C4 and F2; see Section 5.2). The predominant habitat for this species comprised the creeklines and floodplains of Weeli Wolli and Marillana Creeks, where it often formed a continuous tussock grass understorey (see Section 5.3), however it was also found in lower abundance on some of the plains of the study area.

- **Cenchrus setiger* (Birdwood Grass)
  Birdwood Grass is an erect, stoloniferous grass that forms tussocks to 80 cm tall, with a compact, spike inflorescence (DPaW 2014c). Originally a fodder plant, Birdwood Grass has become a serious weed of sand dunes, rangelands, plains, stony hillsides and floodplains from Geraldton to the Kimberley (Hussey et al. 1997). This species is less common than Buffel Grass but it is a similarly serious environmental weed and often infests the same riparian habitats. This species was recorded from 49 locations in the study area, from the same habitats as **C. ciliaris*.

- **Cucumis melo* subsp. *agrestis* (Ulcardo Melon)
  Ulcardo Melon is a trailing annual herb with bristly or softly hairy leaves and yellow flowers in autumn and spring (DPaW 2014c). The mature fruit are ellipsoid, 2-5 cm in length, green to yellow in colour, and become glabrescent with age (The Royal Botanic Gardens and Domain Trust 2014). Ulcardo Melon has been recorded from a variety of habitats including grasslands on cracking clays, *Eucalyptus*, *Corymbia*, *Acacia* or *Grevillea* grassy woodlands on clay flats, and damp areas (DPaW 2014c). This species was recorded from three locations in the study area, all of which were in creekline habitats.

- **Datura leichhardtii* (Native Thornapple)
  Native Thornapple is a stout annual herb that grows to 1 m tall. It has white flowers from June to October, followed by spiny fruits (DPaW 2014c). It is widespread through the Carnarvon, Gascoyne, Little Sandy Desert and Pilbara bioregions and is often located along watercourses and drainage areas (DPaW 2014c). This species was recorded three times in the study area, from a Mulga woodland, a minor creekline and a floodplain of Weeli Wolli Creek.

- **Flaveria trinervia* (Speedy Weed)
  Speedy Weed is an annual daisy, with an inflorescence consisting of a large dense cluster of yellowish flower heads. This species is common and widespread in various habitats with sandy or loamy soils throughout the north of Western Australia, from approximately Carnarvon through to the Kimberley (DPaW 2014c). This species has been recorded from six locations along Weeli Wolli Creek.

- **Malvastrum americanum* (Spiked Malvastrum)
  Spiked Malvastrum typically occurs in Mulga vegetation, drainage lines and on floodplains, and can also be recorded on steep hill slopes and on rockpiles. It is an erect, perennial herb or

shrub to 1.3 m tall, with yellow or orange flowers from April to July (DPaW 2014c). This species has been recorded from 37 locations in the study area. It was found in Mulga woodlands, minor creeklines, and on the floodplains of Weeli Wolli and Marillana Creeks.

- **Setaria verticillata* (Whorled Pigeon Grass)
  Whorled Pigeon Grass is a loosely tufted annual grass that grows to 1.3 m tall (DPaW 2014c). This species commonly occurs in disturbed areas, on the edges of rivers and creeks and in shrublands from the Kimberley to the Pilbara (Hussey et al. 1997). Whorled Pigeon Grass has been recorded from 28 locations in the study area, most of which were associated with creeklines or floodplains.

- **Sigesbeckia orientalis* (Indian Weed)
  Indian Weed is a slender, annual herb that grows to 1 m tall and has yellow flowers all year round. It is typically found growing in loamy soils in rocky gullies, limestone ranges and creek beds (DPaW 2014c). It was recorded twice in the study area, once from a Mulga woodland and once from a floodplain of Weeli Wolli Creek.

- **Sisymbrium orientale* (Indian Hedge Mustard)
  Indian Hedge Mustard is an annual or biennial herb occurring in disturbed areas of the Eremaean and South-West provinces. It grows up to 1 m tall and has yellow flowers from autumn to spring (DPaW 2014c). This species has been recorded from a single location in Weeli Wolli Creek.

- **Solanum nigrum* (Black Berry Nightshade)
  This perennial herb or short-lived shrub grows to 1 m tall and has white flowers all year. It is distributed across most of WA from the south to the north, with the exception of the central portion (DPaW 2014c). This species has been recorded from a single location in Weeli Wolli Creek.

- **Sonchus oleraceus* (Common Sowthistle)
  Common Sowthistle is a short-lived annual herb that grows to 1.5 m tall (DPaW 2014c). This species is common and widespread in disturbed areas of WA from Wittenoom to the Nullarbor (Hussey et al. 1997). This species has been recorded from four locations in the study area on the banks and in the bed of Weeli Wolli Creek.

- **Tribulus terrestris* (Caltrop)
  Caltrop is a prostrate vine with greyish pinnate leaves and small yellow flowers. It is a widespread weed that prefers sandy soils and occurs across most of WA (DPaW 2014c). This species was recorded from 10 locations in the study area. It was found in a variety of habitats including plains, floodplains, Mulga woodlands and minor creeklines.

- **Typha orientalis* (Bulrush)
  Bulrush is a rhizomatous emergent perennial herb with brown flower spikes, which can grow to 4.5 m tall (DPaW 2014c). **Typha orientalis* is known from the southwest of WA, where it grows in winter-wet depressions, permanent wetland and irrigation channels (DPaW 2014c). There are currently no vouchered specimens of this species from the Pilbara region, however a native Bulrush species (*Typha domingensis*) that is similar in appearance is widespread. **Typha orientalis* was recorded from three locations in the study area during a weed survey by GHD (2009): two of these locations have subsequently been cleared for the JSE mine footprint, while the remaining record is located on Weeli Wolli Creek, in the south of the study area adjacent to the JSE mine. The location of the remaining **T. orientalis* record was checked during the Phase 2 survey, and while *T. domingensis* was found at this location, no **T. orientalis* was located. *Typha domingensis* has been recorded several times from Weeli Wolli Creek in the study area, and it is possible that the records of **T. orientalis* from GHD (2009) represent this taxon.

- **Vachellia farnesiana* (Mimosa Bush)
  Mimosa Bush is a spreading, thorny shrub to 4 m tall, with dark grey bark, pinnate leaves, and yellow flowers in winter. It typically grows in stony sand, clay or loam soils, or gravel (DPaW 2014c). This species is widespread from the Kimberley to near Perth, typically occurring along drainage systems and in adjacent low-lying areas (Hussey et al. 1997). Mimosa Bush has been recorded from five locations in the study area, predominantly on floodplains.

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7.0 Key Findings

Key findings of this study are as follows:

- Twenty-three vegetation types have been described and mapped for the study area, none of which represent TECs or PECs (Section 5.0, Appendix 4). This number of units is considered to be within the range expected for a study area of this size in this locality, taking into account the habitats present.
- One ecosystem at risk is present in the study area: vegetation type C1 occurs along Marillana and Weeli Wolli Creeks and would represent a "major ephemeral water course" as described by Kendrick (2003a). Two additional vegetation types (C2 and C3) comprise riparian vegetation along the same major creeklines, however these units do not support dense Eucalypt forests nor obligate phreatophytic species (see Section 5.5.2). The presence of weeds (usually only as scattered individuals) and disturbance from cattle have been noted in these vegetation types, and they are mostly in Very Good to Good condition. Similar vegetation assemblages are widespread through the Pilbara in various major creek systems, and these vegetation types would therefore be of significance at the local, rather than regional, scale.
- A total of 5.7% of the study area was mapped as Disturbed or Completely Degraded. These areas consisted of cleared areas associated with the mining footprint, roads or drill lines. Fourteen quadrats that had been previously sampled in the study area have since been cleared (Section 5.3, Appendix 4).
- The condition of the remaining intact vegetation of the study area ranged from Excellent to Very Poor (Section 5.3, Appendix 5). The main disturbance factors noted were weeds and disturbance from cattle. **Cenchrus ciliaris* (Buffel Grass) was the most prolific weed in the study area and often formed dense populations in the understorey in some creekline and floodplain vegetation types (particularly C4 and F2, where it was a dominant species in the vegetation description).
- A total of 455 native vascular flora species were recorded from the study area. The total number of species recorded is high, but within the range expected for a study area of this size in this locality (Section 6.0).
- Three conservation significant flora species were recorded from the study area during the field survey; *Lepidium catapycnon* (Threatened), *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) and *Goodenia nuda* (Priority 4).
    - *Lepidium catapycnon* is now known from four populations in the study area. This species was recorded from 26 locations comprising three distinct populations in 2014; two new populations (Populations 3 and 4), and an existing population (Population 1) originally located by Biota (2009a). The location of Population 2, which was originally recorded by Hamersley Iron (2006), was searched in 2014 but no plants were found.

      A total of 777 individuals were counted in the study area in 2014. Some 171 individuals in Population 1 that were previously recorded by Biota (2009a) were no longer present, and no plants were found in Population 2.

      Of the four populations known from the study area, two (Populations 3 and 4) are partly located within preliminary proposed waste dump locations (Section 6.4.1; Figure 6.2). A total of 389 individuals (173 individuals in Population 3 and 216 individuals in Population 4) are located within the proposed clearing areas, comprising 50% of the total number of individuals recorded in 2014. While this is a relatively high proportion of the total population identified in the study area, there are a large number of records of this species from the broader locality, and some of these populations comprise hundreds to over a thousand individuals. If the preliminary proposed waste dump locations cannot be modified to reduce the number of individuals affected, clearing of the 389 individuals currently within the works area would be unlikely to affect the conservation status of this species. It should be noted that this species has been under consideration for downgrading to a Priority species since prior to 2011.

Additional suitable habitat for *Lepidium catapycnon* occurs in the study area, not all of which has been searched. All hills and slopes of the study area (vegetation types H1, H2, H3, H4 and H5; see Appendix 4) could comprise suitable habitat for *L. catapycnon*, especially areas that have been burnt recently or have rocky ironstone shale slopes, however vegetation type H1 remains the most prospective unit for this species (see Section 6.4.1). While it is possible that additional populations of *Lepidium catapycnon* occur in the study area, there is a low likelihood of new populations being located in areas where targeted searches have been undertaken (Appendix 7 shows foot traverses in the study area).

- The Priority 3 *Sida* sp. Barlee Range (S. van Leeuwen 1642) was recorded from a free face supporting vegetation type H5 at two locations in close proximity. Three individuals were recorded from the southern boundary of the study area and two individuals were recorded approximately 10 m south of the study area. Both of these records occurred outside the proposed project footprint.
- The Priority 4 *Goodenia nuda* was recorded from nine locations within vegetation types P6, P2 and P3, comprising a total of 76 individuals. Four of these records (totalling 37 individuals) occur within the footprint of the proposed Pocket and Billiards South pit. Given that suitable habitat is present and that *Goodenia nuda* is a small herb, additional populations of this species may occur in the study area.

- While no individuals have been recorded to date, three other Priority species may potentially occur in the study area: *Stylidium weeliwolli* (Priority 2) may potentially occur in the bed of Weeli Wolli or Marillana Creeks; *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) may occur along the floodplains of these creek systems; and *Rostellularia adscendens* var. *latifolia* (Priority 3) may potentially occur in creekline or floodplain habitat (Section 6.4.2).
- Eighteen weed species have been recorded in the study area; with the exception of **Typha orientalis*, all of these are commonly encountered in the locality (Section 6.6). **Argemone ochroleuca* (Mexican Poppy) is listed under the WA *BAM Act 2007* as a Declared Pest for the whole of WA, while **Aerva javanica*, **Acetosa vesicaria*, **Cenchrus ciliaris*, **C. setiger* and **Vachellia farnesiana* are ranked by DPaW as weeds with High ecological impact (CALM 1999). None of the weed species encountered were ranked as a Very High or High priority for management under the Weed Prioritisation Process for the Pilbara region (DPaW 2013b).

8.0 Glossary

*	Used prior to a species name to denote a weed species.
Alluvial	Loose, unconsolidated (not cemented together into a solid rock) soil or sediments, which have been eroded, reshaped by water in some form, and redeposited in a non-marine setting.
Anabranching	An anabranching river consists of multiple channels separated by vegetated (sometimes semi permanent) alluvial islands.
Annual (plant)	A plant that lives for only one year.
BAM Act 2007	The WA *Biosecurity and Agriculture Management Act 2007.*
Conservation Significant	A plant that is recognised to be rare, unusual, new or poorly sampled; may have a formally assigned conservation ranking (see Appendix 1 for more on the WA conservation framework).
Culm	The stem of a grass or sedge.
DPaW	WA Department of Parks and Wildlife (formerly the Department of Environment and Conservation (DEC)).
EPA	Environmental Protection Authority of Western Australia.
EPBC Act 1999	The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*
Ephemeral	A plant that lives a very short time; less than one year, usually less than six months.
Floodout	An area of land, usually adjacent to a river or major drainage system, that receives water during periods of overbank flow associated with normal or extreme flood events. Can be situated at the end of the drainage line.
Flora keys	Botanical publications containing a series of questions regarding the characteristics of plants, aiding in the identification of different taxa.
Foot Traverse	Consists of walking through an area to confirm or note vegetation boundaries or to search for flora (usually sampling a narrow corridor/cross section of vegetation).
Free face	A vertical or near vertical landform element situated part way up a slope but not comprising the entire slope.
GIS	Geographic Information System.
IBRA	Interim Biogeographic Regionalisation for Australia.
NRS	National Reserve System.
NVCP	Native Vegetation Clearing Permit.
Opportunistic	A plant or animal species collected or recorded outside a formal sampling site (e.g. flora quadrats or relevés, or fauna trapping sites). Opportunistic collections are usually made during foot traverses and when travelling between sites.
PEC	Priority Ecological Community (see Appendix 1 for more on the WA conservation framework).
Perennial	A plant that lives for more than two growing seasons.
Priority flora	Flora species listed by DPaW as requiring additional information to properly evaluate their conservation significance; see Appendix 1 for more on the WA conservation framework.
sens. lat.	Abbreviation of *sensu lato* (Latin), meaning “in the broad sense”.
Stratum (plural: strata)	A horizontal level of vegetation defined by growth habit (and sometimes height); e.g. low trees, tall trees, tussock grasses, hummock grasses.
subsp.	Abbreviation of “subspecies.

Taxon (plural: taxa)	A taxonomic entity, typically at species level or below.
TEC	Threatened Ecological Community (see Appendix 1 for more on the WA conservation framework).
Threatened flora	Flora species protected by legislation, either listed under the Commonwealth *EPBC Act 1999* or the WA *Wildlife Conservation Act 1950* (flora species formerly known as Declared Rare Flora); see Appendix 1 for more on the WA conservation framework.
var.	Abbreviation of variety.

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Appendix 1

Framework for Conservation Significance Ranking of Communities and Species in WA

A. Definitions, Categories and Criteria for Threatened and Priority Ecological Communities

1. General Definitions

Ecological Community
A naturally occurring biological assemblage that occurs in a particular type of habitat.

Note: The scale at which ecological communities are defined will often depend on the level of detail in the information source, therefore no particular scale is specified.

A threatened ecological community (TEC) is one which is found to fit into one of the following categories; "presumed totally destroyed", "critically endangered", "endangered" or "vulnerable".

Possible threatened ecological communities that do not meet survey criteria are added to DPaW's Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

An assemblage is a defined group of biological entities.

Habitat is defined as the areas in which an organism and/or assemblage of organisms lives. It includes the abiotic factors (eg. substrate and topography), and the biotic factors.

Occurrence: a discrete example of an ecological community, separated from other examples of the same community by more than 20 metres of a different ecological community, an artificial surface or a totally destroyed community.

By ensuring that every discrete occurrence is recognised and recorded future changes in status can be readily monitored.

Adequately Surveyed is defined as follows:
"An ecological community that has been searched for thoroughly in most likely habitats, by relevant experts."

Community structure is defined as follows:
"The spatial organisation, construction and arrangement of the biological elements comprising a biological assemblage" (eg. Eucalyptus salmonophloia woodland over scattered small shrubs over dense herbs; structure in a faunal assemblage could refer to trophic structure, eg. dominance by feeders on detritus as distinct from feeders on live plants).

Definitions of Modification and Destruction of an ecological community:

Modification: "changes to some or all of ecological processes (including abiotic processes such as hydrology), species composition and community structure as a direct or indirect result of human activities. The level of damage involved could be ameliorated naturally or by human intervention."

Destruction: "modification such that reestablishment of ecological processes, species composition and community structure within the range of variability exhibited by the original community is unlikely within the foreseeable future even with positive human intervention."

Note: Modification and destruction are difficult concepts to quantify, and their application will be determined by scientific judgement. Examples of modification and total destruction are cited below:

Modification of ecological processes: The hydrology of Toolibin Lake has been altered by clearing of the catchment such that death of some of the original flora has occurred due to dependence on fresh water. The system may be bought back to a semblance of the original state by redirecting saline runoff and pumping waters of the rising underground watertable away to restore the hydrological balance. Total destruction of downstream lakes has occurred due to hydrology being altered to the point that few of the original flora or fauna species are able to tolerate the level of salinity and/or water logging.

Modification of structure: The understorey of a plant community may be altered by weed invasion due to nutrient enrichment by addition of fertiliser. Should the additional nutrients be removed from the system the balance may be restored, and the original plant species better able to compete. Total destruction may occur if additional nutrients continue to be added to the system causing the understorey to be completely replaced by weed species, and death of overstorey species due to inability to tolerate high nutrient levels.

Modification of species composition: Pollution may cause alteration of the invertebrate species present in a freshwater lake. Removal of pollutants may allow the return of the original inhabitant species. Addition of residual highly toxic substances may cause permanent changes to water quality, and total destruction of the community.

Threatening processes are defined as follows:
"Any process or activity that threatens to destroy or significantly modify the ecological community and/or affect the continuing evolutionary processes within any ecological community."

Examples of some of the continuing threatening processes in Western Australia include: general pollution; competition, predation and change induced in ecological communities as a result of introduced animals; competition and displacement of native plants by introduced species; hydrological changes; inappropriate fire regimes; diseases resulting from introduced micro-organisms; direct human exploitation and disturbance of ecological communities.

Restoration is defined as returning an ecological community to its pre-disturbance or natural state in terms of abiotic conditions, community structure and species composition.

Rehabilitation is defined as the re-establishment of ecological attributes in a damaged ecological community although the community will remain modified.

2. Definitions and Criteria for Presumed Totally Destroyed, Critically Endangered, Endangered and Vulnerable Ecological Communities

ECOLOGICAL COMMUNITIES

Presumed Totally Destroyed (PD)
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future.

An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant and either of the following applies (A or B):

A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats or

B) All occurrences recorded within the last 50 years have since been destroyed

Critically Endangered (CR)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated.

An ecological community will be listed as Critically Endangered when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting any one or more of the following criteria (A, B or C):

A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% and either or both of the following apply (i or ii):

   i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years);

   ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated.

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

   i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years);

ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes;

iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes.

C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

Endangered (EN)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as Endangered when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement and either or both of the following apply (i or ii):

i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

Vulnerable (VU)
An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as Vulnerable when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

3. Definitions and Criteria for Priority Ecological Communities

PRIORITY ECOLOGICAL COMMUNITY LIST
Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. These three categories are ranked in order of priority for survey and/or definition of the community, and evaluation of conservation status, so that consideration can be given to their declaration as threatened ecological communities. Ecological Communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Priority One: Poorly-known ecological communities
Ecological communities with apparently few, small occurrences, all or most not actively managed for conservation (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) and for which current threats exist. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.

Priority Two: Poorly-known ecological communities
Communities that are known from few small occurrences, all or most of which are actively managed for conservation (e.g. within national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc.) and not under imminent threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.

Priority Three: Poorly known ecological communities

(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or:

(ii) communities known from a few widespread occurrences, which are either large or within significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or;

(iii) communities made up of large, and/or widespread occurrences, that may or not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes.

Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.

Priority Four: Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring.

(a) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands.

(b) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.

(c) Ecological communities that have been removed from the list of threatened communities during the past five years.

Priority Five: Conservation Dependent ecological communities
Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Department of Parks and Wildlife

CONSERVATION CODES

for Western Australian Flora and Fauna

T: **Threatened species -** Specially protected under the *Wildlife Conservation Act 1950*, listed under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.

X: **Presumed extinct species -** Specially protected under the *Wildlife Conservation Act 1950*, listed under Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and there is no reasonable doubt that the last individual has died, and have been gazetted as such.

IA: **Migratory birds protected under an international agreement -** Specially protected under the *Wildlife Conservation Act 1950*, listed under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Birds that are subject to an agreement between governments of Australia and Japan, China and The Republic of Korea relating to the protection of migratory birds and birds in danger of extinction.

S: **Other specially protected fauna -** Specially protected under the *Wildlife Conservation Act 1950*, listed under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Threatened Fauna and Flora are further recognised by the Department according to their level of threat using IUCN Red List criteria. For example Carnaby's Cockatoo *Calyptorynchus latirostris* is specially protected under the *Wildlife Conservation Act 1950* as a threatened species with a ranking of endangered.

Ranking:

CR: Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.

EN: Endangered – considered to be facing a very high risk of extinction in the wild.

VU: Vulnerable - considered to be facing a high risk of extinction in the wild.

A list of the current rankings can be downloaded from the Listing of species and ecological communities webpage http://dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/84-listing-of-species-and-ecological-communities .

Species that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Species that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Conservation Dependent species are placed in Priority 5.

1: Priority One: Poorly-known species

Species that are known from one or a few collections or sight records (generally less than five), all on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, Shire, rail reserves and Main Roads WA road, gravel and soil reserves, and active mineral leases and under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes.

2: Priority Two: Poorly-known species

Species that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes.

3: Priority Three: Poorly-known species

Species that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them.

4: Priority Four: Rare, Near Threatened and other species in need of monitoring

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.
(b) Near Threatened. Species that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.
(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

5: Priority Five: Conservation Dependent species

Species that are not threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

*Species includes all taxa (plural of taxon - a classificatory group of any taxonomic rank, e.g. a family, genus, species or any infraspecific category i.e. subspecies, variety or forma).

Appendix 2

Results of the Flora Desktop Review: Summary of Conservation Significant Flora Species Recorded within 25 km of the Study Area

Species	Habit and Habitat Preference (DPaW 2014c)														Likelihood of Occurrence in the Study Area	
		Nature Map	Mattiske (1995a)	Mattiske (1995b)	Biota (2000)	HGM (2000)	Biota (2002)	Biota (2004a)	Biota (2004b)	Biota (2009a)	Biota (2009b)	Biota (2010)	Biota (2014b)	Biota (2014c)	Initial Ranking Based on Desktop Review	Final Ranking Including Results of Field Survey
Threatened																
Lepidium catapycnon	Low shrub on stony scree slopes	✓								✓					Recorded: two populations.	Recorded: four populations now known.
Priority 1																
Brunonia sp. Long hairs (D.E. Symon 2440)	Erect herb along creeklines	✓													Unlikely to occur: creeklines within the study area may provide suitable habitat, however this species has not been recorded by previous surveys around Yandi.	Unlikely to occur.
Priority 2																
Indigofera ixocarpa	Shrub on skeletal red soils on ironstone hill slopes						✓								Unlikely to occur; rocky slopes within the study area may provide suitable habitat, however this species has not previously been recorded by other surveys close to the study area.	Unlikely to occur.
Stylidium weeliwolli	Annual herb on major watercourses	✓		✓											May potentially occur; the sections of Weeli Wolli Creek and Marillana Creek within the study area may provide suitable habitat.	May potentially occur.
Priority 3																
Acacia subtiliformis	Slender, spindly, erect shrub; Stony calcrete plains	✓													Would not occur; no suitable calcrete habitat in the study area.	Would not occur.
Fimbristylis sieberiana	Shortly rhizomatous, tufted perennial sedge near permanent pools	✓													Unlikely to occur: the sections of Weeli Wolli Creek and Marillana Creek within the study area may provide suitable habitat, however this species has not been recorded by previous surveys close to the study area. There are records from approximately 5-6 km upstream in Weeli Wolli Creek, but these are from the permanently wet areas associated with Weeli Wolli Springs.	Unlikely to occur.

Species	Habit and Habitat Preference (DPaW 2014c)														Likelihood of Occurrence in the Study Area	
		Nature Map	Mattiske (1995a)	Mattiske (1995b)	Biota (2000)	HGM (2000)	Biota (2002)	Biota (2004a)	Biota (2004b)	Biota (2009a)	Biota (2009b)	Biota (2010)	Biota (2014b)	Biota (2014c)	Initial Ranking Based on Desktop Review	Final Ranking Including Results of Field Survey
Goodenia sp. East Pilbara (A.A. Mitchell PRP 727)	Annual to biennial herb; Low undulating plains, typically on calcrete	✓							✓						Would not occur; no suitable calcrete habitat in the study area.	Would not occur.
Gymnanthera cunninghamii	Erect woody shrub; In sandy soils surrounding permanent or semi-permanent watercourses	✓					✓								Unlikely to occur; creeklines within the study area provide suitable habitat, however this species has not previously been recorded by other surveys close to the study area.	Unlikely to occur.
Rhagodia sp. Hamersley (M. Trudgen 17794)	Shrub; Under Mulga		✓	✓											Unlikely to occur; there is only a minimal amount of Mulga shrublands in the study area.	Unlikely to occur.
Rostellularia adscendens var. *latifolia*	Herb or shrub; Creeks, rocky hills				✓									✓	May potentially occur; there is suitable habitat in the study area.	May potentially occur.
Sida sp. Barlee Range (S. van Leeuwen 1642)	Low spreading shrub; Skeletal soils on steep slopes							✓							May potentially occur; there are some areas of rocky slopes in the study area that may provide suitable habitat.	Recorded during the field survey from two locations along a rocky free face of a ridgeline.
Themeda sp. Hamersley Station (M.E. Trudgen 11431)	Annual tussock grass; Clay pan, grass plain	✓			✓		✓	✓							May potentially occur; creeklines and adjacent plains within the study area may provide suitable habitat.	May potentially occur.
Priority 4																
Goodenia nuda	Herb; Drainage areas or floodplains on clay loam to clay	✓			✓		✓					✓	✓	✓	Likely to occur; creeklines and plains within the study area would provide suitable habitat.	Recorded during the field survey from several locations in Mulga woodland and on the floodplains of Weeli Wolli Creek and Marillana Creek.

Species	Habit and Habitat Preference (DPaW 2014c)														Likelihood of Occurrence in the Study Area	
		Nature Map	Mattiske (1995a)	Mattiske (1995b)	Biota (2000)	HGM (2000)	Biota (2002)	Biota (2004a)	Biota (2004b)	Biota (2009a)	Biota (2009b)	Biota (2010)	Biota (2014b)	Biota (2014c)	Initial Ranking Based on Desktop Review	Final Ranking Including Results of Field Survey
Species of Interest																
Eulalia sp. (Three Rivers Station, B. Forsyth AQ6789133)	Perennial tussock grass; Creeks and riverbeds												✓		Likely to occur; this species has been recorded from a plain adjacent to Marillana Creek, upstream of the study area. The creeklines and adjacent plains in the study area would provide suitable habitat.	Recorded during the field survey from three locations.
Glycine sp. aff. *arenaria*	Creeper; Creeks and riverbeds													✓	May potentially occur; this species has been recorded in Marillana Creek, upstream of the study area.	May potentially occur.

Vegetation Structural Classes and Condition Scale

Vegetation Structural Classes*

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970): Aplin T.E.H. (1979). The Flora. Chapter 3 In O'Brien, B.J. (ed.) (1979). *Environment and Science*. University of Western Australia Press; Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum*, Suppl. No. 3; Specht R.L. (1970). Vegetation. In: *The Australian Environment*. 4th edn (Ed. G.W. Leeper). Melbourne.

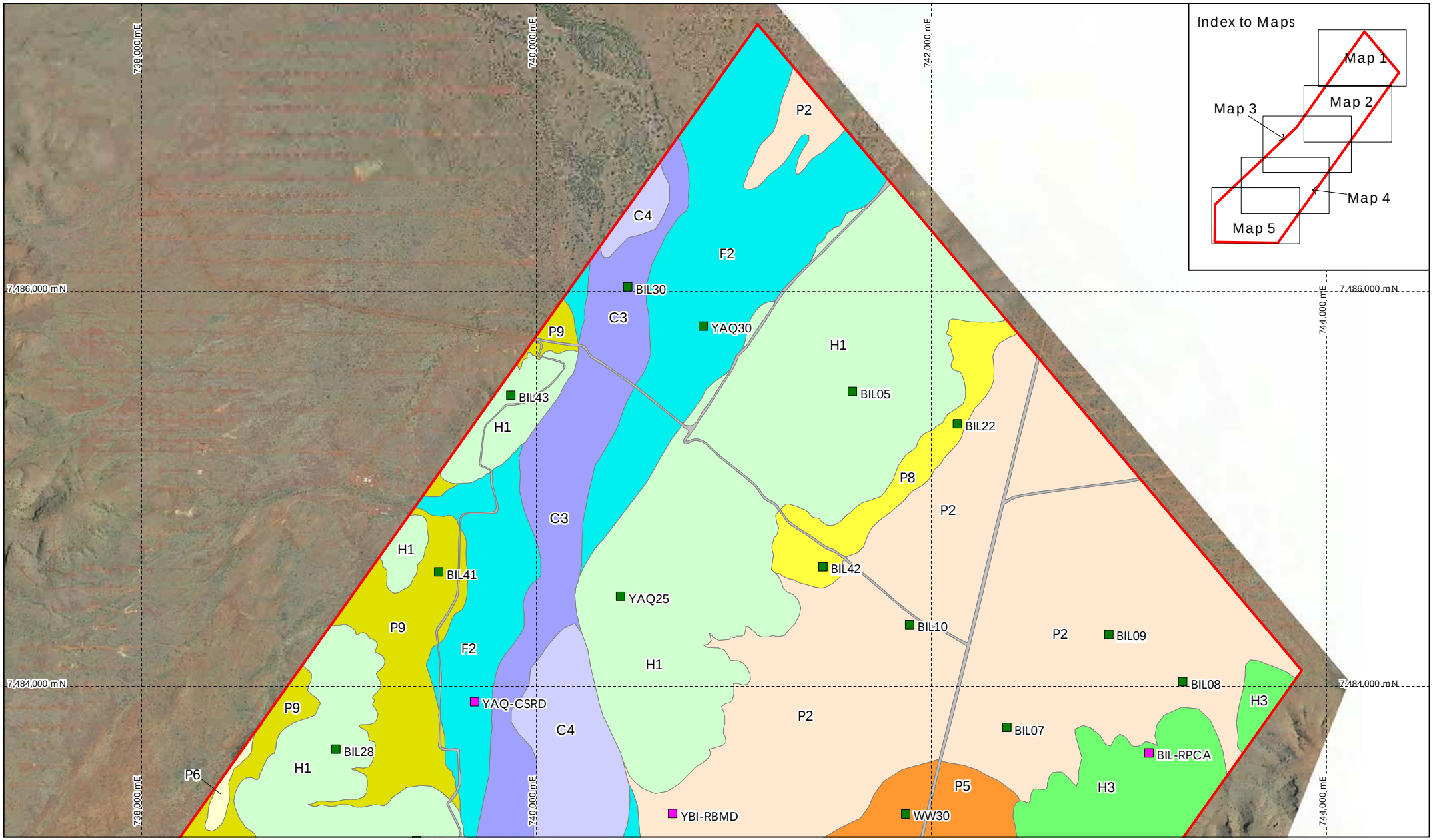
Vegetation Condition Scale for use on Pilbara surveys*

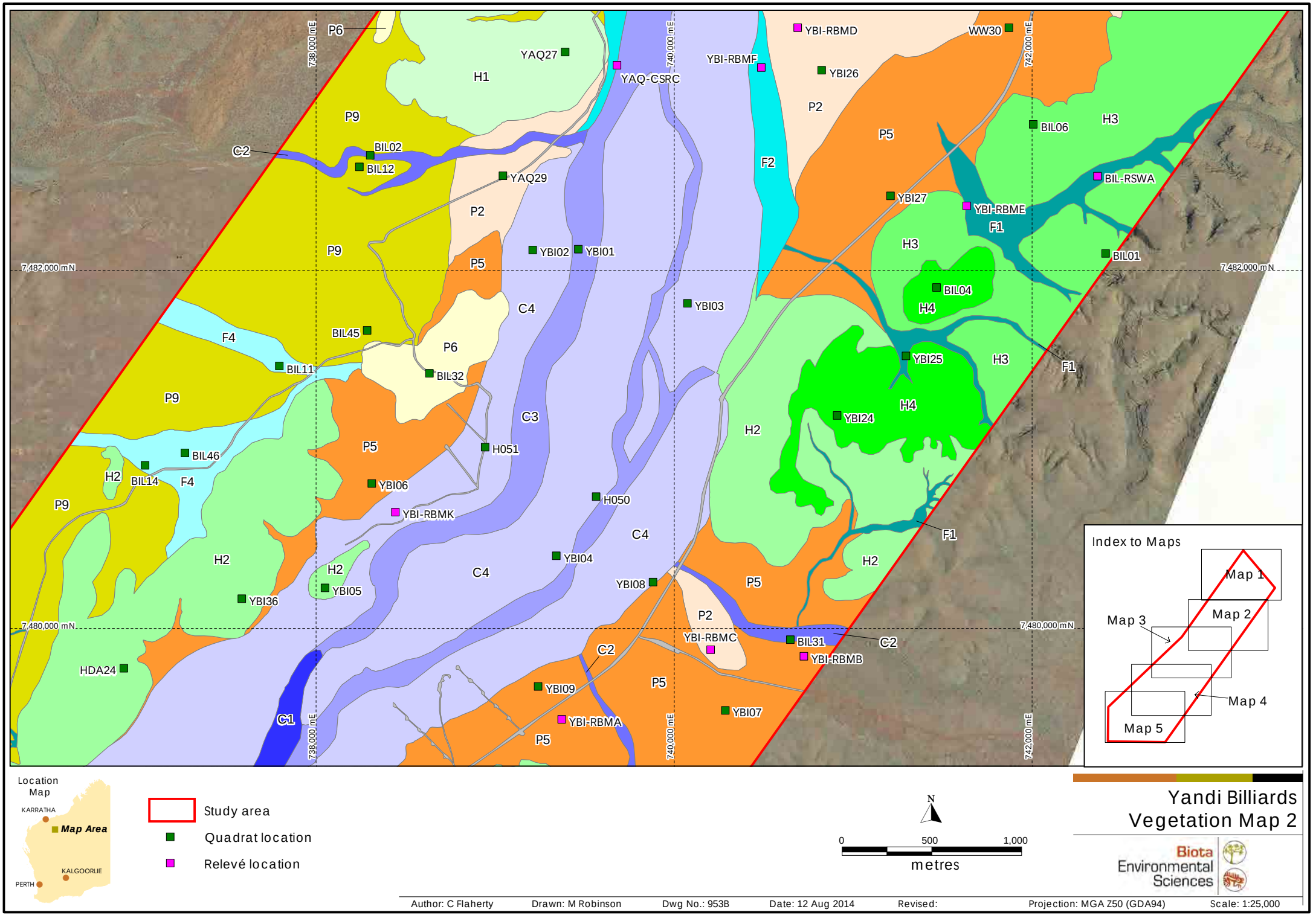
E = Excellent (=Pristine of BushForever) Pristine or nearly so; no obvious signs of damage caused by the activities of European man.
VG = Very Good (= Excellent of BushForever) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Ursinia anthemoides* or **Briza* spp., or occasional vehicle tracks.
G = Good (= Very Good of BushForever) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Ehrharta* spp.
P = Poor (= Good of BushForever) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Ehrharta* spp.
VP = Very Poor (= Degraded of BushForever) Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species.
D = Completely Degraded (= Completely Degraded of BushForever) Areas that are completely or almost completely without native species in the structure of their vegetation; ie. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 4

Vegetation Mapping and Locations of Conservation Significant Flora


Index to Maps
Map 1
Map 2
Map 3
Map 4
Map 5
738,000 mE
740,000 mE
742,000 mE
744,000 mE
7,486,000 mN
7,484,000 mN
C4
F2
P2
BIL30
C3
YAQ30
P9
H1
BIL43
BIL05
BIL22
P8
P2
C3
H1
BIL41
BIL42
YAQ25
BIL10
P9
F2
P2
BIL09
H1
BIL08
H3
YAQ-CSRD
P9
C4
P2
BIL07
BIL28
BIL-RPCA
H1
P6
P5
H3
YBI-RBMD
WW30
Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Study area
Quadrat location
Relevé location
N
0
500
1,000
metres
Yandi Billiards
Vegetation Map 1
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 12 Aug 2014
Revised:
Projection: MGA Z50 (GDA94)
Scale: 1:25,000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P6
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H1
YAQ-CSRC
YBI-RBMF
YBI-RBMD
WW30
YBI26
P2
P5
BIL06
H3
F2
BIL-RSWA
YBI27
YBI-RBME
F1
P9
C2
BIL02
BIL12
YAQ29
P2
YBI02
YBI01
P5
C4
YBI03
BIL01
BIL04
H4
BIL45
F4
P6
BIL11
BIL32
YBI25
H3
F1
P9
C3
H4
YBI24
H2
P5
H051
BIL46
H2
BIL14
F4
YBI06
H050
P9
YBI-RBMK
C4
F1
H2
YBI04
H2
H2
C4
YBI08
YBI05
P5
YBI36
P2
YBI-RBMC
BIL31
C2
C2
YBI-RBMB
HDA24
P5
YBI09
YBI07
C1
YBI-RBMA
P5
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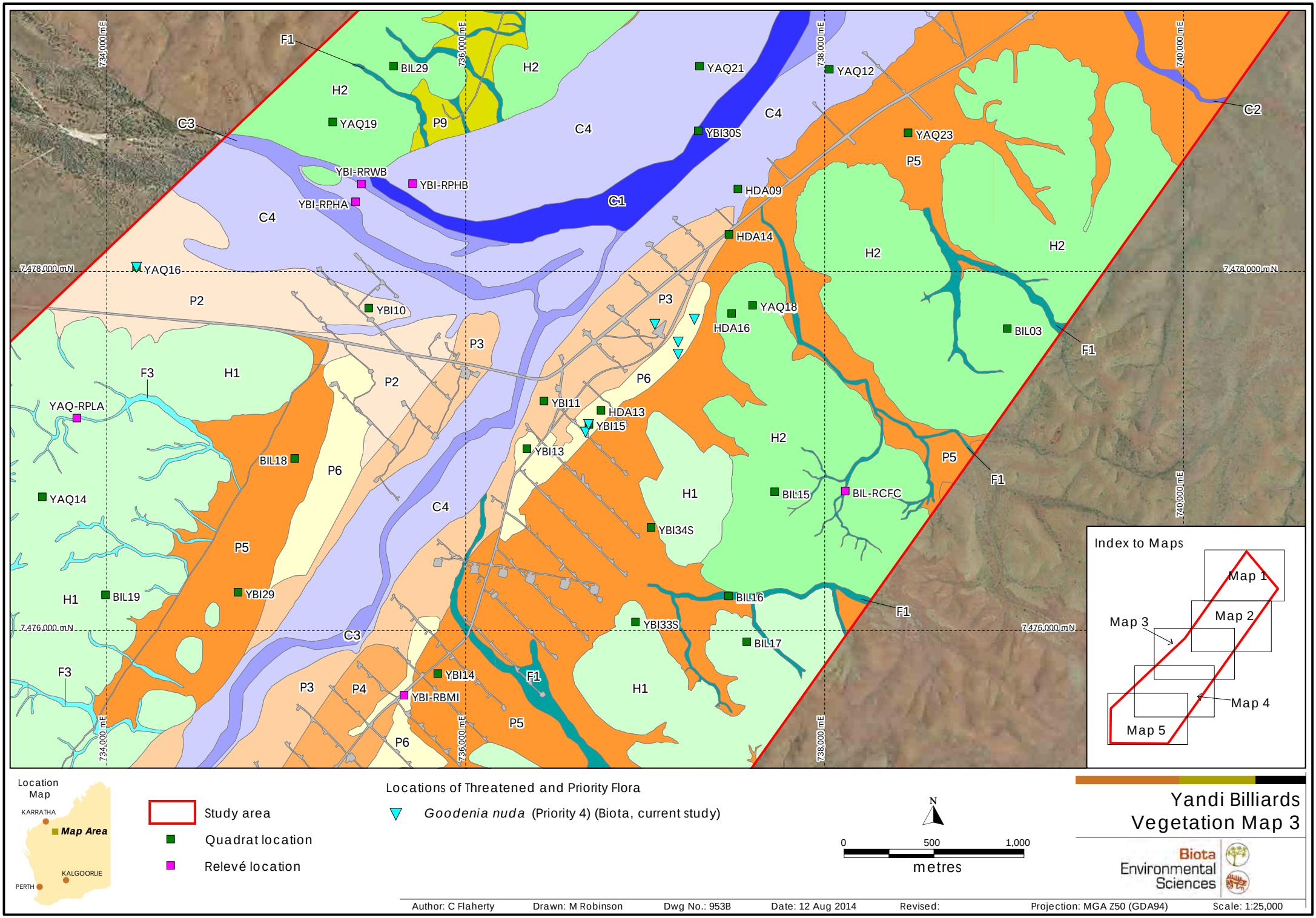
Map 4
Map 5
Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Study area
Quadrat location
Relevé location
N
0
500
1,000
metres
Yandi Billiards
Vegetation Map 2
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 12 Aug 2014
Revised:
Projection: MGA Z50 (GDA94)
Scale: 1:25,000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7,476,000 mN
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F3
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C3
C4
H1
H2
P2
P3
P4
P5
P6
P9
BIL29
YAQ19
YAQ21
YAQ12
YBI30S
YAQ23
HDA09
HDA14
YBI-RRWB
YBI-RPHB
YBI-RPHA
YAQ16
YBI10
YAQ18
HDA16
BIL03
YAQ-RPLA
YBI11
HDA13
YBI15
YBI13
BIL18
YAQ14
BIL15
BIL-RCFC
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YBI29
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YBI33S
BIL17
YBI14
YBI-RBMI
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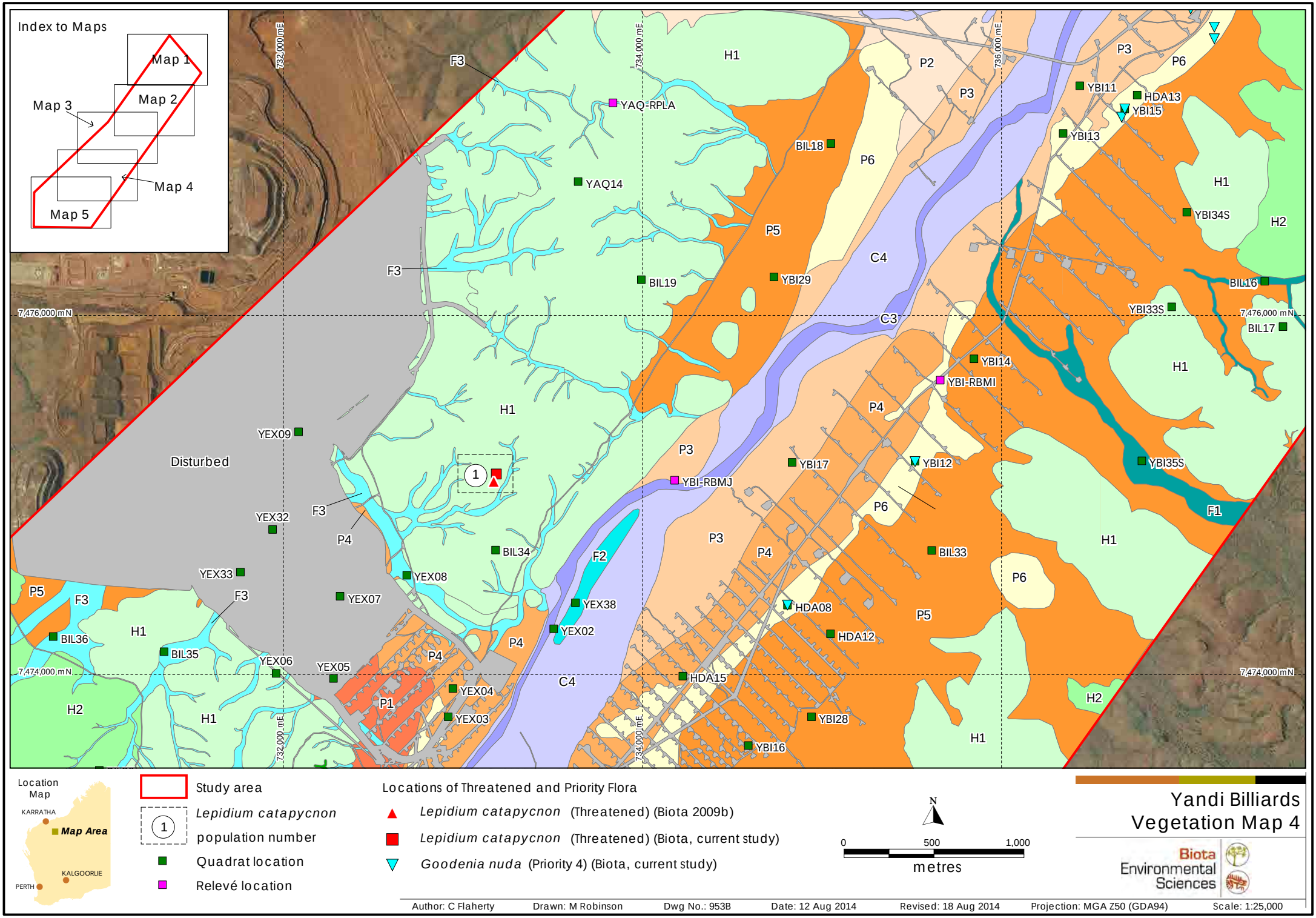
Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Study area
Quadrat location
Relevé location
Locations of Threatened and Priority Flora
Goodenia nuda (Priority 4) (Biota, current study)
N
0
500
1,000
metres
Yandi Billiards
Vegetation Map 3
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 12 Aug 2014
Revised:
Projection: MGA Z50 (GDA94)
Scale: 1:25,000



Location Map

Study area

1 *Lepidium catapycnon* population number

Quadrat location

Relevé location

Locations of Threatened and Priority Flora

▲ *Lepidium catapycnon* (Threatened) (Biota 2009b)

■ *Lepidium catapycnon* (Threatened) (Biota, current study)

▽ *Goodenia nuda* (Priority 4) (Biota, current study)

N

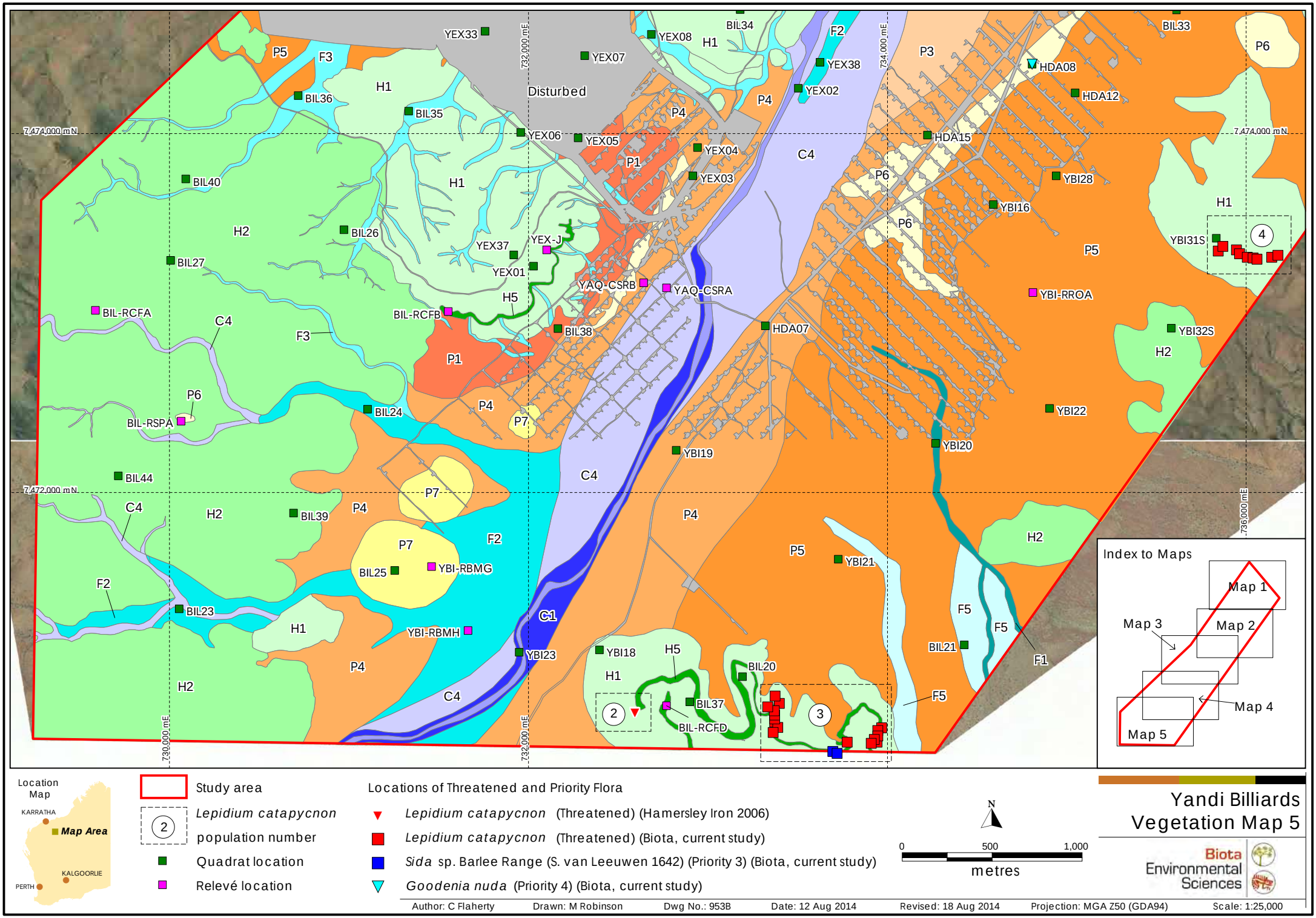
0 500 1,000

metres

Yandi Billiards Vegetation Map 4

Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 953B | Date: 12 Aug 2014 | Revised: 18 Aug 2014 | Projection: MGA Z50 (GDA94) | Scale: 1:25,000


Disturbed
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7,472,000 mN
732,000 mE
734,000 mE
736,000 mE
739,000 mE
YEX33
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YEX08
BIL34
BIL33
YEX38
YEX02
HDA08
HDA12
HDA15
YEX06
YEX05
YEX04
YEX03
YBI28
YBI16
BIL36
BIL35
BIL40
BIL26
BIL27
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YEX01
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YAQ-CSRA
YBI-RROA
BIL-RCFA
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BIL37
BIL-RCFD
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C1
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Map Area
KALGOORLIE
PERTH
Study area
Lepidium catapycnon population number
Quadrat location
Relevé location
Locations of Threatened and Priority Flora
Lepidium catapycnon (Threatened) (Hamersley Iron 2006)
Lepidium catapycnon (Threatened) (Biota, current study)
Sida sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) (Biota, current study)
Goodenia nuda (Priority 4) (Biota, current study)
N
0
500
1,000
metres
Yandi Billiards
Vegetation Map 5
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 12 Aug 2014
Revised: 18 Aug 2014
Projection: MGA Z50 (GDA94)
Scale: 1:25,000

Vegetation of Yandi Billiards

Vegetation of Major Creeklines and Tributaries

C1: EcEvMaMgAc

Eucalyptus camaldulensis subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland

C2: EvChAtuGwTErCYpERItTHt

Eucalyptus victrix, Corymbia hamersleyana scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland

C3: EvAciAcMgCEc

Eucalyptus victrix scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses

C4: EvAciAprAThCEc

Eucalyptus victrix open *woodland* over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland

Vegetation of Minor Creeklines, Floodplains and Valleys

F1: ChAtuGwTp

Corymbia hamersleyana scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland

F2: AprAciCEc

Acacia pruinocarpa, A. citrinoviridis tall open shrubland over **Cenchrus ciliaris* tussock grassland

F3: ElChAtuAaAbGwTspp

Eucalyptus leucophloia, Corymbia hamersleyana low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland

F4: ChAtuAaPcAtenBONeARh-PAmTp

Corymbia hamersleyana scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland

F5: ChAciAaAiSENsppTp

Corymbia hamersleyana scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland

Vegetation of Yandi Billiards

Vegetation of Hills, Ridges and Breakaways

H1: ElHcAiGwTsps

Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

H2: ElAiTwTsps

Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland

H3: ElGwAarTsps

Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland

H4: ChAarTspsTw

Corymbia hamersleyana scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland

H5: ElCfERImTHspp

Eucalyptus leucophloia subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp*. filiformis,* Senna spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade, *T. triandra* open tussock grassland

Vegetation of Yandi Billiards

Vegetation of Plains

P1: ElEgAprAbAaAdTwTpTsps

Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland

P2: ChAprAiAsclApaTp

Corymbia hamersleyana, Acacia pruinocarpa scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland

P3: AprAciAiAsclTlo

Acacia pruinocarpa low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland

P4: AprAsyAiTw

Acacia pruinocarpa low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland

P5: ElEgAbAaTb

Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland

P6: AapERfoERl/g

Acacia aptaneura low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland

P7: ERf/g

Eremophila fraseri subsp. *fraseri* open shrubland over mixed very open grassland

P8: EgAiTs

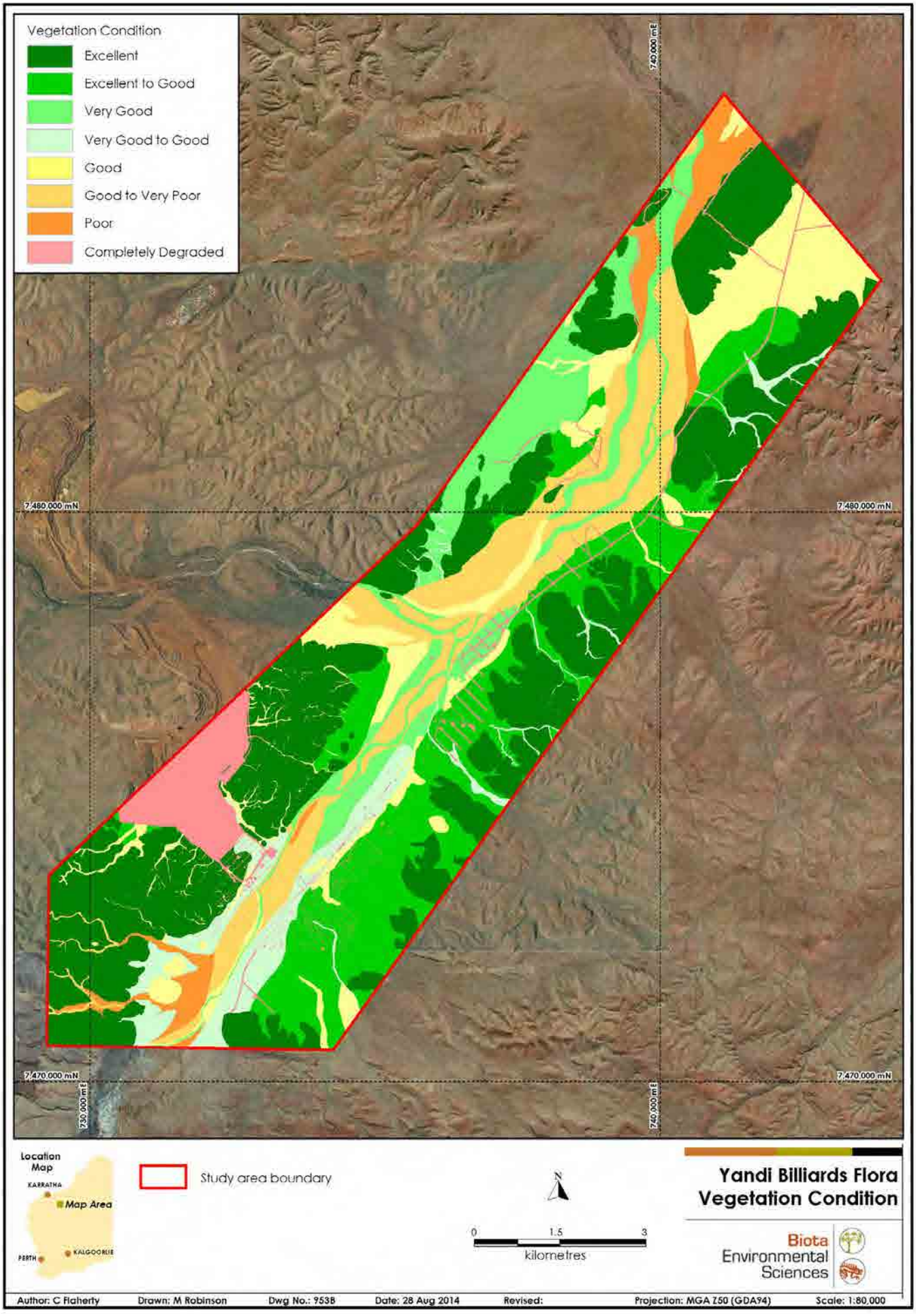
Eucalyptus gamophylla scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland

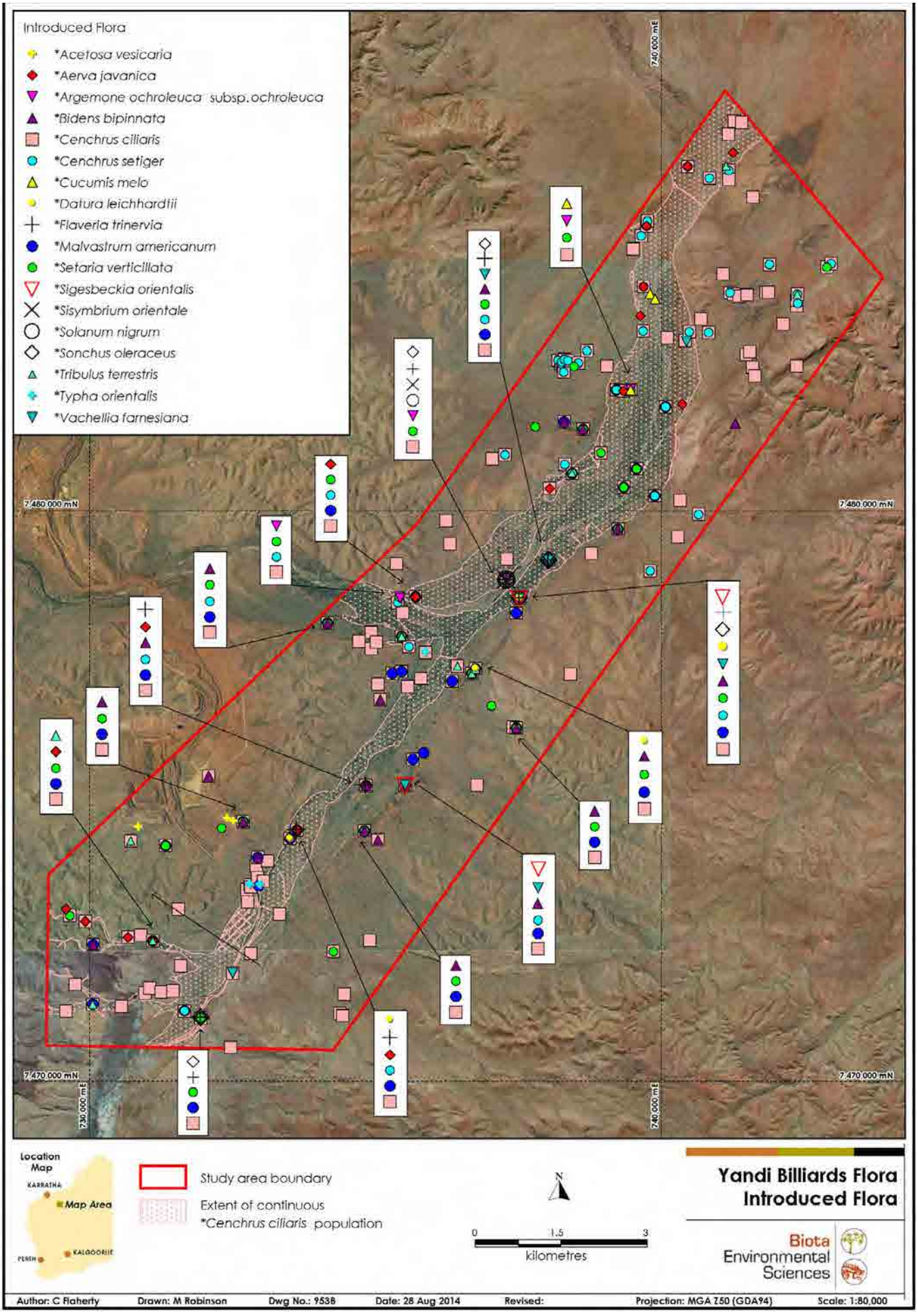
P9: ChEgAiAaAprPcTb

Corymbia hamersleyana scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland

Appendix 5

Vegetation Condition Mapping and Weed Locations


Vegetation Condition
Excellent
Excellent to Good
Very Good
Very Good to Good
Good
Good to Very Poor
Poor
Completely Degraded
740,000 mE
7,480,000 mN
7,470,000 mN
730,000 mE
Location Map
KARRATHA
Map Area
PERTH
KALGOORLIE
Study area boundary
N
0
1.5
3
kilometres
Yandi Billiards Flora
Vegetation Condition
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 28 Aug 2014
Revised:
Projection: MGA Z50 (GDA94)
Scale: 1:80,000


Introduced Flora
*Acetosa vesicaria
*Aerva javanica
*Argemone ochroleuca subsp. ochroleuca
*Bidens bipinnata
*Cenchrus ciliaris
*Cenchrus setiger
*Cucumis melo
*Datura leichhardtii
*Flaveria trinervia
*Malvastrum americanum
*Setaria verticillata
*Sigesbeckia orientalis
*Sisymbrium orientale
*Solanum nigrum
*Sonchus oleraceus
*Tribulus terrestris
*Typha orientalis
*Vachellia farnesiana
7,480,000 mN
7,470,000 mN
730,000 mE
740,000 mE
Location Map
KARRATHA
Map Area
PERTH
KALGOORLIE
Study area boundary
Extent of continuous *Cenchrus ciliaris population
N
0
1.5
3
kilometres
Yandi Billiards Flora
Introduced Flora
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953B
Date: 28 Aug 2014
Revised:
Projection: MGA 50 (GDA94)
Scale: 1:80,000

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Acetosa vesicaria*	Pilbara Iron (unpubl. data)	Not provided	Opportunistic Record	730860	7474450	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	732412	7474595	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	732526	7474550	Not recorded
**Aerva javanica*	Current survey (Phase 1)	14/03/2014	BIL-RCFA	729589	7473017	8
	Current survey (Phase 1)	14/03/2014	Opportunistic Record	729924	7472803	20
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	730676	7472521	20
	Current survey (Phase 1)	19/03/2014	BIL24	731105	7472466	10
	Current survey (Phase 2)	11/07/2014	BIL24	731105	7472466	25
	Current survey (Phase 1)	20/03/2014	YEX02	733504	7474254	1
	Current survey (Phase 1)	15/03/2014	YEX38	733626	7474399	10
	Current survey (Phase 1)	17/03/2014	YBI17	734832	7475182	3
	Biota (2009b)	16/06/2007	YBI-RPHB	735704	7478491	0.1%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738051	7480388	30
	Biota (2014b)	17/06/2012	Opportunistic Record	739338	7482094	7
	Biota (2014b)	17/06/2012	Opportunistic Record	739635	7483408	20
	Biota (2014b)	17/06/2012	YAQ-CSRD	739685	7483923	0.1%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739743	7484980	1
	Biota (2014b)	17/06/2012	Opportunistic Record	740365	7481867	1
	Current survey (Phase 1)	9/03/2014	BIL30	740462	7486024	3
	Current Survey (Phase 2)	8/07/2014	BIL30	740462	7486024	4
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741254	7486273	1
**Argemone ochroleuca* subsp. *ochroleuca*	Biota (2009b)	16/06/2007	YBI-RRWB	735420	7478487	0.1%
	Biota (2014b)	16/06/2012	Opportunistic Record	735434	7478464	1
	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.5%
	Biota (2009b)	4/06/2009	YBI30S	737297	7478783	0.1%
	Biota (2009b)	15/06/2007	YBI01	739465	7482118	0.1%
**Bidens bipinnata*	Current survey (Phase 1)	13/03/2014	BIL-RSPA	730066	7472398	8000
	Biota (2004a)	1/09/2004	YEX09	732084	7475352	0.1%
	Current survey (Phase 1)	15/03/2014	YEX08	732686	7474553	3
	Current survey (Phase 1)	14/03/2014	YEX04	732943	7473923	80
	Current survey (Phase 1)	16/03/2014	YAQ16	734166	7478025	30
	Biota (2004b)	24/04/2003	HDA08	734807	7474388	0.1%
	Current survey (Phase 1)	16/03/2014	HDA08	734807	7474388	70
	Biota (2009b)	17/06/2007	YBI17	734832	7475182	0.1%
	Current survey (Phase 1)	17/03/2014	YBI17	734832	7475182	5
	Biota (2004b)	24/04/2003	HDA12	735047	7474228	0.1%
	Current survey (Phase 1)	15/03/2014	Opportunistic Record	735087	7476683	50
	Current survey (Phase 1)	15/03/2014	YBI10	735461	7477797	75
	Biota (2009b)	3/08/2008	YBI12	735518	7475188	0.1%
	Current survey (Phase 1)	17/03/2014	YBI12	735518	7475188	1000
	Biota (2009b)	3/08/2008	YBI15	736687	7477149	0.1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	570
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	0.1%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Bidens bipinnata*	Current survey (Phase 1)	18/03/2014	BIL16	737466	7476191	1000
	Current survey (Phase 2)	9/07/2014	BIL16	737466	7476191	50
	Current survey (Phase 1)	12/03/2014	HDA09	737517	7478460	7
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	20
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738298	7481550	30
	Current survey (Phase 1)	19/03/2014	BIL32	738634	7481425	5
	Current survey (Phase 1)	20/03/2014	YBI09	739242	7479676	150
	Biota (2009b)	19/06/2007	YBI25	741294	7481523	0.1%
**Cenchrus ciliaris*	Current survey (Phase 1)	13/03/2014	Opportunistic Record	729585	7471233	1000
	Current survey (Phase 1)	14/03/2014	Opportunistic Record	729654	7472905	100
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	729748	7471700	500
	Current survey (Phase 1)	14/03/2014	Opportunistic Record	729924	7472803	100
	Current survey (Phase 1)	13/03/2014	BIL23	730055	7471353	50%
	Current survey (Phase 2)	10/07/2014	BIL23	730055	7471353	40%
	Current survey (Phase 1)	13/03/2014	BIL-RSPA	730066	7472398	0.1%
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	730555	7471314	5000
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	730676	7472521	1000
	Current survey (Phase 1)	14/03/2014	BIL36	730717	7474212	3%
	Current survey (Phase 2)	10/07/2014	BIL36	730717	7474212	4%
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	730895	7472560	500
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	730968	7471551	5000
	Current survey (Phase 1)	13/03/2014	Opportunistic Record	731051	7471628	100
	Current survey (Phase 1)	19/03/2014	BIL24	731105	7472466	15%
	Current survey (Phase 2)	11/07/2014	BIL24	731105	7472466	17%
	Current survey (Phase 1)	13/03/2014	BIL25	731255	7471567	0.1%
	Current survey (Phase 2)	10/07/2014	BIL25	731255	7471567	0.1%
	Current survey (Phase 1)	14/03/2014	BIL35	731333	7474127	900
	Current survey (Phase 2)	10/07/2014	BIL35	731333	7474127	4%
	Biota (2009b)	18/06/2007	YBI-RBMG	731460	7471589	2
	Current survey (Phase 1)	14/03/2014	BIL-RCFB	731555	7473010	1
	Current survey (Phase 2)	11/07/2014	BIL48	731598	7472021	146
	Biota (2009b)	18/06/2007	YBI-RBMH	731663	7471233	75%
	Biota (2009b)	18/06/2007	YBI23	731950	7471111	0.1%
	Biota (2004a)	1/09/2004	YEX09	732084	7475352	0.1%
	Current survey (Phase 1)	17/03/2014	Opportunistic Record	732468	7470596	25
	Current survey (Phase 2)	9/07/2014	Opportunistic Record	732501	7471895	100
	Biota (2004a)	1/09/2004	YEX08	732686	7474553	35%
	Current survey (Phase 1)	15/03/2014	YEX08	732686	7474553	60%
	GHD (2009)	10/05/2009	Opportunistic Record	732757	7473359	Not recorded
	Biota (2014b)	13/06/2012	YAQ-CSRA	732770	7473142	8%
	GHD (2009)	10/05/2009	Opportunistic Record	732809	7473440	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	732820	7473407	Not recorded
	Biota (2009b)	17/06/2007	YBI19	732824	7472236	0.5%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus ciliaris*	GHD (2009)	10/05/2009	Opportunistic Record	732917	7473452	Not recorded
	Biota (2004a)	31/08/2004	YEX03	732917	7473766	0.1%
	GHD (2009)	10/05/2009	Opportunistic Record	732935	7473569	Not recorded
	Biota (2004a)	31/08/2004	YEX04	732943	7473923	0.1%
	GHD (2009)	10/05/2009	Opportunistic Record	733037	7473508	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	733110	7473862	Not recorded
	Biota (2004b)	25/04/2003	HDA07	733320	7472930	0.1%
	Biota (2004a)	31/08/2004	YEX02	733504	7474254	80%
	Current survey (Phase 1)	20/03/2014	YEX02	733504	7474254	87%
	Biota (2004a)	4/09/2004	YEX38	733626	7474399	42.5%
	Current survey (Phase 1)	15/03/2014	YEX38	733626	7474399	45%
	Biota (2014b)	15/06/2012	YAQ16	734166	7478025	13
	Current survey (Phase 1)	16/03/2014	YAQ16	734166	7478025	0.5%
	Biota (2009b)	17/06/2007	YBI20	734268	7472275	0.1%
	Biota (2009b)	4/08/2008	YBI20	734268	7472275	0.1%
	Current survey (Phase 1)	17/03/2014	YBI20	734268	7472275	1%
	Current survey (Phase 1)	17/03/2014	Opportunistic Record	734380	7471195	700
	Current survey (Phase 1)	17/03/2014	BIL21	734428	7471153	5%
	Current survey (Phase 2)	9/07/2014	BIL21	734428	7471153	6%
	Current survey (Phase 2)	9/07/2014	BIL47	734454	7471527	6%
	GHD (2009)	10/05/2009	Opportunistic Record	734710	7477708	Not recorded
	Biota (2004b)	24/04/2003	HDA08	734807	7474388	1
	Current survey (Phase 1)	16/03/2014	HDA08	734807	7474388	1%
	Biota (2009b)	17/06/2007	YBI17	734832	7475182	4%
	Biota (2009b)	4/08/2008	YBI17	734832	7475182	4%
	Current survey (Phase 1)	17/03/2014	YBI17	734832	7475182	8%
	Biota (2009b)	4/08/2008	YBI22	734904	7472469	0.1%
	GHD (2009)	10/05/2009	Opportunistic Record	734931	7477581	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	734933	7477865	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	735018	7477694	Not recorded
	Biota (2004b)	24/04/2003	HDA12	735047	7474228	0.1%
	Current survey (Phase 1)	16/03/2014	BIL18	735048	7476958	70
	Current survey (Phase 1)	15/03/2014	Opportunistic Record	735087	7476683	50
	GHD (2009)	10/05/2009	Opportunistic Record	735297	7477149	Not recorded
	Biota (2014b)	16/06/2012	Opportunistic Record	735372	7479070	200
	Biota (2009b)	16/06/2007	YBI-RPHA	735388	7478389	25%
	GHD (2009)	10/05/2009	Opportunistic Record	735461	7477178	Not recorded
	Biota (2009b)	16/06/2007	YBI10	735461	7477797	1%
	Current survey (Phase 1)	15/03/2014	YBI10	735461	7477797	25%
	Biota (2014b)	16/06/2012	Opportunistic Record	735480	7478209	> 1000
	Biota (2009b)	16/06/2007	YBI12	735518	7475188	0.1%
	Biota (2009b)	3/08/2008	YBI12	735518	7475188	0.1%
	Current survey (Phase 1)	17/03/2014	YBI12	735518	7475188	0.5%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus ciliaris*	GHD (2009)	10/05/2009	Opportunistic Record	735568	7476914	Not recorded
	Biota (2014b)	16/06/2012	Opportunistic Record	735588	7477615	> 100
	Biota (2009b)	17/06/2007	YBI-RBMI	735658	7475639	2%
	Biota (2009b)	16/06/2007	YBI-RPHB	735704	7478491	40%
	GHD (2009)	10/05/2009	Opportunistic Record	735795	7477062	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	735882	7477511	Not recorded
	Current survey (Phase 1)	12/03/2014	BIL13	736238	7479815	2
	Current survey (Phase 1)	12/03/2014	Opportunistic Record	736304	7479418	100
	Biota (2009b)	16/06/2007	YBI13	736342	7477013	6%
	Biota (2009b)	3/08/2008	YBI13	736342	7477013	6%
	Biota (2009b)	15/06/2007	YBI11	736437	7477279	2.5%
	Biota (2009b)	3/08/2008	YBI11	736437	7477279	2.5%
	Current survey (Phase 1)	15/03/2014	YBI11	736437	7477279	2%
	Biota (2009b)	17/06/2007	YBI15	736687	7477149	0.1%
	Biota (2009b)	3/08/2008	YBI15	736687	7477149	0.1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	2%
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	2
	Biota (2009b)	4/06/2009	YBI35S	736781	7475190	0.1%
	Current survey (Phase 1)	12/03/2014	BIL14	737046	7480911	50
	Current survey (Phase 1)	19/03/2014	BIL46	737268	7480980	0.1%
	Current survey (Phase 2)	8/07/2014	BIL46	737268	7480980	40
	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
	Biota (2009b)	4/06/2009	YBI30S	737297	7478783	0.1%
	Biota (2014b)	16/06/2012	YAQ21	737304	7479144	12%
	Current survey (Phase 1)	16/03/2014	Opportunistic Record	737408	7476202	25
	Current survey (Phase 1)	18/03/2014	BIL16	737466	7476191	15%
	Current survey (Phase 2)	9/07/2014	BIL16	737466	7476191	400
	Biota (2004b)	24/04/2003	HDA14	737468	7478207	1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	60%
	Current survey (Phase 1)	12/03/2014	HDA09	737517	7478460	35%
	Biota (2014b)	14/06/2012	YAQ12	738027	7479127	60%
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	60%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738051	7480388	10000
	Current survey (Phase 1)	12/03/2014	Opportunistic Record	738195	7482631	1000
	Current survey (Phase 1)	11/03/2014	BIL12	738244	7482579	14%
	Current survey (Phase 2)	8/07/2014	BIL12	738244	7482579	33%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738261	7482607	5000
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738276	7482515	500
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738293	7482427	200
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738298	7481550	200
	Current survey (Phase 1)	12/03/2014	BIL02	738304	7482643	9%
	Current survey (Phase 2)	8/07/2014	BIL02	738304	7482643	4%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus ciliaris*	Biota (2009b)	15/06/2007	YBI06	738312	7480809	0.10%
	Current survey (Phase 1)	11/03/2014	YBI06	738312	7480809	100
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738364	7482621	300
	Current survey (Phase 1)	16/03/2014	Opportunistic Record	738407	7477134	50
	Biota (2009b)	15/06/2007	YBI-RBMK	738444	7480649	75%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738549	7482580	50
	Current survey (Phase 1)	19/03/2014	BIL32	738634	7481425	5%
	Current survey (Phase 2)	8/07/2014	BIL32	738634	7481425	0.1%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738696	7482802	200
	Biots (2014b)	16/06/2012	Opportunistic Record	738772	7479247	100
	Biota (2002)	27/04/2001	H051	738944	7481012	70%
	Biots (2014b)	17/06/2012	YAQ29	739045	7482529	0.1%
	Biota (2009b)	15/06/2007	YBI02	739211	7482114	60%
	Biota (2009b)	15/06/2007	YBI09	739242	7479676	1.5%
	Current survey (Phase 1)	20/03/2014	YBI09	739242	7479676	200
	Biots (2014b)	16/06/2012	Opportunistic Record	739338	7482094	> 1000
	Biota (2009b)	15/06/2007	YBI04	739343	7480406	45%
	Biota (2009b)	15/06/2007	YBI01	739465	7482118	0.1%
	Current survey (Phase 2)	8/07/2014	BIL41	739505	7484581	1
	Biota (2002)	28/04/2001	H050	739564	7480732	5%
	Current survey (Phase 1)	18/03/2014	H050	739564	7480732	9%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739649	7484814	5000
	Biota (2014b)	17/06/2012	YAQ-CSRC	739681	7483146	20%
	Biota (2014b)	17/06/2012	YAQ-CSRD	739685	7483923	30%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739743	7484980	5000
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739753	7485070	5000
	Current survey (Phase 2)	14/07/2014	Opportunistic Record	739805	7478940	20
	Biota (2009b)	16/06/2007	YBI08	739883	7480259	35%
	Current survey (Phase 1)	16/03/2014	YBI08	739883	7480259	15%
	Biota (2009b)	15/06/2007	YBI03	740075	7481817	90%
	Biota (2014b)	17/06/2012	Opportunistic Record	740100	7483033	50
	Current survey (Phase 1)	18/03/2014	YBI07	740286	7479541	1
	Current survey (Phase 2)	14/07/2014	Opportunistic Record	740325	7480176	100
	Biota (2014b)	17/06/2012	Opportunistic Record	740417	7482977	1000
	Current survey (Phase 1)	9/03/2014	BIL30	740462	7486024	17
	Current survey (Phase 2)	8/07/2014	BIL30	740462	7486024	0.1%
	Biota (2009b)	19/06/2007	YBI-RBMF	740486	7483133	75%
	Current survey (Phase 1)	18/03/2014	BIL31	740648	7479936	2%
	Current survey (Phase 2)	9/07/2014	BIL31	740648	7479936	2%
	Biota (2009b)	19/06/2007	YBI-RBMD	740689	7483356	1
	Biota (2009b)	19/06/2007	YBI26	740825	7483118	4%
	Biota (2014b)	17/06/2012	YAQ30	740844	7485826	13%
	Current survey (Phase 1)	9/03/2014	YAQ30	740844	7485826	15%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus ciliaris*	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741078	7484143	1000
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741173	7486595	20
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741181	7485956	75%
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741182	7485804	5
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741203	7483816	100
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741263	7483791	2000
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741273	7486826	25
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741356	7483756	50
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741404	7486803	25
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	741482	7482732	1000
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741496	7483774	50
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	741545	7482779	100
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	741590	7482510	1000
	Current survey (Phase 1)	9/03/2014	BIL05	741600	7485494	0.1%
	Biota (2009b)	19/06/2007	YBI-RBME	741635	7482360	5%
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741831	7483822	300
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741872	7483822	50
	Current survey (Phase 1)	9/03/2014	BIL10	741890	7484313	100
	Current survey (Phase 2)	8/07/2014	BIL10	741890	7484313	7%
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742128	7483266	50
	Current survey (Phase 1)	10/03/2014	BIL-RSWA	742364	7482528	0.1%
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742366	7483584	1000
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742367	7483683	100
	Current survey (Phase 1)	19/03/2014	BIL07	742381	7483792	150
	Current survey (Phase 2)	8/07/2014	BIL07	742381	7483792	3%
	Current survey (Phase 1)	10/03/2014	BIL09	742897	7484264	400
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742972	7484327	200
**Cenchrus setiger*	Biota (2009b)	18/06/2007	YBI-RBMH	731663	7471233	2%
	Current survey (Phase 1)	15/03/2014	YEX38	733626	7474399	0.1%
	Current survey (Phase 1)	16/03/2014	YAQ16	734166	7478025	0.1%
	Current survey (Phase 1)	16/03/2014	HDA08	734807	7474388	1%
	Biota (2009b)	17/06/2007	YBI17	734832	7475182	0.1%
	Current survey (Phase 1)	17/03/2014	YBI17	734832	7475182	0.1%
	Biota (2009b)	16/06/2007	YBI-RPHA	735388	7478389	25%
	Current survey (Phase 1)	15/03/2014	YBI10	735461	7477797	3%
	Current survey (Phase 1)	17/03/2014	YBI12	735518	7475188	0.5%
	Biota (2014b)	16/06/2012	Opportunistic Record	735588	7477615	> 20
	Biota (2009b)	16/06/2007	YBI-RPHB	735704	7478491	35%
	Biota (2009b)	17/06/2007	YBI15	736687	7477149	0.1%
	Biota (2009b)	3/08/2008	YBI15	736687	7477149	0.1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	0.1%
	Current survey (Phase 1)	16/03/2014	BIL46	737268	7480980	3%
	Current survey (Phase 2)	8/07/2014	BIL46	737268	7480980	20

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus setiger*	Biota (2004b)	24/04/2003	HDA09	737517	7478460	35%
	Current survey (Phase 1)	12/03/2014	HDA09	737517	7478460	60%
	Biota (2014a)	14/06/2012	YAQ12	738027	7479127	15%
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	15%
	Current survey (Phase 1)	12/03/2014	Opportunistic Record	738195	7482631	500
	Current survey (Phase 1)	11/03/2014	BIL12	738244	7482579	4%
	Current survey (Phase 2)	8/07/2014	BIL12	738244	7482579	0.5%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738261	7482607	5000
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738293	7482427	300
	Current survey (Phase 1)	12/03/2014	BIL02	738304	7482643	5%
	Current survey (Phase 2)	8/07/2014	BIL02	738304	7482643	1%
	Current survey (Phase 1)	11/03/2014	YBI06	738312	7480809	100
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738364	7482621	100
	Biota (2009b)	15/06/2007	YBI-RBMK	738444	7480649	2%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738549	7482580	50
	Current survey (Phase 1)	19/03/2014	BIL32	738634	7481425	1%
	Current survey (Phase 2)	8/07/2014	BIL32	738634	7481425	3%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738696	7482802	50
	Biota (2002)	27/04/2001	H051	738944	7481012	0.1%
	Biota (2009b)	15/06/2007	YBI02	739211	7482114	15%
	Biota (2009b)	15/06/2007	YBI09	739242	7479676	0.1%
	Current survey (Phase 1)	20/03/2014	YBI09	739242	7479676	10
	Biota (2009b)	15/06/2007	YBI04	739343	7480406	45%
	Biota (2002)	28/04/2001	H050	739564	7480732	0.1%
	Current survey (Phase 1)	18/03/2014	H050	739564	7480732	0.1%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739649	7484814	5000
	Biota (2014b)	17/06/2012	YAQ-CSRC	739681	7483146	1%
	Biota (2014b)	17/06/2012	YAQ-CSRD	739685	7483923	5%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739743	7484980	5000
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	739753	7485070	5000
	Current survey (Phase 2)	14/07/2014	Opportunistic Record	739805	7478940	30
	Biota (2009b)	16/06/2007	YBI08	739883	7480259	1.5%
	Current survey (Phase 1)	16/03/2014	YBI08	739883	7480259	10%
	Biota (2009b)	15/06/2007	YBI03	740075	7481817	5%
	Current survey (Phase 1)	9/03/2014	BIL30	740462	7486024	3
	Current survey (Phase 2)	8/07/2014	BIL30	740462	7486024	0.1%
	Biota (2009b)	19/06/2007	YBI-RBMF	740486	7483133	2%
	Current survey (Phase 1)	18/03/2014	BIL31	740648	7479936	0.1%
	Current survey (Phase 2)	9/07/2014	BIL31	740648	7479936	0.1%
	Biota (2009b)	19/06/2007	YBI26	740825	7483118	0.1%
	Biota (2014b)	17/06/2012	YAQ30	740844	7485826	0.5%
	Current survey (Phase 1)	9/03/2014	YAQ30	740844	7485826	5%
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741181	7485956	5%

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Cenchrus setiger*	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741203	7483816	100
	Current survey (Phase 1)	9/03/2014	BIL10	741890	7484313	10
	Current survey (Phase 2)	8/07/2014	BIL10	741890	7484313	1%
	Current survey (Phase 1)	19/03/2014	BIL07	742381	7483792	20
	Current survey (Phase 2)	8/07/2014	BIL07	742381	7483792	0.5%
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742383	7483629	1
	Current survey (Phase 1)	10/03/2014	Opportunistic Record	742972	7484327	200
**Cucumis melo subsp. agrestis*	Biota (2009b)	15/06/2007	YBI01	739465	7482118	0.1%
	Biota (2014b)	17/06/2012	Opportunistic Record	739805	7483801	1
	Biota (2014b)	17/06/2012	Opportunistic Record	739895	7483710	2
**Datura leichhardtii*	Biota (2004a)	31/08/2004	YEX02	733504	7474254	0.1%
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
**Flaveria trinervia*	Biota (2009b)	18/06/2007	YBI23	731950	7471111	0.1%
	Biota (2004a)	4/09/2004	YEX38	733626	7474399	0.1%
	Current survey (Phase 1)	15/03/2014	YEX38	733626	7474399	2
	Current survey (Phase 1)	17/03/2014	YBIR17	734832	7475182	5
	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	1
**Malvastrum americanum*	Current survey (Phase 1)	13/03/2014	BIL23	730055	7471353	6
	Current survey (Phase 1)	13/03/2014	BIL-RSPA	730066	7472398	0.1%
	Current survey (Phase 1)	19/03/2014	BIL24	731105	7472466	200
	Current survey (Phase 2)	11/07/2014	BIL24	731105	7472466	90
	Current survey (Phase 1)	14/03/2014	BIL35	731333	7474127	5
	Biota (2009b)	18/06/2007	YBI-RBMH	731663	7471233	1
	Biota (2009b)	18/06/2007	YBI23	731950	7471111	0.1%
	Biota (2004a)	1/09/2004	YEX08	732686	7474553	0.1%
	Current survey (Phase 1)	15/03/2014	YEX08	732686	7474553	100
	Biota (2004a)	31/08/2004	YEX04	732943	7473923	0.1%
	Current survey (Phase 1)	14/03/2014	YEX04	732943	7473923	8
	GHD (2009)	10/05/2009	Opportunistic Record	732957	7473427	Not recorded
	Biota (2004a)	31/08/2004	YEX02	733504	7474254	1%
	Current survey (Phase 1)	20/03/2014	YEX02	733504	7474254	4
	Biota (2004a)	4/09/2004	YEX38	733626	7474399	0.1%
	Current survey (Phase 1)	15/03/2014	YEX38	733626	7474399	23
	Biota (2004a)	15/06/2012	YAQ16	734166	7478025	3
	Current survey (Phase 1)	16/03/2014	YAQ16	734166	7478025	20
	Biota (2004b)	24/04/2003	HDA08	734807	7474388	0.1%
	Current survey (Phase 1)	16/03/2014	HDA08	734807	7474388	0.1%
	Biota (2009b)	17/06/2007	YBI17	734832	7475182	0.1%
	Current survey (Phase 1)	17/03/2014	YBI17	734832	7475182	300
	GHD (2009)	10/05/2009	Opportunistic Record	735297	7477149	Not recorded

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Malvastrum americanum*	GHD (2009)	10/05/2009	Opportunistic Record	735461	7477178	Not recorded
	Biota (2009b)	16/06/2007	YBI10	735461	7477797	0.1%
	Biota (2009b)	16/06/2007	YBI12	735518	7475188	2.5%
	Biota (2009b)	3/08/2008	YBI12	735518	7475188	2.5%
	Current survey (Phase 1)	17/03/2014	YBI12	735518	7475188	2%
	Biota (2009b)	17/06/2007	YBI-RBMI	735658	7475639	1
	Biota (2009b)	16/06/2007	YBI-RPHB	735704	7478491	0.1%
	Biota (2009b)	3/08/2008	YBI14	735845	7475759	1
	Biota (2009b)	16/06/2007	YBI13	736342	7477013	0.1%
	Biota (2009b)	17/06/2007	YBI15	736687	7477149	1%
	Biota (2009b)	3/08/2008	YBI15	736687	7477149	1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	535
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	0.1%
	Current survey (Phase 1)	18/03/2014	BIL16	737466	7476191	70
	Biota (2004b)	24/04/2003	HDA14	737468	7478207	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
	Current survey (Phase 1)	12/03/2014	HDA09	737517	7478460	10
	Biota (2014b)	14/06/2012	YAQ12	738027	7479127	10
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	20
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738298	7481550	10
	Biota (2009b)	15/06/2007	YBI-RBMK	738444	7480649	1
	Current survey (Phase 1)	19/03/2014	BIL32	738634	7481425	6
	Current survey (Phase 2)	8/07/2014	BIL32	738634	7481425	0.1%
	Biota (2009b)	15/06/2007	YBI02	739211	7482114	0.1%
	Biota (2009b)	15/06/2007	YBI09	739242	7479676	0.1%
	Biota (2009b)	15/06/2007	YBI04	739343	7480406	0.1%
	Current survey (Phase 1)	18/03/2014	H050	739564	7480732	0.1%
	Biota (2009b)	16/06/2007	YBI08	739883	7480259	0.1%
	Biota (2009b)	15/06/2007	YBI03	740075	7481817	0.1%
**Setaria verticillata*	Current survey (Phase 1)	14/03/2014	Opportunistic Record	729654	7472905	1
	Current survey (Phase 1)	19/03/2014	BIL24	731105	7472466	2
	Current survey (Phase 2)	11/07/2014	BIL24	731105	7472466	1
	Current survey (Phase 1)	14/03/2014	BIL35	731333	7474127	10
	Current survey (Phase 2)	10/07/2014	BIL35	731333	7474127	3
	Biota (2009b)	18/06/2007	YBI23	731950	7471111	0.1%
	Biota (2004a)	31/08/2004	YEX07	732315	7474436	0.1%
	Current survey (Phase 1)	15/03/2014	YEX08	732686	7474553	6
	Current survey (Phase 1)	16/03/2014	YAQ16	734166	7478025	0.1%
	Biota (2009b)	17/06/2007	YBI20	734268	7472275	0.1%
	Current survey (Phase 1)	16/03/2014	HDA08	734807	7474388	5
	Biota (2009b)	16/06/2007	YBI-RRWB	735420	7478487	0.1%
	Biota (2009b)	16/06/2007	YBI10	735461	7477797	0.1%
	Current survey (Phase 1)	15/03/2014	YBI10	735461	7477797	15

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Setaria verticillata*	Biota (2009b)	16/06/2007	YBI-RPHB	735704	7478491	0.1%
	Biota (2009b)	17/06/2007	YBI15	736687	7477149	0.1%
	Biota (2009b)	3/08/2008	YBI15	736687	7477149	0.1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	1
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	0.1%
	Biota (2009b)	4/06/2009	YBI34S	737033	7476575	0.1%
	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
	Biota (2009b)	4/06/2009	YBI30S	737297	7478783	0.1%
	Current survey (Phase 1)	18/03/2014	BIL16	737466	7476191	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
	Current survey (Phase 1)	11/03/2014	BIL11	737797	7481466	7
	Current survey (Phase 2)	8/07/2014	BIL11	737797	7481466	12
	Biota (2014b)	14/06/2012	YAQ12	738027	7479127	18
	Current survey (Phase 1)	12/03/2014	YAQ12	738027	7479127	1
	Current survey (Phase 1)	12/03/2014	Opportunistic Record	738478	7482520	15
	Current survey (Phase 1)	19/03/2014	BIL32	738634	7481425	0.1%
	Biota (2002)	27/04/2001	H051	738944	7481012	0.1%
	Current survey (Phase 1)	20/03/2014	YBI09	739242	7479676	2
	Biota (2009b)	15/06/2007	YBI04	739343	7480406	0.1%
	Biota (2009b)	15/06/2007	YBI01	739465	7482118	0.1%
	Biota (2002)	28/04/2001	H050	739564	7480732	0.1%
	Current survey (Phase 1)	18/03/2014	H050	739564	7480732	0.1%
	Current survey (Phase 1)	10/03/2014	BIL09	742897	7484264	6
**Sigesbeckia orientalis*	Current survey (Phase 1)	17/03/2014	YBIR12	735518	7475188	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
**Sisymbrium orientale*	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
**Solanum nigrum*	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
**Sonchus oleraceus*	Biota (2009b)	18/06/2007	YBI23	731950	7471111	0.1%
	Biota (2009b)	3/08/2008	YBI30S	737297	7478783	0.1%
	Biota (2009b)	4/06/2009	YBI30S	737297	7478783	0.1%
	Biota (2004b)	24/04/2003	HDA09	737517	7478460	0.1%
	Biota (2014b)	14/06/2012	YAQ12	738027	7479127	0.1%
**Tribulus terrestris*	Current survey (Phase 1)	13/03/2014	BIL23	730055	7471353	0.1%
	Current survey (Phase 1)	14/03/2014	BIL36	730717	7474212	0.1%
	Current survey (Phase 1)	19/03/2014	BIL24	731105	7472466	0.1%
	Current survey (Phase 1)	15/03/2014	YBI10	735461	7477797	0.1%
	Current survey (Phase 1)	15/03/2014	YBI11	736437	7477279	0.1%
	Current survey (Phase 1)	16/03/2014	YBI15	736687	7477149	0.1%
	Biota (2004b)	25/04/2003	HDA13	736755	7477227	0.1%
	Current survey (Phase 1)	11/03/2014	Opportunistic Record	738437	7480658	1
	Current survey (Phase 1)	9/03/2014	Opportunistic Record	741133	7486032	1
	Current survey (Phase 1)	9/03/2014	BIL07	742381	7483792	0.1%
	Current survey (Phase 2)	8/07/2014	BIL07	742381	7483792	2

Species	Source	Date	Site	Easting (mE)	Northing (mN)	Number of Individuals/ % Cover Estimation
**Typha orientalis*	GHD (2009)	10/05/2009	Opportunistic Record	732809	7473440	Not recorded
**Typha orientalis*	GHD (2009)	10/05/2009	Opportunistic Record	732986	7473442	Not recorded
	GHD (2009)	10/05/2009	Opportunistic Record	735882	7477511	Not recorded
**Vachellia farnesiana*	Current survey (Phase 2)	9/07/2014	Opportunistic Record	732501	7471895	2
	Biota (2009b) Current survey (Phase 1)	3/08/2008 17/03/2014	YBI12 YBI12	735518 735518	7475188 7475188	1 1
	Biota (2004b) Current survey (Phase 1)	24/04/2003 12/03/2014	HDA09 HDA09	737517 737517	7478460 7478460	0.1% 4
	Biota (2014b) Current survey (Phase 1)	14/06/2012 12/03/2014	YAQ12 YAQ12	738027 738027	7479127 7479127	1 1
	Biota (2014b)	17/06/2012	Opportunistic Record	740443	7482961	1

Appendix 6

Raw Data from Quadrats and Relevés

Yandi Billiards Level 2 BIL01

Described by Phase 1: SVSW, Phase 2: CEFSW Date Phase 1: 10-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 20 x 125 m

Central Coordinate 742409 mE, 7482095 mN.

Habitat Top of hill (plateau) gently sloping W.

Soil Dark reddish brown (2.5YR 3/3) sandy clay loam with >75% cover of gravel, pebbles and cobbles.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes One juvenile *Corymbia hamersleyana* outside of quadrat.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia arida	14	190 cm		19	210 cm	
Eriachne pulchella	0.1	10 cm				
Eucalyptus leucophloia subsp. *leucophloia*	1	580 cm		0.5	400 cm	
Fimbristylis dichotoma	0.1	15 cm	BIL01-02	0.1	15 cm	
Ptilotus calostachyus	0.1	70 cm		0.1	45 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	40 cm	BIL01-03	0.1	35 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	28	30 cm	BIL01-01	42	30 cm	
Triodia wiseana				0.1	40 cm	

BIL01 Phase 1

BIL01 Phase 2

Yandi Billiards Level 2		BIL02	
Described by	Phase 1: SVSW, Phase 2: CEFSW	Date	Phase 1: 12-Mar-14, Phase 2: 08-Jul-14
Type	Quadrat 20 x 125 m		
Central Coordinate	738304 mE, 7482643 mN		
Habitat	Creek bed (20 m wide) flowing E into major creek (Weeli Wolli).		
Soil	Dark reddish brown (2.5YR 3/4) skeletal sandy loam with 1-25% cover of cobbles, 26-50% cover of pebbles and 26-50% cover of gravel.		
Rock Type	Riverstone, ironstone, basalt, chert, mudstone and sandstone.		
Vegetation	Phase 1: *Eucalyptus victrix* open woodland over *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, A. pyrifolia* var. *pyrifolia* tall open scrub over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) low shrubland over **Cenchrus ciliaris, *C. setiger, Cymbopogon procerus, Themeda tri*andra open tussock grassland. Phase 2: *Eucalyptus victrix* open woodland over *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, A. pyrifolia* var. *pyrifolia* tall shrubland over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon procerus, *Cenchrus ciliaris, *C. setiger* open tussock grassland.		
Veg Condition	Phase 1: Good (**Cenchrus* spp.). Phase 2: Good (**Cenchrus* spp.).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Elevation: 473 m.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	40 cm	BIL02-10			
Acacia pyrifolia var. *pyrifolia*	15	320 cm	BIL02-02	4	350 cm	
Acacia tumida var. *pilbarensis*	22	330 cm		18	400 cm	
Amaranthus undulatus	0.1	60 cm	BIL02-08			
Androcalva luteiflora	0.1	160 cm		0.1	180 cm	
Aristida contorta	0.1	30 cm		0.1	30 cm	
Aristida holathera var. *holathera*	0.1	50 cm		0.1	45 cm	
Aristida inaequiglumis	0.1	80 cm	BIL02-03	0.1	100 cm	
Atalaya hemiglauca				0.1	130 cm	
Boerhavia coccinea	0.1	10 cm		0.1	10 cm	
Cenchrus ciliaris	9	60 cm		4	60 cm	
Cenchrus setiger	5	60 cm		1	70 cm	
Cleome viscosa	0.1	40 cm		0.1	40 cm	
Corchorus crozophorifolius	0.1	85 cm		0.1	140 cm	
Corymbia hamersleyana	2	800 cm		3	800 cm	
Crotalaria medicaginea var. *neglecta*	0.1	45 cm				
Cucumis variabilis	0.1	60 cm	BIL02-05	0.1	30 cm	
Cymbopogon procerus	4	180 cm		6	130 cm	
Enneapogon caerulescens				0.1	20 cm	
Enneapogon lindleyanus	0.1	45 cm		0.1	60 cm	
Enneapogon polyphyllus	0.1	35 cm				
Enneapogon robustissimus	0.1	80 cm	BIL02-12			
Eremophila longifolia				0.1	120 cm	
Eriachne pulchella	0.1	10 cm		0.1	10 cm	
Eriachne tenuiculmis	0.1	70 cm		0.1	60 cm	
Eucalyptus victrix	8	1600 cm		6	1400 cm	
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL02-13	0.1	5 cm	
Euphorbia coghlanii	0.1	30 cm	BIL02-11	0.1	10 cm	
Evolvulus alsinoides var. *decumbens*	0.1	30 cm		0.1	20 cm	
Gomphrena cunninghamii	0.1	25 cm		0.1	10 cm	
Goodenia stobbsiana	0.1	25 cm				
Gossypium australe	0.1	110 cm		0.1	160 cm	
Gossypium robinsonii	0.1	400 cm		0.1	350 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	410 cm		0.1	400 cm	BILR02-01
Heliotropium cunninghamii				0.1	20 cm	BILR02-02
Hybanthus aurantiacus	0.1	50 cm				
Jasminum didymum subsp. *lineare*	0.1	60 cm				
Melhania oblongifolia				0.1	35 cm	
Paraneurachne muelleri	0.1	50 cm		0.1	30 cm	
Petalostylis cassioides	0.1	120 cm	BIL02-09			

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Polycarpaea longiflora	0.1	20 cm		0.1	30 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	40 cm	
Ptilotus calostachyus	0.1	100 cm		0.1	60 cm	
Ptilotus nobilis subsp. *nobilis*				0.1	20 cm	
Salsola australis	0.1	20 cm		0.1	20 cm	
Sida sp. *spiciform panicles* (*E. Leyl*and *s.n. 14/8/90*)	0.1	80 cm	BIL02-06	0.1	110 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	18	40 cm	BIL02-01	12	40 cm	
*Themeda tri*andra	2	110 cm	BIL02-07	0.1	130 cm	
Triodia pungens	0.1	45 cm	BIL02-04	0.1	50 cm	
Triodia wiseana	0.1	35 cm		0.1	10 cm	
Waltheria indica	0.1	70 cm		0.1	60 cm	

BIL02 Phase 1

BIL02 Phase 2

Yandi Billiards Level 2 BIL03
Described by PLSV Date 18-Mar-14
Type Quadrat 42.5 x 60 m
Central Coordinate 739017 mE, 7477681 mN.
Habitat Narrow crest at top of hill sloping in all directions.
Soil 2.5YR 3/3 dark reddish brown sandy clay loam (skeletal) with cobbles (10 %), pebbles (80 %) and gravel (18 %).
Rock Type Ironstone
Vegetation *Senna artemisioides* subsp. *oligophylla, Ptilotus rotundifolius* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* open hummock grassland.
Veg Condition Excellent.
Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia bivenosa	0.1	180 cm	
Acacia inaequilatera	0.1	80 cm	
Amphipogon sericeus	0.1	25 cm	BIL03-05
Bulbostylis barbata	0.1	8 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm	
Eriachne pulchella	0.1	10 cm	
Fimbristylis dichotoma	0.1	15 cm	
Fimbristylis simulans	0.1	15 cm	
Goodenia stobbsiana	0.1	10 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	35 cm	
Mollugo molluginea	0.1	10 cm	
Polycarpaea holtzei	0.1	1 cm	
Ptilotus astrolasius	0.1	40 cm	
Ptilotus calostachyus	0.1	70 cm	
Ptilotus rotundifolius	0.5	90 cm	
Schizachyrium fragile	0.1	10 cm	BIL03-01
Senna artemisioides subsp. *oligophylla*	1	80 cm	BIL03-04, BIL03-02
Senna glutinosa subsp. *glutinosa*	0.1	150 cm	
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*	0.1	120 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	90 cm	
Senna notabilis	0.1	1 cm	
Sida echinocarpa	0.1	50 cm	BIL03-03
Tribulus suberosus	0.1	90 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	7	30 cm	
Triodia wiseana	6	35 cm	

BIL03

Yandi Billiards Level 2 BIL04

Described by Phase 1: PLSV, Phase 2: CEFSW Date Phase 1: 10-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 741467 mE, 7481905 mN.

Habitat Large hill / crest of range.

Soil Dark reddish brown skeletal soil with 1-25% cover of outcropping rock, 1-25% cover of cobbles, >75% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.
Phase 2: *Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia arida	4	170 cm	BIL04-01	13	210 cm	
Acacia citrinoviridis	0.1	260 cm		0.1	280 cm	
Acacia coriacea subsp. *pendens*	0.1	90 cm	BIL04-03	0.1	110 cm	
Acacia pachyacra	0.1	110 cm		0.1	110 cm	
Acacia pruinocarpa				0.1	85 cm	
Acacia synchronicia	0.1	220 cm		0.1	230 cm	
Aristida holathera var. *holathera*	0.1	50 cm		0.1	45 cm	
Corymbia hamersleyana	1	450 cm		1	550 cm	
Cymbopogon obtectus	0.1	110 cm	BIL04-05	0.1	100 cm	
Eriachne mucronata (*arid form*)	0.1	60 cm	BIL04-04	0.1	30 cm	
Eriachne pulchella	0.1	20 cm				
Fimbristylis dichotoma	0.1	15 cm				
Fimbristylis simulans				0.1	15 cm	
Goodenia stobbsiana	0.1	40 cm		0.1	25 cm	
Heliotropium glabellum				0.1	10 cm	BILR04-01
Petalostylis labicheoides	0.1	220 cm		0.1	170 cm	
Ptilotus calostachyus	0.1	80 cm		0.1	40 cm	
Schizachyrium fragile	0.1	30 cm	BIL04-06	0.1	10 cm	
Senna glutinosa subsp. *glutinosa*				0.1	160 cm	
Senna glutinosa subsp. *glutinosa* x *S. stricta*	0.1	80 cm	BIL04-07	0.1	80 cm	
Senna glutinosa subsp. *pruinosa*	0.1	100 cm		0.1	120 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	210 cm		0.1	200 cm	
Solanum lasiophyllum	0.1	50 cm		0.1	30 cm	
Solanum phlomoides	0.1	45 cm	BIL04-02			
Trachymene oleracea subsp. *oleracea*				0.1	15 cm	
Tribulus sp.	0.1	8 cm				
Triodia pungens				0.1	20 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	13	45 cm		36	40 cm	
Triodia wiseana	0.1	80 cm		0.1	40 cm	

BIL04 Phase 1

BIL04 Phase 2

Yandi Billiards Level 2 BIL05

Described by SVSW Date 09-Mar-04

Type Quadrat 40 x 60 m

Central Coordinate 741600 mE, 7485494 mN.

Habitat NW facing upper slope of hill.

Soil 2.5YR 2.5/4 dark reddish brown sandy loam.

Rock Type Ironstone shale cobbles, pebbles and gravel overlying bedrock (90 % cover).

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) closed hummock grassland.

Veg Condition Very Good (**Cenchrus ciliaris*).

Fire Age No sign of recent fire.

Notes Site set up as 40 x 60 m due to old track at crest not allowing for 50 x 50 m.

Species	Cover (%)	Height (cm)	Specimen
Acacia bivenosa	0.1	220 cm	
Acacia pruinocarpa	0.1	150 cm	
Aristida holathera var. *holathera*	0.1	25 cm	
Cenchrus ciliaris	0.1	50 cm	
Digitaria brownii	0.1	60 cm	BIL05-05
Eriachne mucronata (typical form)	0.1	40 cm	
Eriachne pulchella	0.1	10 cm	
Eucalyptus leucophloia subsp. *leucophloia*	6	400 cm	
Euphorbia boophthona	0.1	10 cm	
Fimbristylis dichotoma	0.1	30 cm	BIL05-02
Fimbristylis simulans	0.1	10 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	160 cm	
Paraneurachne muelleri	0.1	40 cm	
Paspalidium clementii	0.1	10 cm	BIL05-06
Salsola australis	0.1	20 cm	
Senna artemisioides subsp. *oligophylla*	0.1	70 cm	BIL05-04
Senna glutinosa subsp. *glutinosa*	0.1	120 cm	
Senna glutinosa subsp. *pruinosa*	0.1	70 cm	
Solanum lasiophyllum	0.1	30 cm	
Triodia epactia	0.1	45 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	78	60 cm	BIL05-03, BIL05-01

BIL05

Yandi Billiards Level 2 BIL06

Described by Phase 1: SVSW, Phase 2: CEFSW Date Phase 1: 10-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 742007 mE, 7482816 mN.

Habitat Gentle mid slope of low range with N aspect.

Soil Dark reddish brown (2.5YR 3/3) skeletal sandy loam with 51-75% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia arida* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia arida* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Surrounding slopes have been burnt recently.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	35 cm		0.1	15 cm	
Acacia arida	29	270 cm	BIL06-03	19	240 cm	
Eriachne lanata	0.1	40 cm	BIL06-02	0.1	35 cm	
Eucalyptus leucophloia subsp. *leucophloia*	3	650 cm		1	350 cm	
Fimbristylis simulans	0.1	15 cm		0.1	8 cm	
Goodenia stobbsiana	0.1	20 cm		0.1	10 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	220 cm		0.1	210 cm	
Ptilotus astrolasius	0.1	25 cm		0.1	20 cm	
Ptilotus calostachyus	0.1	30 cm		0.1	30 cm	
Senna glutinosa subsp. x *luerssenii*				0.1	70 cm	
Triodia pungens	0.1	30 cm	BIL06-01	0.1	30 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	45	40 cm		28	20 cm	

BIL06 Phase 1

BIL06 Phase 2

Yandi Billiards Level 2 BIL07

Described by Phase 1: PLSV, Phase 2: PA/PL Date Phase 1: 19-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 742381 mE, 7483792 mN.

Habitat Flat plain directly NW of range.

Soil Dark reddish brown fine sandy loam with 1-25% cover of cobbles, 1-25% cover of pebbles and 26-50% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana* scattered low trees over *Acacia pruinocarpa,* (*A. citrinoviridis, Atalaya hemiglauca*) tall open shrubland over *Scaevola spinescens, Corchorus sidoides* subsp. *sidoides, Ptilotus obovatus* var. *obovatus* low open shrubland over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris, *C. setiger* very open tussock grassland.
Phase 2: *Corymbia hamersleyana* scattered low trees over *Acacia pruinocarpa, A. citrinoviridis, Atalaya hemiglauca* tall open shrubland over *Scaevola spinescens, Corchorus sidoides* subsp. *sidoides, Ptilotus obovatus* var. *obovatus* scattered low shrubs over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris, *C. setiger* very open tussock grassland.

Veg Condition Phase 1: Good (**Cenchrus ciliaris*). Phase 2: Good (**Cenchrus ciliaris*).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Notes Elevation: 463 m.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon sp. *Pilbara* (W.R. Barker 2025)	0.1	50 cm				
Acacia citrinoviridis	1	250 cm		1	250 cm	
Acacia pruinocarpa	4	450 cm		3	400 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	140 cm		0.1	130 cm	
Acacia synchronicia				0.1	20 cm	
Acacia tenuissima	0.1	170 cm		0.1	190 cm	
Aristida contorta	0.1	15 cm		0.1	30 cm	
Aristida holathera var. *holathera*				0.1	40 cm	
Atalaya hemiglauca	1	300 cm		1	300 cm	
Boerhavia coccinea	0.1	30 cm	BIL07-11	0.1	20 cm	
Bulbostylis barbata	0.1	6 cm		0.1	4 cm	
Cenchrus ciliaris	2	50 cm		3	60 cm	
Cenchrus setiger	0.5	80 cm		0.5	60 cm	
Chrysopogon fallax	0.1	90 cm		0.1	100 cm	
Cleome viscosa	0.1	50 cm		0.1	40 cm	
Corchorus sidoides subsp. *sidoides*	1	40 cm	BIL07-04	0.5	40 cm	
Corchorus tridens	0.1	10 cm				
Corymbia hamersleyana	1	550 cm		1	600 cm	
Crotalaria medicaginea var. *neglecta*	0.1	25 cm				
Dactyloctenium radulans	0.1	15 cm				
Digitaria ctenantha	0.1	40 cm				
Dysphania sp.	0.1	3 cm				
Enneapogon caerulescens	0.1	25 cm				
Enneapogon polyphyllus	0.1	20 cm		0.1	25 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	30 cm	
Eragrostis xerophila				0.1	40 cm	BILR07-02
Eremophila longifolia	0.1	140 cm		0.1	110 cm	
Eriachne pulchella	0.1	15 cm		0.1	10 cm	
Euphorbia australis var. *subtomentosa*	0.1	5 cm	BIL07-02	0.1	6 cm	BILR07-01
Euphorbia trigonosperma	0.1	15 cm	BIL07-06			
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm		0.1	40 cm	
Goodenia prostrata	0.1	3 cm		0.1	8 cm	
Gossypium australe	0.1	160 cm		0.1	120 cm	
Heliotropium inexplicitum	0.1	15 cm	BIL07-10			
Hibiscus sturtii var. *platychlamys*	0.1	45 cm		0.1	40 cm	
Indigofera colutea	0.1	10 cm		0.1	10 cm	
Indigofera linifolia	0.1	25 cm				
Melhania oblongifolia	0.1	30 cm				
Paspalidium clementii	0.1	10 cm	BIL07-07			
Perotis rara	0.1	20 cm				

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Portulaca oleracea/intraterranea	0.1	7 cm	BIL07-03	0.1	5 cm	
Ptilotus obovatus var. *obovatus*	0.5	60 cm		0.5	90 cm	
Rhynchosia minima	0.1	30 cm		0.1	130 cm	
Salsola australis	0.1	15 cm		0.1	10 cm	
Scaevola spinescens	1	90 cm		0.5	90 cm	
Senna artemisioides subsp. *helmsii*	0.1	40 cm				
Senna artemisioides subsp. *oligophylla*	0.5	140 cm	BIL07-13	0.1	90 cm	
Senna glutinosa subsp. *glutinosa*	0.1	150 cm		0.1	150 cm	
Senna notabilis	0.1	10 cm		0.1	60 cm	
Sida arsiniata	0.1	40 cm	BIL07-05	0.1	30 cm	
Sida echinocarpa	0.1	50 cm		0.1	50 cm	
Sida fibulifera	0.1	30 cm	BIL07-08			
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	25 cm		0.1	25 cm	
Solanum lasiophyllum	0.1	45 cm		0.1	50 cm	
Sporobolus australasicus	0.1	15 cm		0.1	15 cm	
Streptoglossa decurrens				0.1	50 cm	
Swainsona formosa				0.1	25 cm	
Swainsona maccullochiana	0.1	20 cm	BIL07-12			
Tragus australianus	0.1	20 cm				
Tribulus astrocarpus	0.1	10 cm		0.1	6 cm	
Tribulus terrestris	0.1	15 cm	BIL07-09	0.1	5 cm	
Triodia pungens	11	50 cm	BIL07-01	15	40 cm	
Waltheria indica	0.1	10 cm				

BIL07 Phase 1

BIL07 Phase 2

Yandi Billiards Level 2 BIL08

Described by PLCA Date 10-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 743271 mE, 7484025 mN.

Habitat Gently sloping plain to the N of range.

Soil Dark reddish brown sandy loam with cobbles (10 %), pebbles (80 %) and gravel (10%).

Rock Type Ironstone

Vegetation *Grevillea wickhamii* subsp. *hispidula, Acacia pruinocarpa, A. ancistrocarpa* tall open shrubland over *Bonamia erecta, Senna artemisioides* subsp. *oligophylla, Corchorus tectus* low open shrubland over *Triodia basedowii* open hummock grassland.

Veg Condition Excellent.

Fire Age Very long unburnt.

Notes Elevation: 478 m. Scattered *Eucalyptus leucophloia* and *Corymbia hamersleyana* in the surrounding area.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	40 cm	
Acacia ancistrocarpa	1	200 cm	BIL08-08
Acacia dictyophleba	0.1	160 cm	
Acacia pachyacra	0.1	40 cm	
Acacia pruinocarpa	1	210 cm	
Aristida holathera var. *holathera*	0.1	30 cm	
Aristida inaequiglumis	0.1	80 cm	BIL08-09
Bonamia erecta	2	70 cm	
Cleome viscosa	0.1	40 cm	
Corchorus tectus	0.5	40 cm	BIL08-06
Cymbopogon obtectus	0.1	90 cm	BIL08-03
Dampiera candicans	0.1	35 cm	
Dicrastylis cordifolia	0.1	50 cm	
Dodonaea coriacea	0.1	20 cm	
Eragrostis eriopoda	0.1	30 cm	
Goodenia microptera	0.1	40 cm	
Gossypium australe	0.1	140 cm	
Grevillea wickhamii subsp. *hispidula*	2	420 cm	BIL08-07
Hakea chordophylla	0.1	30 cm	
Heliotropium pachyphyllum	0.1	25 cm	BIL08-02
Hybanthus aurantiacus	0.1	45 cm	
Indigofera monophylla	0.1	35 cm	
Paraneurachne muelleri	0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	40 cm	
Senna artemisioides subsp. *helmsii*	0.1	100 cm	
Senna artemisioides subsp. *oligophylla*	0.5	90 cm	BIL08-04, BIL08-10
Senna glutinosa subsp. *pruinosa*	0.1	210 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	150 cm	
Senna notabilis	0.1	3 cm	
Sida arenicola	0.1	110 cm	
Sida cardiophylla	0.1	80 cm	BIL08-05
Sida echinocarpa	0.1	70 cm	
Solanum lasiophyllum	0.1	110 cm	
Tribulus macrocarpus	0.1	20 cm	
Triodia basedowii	13	45 cm	BIL08-01

BIL08

Yandi Billiards Level 2 BIL09

Described by PLCA Date 10-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 742897 mE, 7484264 mN

Habitat Floodplain.

Soil Dark red brown sandy loam with Ironstone cobbles (10 %), pebbles (20 %), and gravel (40 %).

Rock Type Ironstone.

Vegetation *Corymbia hamersleyana* scattered low trees over *Acacia sclerosperma* subsp. *sclerosperma, A. pruinocarpa, A. pyrifolia* var. *pyrifolia* tall open shrubland over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris* very open tussock grassland.

Veg Condition Good (**Cenchrus ciliaris, *Setaria verticillata*).

Fire Age No sign of recent fire.

Notes Elevation: 461 m.

Species	Cover (%)	Height (cm)	Specimen
Abutilon leucopetalum	0.1	40 cm	BIL09-04
Abutilon otocarpum	0.1	50 cm	
Acacia citrinoviridis	0.1	250 cm	
Acacia pruinocarpa	1	420 cm	
Acacia pyrifolia var. *pyrifolia*	1	400 cm	
Acacia sclerosperma subsp. *sclerosperma*	3	300 cm	
Aristida contorta	0.1	30 cm	
Aristida holathera var. *holathera*	0.1	50 cm	
Atalaya hemiglauca	0.1	250 cm	
Boerhavia coccinea	0.1	10 cm	
Cenchrus ciliaris	4	60 cm	
Chrysopogon fallax	0.1	150 cm	
Cleome viscosa	0.1	60 cm	
Corchorus sidoides subsp. *sidoides*	0.1	40 cm	
Corymbia hamersleyana	2	750 cm	
Cucumis variabilis	0.1	40 cm	
Duperreya commixta	0.1	100 cm	
Enneapogon caerulescens	0.1	30 cm	BIL09-10
Eragrostis eriopoda	0.1	40 cm	
Eremophila longifolia	0.1	200 cm	
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL09-06
Euphorbia trigonosperma	0.1	40 cm	BIL09-03
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Heliotropium inexplicitum	0.1	10 cm	BIL09-09
Hibiscus sturtii var. *platychlamys*	0.1	60 cm	
Indigofera colutea	0.1	20 cm	
Mollugo molluginea	0.1	20 cm	
Paraneurachne muelleri	0.1	70 cm	
Portulaca oleracea/intraterranea	0.1	8 cm	BIL09-11
Rhynchosia minima	0.1	80 cm	
Senna artemisioides subsp. *helmsii*	0.1	120 cm	
Senna artemisioides subsp. *oligophylla*	0.1	120 cm	BIL09-05
Setaria verticillata	0.1	60 cm	
Sida arsiniata	0.1	50 cm	BIL09-15, BIL09-14
Sida echinocarpa	0.1	60 cm	BIL09-07
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	10 cm	BIL09-13
Solanum lasiophyllum	0.1	30 cm	
Tephrosia supina	0.1	20 cm	BIL09-12
Trianthema pilosum	0.1	5 cm	
Tribulus astrocarpus	0.1	10 cm	
Tribulus macrocarpus	0.1	20 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	5 cm	
Triodia basedowii	0.1	30 cm	

Species	Cover (%)	Height (cm)	Specimen
Triodia pungens	15	40 cm	BIL09-01

BIL09

Yandi Billiards Level 2 BIL10

Described by Phase 1: SVSW, Phase 2: PA/PL Date Phase 1: 09-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 741890 mE, 7484313 mN.

Habitat Plain.

Soil Dark reddish brown (2.5YR 2.5/4) sandy clay.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia pruinocarpa, Atalaya hemiglauca, Acacia inaequilatera, Acacia sclerosperma* subsp. *sclerosperma* tall open shrubland over *Triodia pungens* hummock grassland with **Cenchrus ciliaris, *C. setiger* very open tussock grassland.

Phase 2: *Acacia pruinocarpa, Atalaya hemiglauca, Acacia inaequilatera, Acacia sclerosperma* subsp. *sclerosperma* tall open shrubland over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris, *C. setiger* very open tussock grassland.

Veg Condition Phase 1: Good (**Cenchrus* spp.). Phase 2: Good (**Cenchrus* spp.).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Elevation: 467 m.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	100 cm	BIL10-06	0.1	100 cm	
Acacia citrinoviridis				0.1	180 cm	
Acacia inaequilatera	1	310 cm		1	310 cm	
Acacia pruinocarpa	3	310 cm		2	310 cm	
Acacia sclerosperma subsp. *sclerosperma*	1	220 cm		1	270 cm	
Atalaya hemiglauca	2	240 cm		2	300 cm	
Boerhavia coccinea	0.1	10 cm	BIL10-02	0.1	30 cm	
Bothriochloa ewartiana	0.1	70 cm		0.1	110 cm	
Cenchrus ciliaris	5	45 cm		7	70 cm	
Cenchrus setiger	1	45 cm		1	70 cm	
Chrysopogon fallax	0.1	120 cm		0.1	130 cm	
Cleome viscosa	0.1	30 cm		0.1	50 cm	
Corchorus sidoides subsp. *sidoides*	0.1	40 cm	BIL10-05	0.1	50 cm	
Crotalaria medicaginea var. *neglecta*	0.1	15 cm		0.1	40 cm	
Digitaria ctenantha				0.1	40 cm	
Duperreya commixta	0.1	450 cm		0.1	310 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	40 cm	
Eragrostis tenellula	0.1	15 cm				
Euphorbia australis var. *subtomentosa*				0.1	15 cm	BILR10-04
Euphorbia biconvexa	0.1	10 cm	BIL10-10	0.1	20 cm	BILR10-02
Evolvulus alsinoides var. *villosicalyx*				0.1	25 cm	
Glycine canescens	0.1	10 cm	BIL10-03	0.1	80 cm	
Goodenia microptera	0.1	20 cm		0.1	25 cm	
Gossypium australe	0.1	120 cm		0.1	170 cm	
Hakea lorea subsp. *lorea*	0.1	580 cm		0.1	400 cm	
Hibiscus sturtii var. *platychlamys*	0.1	20 cm	BIL10-07	0.1	30 cm	
Hybanthus aurantiacus	0.1	10 cm				
Indigofera colutea	0.1	25 cm	BIL10-01	0.1	10 cm	
Indigofera linifolia	0.1	20 cm		0.1	25 cm	
Iseilema membranaceum	0.1	25 cm	BIL10-09	0.1	30 cm	
Perotis rara	0.1	10 cm				
Polymeria ambigua	0.1	10 cm	BIL10-08			
Ptilotus obovatus var. *obovatus*	0.1	45 cm		0.1	70 cm	
Rhagodia eremaea	0.1	100 cm		0.1	100 cm	
Rhynchosia minima	0.1	60 cm		0.1	40 cm	
Senna artemisioides subsp. *helmsii*	0.1	40 cm		0.1	60 cm	
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	BIL10-04	0.1	100 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	60 cm	BIL10-13	0.1	75 cm	
Senna glutinosa subsp. *glutinosa*	0.1	220 cm		0.1	210 cm	
Sida echinocarpa	0.1	70 cm		0.1	70 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Sida fibulifera				0.1	25 cm	BILR10-03
Solanum lasiophyllum	0.1	100 cm		0.1	100 cm	
Sporobolus australasicus				0.1	15 cm	
Swainsona formosa				0.1	20 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	25 cm				
Tephrosia supina	0.1	30 cm	BIL10-12	0.1	40 cm	
Tribulus macrocarpus	0.1	20 cm				
Trichodesma zeylanicum var. *zeylanicum*	0.1	100 cm		0.1	100 cm	
Triodia pungens	65	60 cm		25	70 cm	BILR10-01

BIL10 Phase 1

BIL10 Phase 2

Yandi Billiards Level 2 BIL11

Described by Phase 1: PLCA, Phase 2: PA/PL Date Phase 1: 11-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 737797 mE, 7481466 mN.

Habitat Drainage plain.

Soil Dark red brown fine sandy loam with patches of sandy clay loam in low areas with 1-25% cover of pebbles and 25-50% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana, Eucalyptus gamophylla* low open woodland over *Gossypium robinsonii, Acacia adsurgens, A. elachantha* tall open shrubland over *Acacia ancistrocarpa, A. dictyophleba, A. tenuissima, Petalostylis cassioides* open shrubland over *Bonamia erecta* low open shrubland over *Triodia basedowii, T. pungens* very open hummock grassland and *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland.
Phase 2: *Corymbia hamersleyana, Eucalyptus gamophylla* low open woodland over *Acacia elachantha, Gossypium robinsonii* very tall open shrubland over *Petalostylis cassioides, Acacia ancistrocarpa, A. adsurgens, A. dictyophleba* open shrubland over *Bonamia erecta* very open low shrubland over *Triodia basedowii, T. pungens* very open hummock grassland and *Aristida holathera* var. *holathera, Paraneurachne muelleri, Chrysopogon fallax, Themeda tri*andra very open tussock grassland.

Veg Condition Phase 1: Very Good (**Setaria verticillata*, scats). Phase 2: Very Good (**Setaria verticillata*).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	40 cm		0.1	40 cm	
Acacia adoxa var. *adoxa*	0.1	80 cm		0.1	70 cm	
Acacia adsurgens	1	210 cm		2	170 cm	
Acacia ancistrocarpa	0.1	170 cm		5	190 cm	
Acacia aptaneura				0.1	200 cm	BILR11-01
Acacia citrinoviridis	1	210 cm		0.1	220 cm	
Acacia dictyophleba	2	170 cm		2	180 cm	
Acacia elachantha	5	250 cm	BIL11-13	1	260 cm	
Acacia inaequilatera	0.1	270 cm		0.1	350 cm	
Acacia pachyacra				0.1	250 cm	
Acacia pruinocarpa	0.1	230 cm		0.1	250 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	160 cm		0.1	150 cm	
Acacia tenuissima	1	140 cm		0.1	160 cm	
Acacia tumida var. *pilbarensis*	0.1	210 cm		0.1	150 cm	
Aristida holathera var. *holathera*	1	40 cm		1	50 cm	
Atalaya hemiglauca				0.1	50 cm	
Boerhavia coccinea	0.1	30 cm		0.1	25 cm	
Bonamia erecta	2	70 cm		2	50 cm	
Chrysopogon fallax	0.1	110 cm		1	100 cm	
Cleome viscosa	0.1	60 cm		0.1	50 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	60 cm				
Corchorus tectus	0.1	40 cm	BIL11-02	0.1	50 cm	
Corchorus tridens	0.1	20 cm				
Corymbia hamersleyana	2	850 cm		2	450 cm	
Cucumis variabilis	0.1	110 cm		0.1	20 cm	
Dicrastylis cordifolia	0.1	60 cm		0.1	60 cm	
Digitaria brownii	0.1	100 cm		0.1	100 cm	
Duperreya commixta	0.1	150 cm		0.1	40 cm	
Dysphania sp.	0.1	5 cm				
Enneapogon lindleyanus	0.1	60 cm	BIL11-10			
Enneapogon polyphyllus	0.1	40 cm	BIL11-12			
Eragrostis eriopoda	0.1	40 cm	BIL11-03	0.1	30 cm	
Eremophila forrestii subsp. *forrestii*	0.1	100 cm		0.1	90 cm	
Eremophila longifolia	0.1	170 cm		0.1	170 cm	
Eriachne mucronata (typical form)	0.1	40 cm		0.1	40 cm	
Eucalyptus gamophylla	2	400 cm		2	280 cm	
Eulalia sp. (Three Rivers Station, B.Forsyth AQ6789133)	0.1	60 cm	BIL11-11	0.1	40 cm	
Euphorbia australis var. *hispidula*	0.1	20 cm	BIL11-06			
Euphorbia biconvexa/coghlanii/trigonosperma	0.1	40 cm				

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Euphorbia tannensis subsp. *eremophila*				0.1	30 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm		0.1	30 cm	
Gomphrena cunninghamii	0.1	20 cm				
Goodenia microptera				0.1	50 cm	
Gossypium robinsonii	1	320 cm		0.1	400 cm	
Hakea lorea subsp. *lorea*				0.1	180 cm	
Hibiscus burtonii	0.1	60 cm	BIL11-04	0.1	50 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm		0.1	30 cm	
Indigofera georgei	0.1	60 cm		0.1	110 cm	
Indigofera monophylla	0.1	60 cm	BIL11-08	0.1	50 cm	
Iseilema membranaceum	0.1	25 cm	BIL11-09	0.1	25 cm	BILR11-02
Paraneurachne muelleri	1	40 cm		1	40 cm	
Paspalidium clementii				0.1	30 cm	BILR11-04
Paspalidium rarum	0.1	25 cm		0.1	40 cm	
Petalostylis cassioides	7	160 cm	BIL12-17=	6	180 cm	
Ptilotus astrolasius	0.1	40 cm				
Ptilotus obovatus var. *obovatus*	0.1	60 cm		0.1	80 cm	
Rhyncharrhena linearis	0.1	80 cm				
Rhynchosia minima	0.1	40 cm				
Salsola australis				0.1	40 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	50 cm		0.1	30 cm	
Senna artemisioides subsp. *helmsii*				0.1	50 cm	
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	BIL11-07	0.1	90 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*				0.1	70 cm	BILR11-03
Senna notabilis	0.1	20 cm		0.1	25 cm	
Setaria verticillata	0.1	90 cm		0.1	70 cm	
Sida cardiophylla	0.1	80 cm		0.1	90 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)				0.1	100 cm	
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	30 cm		0.1	25 cm	
Solanum phlomoides	0.1	40 cm		0.1	40 cm	
Themeda triandra	0.1	100 cm		1	110 cm	
Tribulopis angustifolia	0.1	30 cm	BIL11-05			
Tribulus macrocarpus	0.1	20 cm				
Trichodesma zeylanicum var. *zeylanicum*	0.1	120 cm		0.1	30 cm	
Triodia basedowii	7	40 cm		5	50 cm	
Triodia pungens	1	40 cm	BIL11-01	0.1	70 cm	
Yakirra australiensis var. *australiensis*				0.1	10 cm	

BIL11 Phase 1

BIL11 Phase 2

Yandi Billiards Level 2 BIL12

Described by Phase 1: PLCA, Phase 2: CEFSW Date Phase 1: 11-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 738244 mE, 7482579 mN.

Habitat Broad drainage plain/valley.

Soil Dark reddish brown fine sandy loam with 1-25% cover of pebbles and gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana* scattered low trees over *Acacia pyrifolia* var. *pyrifolia* (*A. tumida* var. *pilbarensis, Gossypium robinsonii, Petalostylis cassioides*) tall shrubland over *Triodia pungens* very open hummock grassland with **Cenchrus ciliaris, *C. setiger* open tussock grassland.

Phase 2: *Corymbia hamersleyana* scattered low trees over *Acacia pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis* tall shrubland over *Triodia pungens* very open hummock grassland with **Cenchrus ciliaris, *C. setiger* tussock

Veg Condition Phase 1: Good (**Cenchrus* spp., cattle scats). Phase 2: Good (**Cenchrus* spp.; cattle activity).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	40 cm		0.1	8 cm	
Acacia maitlandii	0.1	50 cm		0.1	100 cm	
Acacia pyrifolia var. *pyrifolia*	7	220 cm		11	350 cm	
Acacia spondylophylla	0.1	40 cm		0.1	45 cm	
Acacia tumida var. *pilbarensis*	2	220 cm		3	190 cm	
Aristida contorta	0.1	30 cm		0.1	15 cm	
Aristida holathera var. *holathera*	0.1	45 cm		0.1	30 cm	
Atalaya hemiglauca	0.1	140 cm		0.1	150 cm	
Boerhavia coccinea	0.1	40 cm		0.1	10 cm	
Bonamia erecta	0.1	40 cm		0.1	60 cm	
Cenchrus ciliaris	14	80 cm		33	60 cm	
Cenchrus setiger	4	90 cm		0.5	50 cm	
Cleome viscosa	0.1	50 cm		0.1	50 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	70 cm				
Corchorus tectus	0.1	40 cm	BIL12-12			
Corchorus tridens	0.1	25 cm	BIL12-03			
Corymbia hamersleyana	1.5	700 cm		2	700 cm	
Crotalaria medicaginea var. *neglecta*	0.1	45 cm				
Cucumis variabilis	0.1	90 cm		0.1	100 cm	
Eragrostis eriopoda	0.1	40 cm	BIL12-20	0.1	15 cm	
Euphorbia australis var. *subtomentosa*	0.1	15 cm	BIL12-22	0.1	15 cm	
Euphorbia tannensis subsp. *eremophila*				0.1	30 cm	BILR12-03
Euphorbia trigonosperma	0.1	60 cm	BIL12-18			
Evolvulus alsinoides var. *decumbens*	0.1	20 cm	BIL12-21	0.1	20 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm		0.1	10 cm	
Gomphrena cunninghamii	0.1	15 cm				
Goodenia microptera	0.1	40 cm		0.1	20 cm	
Goodenia stobbsiana				0.1	10 cm	
Gossypium australe	0.1	80 cm				
Gossypium robinsonii	2	210 cm		0.1	250 cm	
Grevillea wickhamii subsp. *hispidula*	1	230 cm	BIL12-09	0.1	230 cm	
Heliotropium cunninghamii	0.1	25 cm	BIL12-11			
Hibiscus sturtii var. *campylochlamys*	0.1	35 cm	BIL12-19	0.1	35 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm		0.1	50 cm	
Hybanthus aurantiacus	0.1	45 cm		0.1	40 cm	
Indigofera georgei	0.1	60 cm	BIL12-23	0.1	45 cm	
Indigofera linifolia	0.1	30 cm				
Maireana villosa				0.1	30 cm	BILR12-05
Melhania oblongifolia	0.1	50 cm	BIL12-06			
Mollugo molluginea	0.1	20 cm				
Paraneurachne muelleri	0.1	40 cm		0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Paspalidium rarum	0.1	30 cm	BIL12-15			
Perotis rara	0.1	10 cm				
Petalostylis cassioides	2	220 cm	BIL12-17	0.1	200 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	25 cm	BIL12-04			
Polymeria ambigua	0.1	20 cm	BIL12-14			
Portulaca intraterranea	0.1	15 cm	BIL12-13			
Ptilotus astrolasius	0.1	50 cm		0.1	30 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm		0.1	110 cm	
Rhynchosia minima				0.1	15 cm	
Salsola australis	0.1	30 cm		0.1	15 cm	
Senna artemisioides subsp. *helmsii*	0.1	50 cm		0.1	20 cm	
Senna artemisioides subsp. *oligophylla*	0.1	80 cm				
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	70 cm	BIL12-08	0.1	45 cm	
Senna notabilis	0.1	20 cm		0.1	10 cm	
Sida fibulifera	0.1	30 cm	BIL12-10	0.1	25 cm	BILR12-01
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	130 cm		0.1	130 cm	
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	35 cm	BIL12-01	0.1	20 cm	BILR12-02
Solanum lasiophyllum	0.1	40 cm		0.1	15 cm	
Solanum phlomoides	0.1	50 cm		0.1	40 cm	
Swainsona maccullochiana				0.1	15 cm	BILR12-07
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	60 cm		0.1	45 cm	BILR12-06
Trianthema pilosum	0.1	25 cm				
Tribulus macrocarpus	0.1	25 cm		0.1	10 cm	
Trichodesma zeylanicum var. *zeylanicum*				0.1	130 cm	
Triodia pungens	2	40 cm	BIL12-02	2	55 cm	
Triraphis mollis	0.1	30 cm	BIL12-05			
Waltheria indica	0.1	60 cm		0.1	55 cm	
Yakirra australiensis var. *australiensis*	0.1	25 cm	BIL12-16			

BIL12 Phase 1

BIL12 Phase 2

Yandi Billiards Level 2 BIL13

Described by SVSW Date 12-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 736238 mE, 7479815 mN.

Habitat Colluvial plain between two low lying undulating hill ranges.

Soil 5YR 3/3 dark reddish brown sandy loam with cobbles (20 %), pebbles (30 %), and gravel (20 %).

Rock Type Ironstone.

Vegetation *Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. inaequilatera* scattered tall shrubs over *Indigofera monophylla, Ptilotus astrolasius, Senna artemisioides* subsp. *oligophylla* low open shrubland over *Triodia basedowii* open hummock grassland.

Veg Condition Very Good (**Cenchrus ciliaris*).

Fire Age No sign of recent fire.

Notes Elevation: 500 m. Greater plain dissected by minor drainages/flowlines of *Acacia tumida, A. citrinoviridis, Gossypium robinsonii, Eucalyptus gamophylla*.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	45 cm	
Acacia bivenosa (wispy/weeping form)	0.1	180 cm	
Acacia citrinoviridis	1	460 cm	
Acacia inaequilatera	0.5	240 cm	
Acacia tumida var. *pilbarensis*	0.1	220 cm	
Aristida holathera var. *holathera*	0.1	40 cm	
Boerhavia coccinea	0.1	5 cm	
Cenchrus ciliaris	0.1	60 cm	
Cleome viscosa	0.1	15 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	25 cm	BIL13-04
Corymbia hamersleyana	1	460 cm	
Cymbopogon obtectus	0.1	100 cm	
Dodonaea coriacea	0.1	80 cm	
Eragrostis eriopoda	0.1	40 cm	
Eriachne pulchella	0.1	20 cm	
Euphorbia australis var. *hispidula*	0.1	12 cm	BIL13-08
Goodenia stobbsiana	0.1	20 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	220 cm	
Hakea chordophylla	0.1	410 cm	
Hybanthus aurantiacus	0.1	15 cm	
Indigofera monophylla	1	70 cm	BIL13-01
Jasminum didymum subsp. *lineare*	0.1	200 cm	
Mollugo molluginea	0.1	15 cm	
Paraneurachne muelleri	0.1	80 cm	
Polymeria ambigua	0.1	25 cm	BIL13-07
Ptilotus astrolasius	0.5	35 cm	
Ptilotus calostachyus	0.1	45 cm	
Ptilotus clementii	0.1	10 cm	BIL13-09
Ptilotus nobilis subsp. *nobilis*	0.1	15 cm	
Senna artemisioides subsp. *oligophylla*	0.5	90 cm	BIL13-03
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	30 cm	BIL13-06
Sida arenicola	0.1	20 cm	BIL13-11
Sida cardiophylla	0.1	45 cm	BIL13-10
Solanum lasiophyllum	0.1	10 cm	
Triodia basedowii	22	40 cm	BIL13-02
Triodia pungens	0.1	70 cm	BIL13-05

BIL13

Yandi Billiards Level 2 BIL14

Described by PLCA Date 12-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 737046 mE, 7480911 mN.

Habitat Broad plain with some drainage.

Soil Dark reddish brown fine sandy loam with ironstone boulders, cobbles, pebbles, and gravel.

Rock Type Ironstone with ?basalt outcropping.

Vegetation *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, Petalostylis cassioides, Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* open shrubland over *Triodia basedowii, T. pungens* very open hummock grassland.

Veg Condition Very Good (**Cenchrus* spp., evidence of cattle).

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	60 cm	
Acacia adsurgens	0.1	90 cm	
Acacia ancistrocarpa	0.1	50 cm	
Acacia bivenosa (wispy/weeping form)	0.1	200 cm	
Acacia citrinoviridis	0.1	150 cm	
Acacia dictyophleba	0.1	80 cm	
Acacia elachantha	0.1	190 cm	
Acacia inaequilatera	0.1	230 cm	
Acacia pachyacra	0.1	170 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	40 cm	
Acacia tenuissima	0.1	140 cm	
Acacia tumida var. *pilbarensis*	3	190 cm	
Aristida holathera var. *holathera*	0.1	50 cm	
Aristida hygrometrica	0.1	20 cm	BIL14-09
Aristida inaequiglumis	1	110 cm	BIL14-13
Boerhavia coccinea	0.1	10 cm	
Bonamia erecta	0.1	40 cm	
Cenchrus ciliaris	0.1	40 cm	
Cleome viscosa	0.1	60 cm	
Corchorus tectus	1	50 cm	BIL14-03
Corchorus tridens	0.1	5 cm	BIL14-12
Corymbia hamersleyana	4	700 cm	
Crotalaria medicaginea var. *neglecta*	0.1	50 cm	
Dicrastylis cordifolia	0.1	40 cm	
Eragrostis eriopoda	0.1	40 cm	
Eriachne aristidea	0.1	50 cm	
Euphorbia australis var. *subtomentosa*	0.1	20 cm	BIL14-14
Euphorbia biconvexa	0.1	10 cm	BIL14-08
Euphorbia tannensis subsp. *eremophila*	0.1	20 cm	BIL14-10
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm	
Gomphrena affinis subsp. *pilbarensis*	0.1	30 cm	BIL14-18
Goodenia microptera	0.1	25 cm	
Gossypium australe	0.1	60 cm	
Gossypium robinsonii	0.1	140 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	80 cm	
Hakea chordophylla	0.1	140 cm	
Hakea lorea subsp. *lorea*	0.1	140 cm	
Hibiscus sturtii var. *platychlamys*	0.1	60 cm	
Hybanthus aurantiacus	0.1	60 cm	
Indigofera monophylla	0.1	40 cm	BIL14-06
Melhania oblongifolia	0.1	20 cm	
Paraneurachne muelleri	0.1	40 cm	
Paspalidium rarum	0.1	10 cm	BIL14-15

Species	Cover (%)	Height (cm)	Specimen
Petalostylis cassioides	2	160 cm	
Polymeria ambigua	0.1	5 cm	BIL14-04
Portulaca oleracea/intraterranea	0.1	5 cm	BIL14-17
Ptilotus astrolasius	0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	30 cm	
Rhagodia eremaea	0.1	110 cm	
Rhynchosia minima	0.1	120 cm	
Salsola australis	0.1	30 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	35 cm	
Senna artemisioides subsp. *oligophylla*	0.1	50 cm	BIL14-02
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	1	120 cm	BIL14-16
Senna notabilis	0.1	20 cm	
Sida cardiophylla	0.1	70 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	30 cm	BIL14-07, BIL14-11
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	20 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	20 cm	
Themeda triandra	0.1	90 cm	
Trianthema pilosum	0.1	10 cm	
Tribulopis angustifolia	0.1	30 cm	
Triodia basedowii	7	40 cm	
Triodia pungens	2	30 cm	BIL14-01
Waltheria indica	0.1	20 cm	
Yakirra australiensis var. *australiensis*	0.1	10 cm	BIL14-05

BIL14

Yandi Billiards Level 2 BIL15

Described by Phase 1: PLSV, Phase 2: PA/PL Date Phase 1: 18-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 737722 mE, 7476773 mN.

Habitat Hill slope up to crest in a broader area of ranges to the E of major drainage.

Soil Dark reddish brown sandy loam with 1-25% cover of cobbles, 51-75% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia inaequilatera* scattered tall shrubs over *Indigofera monophylla, Ptilotus astrolasius, P. rotundifolius* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) open hummock

Phase 2: *Acacia inaequilatera* scattered tall shrubs over *Indigofera monophylla, Ptilotus astrolasius, P. rotundifolius* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) open hummock

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: Burnt 3-5 years ago. Phase 2: Burnt 3-5 years ago.

Notes Elevation: 526 m

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	30 cm		0.1	30 cm	
Acacia inaequilatera	1	300 cm		1	310 cm	
Acacia pruinocarpa	0.1	50 cm		0.1	60 cm	
Amphipogon sericeus	0.1	30 cm	BIL15-05	0.1	35 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	15 cm		0.1	8 cm	
Cleome viscosa	0.1	5 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	50 cm	BIL15-02	0.1	70 cm	
Dampiera candicans	0.1	40 cm		0.1	30 cm	
Dodonaea coriacea	0.1	30 cm				
Eriachne pulchella	0.1	10 cm		0.1	20 cm	
Evolvulus alsinoides	0.1	20 cm				
Fimbristylis dichotoma	0.1	20 cm				
Fimbristylis simulans	0.1	15 cm		0.1	25 cm	
Goodenia microptera	0.1	20 cm				
Goodenia stobbsiana	0.1	35 cm		0.1	40 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	70 cm		0.1	80 cm	
Hakea chordophylla	0.1	190 cm		0.1	170 cm	
Heliotropium pachyphyllum	0.1	20 cm	BIL15-03	0.1	20 cm	
Heliotropium tenuifolium	0.1	25 cm	BIL15-04	0.1	25 cm	
Indigofera monophylla	2	40 cm	BIL15-01	2	40 cm	
Isotropis atropurpurea	0.1	30 cm		0.1	30 cm	
Mollugo molluginea	0.1	25 cm		0.1	25 cm	
Paraneurachne muelleri	0.1	40 cm		0.1	30 cm	
Ptilotus astrolasius	0.5	30 cm		0.5	40 cm	
Ptilotus calostachyus	0.1	50 cm		0.1	80 cm	
Ptilotus clementii				0.1	50 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	10 cm		0.1	25 cm	
Ptilotus rotundifolius	0.5	50 cm		0.5	90 cm	
Senna artemisioides subsp. *helmsii*	0.1	45 cm		0.1	40 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	15 cm		0.1	25 cm	
Senna glutinosa subsp. *glutinosa*	0.1	160 cm		0.1	90 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	40 cm		0.1	80 cm	
Sida sp. *Pilbara* (A.A. Mitchell PRP 1543)	0.1	35 cm		0.1	50 cm	
Solanum lasiophyllum	0.1	40 cm		0.1	50 cm	
Solanum phlomoides	0.1	50 cm		0.1	60 cm	
Tephrosia oxalidea				0.1	6 cm	BILR15-01
Tephrosia supina	0.1	20 cm	BIL15-06			
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	12	30 cm		12	30 cm	
Triodia wiseana	0.5	30 cm		0.5	30 cm	

BIL15 Phase 1

BIL15 Phase 2

Yandi Billiards Level 2		BIL16	
Described by	Phase 1: CEFCASW, Phase 2: PA/PL	Date	Phase 1: 18-Mar-14, Phase 2: 09-Jul-14
Type	Quadrat 25 x 100 m		
Central Coordinate	737466 mE, 7476191 mN.		
Habitat	Minor flow lines and banks of meandering incised drainage line (approx. 2.5 m wide).		
Soil	Dark reddish brown sandy loam with 1-25% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.		
Rock Type	Riverstone.		
Vegetation	Phase 1: *Eucalyptus gamophylla, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, A. pyrifolia* var. *pyrifolia, Grevillea wickhamii* subsp. *hispidula, Gossypium robinsonii* tall shrubland over *Triodia pungens* open hummock grassland and **Cenchrus ciliaris, Themeda tri*andra, *Paraneurachne muelleri, Bothriochloa ewartiana* open tussock grassland. Phase 2: *Eucalyptus gamophylla, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, A. pyrifolia* var. *pyrifolia, Grevillea wickhamii* subsp. *hispidula, Gossypium robinsonii, Petalostylis cassioides* tall shrubland over *Triodia pungens* very open hummock grassland with **Cenchrus ciliaris, Themeda tri*andra, *Paraneurachne muelleri, Digitaria brownii* open tussock grassland.		
Veg Condition	Phase 1: Good (**Cenchrus ciliaris, *Setaria verticillata, *Bidens bipinnata, *Malvastrum americanum*). Phase 2: Good (**Cenchrus ciliaris, *Bidens bipinnata*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon amplum	0.1	150 cm	BIL16-39	0.1	140 cm	
Abutilon lepidum				0.1	50 cm	
Abutilon macrum	0.1	10 cm	BIL16-09			
Abutilon otocarpum	0.1	70 cm		0.1	50 cm	
Acacia adoxa var. *adoxa*	0.1	50 cm		0.1	60 cm	
Acacia ancistrocarpa	0.1	300 cm		0.1	220 cm	
Acacia bivenosa	0.1	200 cm		0.1	220 cm	
Acacia dictyophleba	0.1	320 cm		0.1	240 cm	
Acacia monticola				0.1	70 cm	
Acacia pyrifolia var. *pyrifolia*	3	350 cm		4	320 cm	
Acacia spondylophylla	0.1	120 cm	BIL16-40	0.1	120 cm	
Acacia tenuissima	0.1	150 cm	BIL16-38	0.1	180 cm	
Acacia tumida var. *pilbarensis*	11	250 cm	BIL16-02	12	300 cm	
Alternanthera nana	0.1	10 cm	BIL16-12	0.1	15 cm	
Androcalva luteiflora	0.1	210 cm		0.1	200 cm	
Aristida holathera var. *holathera*	0.1	40 cm		0.1	50 cm	
Aristida pruinosa	1	150 cm	BIL16-26	0.1	110 cm	
Bidens bipinnata	0.1	20 cm		0.1	50 cm	
Boerhavia coccinea	0.1	10 cm	BIL16-07			
Bonamia erecta	0.1	20 cm				
Bothriochloa ewartiana	1	60 cm				
Bulbostylis barbata	0.1	10 cm	BIL16-20	0.1	15 cm	
Cenchrus ciliaris	15	60 cm		11	80 cm	
Cleome viscosa	0.1	60 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm	BIL16-17	0.1	95 cm	
Corchorus tridens	0.1	10 cm				
Corymbia hamersleyana	1	420 cm		1	420 cm	
Crotalaria medicaginea var. *neglecta*	0.1	40 cm	BIL16-06	0.1	40 cm	
Cucumis variabilis	0.1	120 cm		0.1	200 cm	
Cymbopogon ambiguus	0.1	80 cm		0.1	100 cm	
Cymbopogon obtectus	0.1	80 cm		0.1	50 cm	
Cymbopogon procerus				0.1	110 cm	
Dicrastylis cordifolia				0.1	50 cm	
Digitaria brownii	0.1	70 cm	BIL16-04	2	70 cm	
Digitaria ctenantha	0.1	60 cm	BIL16-08	0.1	20 cm	
Duperreya commixta	0.1	400 cm		0.1	200 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	20 cm	BIL16-32			
Enneapogon caerulescens	0.1	15 cm	BIL16-16			
Enneapogon lindleyanus	0.1	60 cm	BIL16-35	0.1	45 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Enneapogon polyphyllus	0.1	30 cm		0.1	30 cm	
Enneapogon robustissimus				0.1	90 cm	
Eragrostis cumingii	0.1	20 cm		0.1	25 cm	
Eragrostis eriopoda				0.1	50 cm	
Eriachne mucronata (typical form)	0.1	60 cm	BIL16-25	0.1	45 cm	
Eucalyptus gamophylla	2	300 cm		3	230 cm	
Euphorbia australis var. *subtomentosa*	0.1	30 cm	BIL16-22	0.1	15 cm	BILR16-01
Euphorbia biconvexa	0.1	30 cm	BIL16-42	0.1	40 cm	BILR16-02
Evolvulus alsinoides var. *decumbens*	0.1	20 cm		0.1	25 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm		0.1	25 cm	
Gomphrena cunninghamii	0.1	20 cm	BIL16-36			
Goodenia microptera				0.1	30 cm	
Goodenia muelleriana	0.1	60 cm	BIL16-14	0.1	45 cm	
Goodenia stobbsiana	0.1	40 cm		0.1	50 cm	
Gossypium australe	0.1	160 cm		0.1	100 cm	
Gossypium robinsonii	2	480 cm		3	350 cm	
Grevillea wickhamii subsp. *hispidula*	3	480 cm	BIL16-01	4	400 cm	
Hibiscus sturtii var. *platychlamys*	0.1	30 cm		0.1	50 cm	
Hybanthus aurantiacus	0.1	40 cm	BIL16-18	0.1	45 cm	
Indigofera colutea	0.1	40 cm	BIL16-27	0.1	30 cm	
Indigofera georgei	0.1	40 cm	BIL16-41	0.1	80 cm	
Indigofera monophylla				0.1	70 cm	
Iseilema membranaceum	0.1	15 cm	BIL16-23			
Isotropis atropurpurea	0.1	30 cm	BIL16-33	0.1	50 cm	
Jasminum didymum subsp. *lineare*	0.1	210 cm		0.1	100 cm	
Malvastrum americanum	0.1	30 cm				
Melhania oblongifolia	0.1	35 cm		0.1	50 cm	
Mollugo molluginea	0.1	20 cm		0.1	15 cm	
Notoleptopus decaisnei var. *decaisnei*	0.1	20 cm	BIL16-19			
Paraneurachne muelleri	2	60 cm		2	40 cm	
Paspalidium rarum	0.1	10 cm	BIL16-13			
Perotis rara	0.1	10 cm		0.1	20 cm	
Petalostylis cassioides	0.1	220 cm		3	240 cm	
Pluchea dunlopii	0.1	60 cm	BIL16-30	0.1	65 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	10 cm		0.1	15 cm	
Polycarpaea longiflora	0.1	20 cm		0.1	20 cm	
Polymeria ambigua	0.1	10 cm	BIL16-15	0.1	20 cm	
Pterocaulon sphacelatum	0.1	50 cm	BIL16-24, BIL16-44	0.1	40 cm	
Ptilotus astrolasius				0.1	40 cm	
Ptilotus calostachyus	0.1	40 cm		0.1	60 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm		0.1	30 cm	
Rhynchosia minima	0.1	130 cm		0.1	20 cm	
Salsola australis	0.1	15 cm				
Santalum lanceolatum	0.1	160 cm	BIL16-43	0.1	250 cm	
Schizachyrium fragile	0.1	20 cm		0.1	25 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	80 cm	BIL16-10	0.1	80 cm	
Senna artemisioides subsp. x *artemisioides*	0.1	210 cm	BIL16-28	0.1	210 cm	
Senna glutinosa subsp. *glutinosa*	0.1	220 cm	BIL16-37	0.1	130 cm	
Senna notabilis	0.1	10 cm		0.1	25 cm	
Setaria surgens	0.1	20 cm	BIL16-21			
Setaria verticillata	0.1	80 cm				
Sida cardiophylla	0.1	50 cm	BIL16-34	0.1	50 cm	
Sida echinocarpa	0.1	110 cm				

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	150 cm		0.1	90 cm	
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	30 cm	BIL16-03, BIL16-05	0.1	30 cm	
Solanum cleistogamum	0.1	20 cm	BIL16-31			
Solanum lasiophyllum	0.1	40 cm		0.1	60 cm	
Sporobolus australasicus	0.1	10 cm				
Themeda triandra	10	80 cm		7	80 cm	
Trianthema pilosum	0.1	5 cm	BIL16-29			
Tribulus macrocarpus	0.1	10 cm				
Trichodesma zeylanicum var. *zeylanicum*	0.1	40 cm		0.1	120 cm	
Triodia basedowii	0.1	50 cm				
Triodia pungens	9	60 cm	BIL16-11	6	50 cm	
Triodia wiseana	0.1	30 cm		0.1	45 cm	
Waltheria indica	0.1	60 cm		0.1	30 cm	

BIL16 Phase 1

BIL16 Phase 2

Yandi Billiards Level 2 BIL17

Described by Phase 1: CASW, Phase 2: PA/PL Date Phase 1: 18-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 737567 mE, 7475938 mN.

Habitat Upper slopes and crest of a low rocky hill.

Soil Dark reddish brown skeletal fine sandy clay loam with 60% cover of cobbles, 2% cover of pebbles, 2% cover of gravel and 1% cover of boulders.

Rock Type Ironstone

Vegetation Phase 1: (*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees) over *Acacia hilliana, A. spondylophylla* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.
Phase 2: (*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees) over *Acacia hilliana, A. spondylophylla* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Phase 1: Excellent Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire Phase 2: No sign of recent fire.

Notes *Hakea chordophylla* is present in the broader landscape but was not recorded in the quadrat.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia ancistrocarpa	0.1	35 cm	BIL17-17	0.1	40 cm	BILR17-01
Acacia dictyophleba	0.1	30 cm				
Acacia hilliana	3	40 cm		4	50 cm	
Acacia spondylophylla	2	40 cm		2	50 cm	
Amphipogon sericeus	0.1	30 cm	BIL17-08	0.1	35 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	5 cm	BIL17-13			
Corchorus lasiocarpus subsp. *parvus*	0.1	50 cm	BIL17-07	0.1	60 cm	
Dampiera candicans				0.1	45 cm	
Eriachne pulchella				0.1	10 cm	
Eucalyptus leucophloia subsp. *leucophloia*	0.1	300 cm		0.5	300 cm	
Fimbristylis dichotoma	0.1	30 cm				
Fimbristylis simulans	0.1	20 cm	BIL17-03	0.1	20 cm	
Gompholobium oreophilum	0.1	35 cm	BIL17-02	0.1	50 cm	
Goodenia stobbsiana	0.1	30 cm		0.1	30 cm	
Goodenia triodiophila	0.1	20 cm		0.1	30 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	100 cm		0.1	220 cm	
Keraudrenia nephrosperma	0.1	50 cm	BIL17-16			
Ptilotus calostachyus	0.1	35 cm		0.1	100 cm	
Ptilotus rotundifolius	0.1	100 cm		0.1	60 cm	
Scaevola browniana subsp. *browniana*	0.1	30 cm	BIL17-05			
Senna artemisioides subsp. *oligophylla*	0.1	20 cm	BIL17-09			
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*				0.1	30 cm	BILR17-02, BILR17-03
Senna glutinosa subsp. *glutinosa*				0.1	140 cm	
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*				0.1	100 cm	
Senna glutinosa subsp. *pruinosa*	0.1	70 cm				
Senna glutinosa subsp. x *luerssenii*	0.1	80 cm	BIL17-18	0.1	25 cm	
Sida arenicola	0.1	150 cm	BIL17-15, BIL17-11	0.1	40 cm	
Sida sp. *Pilbara* (A.A. Mitchell PRP 1543)	0.1	45 cm	BIL17-06	0.1	40 cm	
Solanum lasiophyllum	0.1	50 cm		0.1	60 cm	
Solanum phlomoides	0.1	30 cm	BIL17-10	0.1	40 cm	
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	0.1	5 cm	BIL17-14			
Trianthema glossostigmum				0.1	1 cm	
Triodia schinzii	0.1	70 cm	BIL17-12			
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	20	35 cm	BIL17-01	15	25 cm	
Triodia wiseana	0.1	30 cm	BIL17-04	0.1	25 cm	

BIL17 Phase 1

BIL17 Phase 2

Yandi Billiards Level 2 BIL18

Described by CASV Date 16-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 735048 mE, 7476958 mN.

Habitat Drainage plain.

Soil 2.5YR 3/3 dark reddish brown sandy loam with scattered ironstone pebbles (2 %) and gravel (5 %).

Rock Type Ironstone.

Vegetation *Eucalyptus gamophylla* low open *mallee* woodland over *Acacia pachyacra, A. inaequilatera* tall open shrubland over *Acacia ancistrocarpa* open shrubland over *Triodia basedowii* hummock grassland.

Veg Condition Very Good (*Cenchrus ciliaris).

Fire Age No sign of recent fire.

Notes Elevation: 489 m. *Corymbia hamersleyana* outside of quadrat.

Species	Cover (%)	Height (cm)	Specimen
Abutilon amplum	0.1	140 cm	BIL18-04
Abutilon otocarpum	0.1	20 cm	
Acacia adoxa var. *adoxa*	0.1	40 cm	
Acacia ancistrocarpa	2	160 cm	
Acacia bivenosa	0.1	140 cm	
Acacia coriacea subsp. *pendens*	0.1	160 cm	
Acacia dictyophleba	0.1	160 cm	
Acacia inaequilatera	1	420 cm	
Acacia pachyacra	2	450 cm	BIL18-08
Acacia pruinocarpa	0.1	210 cm	
Acacia tumida var. *pilbarensis*	0.1	180 cm	
Alternanthera nana	0.1	40 cm	BIL18-20
Aristida holathera var. *holathera*	0.1	40 cm	
Boerhavia coccinea	0.1	30 cm	
Bulbostylis barbata	0.1	20 cm	
Cenchrus ciliaris	0.1	60 cm	
Cleome viscosa	0.1	100 cm	
Corchorus sidoides subsp. *sidoides*	0.1	30 cm	BIL18-21
Corchorus tridens	0.1	10 cm	BIL18-05
Crotalaria medicaginea var. *neglecta*	0.1	30 cm	
Cymbopogon ambiguus	0.1	110 cm	BIL18-13
Cymbopogon obtectus	0.1	110 cm	
Dicrastylis cordifolia	0.1	60 cm	
Digitaria brownii	0.1	90 cm	BIL18-17
Digitaria ctenantha	0.1	35 cm	
Duperreya commixta	0.1	200 cm	
Eragrostis eriopoda	0.1	45 cm	
Eucalyptus gamophylla	4	550 cm	
Euphorbia australis var. *hispidula*	0.1	30 cm	BIL18-14
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL18-22
Euphorbia biconvexa	0.1	10 cm	BIL18-07
Evolvulus alsinoides var. *decumbens*	0.1	15 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	10 cm	
Goodenia muelleriana	0.1	30 cm	BIL18-10
Gossypium australe	0.1	120 cm	BIL18-12
Hakea lorea subsp. *lorea*	0.1	450 cm	BIL18-11
Hibiscus burtonii	0.1	40 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm	
Hybanthus aurantiacus	0.1	60 cm	
Indigofera monophylla	0.1	50 cm	
Mollugo molluginea	0.1	15 cm	
Paraneurachne muelleri	0.1	80 cm	
Paspalidium rarum	0.1	10 cm	BIL18-18

Species	Cover (%)	Height (cm)	Specimen
Perotis rara	0.1	15 cm	
Phyllanthus erwinii	0.1	30 cm	BIL18-09
Polycarpaea corymbosa var. *corymbosa*	0.1	20 cm	
Ptilotus astrolasius	0.1	60 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	30 cm	
Rhynchosia minima	0.1	120 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	30 cm	BIL18-24
Senna artemisioides subsp. *oligophylla*	0.1	60 cm	BIL18-23
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	60 cm	BIL18-02
Senna notabilis	0.1	10 cm	
Sida cardiophylla	0.1	60 cm	BIL18-19
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	30 cm	BIL18-03
Solanum lasiophyllum	0.1	30 cm	
Sporobolus australasicus	0.1	10 cm	
Tephrosia supina	0.1	10 cm	BIL18-16
*Themeda tri*andra	0.1	120 cm	
Tribulopis angustifolia	0.1	5 cm	BIL18-06
Triodia basedowii	45	40 cm	BIL18-01
Yakirra australiensis var. *australiensis*	0.1	10 cm	BIL18-15

BIL18

Yandi Billiards Level 2 BIL19

Described by PLSW Date 15-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 733993 mE, 7476199 mN.

Habitat Hilltop/slope to the W of a major valley.

Soil Dark reddish brown sandy clay loam with angular continuous cobbles (50 %) and pebbles (50 %).

Rock Type Ironstone.

Vegetation *Hakea chordophylla* scattered tall shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia hilliana	0.1	50 cm	
Acacia pruinocarpa	0.1	220 cm	
Amphipogon sericeus	0.1	35 cm	BIL19-01
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	10 cm	
Calytrix carinata	0.1	60 cm	
Fimbristylis simulans	0.1	25 cm	
Goodenia stobbsiana	0.1	35 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	160 cm	
Hakea chordophylla	1	350 cm	
Ptilotus calostachyus	0.1	45 cm	
Ptilotus rotundifolius	0.1	60 cm	
Senna glutinosa subsp. *pruinosa*	0.1	130 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	140 cm	
Solanum lasiophyllum	0.1	50 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	12	35 cm	

BIL19

Yandi Billiards Level 2 BIL20

Described by Phase 1: CASW, Phase 2: PA/PL Date Phase 1: 17-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 733194 mE, 7470975 mN.

Soil Dark reddish brown sandy clay loam with 1-25% cover of boulders, 26-50% cover of cobbles, 26-50% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Rock Type BIF, shale, ironstone boulders (1 %), cobbles (40 %), pebbles (30 %) and gravel (20 %).

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla* scattered tall shrubs over *Acacia hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland with *Amphipogon sericeus* scattered grasses.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla* scattered tall shrubs over *Acacia hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland with *Amphipogon sericeus* scattered grasses.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes *Heliotropium glabellum* (dead) found in small post fire patch on N boundary.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	20 cm	BIL20-07			
Acacia ancistrocarpa	0.1	220 cm	BIL20-04	0.1	190 cm	
Acacia bivenosa	0.1	15 cm		0.1	25 cm	
Acacia hilliana	0.5	60 cm		0.5	60 cm	
Acacia pruinocarpa	0.1	240 cm		0.1	240 cm	
Amphipogon sericeus	1	30 cm		1	30 cm	
Aristida holathera var. *holathera*	0.1	45 cm	BIL20-08	0.1	30 cm	
Bonamia erecta	0.1	20 cm	BIL20-10	0.1	30 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)				0.1	5 cm	
Eremophila fraseri subsp. *fraseri*	0.1	70 cm	BIL20-09	0.1	70 cm	
Eremophila latrobei subsp. *latrobei*	0.1	60 cm	BIL20-03	0.1	80 cm	
Eriachne mucronata (typical form)	0.1	30 cm		0.1	30 cm	
Eriachne pulchella	0.1	8 cm		0.1	8 cm	
Eucalyptus leucophloia subsp. *leucophloia*	0.5	450 cm		0.5	500 cm	
Fimbristylis dichotoma	0.1	20 cm		0.1	25 cm	
Fimbristylis simulans	0.1	10 cm		0.1	15 cm	
Goodenia microptera				0.1	40 cm	
Goodenia stobbsiana	0.1	10 cm		0.1	40 cm	
Goodenia triodiophila				0.1	40 cm	
Hakea chordophylla	0.5	300 cm		1	300 cm	
Heliotropium glabellum	0.1	20 cm	BIL20-05			
Hibiscus coatesii	0.1	25 cm	BIL37-01=			
Hybanthus aurantiacus	0.1	30 cm				
Keraudrenia nephrosperma	0.1	30 cm	BIL37-05=	0.1	50 cm	
Paraneurachne muelleri				0.1	40 cm	
Polygala glaucifolia	0.1	5 cm	BIL20-01			
Ptilotus astrolasius				0.1	40 cm	
Ptilotus calostachyus	0.1	100 cm		0.1	70 cm	
Ptilotus rotundifolius	0.1	40 cm		0.1	40 cm	
Rhagodia eremaea	0.1	70 cm		0.1	70 cm	
Schizachyrium fragile	0.1	15 cm		0.1	30 cm	
Senna glutinosa subsp. *glutinosa*	0.1	100 cm		0.1	40 cm	
Senna glutinosa subsp. *pruinosa*	0.1	160 cm		0.1	170 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	110 cm		0.1	60 cm	
Senna sericea	0.1	110 cm	BIL20-02	0.1	90 cm	
Sida echinocarpa	0.1	50 cm	BIL20-06			
Solanum lasiophyllum	0.1	30 cm		0.1	50 cm	
Tribulus suberosus	0.1	100 cm		0.1	85 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	20	40 cm		20	30 cm	
Triodia wiseana	0.1	40 cm		0.1	40 cm	

BIL20 Phase 1

BIL20 Phase 2

Yandi Billiards Level 2 BIL21

Described by Phase 1: PLSV, Phase 2: CEFSW Date Phase 1: 17-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 734428 mE, 7471153 mN.

Habitat Broad floodplain with minor flow channels in broader area.

Soil Dark reddish brown sandy loam with 1-25% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana* scattered low trees over *Acacia ancistrocarpa, A. citrinoviridis, A. inaequilatera* tall open shrubland over *Acacia pyrifolia* var. *pyrifolia* scattered shrubs over *Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* low open shrubland over *Triodia pungens, T. basedowii* open hummock grassland with **Cenchrus ciliaris, Themeda tri*andra very open tussock grassland.
Phase 2: *Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. inaequilatera* scattered tall shrubs over *Senna artemisioides* subsp. *helmsii* scattered shrubs over *Triodia pungens, T. basedowii* open hummock grassland with **Cenchrus ciliaris, Themeda tri*andra very open tussock

Veg Condition Phase 1: Good (**Cenchrus ciliaris*). Phase 2: Good (**Cenchrus ciliaris*).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Elevation: 529 m.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	40 cm				
Acacia ancistrocarpa	1	220 cm		0.1	300 cm	
Acacia aptaneura	0.1	250 cm	BIL21-12	0.1	320 cm	
Acacia bivenosa	0.1	180 cm		0.1	200 cm	
Acacia citrinoviridis	1	240 cm		1	240 cm	
Acacia inaequilatera	0.5	200 cm		0.5	360 cm	
Acacia pyrifolia var. *pyrifolia*	0.5	120 cm		0.1	160 cm	
Acacia tumida var. *pilbarensis*	0.1	170 cm		0.1	200 cm	
Aristida contorta	0.1	25 cm		0.1	20 cm	
Aristida holathera var. *holathera*	0.1	35 cm		0.1	35 cm	
Aristida inaequiglumis	0.1	110 cm	BIL21-10	0.1	120 cm	
Atalaya hemiglauca				0.1	210 cm	
Boerhavia coccinea	0.1	30 cm		0.1	20 cm	
Bonamia erecta	0.1	50 cm		0.1	45 cm	
Bulbostylis barbata	0.1	10 cm				
Cenchrus ciliaris	5	50 cm		6	40 cm	
Cleome viscosa	0.1	35 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm				
Corchorus tectus	0.1	35 cm	BIL21-08	0.1	35 cm	
Corymbia hamersleyana	2	700 cm		1	740 cm	
Crotalaria medicaginea var. *neglecta*	0.1	40 cm		0.1	50 cm	
Cucumis variabilis	0.1	300 cm		0.1	220 cm	
Dactyloctenium radulans	0.1	20 cm				
Digitaria ctenantha	0.1	40 cm				
Enneapogon polyphyllus	0.1	30 cm				
Eragrostis eriopoda	0.1	35 cm		0.1	40 cm	
Eremophila longifolia	0.1	120 cm		0.1	200 cm	
Eriachne mucronata (typical form)	0.1	25 cm		0.1	30 cm	
Eriachne pulchella	0.1	20 cm				
Euphorbia biconvexa	0.1	40 cm	BIL21-02	0.1	20 cm	BILR21-04
Evolvulus alsinoides var. *decumbens*	0.1	30 cm				
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm		0.1	20 cm	
Glycine canescens	0.1	50 cm		0.1	120 cm	
Goodenia microptera	0.1	30 cm		0.1	20 cm	
Gossypium australe	0.1	120 cm		0.1	110 cm	
Gossypium robinsonii	0.1	100 cm		0.1	130 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	180 cm		0.1	220 cm	BILR21-05
Hakea chordophylla	0.1	150 cm		0.1	170 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Heliotropium cunninghamii	0.1	30 cm	BIL21-03	0.1	25 cm	
Hibiscus sturtii var. *platychlamys*	0.1	60 cm		0.1	15 cm	BILR21-03
Hybanthus aurantiacus	0.1	40 cm		0.1	10 cm	
Indigofera monophylla	0.1	40 cm	BIL21-04, BIL21-05	0.1	60 cm	
Ipomoea muelleri	0.1	40 cm		0.1	5 cm	
Isotropis atropurpurea	0.1	40 cm		0.1	60 cm	
Melhania oblongifolia	0.1	25 cm		0.1	20 cm	
Mollugo molluginea	0.1	15 cm		0.1	10 cm	
Paraneurachne muelleri	0.1	45 cm		0.1	50 cm	
Perotis rara	0.1	10 cm				
Pluchea ferdinandi-muelleri	0.1	45 cm		0.1	50 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	15 cm				
Polymeria ambigua	0.1	15 cm	BIL21-06	0.1	5 cm	
Ptilotus astrolasius	0.1	35 cm		0.1	35 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	5 cm		0.1	45 cm	
Ptilotus obovatus var. *obovatus*	0.1	45 cm		0.1	40 cm	
Rhagodia eremaea				0.1	90 cm	
Salsola australis				0.1	15 cm	
Santalum lanceolatum	0.1	170 cm		0.1	250 cm	
Senna artemisioides subsp. *helmsii*	2	90 cm		1	100 cm	
Senna artemisioides subsp. *oligophylla*	0.5	80 cm	BIL21-07	0.1	100 cm	
Senna glutinosa subsp. *glutinosa*				0.1	60 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	170 cm	BIL21-09			
Sida echinocarpa	0.1	100 cm				
Sida fibulifera	0.1	25 cm	BIL21-11	0.1	20 cm	BILR21-02
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	70 cm		0.1	180 cm	
Sida sp. *verrucose g*lands (F.H. Mollemans 2423)	0.1	30 cm		0.1	20 cm	BILR21-01
Solanum lasiophyllum	0.1	45 cm				
Synaptantha tillaeacea var. *tillaeacea*	0.1	7 cm	BIL21-14			
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)				0.1	40 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	45 cm				
Themeda triandra	1	80 cm		2	120 cm	
Trianthema pilosum	0.1	25 cm		0.1	10 cm	
Tribulus macrocarpus	0.1	15 cm		0.1	10 cm	BILR21-06
Trichodesma zeylanicum var. *zeylanicum*	0.1	20 cm		0.1	10 cm	
Triodia basedowii	2	40 cm		2	45 cm	
Triodia pungens	14	50 cm	BIL21-01	12	50 cm	
Waltheria indica	0.1	50 cm		0.1	90 cm	

BIL21 Phase 1

BIL21 Phase 2

Yandi Billiards Level 2 BIL22

Described by Phase 1: CEFCASW, Phase 2: CEFSW Date Phase 1: 18-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 742131 mE, 7485331 mN.

Habitat Colluvial plain to the E of a range of hills.

Soil Dark reddish brown loamy sand.

Rock Type Nil.

Vegetation Phase 1: *Eucalyptus gamophylla* low open *mallee* woodland over *Acacia inaequilatera, A. pruinocarpa* tall open shrubland *Triodia schinzii,* (*T. pungens*) hummock grassland.
Phase 2: *Eucalyptus gamophylla* low open *mallee* woodland over *Acacia inaequilatera, A. pruinocarpa* tall open shrubland over *Triodia schinzii,* (*T. pungens*) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	10 cm				
Acacia bivenosa	0.1	400 cm		0.1	470 cm	
Acacia citrinoviridis				0.1	75 cm	
Acacia dictyophleba	0.1	120 cm		0.1	140 cm	
Acacia inaequilatera	4	400 cm		3	480 cm	
Acacia pachyacra	0.1	40 cm	BIL22-09	0.1	30 cm	
Acacia pruinocarpa	1	500 cm		1.5	520 cm	
Acacia trudgeniana	0.1	150 cm	BIL22-08	0.1	200 cm	
Aristida holathera var. *holathera*				0.1	20 cm	
Aristida hygrometrica	0.1	30 cm	BIL22-16			
Chrysopogon fallax	0.1	40 cm				
Corchorus tectus	0.1	30 cm	BIL22-02	0.1	45 cm	
Cucumis variabilis	0.1	5 cm				
Cullen martinii	0.1	20 cm	BIL22-14	0.1	80 cm	BILR22-02
Dicrastylis cordifolia	0.1	70 cm		0.1	100 cm	
Eragrostis eriopoda	0.1	35 cm		0.1	30 cm	
Eucalyptus gamophylla	2.5	300 cm		2	380 cm	
Hibiscus leptocladus	0.1	40 cm	BIL22-11			
Isotropis atropurpurea	0.1	55 cm	BIL22-12	0.1	60 cm	
Rhynchosia minima	0.1	250 cm		0.1	120 cm	
Santalum lanceolatum	0.1	130 cm	BIL22-15	0.1	130 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	25 cm	BIL22-13	0.1	25 cm	
Senna artemisioides subsp. *helmsii*	0.1	110 cm				
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	BIL22-07	0.1	100 cm	BILR22-01
Senna notabilis	0.1	5 cm		0.1	45 cm	
Sida cardiophylla	0.1	50 cm	BIL22-04, BIL22-06	0.1	115 cm	
Trianthema pilosum	0.1	20 cm	BIL22-10	0.1	15 cm	
Tribulopis angustifolia	0.1	5 cm	BIL22-05			
Trichodesma zeylanicum var. *zeylanicum*	0.1	8 cm		0.1	120 cm	
Triodia pungens	0.5	70 cm	BIL22-03	1	45 cm	
Triodia schinzii	31	140 cm	BIL22-01	27	130 cm	

BIL22 Phase 1

BIL22 Phase 2

Yandi Billiards Level 2 BIL23

Described by Phase 1: PLSW, Phase 2: PLSW Date Phase 1: 13-Mar-14, Phase 2: 10-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 730055 mE, 7471353 mN.

Habitat Banks/floodplain of creek line (tributary to Weeli Wolli Creek).

Soil Red brown clayey sand with 1-25% cover of cobbles, 1-25% cover of pebbles and 25-50% cover of gravel.

Rock Type Ironstone

Vegetation Phase 1: *Acacia pruinocarpa, Eremophila longifolia, Acacia pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis* tall open shrubland over *Triodia wiseana* scattered hummock grasses with **Cenchrus ciliaris* tussock grassland.
Phase 2: *Acacia pruinocarpa, Eremophila longifolia, Acacia pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis* tall open shrubland over *Triodia wiseana* scattered hummock grasses with **Cenchrus ciliaris* tussock grassland.

Veg Condition Phase 1: Poor (**Cenchrus ciliaris, *Malvastrum americanum*). Phase 2: Very Poor (**Cenchrus ciliaris;* evidence of cattle).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	BIL23-13			
Abutilon macrum	0.1	60 cm		0.1	60 cm	
Abutilon otocarpum	0.1	40 cm		0.1	35 cm	
Acacia bivenosa	0.1	300 cm		0.1	220 cm	
Acacia citrinoviridis	0.1	250 cm		1	300 cm	
Acacia maitlandii	0.1	170 cm		0.1	130 cm	
Acacia pruinocarpa	3	400 cm		3	400 cm	
Acacia pyrifolia var. *pyrifolia*	1.5	230 cm		1.5	230 cm	
Acacia tumida var. *pilbarensis*	1	250 cm		1	250 cm	
Alternanthera nana	0.1		BIL23-09	0.1	15 cm	
Amaranthus undulatus	0.1	60 cm	BIL23-04			
Aristida contorta				0.1	20 cm	
Aristida holathera var. *holathera*	0.1	30 cm		0.1	40 cm	
Atalaya hemiglauca	0.1	380 cm		0.1	240 cm	
Boerhavia burbidgeana	0.1	30 cm	BIL23-01			
Boerhavia coccinea	0.1	30 cm		0.1	30 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)				0.1	8 cm	
Cenchrus ciliaris	50	100 cm		40	80 cm	
Chrysopogon fallax	0.1	120 cm		0.1	100 cm	
Cleome viscosa	0.1	30 cm		0.1	40 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*				0.1	50 cm	
Corymbia hamersleyana	0.1	140 cm				
Duperreya commixta				0.1	240 cm	
Enchylaena tomentosa var. *tomentosa*				0.1	10 cm	
Enneapogon polyphyllus	0.1	25 cm		0.1	25 cm	
Enneapogon robustissimus	0.1	60 cm	BIL23-12	0.1	40 cm	
Eragrostis eriopoda	0.1	50 cm		0.1	40 cm	
Eremophila fraseri subsp. *fraseri*	0.1	120 cm		0.1	130 cm	
Eremophila longifolia	2.5	300 cm		2.5	300 cm	
Eriachne mucronata (typical form)	0.1	50 cm		0.1	35 cm	
Eriachne tenuiculmis	0.1	45 cm	BIL23-02	0.1	40 cm	
Euphorbia australis var. *subtomentosa*				0.1	6 cm	BILR23-03
Evolvulus alsinoides var. *decumbens*	0.1	20 cm		0.1	20 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm		0.1	25 cm	
Gossypium australe	0.1	120 cm		0.1	140 cm	
Gossypium robinsonii	0.1	90 cm				
Hibiscus sturtii var. *platychlamys*	0.1	40 cm		0.1	40 cm	
Indigofera colutea	0.1	25 cm		0.1	25 cm	
Indigofera linifolia	0.1	20 cm				
Indigofera linnaei	0.1	20 cm	BIL-CF142=			

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Malvastrum americanum	0.1	40 cm				
Melhania oblongifolia	0.1	40 cm		0.1	45 cm	
Mollugo molluginea	0.1	20 cm		0.1	20 cm	
Paraneurachne muelleri	0.1	40 cm		0.1	40 cm	
Phyllanthus maderaspatensis	0.1	25 cm				
Polycarpaea corymbosa var. *corymbosa*	0.1	15 cm		0.1	15 cm	
Polymeria ambigua	0.1	25 cm	BIL23-03	0.1	25 cm	
Rhagodia eremaea	0.1	40 cm		0.1	65 cm	
Rhynchosia minima	0.1	30 cm		0.1	30 cm	
Salsola australis	0.1	70 cm		0.1	35 cm	
Senna artemisioides subsp. *helmsii*	0.1	30 cm		0.1	40 cm	
Senna artemisioides subsp. *oligophylla*	0.1	40 cm	BIL23-15	0.1	80 cm	
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)				0.1	25 cm	BILR23-01
Senna notabilis	0.1	30 cm		0.1	40 cm	
Sida fibulifera	0.1	40 cm	BIL23-06	0.1	30 cm	
Sida sp. *verrucose g*lands (F.H. Mollemans 2423)	0.1	40 cm	BIL23-10	0.1	25 cm	
Solanum horridum				0.1	25 cm	
Solanum lasiophyllum	0.1	110 cm		0.1	70 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	40 cm	BIL23-05	0.1	50 cm	
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	0.1	30 cm	BIL23-11	0.1	10 cm	BILR23-02
Themeda triandra	0.1	100 cm		0.1	70 cm	
Tribulus terrestris	0.1	25 cm	BIL23-08			
Triodia wiseana	0.5	60 cm		0.5	45 cm	
Zaleya galericulata subsp. *galericulata*	0.1	30 cm	BIL23-07	0.1	40 cm	

BIL23 Phase 1

BIL23 Phase 2

Yandi Billiards Level 2 BIL24

Described by Phase 1: CEFCASW, Phase 2: PLSW Date Phase 1: 19-Mar-14, Phase 2: 11-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 731105 mE, 7472466 mN.

Habitat Floodplain and bed of creek line (indistinct channel).

Soil Dark reddish brown sandy loam with 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus victrix* scattered low trees over *Acacia citrinoviridis* (*A. pruinocarpa*) tall open scrub over *Triodia pungens* scattered hummock grasses with **Cenchrus ciliaris* open tussock grassland and *Boerhavia burbidgeana* very open herbland.
Phase 2: *Eucalyptus victrix* scattered low trees over *Acacia citrinoviridis* (*A. pruinocarpa*) tall open scrub over *Triodia pungens* scattered hummock grasses with **Cenchrus ciliaris* open tussock grassland.

Veg Condition Phase 1: Good (**Cenchrus ciliaris, *Setaria verticillata, *Aerva javanica*, cattle presence). Phase 2: Very Poor (**Cenchrus ciliaris, *Malvastrum americanum*).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	60 cm	BIL24-01	0.1	40 cm	
Abutilon lepidum	0.1	15 cm	BIL24-18	0.1	40 cm	
Abutilon otocarpum	0.1	60 cm		0.1	40 cm	
Acacia bivenosa	0.1	300 cm		0.1	390 cm	
Acacia citrinoviridis	40	450 cm		35	500 cm	
Acacia pruinocarpa	1	300 cm		1	400 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	60 cm		0.1	110 cm	
Acrachne racemosa	0.1	45 cm	BIL24-08	0.1	30 cm	
Aerva javanica	0.1	60 cm		0.1	50 cm	
Alysicarpus muelleri				0.1	30 cm	
Amaranthus undulatus	0.1	30 cm	BIL24-07			
Boerhavia burbidgeana	2	10 cm	BIL24-06			
Boerhavia coccinea	0.1	10 cm	BIL24-02	0.1	30 cm	
Cenchrus ciliaris	15	70 cm		17	50 cm	
Chrysopogon fallax	0.1	110 cm				
Cleome viscosa	0.1	20 cm		0.1	50 cm	
Clerodendrum floribundum var. *angustifolium*	0.1	25 cm	BIL24-23			
Corchorus crozophorifolius	0.1	70 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*				0.1	40 cm	
Corchorus tridens	0.1	15 cm	BIL24-04			
Crotalaria medicaginea var. *neglecta*	0.1	40 cm		0.1	40 cm	
Cymbopogon ambiguus	0.1	120 cm	BIL24-13	0.1	120 cm	
Duperreya commixta	0.1	300 cm		0.1	400 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	10 cm	BIL24-12	0.1	30 cm	BILR24-03
Enchylaena tomentosa var. *tomentosa*	0.1	20 cm	BIL24-20	0.1	50 cm	
Enneapogon caerulescens				0.1	35 cm	
Enneapogon lindleyanus	0.1	70 cm	BIL24-03	0.1	40 cm	
Enneapogon polyphyllus	0.1	30 cm		0.1	30 cm	
Enneapogon robustissimus	0.1	110 cm	BIL24-25	0.1	55 cm	
Eremophila longifolia				0.1	40 cm	
Eriachne mucronata (typical form)	0.1	40 cm	BIL24-14	0.1	35 cm	
Eriachne pulchella				0.1	15 cm	
Eriachne tenuiculmis				0.1	55 cm	
Eucalyptus victrix	0.5	450 cm		0.5	650 cm	
Euphorbia australis var. *subtomentosa*	0.1	5 cm	BIL24-30	0.1	10 cm	BILR24-02
Euphorbia coghlanii	0.1	40 cm	BIL24-11	0.1	40 cm	
Euphorbia tannensis subsp. *eremophila*				0.1	40 cm	
Evolvulus alsinoides var. *decumbens*				0.1	20 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm		0.1	20 cm	
Glycine canescens	0.1	30 cm	BIL24-05	0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Gomphrena cunninghamii	0.1	35 cm	BIL24-27			
Gossypium australe	0.1	110 cm				
Heliotropium cunninghamii	0.1	60 cm	BIL24-28			
Hibiscus sturtii var. *platychlamys*	0.1	30 cm	BIL24-15	0.1	30 cm	
Indigofera colutea	0.1	15 cm	BIL24-17	0.1	8 cm	
Lepidium oxytrichum				0.1	4 cm	BILR24-01
Malvastrum americanum	0.1	30 cm		0.1	40 cm	
Melhania oblongifolia	0.1	60 cm		0.1	40 cm	
Notoleptopus decaisnei var. *decaisnei*	0.1	40 cm	BIL24-10			
Perotis rara	0.1	10 cm				
Phyllanthus maderaspatensis	0.1	60 cm	BIL24-19			
Polycarpaea longiflora	0.1	40 cm		0.1	30 cm	
Ptilotus auriculifolius	0.1	30 cm	BIL24-26			
Ptilotus nobilis subsp. *nobilis*	0.1	10 cm				
Ptilotus obovatus var. *obovatus*	0.1	60 cm		0.1	50 cm	
Rhynchosia minima	0.1	10 cm		0.1	50 cm	
Salsola australis				0.1	30 cm	
Sclerolaena cornishiana				0.1	40 cm	
Senna artemisioides subsp. *helmsii*	0.1	130 cm		0.1	80 cm	
Senna artemisioides subsp. *oligophylla*	0.1	120 cm	BIL24-24	0.1	140 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	150 cm		0.1	180 cm	
Senna notabilis				0.1	15 cm	
Setaria dielsii				0.1	50 cm	
Setaria verticillata	0.1	25 cm		0.1	40 cm	
Sida fibulifera				0.1	25 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)				0.1	50 cm	
Sida sp. *verrucose g*lands (F.H. Mollemans 2423)	0.1	30 cm	BIL24-22	0.1	30 cm	
Solanum horridum				0.1	25 cm	
Solanum lasiophyllum	0.1	10 cm		0.1	60 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	40 cm	BIL24-16	0.1	45 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)				0.1	40 cm	
Themeda triandra	0.1	100 cm		0.1	80 cm	
Tribulus terrestris	0.1	10 cm	BIL24-29			
Trichodesma zeylanicum var. *zeylanicum*	0.1	50 cm		0.1	25 cm	
Triodia pungens	1	30 cm	BIL24-21	1	50 cm	
Triodia wiseana	0.1	25 cm	BIL24-09	0.1	60 cm	

BIL24 Phase 1

BIL24 Phase 2

Yandi Billiards Level 2 BIL25

Described by Phase 1: CASV, Phase 2: PLSW Date Phase 1: 13-Mar-14, Phase 2: 10-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 731255 mE, 7471567 mN.

Habitat NW sloping plain.

Soil Dark reddish brown sandy loam with 1-25% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eremophila fraseri* subsp. *fraseri,* (*Acacia citrinoviridis*) tall shrubland over *Senna artemisioides* subsp. *helmsii* open shrubland over *Eragrostis eriopoda* very open tussock grassland.
Phase 2: Eremophila fraseri subsp. *fraseri,* (*Acacia citrinoviridis*) tall shrubland over *Senna artemisioides* subsp. *helmsii* open shrubland over *Sclerolaena cornishiana* scattered low shrubs over *Eragrostis eriopoda, E. xerophila* very open tussock grassland.

Veg Condition Phase 1: Good (**Cenchrus ciliaris,* cattle evidence). Phase 2: Good (**Cenchrus ciliaris,* evidence of cattle).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes *Corymbia hamersleyana* and *Acacia pruinocarpa* mature individuals outside of quadrat.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	80 cm	BIL25-13	0.1	80 cm	
Abutilon macrum	0.1	80 cm	BIL25-06			
Abutilon otocarpum	0.1	20 cm		0.1	40 cm	
Acacia bivenosa				0.1	50 cm	
Acacia citrinoviridis	1	600 cm	BIL25-21	1	600 cm	
Acacia coriacea subsp. *pendens*	0.1	600 cm	BIL25-16			
Anthobolus leptomerioides	0.1	130 cm	BIL25-20	0.1	150 cm	
Aristida contorta	0.1	20 cm		0.1	30 cm	
Aristida holathera var. *holathera*	0.1	30 cm				
Boerhavia coccinea	0.1	10 cm		0.1	40 cm	
Capparis lasiantha	0.1	120 cm		0.1	140 cm	
Cenchrus ciliaris	0.1	40 cm		0.1	60 cm	
Chrysopogon fallax	0.1	160 cm		0.1	110 cm	
Cleome viscosa	0.1	60 cm		0.1	25 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	BIL25-23			
Crotalaria medicaginea var. *neglecta*	0.1	40 cm		0.1	20 cm	
Cymbopogon ambiguus				0.1	80 cm	
Cymbopogon procerus	0.1	110 cm				
Enchylaena tomentosa var. *tomentosa*	0.1	100 cm		0.1	100 cm	
Enneapogon polyphyllus	0.1	30 cm	BIL25-10	0.1	25 cm	
Eragrostis eriopoda	7	40 cm		6	40 cm	
Eragrostis xerophila				1	40 cm	BILR25-02
Eremophila forrestii subsp. *forrestii*	0.1	70 cm	BIL25-03	0.1	90 cm	
Eremophila fraseri subsp. *fraseri*	20	200 cm	BIL25-01	11	240 cm	
Euphorbia biconvexa	0.1	30 cm	BIL25-12	0.1	40 cm	BILR25-03
Euphorbia boophthona				0.1	45 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	15 cm		0.1	15 cm	
Goodenia microptera	0.1	35 cm		0.1	30 cm	
Gossypium australe	0.1	70 cm		0.1	130 cm	
Grevillea berryana				0.1	650 cm	
Hakea lorea subsp. *lorea*	0.1	400 cm		0.1	240 cm	
Heliotropium cunninghamii	0.1	30 cm	BIL25-18	0.1	30 cm	
Hibiscus burtonii	0.1	30 cm		0.1	35 cm	
Hibiscus sturtii var. *platychlamys*	0.1	50 cm		0.1	40 cm	
Indigofera colutea	0.1	10 cm		0.1	25 cm	
Indigofera linifolia	0.1	20 cm	BIL25-19			
Maireana planifolia				0.1	40 cm	
Melhania oblongifolia	0.1	40 cm		0.1	50 cm	
Paraneurachne muelleri	0.1	40 cm		0.1	45 cm	
Portulaca oleracea/intraterranea				0.1	15 cm	BILR25-04
Ptilotus astrolasius				0.1	35 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Ptilotus obovatus var. *obovatus*	0.1	70 cm		0.1	60 cm	
Rhagodia eremaea	0.1	100 cm		0.1	40 cm	
Salsola australis	0.1	15 cm		0.1	35 cm	
Sclerolaena cornishiana	0.1	10 cm	BIL25-04	1	40 cm	
Senna artemisioides subsp. *helmsii*	2	120 cm	BIL25-02	2	90 cm	
Senna artemisioides subsp. *oligophylla*	0.1	70 cm	BIL25-14	0.1	90 cm	
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035) x subsp. *helmsii*	0.1	80 cm	BIL25-09	0.1	90 cm	
Sida echinocarpa	0.1	60 cm		0.1	120 cm	
Sida fibulifera				0.1	20 cm	
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	10 cm	BIL25-05, BIL25-22	0.1	25 cm	
Solanum lasiophyllum	0.1	60 cm				
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	0.1	25 cm	BIL25-08	0.1	30 cm	BILR25-01
Tribulus macrocarpus	0.1	10 cm		0.1	15 cm	
Triodia basedowii	0.1	20 cm	BIL25-11	0.1	45 cm	
Triodia pungens				0.1	50 cm	
Triodia wiseana	0.1	60 cm	BIL25-17	0.1	45 cm	

BIL25 Phase 1

BIL25 Phase 2

Yandi Billiards Level 2 BIL26

Described by PLSW Date 14-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 730974 mE, 7473466 mN.

Habitat Low hilltop in broad area of low undulating hills.

Soil Dark reddish brown fine sandy clay loam with boulders (10 %), cobbles (40 %), pebbles (40 %), and gravel (10 %).

Rock Type Basalt, BIF.

Vegetation *Acacia inaequilatera* tall open shrubland over *Acacia adoxa, A. hilliana, Ptilotus rotundifolius* low open shrubland over *Triodia wiseana* (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.5	50 cm	
Acacia hilliana	0.5	60 cm	
Acacia inaequilatera	2	430 cm	
Amphipogon sericeus	0.1	35 cm	BIL26-05
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	25 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	80 cm	BIL26-02
Eriachne mucronata (typical form)	0.1	40 cm	
Fimbristylis simulans	0.1	25 cm	
Goodenia stobbsiana	0.1	25 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	180 cm	
Indigofera monophylla	0.1	30 cm	
Polygala glaucifolia	0.1	2 cm	BIL26-03
Ptilotus calostachyus	0.1	75 cm	
Ptilotus rotundifolius	0.5	70 cm	
Senna artemisioides subsp. *oligophylla*	0.1	40 cm	BIL26-01
Senna glutinosa subsp. *glutinosa*	0.1	140 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	170 cm	BIL26-04
Senna glutinosa subsp. *pruinosa*	0.1	190 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	175 cm	
Sida echinocarpa	0.1	40 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	1	30 cm	
Triodia wiseana	27	40 cm	

BIL26

Yandi Billiards Level 2 BIL27

Described by PLSW Date 14-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 730007 mE, 7473294 mN.

Habitat SSE facing ridge/slope (40% incline) amongst broader area of undulating medium hills.

Soil Dark reddish brown sandy clay loam (skeletal) with 10 % large boulders, 30 % boulders, 30 % cobbles, 20 % pebbles, and 10 % gravel

Rock Type Basalt outcropping.

Vegetation *Acacia inaequilatera* scattered tall shrubs over *Indigofera rugosa* low open shrubland over *Triodia wiseana* open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia inaequilatera	1	250 cm	
*Acacia maitl*andii	0.1	40 cm	
Acacia pruinocarpa	0.1	240 cm	
Atalaya hemiglauca	0.1	140 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	30 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	50 cm	BIL27-04
Cymbopogon ambiguus	0.1	80 cm	
Enneapogon caerulescens	0.1	45 cm	BIL27-02
Enneapogon polyphyllus	0.1	25 cm	
Eriachne mucronata (typical form)	0.1	40 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Gomphrena cunninghamii	0.1	20 cm	
Goodenia muelleriana	0.1	25 cm	
Gossypium australe	0.1	195 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	110 cm	
Hybanthus aurantiacus	0.1	40 cm	
Indigofera rugosa	3.5	50 cm	
Mollugo molluginea	0.1	15 cm	
Paraneurachne muelleri	0.1	40 cm	
Polymeria ambigua	0.1	30 cm	BIL27-01
Ptilotus astrolasius	0.1	45 cm	
Ptilotus obovatus var. *obovatus*	0.1	45 cm	
Rhynchosia minima	0.1	50 cm	
Senna artemisioides subsp. *oligophylla*	0.1	60 cm	BIL27-05
Senna glutinosa subsp. *glutinosa*	0.1	20 cm	
Solanum phlomoides	0.1	60 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	45 cm	BIL27-03
Themeda triandra	0.1	80 cm	
Triodia wiseana	25	40 cm	

BIL27

Yandi Billiards Level 2		BIL28	
Described by	SVSW	Date	11-Mar-14
Type	Quadrat 50 x 50 m		
Central Coordinate	738984 mE, 7483683 mN.		
Habitat	Crest of low undulating hill range gently sloping to SE and NW from crest.		
Soil	2.5YR 3/4 dark reddish brown clay loam.		
Rock Type	Ironstone shale cobbles (70 %), pebbles (20 %), and gravel (5 %).		
Vegetation	*Acacia inaequilatera, A. pruinocarpa, Grevillea wickhamii* subsp. *hispidula* scattered tall shrubs over *Acacia hilliana, Ptilotus rotundifolius* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.		
Veg Condition	Excellent.		
Fire Age	No sign of recent fire.		
Notes	Elevation: 497 m.		

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	65 cm	BIL28-08
Acacia hilliana	1	50 cm	BIL28-06
Acacia inaequilatera	0.5	250 cm	
Acacia pruinocarpa	0.5	240 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	5 cm	BIL28-09
Fimbristylis dichotoma	0.1	20 cm	BIL28-05
Fimbristylis simulans	0.1	20 cm	
Goodenia stobbsiana	0.1	15 cm	
Goodenia triodiophila	0.1	40 cm	BIL28-04
Grevillea wickhamii subsp. *hispidula*	0.5	370 cm	
Hakea lorea subsp. *lorea*	0.1	80 cm	
Ptilotus astrolasius	0.1	40 cm	
Ptilotus calostachyus	0.1	60 cm	
Ptilotus rotundifolius	0.5	90 cm	
Schizachyrium fragile	0.1	10 cm	BIL28-10
Senna artemisioides subsp. *oligophylla*	0.1	70 cm	BIL28-02
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	210 cm	BIL28-03
Senna glutinosa subsp. *pruinosa*	0.1	120 cm	
Solanum lasiophyllum	0.1	20 cm	BIL28-07
Trachymene oleracea subsp. *oleracea*	0.1	10 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	35	40 cm	BIL28-01

BIL28

Yandi Billiards Level 2 BIL29

Described by SVSW Date 12-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 735599 mE, 7479145 mN.

Habitat Gentle SSE facing transitional slope of low undulating hills. False crest/plateau situated above quadrat.

Soil 2.5 YR 3/4 dark reddish brown sandy loam (skeletal).

Rock Type Ironstone boulders (2 %), cobbles (35 %), pebbles (35 %), and gravel (20 %).

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Notes Elevation: 522 m.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	25 cm	
Acacia bivenosa (wispy/weeping form)	0.1	40 cm	
Acacia hilliana	2	50 cm	BIL29-07
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	5 cm	BIL29-04
Bulbostylis barbata	0.1	15 cm	
Calytrix carinata	0.1	70 cm	BIL29-06
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	50 cm	BIL29-05
Cymbopogon obtectus	0.1	80 cm	
Dampiera candicans	0.1	60 cm	
Eriachne pulchella	0.1	10 cm	
Eucalyptus leucophloia subsp. *leucophloia*	4	740 cm	
Euphorbia australis var. *hispidula*	0.1	10 cm	BIL29-09
Fimbristylis dichotoma	0.1	20 cm	
Fimbristylis simulans	0.1	15 cm	
Goodenia stobbsiana	0.1	20 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	220 cm	
Hakea chordophylla	0.1	240 cm	
Mollugo molluginea	0.1	15 cm	
Ptilotus astrolasius	0.1	30 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	5 cm	
Ptilotus rotundifolius	0.1	90 cm	
Schizachyrium fragile	0.1	20 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	180 cm	BIL29-03
Senna glutinosa subsp. *pruinosa*	0.1	70 cm	
Solanum phlomoides	0.1	25 cm	BIL29-01
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	26	35 cm	BIL29-02
Triodia wiseana	0.1	20 cm	BIL29-08

BIL29

Yandi Billiards Level 2 BIL30

Described by Phase 1: PLCA, Phase 2: CEFSW Date Phase 1: 09-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 740462 mE, 7486024 mN.

Habitat Major drainage line running N to S.

Soil Dark reddish brown sandy clay loam with 1-25% cover of cobbles, 26-50% cover of pebbles and 26-50% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia citrinoviridis, Eucalyptus victrix* low open woodland over *Acacia pyrifolia* var. *pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius, Indigofera monophylla, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) open shrubland.
Phase 2: Acacia citrinoviridis, Eucalyptus victrix low open woodland over *Acacia pyrifolia* var. *pyrifolia* scattered tall shrubs over *Corchorus crozophorifolius, Indigofera monophylla, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) open shrubland.

Veg Condition Phase 1: Very Good (**Aerva javanica, *Cenchrus spp.;* evidence of cattle). Phase 2: Very Good (**Aerva javanica, *Cenchrus spp.;* evidence of cattle).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon sp. *Dioicum* (A.A. Mitchell PRP 1618)	0.1	150 cm	BIL30-06			
Acacia citrinoviridis	7	600 cm		20	620 cm	
Acacia coriacea subsp. *pendens*	0.1	150 cm		0.1	150 cm	
Acacia pyrifolia var. *pyrifolia*	1.5	350 cm		1	350 cm	
Aerva javanica	0.1	40 cm		0.1	50 cm	
Amaranthus undulatus	0.1	15 cm	BIL30-07			
Aristida inaequiglumis	0.1	40 cm	BIL30-08			
Atalaya hemiglauca	0.1	400 cm		0.1	450 cm	
Boerhavia burbidgeana	0.1	10 cm	BIL30-09			
Boerhavia coccinea	0.1	25 cm		0.1	5 cm	
Cenchrus ciliaris	0.1	40 cm		0.1	40 cm	
Cenchrus setiger	0.1	40 cm		0.1	40 cm	
Cleome viscosa	0.1	20 cm		0.1	20 cm	
Corchorus crozophorifolius	1	150 cm		3	180 cm	
Crotalaria medicaginea var. *neglecta*	0.1	20 cm		0.1	20 cm	
Cucumis variabilis	0.1	180 cm				
Digitaria brownii	0.1	40 cm	BIL30-03	0.1	50 cm	BILR30-01
Enneapogon lindleyanus	0.1	60 cm	BIL30-05	0.1	45 cm	BILR30-02
Enneapogon polyphyllus	0.1	40 cm				
Eriachne mucronata (typical form)	0.1	40 cm				
Eriachne pulchella	0.1	15 cm		0.1	10 cm	
Eucalyptus victrix	2	800 cm		3	860 cm	
Eulalia aurea	0.1	120 cm				
Gomphrena cunninghamii	0.1	5 cm		0.1	5 cm	
Heliotropium cunninghamii	0.1	4 cm	BIL30-04	0.1	50 cm	
Indigofera monophylla	2	150 cm	BIL30-02	2.5	125 cm	
Phyllanthus maderaspatensis	0.1	20 cm		0.1	30 cm	
Polycarpaea longiflora	0.1	15 cm		0.1	10 cm	
Ptilotus obovatus var. *obovatus*	0.1	60 cm		0.1	80 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	2	70 cm	BIL30-01	1	110 cm	
Waltheria indica	0.1	10 cm		0.1	60 cm	

BIL30 Phase 1

BIL30 Phase 2

Yandi Billiards Level 2 BIL31

Described by Phase 1: CEFCASW, Phase 2: CEFSW Date Phase 1: 18-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 25 x 100 m

Central Coordinate 740648 mE, 7479936 mN.

Habitat Meandering creek bed and associated banks running EW (10m wide).

Soil Dark reddish brown sandy clay loam with 1-25% cover of cobbles,51-75% cover of pebbles and 1-25% cover of gravel.

Rock Type Riverstone mix (ironstone, basalt, quartz, sandstone and mudstone).

Vegetation Phase 1: *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula, Gossypium robinsonii* tall open shrubland over *Androcalva luteiflora* open shrubland over *Triodia pungens* hummock grassland with **Cenchrus ciliaris, Themeda tri*andra very open tussock grassland.
Phase 2: Corymbia hamersleyana low open woodland over *Acacia tumida* var. *pilbarensis,* Andr*ocalva luteiflora, Grevillea wickhamii* subsp. *hispidula, Gossypium robinsonii* tall shrubland over *Acacia pyrifolia* var. *pyrifolia* scattered shrubs over *Triodia pungens* hummock grassland with *Cymbopogon procerus, Themeda tri*andra, **Cenchrus ciliaris* very open tussock grassland.

Veg Condition Phase 1: Very Good (**Cenchrus* spp.). Phase 2: Very Good (**Cenchrus* spp.).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Few standing dead trees that could be *Eucalyptus victrix.*

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia pyrifolia var. *pyrifolia*	0.1	120 cm		1	160 cm	
Acacia tumida var. *pilbarensis*	3	450 cm		5	220 cm	
Andr*ocalva luteiflora*	2	120 cm		2	220 cm	
Aristida contorta				0.1	25 cm	
Aristida holathera var. *holathera*	0.1	40 cm		0.1	40 cm	
Atalaya hemiglauca	0.1	60 cm		0.1	55 cm	
Boerhavia coccinea	0.1	20 cm	BIL31-03			
Bonamia erecta	0.1	30 cm		0.1	40 cm	
Bothriochloa ewartiana	0.1	70 cm				
Cenchrus ciliaris	2	40 cm		2	90 cm	
Cenchrus setiger	0.1	60 cm		0.1	70 cm	
Chrysopogon fallax	0.1	110 cm		0.1	90 cm	
Cleome viscosa	0.1	20 cm		0.1	35 cm	
Clerodendrum floribundum var. *angustifolium*	0.1	200 cm	BIL31-05	0.1	210 cm	
Corchorus crozophorifolius	0.1	20 cm	BIL31-12			
Corchorus sidoides subsp. *sidoides*	0.1	50 cm	BIL31-06	0.1	30 cm	
Corchorus tectus	0.1	50 cm	BIL31-13	0.1	25 cm	
Corymbia hamersleyana	4	850 cm		5	1000 cm	
Crotalaria medicaginea var. *neglecta*	0.1	50 cm		0.1	15 cm	
Cucumis variabilis	0.1	40 cm		0.1	25 cm	
Cymbopogon obtectus	0.1	80 cm		0.1	35 cm	
Cymbopogon procerus	0.1	100 cm		3	100 cm	
Dicrastylis cordifolia	0.1	20 cm		0.1	30 cm	
Digitaria brownii				0.1	30 cm	BILR31-01
Digitaria ctenantha	0.1	50 cm				
Enneapogon lindleyanus				0.1	55 cm	
Enneapogon polyphyllus	0.1	40 cm				
Eragrostis eriopoda	0.1	40 cm		0.1	30 cm	
Eremophila longifolia	0.1	120 cm		0.1	150 cm	
Eriachne pulchella				0.1	10 cm	
Euphorbia australis var. *subtomentosa*	0.1	5 cm	BIL31-11			
Euphorbia trigonosperma	0.1	35 cm	BIL31-02			
Evolvulus alsinoides var. *decumbens*				0.1	25 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm		0.1	15 cm	
Gomphrena cunninghamii	0.1	10 cm				
Goodenia stobbsiana	0.1	30 cm		0.1	40 cm	
Gossypium robinsonii	1	600 cm		1	220 cm	
Grevillea wickhamii subsp. *hispidula*	1	480 cm	BIL31-09	2	350 cm	
Hybanthus aurantiacus	0.1	30 cm		0.1	35 cm	
Indigofera georgei	0.1	60 cm		0.1	60 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Ipomoea polymorpha	0.1	30 cm	BIL31-07			
Paraneurachne muelleri	0.1	30 cm		0.1	34 cm	
Paspalidium clementii	0.1	20 cm	BIL31-10			
Perotis rara	0.1	10 cm				
Petalostylis cassioides	0.1	200 cm	BIL31-08	0.1	240 cm	
Polymeria ambigua	0.1	20 cm		0.1	20 cm	
Rhagodia eremaea	0.1	50 cm				
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	1	100 cm	BIL31-14	0.1	55 cm	
Setaria dielsii	0.1	60 cm		0.1	10 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)				0.1	80 cm	
Solanum lasiophyllum	0.1	20 cm		0.1	20 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	60 cm	BIL31-04	0.1	40 cm	
Themeda triandra	1	70 cm		2	110 cm	
Trianthema pilosum	0.1	15 cm				
Tribulopis angustifolia	0.1	20 cm				
Trichodesma zeylanicum var. *zeylanicum*	0.1	60 cm		0.1	120 cm	
Triodia pungens	38	50 cm	BIL31-01	35	45 cm	
Waltheria indica	0.1	60 cm		0.1	60 cm	

BIL31 Phase 1

BIL31 Phase 2

Yandi Billiards Level 2 BIL32

Described by Phase 1: CEFCASW, Phase 2: PA/PL Date Phase 1: 19-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 738634 mE, 7481425 mN.

Habitat Colluvial floodplain on the NW side of Weeli Wolli Creek, with very slight S sloping aspect.

Soil Dark reddish brown sandy loam with 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia aptaneura, A. pruinocarpa* low woodland over **Cenchrus ciliaris, *C. setiger* very open tussock grassland and *Cleome viscosa* scattered herbs.
Phase 2: Acacia aptaneura, A. pruinocarpa low woodland over *Triodia pungens* scattered hummock grasses with **Cenchrus setiger* very open tussock grassland.

Veg Condition Phase 1: Poor (**Malvastrum americanum, *Bidens bipinnata, *Setaria verticillata, *Cenchrus* spp., evidence of cattle). Phase 2: Very Poor (**Cenchrus spp., *Malvastrum americanum*).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Notes Phase 1: Moderate to high level of cattle tracks and scats. Phase 2: Many dead annuals.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon cryptopetalum	0.1	60 cm	BIL32-30			
Abutilon lepidum	0.1	40 cm	BIL32-08, BIL32-20	0.1	40 cm	
Abutilon otocarpum	0.1	30 cm	BIL32-07	0.1	10 cm	
Acacia ancistrocarpa				0.1	120 cm	
Acacia aptaneura	25	680 cm	BIL32-01	9	680 cm	
Acacia pruinocarpa	3	620 cm		3	620 cm	
Anthobolus leptomerioides				0.1	50 cm	
Aristida holathera var. *holathera*	0.1	20 cm				
Bidens bipinnata	0.1	20 cm				
Boerhavia coccinea	0.1	10 cm	BIL32-05	0.1	30 cm	
Bulbostylis barbata	0.1	10 cm	BIL32-17			
Cenchrus ciliaris	5	50 cm		0.1	45 cm	
Cenchrus setiger	1	50 cm		3	80 cm	
Chrysopogon fallax	0.1	70 cm				
Cleome viscosa	0.5	40 cm				
Corchorus sidoides subsp. *sidoides*	0.1	10 cm				
Corchorus tridens	0.1	15 cm	BIL32-18			
Cyperus iria	0.1	25 cm	BIL32-34			
Dactyloctenium radulans	0.1	5 cm				
Digitaria ctenantha	0.1	30 cm				
Dipteracanthus australasicus subsp. *australasicus*	0.1	30 cm	BIL32-33			
Duperreya commixta	0.1	50 cm		0.1	40 cm	
Dysphania kalpari	0.1	20 cm	BIL32-09	0.1	10 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	20 cm				
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	15 cm		0.1	8 cm	BILR32-04
Enchylaena tomentosa var. *tomentosa*	0.1	100 cm	BIL32-38	0.1	40 cm	
Enneapogon polyphyllus	0.1	50 cm		0.1	30 cm	
Eragrostis cumingii	0.1	10 cm				
Eremophila forrestii subsp. *forrestii*				0.1	25 cm	
Eremophila forrestii x *latrobei*	0.1	40 cm	BIL32-15	0.1	50 cm	
Eremophila lanceolata	0.1	40 cm	BIL32-31	0.1	40 cm	
Euphorbia australis var. erythrantha				0.1	15 cm	BILR32-05
Euphorbia australis var. *subtomentosa*	0.1	5 cm	BIL32-04	0.1	15 cm	BILR32-02
Euphorbia biconvexa	0.1	10 cm	BIL32-19			
Euphorbia tannensis subsp. *eremophila*				0.1	40 cm	
Evolvulus alsinoides var. *decumbens*	0.1	15 cm				
Evolvulus alsinoides var. *villosicalyx*	0.1	10 cm		0.1	15 cm	
Gomphrena cunninghamii	0.1	20 cm				
Goodenia microptera	0.1	15 cm	BIL32-28			
Goodenia prostrata	0.1	10 cm	BIL32-06	0.1	10 cm	
Gossypium australe	0.1	100 cm		0.1	75 cm	
Heliotropium inexplicitum	0.1	10 cm	BIL32-13	0.1	15 cm	BILR32-06

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Hibiscus burtonii	0.1	100 cm	BIL32-27	0.1	10 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm				
Indigofera colutea	0.1	10 cm				
Indigofera linnaei	0.1	5 cm	BIL32-12			
Ipomoea muelleri	0.1	15 cm	BIL32-10			
Iseilema membranaceum	0.1	10 cm	BIL32-24			
Malvastrum americanum	0.1	15 cm		0.1	30 cm	
Melhania oblongifolia	0.1	30 cm		0.1	30 cm	
Nicotiana simulans	0.1	20 cm	BIL32-35			
Paspalidium clementii	0.1	30 cm	BIL32-21			
Perotis rara	0.1	10 cm		0.1	10 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	10 cm				
Polycarpaea longiflora	0.1	10 cm				
Portulaca oleracea/intraterranea	0.1	5 cm	BIL32-03	0.1	10 cm	BILR32-01
Psydrax suaveolens				0.1	160 cm	BILR32-03
Pterocaulon sphacelatum	0.1	20 cm	BIL32-22			
Ptilotus gaudichaudii subsp. *gaudichaudii*	0.1	20 cm	BIL32-25			
Ptilotus helipteroides	0.1	10 cm	BIL32-32			
Ptilotus nobilis subsp. *nobilis*	0.1	15 cm		0.1	10 cm	
Ptilotus obovatus var. *obovatus*				0.1	40 cm	
Rhagodia eremaea				0.1	110 cm	
Rhynchosia minima	0.1	30 cm				
Salsola australis	0.1	20 cm		0.1	10 cm	
Sclerolaena cornishiana	0.1	30 cm	BIL32-11	0.1	45 cm	
Senna artemisioides subsp. *helmsii*	0.1	60 cm				
Senna notabilis	0.1	20 cm		0.1	30 cm	
Setaria verticillata	0.1	25 cm	BIL32-29			
Sida ectogama	0.1	40 cm				
Sida fibulifera	0.1	15 cm				
Sida platycalyx	0.1	10 cm	BIL32-16	0.1	30 cm	
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	10 cm	BIL32-23	0.1	25 cm	
Solanum lasiophyllum	0.1	15 cm		0.1	130 cm	
Sporobolus australasicus	0.1	10 cm				
Tragus australianus	0.1	15 cm				
Trianthema pilosum	0.1	10 cm	BIL32-36, BIL32-37			
Tribulus astrocarpus	0.1	2 cm				
Tribulus macrocarpus	0.1	2 cm		0.1	20 cm	
Triodia basedowii	0.1	40 cm	BIL32-26	0.1	40 cm	
Triodia pungens	0.1	50 cm	BIL32-14	0.5	40 cm	
Triodia wiseana	0.1	50 cm	BIL32-02	0.1	40 cm	
Waltheria indica	0.1	40 cm		0.1	30 cm	

BIL32 Phase 1

BIL32 Phase 2

Yandi Billiards Level 2 BIL33

Described by Phase 1: CEFCASW, Phase 2: PA/PL Date Phase 1: 17-Mar-14, Phase 2: 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 735611 mE, 7474691 mN.

Habitat Plain with low hills to the E and S.

Soil Dark reddish brown sandy loam with 1-25% cover or cobbles, pebbles and gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus gamophylla* low open *mallee* woodland over *Acacia pruinocarpa, A. bivenosa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland.
Phase 2: Corymbia hamersleyana scattered low trees over *Eucalyptus gamophylla* low open *mallee* woodland over *Acacia bivenosa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Elevation: 503 m.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum				0.1	30 cm	
Acacia ancistrocarpa	0.1	220 cm		0.1	220 cm	
Acacia aptaneura	0.1	150 cm	BIL33-06	0.1	180 cm	
Acacia aptaneura x *ayersiana*	0.1	190 cm	BIL33-15	0.1	220 cm	
Acacia bivenosa	1	300 cm		3	450 cm	
Acacia dictyophleba	0.1	190 cm		0.1	40 cm	
Acacia inaequilatera	0.1	300 cm		0.1	320 cm	
Acacia pruinocarpa	1	400 cm		1	500 cm	
Anthobolus leptomerioides	0.1	140 cm		0.1	160 cm	
Aristida contorta	0.1	20 cm		0.1	25 cm	
Aristida holathera var. *holathera*	0.1	50 cm		0.1	50 cm	
Boerhavia coccinea	0.1	5 cm	BIL33-16			
Corchorus sidoides subsp. *sidoides*	0.1	40 cm		0.1	40 cm	
Corymbia hamersleyana	0.1	500 cm		0.5	550 cm	
Cymbopogon ambiguus	0.1	100 cm	BIL33-10	0.1	100 cm	
Cymbopogon obtectus	0.1	90 cm		0.1	100 cm	
Digitaria brownii	0.1	130 cm	BIL33-09	0.1	70 cm	
Dodonaea coriacea	0.1	30 cm	BIL33-13	0.1	100 cm	
Duperreya commixta	0.1	70 cm		0.1	100 cm	
Enneapogon polyphyllus	0.1	30 cm		0.1	20 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	40 cm	
Eremophila forrestii subsp. *forrestii*	0.1	100 cm	BIL33-05	0.1	100 cm	
Eremophila longifolia	0.1	40 cm		0.1	50 cm	
Eucalyptus gamophylla	3	450 cm		2	500 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	5 cm		0.1	20 cm	
Goodenia microptera	0.1	35 cm				
Hakea chordophylla				0.1	300 cm	
Hakea lorea subsp. *lorea*	0.1	400 cm		0.1	450 cm	
Hibiscus burtonii	0.1	15 cm	BIL33-11	0.1	20 cm	
Hibiscus leptocladus				0.1	30 cm	BILR33-01
Hibiscus sturtii var. *platychlamys*	0.1	25 cm	BIL33-12	0.1	25 cm	
Paraneurachne muelleri	0.1	60 cm		0.1	40 cm	
Petalostylis cassioides	4	100 cm		2	190 cm	
Ptilotus astrolasius				0.1	30 cm	
Ptilotus calostachyus	0.1	25 cm		0.1	80 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	5 cm		0.1	25 cm	
Ptilotus obovatus var. *obovatus*	0.1	20 cm		0.1	30 cm	
Rhyncharrhena linearis	0.1	5 cm		0.1	40 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	25 cm		0.1	25 cm	
Senna artemisioides subsp. *helmsii*	0.1	50 cm		0.1	90 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	BIL33-04	0.1	100 cm	
Senna glutinosa subsp. *glutinosa*	0.1	90 cm	BIL33-02	0.1	210 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	120 cm		0.1	160 cm	
Sida arenicola				0.1	60 cm	
Sida cardiophylla	0.1	70 cm	BIL33-07	0.1	90 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	35 cm		0.1	60 cm	
Sida sp. *verrucose gl*ands (F.H. Mollemans 2423)	0.1	15 cm	BIL33-08			
Solanum lasiophyllum	0.1	20 cm	BIL33-03	0.1	50 cm	
Triodia basedowii	25	45 cm	BIL33-01	25	50 cm	

BIL33 Phase 1

BIL33 Phase 2

Yandi Billiards Level 2 BIL34

Described by Phase 1: CASV, Phase 2: PACEF Date Phase 1: 14-Mar-14, Phase 2: 10-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 733180 mE, 7474693 mN.

Habitat Hill crest amongst low rolling hills.

Soil Dark reddish brown skeletal sandy clay loam with 1-25% cover of cobbles, 51-75% cover of pebbles, 1-25% cover of gravel and 1-25% outcropping rock.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* subsp. *hispidula, Acacia inaequilatera, Hakea lorea* subsp. *lorea* scattered tall shrubs over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* subsp. *hispidula, Acacia inaequilatera* scattered tall shrubs over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	60 cm		0.1	50 cm	
Acacia hilliana	2	60 cm		3	50 cm	
Acacia inaequilatera	0.5	400 cm		0.5	310 cm	
Acacia pruinocarpa	0.1	180 cm		0.1	220 cm	
Amphipogon sericeus	0.1	10 cm	BIL34-07	0.1	20 cm	
Aristida contorta	0.1	30 cm		0.1	25 cm	
Aristida holathera var. *holathera*	0.1	30 cm		0.1	40 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	1 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	60 cm	BIL34-11	0.1	70 cm	
Eriachne mucronata (typical form)	0.1	30 cm	BIL34-03	0.1	30 cm	
Eriachne pulchella	0.1	10 cm				
Eucalyptus leucophloia subsp. *leucophloia*	1	600 cm		1	500 cm	
Fimbristylis simulans	0.1	10 cm		0.1	20 cm	
Goodenia stobbsiana	0.1	10 cm		0.1	30 cm	
Goodenia triodiophila	0.1	30 cm	BIL34-06	0.1	40 cm	
Grevillea wickhamii subsp. *hispidula*	1	220 cm		0.5	280 cm	BILR34-01
Hakea lorea subsp. *lorea*	0.5	410 cm	BIL34-01	0.1	350 cm	
Paraneurachne muelleri	0.1	30 cm				
Ptilotus calostachyus	0.1	40 cm		0.1	80 cm	
Ptilotus rotundifolius	0.1	50 cm		0.1	70 cm	
Scaevola spinescens	0.1	60 cm		0.1	80 cm	
Senna artemisioides subsp. *oligophylla*	0.1	30 cm	BIL34-09	0.1	40 cm	
Senna glutinosa subsp. *glutinosa*	0.1	120 cm		0.1	130 cm	
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*				0.1	110 cm	
Senna glutinosa subsp. *pruinosa*	0.1	110 cm				
Senna glutinosa subsp. x *luerssenii*	0.1	160 cm	BIL34-08	0.1	120 cm	
Sida sp. *Pilbara* (A.A. Mitchell PRP 1543)	0.1	30 cm	BIL34-04	0.1	40 cm	
Solanum lasiophyllum	0.1	40 cm		0.1	40 cm	
Tribulus suberosus	0.1	40 cm		0.1	50 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	20	50 cm	BIL34-02	15	30 cm	
Triodia wiseana				0.1	40 cm	

BIL34 Phase 1

BIL34 Phase 2

Yandi Billiards Level 2		BIL35	
Described by	Phase 1: CASV, Phase 2: PLSW	Date	Phase 1: 14-Mar-14, Phase 2: 10-Jul-14
Type	Quadrat 50 x 50 m		
Central Coordinate	731333 mE, 7474127 mN.		
Habitat	Drainage line at junction of two minor drainage channels.		
Soil	Dark reddish brown sandy loam with 26-50% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Corymbia hamersleyana* low open woodland over *Acacia pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Acacia adoxa* var. *adoxa* scattered low shrubs over *Triodia pungens, T. wiseana* very open hummock grassland with *Themeda tri*andra, * *Cenchrus ciliaris, Eulalia aurea* open tussock grassland. *Phase 2: Corymbia hamersleyana* low open woodland over *Acacia pyrifolia* var. *pyrifolia, A. tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Santalum lanceolatum* scattered shrubs over *Acacia adoxa* var. *adoxa* scattered low shrubs over *Triodia wiseana, T. pungens* open hummock grassland with *Themeda tri*andra, **Cenchrus ciliaris, Eulalia aurea* open tussock grassland.		
Veg Condition	Phase 1: Good (**Cenchrus ciliaris*). Phase 2: Good (**Cenchrus ciliaris*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Elevation: 521 m.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	60 cm	BIL35-23	0.1	30 cm	
Abutilon otocarpum	0.1	80 cm		0.1	45 cm	
Acacia adoxa var. *adoxa*	1	50 cm		1	50 cm	
Acacia adsurgens	0.1	150 cm	BIL35-18	0.1	220 cm	
Acacia ancistrocarpa	0.1	140 cm		0.1	210 cm	
Acacia dictyophleba	0.1	140 cm		0.1	220 cm	
Acacia pyrifolia var. *pyrifolia*	6	300 cm	BIL35-01	6	300 cm	
Acacia tenuissima	0.1	150 cm		0.1	130 cm	
Acacia tumida var. *pilbarensis*	5	450 cm		5	450 cm	
Alysicarpus muelleri	0.1	120 cm	BIL35-22	0.1	45 cm	
Amaranthus undulatus	0.1	60 cm	BIL35-20			
Aristida holathera var. *holathera*	0.1	40 cm		0.1	40 cm	
Boerhavia coccinea	0.1	10 cm	BIL35-05			
Bonamia erecta	0.1	30 cm		0.1	35 cm	
Cenchrus ciliaris	9	60 cm		4	70 cm	
Chrysopogon fallax				0.1	120 cm	
Cleome viscosa	0.1	50 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	70 cm	BIL35-19	0.1	50 cm	
Corchorus tridens	0.1	20 cm	BIL35-10			
Corymbia hamersleyana	7	1000 cm		6	900 cm	
Crotalaria medicaginea var. *neglecta*	0.1	80 cm	BIL35-11			
Cucumis variabilis	0.1	40 cm		0.1	200 cm	
Cymbopogon procerus	0.1	120 cm		0.1	85 cm	
Digitaria brownii	0.1	30 cm	BIL35-30	0.1	45 cm	
Eragrostis cumingii	0.1	20 cm				
Eragrostis eriopoda				0.1	40 cm	
Eremophila longifolia	0.1	110 cm		0.1	80 cm	
Eriachne aristidea	0.1	30 cm				
Eriachne mucronata (typical form)	0.1	40 cm	BIL35-24, BIL35-29	0.1	40 cm	
Eriachne tenuiculmis				0.1	45 cm	
Eulalia aurea	2	60 cm		0.5	70 cm	
Euphorbia australis var. *australis*	0.1	20 cm	BIL35-12			
Euphorbia australis var. *subtomentosa*				0.1	15 cm	BILR35-01
Euphorbia biconvexa				0.1	50 cm	BILR35-02
Euphorbia biconvexa/coghlanii/trigonosperma	0.1	20 cm	BIL35-04			
Evolvulus alsinoides var. *decumbens*	0.1	20 cm		0.1	30 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm		0.1	20 cm	
Gossypium australe	0.1	80 cm	BIL35-02, BIL35-31	0.1	190 cm	
Grevillea wickhamii subsp. *hispidula*	1	400 cm	BIL35-27	1	400 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Hakea chordophylla	0.1	150 cm		0.1	170 cm	
Hibiscus sturtii var. *platychlamys*	0.1	30 cm	BIL35-26	0.1	50 cm	
Hybanthus aurantiacus	0.1	40 cm		0.1	50 cm	
Indigofera colutea	0.1	25 cm		0.1	25 cm	
Indigofera monophylla	0.1	40 cm	BIL35-28	0.1	40 cm	
Ipomoea muelleri	0.1	10 cm				
Jasminum didymum subsp. *lineare*				0.1	60 cm	
Malvastrum americanum	0.1	100 cm				
Melhania oblongifolia	0.1	45 cm		0.1	100 cm	
Mollugo molluginea	0.1	15 cm				
Paraneurachne muelleri	0.1	80 cm		0.1	40 cm	
Paspalidium clementii	0.1	10 cm	BIL35-21			
Perotis rara	0.1	10 cm				
Polycarpaea longiflora	0.1	25 cm		0.1	25 cm	
Polymeria ambigua	0.1	10 cm	BIL35-09	0.1	25 cm	
Pterocaulon sphacelatum				0.1	70 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	20 cm		0.1	50 cm	
Rhynchosia minima	0.1	70 cm		0.1	60 cm	
Salsola australis	0.1	60 cm				
Santalum lanceolatum	0.1	170 cm	BIL35-15	1	190 cm	
Senna artemisioides subsp. *helmsii*				0.1	120 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	180 cm	BIL35-25, BIL35-14, BIL35-17	0.1	180 cm	BILR35-03
Senna notabilis	0.1	25 cm		0.1	10 cm	
Setaria verticillata	0.1	110 cm		0.1	80 cm	
Sida echinocarpa	0.1	120 cm		0.1	90 cm	
Sida fibulifera				0.1	30 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	80 cm	BIL35-08	0.1	130 cm	
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	25 cm	BIL35-07	0.1	25 cm	
Stemodia grossa	0.1	110 cm		0.1	100 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	60 cm	BIL35-03	0.1	60 cm	BILR35-04
Themeda triandra	12	70 cm		9	110 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	80 cm		0.1	80 cm	
Triodia basedowii	0.1	40 cm	BIL35-16			
Triodia pungens	2	40 cm	BIL35-13	9	40 cm	
Triodia wiseana	1	40 cm		11	40 cm	
Waltheria indica	0.1	70 cm		0.1	110 cm	

BIL35 Phase 1

BIL35 Phase 2

Yandi Billiards Level 2		BIL36	
Described by	Phase 1: PLSW, Phase 2: PLSW	Date	Phase 1: 14-Mar-14, Phase 2: 10-Jul-14
Type	Quadrat 50 x 50 m		
Central Coordinate	730717 mE, 7474212 mN.		
Habitat	Plain to the E NE of low undulating hills.		
Soil	Dark reddish brown fine sandy loam with 1-25% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.		
Rock Type	Ironstone and basalt.		
Vegetation	Phase 1: *Acacia pruinocarpa, Hakea lorea* subsp. *lorea* tall open shrubland over *Acacia bivenosa, Eremophila forrestii* subsp. *forrestii* low open shrubland over *Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* low open shrubland over *Triodia pungens* open hummock grassland and **Cenchrus ciliaris, Eragrostis desertorum* very open tussock grassland. *Phase 2: Acacia pruinocarpa, Hakea lorea* subsp. *lorea, Acacia bivenosa* tall open shrubland over *Senna artemisioides* subsp. *helmsii, S. artemisioides* subsp. *oligophylla* low open shrubland over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris, Eragrostis desertorum* very open tussock grassland.		
Veg Condition	Phase 1: Good (**Cenchrus ciliaris*). Phase 2: Very Good (**Cenchrus ciliaris*)		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Elevation: 522 m.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm		0.1	40 cm	
Abutilon lepidum	0.1	40 cm	BIL36-16			
Abutilon otocarpum	0.1	40 cm		0.1	50 cm	
Acacia bivenosa	1	100 cm		1	300 cm	
Acacia citrinoviridis				0.1	40 cm	
Acacia dictyophleba	0.1	170 cm		0.1	140 cm	
Acacia inaequilatera				0.1	300 cm	
Acacia pachyacra	0.1	150 cm		0.1	160 cm	
Acacia pruinocarpa	1	400 cm		1	270 cm	
Aristida contorta	0.1	30 cm		0.1	40 cm	
Aristida holathera var. *holathera*	0.1	30 cm		0.1	30 cm	
Aristida inaequiglumis				0.1	100 cm	BILR36-01
Atalaya hemiglauca				0.1	170 cm	
Boerhavia burbidgeana	0.1	5 cm	BIL36-08			
Boerhavia coccinea	0.1	20 cm		0.1	10 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	5 cm		0.1	20 cm	
Cenchrus ciliaris	3	45 cm		4	60 cm	
Chrysopogon fallax	0.1	100 cm		0.1	110 cm	
Cleome viscosa	0.1	20 cm		0.1	100 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm		0.1	70 cm	
Crotalaria medicaginea var. *neglecta*	0.1	15 cm				
Cucumis variabilis	0.1	200 cm		0.1	170 cm	
Cymbopogon ambiguus	0.1	110 cm		0.1	120 cm	
Cymbopogon obtectus	0.1	70 cm		0.1	80 cm	
Digitaria ctenantha	0.1	30 cm				
Enneapogon caerulescens	0.1	20 cm	BIL36-15	0.1	25 cm	
Enneapogon lindleyanus	0.1	20 cm	BIL36-11	0.1	40 cm	
Enneapogon polyphyllus	0.1	80 cm	BIL36-13	0.1	20 cm	
Enneapogon robustissimus	0.1	80 cm		0.1	45 cm	
Eragrostis desertorum	1	40 cm	BIL36-10	1	50 cm	
Eragrostis eriopoda	0.1	20 cm		0.1	50 cm	
Eremophila forrestii subsp. *forrestii*	0.5	180 cm		0.1	160 cm	
Eremophila fraseri subsp. *fraseri*	0.1	90 cm		0.1	130 cm	
Eremophila longifolia	0.1	170 cm		0.1	160 cm	
Eriachne mucronata (typical form)	0.1	30 cm		0.1	35 cm	
Euphorbia australis var. *australis*	0.1	10 cm	BIL36-18			
Euphorbia australis var. *subtomentosa*				0.1	10 cm	BILR36-03
Euphorbia biconvexa	0.1	30 cm	BIL36-05			
Euphorbia tannensis subsp. *eremophila*	0.1	40 cm		0.1	30 cm	
Evolvulus alsinoides var. *decumbens*				0.1	25 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm		0.1	20 cm	
Goodenia microptera	0.1	15 cm				
Gossypium australe	0.1	70 cm	BIL36-17	0.1	100 cm	
Hakea lorea subsp. *lorea*	1	500 cm		1	520 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm		0.1	40 cm	
Indigofera colutea	0.1	10 cm		0.1	20 cm	
Indigofera rugosa	0.1	130 cm		0.1	130 cm	
Lepidium phlebopetalum				0.1	20 cm	BILR36-02
Melhania oblongifolia	0.1	50 cm				
Mollugo molluginea	0.1	30 cm		0.1	15 cm	
Notoleptopus decaisnei var. *decaisnei*	0.1	25 cm				
Paraneurachne muelleri	0.1	50 cm		0.1	40 cm	
Perotis rara	0.1	30 cm				
Polycarpaea longiflora	0.1	20 cm				
Polymeria ambigua	0.1	20 cm		0.1	10 cm	
Pterocaulon sphacelatum	0.1	40 cm	BIL36-14			
Ptilotus rotundifolius				0.1	100 cm	
Rhynchosia minima	0.1	40 cm		0.1	40 cm	
Salsola australis	0.1	20 cm		0.1	30 cm	
Sclerolaena cornishiana	0.1	40 cm	BIL36-07	0.1	40 cm	
Senna artemisioides subsp. *helmsii*	2	80 cm		2	90 cm	
Senna artemisioides subsp. *oligophylla*	1	70 cm	BIL36-02	2	75 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	35 cm		0.1	120 cm	
Sida echinocarpa	0.1	60 cm		0.1	100 cm	
Sida fibulifera	0.1	30 cm	BIL36-03	0.1	15 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	80 cm				
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	35 cm		0.1	15 cm	
Solanum lasiophyllum	0.1	50 cm		0.1	90 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)				0.1	30 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	50 cm		0.1	45 cm	
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	0.1	30 cm	BIL36-12			
Themeda triandra	0.1	60 cm		0.1	75 cm	
Tragus australianus	0.1	20 cm				
Tribulus terrestris	0.1	20 cm	BIL36-04			
Triodia pungens	16	45 cm	BIL36-01	13	60 cm	
Triodia wiseana	0.1	60 cm		0.1	60 cm	
Triraphis mollis	0.1	30 cm	BIL36-09			
Zaleya galericulata subsp. *galericulata*				0.1	20 cm	

BIL36 Phase 1

BIL36 Phase 2

Yandi Billiards Level 2 BIL37

Described by CASW Date 17-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 732899 mE, 7470834 mN.

Habitat Gentle N facing hill slope at crest of low hill amongst undulating hill range.

Soil Dark reddish brown sandy clay loam (skeletal) with cobbles (20 %), pebbles (60 %), and gravel (10 %).

Rock Type BIF, shale, ironstone.

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia ancistrocarpa x *arida*	0.1	25 cm	BIL37-04
Acacia hilliana	0.5	40 cm	
Acacia pruinocarpa	0.1	110 cm	
Amphipogon sericeus	0.1	20 cm	
Calytrix carinata	0.1	60 cm	
Cymbopogon ambiguus	0.1	70 cm	
Eremophila latrobei subsp. *latrobei*	0.1	50 cm	BIL37-02
Eriachne mucronata (typical form)	0.1	30 cm	
Eriachne pulchella	0.1	10 cm	
Eucalyptus leucophloia subsp. *leucophloia*	0.5	480 cm	
Fimbristylis simulans	0.1	15 cm	BIL37-03
Goodenia stobbsiana	0.1	15 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	210 cm	
Hakea lorea subsp. *lorea*	0.1	200 cm	
Hibiscus coatesii	0.1	30 cm	BIL37-01
Hybanthus aurantiacus	0.1	20 cm	
Keraudrenia nephrosperma	0.1	60 cm	BIL37-05
Ptilotus calostachyus	0.1	40 cm	
Ptilotus rotundifolius	0.1	55 cm	
Senna glutinosa subsp. *glutinosa*	0.1	60 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	180 cm	
Senna glutinosa subsp. *pruinosa*	0.1	160 cm	
Solanum lasiophyllum	0.1	60 cm	
Themeda triandra	0.1	60 cm	
Tribulus suberosus	0.1	90 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	22	45 cm	
Triodia wiseana	0.1	50 cm	

BIL37

Yandi Billiards Level 2 BIL38

Described by Phase 1: CEFCASW, Phase 2: PLDK Date Phase 1: 14-Mar-14, Phase 2: 11-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 732165 mE, 7472915 mN.

Habitat Colluvial plain extending close to the foot of a mesa.

Soil Dark reddish brown (2.5YR 3/4) sandy loam with 51-75% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana, T. pungens* open hummock grassland.

Phase 2: Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *Acacia bivenosa* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana, T. pungens* open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	80 cm		0.1	60 cm	
Acacia ancistrocarpa	0.1	250 cm		0.1	160 cm	
Acacia bivenosa	25	250 cm		22	260 cm	
Acacia dictyophleba	0.1	250 cm		0.1	250 cm	
Acacia hilliana	0.1	90 cm		0.1	70 cm	
Acacia inaequilatera	0.1	130 cm		0.1	160 cm	
Acacia pruinocarpa	0.1	320 cm		0.1	340 cm	
Acacia synchronicia	0.1	200 cm	BIL38-14	0.1	45 cm	
Aristida contorta	0.1	25 cm		0.1	15 cm	
Bonamia erecta	0.1	35 cm		0.1	40 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	5 cm	BIL38-12			
Brachyachne prostrata	0.1	5 cm	BIL38-20	0.1	3 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	BIL38-15	0.1	50 cm	
Cymbopogon obtectus	0.1	80 cm		0.1	35 cm	
Duperreya commixta	0.1	300 cm		0.1	350 cm	
Enneapogon polyphyllus	0.1	30 cm	BIL38-10	0.1	35 cm	
Eremophila fraseri subsp. *fraseri*	0.1	100 cm		0.1	80 cm	
Eriachne mucronata (typical form)	0.1	45 cm	BIL38-18	0.1	50 cm	
Eriachne pulchella	0.1	5 cm		0.1	10 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	500 cm		2	580 cm	
Goodenia microptera	0.1	20 cm		0.1	50 cm	
Goodenia muelleriana	0.1	10 cm	BIL38-03	0.1	25 cm	
Goodenia stobbsiana	0.1	5 cm		0.1	10 cm	
Hakea chordophylla	0.1	70 cm				
Hakea lorea subsp. *lorea*				0.1	30 cm	
Hibiscus coatesii	0.1	20 cm	BIL38-16	0.1	40 cm	
Hibiscus leptocladus	0.1	20 cm	BIL38-07			
Hybanthus aurantiacus	0.1	30 cm		0.1	45 cm	
Isotropis atropurpurea	0.1	20 cm		0.1	50 cm	
Maireana planifolia	0.1	70 cm	BIL38-19	0.1	30 cm	
Paraneurachne muelleri	0.1	35 cm		0.1	40 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	30 cm	
Ptilotus calostachyus	0.1	30 cm		0.1	20 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	30 cm		0.1	40 cm	
Sclerolaena cornishiana	0.1	7 cm	BIL38-13	0.1	30 cm	
Senna artemisioides subsp. *oligophylla*				0.1	60 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	160 cm		0.1	175 cm	
Senna glutinosa subsp. *pruinosa*	0.1	40 cm		0.1	120 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	130 cm	BIL38-08	0.1	100 cm	
Sida arenicola	0.1	35 cm	BIL38-09			

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Sida echinocarpa	0.1	10 cm		0.1	70 cm	
Sida sp. *Pilbara* (A.A. Mitchell PRP 1543)	0.1	25 cm	BIL38-11			
Solanum horridum	0.1	20 cm	BIL38-17			
Solanum lasiophyllum	0.1	60 cm		0.1	60 cm	
Sporobolus australasicus				0.1	10 cm	
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	0.1	35 cm	BIL38-06			
Themeda triandra	0.1	70 cm		0.1	70 cm	
Triodia pungens	2	45 cm	BIL38-04	2	50 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	22	40 cm	BIL38-01	18	30 cm	
Triodia wiseana	6	40 cm	BIL38-02	4	45 cm	
Tylophora flexuosa	0.1	40 cm	BIL38-05			

BIL38 Phase 1

BIL38 Phase 2

Yandi Billiards Level 2 BIL39

Described by Phase 1: CASV, Phase 2: PLSW Date Phase 1: 13-Mar-14, Phase 2: 10-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 730692 mE, 7471887 mN.

Habitat Hill crest.

Soil Dark reddish brown skeletal sandy loam with 1-25% outcropping rock, 51-75% cover of cobbles, 1-25% cover of pebbles and 26-50% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.
Phase 2: Eucalyptus leucophloia subsp. *leucophloia* scattered low trees over *Ptilotus rotundifolius* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Elevation: 572 m.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	40 cm		0.1	30 cm	
Acacia hilliana	0.1	60 cm		0.1	80 cm	
Acacia pruinocarpa	0.1	350 cm		0.1	430 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)				0.1	5 cm	
Cymbopogon ambiguus				0.1	70 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	450 cm		1	480 cm	
Fimbristylis dichotoma	0.1	15 cm	BIL39-02	0.1	15 cm	
Fimbristylis simulans	0.1	15 cm				
Goodenia stobbsiana	0.1	30 cm		0.1	30 cm	
Polygala glaucifolia	0.1	1 cm	BIL39-03	0.1	1 cm	
Ptilotus calostachyus	0.1	60 cm		0.1	100 cm	
Ptilotus rotundifolius	0.1	70 cm		0.5	110 cm	
Schizachyrium fragile				0.1	15 cm	
Senna glutinosa subsp. *glutinosa*	0.1	170 cm		0.1	200 cm	
Senna glutinosa subsp. *pruinosa*	0.1	40 cm				
Senna glutinosa subsp. x *luerssenii*	0.1	120 cm	BIL39-04	0.1	130 cm	
Trachymene oleracea subsp. *oleracea*				0.1	5 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	40	30 cm	BIL39-01	25	30 cm	
Triodia wiseana	0.1	30 cm		0.1	35 cm	

BIL39 Phase 1

BIL39 Phase 2

Yandi Billiards Level 2 BIL40
Described by CASV Date 14-Mar-14
Type Quadrat 50 x 50 m
Central Coordinate 730092 mE, 7473748 mN.
Habitat Hillcrest and slope of a small hill facing SW.
Soil 2.5YR 3/3 dark reddish brown sandy loam with cobbles (80 %), pebbles (10 %), and gravel (5 %).
Rock Type Ironstone.
Vegetation *Acacia inaequilatera* tall open shrubland over *Indigofera monophylla* low open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition Excellent.
Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia inaequilatera	4	350 cm	
Acacia pruinocarpa	0.1	250 cm	
Boerhavia burbidgeana	0.1	5 cm	BIL40-09
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	10 cm	BIL40-04
Cheilanthes contigua	0.1	10 cm	BIL40-01
Enchylaena tomentosa var. *tomentosa*	0.1	35 cm	BIL40-10
Enneapogon caerulescens	0.1	25 cm	
Enneapogon lindleyanus	0.1	35 cm	
Enneapogon polyphyllus	0.1	25 cm	
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL40-11
Fimbristylis dichotoma	0.1	15 cm	BIL40-06
Gomphrena cunninghamii	0.1	10 cm	
Gossypium australe	0.1	80 cm	
Indigofera monophylla	2	50 cm	BIL40-05
Paspalidium clementii	0.1	10 cm	BIL40-12
Portulaca oleracea/intraterranea	0.1	7 cm	BIL40-08
Ptilotus astrolasius	0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	7 cm	
Salsola australis	0.1	20 cm	
Schizachyrium fragile	0.1	20 cm	
Senna artemisioides subsp. *oligophylla*	0.1	45 cm	BIL40-07
Senna glutinosa subsp. *glutinosa*	0.1	150 cm	
Senna glutinosa subsp. *pruinosa*	0.1	100 cm	
Sida echinocarpa	0.1	20 cm	BIL40-03
Solanum lasiophyllum	0.1	30 cm	
Tribulus suberosus	0.1	110 cm	
Triodia wiseana	50	45 cm	BIL40-02

BIL40

Yandi Billiards Level 2 BIL41

Described by	Phase 1: SVSW, Phase 2: PA/PL	Date	Phase 1: 11-Mar-14, Phase 2: 08-Jul-14
Type	Quadrat 50 x 50 m		
Central Coordinate	739505 mE, 7484581 mN.		
Habitat	Colluvial plain.		
Soil	Dark reddish brown sandy loam with 1-25% cover of pebbles and gravel.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Acacia ancistrocarpa, A. inaequilatera, A. pruinocarpa, A. bivenosa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* hummock grassland.		
	Phase 2: Acacia ancistrocarpa, A. inaequilatera, A. pruinocarpa, A. bivenosa tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Very Good (**Cenchrus ciliaris*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia ancistrocarpa	3	260 cm		3	320 cm	
Acacia bivenosa	0.5	400 cm		0.5	420 cm	
Acacia citrinoviridis	0.1	150 cm		0.1	160 cm	
Acacia elachantha				0.1	190 cm	
Acacia inaequilatera	3	350 cm		2	300 cm	
Acacia pachyacra	0.1	260 cm		0.1	210 cm	
Acacia pruinocarpa	1	410 cm		1	400 cm	
Acacia pyrifolia var. *pyrifolia*				0.1	140 cm	
Aristida holathera var. *holathera*	0.1	45 cm		0.1	50 cm	
Cenchrus ciliaris				0.1	30 cm	
Cleome viscosa	0.1	10 cm				
Corchorus tectus	0.1	15 cm		0.1	50 cm	
Cucumis variabilis	0.1	20 cm		0.1	40 cm	
Cymbopogon ambiguus	0.1	140 cm	BIL41-03	0.1	90 cm	
Cymbopogon obtectus	0.1	110 cm		0.1	90 cm	
Dicrastylis cordifolia	0.1	45 cm		0.1	10 cm	
Dodonaea coriacea	0.1	15 cm		0.1	25 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	40 cm	
Eriachne aristidea				0.1	25 cm	
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL41-06			
Evolvulus alsinoides var. *villosicalyx*	0.1	10 cm				
Goodenia microptera	0.1	35 cm		0.1	40 cm	
Gossypium australe	0.1	60 cm		0.1	100 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	60 cm		0.1	50 cm	
Hakea lorea subsp. *lorea*	0.1	100 cm		0.1	500 cm	
Hibiscus sturtii var. *platychlamys*	0.1	20 cm		0.1	40 cm	
Hybanthus aurantiacus	0.1	70 cm		0.1	40 cm	
Indigofera monophylla				0.1	40 cm	
Paspalidium clementii	0.1	20 cm	BIL41-04			
Paspalidium rarum	0.1	15 cm	BIL41-07			
Petalostylis cassioides	4	160 cm	YAQR23-12=	3	180 cm	
Ptilotus astrolasius	0.1	25 cm		0.1	40 cm	
Schizachyrium fragile				0.1	40 cm	
Senna artemisioides subsp. *helmsii*	0.1	580 cm		0.1	80 cm	
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)	0.1	110 cm	BIL41-09	0.1	110 cm	
Senna notabilis	0.1	15 cm		0.1	20 cm	
Sida arenicola				0.1	40 cm	
Sida cardiophylla	0.1	15 cm	YAQR23-14=	0.1	60 cm	
Solanum horridum				0.1	35 cm	
Solanum phlomoides	0.1	12 cm	BIL41-02, BIL41-05	0.1	30 cm	
Trianthema pilosum	0.1	5 cm				
Triodia basedowii	55	55 cm	BIL41-01	40	35 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Triodia pungens	0.1	60 cm	BIL41-08	0.1	40 cm	
Yakirra australiensis var. *australiensis*	0.1	10 cm		0.1	15 cm	

BIL41 Phase 1

BIL41 Phase 2

Yandi Billiards Level 2 BIL42

Described by	Phase 1: CEFCASW, Phase 2: CEFSW	Date	Phase 1: 18-Mar-14, Phase 2: 08-Jul-14
Type	Quadrat 50 x 50 m		
Central Coordinate	741451 mE, 7484607 mN.		
Habitat	Colluvial plain at the base of low hills to the W.		
Soil	Dark reddish brown loamy sand.		
Rock Type	Nil.		
Vegetation	Phase 1: *Eucalyptus gamophylla* low open *mallee* woodland over *Triodia schinzii* hummock grassland.		
	Phase 2*: Eucalyptus gamophylla* low open *mallee* woodland over *Triodia schinzii* open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia dictyophleba	0.1	160 cm		0.1	120 cm	
Acacia pachyacra	0.1	150 cm	BIL42-03	0.1	170 cm	
Aristida holathera var. *holathera*	0.1	30 cm		0.1	40 cm	
Bonamia erecta	0.1	35 cm		0.1	30 cm	
Corchorus tectus	0.1	30 cm	BIL42-02	0.1	30 cm	
Dicrastylis cordifolia	0.1	30 cm		0.1	35 cm	
Eragrostis eriopoda	0.1	30 cm		0.1	15 cm	
Eucalyptus gamophylla	3	450 cm		4	450 cm	
Hybanthus aurantiacus	0.1	70 cm		0.1	55 cm	
Paraneurachne muelleri	0.1	35 cm		0.1	20 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	30 cm	BIL42-01	0.1	20 cm	
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	100 cm	BIL42-04	0.1	130 cm	
Senna notabilis	0.1	5 cm		0.1	10 cm	
Sida cardiophylla	0.1	40 cm	BIL22-04=	0.1	40 cm	
Trianthema pilosum	0.1	10 cm	BIL22-10=	0.1	10 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	10 cm				
Triodia pungens	0.1	70 cm	BIL22-03=	0.1	45 cm	
Triodia schinzii	35	50 cm	BIL22-01=	29	35 cm	

BIL42 Phase 1

BIL42 Phase 2

Yandi Billiards Level 2		BIL43	
Described by	PLCA	Date	09-Mar-14
Type	Quadrat 50 x 50 m		
Central Coordinate	739869 mE, 7485474 mN.		
Habitat	Rocky BIF hill crest in major valley, on the W side of major drainage.		
Soil	Dark reddish brown sandy loam with cobbles (80 %), pebbles (20 %).		
Rock Type	Ironstone.		
Vegetation	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* subsp. *hispidula* scattered tall shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.		
Veg Condition	Excellent.		
Fire Age	No sign of recent fire.		
Notes	Elevation: 510 m.		

Species	Cover (%)	Height (cm)	Specimen
Acacia bivenosa (wispy/weeping form)	0.1	280 cm	
Acacia pruinocarpa	0.1	210 cm	
Eriachne mucronata (typical form)	0.1	30 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	500 cm	
Fimbristylis dichotoma	0.1	30 cm	
Fimbristylis simulans	0.1	10 cm	
Grevillea wickhamii subsp. *hispidula*	1	370 cm	BIL43-06
Polygala glaucifolia	0.1	2 cm	BIL43-04
Ptilotus calostachyus	0.1	60 cm	
Ptilotus obovatus var. *obovatus*	0.1	130 cm	
Ptilotus rotundifolius	0.1	120 cm	
Senna artemisioides subsp. *helmsii*	0.1	60 cm	
Senna glutinosa subsp. *glutinosa*	0.1	170 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	100 cm	BIL43-03
Senna glutinosa subsp. *pruinosa*	0.1	50 cm	
Senna glutinosa subsp. *pruinosa* x	0.1	120 cm	BIL43-02
Tribulus suberosus	0.1	70 cm	
Triodia pungens	0.1	30 cm	BIL43-05
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	35	30 cm	BIL43-01

BIL43

Yandi Billiards Level 2 BIL44

Described by PLSW Date 13-Mar-14

Type Quadrat 50 x 50 m

Central Coordinate 729716 mE, 7472094 mN.

Habitat Ridge/slope in broader area of continuous hills.

Soil Dark reddish brown sandy clay loam with angular basalt cobbles (50 %), pebbles (30 %), and gravel (20 %).

Rock Type Ironstone.

Vegetation *Acacia inaequilatera* tall open shrubland over *Triodia wiseana* hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Notes W corner not staked.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	50 cm	
Acacia inaequilatera	2.5	430 cm	
Acacia pruinocarpa	0.1	60 cm	
Boerhavia gardneri	0.1	35 cm	BILPL-19=
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	25 cm	
Enneapogon lindleyanus	0.1	45 cm	BIL44-03
Eriachne mucronata (typical form)	0.1	40 cm	
Paraneurachne muelleri	0.1	40 cm	
Paspalidium clementii	0.1	20 cm	
Ptilotus clementii	0.1	20 cm	BIL44-04
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	0.1	40 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	170 cm	BIL44-01
Senna glutinosa subsp. x *luerssenii*	0.1	190 cm	
Solanum lasiophyllum	0.1	50 cm	
Triodia wiseana	37	50 cm	

No photo

Yandi Billiards Level 2 BIL45

Described by	Phase 1: CEFCASW, Phase 2: CEFSW	Date	Phase 1: 19-Mar-14, Phase 2: 08-Jul-14
Type	Quadrat 50 x 50 m		
Central Coordinate	738287 mE, 7481664 mN.		
Habitat	Broad plain.		
Soil	Dark reddish brown loamy sand with 1-25% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Petalostylis cassioides, Acacia pruinocarpa* open shrubland over *Triodia basedowii* open hummock grassland.		
	Phase 2: Petalostylis cassioides, Acacia pruinocarpa open shrubland over *Triodia basedowii* open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	*Eucalyptus gamophylla* and *Corymbia hamersleyana* scattered low open woodland in broader landscape.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	0.1	40 cm				
Acacia adsurgens	0.1	120 cm	BIL45-12	0.1	150 cm	
Acacia ancistrocarpa	0.1	110 cm		0.1	130 cm	
Acacia citrinoviridis				0.1	120 cm	
Acacia dictyophleba	0.1	100 cm		0.1	140 cm	
Acacia elachantha	0.1	170 cm	BIL45-10	0.1	170 cm	
Acacia inaequilatera	0.1	410 cm		0.1	400 cm	
Acacia pachyacra	0.1	60 cm	BIL46-05=	0.1	100 cm	
Acacia pruinocarpa	1	150 cm		1	160 cm	
Acacia tenuissima				0.1	50 cm	BILR45-01
Acacia tumida var. *pilbarensis*	0.1	160 cm				
Amphipogon sericeus				0.1	35 cm	
Aristida holathera var. *holathera*	0.1	40 cm		0.1	50 cm	
Aristida pruinosa	0.1	80 cm	BIL46-21=	0.1	120 cm	
Bonamia erecta	0.1	10 cm		0.1	35 cm	
Cleome viscosa	0.1	80 cm				
Corchorus tectus	0.1	30 cm		0.1	30 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	40 cm	
Euphorbia australis var. *hispidula*	0.1	10 cm	BIL45-11	0.1	5 cm	
Evolvulus alsinoides var. *villosicalyx*				0.1	15 cm	
Goodenia microptera	0.1	40 cm	BIL45-05			
Gossypium australe	0.1	150 cm		0.1	140 cm	
Hibiscus burtonii	0.1	80 cm	BIL45-04			
Hibiscus sturtii var. *platychlamys*	0.1	40 cm		0.1	100 cm	
Hybanthus aurantiacus	0.1	60 cm		0.1	50 cm	
Indigofera monophylla	0.1	60 cm	BIL45-03	0.1	45 cm	
Paraneurachne muelleri	0.1	70 cm		0.1	40 cm	
Petalostylis cassioides	2	180 cm		2	200 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	50 cm	
Ptilotus calostachyus	0.1	60 cm		0.1	70 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	5 cm		0.1	65 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	10 cm		0.1	35 cm	
Senna artemisioides subsp. *helmsii*	0.1	10 cm				
Senna artemisioides subsp. *oligophylla*	0.1	40 cm	BIL45-08	0.1	100 cm	
Senna glutinosa subsp. *glutinosa*	0.1	150 cm	BIL45-06	0.1	140 cm	
Senna glutinosa subsp. *pruinosa*	0.1	160 cm				
Senna glutinosa subsp. x *luerssenii*				0.1	150 cm	
Senna notabilis	0.1	10 cm		0.1	5 cm	
Sida arenicola	0.1	140 cm	BIL45-07	0.1	200 cm	BILR45-02
Sida cardiophylla	0.1	40 cm	BIL46-22=	0.1	60 cm	
Sida echinocarpa	0.1	40 cm	BIL45-09	0.1	120 cm	
Solanum elatius	0.1	80 cm	BIL45-01	0.1	45 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Solanum phlomoides	0.1	40 cm	BIL45-13	0.1	35 cm	
Triodia basedowii	13	40 cm	BIL46-26=	18	50 cm	

BIL45 Phase 1

BIL45 Phase 2

Yandi Billiards Level 2 BIL46

Described by Phase 1: CEFCASW Phase 2: PA/PL Date Phase 1: 19-Mar-14, Phase 2: 08-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 737268 mE, 7480980 mN.

Habitat Plain/diffuse floodplain of tributary of Weeli Wolli Creek.

Soil Dark reddish brown loamy sand with 1-25% cover of cobbles, 1-25% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia tumida* var. *pilbarensis,* (*A. pachyacra*) tall open shrubland over *Petalostylis cassioides, Senna artemisioides* subsp. *oligophylla* (thinly sericeous form MET 15,035), *Acacia ancistrocarpa* open shrubland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grasses and *Bonamia erecta* very open herbland.
Phase 2: Acacia tumida var. *pilbarensis, A. pachyacra* tall open shrubland over *Petalostylis cassioides, Acacia ancistrocarpa, Senna artemisioides* subsp. *oligophylla, S. artemisioides* subsp. *oligophylla* x subsp. *helmsii* open shrubland over *Bonamia erecta, Scaevola parvifolia* subsp. *pilbarae, Corchorus tectus* low open shrubland over *Triodia pungens* scattered hummock grasses with *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland.

Veg Condition Phase 1: Very Good (**Cenchrus* spp., cow scats and grazing). Phase 2: Good (**Cenchrus* spp.; evidence of cattle).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	50 cm	BIL46-09	0.1	25 cm	
Abutilon otocarpum	0.1	60 cm		0.1	30 cm	
Abutilon sp. *Pilbara* (W.R. Barker 2025)				0.1	25 cm	
Acacia adoxa var. *adoxa*	0.1	70 cm		0.1	60 cm	
Acacia adsurgens				0.1	160 cm	
Acacia ancistrocarpa	0.5	150 cm		2	170 cm	
Acacia bivenosa	0.1	120 cm		0.1	60 cm	
Acacia citrinoviridis				0.1	90 cm	
Acacia dictyophleba	0.1	130 cm		0.1	130 cm	
Acacia pachyacra	1	200 cm	BIL46-05	3	190 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	130 cm	BIL46-24	0.1	140 cm	
Acacia tumida var. *pilbarensis*	9	220 cm	BIL46-01	8	270 cm	
Alternanthera nana	0.1	30 cm	BIL46-27			
Amaranthus undulatus	0.1	90 cm	BIL46-23			
Anthobolus leptomerioides				0.1	50 cm	
Aristida holathera var. *holathera*	1	60 cm		1	70 cm	
Aristida pruinosa	0.1	100 cm	BIL46-21	0.1	100 cm	
Boerhavia coccinea	0.1	10 cm	BIL46-02			
Bonamia erecta	6	25 cm		4	50 cm	
Cenchrus ciliaris	0.1	100 cm		0.1	60 cm	
Cenchrus setiger	0.1	70 cm		0.1	60 cm	
Chrysopogon fallax	0.1	150 cm		0.1	160 cm	
Cleome viscosa	0.1	70 cm		0.1	60 cm	
Corchorus tectus	0.1	30 cm		0.5	60 cm	
Corchorus tridens	0.1	15 cm	BIL46-12			
Crotalaria medicaginea var. *neglecta*	0.1	40 cm		0.1	50 cm	
Enneapogon polyphyllus	0.1	30 cm		0.1	30 cm	
Eragrostis cumingii	0.1	10 cm				
Eragrostis eriopoda	0.1	50 cm		0.1	60 cm	
Eriachne aristidea	0.1	40 cm				
Euphorbia australis var. *hispidula*				0.1	15 cm	BILR46-05
Euphorbia australis var. *subtomentosa*	0.1	15 cm	BIL46-17			
Euphorbia coghlanii	0.1	35 cm	BIL46-07			
Euphorbia tannensis subsp. *eremophila*	0.1	35 cm	BIL46-11	0.1	40 cm	
Euphorbia trigonosperma				0.1	50 cm	BILR46-03
Evolvulus alsinoides var. *villosicalyx*	0.1	10 cm		0.1	20 cm	
Gomphrena cunninghamii	0.1	40 cm	BIL46-14			
Goodenia microptera	0.1	20 cm		0.1	40 cm	
Gossypium australe	0.1	50 cm		0.1	30 cm	
Gossypium robinsonii	0.1	230 cm		0.1	300 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Grevillea wickhamii subsp. *hispidula*	0.1	220 cm		0.1	210 cm	
Hakea chordophylla				0.1	230 cm	
Hakea lorea subsp. *lorea*	0.1	350 cm		0.1	350 cm	
Hibiscus sturtii var. *platychlamys*	0.1	80 cm	BIL46-18	0.1	50 cm	
Hybanthus aurantiacus	0.1	60 cm		0.1	40 cm	
Indigofera georgei	0.1	50 cm		0.1	40 cm	
Indigofera monophylla	0.1	60 cm	BIL46-13	0.1	80 cm	
Melhania oblongifolia	0.1	50 cm				
Mollugo molluginea	0.1	20 cm		0.1	10 cm	
Notoleptopus decaisnei var. *decaisnei*	0.1	40 cm	BIL46-20			
Paraneurachne muelleri	1	70 cm		1	40 cm	
Paspalidium rarum	0.1	60 cm	BIL46-19			
Perotis rara	0.1	15 cm				
Petalostylis cassioides	3	160 cm	BIL46-08	3	230 cm	
Polymeria ambigua	0.1	10 cm	BIL46-03	0.1	30 cm	
Ptilotus astrolasius	0.1	40 cm		0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	20 cm		0.1	20 cm	
Rhagodia eremaea	0.1	100 cm		0.1	120 cm	
Rhynchosia minima	0.1	40 cm		0.1	20 cm	
Salsola australis	0.1	60 cm		0.1	70 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	40 cm		1	20 cm	
Schizachyrium fragile				0.1	40 cm	BILR46-01
Senna artemisioides subsp. *oligophylla*				1	100 cm	BILR46-04
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)	1	110 cm	BIL46-04			
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*				1	110 cm	BILR46-06
Senna notabilis	0.1	10 cm		0.1	30 cm	
Sida cardiophylla	0.1	90 cm	BIL46-22	0.1	80 cm	
Sida echinocarpa				0.1	140 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	30 cm		0.1	90 cm	
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	50 cm	BIL46-16	0.1	30 cm	
Solanum elatius	0.1	100 cm	BIL46-25			
Solanum lasiophyllum	0.1	50 cm		0.1	80 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	30 cm	BIL46-10	0.1	50 cm	
Themeda triandra	0.1	120 cm		0.1	90 cm	
Trianthema pilosum	0.1	15 cm				
Tribulopis angustifolia	0.1	5 cm				
Tribulus macrocarpus	0.1	10 cm		0.1	10 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	30 cm		0.1	50 cm	
Triodia basedowii	0.1	40 cm	BIL46-26	0.1	30 cm	
Triodia pungens	0.1	50 cm	BIL46-06	1	40 cm	
Waltheria indica	0.1	120 cm				
Yakirra australiensis var. *australiensis*				0.1	20 cm	BILR46-02

BIL46 Phase 1

BIL46 Phase 2

Yandi Billiards Level 2 BIL47

Described by CEFSW Date 09-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 734454 mE, 7471527 mN.

Habitat Broad floodplain adjacent to minor creek line.

Soil Dark reddish brown (5YR 3/3) sandy clay loam with 1-25% cover of gravel, 1-25% cover of pebbles and 1-25% cover of cobbles.

Rock Type Ironstone.

Vegetation *Corymbia hamersleyana* scattered low trees over *Acacia ancistrocarpa* scattered tall shrubs over *A. pyrifolia* var. *pyrifolia* scattered shrubs over *Triodia pungens* very open hummock grassland with **Cenchrus ciliaris, Themeda tri*andra very open tussock grassland.

Veg Condition Good (**Cenchrus ciliaris,* cow scats, evidence of grazing).

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	30 cm	BIL47-07
Acacia adsurgens	0.1	210 cm	
Acacia ancistrocarpa	0.5	300 cm	
Acacia aptaneura	0.1	180 cm	BIL47-08
Acacia bivenosa	0.1	210 cm	
Acacia inaequilatera	0.1	260 cm	
Acacia pruinocarpa	0.1	160 cm	
Acacia pyrifolia var. *pyrifolia*	1	170 cm	
Acacia tumida var. *pilbarensis*	0.1	60 cm	
Aristida contorta	0.1	20 cm	
Aristida holathera var. *holathera*	0.1	20 cm	
Aristida inaequiglumis	0.1	130 cm	
Atalaya hemiglauca	0.1	320 cm	
Boerhavia coccinea	0.1	5 cm	
Bonamia erecta	0.1	30 cm	
Cenchrus ciliaris	6	40 cm	
Chrysopogon fallax	0.1	130 cm	
Cleome viscosa	0.1	40 cm	
Corchorus crozophorifolius	0.1	110 cm	
Corchorus tectus	0.1	40 cm	BIL47-04
Corymbia hamersleyana	10.5	650 cm	
Crotalaria medicaginea var. *neglecta*	0.1	10 cm	
Duperreya commixta	0.1	70 cm	
Enneapogon polyphyllus	0.1	15 cm	
Enneapogon robustissimus	0.1	100 cm	
Eragrostis eriopoda	0.1	25 cm	
Eremophila latrobei subsp. *filiformis*	0.1	150 cm	
Eremophila longifolia	0.1	175 cm	
Eriachne mucronata (typical form)	0.1	45 cm	
Euphorbia australis var. *subtomentosa*	0.1	5 cm	BIL47-10
Euphorbia biconvexa	0.1	45 cm	BIL47-01
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Goodenia microptera	0.1	20 cm	
Goodenia triodiophila	0.1	50 cm	
Gossypium australe	0.1	35 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	220 cm	
Hakea lorea subsp. *lorea*	0.1	160 cm	
Heliotropium cunninghamii	0.1	30 cm	BIL47-05
Hibiscus sturtii var. *platychlamys*	0.1	35 cm	BIL47-09
Hybanthus aurantiacus	0.1	35 cm	
Indigofera monophylla	0.1	45 cm	
Jasminum didymum subsp. *lineare*	0.1	60 cm	
Melhania oblongifolia	0.1	35 cm	

Species	Cover (%)	Height (cm)	Specimen
Mollugo molluginea	0.1	10 cm	
Paraneurachne muelleri	0.1	35 cm	
Polymeria ambigua	0.1	10 cm	
Ptilotus astrolasius	0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	50 cm	
Ptilotus obovatus var. *obovatus*	0.1	50 cm	
Rhynchosia minima	0.1	200 cm	
Salsola australis	0.1	30 cm	
Scaevola spinescens	0.1	130 cm	
Sclerolaena cornishiana	0.1	20 cm	BIL47-06
Senna artemisioides subsp. *helmsii*	0.1	130 cm	
Senna artemisioides subsp. *oligophylla*	0.1	120 cm	
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	0.1	130 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	120 cm	
Sida sp. *spiciform panicles* (E. Leyland s.n. 14/8/90)	0.1	60 cm	
Sida sp. *verrucose glands* (F.H. Mollemans 2423)	0.1	20 cm	BIL47-02
Solanum lasiophyllum	0.1	35 cm	
Sporobolus australasicus	0.1	10 cm	
Streptoglossa decurrens	0.1	20 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	25 cm	BIL47-03
Themeda triandra	0.5	120 cm	
Tribulus macrocarpus	0.1	5 cm	
Tribulus suberosus	0.1	65 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	20 cm	
Triodia basedowii	0.1	35 cm	
Triodia pungens	9	40 cm	
Triodia wiseana	0.1	30 cm	
Waltheria indica	0.1	120 cm	

BIL47

Yandi Billiards Level 2 BIL48

Described by PACEF Date 11-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 731598 mE, 7472021 mN.

Habitat E facing low rocky rise in between Weeli Wolli Creek and hills to the W.

Soil Dark reddish brown (2.5YR 2.5/3) sandy clay with 1-25% cover of outcropping rock, 1-25% cover of cobbles, 26-50% cover of pebbles and 1-25% cover of gravel.

Rock Type Calcrete.

Vegetation *Acacia pruinocarpa, Alectryon oleifolius* subsp. *oleifolius* scattered tall shrubs over *Acacia bivenosa, Eremophila fraseri* subsp. *fraseri* open shrubland over *Triodia wiseana* open hummock grassland *with*Cenchrus ciliaris* scattered tussock grasses.

Veg Condition Very Good (**Cenchrus ciliaris* scattered tussock grasses).

Fire Age No sign of recent fire.

Notes Old track runs through SW corner of quadrat. *Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* scattered low trees in broader landscape.

Species	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	BIL48-10
Acacia ancistrocarpa	0.1	130 cm	
Acacia bivenosa	2	150 cm	
Acacia pruinocarpa	0.5	220 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	180 cm	
Alectryon oleifolius subsp. *oleifolius*	0.5	220 cm	BIL48-04
Anthobolus leptomerioides	0.1	150 cm	
Cenchrus ciliaris	1	40 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	
Cullen leucochaites	0.1	150 cm	BIL48-11
Digitaria ctenantha	0.1	40 cm	
Duperreya commixta	0.1	120 cm	
Enchylaena tomentosa var. *tomentosa*	0.1	60 cm	
Enneapogon caerulescens	0.1	35 cm	BIL48-07, BIL48-03, BIL48-08
Eremophila fraseri subsp. *fraseri*	3	130 cm	BIL48-01
Eriachne pulchella	0.1	10 cm	
Euphorbia australis var. *subtomentosa*	0.1	10 cm	BIL48-12
Euphorbia tannensis subsp. *eremophila*	0.1	35 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm	
Hakea chordophylla	0.1	250 cm	
Hakea lorea subsp. *lorea*	0.1	300 cm	
Indigofera monophylla	0.1	30 cm	
Melhania oblongifolia	0.1	30 cm	
Paraneurachne muelleri	0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	50 cm	
Rhagodia eremaea	0.1	110 cm	BIL48-05
Rhynchosia minima	0.1	20 cm	
Salsola australis	0.1	20 cm	
Santalum lanceolatum	0.1	50 cm	BIL48-06
Scaevola spinescens	0.1	35 cm	
Sclerolaena cornishiana	0.1	60 cm	
Senna artemisioides subsp. *helmsii*	0.1	50 cm	
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	120 cm	
Sida fibulifera	0.1	25 cm	BIL48-02
Solanum lasiophyllum	0.1	50 cm	
Tragus australianus	0.1	10 cm	
Triodia wiseana	12	45 cm	
Tripogon loliiformis	0.1	15 cm	BIL48-09

BIL48

Yandi Billiards Level 2 BIL49

Described by PACEF Date 11-Jul-14

Type Quadrat 50 x 50 m

Central Coordinate 731707 mE, 7472713 mN.

Habitat Undulating plain; slightly S sloping undulating plane below rocky hills, dissected by minor flow lines.

Soil Dark reddish brown (2.5yr 2.5/4) sandy clay loam with 1-25% cover of cobbles, >75% cover of pebbles and 1-25% cover of gravel.

Rock Type Ironstone.

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia ancistrocarpa* tall open shrubland over *A. adoxa* var. *adoxa* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. pungens*) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. *adoxa*	1	60 cm	
Acacia ancistrocarpa	3	170 cm	
Acacia bivenosa	0.1	90 cm	
Acacia dictyophleba	0.1	140 cm	
Acacia hilliana	0.1	70 cm	
Acacia inaequilatera	0.1	210 cm	
Acacia tenuissima	0.1	150 cm	
Amphipogon sericeus	0.1	25 cm	
Aristida holathera var. *holathera*	0.1	70 cm	BIL49-03
Bonamia erecta	0.1	50 cm	
Bonamia sp. *Dampier* (A.A. Mitchell PRP 217)	0.1	30 cm	
Dampiera candicans	0.1	60 cm	
Eriachne mucronata (typical form)	0.1	40 cm	
Eriachne pulchella	0.1	10 cm	
Eucalyptus gamophylla	1	400 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	600 cm	
Goodenia microptera	0.1	30 cm	
Goodenia stobbsiana	0.1	30 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	280 cm	BIL49-06
Hakea chordophylla	0.1	350 cm	
Heliotropium pachyphyllum	0.1	20 cm	BIL49-01
Hibiscus sturtii var. *platychlamys*	0.1	40 cm	BIL49-05
Hybanthus aurantiacus	0.1	30 cm	
Indigofera monophylla	0.1	70 cm	
Isotropis atropurpurea	0.1	70 cm	
Paraneurachne muelleri	0.1	60 cm	
Ptilotus astrolasius	0.1	40 cm	
Ptilotus calostachyus	0.1	70 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	70 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	25 cm	
Sclerolaena cornishiana	0.1	40 cm	
Senna artemisioides subsp. *oligophylla*	0.1	80 cm	
Senna glutinosa subsp. *glutinosa*	0.1	170 cm	
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*	0.1	150 cm	
Senna glutinosa subsp. x *luerssenii*	0.1	160 cm	BIL49-02
Sida arenicola	0.1	60 cm	
Sida echinocarpa	0.1	60 cm	
Solanum horridum	0.1	40 cm	BIL49-04
Solanum lasiophyllum	0.1	50 cm	
Tribulus suberosus	0.1	45 cm	
Triodia pungens	2	60 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	13	30 cm	

BIL49

Yandi Billiards Level 2 BIL-RCFA

Described by CEF Date 14-Mar-14 Type Relevé

Central Coordinate 729589 mE, 7473017 mN.

Habitat Minor creek line in between two low rocky hills.

Soil Dark reddish brown skeletal.

Rock Type Not recorded.

Vegetation *Senna artemisioides* subsp. *oligophylla*, *Gossypium australe, Acacia pyrifolia* var. *pyrifolia* open shrubland over *Cymbopogon ambiguus, Enneapogon lindleyanus, Enneapogon lindleyanus, Themeda triandra* open tussock grassland.

Veg Condition Very Good (**Aerva javanica*).

Fire Age No sign of recent fire.

Notes Creekline is approximately 3-5 m wide.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	30 cm	BIL-RCFA08
Acacia inaequilatera	0.1	250 cm	
Acacia pyrifolia var. *pyrifolia*	1	150 cm	BIL-RCFA01
Aerva javanica	0.1	110 cm	
Aristida holathera var. *holathera*	0.1	30 cm	
Atalaya hemiglauca	0.1	300 cm	
Boerhavia coccinea	0.1	20 cm	BIL-RCFA06
Bulbostylis barbata	0.1	30 cm	BIL-RCFA09
Cleome viscosa	0.1	40 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm	BIL-RCFA05
Crotalaria medicaginea var. *neglecta*	0.1	50 cm	
Cymbopogon ambiguus	15	120 cm	
Cyperus squarrosus	0.1	10 cm	BIL-RCFA10
Enneapogon lindleyanus	10	60 cm	BIL-CF160=
Enneapogon polyphyllus	0.1	40 cm	
Enneapogon robustissimus	0.1	120 cm	
Eriachne tenuiculmis	0.5	50 cm	BIL-CF161=
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Gossypium australe	2	160 cm	
Heliotropium tenuifolium	0.1	30 cm	BIL-RCFA07
Hibiscus sturtii var. *platychlamys*	0.1	30 cm	BIL-RCFA12
Indigofera monophylla	0.1	40 cm	BIL-RCFA11
Indigofera rugosa	0.1	100 cm	BIL-RCFA03
Melhania oblongifolia	0.1	45 cm	
Polycarpaea longiflora	0.1	30 cm	
Rhynchosia minima	0.1	40 cm	
Senna artemisioides subsp. *oligophylla*	5	150 cm	BIL-RCFA04
Solanum horridum	0.1	15 cm	
Stemodia grossa	0.1	10 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	50 cm	BIL-RCFA02
Themeda triandra	0.5	100 cm	
Triodia wiseana	3	60 cm	

BIL-RCFA

Yandi Billiards Level 2 BIL-RCFB

Described by	CEF	Date	14-Mar-14	Type	Relevé

Central Coordinate 731555 mE, 7473010 mN.
Habitat Rocky ridgeline adjacent to a gully.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Eucalyptus leucophloia* subsp. *leucophloia*, *Corymbia ferriticola* low open woodland over *Senna glutinosa* subsp. *glutinosa*, *Eremophila latrobei* subsp. *filiformis* open shrubland over *Themeda triandra*, *Eriachne mucronata* (typical form), *Cymbopogon ambiguus* open tussock grassland with *Triodia pungens* scattered hummock grasses.
Veg Condition Very Good (**Cenchrus ciliaris*).
Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	30 cm	BIL-RCFB14
Aristida holathera var. *holathera*	0.1	30 cm	
Capparis spinosa var. *nummularia*	0.1	30 cm	
Cenchrus ciliaris	0.1	30 cm	
Clerodendrum floribundum var. *angustifolium*	0.1	10 cm	
Corymbia ferriticola	1	300 cm	BIL-RCFB01
Cymbopogon ambiguus	1	70 cm	BIL-RCFB04
Duperreya commixta	0.1	60 cm	
Enneapogon polyphyllus	0.1	35 cm	
Eremophila latrobei subsp. *filiformis*	1	150 cm	BIL-RCFB07
Eremophila latrobei subsp. *latrobei*	0.1	160 cm	BIL-RCFB08
Eriachne mucronata (typical form)	10	40 cm	BIL-RCFB02
Eucalyptus leucophloia subsp. *leucophloia*	4	500 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Goodenia muelleriana	0.1	40 cm	BIL-RCFB15
Hibiscus sp. Mt Robinson (G. Byrne 3537)	0.1	40 cm	BIL-RCFB13
Maireana planifolia	0.1	40 cm	BIL-RCFB09
Ptilotus obovatus var. *obovatus*	0.1	70 cm	
Rhagodia eremaea	0.1	70 cm	
Senna glutinosa subsp. *glutinosa*	2	150 cm	BIL-RCFB06
Sida sp. Excedentifolia (J.L. Egan 1925)	0.1	40 cm	BIL-RCFB03
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	50 cm	BIL-RCFB11
Solanum lasiophyllum	0.1	30 cm	BIL-RCFB12
Themeda triandra	12	60 cm	BIL-RCFB10
Tribulus suberosus	0.1	40 cm	
Triodia pungens	1	50 cm	BIL-RCFB05

BIL-RCFB

Yandi Billiards Level 2 BIL-RCFC

Described by	CEF	Date	16-Mar-14	Type	Relevé

Central Coordinate 738115 mE, 7476778 mN.
Habitat Minor creek line.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Gossypium robinsonii* tall open scrub over *Triodia pungens* open hummock grassland.
Veg Condition Excellent.
Fire Age No sign of recent fire.
Notes Site unburnt, most of the surrounding landscape has been burnt <3 years ago.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	20 cm	BIL-RCFC10
Acacia pyrifolia var. *pyrifolia*	0.1	160 cm	BIL-RCFC12
Acacia tumida var. *pilbarensis*	50	250 cm	BIL-RCFC01
Aristida holathera var. *holathera*	0.1	45 cm	
Bonamia erecta	0.1	40 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	50 cm	BIL-RCFC04
Corymbia hamersleyana	1	550 cm	
Cymbopogon obtectus	0.1	60 cm	
Cymbopogon procerus	0.1	110 cm	BIL-RCFC13
Enneapogon robustissimus	0.1	100 cm	
Eriachne mucronata (typical form)	0.1	40 cm	BIL-RCFC11
Eucalyptus gamophylla	0.1	300 cm	
Eulalia aurea	0.1	110 cm	BIL-RCFC14
Euphorbia australis var. *subtomentosa*	0.1	15 cm	BIL-RCFC05
Euphorbia biconvexa	0.1	35 cm	BIL-RCFC08
Evolvulus alsinoides var. *villosicalyx*	0.1	15 cm	
Goodenia microptera	0.1	30 cm	
Goodenia muelleriana	0.1	30 cm	
Gossypium robinsonii	3	300 cm	
Hibiscus leptocladus	0.1	30 cm	BIL-RCFC09
Hybanthus aurantiacus	0.1	40 cm	
Indigofera monophylla	0.1	40 cm	BIL-RCFC07
Isotropis atropurpurea	0.1	30 cm	BIL-RCFC02
Melhania oblongifolia	0.1	30 cm	
Paraneurachne muelleri	0.1	30 cm	
Polycarpaea holtzei	0.1	2 cm	
Polycarpaea longiflora	0.1	40 cm	
Senna artemisioides subsp. *oligophylla*	0.1	75 cm	BIL-RCFC15
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	50 cm	BIL-RCFC16
Stemodia grossa	0.1	30 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	70 cm	BIL-RCFC06
Trichodesma zeylanicum var. *zeylanicum*	0.1	10 cm	
Triodia pungens	25	40 cm	BIL-RCFC03

BIL-RCFC

Yandi Billiards Level 2 BIL-RCFD

Described by	CEF	Date	17-Mar-14	Type	Relevé
Central Coordinate	732769 mE, 7470814 mN.				
Habitat	Exposed rocky ridgeline.				
Soil	Dark reddish brown skeletal.				
Rock Type	Not recorded.				
Vegetation	*Corymbia ferriticola, Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia pungens* very open hummock grassland with *Eriachne mucronata* (typical form), *Cymbopogon ambiguus* very open tussock grassland.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				
Notes	Ridgeline has not been burnt but the plain and surrounding low hills have a fire age of approximately 3 years.				

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	35 cm	BIL-RCFD20
Abutilon sp. Pilbara (W.R. Barker 2025)	0.1	35 cm	BIL-RCFD18
Acacia spondylophylla	0.1	50 cm	
Amphipogon sericeus	0.1	30 cm	BIL-CF191=
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	10 cm	
Corchorus crozophorifolius	0.1	30 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	BIL-RCFD07
Corymbia ferriticola	2	300 cm	BIL-RCFD03
Cymbopogon ambiguus	2	100 cm	BIL-RCFD01
Dodonaea coriacea	0.1	20 cm	
Eremophila latrobei subsp. *latrobei*	0.1	40 cm	BIL-RCFD05
Eriachne mucronata (typical form)	3	30 cm	BIL-RCFD02
Eriachne pulchella	0.1	30 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	450 cm	
Gompholobium oreophilum	0.1	15 cm	BIL-RCFD16
Gomphrena cunninghamii	0.1	15 cm	BIL-RCFD06
Goodenia microptera	0.1	60 cm	
Goodenia muelleriana	0.1	15 cm	BIL-RCFD13
Goodenia stobbsiana	0.1	20 cm	
Grevillea wickhamii	0.1	120 cm	
Heliotropium inexplicitum	0.1	20 cm	BIL-RCFD12
Hibiscus coatesii	0.1	40 cm	BIL-RCFD10
Hibiscus sturtii var. *campylochlamys*	0.1	40 cm	BIL-RCFD17
Keraudrenia velutina subsp. *elliptica*	0.1	30 cm	BIL-RCFD14
Paraneurachne muelleri	0.1	60 cm	
Senna glutinosa subsp. *glutinosa*	0.1	30 cm	BIL-RCFD11
Senna glutinosa subsp. *x luerssenii*	0.1	120 cm	BIL-RCFD04
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	50 cm	BIL-RCFD15
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	30 cm	
Solanum horridum	0.1	30 cm	BIL-RCFD09
Themeda triandra	0.1	45 cm	BIL-RCFD19
Triodia pungens	4	40 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	0.1	35 cm	
Triodia wiseana	0.1	60 cm	

BIL-RCFD

Yandi Billiards Level 2 BIL-RPCA

Described by	PLCA	Date	10-Mar-14	Type	Relevé ~40 x 40 m

Central Coordinate	743101 mE, 7483664 mN.
Habitat	Lower hill slope.
Soil	Dark reddish brown silty clay loam.
Rock Type	BIF boulders (1%), cobbles (10%), pebbles (88%), and gravel (1%).
Vegetation	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.
Veg Condition	Excellent.
Fire Age	No sign of recent fire.
Notes	Elevation: 475 m. Relevé in place of quadrat because upslope is burnt and not enough area for quadrat.

Species	Cover (%)	Height	Specimen
Acacia bivenosa (wispy/weeping form)	1	220 cm	
Acacia inaequilatera	0.1	100 cm	
Acacia pachyacra	0.1	170 cm	BIL-RPCA02
Eucalyptus leucophloia subsp. *leucophloia*	1	700 cm	
Fimbristylis simulans	0.1	15 cm	
Goodenia stobbsiana	0.1	10 cm	
Grevillea wickhamii	0.1	250 cm	
Hakea chordophylla	0.1	250 cm	
Ptilotus calostachyus	0.1	60 cm	
Senna glutinosa subsp. *glutinosa*	0.1	180 cm	
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*	0.1	160 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	20	40 cm	BIL-RPCA01

BIL-RPCA

Yandi Billiards Level 2 BIL-RSPA

Described by PLSW Date 13-Mar-14 Type Relevé

Central Coordinate 730066 mE, 7472398 mN.

Habitat Southeast facing moderate hill slope amongst broader undulating hills.

Soil Dark reddish brown sandy clay loam.

Rock Type Mix of ironstone and basalt boulders (1%), cobbles (3%), pebbles (40%), and gravel (20%).

Vegetation *Acacia aptaneura*, (*A. pruinocarpa*) low woodland over *Senna artemisioides* subsp. *helmsii* scattered low shrubs over *Triodia pungens* open hummock grassland with *Digitaria ctenantha* scattered grasses.

Veg Condition Good (**Bidens bipinnata, *Cenchrus ciliaris*).

Fire Age No sign of recent fire.

Notes Elevation: 550 m. Relevé size is approximately 50 x 50 m.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	25 cm	BIL-RSPA02
Abutilon macrum	0.1	30 cm	BIL-RSPA23
Abutilon otocarpum	0.1	40 cm	
Acacia aptaneura	14	850 cm	BIL-RSPA08
Acacia pruinocarpa	1	900 cm	
Amaranthus cuspidifolius	0.1	20 cm	BIL-RSPA04
Aristida contorta	0.1	40 cm	
Aristida holathera var. *holathera*	0.1	30 cm	
Bidens bipinnata	0.1	10 cm	
Boerhavia coccinea	0.1	30 cm	
Bulbostylis barbata	0.1	5 cm	
Cenchrus ciliaris	0.1	40 cm	
Cheilanthes brownii	0.1	10 cm	BIL-RSPA20
Cheilanthes contigua	0.1	10 cm	BIL-RSPA07
Cleome viscosa	0.1	35 cm	
Corchorus crozophorifolius	0.1	30 cm	
Digitaria ctenantha	2	25 cm	
Duperreya commixta	0.1	200 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	20 cm	BIL-RSPA05
Enchylaena tomentosa var. *tomentosa*	0.1	60 cm	BIL-RSPA22
Enneapogon lindleyanus	0.1	30 cm	
Enneapogon polyphyllus	0.1	20 cm	
Enneapogon robustissimus	0.1	50 cm	BIL-RSPA11
Eremophila latrobei subsp. *latrobei*	0.1	250 cm	BIL-RSPA14; -19
Eremophila longifolia	0.1	200 cm	
Eriachne mucronata (typical form)	0.1	45 cm	
Eriachne pulchella	0.1	15 cm	
Eucalyptus leucophloia subsp. *leucophloia*	0.1	600 cm	
Euphorbia coghlanii	0.1	20 cm	BIL-RSPA06
Evolvulus alsinoides var. *decumbens*	0.1	15 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Fimbristylis dichotoma	0.1	20 cm	
Gomphrena cunninghamii	0.1	10 cm	
Goodenia muelleriana	0.1	40 cm	
Hakea lorea subsp. *lorea*	0.1	70 cm	
Hibiscus burtonii	0.1	30 cm	
Hibiscus coatesii	0.1	40 cm	BIL-RSPA17
Hibiscus sturtii var. *campylochlamys*	0.1	40 cm	BIL-RSPA15
Iseilema membranaceum	0.1	20 cm	BIL-RSPA09
Jasminum didymum subsp. *lineare*	0.1	110 cm	
Maireana planifolia	0.1	100 cm	BIL-RSPA13
Maireana planifolia x *villosa*	0.1	70 cm	BIL-RSPA18
Malvastrum americanum	0.1	20 cm	
Melhania oblongifolia	0.1	40 cm	
Paspalidium clementii	0.1	20 cm	

Species	Cover (%)	Height	Specimen
Perotis rara	0.1	10 cm	
Portulaca oleracea/intraterranea	0.1	10 cm	BIL-RSPA03
Ptilotus auriculifolius	0.1	20 cm	
Ptilotus obovatus var. *obovatus*	0.1	30 cm	
Rhagodia eremaea	0.1	30 cm	
Salsola australis	0.1	25 cm	
Santalum lanceolatum	0.1	200 cm	
Senna artemisioides subsp. *oligophylla*	0.1	25 cm	
Senna glutinosa subsp. *x luerssenii*	0.5	80 cm	
Senna notabilis	0.1	10 cm	
Sida fibulifera	0.1	40 cm	BIL-RSPA21
Sida echinocarpa	0.1	45 cm	BIL-RSPA14
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	30 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	20 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	25 cm	
Solanum horridum	0.1	20 cm	BIL-RSPA10
Solanum lasiophyllum	0.1	15 cm	
Sporobolus australasicus	0.1	10 cm	
Themeda triandra	0.1	80 cm	
Tribulus suberosus	0.1	160 cm	
Triodia pungens	2	12 cm	BIL-RSPA12
Triodia schinzii	0.1	50 cm	BIL-RSPA01
Triodia wiseana	0.1	40 cm	

BIL-RSPA

Yandi Billiards Level 2 BIL-RSWA

Described by	SVSW	Date	10-Mar-14	Type	Relevé

Central Coordinate 742364 mE, 7482528 mN.
Habitat Flat 70 m wide valley floor between mesa ranges.
Soil 2.5YR 3/4 dark reddish brown sandy loam.
Rock Type Nil.
Vegetation *Gossypium robinsonii, Senna artemisioides* subsp. *oligophylla*, *Atalaya hemiglauca* tall shrubland over *Triodia epactia* very open hummock grassland over *Cleome viscosa* low open shrubland.
Veg Condition Very Good (**Cenchrus ciliaris*).
Fire Age Burnt 3-5 years ago.
Notes Valley would act as drainage during rainfall events. Surrounding veg. and valley slopes recently burnt (<2 years ago). Elevation: 842 m (SW), 849 m (NE).

Species	Cover (%)	Height	Specimen
Acacia pyrifolia var. *pyrifolia*	0.1	100 cm	
Amaranthus undulatus	0.1	50 m	BIL-RSWA05
Aristida holathera var. *holathera*	0.1	30 cm	
Atalaya hemiglauca	1	340 cm	
Boerhavia coccinea	0.1	10 cm	
Bulbostylis barbata	0.1	10 cm	
Cenchrus ciliaris	0.1	70 cm	
Cleome viscosa	10	100 cm	
Corchorus sidoides subsp. *sidoides*	0.1	60 cm	
Corchorus tectus	0.1	30 cm	
Corchorus tridens	0.1	20 cm	BIL-RSWA14
Cucumis variabilis	0.1	100 cm	
Cymbopogon ambiguus	0.1	110 cm	BIL-RSWA09
Cymbopogon procerus	0.1	120 cm	
Digitaria ctenantha	0.1	60 cm	
Enneapogon lindleyanus	0.1	50 cm	
Enneapogon polyphyllus	0.1	10 cm	
Eragrostis cumingii	0.1	30 cm	
Eragrostis eriopoda	0.1	15 cm	
Eremophila longifolia	0.1	380 cm	
Eriachne tenuiculmis	0.1	100 cm	
Euphorbia australis var. *subtomentosa*	0.1	15 cm	BIL-RSWA02
Euphorbia coghlanii	0.1	20 cm	BIL-RSWA08
Euphorbia tannensis subsp. *eremophila*	0.1	30 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm	
Goodenia microptera	0.1	30 cm	
Gossypium robinsonii	0.5	240 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	380 cm	BIL-RSWA01
Heliotropium cunninghamii	0.1	30 cm	BIL-RSWA21
Hibiscus leptocladus	0.1	25 cm	BIL-RSWA19
Hibiscus sturtii var. *platychlamys*	0.1	80 cm	BIL-RSWA13
Indigofera colutea	0.1	35 cm	
Indigofera monophylla	0.1	70 cm	BIL-RSWA04
Paraneurachne muelleri	0.1	60 cm	
Paspalidium rarum	0.1	20 cm	BIL-RSWA17
Paspalidium rarum	0.1	10 cm	BIL-RSWA22
Perotis rara	0.1	15 cm	
Phyllanthus erwinii	0.1	20 cm	BIL-RSWA18
Phyllanthus maderaspatensis	0.1	15 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	10 cm	
Polycarpaea longiflora	0.1	20 cm	
Polymeria ambigua	0.1	15 cm	BIL-RSWA11
Pterocaulon sphacelatum	0.1	25 cm	BIL-RSWA06
Ptilotus astrolasius	0.1	40 cm	
Ptilotus auriculifolius	0.1	35 cm	
Rhynchosia minima	0.1	100 cm	
Salsola australis	0.1	15 cm	

Species	Cover (%)	Height	Specimen
Santalum lanceolatum	0.1	340 cm	BIL-RSWA10
Senna artemisioides subsp. *helmsii*	0.1	140 cm	
Senna artemisioides subsp. *oligophylla*	15	210 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	60 cm	
Senna notabilis	0.1	15 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	15 cm	BIL-RSWA03, -24
Solanum lasiophyllum	0.1	30 cm	
Swainsona formosa	0.1	40 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	110 cm	BIL-RSWA07
Trachymene oleracea subsp. *oleracea*	0.1	10 cm	
Tragus australianus	0.1	20 cm	
Trianthema pilosum	0.1	10 cm	
Tribulopis angustifolia	0.1	10 cm	BIL-RSWA20
Tribulus macrocarpus	0.1	10 cm	BIL-RSWA23
Trichodesma zeylanicum var. *zeylanicum*	0.1	15 cm	
Triodia epactia	5	45 cm	
Triodia pungens	0.1	50 cm	BIL-RSWA15
Triraphis mollis	0.1	60 cm	
Urochloa holosericea subsp. *velutina*	0.1	25 cm	BIL-RSWA12
Yakirra australiensis var. *australiensis*	0.1	20 cm	BIL-RSWA16

BIL-RSWA

Site WW30: Scattered *Acacia* tall shrubs over *Triodia pungens* steppe.
Coordinates: 741 869 mE, 7483 355 mN.

Landform: Colluvial plain.
Substrate: Red sandy loam.
Litter: 0-2% leaf and wood litter.
Disturbance: Grazing?.

Stratum	Cover Range	Species present
Trees <5 m	0-2 %:	*Corymbia hamersleyana*
Shrubs >2 m	0-2 %:	*Acacia pruinocarpa, Hakea lorea* subsp. lorea
Shrubs 1-2 m	2-10 %:	*Acacia ancistrocarpa, A. dictyophleba, A. inaequilatera, A. pachyacra, Atalaya hemiglauca, Hakea lorea* subsp. lorea
Shrubs 0.5-1 m	0-2 %:	*Acacia inaequilatera, A. pruinocarpa, Hibiscus sturtii*
Shrubs <0.5 m	0-2 %:	*Bonamia erecta, Corchorus tectus, Solanum lasiophyllum*
Spinifex	30-70 %:	*Triodia pungens*
Other grasses	0-2 %:	*Eragrostis eriopoda, Eriachne aristidea*
Herbs	0-2 %:	*Pterocaulon sphacelatum*

No photo

Hope Downs Rail/Yandi Billiards Level 2 H050

Described by Phase 1: MM; Phase 2: PLSV Date Phase 1: 28-Apr-01 Phase 2: 18-Mar-1

Type Quadrat 50 x 50 m

Location 78.6 km SE of Auski Roadhouse, 16.5 km SSW of Marillana and 77.5 km NNW of Newman.

Central Coordinate 739564 mE, 7480732 mN.

Habitat Bank of Weeli Wolli Creek.

Soil 2.5YR 3/3 dark reddish brown sandy loam.

Rock Type Riverstone and ironstone cobbles (5%), pebbles (20%), and gravel (60%).

Vegetation Phase 1: *Eucalyptus victrix* woodland over *Acacia citrinoviridis* low woodland over *Acacia coriacea* subsp. *pendens* tall open shrubland over *Ptilotus obovatus* low open shrubland over **Cenchrus ciliaris, Enneapogon robustissimus* open tussock grassland with *Triodia pungens*, *T. longiceps* very open hummock grassland.
Phase 2: *Eucalyptus victrix* low open woodland over *Acacia citrinoviridis*, *A. coriacea* subsp. *pendens* low open forest over *Corchorus crozophorifolius*, *Ptilotus obovatus* low open shrubland over *Cenchrus ciliaris*, *Enneapogon lindleyanus*, *E. robustissimus* very open tussock grassland over *Triodia pungens, T. longiceps* scattered hummock grasses.

Veg Condition Phase 1: Good; presence of weeds (*Cenchrus ciliaris, *C. setiger). Phase 2: Good (**Cenchrus ciliaris*, **Malvastrum americanum, *Setaria verticillata*).

Fire Age Phase 1: Burnt 1-2 yrs ago. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. fraseri				0.1	40 cm	
Abutilon macrum				0.1	80 cm	
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618) PN				0.1	35 cm	HOR50-06
Acacia citrinoviridis	65	800 cm	H50.4	30	800 cm	
Acacia coriacea subsp. pendens	5	400 cm	H50.7	5	800 cm	
Acacia pyrifolia var. pyrifolia				0.1	40 cm	
Achyranthes aspera	0.1	100 cm				
Acrachne racemosa	0.1		H50.21			
Amaranthus undulatus	0.1	15 cm	H50.12	0.1	15 cm	HOR50-05
Amyema hilliana	0.1	110 cm	H50.18	0.1		
Aristida contorta	0.1	45 cm		0.1	40 cm	
Atalaya hemiglauca	0.1	180 cm		0.1	230 cm	
Boerhavia burbidgeana				0.1	15 cm	HOR50-09
Boerhavia coccinea				0.1	30 cm	HOR50-10
Capparis spinosa var. nummularia	0.1	25 cm				
Cenchrus ciliaris	5	90 cm		9	50 cm	
Cenchrus setiger	0.1	50 cm		0.1	50 cm	
Cleome viscosa	0.1	5 cm				
Corchorus crozophorifolius	0.1	100 cm	H50.3	2	90 cm	
Corchorus tridens				0.1	20 cm	
Cymbopogon ambiguus	0.1	130 cm	H50.8			
Cymbopogon procerus				0.1	130 cm	
Dicladanthera forrestii	0.1	35 cm	H50.15	0.1	25 cm	
Digitaria brownii	0.1	60 cm		0.1	60 cm	
Digitaria ctenantha	0.1	20 cm		0.1	30 cm	
Duperreya commixta	0.1	50 cm		0.1	250 cm	
Enchylaena tomentosa var. tomentosa	0.1	50 cm				
Enneapogon lindleyanus				0.5	40 cm	
Enneapogon polyphyllus	0.1	40 cm				
Enneapogon robustissimus	2	50 cm	H50.2	0.5	45 cm	
Eragrostis cumingii	0.1	15 cm	H50.14			
Eriachne lanata				0.1	30 cm	
Eriachne pulchella	0.1	18 cm	H50.16	0.1	10 cm	
Eucalyptus victrix	15	1200 cm		8	1100 cm	
Eulalia aurea				0.1	60 cm	
Euphorbia alsiniflora	0.1	30 cm	H50.5			
Euphorbia australis var. subtomentosa	0.1	12 cm	H50.20	0.1	10 cm	HOR50-04
Euphorbia trigonosperma				0.1	25 cm	HOR50-02
Evolvulus alsinoides var. decumbens				0.1	10 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Gossypium robinsonii	0.1	240 cm				
Heliotropium cunninghamii				0.1	25 cm	HOR50-03
Hybanthus aurantiacus				0.1	20 cm	
Indigofera monophylla	0.1	35 cm		0.1	100 cm	HOR50-07
Malvastrum americanum				0.1	40 cm	
Paspalidium clementii	0.1	25 cm		0.1	20 cm	HOR50-08
Phyllanthus maderaspatensis	0.1	20 cm	H50.13	0.1	15 cm	
Polycarpaea longiflora	0.1	40 cm	H50.11	0.1	15 cm	
Pterocaulon sphacelatum	0.1	20 cm				
Ptilotus astrolasius				0.1	40 cm	
Ptilotus obovatus var. obovatus	5	60 cm	H50.1	0.5	60 cm	
Rhagodia eremaea	0.1	50 cm		0.1	110 cm	
Rhynchosia minima	0.1	80 cm	H50.9	0.1	60 cm	
Salsola australis				0.1	15 cm	
Senna artemisioides subsp. helmsii	0.1	35 cm		0.1	170 cm	
Setaria verticillata	0.1	40 cm		0.1	50 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	100 cm				
Solanum lasiophyllum	0.1	45 cm		0.1	80 cm	
Solanum phlomoides				0.1	60 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	50 cm	H50.10	0.1	40 cm	
Themeda triandra	0.1	80 cm	H50.19	0.1	40 cm	
Trichodesma zeylanicum var. zeylanicum	0.1	60 cm				
Triodia longiceps	1	50 cm		0.5	40 cm	
Triodia pungens	1	40 cm		1	35 cm	HOR50-01
Triodia wiseana				0.1	25 cm	
Waltheria indica	0.1	70 cm	H50.6	0.1	45 cm	

H050 Phase 1 (no photo)

H050 Phase 2

Hope Downs Rail H051

Described by MM Date 27-Apr-01 Type Quadrat 50 x 50 m

Location 77.9 km SE of Auski Roadhouse, 16.6 km SSW of Marillana and 78.1 km NNW of Newman.

Central Coordinate 738944 mE, 7481012 mN.

Habitat Floodplain.

Soil Red clay loam, hardpan surface.

Rock Type Not recorded.

Vegetation *Eucalyptus victrix* scattered low trees over *Acacia citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris, *C. setiger*).

Fire Age Burnt 1-2 years ago.

Notes Would have been high shrubland many years ago, and probably *Triodia epactia* hummock grassland before invaded by **Cenchrus ciliaris*.

Species	Cover (%)	Height	Specimen
Abutilon macrum	0.1	35 cm	H51.6
Abutilon otocarpum	0.1	40 cm	
Acacia citrinoviridis	2.5	500 cm	
Amaranthus undulatus	0.1	10 cm	
Aristida contorta	0.1	35 cm	
Atalaya hemiglauca	0.1	50 cm	
Boerhavia coccinea	0.1	20 cm	
Cenchrus ciliaris	70	70 cm	
Cenchrus setiger	0.1	50 cm	
Cleome viscosa	0.1	40 cm	
Corchorus crozophorifolius	0.1	35 cm	
Dicladanthera forrestii	0.1	30 cm	H50.15
Dipteracanthus australasicus subsp. *australasicus*	0.1	25 cm	H51.5
Duperreya commixta	0.1	300 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	15 cm	
Enneapogon polyphyllus	0.1	30 cm	
Enneapogon robustissimus	0.1	50 cm	H50.2
Eragrostis cumingii	0.1	15 cm	H50.14
Eragrostis tenellula	0.1	10 cm	
Eriachne mucronata	0.1	55 cm	H51.7
Eriachne pulchella	0.1	15 cm	
Eucalyptus victrix	1	800 cm	
Euphorbia australis var. *subtomentosa*	0.1	5 cm	H51.2
Evolvulus alsinoides var. *decumbens*	0.1	20 cm	H51.4
Glycine canescens	0.1	20 cm	
Gomphrena cunninghamii	0.1	12 cm	H51.1
Goodenia microptera	0.1	40 cm	
Indigofera monophylla	0.1	40 cm	
Melhania oblongifolia	0.1	50 cm	H51.3
Notoleptopus decaisnei var. *decaisnei*	0.1	35 cm	
Paraneurachne muelleri	0.1	45 cm	
Perotis rara	0.1	10 cm	
Phyllanthus erwinii	0.1	25 cm	
Pluchea rubelliflora	0.1	40 cm	
Polycarpaea longiflora	0.1	10 cm	
Portulaca oleracea/intraterranea	0.1	5 cm	
Pterocaulon sphacelatum	0.1	50 cm	
Ptilotus obovatus var. *obovatus*	0.1	60 cm	H50.1
Sclerolaena cornishiana	0.1	35 cm	
Senna artemisioides subsp. *helmsii*	0.1	55 cm	
Setaria verticillata	0.1	20 cm	
Solanum horridum	0.1	20 cm	
Solanum lasiophyllum	0.1	30 cm	
Solanum phlomoides	0.1	45 cm	
Sporobolus australasicus	0.1	10 cm	

Species	Cover (%)	Height	Specimen
Stemodia grossa	0.1	60 cm	
Synaptantha tillaeacea var. *tillaeacea*	0.1	10 cm	
Tragus australianus	0.1	10 cm	
Tribulus astrocarpus	0.1	2 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	60 cm	
Triodia epactia	0.1	40 cm	

No photo

HDA and HDD			HDA07		
Described by	KBM	Date	25-Apr-03	Type	Quadrat 25 x 100 m
Location	26.4 km SSW of Marillana and 74.5 km NW of Newman and 78.4 km SE of Auski Roadhouse.				
Central Coordinate	733320 mE, 7472930 mN.				
Habitat	Stony undulating plain, fringing southern side of Weeli Wolli Creek.				
Soil	Orange sandy clay; stony.				
Rock Type	Mixed calcrete and ironstone.				
Vegetation	*Corymbia hamersleyana* low open woodland over *Acacia inaequilatera*, *A. bivenosa* tall open shrubland over *A. synchronicia, Atalaya hemiglauca* open shrubland over *Senna artemisioides* subsp. *oligophylla* scattered low shrubs over *Triodia wiseana* hummock grassland with *Eragrostis eriopoda* scattered tussock grasses.				
Veg Condition	Very Good; presence of weeds (**Cenchrus ciliaris*) and some earthworks.				
Fire Age	No sign of recent fire.				
Notes	The equivalent burnt vegetation in adjacent areas has 30% *Enneapogon* and 10% *Eragrostis*, with numerous Malvaceae and annuals making up 20% cover, including *Aristida contorta, Ptilotus clementii, Ptilotus exaltatus, Tribulus* sp., *Heliotropium* sp., *Goodenia microptera*. Co-ordinates for corner 4 of quadrat were not recorded.				

Species	Cover (%)	Height	Specimen
Acacia bivenosa	1	300 cm	WW07.01
Acacia citrinoviridis	0.1	120 cm	WW07.24
Acacia inaequilatera	1	400 cm	WW07.04
Acacia pruinocarpa	0.1	300 cm	WW07.22
Acacia synchronicia	1	200 cm	WW07.10
Atalaya hemiglauca	1	200 cm	WW07.13
Cenchrus ciliaris	0.1	60 cm	WW07.07
Corymbia hamersleyana	3	500 cm	WW07.17
Duperreya commixta	0.1	50 cm	WW07.11
Enneapogon caerulescens	0.1	15 cm	WW07.14
Eragrostis eriopoda	1	60 cm	WW07.12
Eucalyptus xerothermica	0.1	400 cm	WW07.16
Euphorbia australis var. *erythrantha*	0.1	3 cm	WW07.27
Hakea lorea subsp. *lorea*	0.1	200 cm	WW07.21
Paraneurachne muelleri	0.1	40 cm	WW07.20
Ptilotus astrolasius	0.1	40 cm	WW07.06
Ptilotus obovatus var. *obovatus*	0.1	70 cm	WW07.05
Ptilotus rotundifolius	0.1	70 cm	WW07.09
Rhagodia eremaea	0.1	60 cm	WW07.18
Sclerolaena cornishiana	0.1	40 cm	WW07.29
Senna artemisioides subsp. *helmsii*	0.1	60 cm	WW07.25
Senna artemisioides subsp. *oligophylla*	1	60 cm	WW07.03
Sida echinocarpa	0.1	40 cm	WW07.08
Sida fibulifera	0.1	40 cm	WW07.23
Solanum lasiophyllum	0.1	40 cm	WW07.28
Sporobolus australasicus	0.1	10 cm	WW07.26
Tephrosia sp. NW Eremaean (S. van Leeuwen et. al. PBS0356) PN	0.1	20 cm	WW07.19
Triodia wiseana	65	80 cm	WW07.02

HDA07

HDA and HDD/ Yandi Billiards Level 2 HDA08

Described by Phase 1: MM Phase 2: PLSV Date Phase 1: 24-Apr-03 Phase 2: 16-Mar-14

Type Quadrat 50 x 50 m

Location 24.4 km SSW of Marillana and 74.8 km NW of Newman and 78.6 km SE of Auski Roadhouse

Central Coordinate 734807 mE, 7474388 mN.

Habitat Clayey Mulga floodplain, fringing southern side of Weeli Wolli Creek.

Soil Dark reddish brown light clay.

Rock Type Nil.

Vegetation Phase 1: *Acacia aptaneura* low open forest over *Senna artemisioides* subsp. *helmsii* scattered shrubs over *Abutilon otocarpum, Pterocaulon sphacelatum* low open shrubland over *Aristida contorta,* (*Enneapogon polyphyllus*) open annual grassland with *Goodenia prostrata*, *Cleome viscosa* very open herbland.
Phase 2: *Acacia aptaneura x ayersiana*, (*Acacia pruinocarpa*) low woodland over *Eremophila forrestii* subsp. *forrestii*, *Senna artemisioides* subsp. *helmsii* scattered shrubs over *Aristida pruinosa, *Cenchrus ciliaris, *C. setiger* very open tussock grassland.

Veg Condition Phase 1: Good; signs of cattle, presence of weeds (**Malvastrum americanum*) and probably subject to repeated fires.
Phase 2: Good (**Cenchrus* spp., **Malvastrum americanum, *Setaria verticillata*, **Bidens bipinnata*).

Fire Age Phase 1: Burnt 1-2 years ago. Phase 2: Not recorded.

Notes Composition of dominant shrubs seems to have shifted in the 10 years between sampling (*A. aptaneura* to *A. aptaneura x ayersiana*).

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon cryptopetalum	0.1	60 cm	WW08.62			
Abutilon fraseri subsp. fraseri	0.1	45 cm	WW08.27	0.1	60 cm	
Abutilon lepidum	0.1	80 cm	WW08.21, WW08.30	0.1	70 cm	HDAR08-11, HDAR-07
Abutilon macrum	0.1	60 cm	WW08.56	0.1	90 cm	
Abutilon otocarpum	1.5	30 cm	WW08.14	0.1	40 cm	
Acacia aptaneura	45	500 cm	WW08.01	0.1	200 cm	HDAR08-20
Acacia aptaneura x ayersiana				27	900 cm	HDAR08-19
Acacia ayersiana	0.1	300 cm	WW08.40			
Acacia bivenosa				0.1	380 cm	
Acacia pruinocarpa	0.1	200 cm		2	600 cm	
Acacia sibirica				0.1	220 cm	HDAR08-17
Acacia synchronicia				0.1	30 cm	
Alternanthera nana				0.1	25 cm	
Amaranthus undulatus				0.1	30 cm	HDAR08-16
Anthobolus leptomerioides				0.1	80 cm	
Aristida contorta	10	40 cm	WW08.20	0.1	40 cm	
Aristida holathera var. holathera				0.1	40 cm	
Aristida latifolia	0.1	70 cm	WW08.55			
Aristida pruinosa				1	110 cm	HDAR08-06
Bidens bipinnata	0.1	10 cm	WW08.59	0.1	50 cm	
Boerhavia coccinea	0.1	15 cm	WW08.32	0.1	30 cm	
Boerhavia repleta	0.1	10 cm	WW08.33	0.1	35 cm	
Bulbostylis barbata				0.1	10 cm	
Bulbostylis turbinata				0.1	20 cm	HDAR08-12
Calandrinia sp.				0.1	8 cm	
Cenchrus ciliaris	0.1	60 cm		1	70 cm	
Cenchrus setiger				1	70 cm	
Chrysopogon fallax	0.1	70 cm		0.1	110 cm	
Cleome viscosa	1	50 cm		0.1	70 cm	
Convolvulus clementii	0.1	40 cm	WW08.47			
Corchorus tectus				0.1	50 cm	HDAR08-08
Corchorus tridens				0.1	40 cm	
Corymbia candida				0.1	90 cm	
Corymbia hamersleyana				0.1	400 cm	
Cucumis variabilis	0.1	30 cm	WW08.72	0.1	65 cm	
Cymbopogon ambiguus				0.1	60 cm	
Cymbopogon obtectus				0.1	90 cm	
Dichanthium sericeum subsp. humilius				0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Dicrastylis cordifolia	0.1	50 cm	WW08.57			
Digitaria brownii	0.1	60 cm	WW08.54	0.1	90 cm	
Digitaria ctenantha	0.5	40 cm	WW08.50	0.1	30 cm	
Dodonaea petiolaris				0.1	70 cm	
Duperreya commixta	0.1	80 cm		0.1	220 cm	
Dysphania melanocarpa forma melanocarpa				0.1	25 cm	HDAR08-13
Enchylaena tomentosa var. tomentosa				0.1	70 cm	
Enneapogon caerulescens	0.1	30 cm	WW08.67	0.1	30 cm	
Enneapogon polyphyllus	1.5	45 cm	WW08.11	0.1	40 cm	
Eragrostis eriopoda	0.1	45 cm	WW08.35			
Eragrostis falcata				0.1	30 cm	HDAR08-18
Eremophila forrestii subsp. forrestii	0.5	100 cm	WW08.03	1	170 cm	
Eremophila longifolia	0.1	120 cm	WW08.24	0.1	110 cm	
Eriachne mucronata (typical form)				0.1	60 cm	
Eriachne pulchella	0.1	12 cm	WW08.48			
Euphorbia biconvexa	0.1	20 cm	WW08.29	0.1	40 cm	HDAR08-01
Euphorbia boophthona	0.1	20 cm	WW08.31			
Evolvulus alsinoides var. villosicalyx	0.1	30 cm	WW08.10	0.1	20 cm	
Glycine canescens	0.1	40 cm	WW08.43	0.1	150 cm	
Gomphrena cunninghamii	0.1	12 cm	WW08.66	0.1	20 cm	
Goodenia microptera	0.1	25 cm	WW08.52	0.1	30 cm	
Goodenia nuda				0.1	35 cm	
Goodenia prostrata	1.5	4 cm	WW08.37	0.1	20 cm	
Gossypium australe				0.1	50 cm	
Hakea lorea subsp. lorea				0.1	230 cm	
Heliotropium cunninghamii	0.1	15 cm	WW08.45			
Heliotropium inexplicitum				0.1	20 cm	HDAR08-14
Hibiscus burtonii	0.1	40 cm	WW08.36			
Hibiscus sturtii var. campylochlamys	0.5	30 cm	WW08.16			
Hibiscus sturtii var. platychlamys	0.1	30 cm	WW08.06	0.1	40 cm	
Hybanthus aurantiacus				0.1	30 cm	
Ipomoea muelleri				0.1	35 cm	
Iseilema macratherum	0.1	15 cm	WW08.58			
Iseilema membranaceum				0.1	20 cm	HDAR08-02
Keraudrenia nephrosperma				0.1	60 cm	
Maireana planifolia x villosa	0.1	60 cm	WW08.05	0.1	50 cm	HDAR08-09
Maireana villosa	0.1	40 cm		0.1		
Malvastrum americanum	0.1	40 cm	WW08.22	0.1	45 cm	
Melhania oblongifolia	0.1	40 cm	WW08.61	0.1	50 cm	
Nicotiana occidentalis subsp. occidentalis	0.1	85 cm	WW08.65			
Paraneurachne muelleri				0.1	40 cm	
Paspalidium clementii	0.1	40 cm	WW08.46	0.1	30 cm	HDAR08-04
Perotis rara	0.1	15 cm	WW08.07	0.1	15 cm	
Phyllanthus erwinii	0.1	6 cm	WW08.34	0.1	10 cm	
Polycarpaea corymbosa var. corymbosa				0.1	20 cm	
Portulaca oleracea/intraterranea	0.1	6 cm	WW08.09	0.1	20 cm	HDAR08-03
Portulaca pilosa				0.1	20 cm	
Pterocaulon sphacelatum	1.5	40 cm	WW08.18	0.1	50 cm	
Ptilotus aervoides	0.1	4 cm	WW08.41			
Ptilotus gaudichaudii subsp. gaudichaudii	0.1	30 cm	WW08.08	0.1	50 cm	
Ptilotus helipteroides	0.1	35 cm	WW08.25			
Ptilotus nobilis subsp. nobilis	0.1	50 cm	WW08.13	0.1	35 cm	
Ptilotus obovatus var. obovatus	0.1	40 cm	WW08.71	0.1	70 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Ptilotus polystachyus	0.1	15 cm	WW08.38			
Rhagodia eremaea	0.1	60 cm	WW08.39	0.1	240 cm	
Salsola australis	0.1	45 cm	WW08.42	0.1	25 cm	
Sclerolaena cornishiana	0.1	25 cm	WW08.60	0.1	30 cm	
Senna artemisioides subsp. helmsii	1.5	100 cm	WW08.02	0.5	140 cm	
Senna artemisioides subsp. oligophylla	0.1	50 cm	WW08.53			
Senna artemisioides subsp. oligophylla (thinly sericeous form MET 15,035) x subsp. *helmsii*				0.1	40 cm	HDAR08-05
Senna glutinosa subsp. x luerssenii	0.1	20 cm	WW08.63			
Senna sp. Meekatharra (E. Bailey 1-26)	0.1	60 cm	WW08.70			
Setaria verticillata				0.1	120 cm	
Sida arsiniata				0.1	40 cm	
Sida fibulifera	0.5	30 cm	WW08.12	0.1	30 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	45 cm	WW08.26	0.1	80 cm	
Solanum elatius	0.1	40 cm	WW08.15	0.1	90 cm	HDAR08-15
Solanum horridum	0.1	30 cm	WW08.23			
Solanum lasiophyllum	0.1	60 cm	WW08.04	0.1		
Spermacoce brachystema	0.1	18 cm	WW08.51	0.1	15 cm	
Sporobolus australasicus	0.1	15 cm	WW08.28	0.1	25 cm	
Streptoglossa bubakii	0.1	30 cm	WW08.44	0.1	30 cm	
Streptoglossa decurrens	0.1	40 cm	WW08.68			
Themeda triandra				0.1	110 cm	
Tribulus astrocarpus	0.1	1 cm	WW08.64			
Tribulus macrocarpus	0.1	6 cm	WW08.17	0.1	25 cm	
Trichodesma zeylanicum var. zeylanicum	0.1	120 cm	WW08.49	0.1	15 cm	
Triodia wiseana				0.1	80 cm	
Waltheria indica				0.1	80 cm	

HDA08 Phase 1

HDA08 Phase 2

HAD and HDD/Yandi Billiards Level 2 HDA09

Described by Phase 1: Phase 2: CFSV Date Phase 1: 24-Apr-03 Phase 2: 12-Mar-14

Type Quadrat 50 x 50 m

Location 19.5 km SSW of Marillana and 76.7 km NNW of Newman and 78.2 km SE of Auski Roadhouse.

Central Coordinate 737517 mE, 7478460 mN.

Habitat Floodplain / broad creek bank; fringing the southern side of Weeli Wolli Creek.

Soil 2.5YR 3/3 dark reddish brown clay loam with hard-set surface.

Rock Type Ironstone gravel (1%).

Vegetation Phase 1: *Eucalyptus victrix, Corymbia hamersleyana* low open woodland over *Acacia citrinoviridis,* (*Atalaya hemiglauca, Acacia coriacea* subsp. *pendens*, *Acacia sclerosperma* subsp. *sclerosperma*) tall closed scrub with **Cenchrus ciliaris*, (**C. setiger*) closed tussock grassland.
Phase 2: *Eucalyptus victrix* open forest over *Acacia citrinoviridis*, *Corymbia hamersleyana, Acacia coriacea* subsp. *pendens*, *Atalaya hemiglauca* low open forest over *Acacia sclerosperma* subsp. *sclerosperma*, *Hakea lorea* subsp. *lorea* tall open shrubland over **Cenchrus setiger, *C. ciliaris* closed tussock grassland.

Veg Condition Phase 1: Poor: signs of cattle (heavy grazing pressure), presence of weeds (**Cenchrus ciliaris, *C. setiger*) and probably repeated fires.
Phase 2: Very Poor (**Cenchrus* spp.).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Phase 2: Most ground cover species absent due to 95% **Cenchrus* spp.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon sp.	0.1	5 cm	WW09.31			
Acacia aptaneura x incurvaneura	0.1	300 cm	WW09.39			
Acacia citrinoviridis	75	500 cm	WW09.02	50	900 cm	
Acacia coriacea subsp. pendens	1	500 cm	WW09.12	3	900 cm	
Acacia sclerosperma subsp. sclerosperma	1	300 cm	WW09.03	3	550 cm	
Achyranthes aspera	0.1	60 cm	WW09.13	0.1	50 cm	
Alternanthera nana	0.1	25 cm	WW09.30			
Atalaya hemiglauca	1	400 cm	WW09.06	2	900 cm	
Bidens bipinnata				0.1	20 cm	
Boerhavia repleta	0.1	20 cm	WW09.46			
Bothriochloa ewartiana				0.1	30 cm	HDAR09-05
Cenchrus ciliaris	60	70 cm	WW09.04	35	130 cm	
Cenchrus setiger	35	70 cm	WW09.05	60	130 cm	
Centipeda minima subsp. macrocephala	0.1	6 cm	WW09.27			
Convolvulus clementii	0.1	30 cm	WW09.23			
Corchorus tridens	0.1	25 cm	WW09.24			
Corymbia candida				0.1	810 cm	HDAR09-06
Corymbia hamersleyana	1	400 cm	WW09.16	8	900 cm	
Cymbopogon ambiguus	0.1	70 cm	WW09.43			
Datura leichhardtii	0.1	30 cm	WW09.17			
Dichanthium sericeum subsp. humilius	0.1	30 cm	WW09.11			
Duperreya commixta	0.1	300 cm		0.1	250 cm	
Dysphania cristata	0.1	10 cm	WW09.19A			
Dysphania melanocarpa forma melanocarpa	0.1	10 cm	WW09.19B			
Enneapogon caerulescens	0.1	20 cm	WW09.33			
Enteropogon ramosus	0.1	90 cm	WW09.35			
Eragrostis cumingii	0.1	30 cm	WW09.10	0.1	20 cm	
Eragrostis tenellula	0.1	15 cm	WW09.15	0.1	15 cm	
Eucalyptus victrix	3.5	1500 cm		45	1200 cm	
Euphorbia australis	0.1	4 cm	WW09.47			
Euphorbia biconvexa	0.1	15 cm	WW09.41	0.1	15 cm	HDAR09-03
Euphorbia boophthona	0.1	35 cm	WW09.22			
Flaveria trinervia	0.1	20 cm	WW09.28			
Gossypium australe	0.1	50 cm	WW09.45			
Hakea lorea subsp. lorea	0.1	400 cm	WW09.09	1	500 cm	
Iseilema macratherum	0.1	15 cm	WW09.29			
Malvastrum americanum	0.1	30 cm		0.1	20 cm	
Nicotiana occidentalis subsp. occidentalis	0.1	40 cm	WW09.37			

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Notoleptopus decaisnei var. decaisnei	0.1	12 cm	WW09.42			
Paspalidium clementii				0.1	30 cm	HDAR09-01
Phyllanthus erwinii	0.1	8 cm	WW09.40			
Phyllanthus maderaspatensis	0.1	20 cm	WW09.38	0.1	20 cm	
Polymeria ambigua	0.1	5 cm	WW09.44			
Portulaca oleracea/intraterranea	0.1	6 cm	WW09.21			
Pterocaulon sphacelatum	0.1	10 cm	WW09.18			
Ptilotus obovatus var. obovatus	0.1	20 cm				
Salsola australis	0.1	30 cm	WW09.34			
Senna artemisioides subsp. x artemisioides	0.1	120 cm	WW09.48			
Setaria verticillata	0.1	20 cm	WW09.36			
Sida fibulifera	0.1	10 cm	WW09.25	0.1	15 cm	HDAR09-04
Sigesbeckia orientalis	0.1	40 cm	WW09.20			
Sonchus oleraceus	0.1	10 cm	WW09.14			
Sporobolus australasicus	0.1	8 cm	WW09.26			
Themeda triandra				0.1	40 cm	
Trichodesma zeylanicum var. zeylanicum	0.1	20 cm	WW09.32			
Vachellia farnesiana	0.1	200 cm	WW09.07	0.1	410 cm	

HDA09 Phase 1

HDA09 Phase 2

HDA and HDD			HDA12		
Described by	KBM	Date	24-Apr-03	Type	Quadrat 50 x 50 m
Location	24.4 km SSW of Marillana and 74.5 km NW of Newman and 78.9 km SE of Auski Roadhouse.				
Central Coordinate	735047 mE, 7474228 mN.				
Habitat	Broad plain, fringing southern side of Weeli Wolli Creek.				
Soil	Red clay loam with hardpan.				
Rock Type	Ironstone and mixed (colluvial).				
Vegetation	*Acacia aneura* var. *longicarpa*, *A. pruinocarpa* tall open shrubland over *Eremophila forrestii* subsp. *forrestii, Solanum lasiophyllum* scattered low shrubs over *Aristida contorta*, (*Perotis rara, Enneapogon polyphyllus*) open tussock grassland with *Triodia basedowii* scattered hummock grasses with *Ptilotus nobilis* subsp. *nobilis, P. helipteroides* very open herbland.				
Veg Condition	Excellent.				
Fire Age	Burnt 1-2 years ago.				
Notes	Co-ordinates for corner 1 of quadrat were not recorded.				

Species	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	WW12.71
Abutilon lepidum	0.1	60 cm	WW12.38
Abutilon otocarpum	0.1	20 cm	WW12.29
Acacia aptaneura	3	500 cm	WW12.53
Acacia ayersiana	0.1	300 cm	WW12.34, WW12.81
Acacia pruinocarpa	2	500 cm	WW12.30
Aristida contorta	27.5	50 cm	WW12.01
Aristida holathera var. *holathera*	0.1	50 cm	WW12.58
Aristida inaequiglumis	0.1	80 cm	WW12.61
Bidens bipinnata	0.1	10 cm	WW12.72
Boerhavia coccinea	0.1	5 cm	WW12.14
Cenchrus ciliaris	0.1	60 cm	WW12.32
Chrysopogon fallax	0.1	120 cm	WW12.65
Cleome viscosa	0.1	40 cm	WW12.13
Cymbopogon obtectus	0.1	60 cm	WW12.56
Dicrastylis cordifolia	0.1	80 cm	WW12.19
Digitaria ctenantha	0.1	40 cm	WW12.78
Dodonaea lanceolata var. *lanceolata*	0.1	160 cm	WW12.33
Duperreya commixta	0.1	40 cm	WW12.36
Dysphania kalpari	0.1	20 cm	WW12.47
Dysphania melanocarpa forma *melanocarpa*	0.1	10 cm	WW12.85
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	15 cm	WW12.00
Enchylaena tomentosa var. *tomentosa*	0.1	80 cm	WW12.84
Enneapogon caerulescens	0.1	20 cm	WW12.70
Enneapogon polyphyllus	1	15 cm	WW12.41
Eremophila forrestii subsp. *forrestii*	1	80 cm	WW12.50
Eremophila latrobei subsp. *filiformis*	0.1	60 cm	WW12.23
Eriachne pulchella	0.1	15 cm	WW12.08
Euphorbia australis var. *subtomentosa*	0.1	10 cm	WW12.57
Euphorbia biconvexa	0.1	40 cm	WW12.75
Euphorbia tannensis subsp. *eremophila*	0.1	40 cm	WW12.22
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	WW12.04
Goodenia microptera	0.1	30 cm	WW12.07
Goodenia muelleriana	0.1	20 cm	WW12.55
Goodenia prostrata	0.1	5 cm	WW12.28A
Gossypium australe	0.1	60 cm	WW12.59
Haloragis gossei var. *gossei*	0.1	10 cm	WW12.44
Hibiscus burtonii	0.1	60 cm	WW12.18
Hibiscus sturtii var. *platychlamys*	0.1	60 cm	WW12.73
Hybanthus aurantiacus	0.1	60 cm	WW12.31
Iseilema macratherum	0.1	10 cm	WW12.77

Species	Cover (%)	Height	Specimen
Lepidium pholidogynum	0.1	5 cm	WW12.87
Maireana planifolia x villosa	0.1	80 cm	WW12.49
Maireana villosa	0.1	40 cm	WW12.24
Mollugo molluginea	0.1	5 cm	WW12.26
Paraneurachne muelleri	0.1	80 cm	WW12.51
Paspalidium clementii	0.1	20 cm	WW12.54
Perotis rara	2	15 cm	WW12.37
Phyllanthus erwinii	0.1	2 cm	WW12.27
Polymeria ambigua	0.1	5 cm	WW12.69
Portulaca oleracea/intraterranea	0.1	2 cm	WW12.15
Portulaca pilosa	0.1	10 cm	WW12.79
Psydrax latifolia	0.1	60 cm	WW12.80
Pterocaulon sphacelatum	0.1	50 cm	WW12.42
Ptilotus aervoides	0.1	2 cm	WW12.12
Ptilotus astrolasius	0.1	40 cm	WW12.11
Ptilotus gaudichaudii subsp. *gaudichaudii*	0.1	40 cm	WW12.17
Ptilotus helipteroides	1	50 cm	WW12.09
Ptilotus nobilis subsp. *nobilis*	2	80 cm	WW12.05
Ptilotus obovatus var. *obovatus*	0.1	60 cm	WW12.63
Ptilotus polystachyus	0.1	40 cm	WW12.46
Rhagodia eremaea	0.1	100 cm	WW12.83
Salsola australis	0.1	60 cm	WW12.02
Sclerolaena cornishiana	0.1	30 cm	WW12.06
Senna artemisioides subsp. *helmsii*	0.1	20 cm	WW12.45
Senna artemisioides subsp. *oligophylla*	0.1	120 cm	WW12.20
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	50 cm	WW12.21
Senna glutinosa subsp. *glutinosa*	0.1	60 cm	WW12.74
Senna glutinosa subsp. *x luerssenii*	0.1	60 cm	WW12.40
Senna notabilis	0.1	40 cm	WW12.52
Senna sp. Meekatharra (E. Bailey 1-26)	0.1	60 cm	WW12.82
Sida cardiophylla	0.1	40 cm	WW12.60
Sida fibulifera	0.1	20 cm	WW12.03
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	120 cm	WW12.25
Solanum elatius	0.1	40 cm	WW12.76
Solanum lasiophyllum	0.5	70 cm	WW12.10
Sporobolus australasicus	0.1	10 cm	WW12.64
Stemodia grossa	0.1	50 cm	WW12.67
Synaptantha tillaeacea var. *tillaeacea*	0.1	5 cm	WW12.28B
Themeda triandra	0.1	80 cm	WW12.62
Tragus australianus	0.1	10 cm	WW12.89
Tribulus astrocarpus	0.1	1 cm	WW12.43
Tribulus macrocarpus	0.1	10 cm	WW12.48
Trichodesma zeylanicum var. *zeylanicum*	0.1	20 cm	WW12.35
Triodia basedowii	1	70 cm	WW12.66

HDA12

HDA and HDD			HDA13		
Described by	MM	Date	25-Apr-03	Type	Quadrat 50 x 50 m
Location	21 km SSW of Marillana and 76 km NW of Newman and 78.3 km SE of Auski Roadhouse.				
Central Coordinate	736755 mE, 7477227 mN.				
Habitat	Clayey plain, a branch of the floodplain fringing Weeli Wolli Creek.				
Soil	Red-brown clay loam with scatters of ironstone pebbles and stones on				
Rock Type	Not recorded.				
Vegetation	*Corymbia hamersleyana* scattered low trees over *Acacia aptaneura*, (*A. pruinocarpa, A. citrinoviridis*) tall open scrub over *Enneapogon polyphyllus* open tussock grassland with *Triodia longiceps* very open hummock grassland with *Cleome viscosa* scattered herbs.				
Veg Condition	Good; signs of cattle (heavy grazing), presence of weeds and probably subject to repeated fires.				
Fire Age	No sign of recent fire.				
Notes	Quadrat not positioned along proposed rail centerline; established in nearby Mulga woodland instead.				
	Co-ordinates for corner 1 of quadrat were not recorded.				

Species	Cover (%)	Height	Specimen
Abutilon cryptopetalum	0.1	60 cm	WW13.38
Abutilon lepidum	0.1	50 cm	WW13.13, WW13.61
Abutilon macrum	0.1	20 cm	WW13.69
Acacia aptaneura	55	250 cm	WW13.02
Acacia citrinoviridis	0.5	500 cm	WW13.20
Acacia coriacea subsp. *pendens*	0.1	50 cm	WW13.32
Acacia pruinocarpa	1	300 cm	
Acacia sclerosperma subsp. *sclerosperma*	0.1	230 cm	WW13.36
Alternanthera nana	0.1	5 cm	WW13.65
Aristida contorta	0.1	40 cm	
Atalaya hemiglauca	0.1	200 cm	
Bidens bipinnata	0.1	15 cm	
Boerhavia coccinea	0.1	5 cm	WW13.71
Boerhavia repleta	0.1	8 cm	WW13.55
Cenchrus ciliaris	0.1	60 cm	
Chrysopogon fallax	0.1	50 cm	WW13.26
Cleome viscosa	0.5	55 cm	WW13.05
Convolvulus clementii	0.1	30 cm	WW13.40
Corchorus crozophorifolius	0.1	30 cm	WW13.78
Corchorus tridens	0.1	10 cm	WW13.10
Corymbia hamersleyana	1	500 cm	WW13.01
Cymbopogon ambiguus	0.1	90 cm	WW13.79
Dactyloctenium radulans	0.1	10 cm	WW13.57
Datura leichhardtii	0.1	25 cm	
Dichanthium sericeum subsp. *humilius*	0.1	30 cm	WW13.39
Digitaria brownii	0.1	70 cm	WW13.23
Digitaria ctenantha	0.1	40 cm	WW13.46
Dipteracanthus australasicus subsp. *australasicus*	0.1	30 cm	WW13.35
Duperreya commixta	0.1	90 cm	
Dysphania melanocarpa forma *melanocarpa*	0.1	8 cm	WW13.67
Enchylaena tomentosa var. *tomentosa*	0.1	50 cm	WW13.21
Enneapogon caerulescens	0.1	15 cm	WW13.73
Enneapogon polyphyllus	10	50 cm	WW13.04
Enteropogon ramosus	0.1	60 cm	WW13.59
Eragrostis cumingii	0.1	8 cm	WW13.56
Eragrostis pergracilis	0.1	5 cm	WW13.63
Eragrostis setifolia	0.1	40 cm	WW13.42
Eremophila forrestii subsp. *forrestii*	0.1	60 cm	WW13.25
Eremophila lanceolata	0.1	50 cm	WW13.24
Eremophila longifolia	0.1	80 cm	WW13.41
Euphorbia australis var. *subtomentosa*	0.1	2 cm	WW13.70
Euphorbia biconvexa	0.1	15 cm	WW13.08

Species	Cover (%)	Height	Specimen
Euphorbia boophthona	0.1	30 cm	WW13.66
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	WW13.09
Glycine canescens	0.1	130 cm	WW13.34
Gomphrena cunninghamii	0.1	12 cm	WW13.44
Goodenia prostrata	0.1	6 cm	WW13.19
Goodenia triodiophila	0.1	25 cm	WW13.28
Hakea lorea subsp. *lorea*	0.1	250 cm	WW13.33
Heliotropium cunninghamii	0.1	25 cm	WW13.54
Heliotropium inexplicitum	0.1	15 cm	WW13.15
Hibiscus burtonii	0.1	40 cm	WW13.37
Hibiscus sturtii var. *platychlamys*	0.1	35 cm	WW13.51
Indigofera linifolia	0.1	25 cm	WW13.72
Iseilema macratherum	0.1	20 cm	WW13.07
Maireana planifolia	0.1	45 cm	WW13.60
Maireana villosa	0.1	30 cm	WW13.52
Malvastrum americanum	0.1	15 cm	
Notoleptopus decaisnei var. *decaisnei*	0.1	13 cm	WW13.14
Paspalidium clementii	0.1	40 cm	WW13.29
Perotis rara	0.1	10 cm	
Phyllanthus erwinii	0.1	8 cm	WW13.18
Portulaca oleracea/intraterranea	0.1	3 cm	WW13.11
Portulaca pilosa	0.1	30 cm	WW13.43
Ptilotus aervoides	0.1	5 cm	WW13.12
Ptilotus gaudichaudii subsp. *gaudichaudii*	0.1	22 cm	WW13.49
Ptilotus helipteroides	0.1	25 cm	WW13.64
Ptilotus obovatus var. *obovatus*	0.1	40 cm	
Rhynchosia minima	0.1	20 cm	WW13.31
Santalum spicatum	0.1	200 cm	WW13.48
Sclerolaena cornishiana	0.1	30 cm	WW13.62
Senna artemisioides subsp. *helmsii*	0.1	120 cm	WW13.22
Senna artemisioides subsp. *oligophylla*	0.1	90 cm	WW13.75
Setaria verticillata	0.1	35 cm	WW13.45
Sida fibulifera	0.1	40 cm	WW13.50
Solanum lasiophyllum	0.1	30 cm	WW13.77
Sporobolus australasicus	0.1	18 cm	WW13.17
Streptoglossa bubakii	0.1	20 cm	WW13.53
Tribulus astrocarpus	0.1	1 cm	WW13.16
Tribulus macrocarpus	0.1	5 cm	WW13.74
Tribulus terrestris	0.1	6 cm	WW13.06
Trichodesma zeylanicum var. *zeylanicum*	0.1	15 cm	WW13.58
Triodia longiceps	2.5	45 cm	WW13.03
Triodia pungens	0.1	40 cm	WW13.76
Urochloa piligera	0.1	10 cm	WW13.30

HDA13

HDA and HDD			HDA14		
Described by	KBM	Date	24-Apr-03	Type	Quadrat 50 x 50 m
Location	19.8 km SSW of Marillana and 76.4 km NNW of Newman and 78.4 km SE of Auski Roadhouse.				
Central Coordinate	737468 mE, 7478207 mN.				
Habitat	Floodplain adjacent to Weeli Wolli Creek.				
Soil	Red clay loam.				
Rock Type	Ironstone and mixed fluvial.				
Vegetation	*Corymbia aspera, C. hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis* open shrubland over *Sida arsiniata* low open shrubland over *Eulalia aurea, Paraneurachne muelleri, Aristida contorta*, *Themeda triandra* open tussock grassland with *Triodia pungens, T. longiceps* open hummock grassland with *Ptilotus nobilis* subsp. *nobilis, Sporobolus australasicus* scattered herbs.				
Veg Condition	Excellent to Very Good; presence of weeds (**Cenchrus ciliaris*).				
Fire Age	Burnt 1-2 years ago.				
Notes	Co-ordinates for corners 2, 3 and 4 of quadrat were not recorded.				

Species	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	40 cm	WW14.51
Acacia bivenosa	0.1	60 cm	WW14.14
Acacia citrinoviridis	0.1	100 cm	WW14.72
Acacia inaequilatera	0.1	180 cm	WW14.13
Acacia tumida var. *pilbarensis*	2	100 cm	WW14.24
Alternanthera nana	0.1	5 cm	WW14.85
Aristida contorta	3	40 cm	WW14.01
Aristida holathera var. *holathera*	0.1	50 cm	WW14.25
Aristida inaequiglumis	0.1	40 cm	WW14.81
Boerhavia coccinea	0.1	20 cm	WW14.47
Boerhavia repleta	0.1	5 cm	WW14.78
Bothriochloa ewartiana	0.1	60 cm	WW14.58
Bulbostylis barbata	0.1	5 cm	WW14.40
Bulbostylis turbinata	0.1	5 cm	WW14.75
Calandrinia ptychosperma	0.1	5 cm	WW14.36
Cenchrus ciliaris	1	50 cm	WW14.29
Chrysopogon fallax	2	130 cm	WW14.17
Cleome viscosa	0.1	40 cm	WW14.05
Corchorus sidoides subsp. *sidoides*	0.1	50 cm	WW14.65
Corymbia aspera	1	600 cm	WW14.30
Corymbia candida		600 cm	WW14.87
Corymbia hamersleyana	1	400 cm	WW14.67
Crotalaria medicaginea var. *neglecta*	0.1	20 cm	WW14.44
Dactyloctenium radulans	0.1	8 cm	WW14.21
Dichanthium sericeum subsp. *humilius*	0.1	30 cm	WW14.04
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	6 cm	WW14.79
Enneapogon caerulescens	0.1	10 cm	WW14.71
Enneapogon polyphyllus	1	50 cm	WW14.45
Eragrostis cumingii	0.1	15 cm	WW14.38
Eragrostis eriopoda	0.1	40 cm	WW14.12
Eragrostis tenellula	0.1	10 cm	WW14.80
Eremophila longifolia	0.1	70 cm	WW14.62
Eriachne aristidea	0.1	20 cm	WW14.28
Eriachne pulchella	0.1	15 cm	WW14.18
Eulalia aurea	6	40 cm	WW14.43
Euphorbia biconvexa	0.1	15 cm	WW14.64
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	WW14.27
Goodenia microptera	0.1	20 cm	WW14.20
Goodenia prostrata	0.1	2 cm	WW14.33
Goodenia triodiophila	0.1	20 cm	WW14.16
Gossypium australe	0.1	100 cm	WW14.34
Hakea lorea subsp. *lorea*	0.1	80 cm	WW14.09
Heliotropium cunninghamii	0.1	30 cm	WW14.32
Heliotropium pachyphyllum	0.1	10 cm	WW14.84
Hibiscus sturtii var. *campylochlamys*	0.1	40 cm	WW14.82

Species	Cover (%)	Height	Specimen
Indigofera linifolia	0.1	15 cm	WW14.35
Iseilema macratherum	0.1	20 cm	WW14.31
Malvastrum americanum	0.1	30 cm	WW14.69
Paraneurachne muelleri	5	50 cm	WW14.03
Perotis rara	2	10 cm	WW14.26
Polycarpaea holtzei	0.1	5 cm	WW14.59
Polymeria ambigua	0.1	5 cm	WW14.73
Portulaca oleracea/intraterranea	0.1	2 cm	WW14.54
Portulaca pilosa	0.1	5 cm	WW14.74
Pterocaulon sphacelatum	0.1	30 cm	WW14.68
Ptilotus aervoides	0.1	2 cm	WW14.55
Ptilotus astrolasius	0.1	100 cm	WW14.10
Ptilotus helipteroides	0.1	20 cm	WW14.19
Ptilotus nobilis subsp. *nobilis*	1	80 cm	WW14.08
Ptilotus obovatus var. *obovatus*	0.1	70 cm	WW14.06
Rhynchosia minima	0.1	120 cm	WW14.42
Salsola australis	0.1	60 cm	WW14.57
Scaevola parvifolia subsp. *pilbarae*	0.1	60 cm	WW14.60
Sclerolaena cornishiana	0.1	40 cm	WW14.52
Senna artemisioides subsp. *helmsii*	0.1	70 cm	WW14.11
Senna artemisioides subsp. *oligophylla*	0.1	60 cm	WW14.15
Senna glutinosa subsp. *x luerssenii*	0.1	20 cm	WW14.50
Senna notabilis	0.1	20 cm	WW14.76
Sida fibulifera	0.1	20 cm	WW14.48
Sida arsiniata	2	50 cm	WW14.07
Sida echinocarpa	0.1	40 cm	WW14.61
Sporobolus australasicus	1	15 cm	WW14.39
Streptoglossa odora	0.1	20 cm	WW14.41
Synaptantha tillaeacea var. *tillaeacea*	0.1	6 cm	WW14.77
Themeda triandra	3	80 cm	WW14.02
Tragus australianus	0.1	10 cm	WW14.37
Tribulopis angustifolia	0.1	2 cm	WW14.70
Tribulus astrocarpus	0.1	2 cm	WW14.56
Tribulus hirsutus	0.1	10 cm	WW14.49
Triodia longiceps	5	150 cm	WW14.22
Triodia pungens	10	120 cm	WW14.23
Waltheria indica	0.1	60 cm	WW14.66

HDA14

HDA and HDD			HDA15		
Described by	MM	Date	25-Apr-03	Type	Quadrat 50 x 50 m
Location	25.1 km SSW of Marillana and 74.8 km NW of Newman and 78.4 km SE of Auski Roadhouse.				
Central Coordinate	734223 mE, 7473992 mN.				
Habitat	Low stony rise, fringing the southern edge of Weeli Wolli Creek.				
Soil	Brown clay loam with more or less continuous surface layer of calcrete and ironstone pebbles.				
Rock Type	Not recorded.				
Vegetation	*Acacia pruinocarpa* scattered tall trees over *A. bivenosa, A. synchronicia* open shrubland over *Senna artemisioides* subsp. *oligophylla* scattered low shrubs over *Triodia wiseana* hummock grassland with *Paraneurachne muelleri* scattered tussock grasses.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	50 cm	WW15.15
Acacia bivenosa	2	200 cm	WW15.01
Acacia pruinocarpa	1	300 cm	
Acacia synchronicia	0.5	200 cm	WW15.10
Aristida contorta	0.1	30 cm	
Corchorus crozophorifolius	0.1	40 cm	WW15.17
Duperreya commixta	0.1	40 cm	
Enneapogon caerulescens	0.1	25 cm	WW15.07
Eragrostis eriopoda	0.1	55 cm	WW15.23
Eremophila forrestii subsp. *forrestii*	0.1	50 cm	WW15.20
Eriachne pulchella	0.1	8 cm	WW15.06
Goodenia muelleriana	0.1	30 cm	WW15.26
Gossypium australe	0.1	110 cm	WW15.21
Hakea chordophylla	0.1	200 cm	
Maireana planifolia	0.1	70 cm	WW15.05
Paraneurachne muelleri	0.5	40 cm	WW15.04
Ptilotus clementii	0.1	50 cm	WW15.13
Ptilotus helipteroides	0.1	30 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	70 cm	WW15.11
Ptilotus rotundifolius	0.1	60 cm	WW15.25
Rhagodia eremaea	0.1	60 cm	WW15.09
Sclerolaena cornishiana	0.1	30 cm	
Senna artemisioides subsp. *helmsii*	0.1	110 cm	WW15.12
Senna artemisioides subsp. *oligophylla*	1.5	70 cm	WW15.02
Senna glutinosa subsp. *glutinosa*	0.1	150 cm	WW15.19
Sida arsiniata	0.1	40 cm	WW15.18
Sida echinocarpa	0.1	50 cm	WW15.08
Solanum lasiophyllum	0.1	45 cm	WW15.22
Tribulus hirsutus	0.1	10 cm	WW15.14
Triodia wiseana	55	50 cm	WW15.03

HDA15

HDA and HDD			HDA16		
Described by	KBM	Date	25-Apr-03	Type	Quadrat 50 x 50 m
Location	20.1 km SSW of Marillana and 76.1 km NNW of Newman and 78.6 km SE of Auski Roadhouse.				
Central Coordinate	737482 mE, 7477767 mN.				
Habitat	Upper slope and mid slope of low stony hill; south aspect.				
Soil	Red sandy clay loam.				
Rock Type	Ironstone.				
Vegetation	*Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia inaequilatera* scattered shrubs over *A. hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) hummock grassland with *Fimbristylis dichotoma* scattered sedges.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				
Notes	Some areas in vicinity were burnt within the last year (2002).				
	Co-ordinates for corner 1 of quadrat were not recorded.				

Name	Cover	Height	Specimen
Acacia bivenosa	0.1	130 cm	WW16.21
Acacia citrinoviridis	0.1	220 cm	WW16.24
Acacia dictyophleba	0.1	120 cm	WW16.19
Acacia hilliana	2	60 cm	WW16.03
Acacia inaequilatera	1	150 cm	WW16.02
Aristida holathera var. *holathera*	0.1	60 cm	WW16.17
Bulbostylis barbata	0.1	3 cm	WW16.28
Chloris pectinata	0.1	30 cm	WW16.10
Cleome viscosa	0.1	20 cm	WW16.07
Corchorus lasiocarpus	0.1	50 cm	WW16.13
Corchorus sidoides	0.1	40 cm	WW16.15
Dampiera candicans	0.1	70 cm	WW16.18
Eriachne pulchella	0.1	10 cm	WW16.11
Eucalyptus leucophloia subsp. *leucophloia*	5	500 cm	WW16.01
Fimbristylis dichotoma	1	25 cm	WW16.20
Fimbristylis simulans	0.1	10 cm	WW16.16
Goodenia microptera	0.1	40 cm	WW16.32
Goodenia muelleriana	0.1	20 cm	WW16.33
Goodenia stobbsiana	0.1	40 cm	WW16.14
Grevillea wickhamii subsp. *hispidula*	0.1	200 cm	
Indigofera monophylla	0.1	30 cm	WW16.30
Paraneurachne muelleri	0.1	40 cm	WW16.31
Paspalidium clementii	0.1	10 cm	WW16.09
Perotis rara	0.1	10 cm	WW16.08
Polycarpaea holtzei	0.1	2 cm	WW16.29
Polygala glaucifolia	0.1	2 cm	WW16.23
Ptilotus obovatus var. *obovatus*	0.1	20 cm	WW16.06
Ptilotus rotundifolius	0.1	70 cm	WW16.27
Senna artemisioides subsp. *oligophylla*	0.1	110 cm	WW16.22
Senna glutinosa subsp. *pruinosa x* subsp. *? glutinosa*	0.1	170 cm	WW16.05
Senna glutinosa subsp. *x luerssenii*	0.1	160 cm	WW16.04
Solanum lasiophyllum	0.1	40 cm	WW16.34
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	55	50 cm	WW16.25
Triodia wiseana	5	90 cm	WW16.26

HDA16

HDA and HDD/Yandi Billiards Level 2 HDA24

Described by	Phase 1: MM Phase 2: PLCA	Date	Phase 1: 29-Apr-03 Phase 2: 12-Mar-14
Type	Quadrat 50 x 50 m		
Location	18.7 km SW of Marillana, 77 km SE of Auski Roadhouse and 78.1 km NNW of Newman.		
Central Coordinate	736928 mE, 7479778 mN.		
Habitat	Slope of low stony hill; gentle slope to northeast.		
Soil	Red-brown skeletal clay loam with continuous surface layer of stones and pebbles.		
Rock Type	Basalt (with outcropping) large boulders (5%), boulders (35%), cobbles (30%), pebbles (20%), and gravel (10%).		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia adoxa* var. *adoxa* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia bivenosa* (wispy/weeping form) scattered tall shrubs over *A. adoxa* var. *adoxa, Goodenia stobbsiana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (*T. wiseana*) very open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: Burnt 3-5 years ago. Phase 2: Burnt 3-5 years ago.		
Notes	Quadrat not pegged.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. adoxa	1.5	40 cm	WW24.03	0.5	40 cm	
Acacia ancistrocarpa	0.1	50 cm				
Acacia bivenosa (wispy/weeping form)	0.1	150 cm	WW24.04	0.5	240 cm	
Acacia dictyophleba				0.1	30 cm	
Acacia hilliana	0.1	40 cm	WW24.12	0.1	40 cm	
Acacia pruinocarpa	0.1	50 cm		0.1	40 cm	
Amphipogon sericeus				0.1	30 cm	HDAR24-02
Aristida holathera var. holathera				0.1	25 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	10 cm	WW24.18	0.1	10 cm	
Calytrix carinata	0.1	35 cm	WW24.07	0.1	60 cm	
Dodonaea coriacea	0.1	50 cm	WW24.05	0.1	100 cm	
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	4 cm	WW24.16			
Eriachne mucronata (typical form)	0.1	40 cm	WW24.20	0.1	40 cm	
Eriachne pulchella	0.1	10 cm	WW24.14	0.1	15 cm	
Eucalyptus leucophloia subsp. *leucophloia*	4	400 cm		5	440 cm	
Goodenia stobbsiana	0.1	30 cm		0.5	30 cm	
Goodenia triodiophila	0.1	35 cm	WW24.17	0.1	40 cm	
Grevillea wickhamii subsp. *hispidula*				0.1	50 cm	
Hakea chordophylla	0.1	200 cm		0.1	200 cm	
Paraneurachne muelleri	0.1	50 cm		0.1	35 cm	
Polycarpaea holtzei	0.1	2 cm	WW24.15			
Polygala glaucifolia	0.1	3 cm	WW24.09			
Ptilotus aervoides	0.1	2 cm				
Ptilotus astrolasius	0.1	40 cm		0.1	45 cm	
Ptilotus calostachyus				0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*				0.1	30 cm	
Ptilotus rotundifolius	0.1	70 cm		0.1	40 cm	
Senna artemisioides subsp. *oligophylla*	0.1	45 cm	WW24.02	0.1	90 cm	
Senna glutinosa subsp. *glutinosa*	0.1	120 cm	WW24.06	0.1	160 cm	
Senna glutinosa subsp. *pruinosa*	0.1	60 cm		0.1	180 cm	
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	60 cm	WW24.08	0.1	30 cm	HDAR24-03
Solanum phlomoides				0.1	35 cm	
Stemodia grossa	0.1	35 cm	WW24.11			
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	0.1	10 cm	WW24.19	0.1	70 cm	HDAR24-01
Trianthema glossostigmum				0.1	10 cm	HDAR24-04
Triodia pungens	0.1	50 cm	WW24.13	0.1	40 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	55	40 cm	WW24.01	9	35 cm	
Triodia wiseana	0.1	40 cm		0.5	45 cm	

HDA24 Phase 1

HDA24 Phase 2

Yandi Expansion/Yandi Billiards Level 2 YEX01

Described by Phase 1: BRM Phase 2: PLSW Date Phase 1: 31-Aug-04 Phase 2: 13-Mar-14

Type Quadrat 50 x 50 m

Location 26.9 km SW of Marillana, 77.3 km SE of Auski Roadhouse and 75.5 km NW of Newman.

Central Coordinate 732029 mE, 7473262 mN.

Habitat Gentle southeast facing slope at upper slope to crest of undulating hill.

Soil Dark reddish brown sandy loam.

Rock Type BIF/ironstone cobbles, pebbles, gravel.

Vegetation Phase 1: *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla* scattered tall shrubs over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia aptaneura	0.1	40 cm	YEX01-02			
Acacia dictyophleba				0.1	100 cm	
Acacia hilliana				2	60 cm	
Amphipogon sericeus				0.1	20 cm	YEXR01-01
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	3 cm	YEX01-19	0.1	5 cm	
Dysphania rhadinostachya subsp. rhadinostachya	0.1	30 cm	YEX01-12			
Eriachne mucronata (typical form)	0.1	35 cm	YEX01-15	0.1	25 cm	
Eriachne pulchella	0.1	3 cm	YEX01-09	0.1	10 cm	
Eucalyptus leucophloia subsp. leucophloia	0.1	600 cm		1	600 cm	
Fimbristylis dichotoma				0.1	15 cm	
Fimbristylis simulans	0.1	12 cm	YEX01-06	0.1	15 cm	
Gomphrena cunninghamii	0.1	12 cm	YEX01-18			
Goodenia microptera	0.1	30 cm	YEX01-17			
Goodenia stobbsiana	0.1	30 cm		0.1	30 cm	
Goodenia triodiophila				0.1	40 cm	YEXR01-02
Grevillea wickhamii subsp. hispidula				0.1	240 cm	
Hakea chordophylla	0.1	400 cm	YEX01-01	0.5	270 cm	
Polycarpaea holtzei	0.1	2 cm	YEX01-05			
Polygala glaucifolia	0.1	3 cm	YEX01-20			
Pterocaulon sphacelatum	0.1	40 cm	YEX01-14			
Ptilotus astrolasius				0.1	50 cm	
Ptilotus calostachyus	0.1	40 cm		0.1	35 cm	
Ptilotus rotundifolius	0.1	50 cm	YEX01-07	0.1	70 cm	
Schizachyrium fragile	0.1	20 cm	YEX01-11			
Senna glutinosa subsp. glutinosa	0.1	200 cm	YEX01-04	0.1	130 cm	
Senna glutinosa subsp. glutinosa x subsp. x luerssenii				0.1	110 cm	YEXR01-03
Senna glutinosa subsp. pruinosa	0.1	160 cm	YEX01-16	0.1	140 cm	
Senna glutinosa subsp. x luerssenii	0.1	120 cm				
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	15 cm	YEX01-13			
Solanum horridum	0.1	3 cm	YEX01-10			
Solanum lasiophyllum				0.1	60 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	65	35 cm	YEX01-03	13	40 cm	
Triodia wiseana	0.1	30 cm	YEX01-08			

YEX01 Phase 1 (no photo)

YEX01 Phase 2

Yandi Expansion/Yandi Billiards Level 2 YEX02
Described by Phase 1: RO Phase 2:CASW DatePhase 1: 31-Aug-04 Phase 2: 20-Mar-14
Type Quadrat 10 x 250 m
Location 25.1 km SW of Marillana, 77.7 km SE of Auski Roadhouse and 75.5 km NW of Newman
Central Coordinate 733504 mE, 7474254 mN.
Habitat East bank of Weeli Wolli Creek.
Soil Dark reddish brown clay with small amount of loam.
Rock Type Ironstone.
Vegetation Phase 1: *Eucalyptus victrix* open woodland over *Acacia citrinoviridis*, *A. coriacea* subsp. *pendens*, *A. pruinocarpa* low open woodland over *Atalaya hemiglauca, Gossypium robinsonii*, *Hakea lorea* subsp. *lorea* tall open shrubland over *Stylobasium spathulatum*, *Ptilotus obovatus* low open shrubland over **Cenchrus ciliaris*, (*Themeda triandra*) closed tussock grassland with **Malvastrum americanum* scattered herbs.
Phase 2: *Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. coriacea* subsp. *pendens*, *Atalaya hemiglauca, Gossypium robinsonii, Gossypium sturtianum* var. *sturtianum* tall open shrubland over **Cenchrus ciliaris* closed tussock grassland.
Veg Condition Phase 1: Very Poor; presence of weeds (**Cenchrus ciliaris*) and signs of cattle (grazing). Phase 2: Very Poor (**Cenchrus* spp., cattle tracks and scats).
Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon amplum				0.1	20 cm	YEXR02-09
Abutilon otocarpum	0.1	40 cm	YEX02-05	0.1	30 cm	YEXR02-11
Acacia citrinoviridis	4	1000 cm	YEX02-04	3	1000 cm	
Acacia coriacea subsp. pendens	4	1000 cm	YEX02-08	2	600 cm	
Acacia pruinocarpa	1	800 cm				
Acacia pyrifolia	0.1	300 cm	YEX02-16			
Acacia pyrifolia var. pyrifolia				0.1	260 cm	
Aerva javanica				0.1	40 cm	
Androcalva luteiflora	0.1	150 cm	YEX02-26			
Atalaya hemiglauca	2	300 cm		2	600 cm	
Boerhavia burbidgeana				0.1	10 cm	YEXR02-10
Bothriochloa ewartiana				0.1	140 cm	YEX02-05, YEX02-06
Cenchrus ciliaris	80	100 cm		87	70 cm	
Corchorus crozophorifolius	0.1	100 cm	YEX02-21	0.1	160 cm	
Cyperus vaginatus	0.1	60 cm	YEX02-27			
Datura leichhardtii	0.1	50 cm				
Dicladanthera forrestii	0.1	30 cm	YEX02-20			
Dodonaea lanceolata var. lanceolata				0.1	130 cm	YEXR02-04
Dodonaea petiolaris	0.1	80 cm	YEX02-13			
Duperreya commixta	0.1		YEX02-01	0.1	130 cm	
Enneapogon lindleyanus				0.1	30 cm	YEXR02-01
Enteropogon ramosus	0.1	90 cm	YEX02-28			
Eragrostis tenellula	0.1	20 cm	YEX02-25			
Eucalyptus victrix	3	1000 cm	YEX02-11	2	1000 cm	
Eulalia aurea	0.1	100 cm	YEX02-14			
Euphorbia australis var. subtomentosa				0.1	10 cm	YEXR02-12
Euphorbia biconvexa/ coghlanii/trigonosperma				0.1	20 cm	YEXR02-07
Euphorbia trigonosperma	0.1	15 cm	YEX02-29			
Evolvulus alsinoides var. decumbens				0.1	20 cm	
Glycine canescens				0.1	30 cm	YEXR02-03
Gossypium australe	0.1	130 cm	YEX02-06	0.1	60 cm	
Gossypium robinsonii	1	300 cm	YEX02-09	1	550 cm	
Gossypium sturtianum var. sturtianum	0.1	100 cm	YEX02-18	1	280 cm	
Hakea lorea subsp. lorea	1	500 cm	YEX02-07			
Jasminum didymum subsp. lineare				0.1	60 cm	
Malvastrum americanum	1	35 cm		0.1	30 cm	
Melaleuca argentea	0.1	300 cm	YEX02-23			
Melhania oblongifolia				0.1	30 cm	
Phyllanthus maderaspatensis				0.1	20 cm	YEXR02-13

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Pluchea rubelliflora	0.1	25 cm	YEX02-24			
Ptilotus nobilis subsp. nobilis				0.1	25 cm	YEXR02-08
Ptilotus obovatus var. obovatus	1	100 cm	YEX02-03			
Rhagodia eremaea	0.1	100 cm	YEX02-17			
Rhynchosia minima				0.1	20 cm	
Salsola australis				0.1	10 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	80 cm	YEX02-02			
Stemodia grossa	0.1	100 cm	YEX02-10			
Streptoglossa decurrens	0.1	30 cm	YEX02-22			
Stylobasium spathulatum	2.5	80 cm	YEX02-15	0.1	480 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)				0.1	30 cm	YEXR02-02
Themeda triandra	1.5	100 cm	YEX02-12	0.1	100 cm	
Triodia longiceps	0.1	140 cm	YEX02-19			

YEX02 Phase 1

YEX02 Phase 2

Yandi Expansion			YEX03		
Described by	BRM	Date	31-Aug-04	Type	Quadrat 50 x 50 m
Location	26 km SW of Marillana, 77.6 km SE of Auski Roadhouse and 75.5 km NW of Newman.				
Central Coordinate	732917 mE, 7473766 mN.				
Habitat	Broad plain, located between Weeli Wolli Creek (to east) and hills (to west).				
Soil	Red-brown loam to clay loam with pebbles.				
Rock Type	Ironstone.				
Vegetation	*Acacia synchronicia*, *Acacia bivenosa* tall open shrubland over *Senna glutinosa* subsp. x *luerssenii*, *S. artemisioides* subsp. *helmsii*, *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* open shrubland over *Solanum lasiophyllum* low scattered shrubland over *Aristida contorta*, (*Enneapogon lindleyanus*) tussock grassland with *Triodia wiseana* open hummock grassland.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	90 cm	YEX03-12
Acacia aptaneura	0.1	600 cm	YEX03-01
Acacia bivenosa	1.5	300 cm	
Acacia pruinocarpa	0.1	500 cm	
Acacia synchronicia	3.5	500 cm	YEX03-02
Aristida contorta	35	30 cm	YEX03-07
Aristida holathera var. *holathera*	0.1	50 cm	YEX03-35
Cenchrus ciliaris	0.1	45 cm	YEX03-18
Chrysocephalum gilesii	0.1	20 cm	YEX03-36
Cleome viscosa	0.1	30 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	35 cm	YEX03-23
Cymbopogon ambiguus	0.1	90 cm	YEX03-26
Enneapogon lindleyanus	7.5	20 cm	YEX03-08
Eragrostis eriopoda	0.1	45 cm	YEX03-29
Eremophila forrestii subsp. *forrestii*	0.1	110 cm	
Eriachne pulchella	0.1	12 cm	YEX03-25
Euphorbia australis var. *subtomentosa*	0.1	10 cm	YEX03-28
Goodenia microptera	0.1	25 cm	YEX03-13
Hakea lorea subsp. *lorea*	0.1	250 cm	YEX03-11
Haloragis gossei	0.1	15 cm	YEX03-37
Hibiscus sturtii var. *platychlamys*	0.1	35 cm	YEX03-19
Iseilema vaginiflorum	0.1	10 cm	YEX03-24
Maireana planifolia	0.1	80 cm	YEX03-10
Maireana villosa	0.1	45 cm	YEX03-34
Paraneurachne muelleri	0.1	40 cm	
Pterocaulon sphacelatum	0.1	40 cm	YEX03-21
Ptilotus helipteroides	0.1	12 cm	YEX03-16
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm	
Ptilotus roei	0.1	10 cm	YEX03-20
Rhodanthe floribunda	0.1	3 cm	YEX03-30
Salsola australis	0.1	25 cm	
Sclerolaena cornishiana	0.1	10 cm	YEX03-14
Senna artemisioides subsp. *helmsii*	2.5	150 cm	YEX03-09
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	1.5	110 cm	YEX03-04
Senna glutinosa subsp. *x luerssenii*	3.5	150 cm	YEX03-03
Sida fibulifera	0.1	25 cm	YEX03-33
Sida echinocarpa	0.1	40 cm	YEX03-15
Solanum horridum	0.1	30 cm	YEX03-22
Solanum lasiophyllum	1	70 cm	YEX03-05
Sporobolus australasicus	0.1	10 cm	
Stemodia grossa	0.1	25 cm	
Streptoglossa decurrens	0.1	30 cm	YEX03-27
Trichodesma zeylanicum var. *zeylanicum*	0.1	40 cm	
Triodia wiseana	17.5	70 cm	YEX03-06
Triraphis mollis	0.1	12 cm	YEX03-17

YEX03

Yandi Expansion/Yandi Billiards Level 2 YEX04

Described by Phase 1: KBM Phase 2: CASV Date Phase 1: 31-Aug-04 Phase 2: 14-Mar-14

Type Quadrat 50 x 50 m

Location 25.8 km SW of Marillana, 77.5 km SE of Auski Roadhouse and 75.6 km NW of Newman.

Central Coordinate 732943 mE, 7473923 mN.

Habitat Broad plain, located between Weeli Wolli Creek (to east) and hills (to west).

Soil Dark reddish brown silty clay.

Rock Type Scattered ironstone cobbles (1%), pebbles (3%), and gravel (3%).

Vegetation Phase 1: *Corymbia hamersleyana, Eucalyptus xerothermica*, *Acacia aptaneura* x incurvaneura low open woodland over *Acacia bivenosa* (*A. pruinocarpa, Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii*) shrubland over *Eremophila forrestii* subsp. *forrestii*, *Pterocaulon sphacelatum* low open shrubland over *Themeda triandra*, *Paraneurachne muelleri* open tussock grassland with *Triodia wiseana, T. pungens* open hummock grassland with *Sporobolus australasicus* scattered herbs.
Phase 2: *Acacia aptaneura, Corymbia hamersleyana, Eucalyptus xerothermica* low woodland over *Acacia sibirica, A. pruinocarpa* tall open shrubland over *Eremophila forrestii* subsp. *forrestii* scattered low shrubs over *Themeda triandra, Chrysopogon fallax, Paraneurachne muelleri* very open tussock grassland and *Triodia wiseana* very open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Very Good to Good (**Malvastrum americanum, *Bidens bipinnata*).

Fire Age Phase 1: Burnt <1 year ago. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. fraseri				0.1	30 cm	YEXR04-22
Abutilon macrum	0.1	40 cm	YEX04-20	0.1	30 cm	YEXR04-09
Abutilon otocarpum	0.1	30 cm	YEX04-14	0.1	35 cm	
Acacia ancistrocarpa	0.1	150 cm				
Acacia aptaneura				20	900 cm	YEXR04-04
Acacia aptaneura x	0.1	200 cm	YEX04-25			
Acacia aptaneura x incurvaneura	1	500 cm	YEX04-23			
Acacia bivenosa	9	200 cm		0.1	300 cm	
Acacia coriacea subsp. pendens	0.1	80 cm	YEX04-27			
Acacia kempeana				0.1	250 cm	YEXR04-05
Acacia pruinocarpa	1	100 cm		1	550 cm	
Acacia sericophylla				0.1	280 cm	YEXR04-29
Acacia sibirica	0.1	300 cm	YEX04-24	7	400 cm	YEXR04-03
Acacia synchronicia	0.1	200 cm		0.1	300 cm	YEXR04-19
Androcalva luteiflora	0.1	200 cm	YEX04-29			
Aristida contorta	1	30 cm		0.1	45 cm	
Aristida holathera var. holathera	0.1	40 cm				
Bidens bipinnata				0.1	15 cm	
Boerhavia coccinea	0.1	10 cm		0.1	10 cm	YEXR04-14
Bonamia erecta	0.1	30 cm	YEX04-12	0.1	30 cm	
Bulbostylis barbata	0.1	10 cm		0.1	2 cm	YEXR04-23
Calandrinia ptychosperma	0.1	1 cm	YEX04-13			
Cenchrus ciliaris	0.1	60 cm				
Chrysocephalum apiculatum	0.1	20 cm				
Chrysocephalum gilesii	0.1	20 cm	YEX04-19			
Chrysopogon fallax	1	100 cm		1	90 cm	
Cleome viscosa	0.1	40 cm		0.1	30 cm	
Corchorus lasiocarpus subsp. parvus				0.1	30 cm	YEXR04-33
Corymbia hamersleyana	1	500 cm		3	700 cm	
Cucumis variabilis	0.1	15 cm				
Cymbopogon obtectus	0.1	60 cm				
Cymbopogon procerus				0.1	110 cm	
Dactyloctenium radulans				0.1	10 cm	
Dichanthium sericeum subsp. humilius	0.1	20 cm		0.1	20 cm	YEXR04-08
Digitaria brownii				0.1	60 cm	
Digitaria ctenantha	1	25 cm		0.1	40 cm	
Duperreya commixta	0.1	200 cm		0.1	120 cm	
Dysphania rhadinostachya				0.1	15 cm	
Dysphania rhadinostachya subsp. rhadinostachya	0.1	15 cm	YEX04-03			

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Enchylaena tomentosa var. tomentosa	0.1	40 cm				
Enneapogon caerulescens	0.1	20 cm	YEX04-08	0.1	30 cm	YEXR04-12
Enneapogon polyphyllus	1	35 cm		0.1	20 cm	
Eragrostis cumingii	0.1	10 cm		0.1	20 cm	
Eremophila forrestii subsp. forrestii	1	60 cm		1	120 cm	
Eremophila longifolia	0.1	150 cm		0.1	70 cm	
Eriachne mucronata (typical form)	0.1	40 cm	YEX04-26			
Eriachne pulchella	0.1	15 cm	YEX04-17			
Eriachne tenuiculmis				0.1	30 cm	YEXR08-02=
Eucalyptus xerothermica	1	500 cm		1	650 cm	YEXR04-25
Euphorbia australis var. hispidula				0.1	10 cm	YEXR04-35, YEXR04-06
Euphorbia drummondii				0.1	10 cm	YEXR04-10
Evolvulus alsinoides var. villosicalyx	0.1	20 cm		0.1	10 cm	
Glycine canescens				0.1	130 cm	YEXR08-20=
Goodenia microptera	0.1	20 cm		0.1	25 cm	
Grevillea wickhamii subsp. hispidula	0.1	300 cm	YEX04-09			
Heliotropium inexplicitum	0.1	20 cm	YEX04-28			
Heliotropium tanythrix				0.1	10 cm	YEXR04-31
Hibiscus burtonii	0.1	35 cm	YEX04-21	0.1	30 cm	
Hibiscus coatesii	0.1	40 cm	YEX04-10	0.1	60 cm	YEXR04-28, YEXR04-34
Hibiscus sturtii var. grandiflorus				0.1	20 cm	YEXR04-24
Hibiscus sturtii var. platychlamys	0.1	30 cm	YEX04-06	0.1	40 cm	
Hybanthus aurantiacus	0.1	30 cm		0.1	30 cm	
Indigofera monophylla				0.1	60 cm	YEXR04-27
Iseilema membranaceum				0.1	30 cm	YEXR04-15
Keraudrenia nephrosperma				0.1	40 cm	YEXR04-32
Keraudrenia velutina subsp. elliptica	0.1	40 cm	YEX04-15			
Maireana planifolia	0.1	60 cm	YEX04-04	0.1	25 cm	YEXR04-11
Malvastrum americanum	0.1	25 cm		0.1	40 cm	
Melhania oblongifolia				0.1	40 cm	
Panicum effusum				0.1	40 cm	YEXR04-17
Paraneurachne muelleri	11	40 cm		1	30 cm	
Paspalidium basicladum	0.1	10 cm	YEX04-07			
Paspalidium clementii				0.1	10 cm	YEXR04-13
Perotis rara	0.1	10 cm		0.1	10 cm	
Polycarpaea corymbosa var. corymbosa	0.1	20 cm		0.1	15 cm	
Portulaca oleracea/intraterranea	0.1	2 cm		0.1	5 cm	YEXR04-20
Psydrax latifolia	0.1	80 cm		0.1	160 cm	
Pterocaulon sphacelatum	0.5	40 cm	YEX04-11	0.1	40 cm	YEXR04-18
Ptilotus astrolasius	0.1	30 cm				
Ptilotus gaudichaudii subsp. gaudichaudii	0.1	20 cm		0.1		YEXR04-02
Ptilotus helipteroides	0.1	20 cm				
Ptilotus nobilis subsp. nobilis	0.1	30 cm		0.1	5 cm	
Ptilotus obovatus var. obovatus	0.1	60 cm		0.1	60 cm	
Ptilotus polystachyus	0.1	35 cm				
Sclerolaena cornishiana	0.1	20 cm		0.1	20 cm	YEXR04-21
Senna artemisioides subsp. helmsii	0.1	80 cm		0.1	140 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	1	100 cm	YEX04-02			
Senna glutinosa subsp. glutinosa	0.1	100 cm		0.1	30 cm	
Senna glutinosa subsp. pruinosa	0.1	160 cm				
Senna glutinosa subsp. x luerssenii				0.1	110 cm	
Senna notabilis	0.1	30 cm		0.1	5 cm	
Sida arsiniata	0.1	40 cm	YEX04-22	0.1	45 cm	YEXR04-16

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Sida echinocarpa				0.1	40 cm	
Sida fibulifera	0.1	20 cm	YEX04-05			
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	180 cm	YEX04-16	0.1	10 cm	YEXR08-25=
Sida sp. verrucose glands (F.H. Mollemans 2423)				0.1		YEXR04-01
Solanum horridum	0.1	20 cm	YEX04-18	0.1	20 cm	YEXR04-30
Solanum lasiophyllum	0.1	20 cm		0.1	30 cm	
Spermacoce brachystema				0.1	7 cm	YEXR04-07
Sporobolus australasicus	1	10 cm		0.1	10 cm	
Themeda triandra	4	70 cm		2	80 cm	
Tribulus suberosus	0.1	30 cm				
Trichodesma zeylanicum var. zeylanicum	0.1	60 cm		0.1	10 cm	
Triodia basedowii				0.1	30 cm	YEXR04-26
Triodia pungens	2	70 cm				
Triodia wiseana	10	100 cm	YEX04-01	2	30 cm	

YEX04 Phase 1

YEX04 Phase 2

Yandi Expansion			YEX05		
Described by	RO	Date	31-Aug-04	Type	Quadrat 50 x 50 m
Location	26.2 km SW of Marillana, 76.9 km SE of Auski Roadhouse and 76 km NW of Newman.				
Central Coordinate	732277 mE, 7473978 mN.				
Habitat	Pediment; gentle rocky slope at base of low hills.				
Soil	Red clay with lots of ironstone pebbles on soil surface; colluvial / alluvial.				
Rock Type	Ironstone.				
Vegetation	*Eucalyptus gamophylla* low open mallee woodland over *Acacia ancistrocarpa, Grevillea wickhamii* subsp. *hispidula*, *Hakea chordophylla* tall open shrubland over *Acacia tenuissima*, *Sida arenicola* open shrubland over *Goodenia stobbsiana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (*T. pungens*) hummock grassland.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				
Notes	Noted in 2012: cleared by mine expansion.				

Species	Cover (%)	Height	Specimen
Acacia adoxa var. *adoxa*	0.1	30 cm	YEX05-22
Acacia ancistrocarpa	5.5	250 cm	YEX05-07
Acacia bivenosa	0.1	400 cm	YEX05-17
Acacia dictyophleba	0.1	300 cm	YEX05-18
Acacia inaequilatera	0.1	250 cm	YEX05-26
Acacia pachyacra	0.1	500 cm	YEX05-20
Acacia pruinocarpa	0.1	400 cm	
Acacia tenuissima	2	200 cm	YEX05-06
Acacia tumida var. *pilbarensis*	0.1	300 cm	YEX05-25
Aristida holathera var. *holathera*	0.1	50 cm	YEX05-12
Bonamia erecta	0.1	30 cm	YEX05-23
Codonocarpus cotinifolius	0.1	1000 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	70 cm	YEX05-08
Cullen leucochaites	0.1	170 cm	YEX05-16
Eucalyptus gamophylla	5.5	500 cm	
Euphorbia australis var. *erythrantha*	0.1	40 cm	YEX05-14
Goodenia microptera	0.1	40 cm	YEX05-13
Goodenia stobbsiana	1.5	100 cm	
Grevillea wickhamii subsp. *hispidula*	2	300 cm	YEX05-02
Hakea chordophylla	1	250 cm	YEX05-01
Paraneurachne muelleri	0.1	40 cm	
Polycarpaea holtzei	0.1	7 cm	
Pterocaulon sphacelatum	0.1	130 cm	YEX05-10
Ptilotus astrolasius	0.1	60 cm	YEX05-19
Scaevola parvifolia subsp. *pilbarae*	0.1	40 cm	YEX05-03
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	120 cm	YEX05-24
Senna glutinosa subsp. *glutinosa*	0.1	160 cm	YEX05-21
Senna glutinosa subsp. *pruinosa*	0.1	160 cm	YEX05-27
Senna glutinosa subsp. *x luerssenii*	0.1	120 cm	
Sida arenicola	1	120 cm	YEX05-11
Solanum lasiophyllum	0.1	50 cm	YEX05-15
Trachymene oleracea subsp. *oleracea*	0.1	60 cm	YEX05-05
Triodia pungens	1	100 cm	YEX05-09
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	67.5	100 cm	YEX05-04

YEX05

Yandi Expansion/Yandi Billiards Level 2 YEX06

Described by Phase 1: BRM Phase 2: SVSW Date Phase 1: 31-Aug-04 Phase 2: 14-Mar-14

Type Quadrat 50 x 50 m

Location 26.3 km SW of Marillana, 76.7 km SE of Auski Roadhouse and 76.2 km NW of Newman.

Central Coordinate 731957 mE, 7474007 mN.

Habitat Transitional slope, facing northeast.

Soil Dark reddish brown fine sandy clay loam with 40% cover of pebbles 30% cover of gravel and 20% cover of cobbles.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* scattered low trees over *Acacia hilliana*, (*A. adoxa* var. *adoxa*) low open heath over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland *Acacia hilliana, A. adoxa* var. *adoxa* low shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Very Good

Fire Age Phase 1: Very long unburnt. Phase 2: No sign of recent fire.

Notes The power line track running through the quadrat is old enough that it doesn't seem to affect the species assemblage.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. adoxa	1.5	45 cm	YEX06-03	1	60 cm	
Acacia adsurgens				0.1	140 cm	
Acacia hilliana	55	45 cm		13	50 cm	
Acacia tenuissima				0.1	90 cm	
Acacia tumida var. pilbarensis				0.1	120 cm	
Aristida holathera var. holathera				0.1	30 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)				0.1	10 cm	
Dysphania rhadinostachya subsp. rhadinostachya	0.1	12 cm	YEX01-12=			
Eriachne aristidea	0.1	10 cm		0.1	10 cm	
Eriachne mucronata (arid form)	0.1	30 cm	YEX06-06			
Eriachne mucronata (typical form)				0.1	40 cm	
Eriachne pulchella	0.1	10 cm	YEX01-09=			
Eucalyptus leucophloia subsp. leucophloia	1.5	600 cm		3	720 cm	
Euphorbia boophthona	0.1	30 cm	YEX06-08			
Fimbristylis dichotoma				0.1	20 cm	
Fimbristylis simulans	0.1	12 cm	YEX01-06=	0.1	15 cm	
Gomphrena cunninghamii	0.1	6 cm	YEX01-18=			
Goodenia microptera	0.1	12 cm	YEX01-17=			
Goodenia stobbsiana	0.1	50 cm		0.1	30 cm	
Goodenia triodiophila	0.1	30 cm	YEX06-07	0.1	20 cm	
Grevillea wickhamii subsp. hispidula	0.1	400 cm		0.1	280 cm	
Hakea chordophylla	0.1	400 cm	YEX01-01=	0.1	250 cm	
Hakea lorea subsp. lorea	0.1	15 cm	YEX06-01			
Mollugo molluginea				0.1	10 cm	
Paraneurachne muelleri	0.1	40 cm				
Polycarpaea holtzei	0.1	3 cm		0.1	1 cm	YEXR06-03
Polycarpaea longiflora	0.1	20 cm				
Ptilotus calostachyus				0.1	15 cm	
Ptilotus rotundifolius	0.1	45 cm	YEX01-07=	0.1	95 cm	
Senna glutinosa subsp. glutinosa x subsp. pruinosa				0.1	110 cm	
Senna glutinosa subsp. glutinosa x subsp. x luerssenii				0.1	120 cm	YEXR06-02
Senna glutinosa subsp. pruinosa	0.1	90 cm	YEX01-16=	0.1	70 cm	
Senna glutinosa subsp. x luerssenii	0.1	230 cm	YEX06-04			
Sida sp. Pilbara (A.A. Mitchell PRP 1543)				0.1	45 cm	
Solanum lasiophyllum				0.1	45 cm	
Triodia pungens	0.1	50 cm	YEX06-05	0.1	50 cm	YEXR06-01
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	65	30 cm	YEX06-02	31	40 cm	

YEX06 Phase 1

YEX06 Phase 2

Yandi Expansion			YEX07		
Described by	RO/KM	Date	31-Aug-04	Type	Quadrat 10 x 250 m
Location	25.9 km SW of Marillana, 76.7 km SE of Auski Roadhouse and 76.3 km NW of Newman.				
Central Coordinate	732315 mE, 7474436 mN.				
Habitat	Minor drainage line on hillslope, 5-10 wide.				
Soil	Red clay loam; alluvial.				
Rock Type	Ironstone.				
Vegetation	*Corymbia hamersleyana* open woodland over *Acacia tumida* var. *pilbarensis, Eremophila longifolia, Androcalva luteiflora* tall open shrubland over *Sida* sp. spiciform panicles (E. Leyland s.n. 14/8/90), *Acacia ancistrocarpa* open shrubland over *Themeda triandra,* (*Paraneurachne muelleri, Eragrostis cumingii*) tussock grassland.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				
Notes	Noted in 2012: cleared by mine expansion.				

Species	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	30 cm	YEX07-37
Acacia ancistrocarpa	1	200 cm	
Acacia bivenosa	1	300 cm	YEX07-07
Acacia citrinoviridis	1	300 cm	YEX07-30
Acacia dictyophleba	0.1	120 cm	
Acacia inaequilatera	0.1	250 cm	
Acacia pruinocarpa	0.1	600 cm	
Acacia pyrifolia	1	300 cm	YEX07-01
Acacia tenuissima	0.1	140 cm	YEX07-39
Acacia tumida var. *pilbarensis*	2.5	300 cm	YEX07-02
Androcalva luteiflora	1.5	250 cm	YEX07-06
Aristida contorta	0.1	30 cm	
Aristida holathera var. *holathera*	0.1	50 cm	
Bonamia erecta	0.1	30 cm	YEX07-21
Bulbostylis barbata	0.1	5 cm	
Chrysopogon fallax	0.1	140 cm	
Cleome viscosa	0.1	20 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	10 cm	YEX07-40
Corymbia hamersleyana	2	1500 cm	
Crotalaria medicaginea var. *neglecta*	0.1	35 cm	
Cucumis variabilis	0.1		
Digitaria brownii	0.1	100 cm	YEX07-13
Digitaria ctenantha	1	20 cm	
Duperreya commixta	0.1		
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	20 cm	YEX07-22
Enneapogon lindleyanus	0.1	70 cm	YEX07-44
Enneapogon polyphyllus	1	20 cm	
Eragrostis cumingii	1.5	7 cm	
Eragrostis eriopoda	0.1	50 cm	
Eremophila longifolia	2	250 cm	
Eriachne aristidea	0.1	10 cm	
Eriachne mucronata (typical form)	0.1	40 cm	YEX07-17
Eriachne pulchella	1	15 cm	YEX07-41
Eriachne tenuiculmis	0.1	100 cm	YEX07-12
Eulalia aurea	0.1	30 cm	
Euphorbia australis var. *subtomentosa*	0.1	20 cm	YEX07-33
Euphorbia coghlanii	0.1	25 cm	YEX07-24
Euphorbia tannensis subsp. *eremophila*	0.1	30 cm	YEX07-38
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Glycine canescens	0.1	10 cm	
Goodenia microptera	0.1	40 cm	YEX07-23
Goodenia muelleriana	0.1	25 cm	YEX07-34
Gossypium australe	0.1	50 cm	
Gossypium robinsonii	0.1	120 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	160 cm	YEX07-32

Species	Cover (%)	Height	Specimen
Heliotropium cunninghamii	0.1	35 cm	YEX07-15
Hibiscus sturtii var. *platychlamys*	0.1	25 cm	YEX07-14
Hybanthus aurantiacus	1	20 cm	
Indigofera monophylla	0.1	50 cm	YEX07-29
Iseilema vaginiflorum	0.1	5 cm	YEX07-16
Isotropis atropurpurea	0.1	35 cm	YEX07-36
Jasminum didymum subsp. *lineare*	0.1	100 cm	
Maireana planifolia	0.1	100 cm	YEX07-43
Nicotiana occidentalis subsp. *obliqua*	0.1	60 cm	YEX07-26
Paraneurachne muelleri	2	40 cm	
Peripleura arida	0.1	50 cm	YEX07-31
Perotis rara	0.1	5 cm	
Phyllanthus erwinii	0.1	3 cm	YEX07-18
Polycarpaea corymbosa var. *corymbosa*	0.1	10 cm	
Polycarpaea holtzei	0.1	5 cm	
Polycarpaea longiflora	0.1	20 cm	YEX07-11
Polymeria ambigua	0.1	5 cm	YEX07-10
Pterocaulon sphacelatum	0.1	40 cm	YEX07-09
Ptilotus nobilis subsp. *nobilis*	0.1	30 cm	
Ptilotus obovatus var. *obovatus*	1	80 cm	YEX07-08
Ptilotus polystachyus	0.1	30 cm	
Rhynchosia minima	0.1	10 cm	
Salsola australis	0.1	30 cm	
Santalum lanceolatum	0.1	200 cm	
Schizachyrium fragile	0.1	20 cm	
Senna artemisioides subsp. *helmsii*	0.1	100 cm	
Senna artemisioides subsp. *oligophylla*	0.1	120 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	40 cm	YEX07-19
Senna glutinosa subsp. *x luerssenii*	0.1	25 cm	
Senna notabilis	0.1	10 cm	
Setaria verticillata	0.1	50 cm	YEX07-27
Sida fibulifera	0.1	20 cm	YEX07-42
Sida cardiophylla	0.1	15 cm	YEX07-28
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	1.5	120 cm	YEX07-03
Stemodia grossa	0.1	50 cm	
Streptoglossa decurrens	0.1	10 cm	YEX07-45
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	1	80 cm	YEX07-05
Themeda triandra	42.5	100 cm	YEX07-04
Trachymene oleracea subsp. *oleracea*	0.1	40 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	40 cm	
Triodia pungens	1	80 cm	YEX07-20
Wahlenbergia tumidifructa	0.1	20 cm	YEX07-25

YEX07

Yandi Expansion/Yandi Billiards Level 2		YEX08	
Described by	Phase 1: BRM Phase 2: CASV	Date	Phase 1: 01-Sep-04 Phase 2: 15-Mar-14
Type	Quadrat 25 x 105 m		
Location	25.5 km SW of Marillana, 77 km SE of Auski Roadhouse and 76.1 km NW of Newman.		
Central Coordinate	732686 mE, 7474553 mN.		
Habitat	Banks of minor drainage line (<10 m wide) flowing east to Weeli Wolli Creek.		
Soil	2.5YR 3/3 dark reddish brown sandy clay loam.		
Rock Type	Ironstone cobbles (7%), pebbles (2%), and gravel (1%).		
Vegetation	Phase 1: *Eucalyptus victrix, E. xerothermica, Corymbia hamersleyana* low open woodland over *Acacia dictyophleba, Eremophila longifolia, A. pyrifolia, Gossypium robinsonii, Petalostylis labicheoides* tall open scrub over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii*, *Androcalva luteiflora* low open shrubland over **Cenchrus ciliaris*, *Themeda triandra*, (*Paraneurachne muelleri*) closed tussock grassland with *Triodia pungens* very open hummock grassland with *Euphorbia* australis var. *subtomentosa* scattered herbs. Phase 2: *Corymbia hamersleyana, Eucalyptus victrix* open woodland over *Eucalyptus xerothermica* scattered low trees over *Eremophila longifolia, Acacia dictyophleba* tall open scrub over **Cenchrus ciliaris, Themeda triandra* closed tussock grassland.		
Veg Condition	Phase 1: Very Good - Good; presence of weeds (**Cenchrus ciliaris*). Phase 2: Poor (**Cenchrus ciliaris, *Malvastrum americanum*)		
Fire Age	Phase 1: Very long unburnt. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon otocarpum	0.1	25 cm	YEX08-60	0.1	20 cm	
Acacia ancistrocarpa	0.1	150 cm		0.1	260 cm	
Acacia aptaneura				0.1	420 cm	YEXR08-21
Acacia aptaneura x macraneura	0.1	250 cm	YEX08-14			
Acacia bivenosa				0.1	220 cm	
Acacia citrinoviridis	0.1	400 cm	YEX08-22	1	500 cm	
Acacia coriacea subsp. pendens	0.1	200 cm	YEX08-20	0.1	220 cm	
Acacia dictyophleba	25	350 cm	YEX08-10	15	200 cm	
Acacia elachantha	0.1		YEX08-63			
Acacia pruinocarpa	0.1	250 cm		0.1	220 cm	
Acacia pyrifolia	7.5	400 cm	YEX08-11			
Acacia pyrifolia var. pyrifolia				0.1		YEXR08-03
Acacia tumida var. pilbarensis	0.1	180 cm		0.1	450 cm	
Alternanthera nana	0.1	30 cm	YEX08-40	0.1	10 cm	YEXR08-04
Ammannia multiflora				0.1	30 cm	YEXR08-28
Androcalva luteiflora	1	90 cm	YEX08-08	0.1	180 cm	
Aristida contorta	0.1	30 cm				
Aristida holathera var. holathera	0.1	30 cm	YEX08-09	0.1	35 cm	
Atalaya hemiglauca	0.1	400 cm	YEX08-55	0.1	500 cm	
Bidens bipinnata				0.1	40 cm	
Boerhavia coccinea				0.1	15 cm	
Boerhavia repleta				0.1	10 cm	YEXR08-17
Bonamia erecta	0.1	30 cm	YEX08-31			
Bulbostylis barbata	0.1	10 cm				
Calandrinia ptychosperma	0.1	5 cm	YEX08-07			
Calotis plumulifera	0.1	25 cm	YEX08-41			
Cenchrus ciliaris	35	60 cm		60	50 cm	
Centipeda minima subsp. macrocephala				0.1	5 cm	YEXR08-11
Chrysopogon fallax	0.1	130 cm	YEX08-23	0.1	120 cm	
Cleome viscosa				0.1	70 cm	
Convolvulus clementii	0.1	30 cm	YEX08-19			
Corchorus lasiocarpus subsp. parvus	0.1	45 cm	YEX08-29			
Corymbia candida	0.1	500 cm	YEX08-13	0.1	600 cm	YEXR08-06
Corymbia hamersleyana	1	800 cm	YEX08-35	4	1200 cm	
Crotalaria medicaginea var. neglecta				0.1	30 cm	
Cucumis variabilis				0.1	180 cm	
Cyperus difformis				0.1	40 cm	YEXR08-14
Digitaria brownii				0.1	70 cm	YEXR08-29
Duperreya commixta	0.1	350 cm	YEX08-33	0.1	250 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Dysphania melanocarpa forma melanocarpa	0.1	30 cm	YEX08-39			
Dysphania rhadinostachya subsp. rhadinostachya	0.1	20 cm	YEX08-04			
Enneapogon lindleyanus	0.1	20 cm	YEX08-26			
Enneapogon polyphyllus	0.1	30 cm	YEX08-16			
Eragrostis cumingii	0.1	12 cm	YEX08-05	0.1	20 cm	
Eragrostis eriopoda	0.1	40 cm	YEX03-29=	0.1	30 cm	
Eragrostis tenellula	0.1	12 cm	YEX08-44	0.1	10 cm	
Eremophila longifolia	17.5	400 cm		20	250 cm	
Eriachne mucronata (typical form)	0.1	35 cm	YEX08-56			
Eriachne pulchella	0.1	12 cm	YEX08-03			
Eriachne tenuiculmis	0.1	30 cm	YEX08-52	0.1	40 cm	YEXR08-02
Eucalyptus victrix	3	1000 cm	YEX08-57	3	1500 cm	
Eucalyptus xerothermica	1.5	600 cm	YEX08-54	1	800 cm	
Eulalia aurea				0.1	60 cm	
Euphorbia australis var. subtomentosa	1	5 cm	YEX08-38			
Euphorbia biconvexa				0.1	35 cm	YEXR08-01
Euphorbia tannensis subsp. eremophila	0.1	30 cm	YEX08-58			
Evolvulus alsinoides var. decumbens	0.1	10 cm	YEX08-28	0.1	15 cm	
Evolvulus alsinoides var. villosicalyx	0.1	12 cm		0.1	15 cm	
Fimbristylis microcarya				0.1	10 cm	YEXR08-12
Glycine canescens	0.1	200 mc	YEX08-32	0.1	260 cm	YEXR08-20, YEX08-22
Goodenia microptera	0.1	35 cm		0.1	35 cm	
Goodenia muelleriana				0.1	35 cm	YEXR08-27
Goodenia stellata	0.1	2 cm	YEX08-50	0.1	5 cm	YEXR08-19
Goodenia triodiophila	0.1	30 cm	YEX08-45			
Gossypium australe	0.1	30 cm	YEX08-17	0.1	110 cm	
Gossypium robinsonii	1.5	400 cm		0.1	210 cm	
Gossypium sturtianum var. sturtianum	0.1	40 cm	YEX08-61			
Hakea lorea subsp. lorea	0.1	260 cm	YEX08-15	0.1	350 cm	
Heliotropium cunninghamii	0.1	20 cm	YEX08-62			
Hibiscus sturtii var. platychlamys	0.1	40 cm	YEX08-24	0.1	20 cm	
Hybanthus aurantiacus	0.1	35 cm				
Indigofera linnaei				0.1	30 cm	YEXR08-15
Indigofera monophylla	0.1	35 cm	YEX08-37			
Ipomoea muelleri				0.1	1 cm	YEXR08-10
Ipomoea polymorpha				0.1	15 cm	YEXR08-08
Iseilema membranaceum				0.1	15 cm	YEXR08-30
Jasminum didymum subsp. lineare	0.1	70 cm	YEX08-34	0.1	70 cm	
Maireana planifolia	0.1	60 cm	YEX08-47			
Malvastrum americanum	0.1	35 cm		0.1	40 cm	
Melhania oblongifolia	0.1	35 cm	YEX08-27			
Mollugo molluginea	0.1	15 cm		0.1	10 cm	
Operculina aequisepala				0.1	100 cm	
Paraneurachne muelleri	1.5	40 cm		0.1	35 cm	
Perotis rara				0.1	20 cm	
Petalostylis labicheoides	1.5	250 cm				
Polycarpaea corymbosa var. corymbosa	0.1	15 cm	YEX08-06	0.1	10 cm	
Polymeria ambigua	0.1	25 cm	YEX08-46, YEX08-25	0.1	2 cm	YEXR08-26, YEXR08-32
Portulaca oleracea/intraterranea	0.1	5 cm	YEX08-30			
Pterocaulon sphacelatum	0.1	50 cm	YEX03-21=	0.1	15 cm	YEXR08-05
Ptilotus astrolasius				0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Ptilotus nobilis subsp. nobilis	0.1	20 cm				
Ptilotus obovatus var. obovatus	0.1	70 cm		0.1	70 cm	
Ptilotus polystachyus	0.1	50 cm	YEX08-21			
Rhynchosia minima	0.1	40 cm	YEX08-18	0.1	30 cm	
Salsola australis				0.1	30 cm	
Santalum lanceolatum	0.1	200 cm		0.1	170 cm	
Scaevola parvifolia subsp. pilbarae	0.1	30 cm	YEX08-48			
Senna artemisioides subsp. helmsii	0.1	70 cm				
Senna artemisioides subsp. oligophylla				0.1	100 cm	YEXR08-13, YEXR08-33
Senna artemisioides subsp. oligophylla x subsp. helmsii	3	80 cm	YEX08-12			
Setaria surgens				0.1	50 cm	YEXR08-23
Setaria verticillata				0.1	20 cm	
Sida arsiniata				0.1	50 cm	YEXR08-31
Sida fibulifera	0.1	20 cm	YEX08-43	0.1	30 cm	YEXR08-07, YEXR08-16
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)				0.1	150 cm	YEXR08-25
Solanum lasiophyllum	0.1	45 cm	YEX08-51	0.1	50 cm	
Sporobolus australasicus	0.1	20 cm				
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	50 cm	YEX08-02	0.1	50 cm	YEXR08-09
Themeda triandra	35	70 cm	YEX08-01	25	70 cm	
Trachymene oleracea subsp. oleracea	0.1	35 cm				
Trichodesma zeylanicum var. zeylanicum	0.1	40 cm		0.1	60 cm	
Triodia pungens	4	40 cm	YEX08-36	0.1	40 cm	YEXR08-18
Waltheria indica				0.1	40 cm	

YEX08 Phase 1

YEX08 Phase 2

Yandi Expansion			YEX09		
Described by	RO	Date	01-Sep-04	Type	Quadrat 50 x 50 m

Location: 25.2 km SW of Marillana, 75.9 km SE of Auski Roadhouse and 77.2 km NW of Newman.

Central Coordinate: 732084 mE, 7475352 mN.

Habitat: Alluvial clay flat between minor drainage line (east) and hills (west).

Soil: Red clay loam with small ironstone pebbles on soil surface; alluvial.

Rock Type: Ironstone.

Vegetation: *Acacia aptaneura, A. ayersiana, A. pruinocarpa, Codonocarpus cotinifolius* low open forest over *Eremophila forrestii* subsp. *forrestii*, *Eremophila longifolia*, *Senna artemisioides* subsp. *helmsii, Acacia tenuissima* shrubland over *Pterocaulon sphacelatum* scattered low shrubs over *Aristida contorta, A. Inaequiglumis, Enneapogon polyphyllus, Cymbopogon ambiguus* tussock grassland with *Triodia basedowii, T. pungens* scattered hummock grasses.

Veg Condition: Excellent.

Fire Age: No sign of recent fire.

Notes: Noted in 2012: cleared by mine expansion.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	50 cm	YEX09-04
Abutilon otocarpum	0.1	25 cm	YEX09-08
Acacia aptaneura	17.5	800 cm	YEX09-01
Acacia ayersiana	11	900 cm	YEX09-02
Acacia coriacea subsp. *pendens*	0.1	40 cm	YEX09-17
Acacia pruinocarpa	3	500 cm	
Acacia tenuissima	1	130 cm	YEX09-31
Alternanthera nana	0.1	10 cm	
Anthobolus leptomerioides	0.1	60 cm	YEX09-14
Aristida contorta	3.5	30 cm	YEX09-07
Aristida inaequiglumis	2.5	100 cm	YEX09-18
Bidens bipinnata	0.1	20 cm	
Boerhavia coccinea	0.1	25 cm	YEX09-10
Cenchrus ciliaris	0.1	40 cm	
Chrysocephalum gilesii	0.1	30 cm	YEX09-28
Codonocarpus cotinifolius	1	1000 cm	
Corymbia hamersleyana	0.1	700 cm	YEX09-09
Cucumis variabilis	0.1		
Cymbopogon ambiguus	1	90 cm	YEX09-06
Dodonaea petiolaris	0.1	120 cm	YEX09-37
Duperreya commixta	0.1		
Dysphania kalpari	0.1	10 cm	YEX09-38
Enneapogon lindleyanus	0.1	25 cm	YEX09-30
Enneapogon polyphyllus	1.5	20 cm	
Eragrostis cumingii	0.1	15 cm	
Eragrostis pergracilis	0.1	15 cm	YEX09-19
Eremophila forrestii subsp. *forrestii*	5.5	120 cm	
Eremophila longifolia	4	200 cm	
Eriachne aristidea	0.1	25 cm	YEX09-33
Eriachne mucronata	0.1	50 cm	YEX09-13
Eriachne pulchella	0.1	10 cm	YEX09-11
Euphorbia australis var. *subtomentosa*	0.1	5 cm	YEX09-35
Evolvulus alsinoides var. villosicalyx	0.1	8 cm	
Goodenia microptera	0.1	25 cm	YEX09-34
Gossypium australe	0.1	120 cm	YEX09-27
Hibiscus burtonii	0.1	25 cm	YEX09-05
Maireana planifolia x villosa	0.1	50 cm	YEX09-25
Nicotiana occidentalis subsp. *obliqua*	0.1	35 cm	YEX09-16
Psydrax latifolia	0.1	100 cm	
Pterocaulon sphacelatum	1	25 cm	YEX09-24
Ptilotus astrolasius	0.1	25 cm	YEX09-29
Ptilotus calostachyus	0.1	100 cm	

Species	Cover (%)	Height	Specimen
Ptilotus gaudichaudii subsp. *gaudichaudii*	0.1	20 cm	YEX09-15
Ptilotus helipteroides	0.1	15 cm	YEX09-26
Ptilotus nobilis subsp. *nobilis*	0.1	30 cm	
Sclerolaena eriacantha	0.1	10 cm	YEX09-12
Senna artemisioides subsp. *helmsii*	2	120 cm	YEX09-03
Senna glutinosa subsp. *x luerssenii*	0.1	25 cm	
Solanum horridum	0.1	20 cm	YEX09-36
Solanum lasiophyllum	0.1	50 cm	
Sporobolus australasicus	0.1	10 cm	
Triodia basedowii	1	100 cm	YEX09-23
Triodia pungens	1	140 cm	YEX09-32

YEX09

Yandi Expansion			YEX32		
Described by	RO	Date	04-Sep-04	Type	Quadrat 50 x 50 m
Location	25.7 km SW of Marillana, 76.1 km SE of Auski Roadhouse and 76.9 km NW of Newman.				
Central Coordinate	731938 mE, 7474808 mN.				
Habitat	Broad plain, located between minor drainage line (west) and hills (east).				
Soil	Red clay over ironstone with lots of ironstone pebbles on soil surface.				
Rock Type	Ironstone.				
Vegetation	*Acacia pruinocarpa*, *A. aptaneura*, *A.* catenulata low open woodland over *Senna artemisioides* subsp. *oligophylla, A. synchronicia*, *A. dictyophleba*, *Eremophila longifolia, Eremophila forrestii* subsp. *forrestii* open shrubland over *Aristida contorta, Paraneurachne muelleri* open tussock grassland with *Triodia pungens, T. wiseana* open hummock grassland with *Ptilotus nobilis* subsp. *nobilis, Sclerolaena cornishiana* very open herbland.				
Veg Condition	Excellent.				
Fire Age	Burnt 3-5 years ago.				
Notes	Noted in 2012: cleared by mine expansion.				

Species	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	10 cm	
Abutilon sp. Pilbara (W.R. Barker 2025)	0.1	40 cm	YEX32-12
Acacia aptaneura	2	700 cm	YEX32-09
Acacia bivenosa	0.1	200 cm	
Acacia catenulata	1.5	500 cm	YEX32-10
Acacia dictyophleba	2	200 cm	
Acacia pachyacra	0.1	350 cm	YEX32-05
Acacia pruinocarpa	3	300 cm	
Acacia synchronicia	2.5	200 cm	YEX32-21
Amyema hilliana	0.1	30 cm	YEX32-26
Aristida contorta	27.5	30 cm	
Aristida holathera var. *holathera*	1	60 cm	
Atalaya hemiglauca	0.1	70 cm	
Boerhavia coccinea	0.1	25 cm	
Bulbostylis barbata	0.1	8 cm	
Chrysocephalum apiculatum	0.1	50 cm	YEX32-29
Cleome viscosa	0.1	30 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	100 cm	YEX32-06
Cymbopogon ambiguus	1	70 cm	YEX32-16
Duperreya commixta	0.1		
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	15 cm	YEX32-02
Enneapogon caerulescens	0.1	25 cm	
Enneapogon polyphyllus	1	25 cm	
Eragrostis dielsii	0.1	10 cm	YEX32-13
Eragrostis eriopoda	1	60 cm	
Eremophila forrestii subsp. *forrestii*	1.5	170 cm	
Eremophila longifolia	1.5	140 cm	
Eriachne pulchella	0.1	8 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm	
Goodenia microptera	0.1	50 cm	YEX32-17
Gossypium australe	0.1	40 cm	
Hibiscus burtonii	0.1	30 cm	YEX32-27
Hibiscus sturtii var. *platychlamys*	0.1	30 cm	YEX32-19
Lepidium phlebopetalum	0.1	10 cm	YEX32-14
Maireana planifolia	1	120 cm	YEX32-11
Paraneurachne muelleri	8.5	50 cm	
Polycarpaea longiflora	0.1	25 cm	
Pterocaulon sphacelatum	0.1	YEX32-32	
Ptilotus auriculifolius	0.1	10 cm	YEX32-01
Ptilotus helipteroides	0.1	25 cm	YEX32-08
Ptilotus nobilis subsp. *nobilis*	2.5	45 cm	
Ptilotus obovatus var. *obovatus*	0.1	25 cm	
Ptilotus polystachyus	0.1	20 cm	

Species	Cover (%)	Height	Specimen
Ptilotus roei	0.1	3 cm	YEX32-20
Salsola australis	0.1	40 cm	
Sclerolaena cornishiana	1.5	20 cm	YEX32-04
Senna artemisioides subsp. *oligophylla*	3	150 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	170 cm	YEX32-25
Senna glutinosa subsp. *x luerssenii*	1	200 cm	
Sida fibulifera	1	30 cm	YEX32-03
Sida arsiniata	0.1	25 cm	YEX32-15
Sida echinocarpa	0.1	170 cm	YEX32-28
Solanum horridum	0.1	30 cm	YEX32-24
Solanum lasiophyllum	1	80 cm	
Sporobolus australasicus	0.1	12 cm	
Stemodia grossa	0.1	70 cm	
Streptoglossa decurrens	0.1	25 cm	YEX32-07
Tribulus macrocarpus	0.1	15 cm	YEX32-18
Trichodesma zeylanicum var. *zeylanicum*	0.1	50 cm	
Triodia pungens	12.5	140 cm	YEX32-23
Triodia wiseana	10	120 cm	YEX32-22

YEX32

Yandi Expansion			YEX33		
Described by	KBM	Date	04-Sep-04	Type	Quadrat 50 x 50 m
Location	26 km SW of Marillana, 76.2 km SE of Auski Roadhouse and 76.8 km NW of Newman.				
Central Coordinate	731760 mE, 7474571 mN.				
Habitat	Broad plain, located between hills.				
Soil	Red sandy clay with patches of sand on surface.				
Rock Type	Ironstone.				
Vegetation	*Acacia dictyophleba, A. pruinocarpa, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Acacia pachyacra* scattered shrubs over *Senna artemisioides* subsp. *oligophylla* low shrubland over *Triodia basedowii* closed hummock grassland with *Paraneurachne muelleri, Eragrostis eriopoda, Aristida holathera* var. *holathera* very open tussock grassland.				
Veg Condition	Excellent.				
Fire Age	No sign of recent fire.				
Notes	Noted in 2012: cleared by mine expansion.				

Species	Cover (%)	Height	Specimen
Abutilon sp. Pilbara (W.R. Barker 2025)	0.1	20 cm	YEX33-08
Acacia ancistrocarpa	1.5	300 cm	
Acacia dictyophleba	4	300 cm	
Acacia inaequilatera	1.5	300 cm	
Acacia pachyacra	1	200 cm	YEX33-12
Acacia pruinocarpa	2	300 cm	
Aristida contorta	0.1	20 cm	
Aristida holathera var. *holathera*	1	50 cm	
Bonamia pannosa	0.1	40 cm	
Cleome viscosa	0.1	30 cm	
Corchorus crozophorifolius	0.1	90 cm	YEX33-02
Cymbopogon obtectus	0.1	100 cm	
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	5 cm	
Eragrostis eriopoda	1	40 cm	
Eremophila latrobei subsp. *filiformis*	0.1	200 cm	
Eremophila longifolia	0.1	200 cm	
Eriachne aristidea	0.1	20 cm	
Eriachne pulchella	0.1	5 cm	
Euphorbia tannensis subsp. *eremophila*	0.1	40 cm	YEX33-06
Goodenia microptera	0.1	20 cm	
Gossypium australe	0.1	60 cm	
Hakea lorea subsp. *lorea*	0.1	30 cm	
Haloragis gossei	0.1	20 cm	
Heliotropium tenuifolium	0.1	20 cm	
Hibiscus sturtii var. *platychlamys*	0.1	30 cm	YEX33-04
Maireana planifolia	0.1	110 cm	YEX33-11
Mollugo molluginea	0.1	5 cm	
Paraneurachne muelleri	4	40 cm	
Phyllanthus erwinii	0.1	20 cm	YEX33-07
Polycarpaea holtzei	0.1	2 cm	
Pterocaulon sphacelatum	0.1	120 cm	YEX33-03
Ptilotus astrolasius	0.1	30 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm	
Ptilotus obovatus var. *obovatus*	0.1	60 cm	
Rhynchosia minima	0.1	30 cm	
Senna artemisioides subsp. *helmsii*	0.1	60 cm	
Senna artemisioides subsp. *oligophylla*	11	80 cm	
Sida fibulifera	0.1	20 cm	
Sida cardiophylla	0.1	60 cm	YEX33-05
Solanum lasiophyllum	0.1	35 cm	
Stemodia grossa	0.1	45 cm	
Trianthema pilosum	0.1	5 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	100 cm	
Triodia basedowii	80	60 cm	YEX33-01

YEX33

Yandi Expansion YEX37

Described by BRM Date 04-Sep-04 Type Quadrat 40 x 60 m

Location 26.9 km SW of Marillana, 77.1 km SE of Auski Roadhouse and 75.7 km NW of Newman.

Central Coordinate 731920 mE, 7473324 mN.

Habitat Crest of hill.

Soil Red-brown sand with pebbles and stones.

Rock Type Ironstone.

Vegetation *Acacia aptaneura* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia aptaneura	2.5	30 cm	YEX01-02=
Amphipogon sericeus	0.1	30 cm	YEX37-07
Aristida holathera var. *holathera*	0.1	30 cm	YEX24-06=
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	20 cm	YEX37-08
Bulbostylis barbata	0.1	12 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	45 cm	YEX37-09
Dampiera candicans	0.1	35 cm	
Eriachne pulchella	0.1	10 cm	YEX01-09=
Fimbristylis dichotoma	0.1	30 cm	YEX37-04
Fimbristylis simulans	0.1	12 cm	YEX01-06=
Goodenia stobbsiana	0.1	30 cm	
Gossypium australe	0.1	25 cm	YEX21-26
Grevillea wickhamii subsp. *hispidula*	0.1	600 cm	YEX37-01
Hakea chordophylla	0.1	400 cm	YEX01-01=
Mollugo molluginea	0.1	15 cm	YEX37-06
Polycarpaea holtzei	0.1	2 cm	
Pterocaulon sphacelatum	0.1	50 cm	YEX03-21=
Ptilotus calostachyus	0.1	35 cm	
Ptilotus rotundifolius	0.1	80 cm	YEX01-07=
Schizachyrium fragile	0.1	20 cm	YEX37-03
Senna glutinosa subsp. *pruinosa*	0.1	130 cm	YEX01-16=
Trachymene oleracea subsp. *oleracea*	0.1	70 cm	
Triodia pungens	0.1	20 cm	YEX37-05
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	60	35 cm	YEX37-02
Triodia wiseana	0.1	15 cm	

YEX37

Yandi Expansion/Yandi Billiards Level 2 YEX38

Described by Phase 1: RO Phase 2: PLSW Date Phase 1: 04-Sep-04 Phase 2: 15-Mar-14

Type Quadrat 50 x 50 m

Location 25.1 km SW of Marillana, 77.7 km SE of Auski Roadhouse and 75.5 km NW of Newman.

Central Coordinate 733626 mE, 7474399 mN.

Habitat Floodplain fringing river channel (Weeli Wolli Creek).

Soil Dark reddish brown sandy clay loam.

Rock Type Ironstone.

Vegetation Phase 1: *Corymbia hamersleyana, Acacia pruinocarpa* low open woodland over *A. citrinoviridis, Atalaya hemiglauca* tall open shrubland over *Ptilotus obovatus*, *Rhagodia eremaea* low open shrubland over **Cenchrus ciliaris, Themeda triandra* tussock grassland with *Triodia longiceps* hummock grassland.
Phase 2: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa* (*A. pruinocarpa, Gossypium robinsonii, A. citrinoviridis*) tall shrubland over *Gossypium sturtianum* var. *sturtianum* scattered shrubs over **Cenchrus ciliaris* tussock grassland.

Veg Condition Phase 1: Very Poor; presence of weeds (infestation of **Cenchrus ciliaris*, **Flaveria trinervia*, **Malvastrum americanum*).
Phase 2: Good (**Cenchrus* spp., **Malvastrum americanum*, cow disturbance).

Fire Age Phase 1: Very long unburnt. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. fraseri				0.1	40 cm	
Abutilon lepidum	0.1	25 cm	YEX38-17			
Abutilon otocarpum				0.1	40 cm	
Acacia aptaneura	0.1	600 cm	YEX38-06			
Acacia bivenosa	1	300 cm		8	400 cm	
Acacia citrinoviridis	2	600 cm		1	900 cm	
Acacia pruinocarpa	4.5	1000 cm		2	300 cm	
Acacia pyrifolia	1	400 cm				
Acacia synchronicia	0.1	500 cm		0.1	350 cm	
Acacia tenuissima				0.1	160 cm	
Aerva javanica				0.1	60 cm	
Androcalva luteiflora				0.1	140 cm	
Aristida contorta	0.1	40 cm				
Aristida holathera var. holathera				0.1	30 cm	
Aristida inaequiglumis	1	90 cm	YEX38-03			
Aristida pruinosa				0.1	140 cm	YEXR38-03
Atalaya hemiglauca	1.5	500 cm		0.1	400 cm	
Boerhavia coccinea				0.1	30 cm	
Bothriochloa ewartiana				0.1	120 cm	
Cenchrus ciliaris	42.5	100 cm		45	80 cm	
Cenchrus setiger				0.1	80 cm	
Corchorus crozophorifolius	0.1	50 cm	YEX38-02			
Corchorus lasiocarpus subsp. lasiocarpus				0.1	50 cm	
Corchorus tridens				0.1	10 cm	
Corymbia hamersleyana	1.5	1000 cm		6	800 cm	
Cymbopogon obtectus	0.1	100 cm	YEX38-05			
Dicladanthera forrestii	0.1	30 cm	YEX38-15			
Duperreya commixta	0.1			0.1	140 cm	
Enchylaena tomentosa var. tomentosa	0.1	100 cm	YEX38-08			
Enneapogon polyphyllus	1	20 cm		0.1	30 cm	
Eragrostis eriopoda	1	60 cm		0.1	50 cm	
Eriachne tenuiculmis	0.1	80 cm	YEX38-13			
Eulalia aurea				0.1	60 cm	
Euphorbia australis var. subtomentosa				0.1	10 cm	YEXR38-01
Euphorbia biconvexa				0.1	30 cm	YEXR38-02
Euphorbia tannensis subsp. eremophila				0.1	45 cm	
Evolvulus alsinoides var. decumbens				0.1	25 cm	
Evolvulus alsinoides var. villosicalyx				0.1	20 cm	
Flaveria trinervia	0.1	20 cm	YEX38-04	0.1	30 cm	
Goodenia muelleriana				0.1	30 cm	YEXR38-05

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Gossypium australe	0.1	180 cm		0.1	160 cm	
Gossypium robinsonii				2	350 cm	
Gossypium sturtianum var. sturtianum				1	180 cm	YEXR38-06
Hakea lorea subsp. lorea				0.1	100 cm	
Hibiscus sturtii var. platychlamys				0.1	40 cm	
Malvastrum americanum	0.1	25 cm		0.1	30 cm	
Melhania oblongifolia				0.1	40 cm	
Paraneurachne muelleri	1	70 cm		0.1	45 cm	
Pluchea ferdinandi-muelleri	0.1	80 cm	YEX38-11	0.1	50 cm	
Polymeria ambigua				0.1	25 cm	YEXR38-04
Pterocaulon sphacelatum	0.1	25 cm	YEX38-16	0.1	30 cm	
Ptilotus obovatus var. obovatus	2.5	70 cm		0.1	40 cm	
Rhagodia eremaea	2	110 cm	YEX38-09			
Rhynchosia minima				0.1	35 cm	
Salsola australis				0.1	40 cm	
Santalum lanceolatum	0.1	150 cm	YEX38-18			
Senna artemisioides subsp. oligophylla	0.1	120 cm				
Senna artemisioides subsp. oligophylla x subsp. helmsii				0.1	50 cm	
Sida fibulifera	0.1	25 cm	YEX38-10	0.1	35 cm	
Solanum lasiophyllum	0.1	30 cm		0.1	45 cm	
Solanum phlomoides				0.1	50 cm	
Sporobolus australasicus	0.1	15 cm				
Stemodia grossa	0.1	60 cm				
Streptoglossa decurrens	0.1	30 cm	YEX38-14	0.1	35 cm	
Stylobasium spathulatum				1	300 cm	
Swainsona kingii	0.1	15 cm	YEX38-19			
Tephrosia sp. Fortescue (A.A. Mitchell 606)				0.1	40 cm	
Themeda triandra	2	100 cm		0.1	130 cm	
Triodia longiceps	40	200 cm	YEX38-01	13	100 cm	
Triodia pungens	0.1	70 cm	YEX38-07			
Triodia wiseana	0.1	110 cm	YEX38-12			

YEX38 Phase 1

YEX38 Phase 2

Yandi Expansion					YEX-J
Described by	BRM	Date	04-Sep-04	Type	Relevé; Unbounded
Location	26.8 km SW of Marillana, 77.3 km SE of Auski Roadhouse and 75.6 km NW of Newman				
Central Coordinate	732102 mE, 7473352 mN.				
Habitat	Rocky gully on side of ridge between hills.				
Soil	Not recorded.				
Rock Type	Not recorded.				
Vegetation	*Eucalyptus leucophloia* low open woodland over *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia pungens* open hummock grassland with *Eriachne mucronata, Cymbopogon ambiguus, Themeda triandra* open tussock grassland.				
Veg Condition	Not recorded.				
Fire Age	Not recorded.				
Notes	Incomplete; do not include in analysis.				

Species	Cover (%)	Height	Specimen
Cheilanthes sieberi subsp. *sieberi*	0.1	20 cm	YEXJ-03
Hibiscus goldsworthii	0.1	70 cm	YEXJ-01
Paspalidium basicladum	0.1	12 cm	YEXJ-05
Ptilotus obovatus var. *obovatus*	0.1	60 cm	YEXJ-06
Rhagodia eremaea	0.1	60 cm	YEXJ-04

YEX-J

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI01

Described by Phase 1: RW/PH Phase 2: SVSW Date Phase 1: 15-Jun-07 Phase 2: 11-Mar-14

Type Quadrat 50 x 50 m

Location 15.4 km SSW of Marillana, 77.7 km ESE of Auski Roadhouse and 78.8 km NNW of Newman.

Central Coordinate 739465 mE, 7482118 mN.

Habitat Braided creek bed (Weeli Wolli Creek).

Soil 5YR 3/3 dark reddish brown skeletal sand.

Rock Type Ironstone, basalt, sandstone, chert, dolerite, shale cobbles (5%), pebbles (60%), and gravel (30%).

Vegetation Phase 1: *Eucalyptus victrix* woodland over *Cleome viscosa*, *Heliotropium pachyphyllum, Pluchea rubelliflora, Phyllanthus maderaspatensis* herbland.
Phase 2: *Eucalyptus victrix* woodland over *Acacia citrinoviridis* scattered tall shrubs.

Veg Condition Phase 1: Very Good; presence of weeds (**Cenchrus ciliaris, *Argemone ochroleuca* subsp. *ochroleuca*, **Setaria verticillata*).
Phase 2: Very Good (cow scats throughout).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Phase 2: A lot of dead shrubs and herbs due to lack of water.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon amplum	0.1	30 cm	YBI01-13			
Acacia citrinoviridis	0.1	100 cm		0.5	240 cm	
Acacia pyrifolia var. pyrifolia	0.1	15 cm		0.1	110 cm	YBIR01-02
Argemone ochroleuca subsp. ochroleuca	0.1	40 cm				
Aristida contorta	0.1	30 cm				
Aristida holathera var. holathera	0.1	20 cm				
Boerhavia coccinea	0.1	20 cm	YBI01-16	0.1	5 cm	
Cenchrus ciliaris	0.1	40 cm				
Cleome viscosa	25	60 cm		0.1	10 cm	
Corchorus crozophorifolius	0.1	25 cm		0.1	110 cm	
Crotalaria medicaginea var. neglecta	0.1	10 cm				
Cucumis melo subsp. agrestis	0.1	10 cm	YBI01-12			
Cymbopogon ambiguus	0.1	100 cm	YBI01-11			
Cymbopogon procerus				0.1	140 cm	
Cyperus ixiocarpus	0.1	5 cm	YBI01-04			
Digitaria brownii	0.1	50 cm	YBI01-01			
Eriachne pulchella	0.1	30 cm		0.1	8 cm	
Eriachne tenuiculmis				0.1	40 cm	
Eucalyptus victrix	15	1500 cm		15	1800 cm	
Eulalia aurea	0.1	100 cm		0.1	45 cm	YBIR01-04
Euphorbia australis var. subtomentosa	0.1	6 cm	YBI01-07			
Euphorbia trigonosperma	0.1	30 cm	YBI01-17			
Evolvulus alsinoides var. villosicalyx	0.1	10 cm				
Gomphrena cunninghamii	0.1	20 cm		0.1	3 cm	YBIR01-06
Goodenia lamprosperma	0.1	40 cm	YBI01-05	0.1	25 cm	YBIR01-05
Heliotropium cunninghamii	0.1	40 cm	YBI01-18	0.1	15 cm	YBIR01-01
Heliotropium pachyphyllum	3	30 cm	YBI01-14			
Hybanthus aurantiacus	0.1	35 cm				
Indigofera monophylla	0.1	30 cm	YBI01-03	0.1	15 cm	
Ipomoea muelleri	0.1	10 cm	YBI01-10			
Phyllanthus maderaspatensis	1	50 cm	YBI01-15	0.1	40 cm	
Pluchea dentex	0.1	40 cm	YBI01-06			
Pluchea rubelliflora	2	30 cm	YBI01-08			
Polycarpaea longiflora	0.1	20 cm				
Pterocaulon sphacelatum	0.1	30 cm	YBI01-02			
Ptilotus nobilis subsp. nobilis	0.1	10 cm				
Setaria verticillata	0.1	15 cm				
Stemodia grossa	0.1	30 cm				
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	45 cm	YBI01-09	0.1	45 cm	
Waltheria indica	0.1	25 cm		0.1	30 cm	

YBI01 Phase 1

YBI01 Phase 2

Yandi Billiards & Junction SW YBI02

Described by B/RO Date 15-Jun-07 Type Quadrat 50 x 50 m

Location 15.5 km SSW of Marillana, 77.5 km ESE of Auski Roadhouse and 78.9 km NNW of Newman

Central Coordinate 739211 mE, 7482114 mN.

Habitat Broad floodplain fringing river (Weeli Wolli Creek).

Soil Red-brown clay; alluvial.

Rock Type Ironstone.

Vegetation *Acacia citrinoviridis*, *Atalaya hemiglauca* low open forest over **Cenchrus ciliaris*, (**C. setiger*, *Enneapogon lindleyanus*) closed tussock grassland with *Triodia wiseana* scattered hummock grasses.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*, **C. setiger*, **Malvastrum americanum*).

Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	25 cm	YBI02-03, YBI02-10
Abutilon macrum	0.1	25 cm	YBI02-08
Acacia citrinoviridis	40	700 cm	
Acacia pruinocarpa	0.1	200 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	80 cm	
Aristida contorta	0.1	40 cm	
Atalaya hemiglauca	2	800 cm	
Cenchrus ciliaris	60	30 cm	
Cenchrus setiger	15	30 cm	
Corchorus crozophorifolius	0.1	100 cm	YBI02-02
Duperreya commixta	0.1	30 cm	
Enchylaena tomentosa var. *tomentosa*	0.1	30 cm	
Enneapogon lindleyanus	1	35 cm	YSW1-28=
Enneapogon polyphyllus	0.1	30 cm	
Euphorbia australis var. *subtomentosa*	0.1	20 cm	YBI02-07
Euphorbia tannensis subsp. *eremophila*	0.1	80 cm	YBI02-05
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm	
Gossypium australe	0.1	150 cm	
Isotropis atropurpurea	0.1	20 cm	
Malvastrum americanum	0.1	35 cm	
Melhania oblongifolia	0.1	20 cm	
Perotis rara	0.1	5 cm	
Pterocaulon sphacelatum	0.1	80 cm	YBI02-04
Ptilotus obovatus	0.1	110 cm	
Rhagodia eremaea	0.1	80 cm	
Senna artemisioides subsp. *helmsii*	0.1	120 cm	YBI02-06
Streptoglossa decurrens	0.1	50 cm	
Themeda triandra	0.1	50 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	100 cm	
Triodia wiseana	1.5	25 cm	YBI02-01
Waltheria indica	0.1	50 cm	

No photo.

Yandi Billiards & Junction SW YBI03

Described by RB/B Date 15-Jun-07 Type Quadrat 50 x 50 m

Location 15.3 km SSW of Marillana, 78.2 km NNW of Newman and 78.4 km ESE of Auski Roadhouse.

Central Coordinate 740075 mE, 7481817 mN.

Habitat Broad floodplain between channels of river (Weeli Wolli Creek); flat to very gently undulating.

Soil Red-brown loamy sand.

Rock Type Not recorded.

Vegetation *Eucalyptus victrix*, *E. xerothermica* open woodland over *Acacia citrinoviridis* low open forest over **Cenchrus ciliaris*, (**C. setiger*) closed tussock grassland.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*, **C. setiger*).

Fire Age No sign of recent fire.

Notes *Eucalyptus victrix* has higher cover in quadrat than in general vegetation unit, where it is only scattered (up to 2% cover).

Species	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	YBI03-03
Acacia citrinoviridis	35	1000 cm	YBI03-02
Acacia coriacea subsp. *pendens*	0.1	600 cm	YBI03-11
Atalaya hemiglauca	0.1	500 cm	
Cenchrus ciliaris	90	80 cm	
Cenchrus setiger	5	80 cm	YBI03-01
Duperreya commixta	0.1	400 cm	YSW9-06=
Eucalyptus victrix	6	1500 cm	
Eucalyptus xerothermica	2.5	1200 cm	YBI03-10
Euphorbia tannensis subsp. *eremophila*	0.1	90 cm	YBI03-09
Jasminum didymum subsp. *lineare*	0.1	300 cm	
Malvastrum americanum	0.1	90 cm	
Melhania oblongifolia	0.1	30 cm	YBI03-05
Ptilotus obovatus var. *obovatus*	0.1	140 cm	YBI03-06
Rhagodia eremaea	0.1	150 cm	YBI03-04
Rhynchosia minima	0.1	30 cm	YBI03-08
Sida fibulifera	0.1	25 cm	YBI03-07
Trichodesma zeylanicum var. *zeylanicum*	0.1	130 cm	

YBI03

Yandi Billiards & Junction SW YBI04

Described by RW/PH Date 15-Jun-07 Type Quadrat 50 x 50 m

Location 16.9 km SSW of Marillana, 77.4 km NNW of Newman and 78.6 km SE of Auski Roadhouse.

Central Coordinate 739343 mE, 7480406 mN.

Habitat Floodplain fringing river channels (Weeli Wolli Creek).

Soil Red-brown sandy loam.

Rock Type Few rocks present; Ironstone, Basalt, Chert.

Vegetation *Acacia citrinoviridis* low open forest over *A. pruinocarpa* scattered tall shrubs over *Atalaya hemiglauca* open shrubland over **Cenchrus ciliaris*, **C. setiger* closed tussock grassland.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*, **C. setiger*, **Malvastrum americanum, *Setaria verticillata*).

Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	YBI04-02
Acacia citrinoviridis	40	1000 cm	
Acacia coriacea subsp. *pendens*	0.1	700 cm	
Acacia pruinocarpa	1	210 cm	
Amyema hilliana	0.1	200 cm	YBI04-03
Atalaya hemiglauca	5	170 cm	YBI04-05
Cenchrus ciliaris	45	50 cm	
Cenchrus setiger	45	50 cm	
Duperreya commixta	0.1	170 cm	
Enteropogon ramosus	0.1	50 cm	YBI04-04
Gossypium australe	0.1	30 cm	
Malvastrum americanum	0.1	100 cm	
Pterocaulon sphacelatum	0.1	30 cm	YBI1-02=
Ptilotus obovatus var. *obovatus*	0.1	100 cm	YBI04-01
Rhynchosia minima	0.1	5 cm	
Senna artemisioides subsp. *helmsii*	0.1	210 cm	YBI04-06
Setaria verticillata	0.1	15 cm	
Stylobasium spathulatum	0.1	150 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	150 cm	

YBI04

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI05

Described by	Phase 1: B/RO Phase 2: PLSV	Date	Phase1: 15-Jun-07 Phase 2: 11-Mar-14
Type	Quadrat 50 x 50 m		
Location	17.8 km SSW of Marillana, 77.6 km SE of Auski Roadhouse and 77.9 km NNW of Newman.		
Central Coordinate	738051 mE, 7480225 mN.		
Habitat	Steep, northeast facing slope of low hill; adjacent to broad floodplain of river (Weeli Wolli Creek).		
Soil	Dark reddish brown sandy loam.		
Rock Type	Ironstone and shale cobbles (80%), pebbles, and gravel over bedrock.		
Vegetation	Phase 1: *Corymbia hamersleyana* scattered low trees over *Triodia wiseana* closed hummock grassland.		
	Phase 2: *Corymbia hamersleyana* scattered low trees over *Triodia wiseana* hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum				0.1	30 cm	YBIR05-10
Acacia aptaneura	0.1	80 cm	YBI05-03			
Acacia bivenosa	0.1	120 cm				
Acacia bivenosa (wispy/weeping form)				0.1	220 cm	
Acacia citrinoviridis	0.1	70 cm		0.1	150 cm	
Acacia pruinocarpa	0.1	150 cm		0.1	160 cm	
Aristida holathera var. holathera	0.1	20 cm				
Atalaya hemiglauca	0.1	100 cm		0.1	200 cm	
Boerhavia coccinea				0.1	30 cm	
Bulbostylis barbata				0.1	10 cm	
Cleome viscosa	0.1	100 cm		0.1	20 cm	
Corchorus lasiocarpus subsp. parvus				0.1	20 cm	YBIR05-06
Corymbia hamersleyana	1	600 cm		1	600 cm	
Cucumis variabilis	0.1	80 cm		0.1	150 cm	
Dicladanthera forrestii				0.1	30 cm	YBIR05-04
Enneapogon caerulescens	0.1	30 cm				
Enneapogon polyphyllus	0.1	25 cm				
Eriachne mucronata (arid form)				0.1	40 cm	YBIR05-02
Eriachne mucronata (typical form)	0.1	40 cm				
Eucalyptus leucophloia subsp. leucophloia	0.1	500 cm		0.1	580 cm	
Euphorbia australis var. subtomentosa				0.1	6 cm	YBIR05-05
Euphorbia tannensis subsp. eremophila	0.1	60 cm	YBI05-02	0.1	50 cm	YBIR05-08
Gomphrena cunninghamii				0.1	10 cm	
Goodenia stobbsiana	0.1	30 cm				
Grevillea wickhamii subsp. hispidula	0.1	200 cm				
Hakea chordophylla	0.1	300 cm		0.1	560 cm	
Heliotropium cunninghamii				0.1	35 cm	YBIR05-11
Paraneurachne muelleri	0.1	30 cm				
Paspalidium clementii				0.1	35 cm	YBIR05-03
Polycarpaea longiflora	0.1	15 cm		0.1	15 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	30 cm	
Ptilotus rotundifolius	0.1	60 cm		0.1	40 cm	
Rhynchosia minima	0.1	40 cm		0.1	35 cm	
Salsola australis	0.1	70 cm				
Senna artemisioides subsp. oligophylla	0.1	40 cm	YBI05-01	0.1	60 cm	YBIR05-07
Senna glutinosa subsp. glutinosa	0.1	110 cm		0.1	140 cm	
Solanum lasiophyllum	0.1	40 cm				
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)				0.1	15 cm	YBIR05-09
Tribulus suberosus				0.1	40 cm	
Triodia wiseana	80	30 cm		65	40 cm	

YBI05 Phase 1 (no photo)

YBI05 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI06
Described by Phase 1: RB/B Phase 2: PLCA Date Phase 1: 15-Jun-07 Phase 2: 11-Mar-14
Type Quadrat 50 x 50 m
Location 17.1 km SSW of Marillana, 77.5 km SE of Auski Roadhouse and 78.2 km NNW of Newman
Central Coordinate 738312 mE, 7480809 mN.
Habitat Flat alluvial plain; west of river floodplain (Weeli Wolli Creek).
Soil Dark reddish brown sandy clay loam.
Rock Type Ironstone.
Vegetation Phase 1: *Acacia pruinocarpa* scattered tall shrubs over *Triodia basedowii* hummock grassland.
Phase 2: *Acacia inaequilatera, A. pruinocarpa, A. ancistrocarpa* tall open shrubland over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia basedowii* (*T. pungens*) hummock grassland with **Cenchrus ciliaris, *C. setiger* very open tussock grassland.
Veg Condition Phase 1: Good; presence of weeds (**Cenchrus ciliaris*). Phase 2: Good (**Cenchrus* spp.).
Fire Age Phase 1: No sign of recent fire. Phase 2: Very long unburnt.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum				0.1	50 cm	YBIR06-09
Abutilon otocarpum	0.1	35 cm	YBI06-10			
Acacia adsurgens				0.1	230 cm	
Acacia ancistrocarpa	0.1	250 cm		1	260 cm	
Acacia aptaneura	0.1	250 cm	YBI06-15	0.1	230 cm	YBIR06-06
Acacia bivenosa	0.1	350 cm				
Acacia bivenosa (wispy/weeping form)				0.1	260 cm	
Acacia citrinoviridis	0.1	180 cm	YBI06-04	0.1	210 cm	
Acacia dictyophleba	0.1	250 cm	YSW6-02=	0.1	50 cm	
Acacia hilliana	0.1	90 cm		0.1	40 cm	
Acacia inaequilatera	0.1	350 cm		2	300 cm	
Acacia pruinocarpa	1	250 cm		1	320 cm	
Acacia trudgeniana	0.1	130 cm	YBI06-16			
Acacia tumida var. pilbarensis	0.1	50 cm	YBI06-22			
Anthobolus leptomerioides	0.1	90 cm	YBI06-21	0.1	90 cm	
Aristida contorta				0.1	30 cm	
Aristida holathera var. holathera	0.1	30 cm		0.1	40 cm	
Atalaya hemiglauca				0.1	200 cm	
Boerhavia coccinea				0.1	30 cm	
Cenchrus ciliaris	0.1	30 cm		1	80 cm	
Cenchrus setiger				1	100 cm	
Corchorus sp.	0.1	70 cm	YBI06-06			
Corchorus tectus	0.1	30 cm	YBI06-11	0.1	40 cm	
Cymbopogon ambiguus	0.1	60 cm	YBI06-09			
Duperreya commixta				0.1	40 cm	
Eragrostis eriopoda	0.1	35 cm	YBI06-05	0.1	45 cm	
Eremophila forrestii subsp. forrestii	0.1	90 cm		0.1	80 cm	
Eriachne aristidea	0.1	25 cm				
Euphorbia australis var. australis				0.1	15 cm	YBIR06-03
Euphorbia australis var. erythrantha	0.1	40 cm	YBI06-19			
Euphorbia biconvexa				0.1	45 cm	YBIR06-02
Euphorbia tannensis subsp. eremophila				0.1	30 cm	YBIR06-01
Evolvulus alsinoides var. decumbens				0.1	20 cm	
Evolvulus alsinoides var. villosicalyx	0.1	30 cm				
Gomphrena affinis subsp. pilbarensis				0.1	20 cm	
Gomphrena cunninghamii				0.1	15 cm	
Goodenia stobbsiana	0.1	30 cm				
Gossypium australe	0.1	30 cm		0.1	40 cm	
Gossypium robinsonii				0.1	190 cm	
Hakea lorea subsp. lorea	0.1	40 cm	YBI06-07	0.1	260 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Hibiscus burtonii				0.1	50 cm	
Hibiscus sturtii var. platychlamys	0.1	90 cm	YBI06-20	0.1	70 cm	
Hybanthus aurantiacus				0.1	40 cm	
Maireana villosa				0.1	50 cm	YBIR06-07
Paraneurachne muelleri	0.1	50 cm		0.1	40 cm	
Paspalidium clementii				0.1	25 cm	YBIR06-05
Perotis rara	0.1	4 cm		0.1	20 cm	
Polycarpaea longiflora	0.1	30 cm				
Polygala glaucifolia				0.1	6 cm	YBIR06-04
Pterocaulon sphacelatum	0.1	40 cm				
Ptilotus astrolasius	0.1	60 cm		0.1	40 cm	
Ptilotus obovatus var. obovatus				0.1	80 cm	
Rhagodia eremaea	0.1	140 cm	YBI3-04=			
Senna artemisioides subsp. helmsii	0.1	35 cm	YBI06-13	0.1	100 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	50 cm	YBI06-03	0.5	90 cm	
Senna glutinosa subsp. glutinosa x S. stricta	0.1	140 cm	YBI06-12	0.1	160 cm	
Senna notabilis				0.1	10 cm	
Sida cardiophylla				0.1	90 cm	
Sida echinocarpa	0.1	35 cm	YBI06-08	0.1	90 cm	
Sida fibulifera				0.1	30 cm	YBIR06-08
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	25 cm	YBI06-14	0.1	25 cm	
Solanum lasiophyllum				0.1	80 cm	
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.1	60 cm	YBI06-18			
Themeda triandra	0.1	120 cm		0.1	90 cm	
Tribulopis angustifolia				0.1		
Tribulus macrocarpus				0.1	20 cm	
Triodia basedowii	65	40 cm	YBI06-01	40	35 cm	
Triodia pungens	0.1	70 cm	YBI06-02	1	50 cm	
Triodia wiseana	0.1	40 cm	YBI06-17	0.1	40 cm	

YBI06 Phase 1

YBI06 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI07

Described by Phase 1: RW/PH Phase 2: PLSV Date Phase 1: 15-Jun-07 Phase 2: 18-Mar-14

Type Resampled quadrat 50 x 50 m

Location 17.2 km SSW of Marillana, 76.1 km NNW of Newman and 79.9 km SE of Auski Roadhouse.

Central Coordinate 740286 mE, 7479541 mN.

Habitat Broad plain surrounded by low hills.

Soil Dark reddish brown fine sandy loam.

Rock Type Ironstone.

Vegetation Phase 1: *Acacia ancistrocarpa*, *A. pachyacra*, *Indigofera georgei* shrubland over *Senna artemisioides* subsp. *oligophylla* (thinly sericeous form MET 15,035) scattered low shrubs over *Triodia basedowii* hummock grassland with *Aristida holathera* var. *holathera*, *Paraneurachne muelleri*, *Eriachne aristidea* open tussock grassland.
Phase 2: *Acacia ancistrocarpa* (*A. pachyacra, A. tumida* var. *pilbarensis*) tall open shrubland over *Solanum elatius* open shrubland over *Senna artemisioides* subsp. *oligophylla*, *Bonamia erecta* low open shrubland over *Triodia basedowii* hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Very Good (**Cenchrus ciliaris*).

Fire Age Phase 1: Burnt 3-5 years ago Phase 2: Not recorded.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	30 cm	YBI07-13	0.1	60 cm	YBIR07-06
Abutilon otocarpum				0.1	40 cm	
Acacia adsurgens				0.1	170 cm	
Acacia ancistrocarpa	15	200 cm		6	240 cm	
Acacia dictyophleba	0.1	160 cm				
Acacia pachyacra	15	170 cm	YBI07-17	2	220 cm	
Acacia pruinocarpa	0.1	40 cm				
Acacia tumida var. pilbarensis	0.1	200 cm	YBI07-21	0.5	280 cm	
Anthobolus leptomerioides				0.1	190 cm	
Aristida contorta	0.1	15 cm		0.1	30 cm	
Aristida holathera var. holathera	10	30 cm		0.1	40 cm	
Bonamia erecta	0.1	40 cm	YBI07-07	1	40 cm	
Cenchrus ciliaris				0.1	60 cm	
Cleome viscosa	0.1	40 cm		0.1	60 cm	
Corchorus tectus	0.1	50 cm	YBI07-06	0.1	45 cm	
Cucumis variabilis	0.1	250 cm				
Cullen lachnostachys	0.1	25 cm	YBI07-02			
Cymbopogon ambiguus	0.1	160 cm	YBI07-04			
Cymbopogon obtectus				0.1	75 cm	
Dicrastylis cordifolia	0.1	40 cm	YBI07-15	0.1	45 cm	
Enneapogon polyphyllus				0.1	30 cm	
Eragrostis eriopoda	0.1	45 cm	YBI07-18	0.1	45 cm	
Eremophila forrestii subsp. forrestii	0.1	40 cm	YBI07-08	0.1	100 cm	
Eremophila longifolia	0.1	100 cm		0.1	210 cm	
Eriachne aristidea	1	30 cm	YBI07-09	0.1	25 cm	
Euphorbia australis var. erythrantha	0.1	20 cm	YBI07-20			
Euphorbia australis var. hispidula				0.1	15 cm	YBIR07-04
Euphorbia australis var. subtomentosa				0.1	15 cm	YBIR07-03
Euphorbia boophthona				0.1	20 cm	
Gomphrena affinis subsp. pilbarensis				0.1	30 cm	
Gomphrena cunninghamii				0.1	15 cm	
Goodenia microptera				0.1	25 cm	
Grevillea wickhamii subsp. hispidula	0.1	150 cm		0.1	210 cm	YBIR07-05
Hakea chordophylla	0.1	210 cm		0.1	190 cm	
Hakea lorea subsp. lorea	0.1	200 cm		0.1	240 cm	
Hibiscus burtonii	0.1	100 cm	YBI07-16			
Hibiscus sturtii var. platychlamys	0.1	100 cm	YBI07-05	0.1	50 cm	
Indigofera georgei	2	150 cm	YBI07-10	0.1	70 cm	
Mollugo molluginea				0.1	25 cm	
Paraneurachne muelleri	7	40 cm		0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Perotis rara				0.1	20 cm	
Petalostylis cassioides				0.1	110 cm	
Petalostylis labicheoides	0.1	160 cm				
Pterocaulon sphacelatum	0.1	30 cm				
Ptilotus astrolasius				0.1	40 cm	
Ptilotus obovatus var. obovatus	0.1	100 cm	YBI07-01	0.1	50 cm	
Scaevola parvifolia subsp. pilbarae	0.1	25 cm		0.1	30 cm	
Senna artemisioides subsp. helmsii	0.1	150 cm	YBI07-19	0.1	70 cm	
Senna artemisioides subsp. oligophylla				4	90 cm	YBIR07-01
Senna artemisioides subsp. oligophylla (thinly sericeous form MET 15,035)	1	50 cm	YBI07-12			
Sida cardiophylla	0.1	40 cm	YBI07-14	0.1	55 cm	
Solanum elatius	0.1	170 cm		2	190 cm	YBIR07-02
Solanum lasiophyllum	0.1	40 cm	YBI07-11	0.1	70 cm	
Tribulus macrocarpus				0.1	25 cm	
Tribulus platypterus				0.1	30 cm	BILPL-35=
Trichodesma zeylanicum var. zeylanicum	0.1	100 cm		0.1	30 cm	
Triodia basedowii	35	40 cm	YBI07-03	35	45 cm	
Yakirra australiensis var. australiensis				0.1	25 cm	

YBI07 Phase 1

YBI07 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI08

Described by Phase 1: B/RO Phase 2: CASW Date Phase 1: 16-Jun-07 Phase 2: 16-Mar-14

Type Quadrat 50 x 50 m

Location 16.8 km SSW of Marillana, 77 km NNW of Newman and 79.1 km SE of Auski Roadhouse.

Central Coordinate 739883 mE, 7480259 mN.

Habitat Floodplain fringing river (eastern side of Weeli Wolli Creek).

Soil 2.5YR 3/3 dark reddish brown sandy loam.

Rock Type Ironstone cobbles (1%), pebbles (1%), and gravel (1%).

Vegetation Phase 1: *Acacia citrinoviridis, A. pruinocarpa* low open woodland over *Acacia aptaneura* scattered shrubs over *Senna notabilis* low open shrubland over **Cenchrus ciliaris*, (**C. setiger, Eragrostis eriopoda*) open tussock grassland with *Triodia pungens* open hummock grassland.
Phase 2: *Acacia citrinoviridis, A. pruinocarpa*, *A. ayersiana, Corymbia hamersleyana*, *Atalaya hemiglauca* low woodland over *Triodia pungens* very open hummock grassland with **Cenchrus ciliaris, *C. setiger* open tussock grassland.

Veg Condition Phase 1: Very Poor; presence of weeds (**Cenchrus ciliaris*). Phase 2: Poor (weeds and cattle scats).

Fire Age Phase 1: Not recorded. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum	0.1	40 cm	YBI08-07			
Abutilon otocarpum	0.1	35 cm		0.1	30 cm	
Abutilon sp. Pilbara (W.R. Barker 2025)	0.1	40 cm		0.1	60 cm	YBIR08-06, YBIR08-17, YBIR08-26
Acacia aptaneura	1.5	120 cm	YBI08-02	0.1	600 cm	YBIR08-01
Acacia ayersiana	0.1	500 cm	YBI08-01	4	600 cm	YBIR08-02
Acacia citrinoviridis	3	600 cm		16	800 cm	
Acacia inaequilatera	0.1	40 cm		0.1	130 cm	
Acacia pruinocarpa	1	600 cm		7	800 cm	
Acacia pyrifolia var. pyrifolia	0.1	100 cm		0.1	120 cm	YBIR08-05
Acacia sclerosperma subsp. sclerosperma				0.1	170 cm	
Amyema hilliana	0.1	400 cm	YBI08-13	0.1		YBIR08-25
Aristida contorta	0.1	20 cm		0.1	30 cm	
Aristida holathera var. holathera	0.1	20 cm				
Aristida inaequiglumis	0.1	100 cm	YBI08-10			
Aristida pruinosa				0.1	120 cm	YBIR08-14
Atalaya hemiglauca	0.1	150 cm		0.5	600 cm	
Boerhavia coccinea	0.1	30 cm	YBI08-21	0.1	5 cm	YBIR08-13
Bonamia erecta	0.1	30 cm		0.1	40 cm	
Cenchrus ciliaris	35	40 cm		15	45 cm	
Cenchrus setiger	1.5	40 cm		10	45 cm	
Chrysopogon fallax				0.1	100 cm	
Cleome viscosa	0.1	20 cm		0.1	35 cm	
Corchorus sidoides subsp. sidoides	0.1	50 cm	YBI08-09	0.1	45 cm	BIL18-21=
Corymbia hamersleyana	0.1	800 cm		1	700 cm	
Crotalaria medicaginea var. neglecta	0.1	20 cm				
Dicrastylis cordifolia	0.1	50 cm	YBI08-19	0.1	50 cm	
Duperreya commixta	0.1	50 cm		0.1	20 cm	
Enneapogon caerulescens	0.1	15 cm		0.1	25 cm	YBIR08-15
Enneapogon polyphyllus	0.1	25 cm		0.1	20 cm	
Eragrostis cumingii	0.1	10 cm				
Eragrostis eriopoda	2	30 cm	YBI08-03	0.1	40 cm	
Eremophila forrestii subsp. forrestii	0.1	30 cm	YBI08-15			
Eriachne aristidea	0.1	15 cm				
Euphorbia australis var. subtomentosa	0.1	10 cm	YBI08-17	0.1	18 cm	YBIR08-21
Euphorbia trigonosperma				0.1	40 cm	YBIR08-10
Evolvulus alsinoides var. decumbens				0.1	10 cm	
Evolvulus alsinoides var. villosicalyx	0.1	30 cm		0.1	25 cm	
Gossypium robinsonii	0.1	180 cm				
Grevillea wickhamii subsp. hispidula	0.1	100 cm				

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Hakea lorea subsp. lorea	0.1	250 cm		0.1	400 cm	
Heliotropium inexplicitum				0.1	15 cm	YBIR08-19
Hibiscus sturtii var. platychlamys	0.1	25 cm	YBI08-06	0.1	40 cm	YBIR08-07, YBIR08-12
Maireana planifolia	0.1	8 cm	YBI08-20	0.1	50 cm	
Malvastrum americanum	0.1	30 cm				
Melhania oblongifolia				0.1	20 cm	
Paraneurachne muelleri	0.1	70 cm				
Paspalidium rarum				0.1	10 cm	YBIR08-18
Petalostylis cassioides	0.1	25 cm		0.1	250 cm	
Polymeria ambigua	0.1	12 cm	YBI08-14	0.1	5 cm	YBIR08-09
Pterocaulon sphacelatum	0.1	30 cm				
Ptilotus astrolasius				0.1	35 cm	
Ptilotus nobilis subsp. nobilis	0.1	30 cm		0.1	3 cm	
Ptilotus obovatus var. obovatus	0.1	30 cm		0.1	50 cm	
Rhagodia eremaea	0.1	80 cm		0.1	35 cm	
Rhynchosia minima	0.1	30 cm		0.1	60 cm	
Salsola australis	0.1	20 cm				
Sclerolaena cornishiana	0.1	50 cm	YBI08-11	0.1	20 cm	YBIR08-16
Senna artemisioides subsp. helmsii	0.1	40 cm	YBI08-18	0.1	40 cm	
Senna artemisioides subsp. oligophylla				0.1	60 cm	YBIR08-08
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	60 cm	YBI08-05			
Senna notabilis	2	40 cm				
Sida cardiophylla	0.1	45 cm	YBI08-12	0.1	60 cm	YBIR08-24
Sida echinocarpa	0.1	40 cm	YBI08-08	0.1	50 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	30 cm	YBI08-04	0.1	30 cm	YBIR08-04
Solanum lasiophyllum	0.1	15 cm		0.1	35 cm	
Sporobolus australasicus				0.1	10 cm	
Stylobasium spathulatum	0.1	60 cm		0.1	220 cm	
Themeda triandra	0.1	100 cm		0.1	80 cm	
Tribulopis angustifolia				0.1		YBIR08-20
Tribulus macrocarpus				0.1	35 cm	YBIR08-23
Triodia longiceps				0.1	60 cm	YBIR08-11
Triodia pungens	15	30 cm	YBI08-22	6	45 cm	YBIR08-03
Triumfetta clementii	0.1	20 cm	YBI08-16	0.1	60 cm	YBIR08-22

YBI08 Phase 1 (no photo)

YBI08 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI09

Described by Phase 1: RB/B Phase 2: PLSV Date Phase 1: 15-Jun-07 Phase 2: 20-Mar-14

Type Resampled quadrat 50 x 50 m

Location 17.6 km SSW of Marillana, 76.8 km NNW of Newman and 78.9 km SE of Auski Roadhouse.

Central Coordinate 739242 mE, 7479676 mN.

Habitat Flat alluvial plain; adjacent to river floodplain (eastern side of Weeli Wolli Creek).

Soil Dark reddish brown fine sandy loam.

Rock Type Ironstone cobbles (5%), and gravel (5%).

Vegetation Phase 1: *Corymbia hamersleyana* low open woodland over *Acacia sclerosperma* subsp. *sclerosperma* tall open shrubland over *Senna artemisioides* subsp. *oligophylla* (thinly sericeous form MET 15,035) low scattered shrubs over *Triodia basedowii*, (*T. pungens*) hummock grassland with *Aristida holathera* var. *holathera, Eragrostis eriopoda, *Cenchrus ciliaris* open tussock grassland. Phase 2: *Corymbia hamersleyana* low open woodland over *Acacia sclerosperma* subsp. *sclerosperma*, (*A. inaequilatera, A. aptaneura* x, *Hakea lorea* subsp. *lorea*) tall open shrubland over *Eremophila longiflora* scattered shrubs over *Senna artemisioides* subsp. *oligophylla*, *Ptilotus obovatus* scattered low shrubs over *Triodia basedowii* (*T. pungens*) open hummock grassland and **Cenchrus ciliaris* very open tussock grassland.

Veg Condition Phase 1: Good; presence of weeds (**Cenchrus ciliaris, *C. setiger, *Malvastrum americanum*). Phase 2: Good (**Cenchrus ciliaris, *Bidens bipinnata*).

Fire Age Phase 1: No sign of recent fire. Phase 2: Very long unburnt.

Notes Phase 1: Higher percentage of *Corymbia hamersleyana* in quadrat than in general vegetation unit, where it is typically scattered (to 2% cover).

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. fraseri	0.1	40 cm	YBI09-25	0.1	40 cm	
Abutilon lepidum	0.1	35 cm	YBI09-26	0.1	70 cm	YBIR09-07
Acacia aptaneura x				0.5	400 cm	YBIR09-08
Acacia citrinoviridis	0.1	160 cm	YBI09-21	0.1	230 cm	
Acacia dictyophleba	0.1	110 cm	YSW6-02=	0.1	230 cm	
Acacia inaequilatera	0.1	500 cm		1	230 cm	
Acacia pachyacra	0.1	40 cm	YBI09-12	0.1	130 cm	
Acacia pruinocarpa	0.1	120 cm		0.1	230 cm	
Acacia sclerosperma hybrid	0.1	180 cm	YBI09-17	0.1	180 cm	
Acacia sclerosperma subsp. sclerosperma	3.5	300 cm	YBI09-01	4	350 cm	
Acacia trudgeniana	0.1	40 cm	YBI09-16			
Acrachne racemosa				0.1	25 cm	
Amyema hilliana				0.1	190 cm	YBIR09-05
Aristida contorta	0.1	30 cm		0.1	30 cm	
Aristida holathera var. holathera	8.5	30 cm		0.1	40 cm	
Aristida inaequiglumis	0.1	45 cm	YBI09-09			
Aristida pruinosa				0.1	90 cm	YBIR09-03
Bidens bipinnata				0.1	40 cm	
Boerhavia coccinea				0.1	30 cm	
Bulbostylis barbata				0.1	15 cm	
Cenchrus ciliaris	1.5	40 cm		3	60 cm	
Cenchrus setiger	0.1	35 cm	YBI3-01=	0.1	80 cm	
Cleome viscosa	0.1	70 cm		0.1	25 cm	
Corchorus sidoides subsp. sidoides				0.1	45 cm	YBIR09-04
Corchorus tectus	0.1	20 cm	YBI09-14			
Corymbia hamersleyana	4.5	700 cm		4	700 cm	
Cymbopogon obtectus	0.1	70 cm		0.1	120 cm	
Dactyloctenium radulans				0.1	20 cm	
Dicrastylis cordifolia	0.1	45 cm	YBIB1=			
Duperreya commixta	0.1	190 cm	YSW9-06=	0.1	100 cm	
Enchylaena tomentosa var. tomentosa	0.1	20 cm	YBI09-27	0.1	80 cm	
Enneapogon caerulescens	0.1	30 cm		0.1	30 cm	
Enneapogon polyphyllus	0.1	20 cm		0.1	35 cm	
Eragrostis eriopoda	6	30 cm	YBI09-04	0.1	40 cm	
Eremophila longifolia	0.1	190 cm		0.5	190 cm	
Eriachne aristidea	0.1	35 cm		0.1	40 cm	
Eriachne pulchella				0.1	10 cm	
Euphorbia australis var. subtomentosa	0.1	3 cm	YBI09-23	0.1	5 cm	YBIR09-11

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Euphorbia tannensis subsp. eremophila				0.1	40 cm	
Evolvulus alsinoides var. decumbens	0.1	15 cm	YBI09-22	0.1	25 cm	
Evolvulus alsinoides var. villosicalyx	0.1	30 cm	YBI09-24	0.1	25 cm	
Gossypium australe	0.1	90 cm		0.1	80 cm	
Hakea lorea subsp. lorea	0.1	500 cm	YBI09-20	0.5	400 cm	
Hibiscus burtonii	0.1	90 cm	YBI09-18			
Hibiscus sturtii var. platychlamys	0.1	45 cm	YBI09-15	0.1	35 cm	
Maireana villosa	0.1	30 cm	YBI09-11	0.1	45 cm	
Malvastrum americanum	0.1	45 cm				
Melhania oblongifolia				0.1	40 cm	
Paraneurachne muelleri	0.1	45 cm		0.1	35 cm	
Paspalidium rarum				0.1	30 cm	YBIR09-06
Perotis rara	0.1	4 cm		0.1	15 cm	
Polycarpaea corymbosa var. corymbosa				0.1	20 cm	
Polycarpaea longiflora	0.1	30 cm				
Pterocaulon sphacelatum	0.1	20 cm	YSW6-13=			
Ptilotus astrolasius	0.1	40 cm		0.1	35 cm	
Ptilotus nobilis subsp. nobilis	0.1	80 cm		0.1	40 cm	
Ptilotus obovatus var. obovatus	0.1	60 cm	YBI09-13	0.5	70 cm	
Rhagodia eremaea	0.1	160 cm	YBI09-03	0.1	100 cm	
Rhyncharrhena linearis				0.1	45 cm	
Rhynchosia minima	0.1	30 cm		0.1	35 cm	
Sclerolaena cornishiana	0.1	20 cm	YBI09-07, YBI09-27B	0.1	40 cm	
Senna artemisioides subsp. helmsii	0.1	70 cm		0.1	80 cm	
Senna artemisioides subsp. oligophylla				1	90 cm	YBIR09-02
Senna artemisioides subsp. oligophylla (thinly sericeous form MET 15,035)	1.5	60 cm	YBI09-10	0.1	70 cm	YBIR09-10
Setaria dielsii				0.1	25 cm	
Setaria verticillata				0.1	30 cm	
Sida echinocarpa				0.1	90 cm	
Sida fibulifera	0.1	20 cm	YBI09-08			
Sida sp. verrucose glands (F.H. Mollemans 2423)				0.1	25 cm	
Solanum lasiophyllum	0.1	500 cm	YBI09-06	0.1	50 cm	
Sporobolus australasicus				0.1	10 cm	
Themeda triandra	0.1	80 cm				
Tribulus macrocarpus				0.1	10 cm	
Trichodesma zeylanicum var. zeylanicum				0.1	10 cm	
Triodia basedowii	32.5	40 cm	YBI09-02	25	40 cm	
Triodia pungens	1.5	60 cm	YBI09-05	2	50 cm	YBIR09-01
Triraphis mollis	0.1	15 cm	YBI09-19			
Urochloa subquadripara				0.1	30 cm	YBIR09-09

YBI09 Phase 1

YBI09 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2		YBI10
Described by	Phase 1: RW/PH Phase 2: CASW	Phase 1: 16-Jun-07 Phase 2: 15-Mar-14
Type	Quadrat 50 x 50 m	
Location	21.2 km SW of Marillana, 77 km SE of Auski Roadhouse and 77.2 km NW of Newman.	
Central Coordinate	735461 mE, 7477797 mN.	
Habitat	Broad colluvial floodplain of river (Marillana Creek).	
Soil	2.5YR 3/3 dark reddish brown loamy sand.	
Rock Type	Ironstone cobbles (2%), pebbles (2%), and gravel (1%).	
Vegetation	Phase 1: *Acacia pruinocarpa*, (*A. citrinoviridis*) low open forest over *Acacia sclerosperma* subsp. *sclerosperma*, (*Atalaya hemiglauca*) tall open scrub over *Triodia pungens* open hummock grassland with **Cenchrus ciliaris* scattered tussock grasses. Phase 2: *Acacia pruinocarpa, A. citrinoviridis*, *A. sclerosperma* subsp. *sclerosperma*, *Atalaya hemiglauca* open scrub over *Triodia pungens* very open hummock grassland and **Cenchrus ciliaris, *C. setiger* open tussock grassland.	
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris, *Malvastrum americanum*). Phase 2: Poor (**Cenchrus* spp., **Setaria verticillata, *Tribulus terrestris*)	
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon fraseri subsp. fraseri	0.1	25 cm	YBI10-14	0.1	50 cm	YBIR10-09
Abutilon otocarpum	0.1	20 cm	YBI10-16	0.1	50 cm	
Acacia citrinoviridis	3	1000 cm		12	650 cm	
Acacia coriacea subsp. pendens	0.1	350 cm		0.1	170 cm	
Acacia dictyophleba	0.1	170 cm		0.1	180 cm	
Acacia pruinocarpa	30	800 cm		30	650 cm	
Acacia sclerosperma subsp. sclerosperma	35	210 cm	YBI10-15	6	500 cm	
Aristida holathera var. holathera	0.1	40 cm		0.1	45 cm	
Atalaya hemiglauca	2	500 cm		3	600 cm	
Bidens bipinnata				0.1	25 cm	
Boerhavia coccinea				0.1	10 cm	YBIR10-19
Cenchrus ciliaris	1	30 cm		25	45 cm	
Cenchrus setiger				3	60 cm	
Cleome viscosa	0.1	45 cm		0.1	50 cm	
Corchorus crozophorifolius				0.1	50 cm	YBIR10-16
Corchorus tridens				0.1	10 cm	YBIR10-06
Duperreya commixta	0.1	200 cm		0.1	400 cm	
Dysphania melanocarpa forma melanocarpa				0.1	10 cm	YBIR10-14
Enchylaena tomentosa var. tomentosa	0.1	30 cm	YBI10-13	0.1	40 cm	YBIR10-08
Eragrostis cumingii	0.1	10 cm	YBI10-08			
Eragrostis eriopoda	0.1	30 cm	YBI10-09	0.1	40 cm	
Euphorbia tannensis subsp. eremophila				0.1	45 cm	YBIR10-17
Euphorbia trigonosperma				0.1	20 cm	YBIR10-05
Evolvulus alsinoides var. decumbens				0.1	40 cm	
Evolvulus alsinoides var. villosicalyx	0.1	20 cm		0.1	20 cm	
Glycine canescens	0.1	60 cm	YBI10-01			
Hakea lorea subsp. lorea	0.1	450 cm				
Indigofera colutea				0.1	10 cm	YBIR10-20
Jasminum didymum subsp. lineare				0.1	150 cm	
Malvastrum americanum	0.1	30 cm				
Melhania oblongifolia				0.1	30 cm	
Perotis rara				0.1	10 cm	
Pterocaulon sphacelatum	0.1	35 cm				
Rhagodia eremaea	0.1	160 cm		0.1	140 cm	
Salsola australis	0.1	50 cm		0.1	25 cm	
Santalum lanceolatum	0.1	50 cm	YBI10-06			
Sclerolaena cornishiana	0.1	30 cm	YBI10-12			
Senna artemisioides subsp. helmsii	0.1	200 cm	YBI10-07	0.1	50 cm	
Senna glutinosa subsp. glutinosa	0.1	150 cm	YBI10-03			
Senna glutinosa subsp. glutinosa x S. stricta				0.1	160 cm	YBIR10-07

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Setaria dielsii				0.1	70 cm	YBIR10-15
Setaria verticillata	0.1	100 cm		0.1	30 cm	
Sida fibulifera	0.1	10 cm	YBI10-05	0.1	20 cm	YBIR10-02, YBIR10-18
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	15 cm	YBI10-04, YBI10-02			
Solanum horridum	0.1	20 cm	YBI10-10			
Solanum sp.	0.1	30 cm	YBI10-11			
Trianthema pilosum				0.1	10 cm	
Tribulus macrocarpus				0.1		
Tribulus terrestris				0.1	10 cm	YBIR10-12
Triodia basedowii				0.1	35 cm	
Triodia longiceps	0.1	50 cm		0.1	35 cm	YBIR10-04
Triodia pungens	17.5	50 cm		5	40 cm	YBIR10-01
Triraphis mollis				0.1	40 cm	YBIR10-11
Urochloa piligera				0.1	15 cm	YBIR10-03

YBI10 Phase 1

YBI10 Phase 2 (no photo)

Yandi Billiards & Junction SW/Yandi Billiards Level 2 Site YBI11

Described by	Phase 1: RB/RO; Phase 2:RO/PC; Phase 3: PLSW.
Date	Phase 1:15-Jun-07; Phase 2:03-Aug-08 ;Phase 3: 15-Mar-14.
Type	Quadrat 50 x 50 m
Location	21.1 km SSW of Marillana, 76.3 km NW of Newman and 78.1 km SE of Auski Roadhouse.
Central Coordinate	736437 mE, 7477279 mN.
Habitat	Gently sloping alluvial plain between river (Weeli Wolli Creek) and drainage area to the east; sloping to the west.
Soil	Dark reddish-brown fine sandy clay-loam; alluvial.
Rock Type	Calcareous with small amount of ironstone pebbles (10%).
Vegetation	Phase 1: *Acacia pruinocarpa* low open woodland over *Acacia citrinoviridis*, *A. inaequilatera*, *A. sclerosperma* subsp. *sclerosperma* tall open shrubland over *Senna artemisioides* subsp. *oligophylla* open shrubland over *Triodia longiceps*, (*T. basedowii*) hummock grassland with **Cenchrus ciliaris*, *Aristida holathera* var. *holathera*, *Enneapogon caerulescens*, *Eragrostis eriopoda* very open tussock grassland over *Rhynchosia minima* scattered herbs. Phase 2: *Acacia pruinocarpa* low open woodland over *Acacia citrinoviridis*, *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* tall open shrubland over *Senna artemisioides* subsp. *oligophylla* open shrubland over *Triodia longiceps*, (*T. basedowii, T. wiseana*) hummock grassland with **Cenchrus ciliaris*, *Aristida holathera* var. *holathera*, *Enneapogon caerulescens, Eragrostis eriopoda* very open tussock grassland over *Rhynchosia minima* scattered herbs. Phase 3: *Corymbia hamersleyana* scattered low trees over *Acacia pruinocarpa, A. sclerosperma* subsp. *sclerosperma*, *A. aptaneura, A. citrinoviridis, A. tenuissima* tall shrubland over *Corchorus sidoides* subsp. *sidoides* scattered low shrubs over *Triodia longiceps*, (*T. basedowii*) hummock grassland over **Cenchrus ciliaris, Paraneurachne muelleri, Eragrostis eriopoda* scattered tussock grasses.
Veg Condition	Phase 1/Phase 2: Good; presence of weeds (**Cenchrus ciliaris*). Phase 3: Very Good (**Cenchrus ciliaris*).
Fire Age	Phase 1: No sign of recent fire. Phase 2: Not recorded Phase 3: No sign of recent fire.
Notes	This quadrat was sampled a third time as both Phase 1 and Phase 2 occurred at times considered unfavourable for plant growth.

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon lepidum							0.1	80 cm	YBIR11-08
Abutilon otocarpum	0.1	30 cm		-	-	-	0.1	30 cm	
Abutilon sp. Pilbara (W.R. Barker 2025)							0.1	50 cm	
Acacia aptaneura							1	420 cm	YBIR11-11
Acacia citrinoviridis	1	300 cm	YBI11-13	1	300 cm		1	410 cm	
Acacia coriacea subsp. *pendens*	0.5	300 cm		0.5	300 cm		0.1	430 cm	
Acacia inaequilatera	1	400 cm		1	400 cm		0.1	400 cm	
Acacia pruinocarpa	4	600 cm		4	600 cm		3	570 cm	
Acacia sclerosperma subsp. *sclerosperma*	1	400 cm		1	400 cm		3	400 cm	
Acacia tenuissima	0.1	190 cm	YBI11-12	0.1	190 cm		1	260 cm	
Acrachne racemosa							0.1	30 cm	YBIR11-14
Aristida contorta	0.1	20 cm					0.1	30 cm	
Aristida holathera var. *holathera*	1	40 cm		0.1	40 cm		0.1	40 cm	YBIR11-16
Cenchrus ciliaris	2.5	65 cm		2.5	65 cm		2	60 cm	
Cleome viscosa	0.1	50 cm		0.1	50 cm		0.1	20 cm	
Corchorus crozophorifolius							0.1	50 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*							0.1	40 cm	
Corchorus sidoides subsp. *sidoides*							0.5	70 cm	YBIR11-01
Corchorus tectus	0.5	60 cm	YBI11-08	0.5	60 cm				
Corchorus tridens							0.1	10 cm	
Corymbia hamersleyana	0.5	450 cm		0.5	450 cm		1	550 cm	
Dichanthium sericeum subsp. *humilius*							0.1	20 cm	YBIR11-15
Digitaria ctenantha							0.1	30 cm	
Duperreya commixta	0.5			0.5			0.1	310 cm	
Enneapogon caerulescens	1	25 cm		0.1	25 cm		0.1	40 cm	
Enneapogon polyphyllus	0.1	25 cm							
Enteropogon ramosus	0.1	100 cm	YBI11-16						
Eragrostis eriopoda	1	50 cm		1	50 cm		0.5	30 cm	
Eremophila forrestii subsp. *forrestii*				0.1	120 cm	YBI11-20S	0.1	90 cm	
Eremophila jucunda subsp. *pulcherrima*	0.5	140 cm	YBI11-09	0.1	140 cm	YBI11-22S			
Eremophila longifolia	0.1	200 cm		0.1	200 cm		0.1	245 cm	
Eriachne aristidea	0.1	30 cm				-			
Euphorbia australis var. *subtomentosa*							0.1	15 cm	YBIR11-04
Euphorbia biconvexa							0.1	15 cm	YBIR11-05

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Euphorbia boophthona							0.1	30 cm	
Euphorbia tannensis subsp. *eremophila*							0.1	20 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm					0.1	15 cm	
Goodenia microptera	0.1	30 cm	YBI11-10				0.1	30 cm	
Heliotropium cunninghamii							0.1	30 cm	YBIR11-18
Heliotropium inexplicitum							0.1	20 cm	YBIR11-07
Hibiscus burtonii	0.1	60 cm							
Hibiscus sturtii var. *platychlamys*	0.5	50 cm	YBI11-07	0.5	50 cm		0.1	400 cm	
Indigofera linifolia							0.1	15 cm	
Iseilema dolichotrichum							0.1	20 cm	YBIR11-17
Maireana planifolia				0.1	45 cm	YBI11-19S			
Maireana villosa				0.1	20 cm	YBI11-18S	0.1	5 cm	YBIR11-12
Melhania oblongifolia	0.1	30 cm				-	0.1	40 cm	
Paraneurachne muelleri	0.5	60 cm		0.5	60 cm		0.5	70 cm	
Polycarpaea longiflora	0.1	30 cm				-			
Pterocaulon sphacelatum	0.1	15 cm		0.1	15 cm		0.1	15 cm	
Ptilotus astrolasius	0.5	40 cm		0.5	40 cm		0.1	80 cm	
Ptilotus nobilis subsp. *nobilis*							0.1	10 cm	
Ptilotus obovatus var. *obovatus*	0.1	90 cm				-	0.1	50 cm	
Ptilotus rotundifolius	0.1	40 cm		0.1	40 cm				
Rhagodia eremaea	0.1	190 cm		0.1	190 cm		0.1	210 cm	
Rhynchosia minima	1	80 cm		1	80 cm		0.1	110 cm	
Sclerolaena cornishiana	0.1	30 cm	YBI11-04	0.1	30 cm				
Senna artemisioides subsp. *helmsii*	0.5	125 cm					0.1	70 cm	
Senna artemisioides subsp. *oligophylla*	3	120 cm	YBI11-01	0.5	125 cm		0.1	100 cm	YBIR11-02
Sida arsiniata							0.1	40 cm	
Sida echinocarpa							0.1	60 cm	YBIR11-10
Sida fibulifera	0.1	20 cm	YBI11-05	0.1	20 cm		0.1	30 cm	
Sida cardiophylla	0.1	50 cm	YBI11-11	-	-	-			
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)							0.1	20 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)							0.1	35 cm	
Solanum horridum	0.1	40 cm	YBI11-14						
Solanum lasiophyllum	0.1	15 cm		0.1	15 cm		0.1	45 cm	
Sporobolus australasicus							0.1	15 cm	
Tephrosia supina	0.1	40 cm	YBI11-15				0.1	40 cm	YBIR11-09
Tribulus macrocarpus							0.1	10 cm	
Tribulus terrestris							0.1	10 cm	YBIR11-03
Triodia basedowii	7.5	50 cm	YBI11-03	1	50 cm	YBI11-21S	0.5	60 cm	
Triodia longiceps	62.5	100 cm	YBI11-02	60	500 cm		40	80 cm	
Triodia pungens							0.1	40 cm	YBIR11-13
Triodia wiseana	1	50 cm							
Zygophyllum eichleri				0.1	3 cm	YBI11-17S			

YBl11 Phase 1

YBl11 Phase 2

YBl11 Phase 3

Yandi Billiards Level 2	YBI12
Described by	Phase 1: RB/RO Phase 2: RO/PC Phase 3: PLSV Date Phase 1: 16-Jun-07 Phase 2: 03-Aug-08 Phase 3: 17-Mar-14
Type	Quadrat 50 x 50 m
Location	23.4 km SSW of Marillana, 75.1 km NW of Newman and 78.6 km SE of Auski Roadhouse
Central Coordinate	735518 mE, 7475188 mN.
Habitat	Flat alluvial clay plain, associated with drainage area to the east of Weeli Wolli Creek; plain is bordered by hills to the east.
Soil	Dark reddish brown light clay; alluvial.
Rock Type	Some quartz present (very small amounts); probably ironstone underneath.
Vegetation	Phase 1: *Acacia aptaneura*. (*Acacia catenulata*, *Acacia pruinocarpa*) low open forest over *Eremophila forrestii* subsp. *forrestii, E. lanceolata*, *Pterocaulon sphacelatum, Gossypium australe*, *Senna artemisioides* subsp. *helmsii* low open shrubland over *Aristida contorta, Enneapogon polyphyllus, Aristida inaequiglumis* very open tussock grassland with **Malvastrum americanum*, *Evolvulus alsinoides* var. *villosicalyx* scattered herbs Phase 2: *Acacia* aptaneura, (*Acacia pruinocarpa*) low open forest over *Eremophila lanceolata, E. forrestii* subsp. *forrestii, Pterocaulon sphacelatum, Gossypium australe* low open shrubland over *Aristida contorta, Enneapogon polyphyllus*, *Aristida inaequiglumis* very open tussock grassland over **Malvastrum americanum, Evolvulus alsinoides* var. *villosicalyx* scattered herbs. Phase 3: *Acacia aptaneura, A. pruinocarpa* low open forest over *A. aptaneura x ayersiana* tall open shrubland over *Eremophila forrestii* subsp. *forrestii*, *Senna artemisioides* subsp. *helmsii* (*Gossypium australe*) open shrubland over **Malvastrum americanum*, *Abutilon macrum, A. fraseri* scattered low shrubs over *Themeda triandra, Aristida pruinosa, *Cenchrus ciliaris, *C. setiger, Paspalidium clementii* very open tussock grassland and *Bidens bipinnata* very open herbland.
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris, *Malvastrum americanum*) and signs of cattle (scats and grazing). Phase 2: Good; presence of weeds (**Cenchrus ciliaris, *Malvastrum americanum*) and signs of cattle (scats and grazing). Phase 3: Good (**Bidens bipinnata, *Malvastrum americanum, *Cenchrus* spp, other weeds, cattle scats).
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire. Phase 3: Very long unburnt.
Notes	This quadrat was sampled a third time as both Phase 1 and Phase 2 occurred at times considered unfavourable for plant growth.

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*							0.5	45 cm	
Abutilon lepidum	0.1	75 cm	YBI12-11	0.1	30 cm	YBI12-37S	0.1	40 cm	
Abutilon macrum	0.1	55 cm	YBI12-17	0.1	40 cm	YBI12-32S	0.5	70 cm	
Abutilon otocarpum	0.1	40 cm					0.1	45 cm	
Acacia aptaneura	42.5	1000 cm	YBI12-04	42.5	1000 cm		40	1000 cm	YBIR12-01
Acacia aptaneura x ayersiana							2	300 cm	YBIR12-11
Acacia catenulata	3	650 cm	YBI12-14						
Acacia coriacea subsp. *pendens*	0.1	250 cm	YBI12-24	0.1	350 cm		0.1	400 cm	
Acacia pruinocarpa	2	1000 cm		2	1000 cm		2	800 cm	
Acacia tumida var. *pilbarensis*	0.1	170 cm							
Alternanthera denticulata							0.1	25 cm	YBIR12-16
Alternanthera nana	0.1	20 cm		0.1	25 cm		0.1	15 cm	
Aristida contorta	2	30 cm		2	30 cm		0.1	40 cm	
Aristida holathera var. *holathera*	0.5	50 cm		0.1	50 cm		0.1	35 cm	
Aristida inaequiglumis	1	70 cm	YBI12-01	1	70 cm		0.1	170 cm	
Aristida pruinosa							1	120 cm	YBIR12-12
Aristida sp.	0.5	100 cm	YBI12-06						
Atalaya hemiglauca	0.1	50 cm					0.1	150 cm	
Bidens bipinnata				0.1	30 cm		2	70 cm	
Blumea tenella				0.1	30 cm	YBI12-41S			
Boerhavia coccinea							0.1	40 cm	YBIR12-04
Boerhavia repleta							0.1	25 cm	
Bulbostylis barbata				0.1	12 cm		0.1	10 cm	
Calandrinia ptychosperma				0.1	3 cm	YBI12-42S	0.1	8 cm	YBIR12-02
Cenchrus ciliaris	0.1	65 cm		0.1	65 cm		0.5	80 cm	
Cenchrus setiger							0.5	80 cm	
Chloris pectinata									
Chrysocephalum gilesii							0.1	10 cm	YBIR12-21
Chrysocephalum pterochaetum	0.1	20 cm	YBI12-16						
Chrysopogon fallax	0.1	15 cm					0.1	110 cm	
Cleome viscosa	0.1	70 cm		0.1	70 cm				
Convolvulus clementii	0.1		YBI12-25	0.1		YBI12-31S	0.1	80 cm	YBIR12-06
Corchorus crozophorifolius				0.1	100 cm		0.1	140 cm	
Corchorus sidoides subsp. *sidoides*	0.1	45 cm	YBI12-10				0.1	45 cm	YBIR12-24

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Corchorus tridens							0.1	25 cm	
Corymbia hamersleyana	0.1	160 cm					0.1	500 cm	
Cucumis variabilis	0.5			0.1			0.1	190 cm	
Cullen leucochaites							0.1	70 cm	
Cymbopogon ambiguus	0.1	100 cm	YBI12-27	0.1	60 cm	YBI12-48S	0.1	120 cm	
Cymbopogon obtectus							0.1	80 cm	
Cymbopogon procerus							0.1	140 cm	
Dichanthium sericeum subsp. *humilius*				0.1	25 cm		0.1	40 cm	YBIR12-03
Digitaria brownii	0.1	75 cm	YBI12-18				0.1	20 cm	YBIR12-19
Digitaria ctenantha					0.1	18 cm	0.1	50 cm	
Duperreya commixta	0.5			0.1			0.1	120 cm	
Dysphania melanocarpa forma *melanocarpa*				0.1	20 cm		0.1	25 cm	YBIR12-10
Dysphania rhadinostachya	0.1	6 cm		0.1	6 cm	YBI12-44s			
Enchylaena tomentosa var. *tomentosa*	0.1	125 cm		0.1	125 cm		0.1	80 cm	
Enneapogon lindleyanus	0.1	55 cm	YBI12-09	0.1	55 cm				
Enneapogon polyphyllus	2	40 cm		2	40 cm		0.1	60 cm	
Enneapogon robustissimus	0.1	60 cm	YBI12-28				0.1	100 cm	
Eragrostis cumingii				1	10 cm		0.1	20 cm	
Eremophila forrestii subsp. *forrestii*	8	50 cm	YBI12-02	0.1	50 cm		2	140 cm	
Eremophila lanceolata	3.5	70 cm	YBI12-22	0.1	60 cm	YBI12-29S	0.1	40 cm	
Eremophila longifolia	0.1	100 cm		0.1	220 cm				
Eriachne mucronata (typical form)							0.1	60 cm	YBIR12-14
Eulalia aurea							0.1	110 cm	
Euphorbia biconvexa							0.1	40 cm	YBIR12-09
Evolvulus alsinoides var. *villosicalyx*	1	25 cm		1	25 cm		0.1	25 cm	
Glycine canescens	0.5	Climber		0.1	Climber		0.1	110 cm	
Gomphrena cunninghamii				0.1	10 cm				
Goodenia nuda							0.1	35 cm	YBIR12-22
Goodenia prostrata				0.1	20 cm	YBI12-45S	0.1	10 cm	
Gossypium australe	1.5	65 cm	YBI12-05	1.5	40 cm		0.5	150 cm	
Hakea chordophylla				0.1	65 cm		0.1	140 cm	
Hakea lorea subsp. *lorea*							0.1	60 cm	
Hibiscus sturtii var. *grandiflorus*							0.1	25 cm	YBIR12-01b
Hybanthus aurantiacus				0.1	15 cm		0.1	45 cm	
Iseilema membranaceum				0.1	12 cm	YBI12-38S	0.1	20 cm	YBIR12-07
Maireana planifolia				0.1	40 cm	YBI12-49Sb	0.1	70 cm	
Maireana planifolia x villosa							0.1	40 cm	YBIR12-20
Maireana villosa				0.1	30 cm	YBI12-49S	0.1	45 cm	
Malvastrum americanum	2.5	60 cm		2.5	60 cm		2	50 cm	
Melhania oblongifolia	0.1	20 cm		0.1	20 cm		0.1	30 cm	
Nicotiana occidentalis subsp. *occidentalis*				0.1	35 cm	YBI12-40S			
Nicotiana rosulata				0.1	70 cm	YBI12-33S			
Panicum effusum							0.1	80 cm	
Paraneurachne muelleri	0.1	90 cm					0.1	90 cm	
Paspalidium clementii				0.1	15 cm	YBI12-36S	0.5	25 cm	YBIR12-05
Perotis rara				0.1	10 cm		0.1	15 cm	
Phyllanthus erwinii				0.1	10 cm		0.1	10 cm	
Phyllanthus maderaspatensis							0.1	40 cm	
Pluchea ferdinandi-muelleri	0.1	100 cm	YBI12-07	0.1	100 cm				
Polycarpaea corymbosa var. *corymbosa*							0.1	10 cm	
Portulaca oleracea/intraterranea				0.1	5 cm		0.1	10 cm	YBIR12-17
Psydrax latifolia				0.1	50 cm		0.1	100 cm	
Psydrax suaveolens	0.1	80 cm							
Pterocaulon sphacelatum	2	85 cm	YBI12-03	2	85 cm		0.1	60 cm	
Ptilotus aervoides				0.1	6 cm	YBI12-43S			

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Ptilotus astrolasius				0.1	8 cm				
Ptilotus gaudichaudii subsp. *gaudichaudii*				0.1	20 cm	YBI12-35S	0.1	35 cm	
Ptilotus helipteroides				0.1	10 cm				
Ptilotus nobilis subsp. *nobilis*				0.1	6 cm				
Ptilotus obovatus var. *obovatus*				0.1	25 cm		0.1	70 cm	
Rhagodia eremaea	0.1	70 cm					0.1	100 cm	
Rhynchosia minima	0.1	45 cm					0.1	100 cm	
Salsola australis							0.1	25 cm	
Schizachyrium fragile				0.1	10 cm				
Sclerolaena cornishiana	0.1	35 cm	YBI12-26						
Senna artemisioides subsp. *helmsii*	1.5	55 cm		1.5	55 cm		1	120 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	65 cm	YBI12-20				0.1	70 cm	
Sida fibulifera							0.1	40 cm	YBIR12-23
Sida platycalyx							0.1	10 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	90 cm	YBI12-21				0.1	90 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.5	30 cm	YBI12-15	0.1	50 cm	YBI12-47S	0.1	35 cm	
Sigesbeckia orientalis							0.1	40 cm	YBIR12-08
Solanum elatius	0.5	65 cm	YBI12-13	0.1	65 cm				
Solanum lasiophyllum	0.5	60 cm		0.1	60 cm		0.1	40 cm	
Spermacoce brachystema				0.1	20 cm	YBI12-39S	0.1	20 cm	
Sporobolus australasicus				0.1	10 cm		0.1	20 cm	
Stemodia grossa							0.1	90 cm	
Streptoglossa bubakii	0.1	40 cm	YBI12-23						
Streptoglossa decurrens	0.1	65 cm							
Themeda triandra	0.1	85 cm					3	140 cm	YBIR12-18
Trachymene oleracea subsp. *oleracea*				0.1	75 cm				
Tribulus macrocarpus				0.1	5 cm	YBI12-46S	0.1	25 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	110 cm							
Triodia basedowii	0.1	40 cm	YBI12-12						
Triodia wiseana				0.1	40 cm		0.1	30 cm	
Vachellia farnesiana				0.1	60 cm		0.1	30 cm	
Waltheria indica	0.5	50 cm	<1%.	0.1	50 cm		0.1	80 cm	

YBI12 Phase 1

YBI12 Phase 2

YBI12 Phase 3

Yandi Billiards & Junction SW		YBI13	
Described by	Phase 1: RW/PH Phase 2: JA/RB	Date	Phase 1: 16-Jun-07 Phase 2: 03-Aug-08
Type	Quadrat 50 x 50 m		
Location	21.4 km SSW of Marillana, 76.1 km NW of Newman and 78.2 km SE of Auski Roadhouse.		
Central Coordinate	736342 mE, 7477013 mN.		
Habitat	Gently sloping alluvial plain between river (Weeli Wolli Creek) and drainage area to the east.		
Soil	Red-brown sandy clay.		
Rock Type	Not recorded.		
Vegetation	Phase 1: *Acacia aptaneura*, (*Corymbia hamersleyana*) low open forest over *Senna artemisioides* subsp. *helmsii*, *Eremophila jucunda* subsp. *pulcherrima* open shrubland over *Triodia longiceps* hummock grassland with **Cenchrus ciliaris* very open tussock grassland. Phase 2: *Acacia* apt*aneura*, (*Corymbia hamersleyana*) low open forest over *Senna artemisioides* subsp. *helmsii*, *Eremophila forrestii* subsp. *forrestii* open shrubland over *Triodia longiceps* hummock grassland with **Cenchrus ciliaris* very open tussock grassland.		
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris*) and signs of cattle (scats and grazing). Phase 2: presence of weeds (**Cenchrus ciliaris*) and signs of cattle grazing, track).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire		
Notes	This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	40 cm		-	-	-
Abutilon otocarpum	0.1	15 cm		0.1	15 cm	
Acacia aptaneura	40	750 cm	YBI13-14	40	750 cm	
Acacia citrinoviridis	0.1	150 cm		0.1	300 cm	
Acacia inaequilatera	0.1	160 cm		0.1	160 cm	
Acacia pruinocarpa	0.1	200 cm		0.1	200 cm	
Aristida contorta	0.1	30 cm		0.1	30 cm	
Aristida inaequiglumis				0.1	30 cm	
Aristida sp.				0.1	30 cm	
Cenchrus ciliaris	6	25 cm		6	25 cm	
Cleome viscosa	0.1	30 cm				
Corchorus crozophorifolius	0.1	50 cm		0.1	50 cm	
Corymbia candida	0.1	40 cm	YBI13-15	0.1	40 cm	
Corymbia hamersleyana	1	450 cm		1	450 cm	
Duperreya commixta	0.1	140 cm		0.1	140 cm	
Enchylaena tomentosa var. *tomentosa*	0.1	100 cm		0.1	100 cm	
Enneapogon caerulescens	0.1	30 cm	YBI13-09	0.1	30 cm	
Eragrostis eriopoda	0.1	30 cm	YBI13-11	0.1	30 cm	
Eremophila forrestii subsp. *forrestii*				1	150 cm	YBI13-17S
Eremophila jucunda subsp. *pulcherrima*	1	150 cm	YBI13-17			
Euphorbia tannensis subsp. *eremophila*	0.1	40 cm	YBI13-01	0.1	40 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	15 cm		0.1	15 cm	
Hibiscus burtonii				0.1	60 cm	YBI13-20S
Hibiscus sturtii var. *platychlamys*	0.1	40 cm	YBI13-08	0.1	40 cm	
Maireana planifolia	0.1	100 cm	YBI13-18	0.1	110 cm	YBI13-18S
Malvastrum americanum	0.1	40 cm				
Melhania oblongifolia	0.1	20 cm	YBI13-16	0.1	20 cm	
Paraneurachne muelleri	0.1	30 cm		0.1	30 cm	
Peripleura arida	0.1	30 cm	YBI13-03			
Pterocaulon sphacelatum				0.1	70 cm	YBI13-19S
Ptilotus nobilis subsp. *nobilis*	0.1	25 cm				
Rhynchosia minima	0.1	170 cm		0.1	170 cm	
Sclerolaena cornishiana	0.1	20 cm	YBI13-13	0.1	20 cm	
Senna artemisioides subsp. *helmsii*	1.5	200 cm	YBI13-05	1.5	200 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	150 cm	YBI13-12	0.1	150 cm	
Sida fibulifera	0.1	15 cm	YBI13-10	0.1	15 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	170 cm	YBI13-04			
Solanum horridum				0.1	20 cm	YBI13-21S
Solanum lasiophyllum	0.1	40 cm	YBI13-06	0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Themeda triandra	0.1	100 cm				
Triodia basedowii	0.1	35 cm	YBI13-02			
Triodia longiceps	60	150 cm		60	150 cm	
Triraphis mollis	0.1	35 cm	YBI13-07			
Zygophyllum eichleri				0.1	3 cm	YBI13-22S

YBI13 Phase 1

YBI13 Phase 2 (no photo)

Yandi Billiards & Junction SW YBI14

Described by Phase 1: BB Phase 2: JA/RB Date Phase 1: 16-Jun-07 Phase 2: 03-Aug-08

Type Quadrat 50 x 50 m

Location 22.7 km SSW of Marillana, 75.3 km NW of Newman and 78.5 km SE of Auski Roadhouse.

Central Coordinate 735845 mE, 7475759 mN.

Habitat Broad plain between river (Weeli Wolli Creek) and low hills to the east; plain has very gentle slope to west.

Soil Red-brown loamy sand.

Rock Type Ironstone.

Vegetation Phase 1: *Petalostylis cassioides* scattered tall shrubs over *Senna artemisioides* subsp. *oligophylla* (thinly sericeous form MET 15,035) shrubland over *Solanum sturtianum* scattered low shrubs over *Aristida holathera* var. *holathera*, (*Paraneurachne muelleri*) open tussock grassland with *Triodia basedowii* open hummock grassland.
Phase 2: *Petalostylis cassioides* scattered tall shrubs over *Senna artemisioides* subsp. *oligophylla* (thinly sericeous form MET 15,035) shrubland over *Solanum sturtianum* low scattered shrubland over *Aristida holathera* var. *holathera*, (*Paraneurachne muelleri*) open tussock grassland with *Triodia basedowii* open hummock grassland.

Veg Condition Phase1: Excellent. Phase 2: Very Good; signs of cattle.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Phase 1: Poor seasonal conditions for recording quadrat, annuals were degraded/deteriorated.
Phase 2: Same conditions; very dry; many shrubs have died. This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia citrinoviridis	0.1	230 cm	YBI14-13	0.1	230 cm	
Acacia coriacea subsp. *pendens*	0.1	70 cm				
Acacia dictyophleba	0.1	180 cm				
Acacia pachyacra	0.1	30 cm	YBI14-09	0.1	30 cm	
Acacia pruinocarpa	0.5	300 cm		0.1	500 cm	
Aristida contorta	0.1	30 cm				
Aristida holathera var. *holathera*	22.5	30 cm		22.5	30 cm	
Aristida inaequiglumis	0.1	80 cm	YBI14-05	0.1	80 cm	
Cleome viscosa	0.1	40 cm				
Corchorus sidoides subsp. *vermicularis*	0.1	45 cm	YBI14-03	0.1	45 cm	
Corymbia hamersleyana	0.1	150 cm				
Cymbopogon ambiguus	0.1	90 cm	YBI14-08			
Digitaria brownii	0.1	50 cm	YBI14-11			
Dodonaea coriacea				0.1	35 cm	
Enneapogon polyphyllus	0.1	30 cm				
Eragrostis eriopoda				0.1	30 cm	
Eremophila forrestii subsp. *forrestii*	0.1	90 cm		0.1	100 cm	
Eremophila longifolia	0.1	160 cm				
Eriachne aristidea	0.1	30 cm				
Evolvulus alsinoides var. *villosicalyx*				0.1	15 cm	
Hakea lorea subsp. *lorea*	0.1	180 cm	YBI9-20=	0.1	200 cm	
Hibiscus burtonii	0.1	35 cm	YBI14-02	0.1	35 cm	
Hibiscus sturtii var. *platychlamys*	0.1	40 cm	YBI14-07	0.1	40 cm	
Malvastrum americanum				0.1	2 cm	
Paraneurachne muelleri	1.5	40 cm		1.5	40 cm	
Petalostylis cassioides	1	220 cm	YBI14-06	1	220 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	20 cm	YBI14-10			
Ptilotus astrolasius	0.1	35 cm		0.1	35 cm	
Ptilotus helipteroides	0.1	30 cm	YBI15-23S=			
Ptilotus nobilis subsp. *nobilis*	0.1	80 cm		0.1	80 cm	
Ptilotus obovatus var. *obovatus*				0.1	55 cm	
Sclerolaena cornishiana	0.1	30 cm	YBI14-04	0.1	30 cm	
Senna artemisioides subsp. *helmsii*	0.1	150 cm		0.1	150 cm	
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)	12.5	160 cm	YBI9-10=			
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*				10	40 cm	YBI14-02S
Sida cardiophylla	0.1	35 cm	YBI14-01	0.1	35 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)				0.1	20 cm	YBI14-01S
Solanum elatius	1	50 cm		1	50 cm	
Solanum lasiophyllum	0.1	45 cm	YBI9-06=	0.1	50 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Trichodesma zeylanicum var. *zeylanicum*	0.1	50 cm		0.1	110 cm	
Triodia basedowii	17.5	50 cm	YBl14-12	0.1	50 cm	YBl14-03S

YBl14 Phase 1

YBl14 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI15

Described by	Phase 1: RW/PH Phase 2: JA/RB Phase 3: PLSW Date Phase 1: 17-Jun-07 Phase 2: 03-Aug-08 Phase 3: 16-Mar-14
Type	Quadrat 50 x 50 m
Location	21.1 km SSW of Marillana, 76 km NW of Newman and 78.3 km SE of Auski Roadhouse.
Central Coordinate	736687 mE, 7477149 mN.
Habitat	Drainage area through broad plain, to the east of a river (Weeli Wolli Creek).
Soil	Red-brown sandy clay.
Rock Type	Nil.
Vegetation	Phase 1: *Acacia aptaneura*, *Corymbia candida*, (*A. pruinocarpa*, *Hakea lorea* subsp. *lorea*) low open forest over *Acacia citrinoviridis*, *Atalaya hemiglauca* tall open shrubland over *Eulalia aurea, Enneapogon polyphyllus* very open tussock grassland with **Malvastrum americanum* scattered herbs. Phase 2: *Acacia aptaneura*, *Corymbia candida*, (*A. pruinocarpa, Hakea lorea* subsp. *lorea*) low open forest over *Acacia citrinoviridis, Atalaya hemiglauca* tall open shrubland over *Enneapogon polyphyllus* very open tussock grassland with **Malvastrum americanum* scattered herbs. Phase 3: *Acacia aptaneura,* (*Corymbia candida, Acacia pruinocarpa, A. citrinoviridis, Atalaya hemiglauca, Hakea lorea* subsp. *lorea*) low open forest over *Triodia longiceps* scattered hummock grasses with *Bothriochloa ewartiana *Cenchrus setiger, *C. ciliaris* very open tussock grassland.
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris*, **C. setiger*, **Malvastrum americanum*, **Setaria verticillata*). Phase 2: Good; presence of weeds (**Cenchrus ciliaris, *C. setiger, *Malvastrum americanum, *Setaria verticillata*). Phase 3: Good (**Cenchrus* spp, **Malvastrum americanum, *Bidens bipinnata, *Setaria verticillata*, cattle activity).
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire. Phase 3: No sign of recent fire.
Notes	Phase 2: Extremely dry conditions, many annuals too poor to determine or collect. Phase 3: This quadrat was sampled a third time as both Phase 1 and Phase 2 occurred at times considered unfavourable for plant growth.

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*							0.1	40 cm	
Abutilon lepidum	0.1	25 cm		0.1	25 cm		0.1	40 cm	YBIR15-14
Abutilon macrum	0.1	35 cm	YBI15-11	0.1	35 cm		0.1	40 cm	
Abutilon otocarpum	0.1	4 cm					0.1	20 cm	
Acacia aptaneura	40	800 cm	YBI15-15	40	800 cm		22	800 cm	YBIR15-01
Acacia ayersiana							0.1	210 cm	YBIR15-26
Acacia catenulata	0.1	200 cm	YBI15-03						
Acacia citrinoviridis	2.5	400 cm		2.5	400 cm		2	800 cm	
Acacia coriacea subsp. *pendens*				0.1	90 cm	YBI15-16	0.1	180 cm	
Acacia pruinocarpa	3	800 cm		3	800 cm		3	1000 cm	
Acrachne racemosa							0.1	30 cm	
Alternanthera angustifolia							0.1	10 cm	YBIR15-33
Alternanthera nana	0.1	15 cm	YBI15-20	0.1	6 cm	YBI15-26S	0.1	25 cm	
Aristida contorta	0.1	25 cm		0.1	25 cm		0.1	15 cm	
Aristida holathera var. *holathera*							0.1	40 cm	
Aristida hygrometrica							0.1	40 cm	YBIR15-25
Aristida pruinosa							0.1	70 cm	YBIR15-31
Atalaya hemiglauca	1	500 cm		1	500 cm		1	800 cm	
Bidens bipinnata				0.1	20 cm		0.1	10 cm	
Blumea tenella							0.1	10 cm	YBIR15-22
Boerhavia burbidgeana							0.1	10 cm	YBIR15-06
Boerhavia coccinea				0.1	10 cm	YBI15-31S	0.1	25 cm	
Boerhavia repleta							0.1	5 cm	YBIR15-36
Bothriochloa ewartiana				0.1	130 cm	YBI15-25S	4	60 cm	
Bulbostylis barbata							0.1	10 cm	
Bulbostylis turbinata							0.1	20 cm	YBIR15-38
Calandrinia ptychosperma				0.1	3 cm	YBI15-32S	0.1	5 cm	YBIR15-29
Cenchrus ciliaris	0.1	50 cm		0.1	50 cm		2	60 cm	
Cenchrus setiger	0.1	45 cm		0.1	45 cm		3	60 cm	
Cheilanthes sieberi subsp. *sieberi*	0.1	15 cm							
Chrysopogon fallax	0.1	45 cm		0.1	45 cm		0.1	60 cm	
Cleome viscosa	0.1	40 cm		0.1	40 cm		0.1	60 cm	
Corchorus sidoides subsp. *sidoides*							0.1	30 cm	YBIR15-32
Corchorus tridens				0.1	5 cm	YBI15-37S	0.1	20 cm	
Corymbia candida	30	600 cm	YBI15-04	30	600 cm		11	800 cm	

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Corymbia hamersleyana	0.1	350 cm		0.1	350 cm				
Cucumis variabilis							0.1	10 cm	
Dactyloctenium radulans							0.1	10 cm	
Dichanthium sericeum subsp. *humilius*							0.1	25 cm	YBIR15-16
Digitaria brownii							0.1	50 cm	
Digitaria ctenantha				0.1	5 cm	YBI15-33S	0.1	30 cm	
Duperreya commixta	0.1	200 cm		0.1	200 cm		0.1	600 cm	
Dysphania melanocarpa forma *melanocarpa*				0.1	15 cm	YBI15-38S	0.1	25 cm	YBIR15-28
Dysphania rhadinostachya subsp. *inflata*							0.1	30 cm	YBIR15-08
Enchylaena tomentosa var. *tomentosa*				0.1	150 cm		0.1	100 cm	
Enneapogon polyphyllus	1	10 cm	YBI15-18	1	10 cm		0.1	30 cm	
Enteropogon ramosus							0.1	80 cm	
Eragrostis cumingii				0.1	10 cm		0.1	15 cm	
Eragrostis eriopoda	0.1	30 cm	YBI15-01	0.1	30 cm				
Eragrostis falcata							0.1	15 cm	YBIR15-10
Eragrostis leptocarpa							0.1	20 cm	YBIR15-19
Eragrostis pergracilis							0.1	20 cm	YBIR15-07
Eragrostis tenellula				0.1	20 cm		0.1	25 cm	YBIR15-24
Eragrostis xerophila	0.1	35 cm	YBI15-02				0.1	40 cm	
Eremophila lanceolata	0.1	50 cm	YBI15-09	0.1	50 cm		0.1	40 cm	
Eremophila longifolia	0.1	100 cm		0.1	100 cm				
Eriachne mucronata (typical form)	0.1	40 cm	YBI15-13	0.1	40 cm		0.1	60 cm	YBIR15-17
Eulalia aurea	4	150 cm							
Eriachne pulchella							0.1	15 cm	
Euphorbia trigonosperma							0.1	10 cm	YBIR15-02
Evolvulus alsinoides var. *villosicalyx*	0.1	20 cm		0.1	20 cm		0.1	20 cm	
Glycine canescens	0.1	150 cm	YBI15-19	0.1	5 cm	YBI15-35S	0.1	40 cm	
Goodenia nuda							0.1	25 cm	YBIR15-03
Goodenia prostrata				0.1	3 cm	YBI15-24S	0.1	5 cm	YBIR15-04
Goodenia triodiophila				0.1	25 cm	YBI15-29S			
Gossypium australe							0.1	40 cm	
Hakea lorea subsp. lorea	2	700 cm		2	700 cm		1	690 cm	
Heliotropium cunninghamii							0.1	20 cm	YBIR15-34
Hibiscus sturtii var. *campylochlamys*	0.1	20 cm	YBI15-21	0.1	20 cm				
Hibiscus sturtii var. *grandiflorus*				0.1	20 cm	YBI15-30S			
Indigofera linifolia							0.1	20 cm	
Iseilema membranaceum				0.1	800 cm	YBI15-34S	0.1	10 cm	YBIR15-05
Maireana planifolia	0.1	40 cm	YBI15-17	0.1	40 cm		0.1	20 cm	
Maireana villosa							0.1	60 cm	YBIR15-23
Malvastrum americanum	1	40 cm		1	40 cm		0.1	15 cm	
Melhania oblongifolia	0.1	20 cm	YBI15-08	0.1	20 cm		0.1	15 cm	
Nicotiana simulans				0.1	7 cm	YBI15-36S			
Paspalidium clementii							0.1	15 cm	YBIR15-18
Perotis rara				0.1	5 cm		0.1	10 cm	
Phyllanthus erwinii							0.1	10 cm	YBIR15-20
Phyllanthus maderaspatensis							0.1	30 cm	
Pluchea dunlopii							0.1	15 cm	YBIR15-11
Polycarpaea corymbosa var. *corymbosa*							0.1	10 cm	
Portulaca filifolia							0.1	10 cm	YBIR15-12
Portulaca oleracea/intraterranea				0.1	2 cm		0.1	5 cm	YBIR15-21
Portulaca pilosa				0.1	8 cm	YBI15-28S			
Pterocaulon sphacelatum	0.1	60 cm					0.1	40 cm	
Ptilotus gaudichaudii subsp. *gaudichaudii*				0.1	25 cm		0.1	40 cm	YBIR15-13
Ptilotus helipteroides				0.1	8 cm	YBI15-23S			
Ptilotus nobilis subsp. *nobilis*				0.1	20 cm		0.1	10 cm	YBIR15-29

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Ptilotus obovatus var. *obovatus*	0.1	50 cm	YBl15-10	0.1	50 cm		0.1	40 cm	
Rhagodia eremaea	0.1	60 cm		0.1	60 cm		0.1	130 cm	
Rhynchosia minima	0.1	30 cm		0.1	30 cm		0.1	10 cm	
Salsola australis							0.1	10 cm	
Sclerolaena cornishiana	0.1	30 cm	YBl15-07	0.1	30 cm		0.1	10 cm	
Senna artemisioides subsp. *helmsii*	0.1	150 cm		0.1	150 cm		0.1	170 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	60 cm	YBl15-06	0.1	60 cm		0.1	70 cm	
Setaria dielsii							0.1	50 cm	YBlR15-27
Setaria verticillata	0.1	100 cm		0.1	100 cm		0.1	60 cm	
Sida fibulifera	0.1	40 cm	YBl15-05	0.1	40 cm		0.1	25 cm	YBlR15-15
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	30 cm	YBl15-14				0.1	20 cm	
Spermacoce brachystema							0.1	10 cm	
Sporobolus australasicus							0.1	10 cm	
Stemodia grossa							0.1	20 cm	
Streptoglossa bubakii							0.1	10 cm	
Tragus australianus							0.1	20 cm	
Tribulus terrestris							0.1	15 cm	YBlR15-35
Triodia basedowii	0.1	40 cm	YBl15-12				0.1	40 cm	
Triodia longiceps	0.1	50 cm		0.1	50 cm		0.5	60 cm	
Triodia pungens	0.1	40 cm		0.1	40 cm		0.1	40 cm	
Triodia wiseana	0.1	30 cm		0.1	30 cm				
Waltheria indica							0.1	30 cm	

YBl15 Phase 1

YBl15 Phase 2

YBl15 Phase 3

Yandi Billiards & Junction SW YBI16

Described by Phase 1: RB/RO Phase 2: RO/PC Date Phase 1: 17-Jun-07 Phase 2: 04-Aug-14

Type Quadrat 50 x 50 m

Location 25.2 km SSW of Marillana, 74.3 km NW of Newman and 78.9 km SE of Auski Roadhouse.

Central Coordinate 734590 mE, 7473606 mN.

Habitat Broad plain; very gently sloping to the west.

Soil Red-brown sandy loam.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus gamophylla* low open mallee woodland over *Acacia ancistrocarpa, A. bivenosa* tall open shrubland over *Keraudrenia velutina* subsp. *elliptica* scattered shrubs over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia basedowii* closed hummock grassland with *Digitaria brownii* scattered tussock grasses.
Phase 2: *Eucalyptus gamophylla* low open mallee woodland over *Acacia ancistrocarpa, A. bivenosa* tall open shrubland over *Keraudrenia velutina* subsp. *elliptica* scattered shrubs over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia basedowii* hummock grassland with *Digitaria brownii* scattered tussock grasses.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Notes Elevation at southeast corner is 503 m. This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia ancistrocarpa	2	220 cm		2	220 cm	
Acacia bivenosa	2	300 cm		2	300 cm	
Acacia pruinocarpa	0.1	300 cm		0.1	300 cm	
Acacia sibirica	0.1	30 cm	YBI16-13	0.1	30 cm	
Acacia tenuissima				0.1	50 cm	YBI32S-05=
Acacia tumida var. *pilbarensis*	0.1	240 cm	YBI16-12			
Amphipogon sericeus	0.1	40 cm		0.1	40 cm	
Aristida contorta	0.1	30 cm		0.1	30 cm	
Aristida holathera var. *holathera*	0.5	30 cm		0.5	30 cm	
Bonamia erecta	0.1	55 cm		0.1	55 cm	
Codonocarpus cotinifolius	0.5	700 cm		0.5	700 cm	
Corchorus tectus	0.1	40 cm	YBI16-08			
Cymbopogon ambiguus	0.1	65 cm	YBI16-09			
Digitaria brownii	1	50 cm	YBI16-07	1	50 cm	
Duperreya commixta	0.1	Climber		0.1	Climber	
Eremophila forrestii subsp. *forrestii*	0.1	60 cm		0.1	60 cm	
Eremophila longifolia	0.1	75 cm	YBI16-14S			
Eucalyptus gamophylla	2.5	350 cm		2.5	350 cm	
Hibiscus burtonii	0.1	160 cm	YBI16-11			
Hibiscus sturtii var. *platychlamys*				0.1	25 cm	YBI16-15S
Indigofera monophylla	0.1	50 cm	YBI16-05	0.1	25 cm	YBI16-17S
Keraudrenia velutina subsp. *elliptica*	1	110 cm	YBI16-03	1	110 cm	
Paraneurachne muelleri	0.1	70 cm		0.1	70 cm	
Polycarpaea longiflora				0.1	45 cm	
Ptilotus astrolasius	0.5	35 cm		0.5	35 cm	
Ptilotus calostachyus	0.1	110 cm				
Ptilotus nobilis subsp. *nobilis*	0.1	70 cm		0.1	70 cm	
Ptilotus obovatus var. obovatus				0.1	50 cm	
Sclerolaena cornishiana				0.1	35 cm	YBI16-16S
Senna artemisioides subsp. *helmsii*	0.1	15 cm		0.1	15 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	1	80 cm	YBI16-02	1	80 cm	
Senna glutinosa subsp. *glutinosa*	0.1	140 cm	YBI16-04	0.1	185 cm	
Senna glutinosa subsp. *pruinosa*	0.1	40 cm				
Senna glutinosa subsp. *x luerssenii*	0.1	85 cm		0.1	85 cm	
Sida cardiophylla	0.5	185 cm	YBI16-10			
Solanum elatius	0.1	65 cm		0.1	65 cm	
Solanum lasiophyllum	0.1	100 cm		0.1	100 cm	
Streptoglossa decurrens				0.1	60 cm	Dead.
Themeda triandra	0.1	100 cm				
Trianthema glossostigmum	0.1	5 cm	YBI16-06			
Triodia basedowii	72.5	50 cm	YBI16-01	52.5	60 cm	YBI16-18S

YBI16 Phase 1

YBI16 Phase 2

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI17

Described by Phase 1: BB Phase 2: RO/PC Phase 3: CEFCASW Date Phase 1: 17-Jun-07 Phase 2: 04-Aug-14 Phase 3: 17-Mar-14

Type Quadrat 50 x 50 m

Location 23.7 km SSW of Marillana, 75.4 km NW of Newman and 78.1 km SE of Auski Roadhouse.

Central Coordinate 734832 mE, 7475182 mN.

Habitat Flat plain just east of river floodplain (Weeli Wolli Creek).

Soil Dark reddish brown silty clay with 5% cover of pebbles.

Rock Type Not recorded.

Vegetation Phase 1: *Acacia bivenosa, A. citrinoviridis, Acacia pyrifolia* var. *pyrifolia* tall open shrubland over *Acacia pruinocarpa* scattered shrubs over *Triodia longiceps* closed hummock grassland with **Cenchrus ciliaris* very open tussock grassland.
Phase 2: *Acacia bivenosa, A. pyrifolia* var. *pyrifolia*, *Hakea lorea* subsp. *lorea*, *Acacia citrinoviridis* tall open shrubland over *A. pruinocarpa* scattered shrubs over *Ptilotus obovatus*, *Pterocaulon sphacelatum* low open shrubland over *Triodia longiceps* closed hummock grassland with **Cenchrus ciliaris* very open tussock grassland.
Phase 3: *Acacia bivenosa, A. pyrifolia* var. *pyrifolia* open shrubland over *Sida fibulifera* scattered low shrubs over *Triodia longiceps* very open hummock grassland with **Cenchrus ciliaris* very open tussock grassland and **Malvastrum americanum* open herbland.

Veg Condition Phase 1: Good; presence of weeds (**Cenchrus ciliaris, *C. setiger, *Bidens bipinnata, *Malvastrum americanum*).
Phase 2: Good; signs of cattle (grazing) and presence of weeds (**Cenchrus ciliaris, *C. setiger, *Bidens bipinnata, *Malvastrum americanum*).
Phase 3: Poor (**Cenchrus* spp., **Malvastrum americanum, *Aerva javanica, *Flaveria trinervia, *Bidens bipinnata*; cow scats; very close to cleared drill lines).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire. Phase 3: Burnt 3-5 years ago.

Notes Phase 1: *Triodia longiceps* hummocks are very large. This vegetation unit is continuous for another 60 m to the northwest, before the plain surrounding the river becomes infested with **Cenchrus ciliaris*.
Phase 3: This quadrat was sampled a third time as both Phase 1 and Phase 2 occurred at times considered unfavourable for plant growth.
Site has been burnt since the first and second phase of sampling. *Triodia* hummocks are still large but many of the tall shrubs (*Hakea lorea, Acacia citrinoviridis* etc.) are resprouting from the base.
Could not find *Corymbia hamersleyana*; possibly killed by fire.

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon amplum							0.1	50 cm	YBIR17-31
Abutilon lepidum				0.1	15 cm				
Abutilon macrum				0.1	20 cm				
Abutilon otocarpum				0.1	20 cm	Dead.	0.1	30 cm	YBIR17-22
Acacia bivenosa	6.5	400 cm		6.5	400 cm		2	160 cm	
Acacia citrinoviridis	0.5	300 cm		0.5	450 cm		0.1	250 cm	
Acacia dictyophleba							0.1	40 cm	
Acacia pruinocarpa	1	140 cm		1	140 cm				
Acacia pyrifolia var. *pyrifolia*	0.5	250 cm		2.5	350 cm		1	120 cm	
Acrachne racemosa							0.1	20 cm	YBIR17-26
Aerva javanica							0.1	40 cm	
Alternanthera nana							0.1	5 cm	YBIR17-16
Aristida contorta	0.1	30 cm					0.1	30 cm	
Atalaya hemiglauca	0.1	200 cm		0.1	200 cm		0.1	110 cm	
Bidens bipinnata	0.1	15 cm					0.1	20 cm	
Boerhavia coccinea	0.1	30 cm	YBI17-07				0.1	30 cm	YBIR17-03
Capparis spinosa var. *nummularia*	0.1	100 cm		0.1	100 cm				
Cenchrus ciliaris	4	45 cm		4	45 cm		8	60 cm	
Cenchrus setiger	0.1	40 cm					0.1	35 cm	
Cleome viscosa	0.1	50 cm					0.1	50 cm	
Codonocarpus cotinifolius				0.1	180 cm		0.1	170 cm	
Corchorus crozophorifolius	0.1	30 cm	YBI17-17	0.1	30 cm		0.1	120 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*							0.1	35 cm	YBIR17-14
Corchorus sidoides subsp. *sidoides*				0.1	45 cm	YBI17-27S	0.1	15 cm	
Corchorus tridens							0.1	5 cm	YBIR17-30
Corymbia hamersleyana				0.1	140 cm				
Crotalaria medicaginea var. *neglecta*							0.1	30 cm	
Cymbopogon procerus							0.1	150 cm	YBIR17-23
Dicladanthera forrestii	0.1	40 cm	YBI17-14						
Duperreya commixta	0.1	250 cm		0.1	250 cm		0.1	60 cm	
Enchylaena tomentosa var. *tomentosa*							0.1	45 cm	YBIR17-25

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Enneapogon caerulescens	0.1	20 cm	YBI17-12	0.1	30 cm				
Enneapogon lindleyanus							0.1	55 cm	YBIR17-28, YBIR17-07
Enneapogon polyphyllus	0.1	20 cm					0.1	20 cm	
Eragrostis cumingii							0.1	5 cm	
Eragrostis eriopoda				0.1	30 cm		0.1	25 cm	
Eragrostis pergracilis							0.1	25 cm	YBIR17-29
Eragrostis tenellula	0.1	20 cm					0.1	20 cm	
Eremophila longifolia	0.1	200 cm		0.1	200 cm		0.1	20 cm	
Eriachne mucronata (typical form)	0.1	35 cm	YBI17-09	0.1	35 cm		0.1	35 cm	
Eulalia aurea	0.1	35 cm							
Euphorbia australis var. *subtomentosa*	0.1	4 cm	YBI17-13				0.1	5 cm	YBIR17-02
Euphorbia biconvexa	0.1	15 cm	YBI17-04						
Euphorbia sp.				0.1	15 cm				
Euphorbia tannensis subsp. *eremophila*							0.1	120 cm	YBIR17-24
Euphorbia trigonosperma							0.1	20 cm	YBIR17-05
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm		0.1	30 cm		0.1	10 cm	
Flaveria trinervia							0.1	20 cm	
Glycine canescens	0.1	100 cm	YBI17-03	0.1	100 cm				
Gossypium sturtianum var. *sturtianum*							0.1	130 cm	
Hakea lorea subsp. *lorea*	0.1	450 cm		1	500 cm		0.1	110 cm	
Heliotropium cunninghamii							0.1	15 cm	YBIR17-13
Heliotropium inexplicitum	0.1	5 cm	YBI17-21	0.1	5 cm				
Heliotropium pachyphyllum	0.1	20 cm	YBI17-20						
Hibiscus sturtii var. *platychlamys*							0.1	10 cm	
Hybanthus aurantiacus							0.1	15 cm	
Indigofera georgei	0.1	30 cm	YBI17-02	0.1	65 cm	YBI17-23S			
Indigofera linifolia							0.1	20 cm	YBIR17-20
Lepidium phlebopetalum				0.1	10 cm	YBI17-26S			
Malvastrum americanum	0.1	30 cm		0.1	30 cm		1	10 cm	
Melhania oblongifolia	0.1	35 cm		0.1	35 cm		0.1	30 cm	
Notoleptopus decaisnei var. *decaisnei*							0.1	15 cm	YBIR17-17
Paraneurachne muelleri							0.1	20 cm	
Peripleura arida	0.1	20 cm	YBI17-15						
Perotis rara	0.1	5 cm							
Phyllanthus maderaspatensis							0.1	20 cm	YBIR17-08
Pluchea dunlopii	0.1	30 cm	YBI17-19						
Polymeria ambigua	0.1	100 cm	YBI17-06	0.1	100 cm		0.1	2 cm	YBIR17-01
Portulaca oleracea/intraterranea				0.1	5 cm		0.1	10 cm	YBIR17-09
Pterocaulon sphacelatum				0.5	45 cm	YBI17-22S	0.1	25 cm	YBIR17-15
Ptilotus astrolasius							0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*							0.1	5 cm	
Ptilotus obovatus var. *obovatus*	0.1	50 cm		1.5	50 cm		0.1	80 cm	
Rhagodia eremaea	0.1	180 cm		0.1	180 cm				
Rhynchosia minima	0.1	30 cm					0.1	5 cm	
Salsola australis							0.1	30 cm	
Scaevola amblyanthera var. *centralis*							0.1	25 cm	YBIR17-21
Schizachyrium fragile	0.1	4 cm							
Sclerolaena cornishiana	0.1	30 cm	YBI17-08	0.1	30 cm	YBI17-25S	0.1	5 cm	YBIR17-10
Senna artemisioides subsp. *helmsii*							0.1	40 cm	
Senna artemisioides subsp. *oligophylla*							0.1	20 cm	YBIR17-12
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	30 cm	YBI17-05	0.1	30 cm				
Setaria dielsii							0.1	40 cm	
Sida fibulifera	0.1	20 cm	YBI17-11	0.1	20 cm		1	20 cm	YBIR17-04

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)							0.1	100 cm	
Solanum lasiophyllum							0.1	30 cm	
Sporobolus australasicus							0.1	10 cm	
Stemodia grossa	0.1	40 cm					0.1	30 cm	
Streptoglossa decurrens	0.1	35 cm	YBl17-16						
Stylobasium spathulatum	0.1	250 cm		0.1	250 cm		0.1	220 cm	
Themeda triandra	0.1	90 cm		0.1	90 cm		0.1	100 cm	
Tragus australianus							0.1	15 cm	
Tribulus macrocarpus							0.1	5 cm	YBlR17-27
Trichodesma zeylanicum var. *zeylanicum*	0.1	40 cm		0.1	40 cm		0.1	20 cm	
Triodia longiceps	85	700 cm		85	100 cm		2	40 cm	
Triraphis mollis							0.1	35 cm	YBlR17-11
Zygophyllum eichleri				0.1	12 cm	YBl17-24S			

YBl17 Phase 1

YBl17 Phase 2

YBl17 Phase 3

Yandi Billiards & Junction SW YBI18

Described by RW/PH Date 18-Jun-07 Type Quadrat 50 x 50 m

Location 28.5 km SSW of Marillana, 73.7 km NW of Newman and 78.9 km SE of Auski Roadhouse.

Central Coordinate 732396 mE, 7471125 mN.

Habitat Slope of a low stony hill; slope faces northwest.

Soil Red-brown sandy loam.

Rock Type Ironstone.

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* tall open shrubland over *Acacia spondylophylla* shrubland over *Acacia hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), T. wiseana hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia hilliana	1.5	40 cm	1-2%.
Acacia inaequilatera	2	210 cm	
Acacia pruinocarpa	0.1	30 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	30 cm	
Acacia spondylophylla	26	150 cm	YBI18-01
Acacia synchronicia	0.1	100 cm	
Aristida holathera var. *holathera*	0.1	45 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	5 cm	YBI18-05
Eriachne mucronata (typical form)	0.1	30 cm	YBI18-03
Eucalyptus leucophloia subsp. *leucophloia*	1	500 cm	
Goodenia stobbsiana	0.1	40 cm	
Gossypium robinsonii	0.1	170 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	250 cm	Sterile.
Polycarpaea holtzei	0.1	5 cm	
Polycarpaea longiflora	0.1	25 cm	
Ptilotus astrolasius	0.1	30 cm	YBI18-07
Ptilotus obovatus var. *obovatus*	0.1	50 cm	YBI18-04
Ptilotus rotundifolius	0.1	130 cm	
Senna glutinosa subsp. *glutinosa*	0.1	140 cm	YBI18-06, YBI18-08
Senna glutinosa subsp. *pruinosa*	0.1	140 cm	
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	40 cm	YBI18-09
Solanum lasiophyllum	0.1	40 cm	
Tribulus suberosus	0.1	100 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	40	35 cm	YBI18-02
Triodia wiseana	20	25 cm	

YBI18

Yandi Billiards & Junction SW YBI19

Described by RB/RO Date 17-Jun-07 Type Quadrat 50 x 50 m

Location 27.3 km SSW of Marillana, 74.3 km NW of Newman and 78.5 km SE of Auski Roadhouse.

Central Coordinate 732824 mE, 7472236 mN.

Habitat Low stony rise adjacent to river (Weeli Wolli Creek).

Soil Red-brown loamy clay.

Rock Type Ironstone and accreted clay.

Vegetation *Eucalyptus xerothermica* scattered low trees over *Ptilotus obovatus* scattered low shrubs over *Triodia wiseana* hummock grassland with *Aristida contorta, *Cenchrus ciliaris, Eragrostis eriopoda, Paraneurachne muelleri* very open tussock grassland.

Veg Condition Good; presence of weeds (**Cenchrus ciliaris*).

Fire Age No sign of recent fire.

Notes *Eucalyptus leucophloia* present just outside quadrat.

Species	Cover (%)	Height	Specimen
Abutilon leucopetalum	0.1	90 cm	YBI19-20
Acacia bivenosa	0.1	170 cm	
Acacia pachyacra	0.1	230 cm	YBI19-06
Acacia synchronicia	0.1	400 cm	YBI19-07
Aristida contorta	4	20 cm	
Aristida holathera var. *holathera*	0.1	30 cm	
Atalaya hemiglauca	0.1	300 cm	
Cenchrus ciliaris	0.5	60 cm	
Corchorus crozophorifolius	0.1	35 cm	YBI19-21
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	YBI19-27
Corymbia hamersleyana	0.1	300 cm	
Cymbopogon ambiguus	0.1	40 cm	
Duperreya commixta	0.1	200 cm	
Enneapogon caerulescens	0.1	20 cm	
Enneapogon polyphyllus	0.1	30 cm	YBI19-26
Enneapogon robustissimus	0.1	70 cm	YBI19-08
Eragrostis eriopoda	0.5	30 cm	YBI09-04=
Eremophila forrestii subsp. *forrestii*	0.1	45 cm	
Eucalyptus xerothermica	1.5	400 cm	
Eulalia aurea	0.1	60 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm	
Goodenia muelleriana	0.1	20 cm	YBI19-24
Gossypium australe	0.1	40 cm	YBI19-23
Heliotropium inexplicitum	0.1	15 cm	YBI19-03
Paraneurachne muelleri	0.5	40 cm	
Polycarpaea corymbosa var. *corymbosa*	0.1	30 cm	
Ptilotus astrolasius	0.1	45 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	60 cm	
Ptilotus obovatus var. *obovatus*	0.5	80 cm	
Rhagodia eremaea	0.1	110 cm	
Sclerolaena cornishiana	0.1	30 cm	YBI19-04
Senna artemisioides subsp. *helmsii*	0.1	90 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	35 cm	YBI19-02
Senna glutinosa subsp. *x luerssenii*	0.1	70 cm	YBI19-05
Solanum horridum	0.1	30 cm	YBI19-09
Solanum lasiophyllum	0.1	45 cm	YBI19-25
Streptoglossa decurrens	0.1	10 cm	YBI19-22
Triodia wiseana	40	60 cm	YBI19-01

YBI19

Yandi Billiards & Junction SW/ Yandi Billiards Level 2 YBI20

Described by	Phase 1: RW/PH Phase 2: RO/PC Phase 3: PLSV Date Phase 1: 07-Jun-07 Phase 2: 04-Aug-14 Phase 3: 17-Mar-14
Type	Quadrat 12.5 x 200 m
Location	26.5 km SSW of Marillana, 73.5 km NW of Newman and 79.5 km SE of Auski Roadhouse.
Central Coordinate	734268 mE, 7472275 mN.
Habitat	Bed of moderate-sized creekline (feeds into Weeli Wolli Creek).
Soil	Red-brown river sand between alluvial cobbles and pebbles.
Rock Type	Alluvial material; Ironstone, Basalt, Chert.
Vegetation	Phase 1: *Eucalyptus victrix, Corymbia hamersleyana* woodland over *Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) scattered low shrubs over *Aristida contorta, Aristida holathera* var. *holathera*, *Cymbopogon ambiguus* very open tussock grassland. Phase 2: *Eucalyptus victrix, Corymbia hamersleyana* woodland over *Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) scattered low shrubs over *Aristida contorta, Aristida holathera* var. *holathera* very open tussock grassland. Phase 3: *Eucalyptus victrix* open woodland over *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, (*Grevillea wickhamii* subsp. *hispidula, A. pyrifolia* var. *pyrifolia*) tall shrubland over *Cymbopogon ambiguus, *Cenchrus ciliaris* very open tussock grassland.
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris*). Phase 2: Not recorded. Phase 3: Good (**Cenchrus ciliaris*).
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire. Phase 3: No sign of recent fire.
Notes	Phase 1: Quadrat shape modified to fit creekbed habitat; 200 m tape was positioned along the edge of the creekline, and the 9 m - 12.5 m wide creekbed was then surveyed along this length.

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.1	120 cm	YBI20-21	0.1	120 cm	YBI20-26S			
Acacia pyrifolia var. *pyrifolia*	0.1	100 cm		0.1	100 cm		1	210 cm	
Acacia tumida var. *pilbarensis*	15	350 cm	YBI20-11	15	350 cm		20	350 cm	
Aristida contorta	1	30 cm		1	30 cm		0.1	35 cm	
Aristida holathera var. *holathera*	1	30 cm		1	30 cm		0.1	20 cm	
Aristida hygrometrica							0.1	40 cm	YBIR20-07
Aristida inaequiglumis	0.1	90 cm							
Aristida ingrata	0.1	100 cm	YBI20-17						
Aristida pruinosa							0.1	45 cm	YBIR20-06
Atalaya hemiglauca							0.1	180 cm	
Bonamia erecta	0.1	50 cm	YBI20-18	0.1	50 cm		0.1	35 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)							0.1	5 cm	
Cenchrus ciliaris	0.1	40 cm		0.1	40 cm		1	40 cm	
Cleome viscosa	0.1	20 cm		0.1	20 cm		0.1	40 cm	
Corchorus crozophorifolius	0.1	80 cm		0.1	80 cm		0.1	150 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*							0.1	50 cm	
Corchorus tectus							0.1	30 cm	
Corymbia hamersleyana	10	1200 cm		10	1200 cm		10	800 cm	
Cucumis variabilis	0.1	150 cm							
Cymbopogon ambiguus	1	140 cm	YBI20-09	0.1	85 cm	YBI20-23S	1	50 cm	
Cymbopogon procerus							0.1	110 cm	
Cyperus cunninghamii subsp. *cunninghamii*	0.1	40 cm	YBI20-10						
Digitaria brownii				0.1	65 cm		0.1	40 cm	
Digitaria ctenantha							0.1	20 cm	
Duperreya commixta							0.1	300 cm	
Enchylaena tomentosa var. *tomentosa*				0.1	75 cm				
Enneapogon lindleyanus	0.1	45 cm	YBI20-20	0.1	45 cm		0.1	40 cm	
Enneapogon polyphyllus	0.1	20 cm							
Enneapogon robustissimus	0.1	60 cm	YBI20-19	0.1	60 cm		0.1	60 cm	YBIR20-02
Eragrostis eriopoda	0.1	40 cm	YBI20-14	0.1	40 cm		0.1	30 cm	
Eriachne mucronata (typical form)	0.1	40 cm	YBI20-16	0.1	40 cm		0.1	40 cm	
Eriachne pulchella	0.1	15 cm		0.1	15 cm		0.1	20 cm	
Eriachne tenuiculmis							0.1	30 cm	
Eucalyptus victrix	20	1200 cm	YBI20-22	20	1200 cm		8	1100 cm	
Euphorbia australis var. *subtomentosa*	0.1	8 cm	YBI20-08	0.1	8 cm	YBI20-25S	0.1	10 cm	YBIR20-13
Evolvulus alsinoides var. *villosicalyx*							0.1	10 cm	
Gomphrena cunninghamii				0.1	10 cm		0.1	15 cm	
Goodenia muelleriana							0.1	40 cm	

Species	Phase 1			Phase 2			Phase 3		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Goodenia stobbsiana	0.1	40 cm							
Gossypium australe				0.1	80 cm		0.1	50 cm	
Gossypium robinsonii	0.1	160 cm		0.1	160 cm		0.1	230 cm	
Grevillea wickhamii subsp. *hispidula*	3	400 cm		3	400 cm		1	350 cm	YBIR20-04
Heliotropium cunninghamii							0.1	20 cm	YBIR20-10
Heliotropium pachyphyllum							0.1	25 cm	YBIR20-11
Hibiscus coatesii							0.1	20 cm	YBIR20-12
Hybanthus aurantiacus	0.1	30 cm		0.1	30 cm		0.1	40 cm	
Indigofera monophylla	0.1	45 cm	YBI20-05	0.1	70 cm	YBI20-24S	0.1	70 cm	YBIR20-09
Mollugo molluginea	0.1	8 cm					0.1	10 cm	
Paraneurachne muelleri				0.1	45 cm		0.1	25 cm	
Paspalidium clementii				0.1	12 cm	YBI20-27S			
Phyllanthus maderaspatensis	0.1	25 cm	YBI20-06	0.1	25 cm		0.1	30 cm	
Pluchea dentex	0.1	40 cm	YBI20-13						
Polycarpaea longiflora	0.1	20 cm		0.1	20 cm				
Polymeria ambigua	0.1	30 cm	YBI20-12				0.1	10 cm	
Ptilotus astrolasius	0.1	50 cm	YBI20-07				0.1	50 cm	
Ptilotus helipteroides				0.1	12 cm				
Ptilotus nobilis subsp. *nobilis*				0.1	25 cm		0.1	15 cm	
Ptilotus obovatus var. *obovatus*				0.1	50 cm		0.1	50 cm	
Rhynchosia minima	0.1	40 cm							
Senna artemisioides subsp. *helmsii*							0.1	60 cm	
Setaria verticillata	0.1	60 cm							
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	160 cm	YBI20-04	0.1	160 cm		0.1	70 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)							0.1	25 cm	
Stemodia grossa	0.1	40 cm		0.1	40 cm				
Streptoglossa decurrens	0.1	110 cm	YBI20-15						
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	1.5	60 cm	YBI20-02	1.5	60 cm		0.1	45 cm	
Themeda triandra	0.1	100 cm		0.1	100 cm		0.1	50 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	160 cm		0.1	160 cm				
Triodia pungens	0.1	45 cm		0.1	45 cm		0.1	40 cm	YBIR20-03
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	0.1	25 cm	YBI20-03				0.1	25 cm	
Triodia wiseana	0.1	30 cm		0.1	30 cm		0.1	40 cm	
Waltheria indica	0.1	100 cm		0.1	100 cm		0.1	60 cm	

YBI20 Phase 1 (no photo)

YBI20 Phase 2

YBI20 Phase 3

Yandi Billiards & Junction SW YBI21

Described by RW/PH Date 18-Jun-07 Type Quadrat 50 x 50 m

Location 27.4 km SSW of Marillana, 73.3 km NW of Newman and 79.6 km SE of Auski Roadhouse.

Central Coordinate 733728 mE, 7471629 mN.

Habitat Broad plain; located between Weeli Wolli Creek (to west) and a series of low hills (to east).

Soil Red-brown sandy loam.

Rock Type Ironstone.

Vegetation *Eucalyptus gamophylla* low open mallee woodland over *Acacia inaequilatera* tall shrubland over *A. ancistrocarpa* shrubland over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii*, *Sida* sp. verrucose glands (F.H. Mollemans 2423) low open shrubland over *Aristida holathera* var. *holathera*, *Paraneurachne muelleri* open tussock grassland with *Triodia basedowii* open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia adsurgens	0.1	150 cm	YBI21-04
Acacia ancistrocarpa	25	200 cm	
Acacia coriacea subsp. *pendens*	0.1	170 cm	
Acacia inaequilatera	15	400 cm	
Acacia pachyacra	0.1	150 cm	YBI21-05
Acacia pruinocarpa	0.1	100 cm	
Aristida contorta	0.1	20 cm	
Aristida holathera var. *holathera*	13	40 cm	
Bonamia erecta	0.1	15 cm	YBI21-02
Corchorus tectus	0.1	25 cm	YBI21-19, YBI21-17
Cucumis variabilis	0.1	200 cm	
Cymbopogon ambiguus	0.1	150 cm	YBI21-16
Digitaria brownii	0.1	50 cm	YBI21-13
Duperreya commixta	0.1	200 cm	
Eremophila forrestii subsp. *forrestii*	0.1	80 cm	YBI21-07
Eriachne aristidea	0.1	40 cm	YBI21-12
Eucalyptus gamophylla	5	400 cm	
Gossypium australe	0.1	30 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	300 cm	
Hakea chordophylla	0.1	350 cm	
Hakea lorea subsp. *lorea*	0.1	130 cm	
Heliotropium pachyphyllum	0.1	20 cm	YBI21-15
Hibiscus sturtii var. *platychlamys*	0.1	70 cm	YBI21-06
Paraneurachne muelleri	10	30 cm	
Polycarpaea longiflora	0.1	30 cm	
Pterocaulon sphacelatum	0.1	100 cm	
Ptilotus astrolasius	0.1	30 cm	YBI21-14
Ptilotus calostachyus	0.1	50 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	30 cm	
Senna artemisioides subsp. *oligophylla*	0.1	45 cm	YBI21-20
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	1	70 cm	YBI21-03
Senna glutinosa subsp. *x luerssenii*	0.1	120 cm	YBI21-11
Sida arenicola	0.1	30 cm	YBI21-18
Sida cardiophylla	0.1	100 cm	YBI21-08
Sida sp. verrucose glands (F.H. Mollemans 2423)	1	30 cm	YBI21-10
Solanum elatius	0.1	150 cm	
Solanum horridum	0.1	25 cm	
Solanum lasiophyllum	0.1	70 cm	
Streptoglossa decurrens	0.1	80 cm	YBI21-09
Tribulus suberosus	0.1	120 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	100 cm	
Triodia basedowii	20	40 cm	YBI21-01

YBI21

Yandi Billiards & Junction SW		YBI22	
Described by	Phase 1: RB/B Phase 2: JA/RB	Date	Phase 1: 18-Jun-07 Phase 2: 04-Aug-08
Type	Quadrat 33 x 63 m		
Location	26 km SSW of Marillana, 73.2 km NW of Newman and 79.9 km SE of Auski Roadhouse		
Central Coordinate	734904 mE, 7472469 mN.		
Habitat	Lower slope of colluvial spur; edge of shallow depression included.		
Soil	Not recorded.		
Rock Type	Ironstone.		
Vegetation	Phase 1 *Eucalyptus gamophylla* low open mallee woodland over *Indigofera monophylla* scattered low shrubs over *Triodia basedowii* hummock grassland with *Aristida holathera* var. *holathera*, *Amphipogon sericeus, Eragrostis eriopoda, Paraneurachne muelleri* very open tussock grassland. Phase 2: *Eucalyptus gamophylla* low open mallee woodland over *Triodia basedowii* hummock grassland with *Aristida holathera* var. *holathera*, *Amphipogon sericeus, Eragrostis eriopoda* very open tussock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Good; presence of weeds (**Cenchrus ciliaris*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Phase 1 Poor quadrat location, difficult to locate in single vegetation type. Area comprises narrow colluvial spurs interspersed with very shallow flowlines/depressions; Eucalyptus gamophylla is mostly in the depressions. Irregular shape to quadrat. Phase 2: Very dry conditions. This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia ancistrocarpa	0.1	90 cm		0.1	90 cm	
Acacia aptaneura x	0.1	35 cm	YBI22-23	0.1	40 cm	YBI22-27S
Acacia dictyophleba	0.1	120 cm	YSW06-02=	0.1	120 cm	
Acacia elachantha	0.1	200 cm	YBI22-11			
Acacia inaequilatera	0.1	400 cm		0.1	400 cm	
Acacia pachyacra	0.1	300 cm	YBI22-21	0.1	50 cm	YBI22-25S
Acacia pruinocarpa	0.1	250 cm		0.1	250 cm	
Acacia tenuissima	0.1	50 cm	YBI22-13	0.1	50 cm	
Amphipogon sericeus	1.5	90 cm	YBI22-02	1.5	90 cm	
Aristida contorta	0.1	30 cm				
Aristida holathera var. *holathera*	3.5	20 cm		3.5	20 cm	
Aristida pruinosa	0.1	70 cm	YBI22-18			
Bonamia erecta				0.1	30 cm	
Cenchrus ciliaris				0.1	25 cm	
Corchorus tectus	0.1	20 cm	YBI22-07			
Cullen leucochaites	0.1	15 cm	YBI22-20			
Cymbopogon ambiguus	0.1	20 cm		0.1	20 cm	
Dampiera candicans	0.1	45 cm				
Dicrastylis cordifolia	0.1	50 cm	YBIB01=			
Digitaria brownii	0.1	45 cm	YBI22-16	0.1	45 cm	
Duperreya commixta	0.1	35 cm		0.1	35 cm	
Eragrostis eriopoda	1	30 cm	YBI22-05	1	30 cm	
Eriachne aristidea				0.1	20 cm	
Eucalyptus gamophylla	7.5	500 cm	YBI22-10	7.5	500 cm	
Goodenia stobbsiana	0.1	20 cm		0.1	20 cm	
Gossypium australe	0.1	30 cm		0.1	30 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	210 cm		0.1	210 cm	
Hakea lorea subsp. *lorea*	0.1	100 cm		0.1	100 cm	
Heliotropium pachyphyllum				0.1	20 cm	=YBI22-28S
Hibiscus burtonii	0.1	110 cm	YBI22-15	0.1	60 cm	=YBI22-30S
Hibiscus leptocladus	0.1	30 cm	YBI22-17			
Hibiscus sturtii var. *platychlamys*	0.1	25 cm	YBI22-08	0.1	25 cm	
Hybanthus aurantiacus	0.1	30 cm		0.1	30 cm	
Indigofera monophylla	0.5	25 cm		0.1	25 cm	
Mollugo molluginea	0.1	20 cm				
Paraneurachne muelleri	0.5	35 cm		0.1	35 cm	
Polycarpaea longiflora	0.1	30 cm		0.1	30 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	30 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Ptilotus calostachyus	0.1	60 cm		0.1	60 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	50 cm		0.1	50 cm	
Ptilotus obovatus var. *obovatus*	0.1	70 cm		0.1	70 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	25 cm	YBI22-14	0.1	25 cm	
Senna artemisioides subsp. *helmsii*				0.1	100 cm	YBI22-26S
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	80 cm	YBI22-03	0.1	80 cm	
Senna glutinosa subsp. *glutinosa*	0.1	180 cm	YBI22-09	0.1	180 cm	
Senna glutinosa subsp. *x luerssenii*				0.1	70 cm	YBI22-24S
Sida cardiophylla	0.1	40 cm	YBI22-19			
Solanum elatius	0.1	90 cm		0.1	90 cm	
Solanum lasiophyllum	0.1	30 cm	YBI19-25=	0.1	30 cm	
Solanum phlomoides	0.1	90 cm	YBI22-06	0.1	90 cm	
Streptoglossa decurrens	0.1	35 cm				
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	70 cm	YBI22-22	0.1	70 cm	
Trachymene oleracea subsp. *oleracea*	0.1	50 cm				
Trichodesma zeylanicum var. *zeylanicum*	0.1	100 cm		0.1	100 cm	
Triodia basedowii	47.5	60 cm	YBI22-01	47.5	50 cm	YBI22-23S
Triodia pungens				0.1	70 cm	YBI22-29S

YBI22 Phase 1

YBI22 Phase 2

Yandi Billiards & Junction SW — Site YBI23

Described by RW/PH — Date 18-Jun-07 — Type Quadrat12.5 x 200 m

Location 28.7 km SSW of Marillana, 74 km NW of Newman and 78.6 km SE of Auski Roadhouse.

Central Coordinate 731950 mE, 7471111 mN.

Habitat Banks of river channel (Weeli Wolli Creek).

Soil Red-brown silty loam.

Rock Type Riverstone.

Vegetation *Eucalyptus victrix* open forest over *Melaleuca argentea* low open woodland over *Acacia citrinoviridis, A. coriacea* subsp. *pendens* tall open shrubland over *Sesbania cannabina* scattered shrubs over *Stemodia grossa*, *Pluchea rubelliflora* herbland with *Cyperus vaginatus* open sedgeland.

Veg Condition Good; presence of weeds (**Cenchrus ciliaris, *Malvastrum americanum, *Setaria verticillata*) and signs of cattle (tracks, grazing and scats).

Fire Age No sign of recent fire.

Notes Quadrat shape modified to fit the creekbank vegetation of Weeli Wolli Creek; both sides of the creek were surveyed.

Species	Cover (%)	Height	Specimen
Abutilon leucopetalum	0.1	40 cm	YBI23-14
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.1	150 cm	YBI23-04
Acacia citrinoviridis	1.5	400 cm	
Acacia coriacea subsp. *pendens*	1	600 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	110 cm	
Amaranthus undulatus	0.1	25 cm	YBI23-11
Ammannia baccifera	0.1	20 cm	YBI23-05
Atalaya hemiglauca	0.1	200 cm	
Cassytha filiformis	0.1	60 cm	YBI23-02
Cenchrus ciliaris	0.1	30 cm	
Cleome viscosa	0.1	15 cm	
Corchorus crozophorifolius	0.1	10 cm	
Cymbopogon ambiguus	0.1	100 cm	YBI20-09=
Cyperus vaginatus	25	60 cm	YBI23-09
Dicladanthera forrestii	0.1	20 cm	YBI23-19
Eleocharis atropurpurea	0.1	20 cm	YBI23-12
Enteropogon ramosus	0.1	30 cm	YBI23-17
Eragrostis tenellula	0.1	25 cm	YBI23-07
Eriachne tenuiculmis	0.1	60 cm	YBI23-18
Eucalyptus victrix	65	1800 cm	60-70%.
Eulalia aurea	0.1	100 cm	
Euphorbia trigonosperma	0.1	20 cm	YBI23-15
Evolvulus alsinoides var. *decumbens*	0.1	25 cm	YBI23-21
Flaveria trinervia	0.1	20 cm	
Gomphrena cunninghamii	0.1	6 cm	
Gossypium robinsonii	0.1	100 cm	
Gossypium sturtianum var. *sturtianum*	0.1	100 cm	YBI23-13
Heliotropium pachyphyllum	0.1	30 cm	YBI23-20
Lobelia arnhemiaca	0.1	20 cm	YBI23-16
Malvastrum americanum	0.1	25 cm	
Melaleuca argentea	8	900 cm	
Phyllanthus maderaspatensis	0.1	30 cm	YBI23-03
Pluchea dentex	0.1	20 cm	YBI23-26
Pluchea rubelliflora	2	30 cm	YBI23-06
Polymeria ambigua	0.1	10 cm	YBI23-23
Rhynchosia minima	0.1	30 cm	
Schoenoplectus subulatus	0.1	110 cm	YBI23-10
Sesbania cannabina	1	200 cm	
Setaria verticillata	0.1	15 cm	
Sonchus oleraceus	0.1	20 cm	YBI23-08 YBI23-25
Stemodia grossa	0.1	40 cm	YBI23-24
Stemodia grossa	55	60 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	30 cm	YBI23-22
Themeda triandra	0.1	30 cm	
Trachymene oleracea subsp. *oleracea*	0.1	20 cm	
Wahlenbergia tumidifructa	0.1	70 cm	YBI23-01

YBI23

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI24

Described by Phase 1: RW/PH Phase 2: CASV Date Phase 1: 19-Jun-07 Phase 2: 16-Mar-14

Type Quadrat 50 x 50 m

Location 15.5 km SSW of Marillana, 77.2 km NNW of Newman and 79.4 km ESE of Auski Roadhouse.

Central Coordinate 740911 mE, 7481189 mN.

Habitat Crest of low stony hill.

Soil 2.5YR 3/3 dark reddish brown skeletal sandy clay loam.

Rock Type Ironstone cobbles (80%), pebbles (10%), and gravel (5%).

Vegetation Phase 1: *Hakea chordophylla* tall shrubland over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland with *Amphipogon sericeus, Eriachne mucronata* open tussock grassland.
Phase 2: *Hakea chordophylla, Acacia arida* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia arida	3	110 cm	YBI24-08	2	250 cm	
Acacia inaequilatera	0.1	70 cm		0.1	110 cm	
Amphipogon sericeus	10	30 cm	YBI24-06	0.1	20 cm	YBIR24-03
Amyema hilliana				0.1		YBIR24-07
Aristida holathera var. holathera				0.1	30 cm	
Calytrix carinata	0.1	70 cm	YBI24-02	0.1	90 cm	
Corchorus lasiocarpus	0.1	40 cm				
Corymbia hamersleyana	0.1	210 cm		0.1	250 cm	
Cymbopogon obtectus	0.1	50 cm	YBI24-04	0.1	110 cm	
Dampiera candicans	0.1	40 cm		0.1	20 cm	
Eriachne mucronata (typical form)	2	30 cm		0.1	15 cm	YBIR24-04, YBIR24-06
Fimbristylis simulans				0.1	10 cm	YBIR24-02
Goodenia stobbsiana	0.1	40 cm		0.1	15 cm	
Gossypium robinsonii				0.1	160 cm	
Grevillea wickhamii subsp. hispidula	0.1	40 cm		0.1	180 cm	
Hakea chordophylla	15	400 cm		2	300 cm	
Keraudrenia velutina subsp. elliptica	0.1	50 cm	YBI24-03			
Polycarpaea longiflora	0.1	25 cm				
Pterocaulon sphacelatum				0.1	20 cm	YBIR24-05
Ptilotus calostachyus	0.1	60 cm		0.1	60 cm	
Ptilotus rotundifolius	0.1	90 cm		0.1	90 cm	
Schizachyrium fragile				0.1	15 cm	
Senna artemisioides subsp. oligophylla				0.1	60 cm	YBIR24-01
Senna glutinosa subsp. glutinosa	0.1	170 cm	YBI24-01	0.1	220 cm	
Senna glutinosa subsp. glutinosa x subsp. pruinosa				0.1	120 cm	
Senna glutinosa subsp. glutinosa x subsp. x luerssenii				0.1	130 cm	
Senna glutinosa subsp. pruinosa	0.1	200 cm				
Senna glutinosa subsp. x luerssenii	0.1	160 cm	YBI24-07			
Solanum lasiophyllum	0.1	50 cm				
Tribulus suberosus	0.1	40 cm				
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	25	35 cm	YBI24-05	35	35 cm	YBIR24-08
Triodia wiseana	0.1	50 cm		0.1	40 cm	

YBl24 Phase 1

YBl24 Phase 2

Yandi Billiards & Junction SW YBI25

Described by RW/PH Date 19-Jun-07 Type Quadrat 12.5 x 200 m

Location 15 km SSW of Marillana, 77.4 km NNW of Newman and 79.6 km ESE of Auski Roadhouse.

Central Coordinate 741294 mE, 7481523 mN.

Habitat Minor flowline, running between moderate-sized stony hills.

Soil Red-brown sandy loam.

Rock Type Ironstone.

Vegetation *Grevillea wickhamii* subsp. *hispidula* tall open scrub over *Acacia tumida* var. *pilbarensis*, *Gossypium robinsonii, Trichodesma zeylanicum* var. *zeylanicum, A. monticola*, *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* shrubland over *Indigofera monophylla* scattered low shrubs over *Triodia pungens* very open hummock grassland.

Veg Condition Very Good; presence of weeds (**Bidens bipinnata*).

Fire Age No sign of recent fire.

Notes Quadrat shape modified to fit creek vegetation.

Species	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	50 cm	YBI25-18
Acacia inaequilatera	0.1	200 cm	
Acacia monticola	1	150 cm	
Acacia pachyacra	0.1	180 cm	YBI25-16
Acacia pyrifolia var. *pyrifolia*	0.1	150 cm	
Acacia tetragonophylla	0.1	100 cm	YBI25-12
Acacia tumida var. *pilbarensis*	8	150 cm	YBI25-11
Aristida holathera var. *holathera*	0.1	50 cm	
Atalaya hemiglauca	0.1	250 cm	
Bidens bipinnata	0.1	25 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	40 cm	YBI25-07
Corymbia hamersleyana	0.1	400 cm	
Cymbopogon ambiguus	0.1	120 cm	YBI25-05
Dicrastylis cordifolia	0.1	60 cm	YBI25-01
Enneapogon lindleyanus	0.1	40 cm	YBI25-13
Enneapogon polyphyllus	0.1	25 cm	
Eriachne mucronata (typical form)	0.1	40 cm	YBI25-10
Eucalyptus leucophloia subsp. *leucophloia*	0.1	400 cm	
Euphorbia australis var. *subtomentosa*	0.1	15 cm	YBI25-02
Gossypium robinsonii	6	200 cm	
Grevillea wickhamii subsp. *hispidula*	65	500 cm	
Hibiscus coatesii	0.1	100 cm	YBI25-14
Indigofera monophylla	1	80 cm	YBI25-09
Mollugo molluginea	0.1	30 cm	
Paraneurachne muelleri	0.1	60 cm	
Polycarpaea longiflora	0.1	40 cm	
Pterocaulon sphacelatum	0.1	40 cm	
Ptilotus obovatus	0.1	50 cm	YBI25-03
Rhynchosia minima	0.1	150 cm	
Salsola australis	0.1	40 cm	YBI25-20
Santalum lanceolatum	0.1	250 cm	YBI25-19
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	1	150 cm	YBI25-17
Senna glutinosa subsp. *glutinosa*	0.1	150 cm	YBI25-15
Sida arenicola	0.1	200 cm	YBI25-04
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	50 cm	YBI25-21
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	70 cm	YBI25-08
Themeda triandra	0.1	100 cm	
Trichodesma zeylanicum var. *zeylanicum*	1.5	200 cm	
Triodia pungens	8	60 cm	
Triumfetta maconochieana	0.1	40 cm	YBI25-06

YBI25

Yandi Billiards & Junction SW YBI26

Described by	RB/B	Date	19-Jun-07	Type	Quadrat 50 x 50 m

Location 13.8 km SSW of Marillana, 78.4 km ESE of Auski Roadhouse and 79 km NNW of Newman.
Central Coordinate 740825 mE, 7483118 mN.
Habitat Slightly elevated area within broad plain; sloping gently to southwest.
Soil Red-brown loamy sand.
Rock Type Not recorded.
Vegetation *Acacia sclerosperma* subsp. *sclerosperma* scattered tall shrubs over *Triodia pungens* hummock grassland with **Cenchrus ciliaris* very open tussock grassland.
Veg Condition Good; presence of weeds (**Cenchrus ciliaris, *C. setiger*).
Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia dictyophleba	0.1	45 cm	YSW06-02=
Acacia pruinocarpa	0.1	600 cm	
Acacia sclerosperma subsp. *sclerosperma*	1.5	300 cm	YBI09-01=
Aristida contorta	0.1	30 cm	
Aristida holathera var. *holathera*	0.1	30 cm	
Cenchrus ciliaris	4	40 cm	
Cenchrus setiger	0.1	50 cm	YBI03-01=
Cleome viscosa	0.1	60 cm	
Enneapogon caerulescens	0.1	25 cm	
Eragrostis eriopoda	0.1	20 cm	YBI09-04=
Eriachne mucronata (typical form)	0.1	35 cm	
Heliotropium pachyphyllum	0.1	30 cm	YBI26-05
Ptilotus nobilis subsp. *nobilis*	0.1	50 cm	
Ptilotus obovatus var. *obovatus*	0.1	60 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	45 cm	YBI26-03
Senna glutinosa subsp. *pruinosa*	0.1	30 cm	
Sida arsiniata	0.1	30 cm	YBI26-04
Solanum lasiophyllum	0.1	30 cm	YBI19-25=
Solanum phlomoides	0.1	30 cm	YBI26-02
Triodia pungens	47.5	40 cm	YBRB06-01=

YBI26

Yandi Billiards & Junction SW/Yandi Billiards Level 2 YBI27

Described by	Phase 1: RB/B Phase 2: PLSV	Date	Phase 1: 19-Jun-07 Phase 2: 14-Mar-14
Type	Quadrat 50 x 50 m		
Location	14.2 km SSW of Marillana, 78.2 km NNW of Newman and 79 km ESE of Auski Roadhouse.		
Central Coordinate	741208 mE, 7482416 mN.		
Habitat	Lower slope of colluvial rise between base of ridge (to east) and river floodplain (Weeli Wolli Creek, to west); sloping gently to the northwest.		
Soil	Dark reddish brown fine sandy loam with 1% cover of pebbles and 1% cover of gravel.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Acacia pachyacra* scattered tall shrubs over *Sida cardiophylla, Corchorus tectus* low open shrubland over *Aristida holathera* var. *holathera, Eragrostis eriopoda* tussock grassland with *Triodia basedowii* open hummock grassland. Phase 2: *Acacia ancistrocarpa, Grevillea wickhamii* subsp. *hispidula* scattered tall shrubs over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia basedowii* hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: Burnt 3-5 years ago. Phase 2: No sign of recent fire.		
Notes	Phase 1: Poor seasonal conditions for sampling; annuals were in poor condition. Phase 2: A number of species that were recorded in the previous phase of sampling were not recorded. The vegetation appears to have changed from a post-fire successional community to mature/climax community.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia ancistrocarpa	0.1	220 cm		0.5	300 cm	
Acacia dictyophleba	0.1	30 cm	YBI27-04	0.1	60 cm	
Acacia inaequilatera	0.1	350 cm		0.1	250 cm	
Acacia pachyacra	1	300 cm	YBI27-05	0.1	90 cm	
Acacia tumida var. pilbarensis	0.1	100 cm				
Amphipogon sericeus	0.1	80 cm	YBI22-02=			
Aristida holathera var. holathera	35	30 cm		0.1	45 cm	
Bonamia erecta	0.1	35 cm	YBI27-08	0.1	50 cm	
Cleome viscosa	0.1	50 cm				
Codonocarpus cotinifolius	0.1	200 cm				
Corchorus crozophorifolius	0.1	20 cm	YBI27-10			
Corchorus tectus	1.5	30 cm	YBI06-11=			
Dicrastylis cordifolia				0.1	60 cm	
Eragrostis eriopoda	3.5	30 cm	YBI09-04=	0.1	40 cm	
Eriachne aristidea	0.1	30 cm				
Grevillea wickhamii subsp. hispidula	0.1	400 cm	YBI27-11	0.5	220 cm	
Hakea chordophylla	0.1	350 cm	YBI27-07	0.1	350 cm	
Hibiscus burtonii	0.1		YBI27-14			
Hybanthus aurantiacus	0.1	70 cm		0.1	45 cm	
Indigofera monophylla	0.1	30 cm				
Paraneurachne muelleri	0.1	40 cm				
Ptilotus astrolasius	0.1	40 cm		0.1	35 cm	
Ptilotus calostachyus	0.1	70 cm		0.1	40 cm	
Ptilotus obovatus var. obovatus	0.1	35 cm				
Rhagodia eremaea	0.1	110 cm				
Senna artemisioides subsp. helmsii	0.1	30 cm				
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	40 cm	YBI27-03	0.5	80 cm	
Sida arenicola	0.1	60 cm	YBI27-02			
Sida cardiophylla	4	70 cm	YBI27-01	0.1	50 cm	
Solanum lasiophyllum	0.1	35 cm	YBI27-09			
Solanum phlomoides				0.1	35 cm	
Solanum sp.	0.1	35 cm	YBI27-06			
Trianthema pilosum				0.1	20 cm	
Tribulopis angustifolia				0.1	10 cm	
Trichodesma zeylanicum var. zeylanicum	0.1	90 cm				
Triodia basedowii	17.5	70 cm	YBI22-01=	35	45 cm	
Yakirra australiensis var. australiensis				0.1	20 cm	

YBI27 Phase 1

YBI27 Phase 2

Yandi Billiards & Junction SW		YBI28	
Described by	Phase 1: RW/PH Phase 2: JA/RW	Date	Phase 1: 20-Jun-07 Phase 2: 04-Aug-08
Type	Quadrat 50 x 50 m		
Location	24.9 km SSW of Marillana, 74.2 km NW of Newman and 79.1 km SE of Auski Roadhouse.		
Central Coordinate	734940 mE, 7473765 mN.		
Habitat	Broad plain, east of river (Weeli Wolli Creek).		
Soil	Red-brown sandy loam.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Petalostylis cassioides, Acacia ancistrocarpa* open heath over *Dicrastylis cordifolia* scattered low shrubs over *Amphipogon sericeus, Aristida holathera* var. *holathera*, *A. contorta, Paraneurachne muelleri* tussock grassland with *Triodia basedowii, T.* sp. Shovelanna Hill (S. van Leeuwen 3835) very open hummock grassland. Phase 2: *Petalostylis cassioides, Acacia ancistrocarpa* open heath over *Dicrastylis cordifolia* scattered low shrubs over *Amphipogon sericeus, Aristida holathera* var. *holathera*, *A. contorta, Paraneurachne muelleri* tussock grassland with *Triodia basedowii* very open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Very Good; signs of cattle (tracks).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia ancistrocarpa	1	140 cm		1	140 cm	
Acacia dictyophleba	0.1	200 cm	YBI28-10	0.1	200 cm	
Acacia inaequilatera	0.1	160 cm		0.1	160 cm	
Acacia pachyacra				0.1	150 cm	YBI28-17S
Acacia pruinocarpa	0.1	40 cm		0.1	40 cm	
Amphipogon sericeus	20	40 cm		20	40 cm	
Aristida contorta	4	15 cm		4	15 cm	
Aristida holathera var. *holathera*	10	30 cm		10	30 cm	
Bonamia erecta	0.1	30 cm	YBI28-05			
Corchorus sidoides subsp. *sidoides*				0.1	40 cm	YBI28-18S
Corchorus tectus	0.1	15 cm	YBI28-14			
Cymbopogon ambiguus	0.1	160 cm	YBI28-12			
Cymbopogon obtectus				0.1	60 cm	Dead.
Dicrastylis cordifolia	1.5	60 cm	YBI28-07	1.5	60 cm	
Dodonaea coriacea	0.1	YBI28-01				
Eragrostis eriopoda	0.1	50 cm	YBI28-08	0.1	50 cm	
Eremophila latrobei subsp. *filiformis*	0.1	130 cm	YBI28-06	0.1	130 cm	
Evolvulus alsinoides var. *villosicalyx*				0.1	25 cm	
Hakea lorea subsp. *lorea*				0.1	60 cm	
Hybanthus aurantiacus	0.1	60 cm		0.1	60 cm	
Indigofera monophylla	0.1	70 cm	YBI28-04	0.1	40 cm	
Maireana villosa	0.1	20 cm	YBI28-09			
Mollugo molluginea	0.1	15 cm		0.1	15 cm	
Paraneurachne muelleri	1	40 cm		1	40 cm	
Petalostylis cassioides	30	200 cm		30	200 cm	
Ptilotus astrolasius	0.1	30 cm	YBI28-13	0.1	30 cm	
Ptilotus calostachyus	0.1	40 cm		0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	140 cm		0.1	140 cm	
Scaevola parvifolia subsp. *pilbarae*	0.1	40 cm		0.1	40 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	70 cm	YBI28-02	0.1	72 cm	
Senna glutinosa subsp. *x luerssenii*	0.1	100 cm	YBI28-11	0.1	100 cm	
Sida arenicola				0.1	6 cm	YBI28-19S
Sida cardiophylla	0.1	25 cm	YBI28-15	0.1	25 cm	
Solanum elatius	0.1	100 cm		0.1	100 cm	
Solanum lasiophyllum				0.1	15 cm	
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	0.1	25 cm	YBI28-05			
Trichodesma zeylanicum var. *zeylanicum*				0.1	50 cm	Dead.
Triodia basedowii	5	60 cm	YBI28-03	25	80 cm	YBI28-16S
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	5	60 cm	YBI28-03			

YBI28 Phase 1

YBI28 Phase 2

Yandi Billiards & Junction SW YBI29

Described by Phase 1: PH/RB Phase 2: JA/RB Date Phase 1: 20-Jun-07 Phase 2: 04-Aug-08

Type Quadrat 50 x 50 m

Location 22.9 km SW of Marillana, 76.4 km NW of Newman and 77.4 km SE of Auski Roadhouse.

Central Coordinate 734732 mE, 7476214 mN.

Habitat Broad plain, west of river (Weeli Wolli Creek); sloping gently to east.

Soil Red-brown sandy loam.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Codonocarpus cotinifolius* open shrubland over *Acacia bivenosa*, *Senna glutinosa* subsp. x *luerssenii* low open shrubland over *Triodia basedowii,* (*T. wiseana*) open hummock grassland with *Aristida holathera* var. *holathera*, *Amphipogon sericeus*, *Eragrostis eriopoda* open tussock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Codonocarpus cotinifolius* open shrubland over *Acacia bivenosa*, *Senna glutinosa* subsp. x *luerssenii* low open shrubland over (*Triodia basedowii, T. wiseana*) open hummock grassland with *Aristida holathera* var. *holathera*, *Eragrostis eriopoda* open tussock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: Burnt 1-2 years ago. Phase 2: Burnt 3-5 years ago.

Notes Phase 2: Poor seasonal conditions for sampling. This quadrat is not considered to be seasonally sampled as both phases of sampling were undertaken at times considered to be unfavourable for plant growth

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	20 cm				
Acacia bivenosa	2	50 cm		2	50 cm	
Acacia inaequilatera	0.1	40 cm				
Acacia pruinocarpa				0.1	130 cm	
Acacia tumida var. *pilbarensis*	0.1	70 cm	YBI29-09	0.1	70 cm	
Amphipogon sericeus	1	40 cm		0.1	35 cm	YBI29-25S
Aristida contorta	0.1	20 cm		0.1	20 cm	
Aristida holathera var. *holathera*	15	40 cm		15	40 cm	
Bonamia erecta				0.1	40 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)				0.1	6 cm	
Codonocarpus cotinifolius	2	160 cm		2	160 cm	
Corchorus lasiocarpus	0.1	30 cm				
Dodonaea coriacea				0.1	55 cm	
Enneapogon caerulescens	0.1	20 cm				
Enneapogon polyphyllus	0.1	15 cm				
Eragrostis eriopoda	1	40 cm	YBI28-08=	1	40 cm	
Eriachne aristidea	0.1	10 cm				
Eriachne pulchella				0.1	4 cm	
Eucalyptus gamophylla				0.1	35 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	400 cm		1	400 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	30 cm	YBI29-07	0.1	5 cm	
Gomphrena cunninghamii				0.1	10 cm	
Goodenia microptera	0.1	30 cm	YBI29-05			
Goodenia muelleriana	0.1	40 cm	YBI29-04			
Goodenia stobbsiana	0.1	40 cm		0.1	40 cm	
Heliotropium pachyphyllum	0.1	20 cm	YBI29-08	0.1	20 cm	
Hibiscus coatesii	0.1	45 cm	YBI29-12	0.1	45 cm	
Hibiscus sp.	0.1	40 cm	YBI29-14			
Hibiscus sturtii var. *platychlamys*	0.1	10 cm	YBI29-13	0.1	10 cm	
Hybanthus aurantiacus	0.1	40 cm		0.1	40 cm	
Indigofera monophylla	0.1	20 cm	YBI29-17	0.1	60 cm	YBI29-26S
Maireana planifolia				0.1	110 cm	YBI29-21S
Mollugo molluginea	0.1	20 cm				
Paraneurachne muelleri	0.1	50 cm		0.1	60 cm	
Polycarpaea longiflora	0.1	10 cm	YBI29-02			
Ptilotus astrolasius	0.1	40 cm	YBI29-03	0.1	40 cm	
Ptilotus calostachyus	0.1	120 cm		0.1	120 cm	
Ptilotus nobilis subsp. nobilis	0.1	50 cm		0.1	50 cm	
Rhyncharrhena linearis				0.1	Climber	YBI29-23S
Scaevola parvifolia subsp. *pilbarae*	0.1	30 cm		0.1	30 cm	
Sclerolaena cornishiana	0.1	30 cm	YBI29-15	0.1	30 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	30 cm	YBI28-02=	0.1	100 cm	
Senna glutinosa subsp. *x luerssenii*	1	100 cm		1	100 cm	
Sida arenicola	0.1	35 cm	YBI29-06	0.1	140 cm	YBI29-20S
Sida cardiophylla	0.1	100 cm	YBI29-18	0.1	100 cm	
Sida echinocarpa	0.1	110 cm	YBI29-16	0.1	110 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)				0.1	35 cm	YBI29-24S
Trichodesma zeylanicum var. *zeylanicum*	0.1	70 cm		0.1	70 cm	
Triodia basedowii	20	20 cm	YBI29-01	20	40 cm	YBI29-19S
Triodia pungens				0.1	45 cm	YBI29-22S
Triodia wiseana	5	20 cm		5	20 cm	

YBI29 Phase 1

YBI29 Phase 2

Yandi Billiards & Junction SW		YBI30S	
Described by	Phase 1: RO/PC Phase 2: PA/RB	Date	Phase 1: 03-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 20 x 125 m		
Location	19.3 km SSW of Marillana, 77.1 km NNW of Newman and 77.9 km SE of Auski Roadhouse.		
Central Coordinate	737297 mE, 7478783 mN.		
Habitat	Broad, flat channel within river (Weeli Wolli Creek).		
Soil	Red-brown clay loam; alluvial.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* low woodland over *Melaleuca argentea* tall open shrubland over Ste*modia grossa, Heliotropium pachyphyllum, Phyllanthus maderaspatensis* very open herbland with *Cyperus vaginatus* very open sedgeland.		
	Phase 2: *Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* low open woodland over *Melaleuca argentea* tall open shrubland over *Cyperus vaginatus* very open sedgeland.		
Veg Condition	Phase 1: Good; presence of weeds (**Cenchrus ciliaris, *Setaria verticillata, *Argemone ochroleuca* subsp. *ochroleuca*).		
	Phase 2: Good - Poor; signs of cattle and presence of weeds (**Cenchrus ciliaris, *Setaria verticillata*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon amplum				0.1	10 cm	YBI30S-22
Acacia citrinoviridis	0.1	150 cm		0.1	300 cm	
Amaranthus undulatus	0.1	15 cm	YBI30S-09	0.1	25 cm	YBIS30S-13
Ammannia baccifera	0.1	30 cm	YBI30S-11	0.1	10 cm	
Argemone ochroleuca subsp. *ochroleuca*	0.5	20 cm		0.1	10 cm	
Atalaya hemiglauca	0.1	50 cm		0.1	250 cm	
Cenchrus ciliaris	0.1	7 cm		0.1	40 cm	
Centipeda minima subsp. *macrocephala*	0.1	10 cm	YBI30S-04	0.1	20 cm	
Cleome viscosa	0.5	30 cm		0.1	20 cm	
Corchorus crozophorifolius	0.1	5 cm		0.1	15 cm	
Crotalaria medicaginea var. *neglecta*	0.1	25 cm				
Cymbopogon ambiguus	0.1	90 cm				
Cymbopogon procerus				0.1	110 cm	YBIS30S-11
Cyperus vaginatus	6.5	150 cm		5	130 cm	YBIS30S-12
Digitaria brownii				0.1	60 cm	YBIS30S-21
Dysphania plantaginella	0.1	15 cm	YBI30S-19	0.1	7 cm	YBIS30S-08
Dysphania rhadinostachya	0.1	20 cm				
Enneapogon caerulescens	0.1	20 cm				
Enneapogon lindleyanus				0.1	30 cm	YBIS30S-02
Eragrostis tenellula	0.5	40 cm	YBI30S-02	0.1	4 cm	YBI30S-05
Eriachne mucronata (typical form)				0.1	35 cm	YBIS30S-01
Eriachne pulchella	0.1	15 cm		0.1	15 cm	YBIS30S-03
Eriachne tenuiculmis				0.1	40 cm	YBIS30S-05
Eucalyptus camaldulensis subsp. *refulgens*	12.5	800 cm	10-15%.	5	350 cm	
Eucalyptus victrix	2	1000 cm		2	1500 cm	
Eulalia aurea				0.1	30 cm	
Euphorbia australis var. *subtomentosa*	0.1		YBI30S-20			
Euphorbia biconvexa	0.1	15 cm	YBI30S-07			
Euphorbia coghlanii				0.1	10 cm	YBIS30S-09
Evolvulus alsinoides var. *villosicalyx*	0.1	25 cm				
Flaveria trinervia	0.1	25 cm				
Gomphrena cunninghamii	0.1	15 cm		0.1	10 cm	
Goodenia lamprosperma	0.1	40 cm	YBI30S-06			
Helichrysum luteoalbum	0.1	40 cm	YBI30S-23			
Heliotropium cunninghamii	0.1	20 cm	YBI30S-17	0.1	20 cm	YBIS30S-18
Heliotropium pachyphyllum	1	20 cm	YBI30S-01	0.1	15 cm	YBIS30S-07
Hybanthus aurantiacus				0.1	15 cm	
Indigofera monophylla	0.1	5 cm	YBI30S-25			
Ipomoea muelleri	0.1	Climber		0.1	Creeper	
Ixiochlamys cuneifolia	0.1	15 cm	YBI30S-12			
Lobelia arnhemiaca	0.1	10 cm	YBI30S-10	0.1	5 cm	YBIS30S-17

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Melaleuca argentea	2	200 cm	YBI30S-03	3	300 cm	YBIS30S-16
Paspalidium basicladum	0.1	25 cm	YBI30S-16			
Phyllanthus maderaspatensis	1	Creeper		0.1	12 cm	YBIS30S-06
Pluchea dentex				0.1	15 cm	YBIS30S-14
Pluchea rubelliflora	0.1	30 cm	YBI30S-08	0.1	10 cm	YBIS30S-15
Polycarpaea longiflora	0.1	6 cm				
Pterocaulon sphacelatum	0.1	30 cm	YBI30S-14			
Ptilotus nobilis subsp. *nobilis*	0.1	25 cm				
Rhynchosia minima	0.1	Climber		0.1	Creeper	
Sesbania cannabina	0.1	15 cm		0.1	60 cm	
Setaria verticillata	0.1	25 cm	YBI30S-18	0.1	35 cm	
Sisymbrium orientale	0.1	5 cm	YBI30S-13			
Solanum nigrum	0.1	30 cm				
Sonchus oleraceus	0.1	15 cm		0.1	15 cm	YBIS30S-19
Sorghum plumosum	0.1	40 cm	YBI30S-15	0.1	120 cm	YBIS30S-04
Stemodia grossa	6.5	20 cm		0.1	30 cm	
Streptoglossa decurrens	0.1	30 cm		0.1	15 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.1	25 cm		0.1	20 cm	YBIS30S-20
Trachymene oleracea subsp. *oleracea*	0.1	20 cm				
Tribulus hirsutus	0.1	10 cm	YBI30S-21			
Typha domingensis	0.1	180 cm		0.1	120 cm	
Wahlenbergia tumidifructa	0.1	40 cm	YBI30S-24			
Waltheria indica				0.1	30 cm	

YBI30S Phase 1

YBI30S Phase 2

Yandi Billiards & Junction SW YBI31S

Described by	Phase 1: JA/RB Phase 2: RW/PC	Date	Phase 1: 05-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 50 x 50 m		
Location	24.8 km SSW of Marillana, 73.4 km NW of Newman and 80 km SE of Auski Roadhouse.		
Central Coordinate	735832 mE, 7473419 mN.		
Habitat	Moderately steep, rocky slope of a large hill; facing north.		
Soil	Red-brown loam with pebbles, stones and some outcropping rock; skeletal.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Acacia hilliana* low shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* subsp. *hispidula* scattered tall shrubs over *Acacia hilliana* low shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia adoxa var. *adoxa*	0.1	60 cm		0.1	30 cm	
Acacia arida	0.1	90 cm	YBI31S-06			
Acacia arida x hilliana				0.1	60 cm	YBIS31S-01
Acacia bivenosa	0.1	100 cm		0.1	170 cm	
Acacia hilliana	30	70 cm	YBI31S-01	30	100 cm	
Acacia tenuissima	0.1	150 cm	YBI31S-07			
Eriachne mucronata (typical form)				0.1	30 cm	YBIS31S-05
Eucalyptus leucophloia subsp. *leucophloia*	2	800 cm		2	800 cm	
Fimbristylis dichotoma	0.1	4 cm		0.1	10 cm	YBIS31S-06
Fimbristylis simulans				0.1	6 cm	YBIS31S-07
Goodenia stobbsiana	0.1	15 cm				
Goodenia triodiophila				0.1	40 cm	YBIS31S-02
Grevillea wickhamii subsp. *hispidula*	3	400 cm	YBI31S-04	2	300 cm	
Jasminum didymum subsp. *lineare*	0.1	60 cm	YBI31S-05	0.1	30 cm	
Polycarpaea holtzei				0.1	2 cm	
Schizachyrium fragile	0.1	4 cm		0.1	5 cm	
Senna glutinosa subsp. *glutinosa*	0.1	100 cm		0.1	150 cm	
Senna glutinosa subsp. *x luerssenii*	0.1	120 cm		0.1	150 cm	
Solanum horridum				0.1	2 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	40	40 cm	YBI31S-03	35	20 cm	YBIS31S-03
Triodia wiseana	10	45 cm	YBI31S-02	1	25 cm	YBIS31S-04

YBI31S Phase 1

YBI31S Phase 2

Yandi Billiards & Junction SW YBI32S

Described by	Phase 1: RO/PC Phase 2: PA/RB	Date	Phase 1: 05-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 50 x 50 m		
Location	25.3 km SSW of Marillana, 73.2 km NW of Newman and 80.1 km SE of Auski Roadhouse.		
Central Coordinate	735582 mE, 7472918 mN.		
Habitat	Crest of low stony hill; bordered to west and north by a broad plain.		
Soil	Red-brown clay loam; skeletal.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia aptaneura* scattered tall shrubs over *Acacia bivenosa, A. spondylophylla, Senna glutinosa* subsp. x *luerssenii* open shrubland over *A. hilliana, Tribulus suberosus* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* closed hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* tall open shrubland over *A. spondylophylla* scattered shrubs over *A. hilliana* scattered low shrubs over *Triodia wiseana, T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia ancistrocarpa	0.1	140 cm		0.1	150 cm	
Acacia aptaneura	0.5	420 cm	YBI32S-03			
Acacia bivenosa	9	200 cm		2	250 cm	
Acacia hilliana	1	60 cm		1	60 cm	YBIS32S-12
Acacia spondylophylla	1.5	140 cm		1	120 cm	
Acacia synchronicia	0.1	170 cm				
Acacia tenuissima	0.1	190 cm	YBI32S-05			
Aristida contorta	0.1	20 cm				
Aristida holathera var. *holathera*	0.1	40 cm				
Bulbostylis barbata				0.1	15 cm	YBIS32S-04
Cymbopogon obtectus				0.1	80 cm	YBIS32S-08
Dicrastylis cordifolia				0.1	50 cm	YBIS32S-11
Duperreya commixta				0.1	Climber	
Eriachne pulchella				0.1	15 cm	YBIS32S-02
Eucalyptus gamophylla	0.1	170 cm		0.1	200 cm	
Eucalyptus leucophloia subsp. *leucophloia*	2	900 cm		1	700 cm	
Fimbristylis simulans				0.1	10 cm	YBIS32S-07
Gompholobium oreophilum	0.1	60 cm	YBI32S-06			
Goodenia triodiophila	0.1	30 cm		0.1	25 cm	YBIS32S-06
Grevillea wickhamii	0.1	150 cm				
Hakea lorea subsp. *lorea*	0.1	45 cm		0.1	40 cm	YBIS32S-15
Paraneurachne muelleri	0.1	60 cm		0.1	35 cm	
Polycarpaea corymbosa var. *corymbosa*				0.1	15 cm	YBIS32S-05
Ptilotus obovatus var. *obovatus*				0.1	100 cm	
Sclerolaena cornishiana	0.1	30 cm	YBI32S-07			
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	120 cm	YBI32S-01	0.1	120 cm	YBIS32S-13
Senna glutinosa subsp. *glutinosa*	0.1	150 cm				
Senna glutinosa subsp. *glutinosa x* subsp. *x luerssenii*				0.1	100 cm	YBIS32S-10
Senna glutinosa subsp. *pruinosa*				0.1	45 cm	
Senna glutinosa subsp. *x luerssenii*	1	110 cm		0.1	70 cm	YBIS32S-14
Senna sericea				0.1	50 cm	YBIS32S-09
Senna sp. Meekatharra (E. Bailey 1-26)	0.1	200 cm	YBI32S-04			
Solanum elatius	0.1	40 cm	YBI32S-08			
Solanum horridum	0.1	30 cm		0.1	20 cm	
Solanum lasiophyllum	0.1	60 cm		0.1	60 cm	
Tribulus suberosus	0.5	65 cm		0.1	50 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	35	40 cm	YBI32S-02	20	25 cm	YBIS32S-03
Triodia wiseana	32.5	70 cm		40	40 cm	YBIS32S-01

YBI32S Phase 1

YBI32S Phase 2

Yandi Billiards & Junction SW		YBI33S	
Described by	Phase 1: JA/RB Phase 2: RW/PC	Date	Phase 1: 05-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 50 x 50 m		
Location	21.9 km SSW of Marillana, 75 km NW of Newman and 79.2 km SE of Auski Roadhouse.		
Central Coordinate	736947 mE, 7476048 mN.		
Habitat	Crest of a low rocky hill.		
Soil	Red-brown loam.		
Rock Type	Ironstone and Quartz - brittle.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Acacia hilliana*, (*Gompholobium oreophilum*) low open heath over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana, T. pungens*) open hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Grevillea wickhamii* subsp. *hispidula* tall open shrubland over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. pungens*) open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: Burnt 1-2 years ago. Phase 2:		
Notes	Phase 1: Dry conditions; annuals were dead.		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia adoxa var. *adoxa*				0.1	40 cm	YBIS33S-10
Acacia ayersiana				0.1	160 cm	YBIS33S-09
Acacia hilliana	40	70 cm		7.5	30 cm	
Acacia pruinocarpa	0.1	120 cm		0.1	200 cm	
Aristida holathera var. *holathera*	0.1	20 cm		0.1	25 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)				0.1	5 cm	YBIS33S-01
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm	YBI33S-05			
Corchorus lasiocarpus subsp. *parvus*				0.1	40 cm	YBIS33S-08
Eriachne mucronata (arid form)				0.1	35 cm	YBIS33S-13
Eriachne mucronata (typical form)	0.1	45 cm				
Eriachne pulchella				0.1	3 cm	YBIS33S-03
Eucalyptus leucophloia subsp. *leucophloia*	2	400 cm		3.5	600 cm	
Fimbristylis simulans				0.1	20 cm	YBIS33S-02
Gompholobium oreophilum	3	70 cm		0.1	110 cm	YBIS33S-11
Goodenia stobbsiana				0.1	20 cm	
Goodenia triodiophila				0.1	50 cm	YBIS33S-12
Grevillea wickhamii subsp. *hispidula*	3	350 cm	YBI33S-01	7.5	300 cm	
Petalostylis cassioides	0.1	140 cm		0.1	60 cm	YBIS33S-07
Polycarpaea longiflora	0.1	40 cm				
Ptilotus calostachyus	0.1	60 cm		0.1	100 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*				0.1	40 cm	YBIS33S-06
Senna glutinosa subsp. *x luerssenii*	0.1	200 cm	YBI33S-03	0.1	80 cm	
Solanum lasiophyllum	0.1	70 cm	YBI33S-02	0.1	50 cm	
Triodia pungens	1	90 cm	YBI33S-06	1	35 cm	YBIS33S-05
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	40	30 cm	YBIS31S-03	25	30 cm	YBIS33S-04
Triodia wiseana	5	40 cm				

YBl33S Phase 1

YBl33S Phase 2

Yandi Billiards & Junction SW		YBI34S	
Described by	Phase 1: RO/PC Phase 2: PA/RB	Date	Phase 1: 05-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 50 x 50 m		
Location	21.4 km SSW of Marillana, 75.3 km NW of Newman and 79 km SE of Auski Roadhouse.		
Central Coordinate	737033 mE, 7476575 mN.		
Habitat	Broad plain located at foot of surrounding hills.		
Soil	Red-brown loam with medium to high clay content; colluvial and alluvial deposition.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Eucalyptus gamophylla* scattered low mallee tress over *Acacia bivenosa*, *Petalostylis cassioides* open shrubland over *Acacia tenuissima*, *A. adsurgens* low open shrubland over *Triodia basedowii*, (*T. wiseana, T. pungens, T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) hummock grassland over *Paraneurachne muelleri* scattered tussock grasses. Phase 2: *Eucalyptus gamophylla* scattered low mallees over *Acacia bivenosa*, *A. ancistrocarpa* tall open shrubland over *Petalostylis cassioides* scattered low shrubs over *Triodia basedowii*, (*T. pungens, T. wiseana*) open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Very Good; presence of weeds (**Setaria verticillata*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Acacia adoxa var. *adoxa*	0.5	65 cm		0.1	100 cm	YBIS34S-28
Acacia adsurgens	1	75 cm	YBI34S-03	0.1	100 cm	YBIS34S-40
Acacia ancistrocarpa	3	120 cm	YBI34S-14	1	300 cm	
Acacia aptaneura	0.1	120 cm	YBIS34S-38			
Acacia bivenosa	8.5	210 cm		3	250 cm	
Acacia citrinoviridis	0.1	220 cm	YBI34S-15	0.1	300 cm	
Acacia dictyophleba	0.1	50 cm		0.1	150 cm	
Acacia hilliana	0.5	80 cm		0.1	60 cm	
Acacia tenuissima	2.5	70 cm	YBI34S-04	0.1	170 cm	YBIS34S-33
Acacia tumida var. *pilbarensis*				0.1	15 cm	YBIS34S-11
Aristida contorta				0.1	25 cm	
Aristida holathera var. *holathera*	0.5	30 cm		0.1	65 cm	
Bonamia erecta				0.1	40 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	0.1	30 cm				
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	80 cm	YBI34S-16	0.1	100 cm	YBIS34S-25
Crotalaria medicaginea var. *neglecta*	0.1	20 cm		0.1	35 cm	YBIS34S-07
Cucumis variabilis				0.1	15 cm	
Cymbopogon obtectus	0.5	55 cm	YBI34S-13	0.1	130 cm	YBIS34S-23
Dicrastylis cordifolia				0.1	30 cm	YBIS34S-08
Digitaria brownii				0.1	60 cm	YBIS34S-01
Dodonaea coriacea	0.1	135 cm		0.1	110 cm	
Duperreya commixta	0.1	Climber		0.1	Climber	
Enneapogon polyphyllus	0.1	35 cm		0.1	35 cm	
Eragrostis eriopoda	0.1	40 cm		0.1	40 cm	YBIS34S-34
Eriachne aristidea				0.1	30 cm	
Eriachne pulchella				0.1	15 cm	YBIS34S-05
Eucalyptus gamophylla	2	320 cm		1	350 cm	
Eucalyptus leucophloia subsp. *leucophloia*	1	700 cm				
Euphorbia australis var. *erythrantha*				0.1	20 cm	YBIS34S-31
Evolvulus alsinoides var. *villosicalyx*				0.1	15 cm	
Goodenia microptera				0.1	35 cm	YBIS34S-22
Goodenia muelleriana				0.1	40 cm	YBIS34S-14
Goodenia stobbsiana				0.1	40 cm	YBIS34S-27
Grevillea wickhamii subsp. *hispidula*	0.5	260 cm		0.1	350 cm	YBIS34S-24
Hakea chordophylla				0.1	250 cm	YBIS34S-29
Haloragis gossei				0.1	15 cm	YBIS34S-37
Heliotropium pachyphyllum				0.1	15 cm	YBIS34S-19
Hibiscus coatesii	0.1	165 cm	YBI34S-17			
Hibiscus sturtii var. *campylochlamys*	0.1	25 cm	YBI34S-12	0.1	10 cm	YBIS34S-15
Hybanthus aurantiacus				0.1	20 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Indigofera monophylla	0.1	35 cm	YBI34S-02	0.1	30 cm	YBIS34S-16
Isotropis atropurpurea	0.1	40 cm	YBI34S-09			
Keraudrenia nephrosperma				0.1	150 cm	YBIS34S-17
Keraudrenia velutina subsp. *elliptica*	0.1	100 cm	YBI34S-11			
Mollugo molluginea				0.1	15 cm	YBIS34S-09
Paraneurachne muelleri	1.5	40 cm		0.1	30 cm	
Petalostylis cassioides	2	170 cm		1	130 cm	YBIS34S-12
Phyllanthus erwinii				0.1	15 cm	YBIS34S-06
Polycarpaea longiflora	0.1	30 cm				
Pterocaulon sphacelatum	0.1	60 cm		0.1	4 cm	YBIS34S-39
Ptilotus astrolasius	0.1	50 cm		0.1	40 cm	
Ptilotus auriculifolius				0.1	25 cm	YBIS34S-02
Ptilotus calostachyus				0.1	85 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	40 cm		0.1	4 cm	
Ptilotus obovatus var. *obovatus*	0.1	60 cm				
Scaevola parvifolia subsp. *pilbarae*	0.1	30 cm		0.1	30 cm	
Schizachyrium fragile				0.1	40 cm	YBIS34S-21
Sclerolaena cornishiana	0.1	35 cm	YBI34S-08	0.1	50 cm	YBIS34S-03
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.5	65 cm	YBI34S-18	0.1	50 cm	
Senna glutinosa subsp. *glutinosa x* subsp. *x luerssenii*				0.1	100 cm	YBIS34S-32
Senna glutinosa subsp. *x luerssenii*	0.1	100 cm				
Senna notabilis				0.1	10 cm	
Setaria verticillata				0.1	35 cm	
Sida arenicola				0.1	20 cm	YBIS34S-13
Sida cardiophylla	0.1	55 cm	YBI34S-07	0.1	3 cm	YBIS34S-35
Solanum lasiophyllum	0.1	60 cm		0.1	100 cm	
Streptoglossa decurrens				0.1	20 cm	YBIS34S-10
Tephrosia sp. Fortescue (A.A. Mitchell 606) PN				0.1	10 cm	YBIS34S-26
Tephrosia sp. NW Eremaean (S. van Leeuwen et. al PBS 0356) PN				0.1	10 cm	YBIS34S-20
Tephrosia supina				0.1	15 cm	YBIS34S-30
Trachymene oleracea subsp. *oleracea*				0.1	40 cm	
Trichodesma zeylanicum var. *zeylanicum*				0.1	35 cm	
Triodia basedowii	30			20	25 cm	YBIS34S-04
Triodia pungens	4	45 cm	YBI34S-10	4	100 cm	YBIS34S-18
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	1.5	50 cm				
Triodia wiseana	6	30 cm	YBI34S-05	1	50 cm	

YBI34S Phase 1

YBI34S Phase 2

Yandi Billiards & Junction SW		YBI35S	
Described by	Phase 1: RB/RO Phase 2: RW/PC	Date	Phase 1: 05-Aug-08 Phase 2: 04-Jun-09
Type	Quadrat 50 x 50 m		
Location	22.8 km SSW of Marillana, 74.3 km NW of Newman and 79.6 km SE of Auski Roadhouse.		
Central Coordinate	736781 mE, 7475190 mN.		
Habitat	Floodplain adjacent to minor creekline; at base of low foothills.		
Soil	Red sandy loam. Creek is loamy.		
Rock Type	Banded Ironstone Formation; stony on higher ground.		
Vegetation	Phase 1: *Corymbia hamersleyana* low open woodland over *Acacia pyrifolia* var. *pyrifolia*, *A. tumida* var. *pilbarensis*, *A. pachyacra* tall shrubland over *Senna artemisioides* subsp. *helmsii*, *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii*, *Indigofera georgei* open shrubland over *Petalostylis cassioides* low scattered shrubs over *Triodia pungens* hummock grassland. Phase 2: *Corymbia hamersleyana* low open woodland over *Acacia pyrifolia* var. *pyrifolia, Grevillea wickhamii* tall shrubland over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia pungens*, (*T. basedowii*) open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Very Good; presence of weeds (**Cenchrus ciliaris*).		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Phase 1: Drainage line vegetation on southern edge of quadrat is the same as rest of vegetation in the quadrat, except there are more tall shrubs (higher density) and the substrate is sandy loam and less rocky.		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon otocarpum				0.1	3 cm	
Acacia bivenosa				0.1	160 cm	
Acacia pachyacra	0.1	200 cm		1	350 cm	YBI35S-09
Acacia pruinocarpa	0.1	60 cm		0.1	30 cm	
Acacia pyrifolia var. *pyrifolia*	15	350 cm		10	300 cm	
Acacia tumida var. *pilbarensis*	5	350 cm		0.1	170 cm	
Alternanthera nana				0.1	10 cm	
Aristida holathera var. *holathera*				0.1	10 cm	
Boerhavia coccinea				0.1	25 cm	YBIS35S-07
Bonamia erecta	0.1	30 cm		0.1	30 cm	
Bulbostylis barbata				0.1	15 cm	
Cenchrus ciliaris				0.1	15 cm	
Cleome viscosa				0.1	100 cm	
Corymbia hamersleyana	2	800 cm		3	800 cm	
Crotalaria medicaginea var. *neglecta*				0.1	30 cm	
Cucumis variabilis				0.1	Climber	
Dicrastylis cordifolia				0.1	100 cm	YBI35S-01
Duperreya commixta	0.1	Climber		0.1	Climber	
Enneapogon caerulescens				0.1	25 cm	YBIS35S-08
Enneapogon polyphyllus				0.1	25 cm	YBIS35S-04
Eragrostis cumingii				0.1	15 cm	YBIS35S-05
Eragrostis eriopoda	0.1	50 cm		0.1	10 cm	YBIS35S-03
Eucalyptus gamophylla	0.1	300 cm		0.1	350 cm	
Euphorbia australis var. *erythrantha*				0.1	30 cm	YBIS35S-02
Euphorbia tannensis subsp. *eremophila*				0.1	30 cm	YBIS35S-12
Evolvulus alsinoides var. *villosicalyx*	0.1	10 cm		0.1	20 cm	
Gomphrena cunninghamii				0.1	5 cm	
Goodenia microptera				0.1	20 cm	
Gossypium robinsonii	0.1	120 cm		0.1	200 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	250 cm		1	300 cm	
Heliotropium cunninghamii	0.1	20 cm	YBIS35S-09			
Hibiscus sturtii var. *platychlamys*	0.1	40 cm	YBI35S-08	0.1	8 cm	
Hybanthus aurantiacus				0.1	30 cm	
Indigofera georgei	1	100 cm	YBI35S-06	0.1	45 cm	
Jasminum didymum subsp. *lineare*	0.1	400 cm		0.1	6 cm	
Paspalidium basicladum	0.1	20 cm	YBI35S-04	0.1	20 cm	
Perotis rara				0.1	4 cm	YBIS35S-06
Petalostylis cassioides	1	90 cm		0.1	100 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Phyllanthus erwinii				0.1	30 cm	YBIS35S-13
Polycarpaea longiflora				0.1	20 cm	
Pterocaulon sphacelatum				0.1	30 cm	
Ptilotus astrolasius	0.1	30 cm		0.1	10 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	75 cm		0.1	25 cm	
Ptilotus polystachyus				0.1	25 cm	YBIS35S-10
Scaevola parvifolia subsp. *pilbarae*				0.1	20 cm	
Senna artemisioides subsp. *helmsii*	1	130 cm		0.1	150 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	1	100 cm	YBI35S-03	1	60 cm	
Senna notabilis				0.1	20 cm	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	30 cm	YBI35S-07	0.1	20 cm	
Solanum lasiophyllum	0.1	70 cm		0.1	40 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	20 cm	YBIS35S-01			
Trachymene oleracea subsp. *oleracea*				0.1	30 cm	
Trianthema pilosum				0.1	10 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	70 cm		0.1	120 cm	
Triodia basedowii	0.1	40 cm	YBI35S-05	1.5	50 cm	YBIS35S-11
Triodia pungens	45	70 cm	YBI35S-02	20	50 cm	
Waltheria indica				0.1	12 cm	YBIS35S-14

YBI35S Phase 1

YBI35S Phase 2

Yandi Billiards & Junction SW /Yandi Billiards Level 2 YBI36

Described by Phase 1: PH/RB Phase 2: PLDK Date Phase 1: 19-Jun-07 Phase 2: 12-Mar-14

Type Quadrat 50 x 50 m

Location 18 km SW of Marillana, 77.3 km SE of Auski Roadhouse and 78.1 km NNW of Newman.

Central Coordinate 737586 mE, 7480165mN.

Habitat Slope of colluvial spur; east-facing.

Soil Red-brown sandy loam with 10% cover of boulders 10% cover of cobbles and 80% cover of pebbles.

Rock Type Ironstone.

Vegetation Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia pruinocarpa, A. bivenosa* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) closed hummock grassland.
Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Acacia bivenosa* (wispy/weeping form) scattered shrubs over *Goodenia stobbsiana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) open hummock grassland.

Veg Condition Phase 1: Excellent. Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: Burnt 3-5 years ago.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon lepidum				0.1	20 cm	YBIR36-04
Acacia adoxa var. adoxa	0.1	50 cm		0.1	50 cm	
Acacia bivenosa	2	350 cm				
Acacia bivenosa (wispy/weeping form)				0.5	200 cm	
Acacia inaequilatera	0.1	150 cm		0.1	70 cm	
Acacia pruinocarpa	2	350 cm		2	500 cm	
Amphipogon sericeus				0.1	30 cm	YBIR36-01
Aristida holathera var. holathera				0.1	40 cm	
Bonamia sp. Dampier (A.A. Mitchell PRP 217)				0.1	15 cm	
Corchorus lasiocarpus subsp. lasiocarpus				0.1	90 cm	YBIR36-07
Corymbia hamersleyana	0.1	40 cm	YBI28-06			
Dodonaea coriacea				0.1	80 cm	
Dodonaea viscosa	0.1	35 cm	YBI28-02			
Eriachne aristidea				0.1	25 cm	
Eriachne mucronata (typical form)	0.1	30 cm		0.1	40 cm	
Eriachne pulchella				0.1	10 cm	
Eucalyptus leucophloia subsp. leucophloia	3	600 cm		1.5	600 cm	
Gomphrena cunninghamii				0.1	15 cm	
Goodenia microptera				0.1	25 cm	
Goodenia muelleriana				0.1	40 cm	YBIR36-02
Goodenia stobbsiana	0.1	5 cm		0.5	50 cm	
Goodenia triodiophila				0.1	30 cm	
Grevillea wickhamii subsp. hispidula	0.1	100 cm		0.1	160 cm	
Hakea lorea subsp. lorea	0.1	40 cm		0.1	60 cm	
Mollugo molluginea				0.1	5 cm	
Paraneurachne muelleri	0.1	50 cm		0.1	40 cm	
Polycarpaea holtzei	0.1	4 cm				
Polycarpaea longiflora	0.1	30 cm				
Polygala glaucifolia				0.1	2 cm	YBIR36-06
Ptilotus astrolasius				0.1	50 cm	
Ptilotus calostachyus	0.1	50 cm		0.1	60 cm	
Ptilotus nobilis subsp. nobilis				0.1	40 cm	
Ptilotus obovatus var. obovatus	0.1	30 cm	YBI28-01			
Ptilotus rotundifolius	0.1	40 cm		0.1	140 cm	
Salsola australis				0.1	25 cm	
Senna glutinosa subsp. glutinosa				0.1	190 cm	
Senna glutinosa subsp. glutinosa x subsp. x luerssenii	0.1	60 cm	YBI28-04	0.1	190 cm	YBIR36-05
Senna glutinosa subsp. pruinosa	0.1	100 cm		0.1	140 cm	
Solanum lasiophyllum	0.1	40 cm		0.1	50 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Solanum phlomoides				0.1	30 cm	
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356) PN	0.1	5 cm	YBI28-05	0.1	20 cm	YBIR36-03
Tribulus suberosus	0.1	70 cm		0.1	60 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	70	20 cm	YBI28-03	11	30 cm	
Triodia wiseana	5	30 cm		2	40 cm	

YBI36S Phase 1

YBI36S Phase 2

Yandi Billiards & Junction SW YBI-RBMA

Described by	BRM	Date	20-Jun-07	Type	Relevé; Unbounded

Location 17.7 km SSW of Marillana, 76.5 km NNW of Newman and 79.2 km SE of Auski Roadhouse.
Central Coordinate 739373 mE, 7479492 mN.
Habitat Crest of low hill.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Eucalyptus leucophloia*, *Acacia pruinocarpa* scattered low trees over *A. pachyacra, A. dictyophleba* scattered tall shrubs over *Senna artemisioides* subsp. *helmsii* scattered shrubs over *Ptilotus rotundifolius* scattered low shrubs over *Triodia basedowii* hummock grassland.
Veg Condition Excellent.
Fire Age Not recorded.

Species	Specimen
Acacia citrinoviridis	
Acacia dictyophleba	YSW06-02=
Acacia pachyacra	YBI27-05
Acacia pruinocarpa	
Corchorus crozophorifolius	
Cymbopogon ambiguus	
Eucalyptus leucophloia subsp. *leucophloia*	
Goodenia stobbsiana	
Hakea chordophylla	
Heliotropium pachyphyllum	YBRB11-01
Ptilotus rotundifolius	
Senna artemisioides subsp. *helmsii*	
Triodia basedowii	

YBI-RBMA

Yandi Billiards & Junction SW YBI-RBMB

Described by	BRM	Date	20-Jun-07	Type	Relevé; Unbounded

Location	16.8 km SSW of Marillana, 76.1 km NNW of Newman and 80.1 km SE of Auski Roadhouse.
Central Coordinate	740724 mE, 7479843 mN.
Habitat	Broad plain south of minor creekline; very gentle slope to northwest.
Soil	Not recorded.
Rock Type	Not recorded.
Vegetation	*Acacia inaequilatera, Petalostylis cassioides* tall open shrubland over *Triodia basedowii* hummock grassland.
Veg Condition	Not recorded.
Fire Age	Not recorded.

Species	Specimen
Acacia inaequilatera	
Acacia pachyacra	YBI27-05=
Anthobolus leptomerioides	
Aristida holathera var. *holathera*	
Eragrostis eriopoda	
Petalostylis cassioides	
Triodia basedowii	YBI22-01=

YBI-RBMB

Yandi Billiards & Junction SW YBI-RBMC

Described by	BRM	Date	20-Jun-07	Type	Relevé Unbounded

Location 17 km SSW of Marillana, 76.4 km NNW of Newman and 79.6 km SE of Auski Roadhouse.
Central Coordinate 740204 mE, 7479880 mN.
Habitat Broad plain south of minor creekline; very gentle slope to northeast.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. pachyacra*,*A. sclerosperma* subsp. *sclerosperma* tall open shrubland over *Senna artemisioides* subsp. *oligophylla*, *S. artemisioides* subsp. *helmsii* scattered shrubs over *Triodia pungens* hummock grassland.
Veg Condition Not recorded.
Fire Age Not recorded.

Species	Specimen
Acacia inaequilatera	
Acacia pachyacra	YBI27-05=
Acacia pruinocarpa	
Acacia sclerosperma subsp. *sclerosperma*	YBI09-01=
Senna artemisioides subsp. *helmsii*	
Senna artemisioides subsp. *oligophylla*	
Triodia pungens	YBRB06-01=

YBI-RBMC

Yandi Billiards & Junction SW YBI-RBMD

Described by	BRM	Date	19-Jun-07	Type	Relevé; Unbounded

Location	13.7 km SSW of Marillana, 78.1 km ESE of Auski Roadhouse and 79.2 km NNW of Newman.
Central Coordinate	740689 mE, 7483356 mN.
Habitat	Crest of low rise within broad plain.
Soil	Not recorded.
Rock Type	Not recorded.
Vegetation	*Corymbia hamersleyana*, *Acacia pruinocarpa* scattered low trees over *Acacia sclerosperma* subsp. *sclerosperma* scattered tall shrubs over *Triodia pungens* hummock grassland.
Veg Condition	Good; presence of weeds (**Cenchrus ciliaris*).
Fire Age	Not recorded.

Species	Specimen
Acacia pruinocarpa	
Acacia sclerosperma subsp. *sclerosperma*	YBI09-01=
Atalaya hemiglauca	
Cenchrus ciliaris	
Corymbia hamersleyana	
Senna artemisioides subsp. *oligophylla*	
Triodia pungens	YBI06-01=

YBI-RBMD

Yandi Billiards & Junction SW YBI-RBME

Described by	BRM	Date	19-Jun-07	Type	Relevé; Unbounded

Location 14.1 km SSW of Marillana, 77.9 km NNW of Newman and 79.4 km ESE of Auski Roadhouse.
Central Coordinate 741635 mE, 7482360 mN.
Habitat Flowline at base of steep low ridge; narrow creek channel and adjacent low banks.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis*, (*A. pyrifolia*, *Gossypium robinsonii*) tall open scrub over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) scattered low shrubs over *Triodia pungens* hummock grassland with **Cenchrus ciliaris* open tussock grassland.
Veg Condition Poor; presence of weeds (**Cenchrus ciliaris*).
Fire Age Not recorded.

Species	Specimen
Acacia bivenosa	
Acacia pyrifolia var. *pyrifolia*	
Acacia tumida var. *pilbarensis*	
Atalaya hemiglauca	
Cenchrus ciliaris	
Corymbia hamersleyana	
Cymbopogon obtectus	
Eriachne mucronata (typical form)	
Gossypium robinsonii	
Grevillea wickhamii subsp. *hispidula*	YBRB7-5
Melhania oblongifolia	
Paraneurachne muelleri	
Pterocaulon sphacelatum	YSW06-13=
Rhynchosia minima	
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	YBRB7-1; YBRB7-3
Tephrosia rosea var. Fortescue creeks M.I.H. (Brooker 2186) PN	
Themeda triandra	
Triodia pungens	YBRB7-2

YBI-RBME

Yandi Billiards & Junction SW YBI-RBMF

Described by	BRM	Date	19-Jun-07	Type	Relevé; Unbounded

Location 14 km SSW of Marillana, 78.1 km ESE of Auski Roadhouse and 79.1 km NNW of Newman

Central Coordinate 740486 mE, 7483133 mN.

Habitat Flat floodplain of river (eastern side of Weeli Wolli Creek).

Soil Not recorded.

Rock Type Not recorded.

Vegetation *Acacia citrinoviridis, Corymbia hamersleyana, Acacia pruinocarpa, Atalaya hemiglauca, Hakea lorea* subsp. *lorea* low open woodland over *Acacia sclerosperma* subsp. *sclerosperma* scattered tall shrubs over **Cenchrus ciliaris*,(**Cenchrus setiger*) closed tussock grassland with *Triodia pungens* scattered hummock grasses.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*).

Fire Age Not recorded.

Species	Specimen
Acacia citrinoviridis	
Acacia pruinocarpa	
Acacia sclerosperma subsp. *sclerosperma*	
Atalaya hemiglauca	
Cenchrus ciliaris	
Cenchrus setiger	
Corymbia hamersleyana	
Euphorbia biconvexa	YBRB6-02
Hakea lorea subsp. *lorea*	
Rhagodia eremaea	
Triodia pungens	YBRB06-01

YBI-RBMF

Yandi Billiards & Junction SW YBI-RBMG

Described by BRM Date 18-Jun-07 Type Relevé; Unbounded

Location 28.6 km SW of Marillana, 74.6 km NW of Newman and 78 km SE of Auski Roadhouse.

Central Coordinate 731460 mE, 7471589 mN.

Habitat Low stony rise, west of river (Weeli Wolli Creek).

Soil Not recorded.

Rock Type Not recorded.

Vegetation *Acacia synchronicia* scattered tall shrubs over *Eremophila fraseri*, *Senna artemisioides* subsp. *helmsii* open shrubland over *Aristida contorta*, *Paraneurachne muelleri, Enneapogon polyphyllus*, *Eragrostis eriopoda*, (**Cenchrus ciliaris*) grassland

Veg Condition Good; presence of weeds (**Cenchrus ciliaris*).

Fire Age No sign of recent fire.

Species	Specimen
Acacia synchronicia	
Amyema hilliana	YBRB05-01
Aristida contorta	
Cenchrus ciliaris	
Chrysopogon fallax	
Enneapogon polyphyllus	
Eragrostis eriopoda	
Eremophila fraseri subsp. *fraseri*	
Paraneurachne muelleri	
Ptilotus obovatus	
Rhagodia eremaea	
Sclerolaena cornishiana	YBI19-04=
Senna artemisioides subsp. *helmsii*	
Senna artemisioides subsp. *oligophylla*	
Solanum lasiophyllum	YBI19-25=
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	YBRB5-02

YBI-RBMG

Yandi Billiards & Junction SW YBI-RBMH

Described by	BRM	Date	18-Jun-07	Type	Relevé; Unbounded

Location 28.8 km SW of Marillana, 74.2 km NW of Newman and 78.4 km SE of Auski Roadhouse.
Central Coordinate 731663 mE, 7471233 mN.
Habitat Flat floodplain of river (west side of Weeli Wolli Creek); wide plain between river and range of hills to west and northwest.
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *Hakea lorea* subsp. *lorea* scattered tall shrubs over **Cenchrus ciliaris*, (**C. setiger*) closed tussock grassland.
Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*).
Fire Age No sign of recent fire.

Species	Specimen
Acacia pruinocarpa	
Capparis lasiantha	YBRB04-01
Cenchrus ciliaris	
Cenchrus setiger	
Corymbia hamersleyana	
Hakea lorea subsp. *lorea*	
Malvastrum americanum	
Pterocaulon sphacelatum	

YBI-RBMH

Yandi Billiards & Junction SW YBI-RBMI

Described by BRM Date 17-Jun-07 Type Relevé; Unbounded

Location 22.9 km SSW of Marillana, 75.3 km NW of Newman and 78.5 km SE of Auski Roadhouse.

Central Coordinate 735658 mE, 7475639 mN.

Habitat Broad, shallow drainage area through broad plain; feeds into floodplain fringing river (Weeli Wolli Creek).

Soil Not recorded.

Rock Type Not recorded.

Vegetation *Corymbia candida, Acacia aptaneura* woodland over *A. citrinoviridis, A. pruinocarpa* low woodland over *Eremophila longifolia*, *A. bivenosa* scattered shrubs over *Senna artemisioides* subsp. *oligophylla*, *Eremophila forrestii* subsp. *forrestii* low open shrubland over *Eulalia aurea*, **Cenchrus ciliaris, Chrysopogon fallax, Themeda triandra, Eriachne mucronata* open tussock grassland with *Triodia longiceps* very open hummock grassland.

Veg Condition Good; presence of weeds (**Cenchrus ciliaris, *Malvastrum americanum*).

Fire Age No sign of recent fire.

Species	Specimen
Acacia aptaneura	YBRB3-10 YBRB3-02
Acacia ayersiana	YBRB3-04
Acacia bivenosa	
Acacia citrinoviridis	
Acacia pruinocarpa	
Alternanthera nana	
Cenchrus ciliaris	
Chrysopogon fallax	
Corymbia candida	YBRB3-01
Corymbia hamersleyana	
Cucumis variabilis	YBRB3-07
Cullen leucochaites	YBRB3-5
Digitaria brownii	YBRB3-03
Dipteracanthus australasicus subsp. *australasicus*	YBRB3-09
Duperreya commixta	
Enneapogon polyphyllus	
Eremophila forrestii subsp. *forrestii*	
Eremophila longifolia	
Eriachne mucronata (typical form)	
Eulalia aurea	
Glycine canescens	YBRB3-11
Gossypium australe	
Malvastrum americanum	
Panicum effusum	YBRB3-8
Psydrax latifolia	
Senna artemisioides subsp. *oligophylla*	
Senna artemisioides subsp. *x artemisioides*	YBRB3-06
Stemodia grossa	
Themeda triandra	
Triodia longiceps	

YBI-RBMI

Yandi Billiards & Junction SW YBI-RBMJ

Described by BRM Date 16-Jun-07 Type Relevé; Unbounded

Location 24.2 km SW of Marillana, 75.7 km NW of Newman and 77.7 km SE of Auski Roadhouse.

Central Coordinate 734179 mE, 7475082 mN.

Habitat Banks fringing river channel (Weeli Wolli Creek).

Soil Not recorded.

Rock Type Not recorded.

Vegetation *Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp.*pendens* low woodland over *Themeda triandra, Cymbopogon ambiguus* tussock grassland with *Triodia longiceps* hummock grassland.

Veg Condition Very Good.

Fire Age Not recorded.

Name	Specimen
Acacia citrinoviridis	
Acacia coriacea subsp. *pendens*	
Corchorus lasiocarpus	YBRB2-03
Cymbopogon ambiguus	YBRB2-01
Duperreya commixta	
Enneapogon robustissimus	YBRB2-04
Eriachne tenuiculmis	
Eucalyptus victrix	
Stemodia grossa	
Stylobasium spathulatum	
Themeda triandra	
Triodia longiceps	YBRB2-02

No photo.

Yandi Billiards & Junction SW YBI-RBMK

Described by	BRM	Date	15-Jun-07	Type	Relevé; Unbounded

Location 17.2 km SSW of Marillana, 77.7 km SE of Auski Roadhouse and 78 km NNW of Newman
Central Coordinate 738444 mE, 7480649 mN.
Habitat Flat floodplain of river (Weeli Wolli Creek).
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Acacia citrinoviridis, Atalaya hemiglauca* low woodland over *Rhagodia eremaea, Ptilotus obovatus* var. *obovatus* scattered shrubs over **Cenchrus ciliaris*, (**C. setiger*) closed tussock grassland.
Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris*).
Fire Age No sign of recent fire.

Species	Specimen
Acacia citrinoviridis	
Acacia coriacea subsp. *pendens*	
Acacia pruinocarpa	
Atalaya hemiglauca	
Cenchrus ciliaris	
Cenchrus setiger	
Gossypium australe	
Malvastrum americanum	
Pterocaulon sphacelatum	
Ptilotus obovatus var. *obovatus*	
Rhagodia eremaea	YBI03-04=

YBI-RBMK

Yandi Billiards & Junction SW YBI-RPHA

Described by RW/PH Date 16-Jun-07 Type Relevé; Unbounded

Location 20.8 km SW of Marillana, 76.6 km SE of Auski Roadhouse and 77.7 km NW of Newman.

Central Coordinate 735388 mE, 7478389 mN.

Habitat Bank / floodplain of major creek (Marillana Creek).

Soil Not recorded.

Rock Type Not recorded.

Vegetation *Acacia citrinoviridis, Atalaya hemiglauca* low open forest over **Cenchrus ciliaris, *C. setiger* tussock grassland with *Triodia pungens* very open hummock grassland.

Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris, *C. setiger*).

Fire Age Not recorded.

Species	Cover (%)	Height	Specimen
Acacia citrinoviridis	27.5	1000 cm	
Acacia coriacea subsp. *pendens*	0.1	350 cm	
Achyranthes aspera	0.1	40 cm	
Aristida inaequiglumis	0.1	100 cm	
Atalaya hemiglauca	20	800 cm	
Cenchrus ciliaris	25	30 cm	
Cenchrus setiger	25	30 cm	
Corchorus crozophorifolius	0.1	50 cm	
Cymbopogon ambiguus	0.1	160 cm	
Enneapogon lindleyanus	0.1	50 cm	
Gossypium australe	0.1	30 cm	PH-RA-02, PH-RA-01
Gossypium robinsonii	0.1	300 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	50 cm	
Polycarpaea longiflora	0.1	20 cm	
Triodia longiceps	0.1	40 cm	
Triodia pungens	8	30 cm	
Triodia wiseana	0.1	50 cm	

No photo

Yandi Billiards & Junction SW YBI-RPHB

Described by	RW/PH	Date	16-Jun-07	Type	Relevé; Unbounded

Location 20.5 km SW of Marillana, 76.8 km SE of Auski Roadhouse and 77.7 km NW of Newman.
Central Coordinate 735704 mE, 7478491 mN.
Habitat Broad floodplain of river (Marillana Creek).
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa*, *Atalaya hemiglauca* low open forest over **Cenchrus ciliaris, *C. setiger* closed tussock grassland.
Veg Condition Very Poor; presence of weeds (**Cenchrus ciliaris, *C. setiger, *Aerva javanica, *Malvastrum americanum*).
Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia citrinoviridis	25	1000 cm	
Acacia pruinocarpa	20	1000 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	170 cm	
Aerva javanica	0.1	30 cm	
Atalaya hemiglauca	20	1000 cm	
Cenchrus ciliaris	40	50 cm	
Cenchrus setiger	35	50 cm	
Corchorus crozophorifolius	0.1	50 cm	
Cucumis variabilis	0.1	150 cm	
Duperreya commixta	0.1	100 cm	
Eucalyptus victrix	7.5	2000 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	15 cm	
Gossypium australe	0.1	100 cm	
Hakea chordophylla	0.1	500 cm	
Jasminum didymum subsp. *lineare*	0.1	200 cm	
Malvastrum americanum	0.1	20 cm	
Rhynchosia minima	0.1	40 cm	
Senna sp.	0.1	100 cm	PH-RB-03
Senna sp.	0.1	100 cm	PH-RB-02
Setaria verticillata	0.1	30 cm	
Streptoglossa decurrens	0.1	60 cm	PH-RB-01
Triodia pungens	0.1	30 cm	

No photo

Yandi Billiards & Junction SW		YBI-RROA	
Described by	Phase 1: RB/RO Phase 2: RO/PC	Date	Phase 1: 17-Jun-07 Phase 2: 04-Aug-08
Type	Relevé; Unbounded		
Location	25.5 km SSW of Marillana, 73.8 km NW of Newman and 79.5 km SE of Auski Roadhouse.		
Central Coordinate	734811 mE, 7473115 mN.		
Habitat	Alluvial clay patch in a broad plain; plain is located between a river (Weeli Wolli Creek, to the west) and a series of low hills (to the east).		
Soil	Red-brown clay to loamy clay; alluvial.		
Rock Type	Ironstone.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia catenulata* tall open scrub over *Psydrax latifolia, Senna glutinosa* subsp. x *luerssenii* open shrubland over *Eremophila latrobei* subsp. *filiformis*, *Enchylaena tomentosa* var. *tomentosa* low scattered shrubs over *Triodia basedowii* open hummock grassland with *Digitaria brownii, Paraneurachne muelleri* very open tussock grassland with *Duperreya commixta* very open herbland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia catenulata* tall open scrub over *Psydrax latifolia, Senna glutinosa* subsp. x *luerssenii* open shrubland over *Eremophila latrobei* subsp. *filiformis*, *Enchylaena tomentosa* var. *tomentosa* low scattered shrubs over *Triodia basedowii* open hummock grassland with *Digitaria brownii*, *Paraneurachne muelleri* very open tussock grassland with *Duperreya commixta* very open herbland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		
Notes	Relevé in a Mulga drainage grove/patch, surrounded by a plain supporting a tall shrubland of mixed species over a *Triodia* hummock grassland.		

Species	Phase 1			Phase 2		
	Cover (%)	Height	Specimen	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	45 cm	RO-RA-04	0.1	45 cm	RO-RA-04=
Acacia adsurgens	0.1	190 cm	RO-RA-06	0.1	190 cm	RO-RA-06=
Acacia aptaneura	0.5	550 cm	RO-RA-05	0.1	550 cm	RO-RA-05=
Acacia catenulata	50	600 cm	RO-RA-01	50	600 cm	RO-RA-01=
Acacia pruinocarpa	0.1	700 cm		0.1	700 cm	
Anthobolus leptomerioides	0.1	150 cm		0.1	150 cm	
Aristida contorta	0.5	30 cm		0.1	30 cm	
Aristida holathera var. *holathera*	0.5	50 cm				
Cucumis variabilis	0.1	Climber		0.1	Climber	
Cymbopogon ambiguus	0.1	70 cm	YBI16-09=	0.1	70 cm	YBI-16-09=
Digitaria brownii	2.5	45 cm	YBI16-07=	2.5	45 cm	YBI16-07=
Duperreya commixta	1.5	Climber		1.5	Climber	
Enchylaena tomentosa var. *tomentosa*	1	50 cm		1	50 cm	
Enneapogon caerulescens	0.1	50 cm				
Enneapogon polyphyllus	0.1	20 cm				
Eremophila latrobei subsp. *filiformis*	1	90 cm		1	90 cm	
Eucalyptus leucophloia subsp. *leucophloia*	2.5	700 cm		2.5	700 cm	
Hakea chordophylla	0.1	25 cm	RA-X			
Hibiscus burtonii	0.1	40 cm		0.1	40 cm	
Paraneurachne muelleri	1	40 cm		1	40 cm	
Polycarpaea longiflora	0.1	25 cm		0.1	25 cm	
Psydrax latifolia	2.5	160 cm		2.5	160 cm	
Pterocaulon sphacelatum	0.1	25 cm	YBI12-03=	0.1	25 cm	YBI12-03=
Ptilotus nobilis subsp. *nobilis*	0.5	90 cm		0.1	90 cm	
Sclerolaena cornishiana	0.1	50 cm	YBI12-26=	0.1	50 cm	YBI12-26=
Senna artemisioides subsp. *helmsii*	0.1	65 cm		0.1	65 cm	
Senna artemisioides subsp. *oligophylla*	0.1	100 cm	RO-RA-03	0.1	100 cm	RO-RA-03=
Senna glutinosa subsp. *x luerssenii*	1	180 cm	RO-RA-02	1	180 cm	RO-RA-02=
Solanum lasiophyllum	0.5	100 cm		0.1	100 cm	
Streptoglossa decurrens	0.1	80 cm		0.1	80 cm	
Tribulus suberosus	0.1	100 cm	RA-X			
Triodia basedowii	27.5	40 cm	YBI11-03=	27.5	40 cm	

YBI-RROA Phase 1

YBI-RROA Phase 2 (no photo)

Yandi Billiards & Junction SW YBI-RRWB

Described by	RW/PH	Date	16-Jun-07	Type	Relevé; Unbounded

Location 20.7 km SW of Marillana, 76.6 km SE of Auski Roadhouse and 77.8 km NW of Newman.
Central Coordinate 735420 mE, 7478487 mN.
Habitat Channel of river (Marillana Creek).
Soil Not recorded.
Rock Type Not recorded.
Vegetation *Eucalyptus victrix* open forest.
Veg Condition Very Good; presence of weeds (**Argemone ochroleuca* subsp. *ochroleuca*, **Setaria verticillata*).
Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia synchronicia	0.1	200 cm	
Achyranthes aspera	0.1	100 cm	
Amaranthus undulatus	0.1	30 cm	RW-RB-04
Argemone ochroleuca subsp. *ochroleuca*	0.1	10 cm	
Atalaya hemiglauca	0.1	500 cm	
Chrysocephalum apiculatum	0.1	50 cm	RW-RB-07
Chrysopogon fallax	0.1	50 cm	
Cleome viscosa	0.1	40 cm	
Corchorus crozophorifolius	0.1	30 cm	
Cyperus vaginatus	0.1	50 cm	RW-RB-02
Dysphania plantaginella	0.1	20 cm	RW-RB-01
Eriachne pulchella	0.1	20 cm	
Eucalyptus victrix	40	2000 cm	
Eulalia aurea	0.1	40 cm	
Euphorbia coghlanii	0.1	20 cm	RW-RB-08
Gomphrena cunninghamii	0.1	15 cm	
Heliotropium chrysocarpum	0.1	30 cm	
Heliotropium cunninghamii	0.1	30 cm	RW-RB-09
Indigofera monophylla	0.1	30 cm	
Ipomoea muelleri	0.1	30 cm	RW-RB-06
Melaleuca argentea	0.1	150 cm	
Phyllanthus maderaspatensis	0.1	20 cm	RW-RB-05
Pluchea rubelliflora	0.1	40 cm	RW-RB-03
Salsola australis	0.1	45 cm	
Senna notabilis	0.1	25 cm	
Setaria verticillata	0.1	30 cm	
Stemodia grossa	0.1	40 cm	
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	30 cm	
Waltheria indica	0.1	40 cm	

No photo

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ12

Described by Phase 1: PLSW Phase 2: PLCA Date Phase 1: 14-Jun-12 Phase 2: 12-Mar-14

Type Quadrat 50 x 50 m

Location 18.7 km SSW of Marillana, 77 km NNW of Newman and 78.2 km SE of Auski Roadhouse.

Central Coordinate 738027 mE, 7479127 mN.

Habitat Low-lying, flat bank of major creek (Weeli Wolli Creek); dissected by creek channels, draining southwest to northeast.

Soil Brown sandy clay.

Rock Type Nil.

Vegetation Phase 1: *Acacia citrinoviridis*, (*Eucalyptus victrix*) open forest over *Atalaya hemiglauca* scattered tall shrubs over **Cenchrus ciliaris, *C. setiger* closed tussock grassland.
Phase 2: *Acacia citrinoviridis, Eucalyptus victrix* open forest over *Atalaya hemiglauca* tall open shrubland over **Cenchrus ciliaris, *C. setiger* closed tussock grassland.

Veg Condition Phase 1: Very Poor; presence of weeds (**Cenchrus ciliaris, *C. setiger, *Malvastrum americanum, *Vachellia farnesiana, *Setaria verticillata*).
Phase 2: Very Poor (high cover of **Cenchrus* spp. **Setaria verticillata*, **Vachellia farnesiana, *Bidens bipinnata, *Malvastrum americanum*).

Fire Age Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon amplum	0.1	140 cm	YAQ12-19	0.1	50 cm	
Abutilon fraseri subsp. fraseri	0.1	40 cm	YAQ12-13	0.1	70 cm	
Acacia citrinoviridis	35	1200 cm	YAQ12-01	35	1200 cm	
Acacia coriacea subsp. pendens	0.1	350 cm	YAQ12-07	0.1	350 cm	
Acacia pyrifolia var. pyrifolia	0.1	230 cm		0.1	230 cm	
Acacia sclerosperma subsp. sclerosperma	0.1	220 cm		0.1	220 cm	
Achyranthes aspera	0.1	40 cm	YAQ12-21	0.1	110 cm	
Acrachne racemosa				0.1	30 cm	YAQR12-04
Amaranthus undulatus				0.1	20 cm	YAQR12-02
Amphipogon sericeus				0.1	70 cm	
Amyema hilliana	0.1	-	YAQ12-11	0.1	300 cm	YAQR12-03
Atalaya hemiglauca	2	400 cm		2	400 cm	
Bidens bipinnata				0.1	20 cm	
Boerhavia coccinea				0.1	10 cm	
Cenchrus ciliaris	60	70 cm		60	70 cm	
Cenchrus setiger	15	70 cm		15	70 cm	
Cleome viscosa				0.1	40 cm	
Clerodendrum floribundum var. angustifolium				0.1	100 cm	
Corchorus crozophorifolius	0.1	40 cm	YAQ12-08			
Corchorus tridens				0.1	10 cm	
Cymbopogon procerus	0.1	110 cm	YAQ12-10	0.1	120 cm	
Digitaria brownii	0.1	60 cm	YAQ12-17			
Duperreya commixta	0.1	220 cm		0.1	80 cm	
Enneapogon lindleyanus	0.1	45 cm	YAQ12-06	0.1	30 cm	
Enteropogon ramosus	0.1	100 cm	YAQ12-03			
Eucalyptus victrix	15	1500 cm		15	1500 cm	
Eulalia aurea	0.1	60 cm	YAQ12-20	0.1	130 cm	
Euphorbia biconvexa	0.1	15 cm	YAQ02-10=			
Euphorbia biconvexa/coghlanii/trigonosperma				0.1	40 cm	
Flaveria trinervia				0.1	15 cm	
Malvastrum americanum	0.1	15 cm		0.1	20 cm	
Melhania oblongifolia	0.1	40 cm	YAQ12-16	0.1	20 cm	
Nicotiana simulans	0.1	15 cm	YAQ12-14			
Notoleptopus decaisnei var. decaisnei				0.1	10 cm	
Peripleura hispidula var. hispidula	0.1	20 cm	YAQ12-05, YAQ12-23	0.1	30 cm	YAQR12-06
Phyllanthus maderaspatensis				0.1	30 cm	
Portulaca oleracea/intraterranea				0.1	10 cm	YAQR12-05
Pterocaulon sphacelatum	0.1	30 cm	YAQ12-12	0.1	40 cm	
Rhagodia eremaea	0.1	35 cm		0.1	130 cm	
Rhynchosia minima	0.1	15 cm		0.1	20 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Scaevola spinescens				0.1	60 cm	
Senna glutinosa subsp. glutinosa	0.1	80 cm	YAQ12-09	0.1	120 cm	
Setaria dielsii				0.1	60 cm	YAQR12-01
Setaria verticillata	0.1	30 cm	YAQ12-22	0.1	60 cm	
Sonchus oleraceus	0.1	1 cm	YAQ12-18			
Stemodia grossa	0.1	10 cm		0.1	10 cm	
Stylobasium spathulatum	0.1	400 cm		0.1	400 cm	
Themeda triandra	0.1	100 cm	YAQ12-02	0.1	120 cm	
Triodia longiceps	0.1	40 cm	YAQ12-15	0.1	70 cm	
Vachellia farnesiana	0.1	200 cm		0.1	230 cm	
Waltheria indica				0.1	30 cm	

YAQ12 Phase 1

YAQ12 Phase 2

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ14

Described by	Phase 1: PLSW Phase 2: PLSW	Date	Phase 1: 15-Jun-12 Phase 2: 15-Mar-14
Type	Quadrat 50 x 50 m		
Location	23.1 km SW of Marillana, 76.2 km SE of Auski Roadhouse and 77.4 km NW of Newman.		
Central Coordinate	733641 mE, 7476745 mN.		
Habitat	Crest of low stony hill; moderately sloping to the east.		
Soil	Dark reddish brown sandy clay loam.		
Rock Type	Ironstone and basalt cobbles (40%), pebbles (30%), and gravel (15%).		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia bivenosa* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. adoxa	0.1	40 cm		0.1	35 cm	
Acacia bivenosa	2	160 cm		3.5	210 cm	
Acacia hilliana	0.1	40 cm		0.1	30 cm	
Acacia inaequilatera	0.5	220 cm		0.1	330 cm	
Acacia pruinocarpa	0.1	50 cm		0.1	100 cm	
Amphipogon sericeus	0.1	25 cm	YAQ14-05	0.1	35 cm	
Aristida holathera var. holathera	0.1	30 cm	YAQ14-07			
Cymbopogon obtectus				0.1	40 cm	
Cymbopogon sp.	0.1	20 cm				
Enneapogon polyphyllus				0.1	35 cm	
Eriachne pulchella	0.1	10 cm	YAQ14-02	0.1	20 cm	
Eucalyptus leucophloia subsp. leucophloia	2	450 cm		2	420 cm	
Fimbristylis dichotoma	0.1	20 cm	YAQ14-03	0.1	20 cm	
Fimbristylis simulans	0.1	10 cm		0.1	10 cm	
Goodenia microptera	0.1	30 cm				
Goodenia muelleriana	0.1	30 cm	YAQ14-09	0.1	25 cm	
Goodenia stobbsiana	0.1	10 cm		0.1	20 cm	
Goodenia triodiophila	0.1	40 cm		0.1	40 cm	
Indigofera monophylla	0.1	40 cm	YAQ14-08	0.1	40 cm	
Mollugo molluginea				0.1	15 cm	
Polycarpaea holtzei	0.1	1 cm		0.1	1 cm	
Ptilotus calostachyus	0.1	110 cm		0.1	70 cm	
Ptilotus clementii	0.1	20 cm				
Ptilotus rotundifolius	0.1	130 cm		0.1	90 cm	
Senna artemisioides subsp. oligophylla				0.1	55 cm	YAQR14-01
Senna glutinosa subsp. pruinosa	0.1	50 cm		0.1	160 cm	
Senna glutinosa subsp. x luerssenii	0.1	150 cm	YAQ14-04, YAQ14-06	0.1	130 cm	
Tribulus suberosus	0.1	70 cm		0.1	100 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	16	40 cm	YAQ14-01	16	40 cm	
Triodia wiseana	0.1	30 cm		0.1	40 cm	

YAQ14 Phase 1

YAQ14 Phase 2 (no Photo)

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ16

Described by Phase 1: PLSW Phase 2: PLSW Date Phase 1: 15-Jun-12 Phase 2: 16-Mar-14

Type Quadrat 50 x 50 m

Location 21.8 km SW of Marillana, 75.8 km SE of Auski Roadhouse and 78.2 km NW of Newman.

Central Coordinate 734166 mE, 7478025 mN.

Habitat Flat plain, immediately south of floodplain fringing major creek (Marillana Creek).

Soil Dark reddish brown sandy loam (with some clay).

Rock Type Ironstone pebbles (5%) and gravel (2%).

Vegetation Phase 1: *Corymbia hamersleyana* low open woodland over *Acacia dictyophleba*, *A. pruinocarpa*, (*A. sclerosperma* subsp. *sclerosperma*) tall open shrubland over *Scaevola spinescens* scattered shrubs over *Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* scattered low shrubs over *Triodia pungens* open hummock grassland with *Themeda triandra* scattered tussock grasses.
Phase 2: *Corymbia hamersleyana* low open woodland over *Acacia dictyophleba, A. pruinocarpa, A. sclerosperma* subsp. *sclerosperma*, *Atalaya hemiglauca* tall open shrubland over *Scaevola spinescens, Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii* open shrubland over *Triodia pungens* hummock grassland and *Eulalia* sp. (Three Rivers Station, B.Forsyth AQ6789133), **Cenchrus ciliaris*, *Themeda triandra* scattered tussock grasses.

Veg Condition Phase 1: Good; presence of weeds (**Cenchrus ciliaris*, **Malvastrum americanum*). Phase 2: Good (**Cenchrus ciliaris, *Bidens bipinnata, *Malvastrum americanum*).

Fire Age Phase 1: Very long unburnt. Phase 2: No sign of recent fire.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Abutilon amplum	0.1	15 cm	YAQ16-32			
Abutilon fraseri subsp. fraseri				0.1	60 cm	
Abutilon macrum				0.1	50 cm	
Abutilon otocarpum				0.1	30 cm	
Acacia ancistrocarpa	0.1	170 cm		0.1	240 cm	
Acacia citrinoviridis	0.1	300 cm		0.1	320 cm	
Acacia coriacea subsp. pendens				0.1	170 cm	
Acacia dictyophleba	4	350 cm		4.5	300 cm	
Acacia inaequilatera	0.1	300 cm		0.1	130 cm	
Acacia pachyacra	0.1	450 cm		0.1	370 cm	
Acacia pruinocarpa	3.5	500 cm		3.5	580 cm	
Acacia pyrifolia var. pyrifolia	0.1	280 cm		0.1	340 cm	
Acacia sclerosperma subsp. sclerosperma	1	300 cm	YAQ16-05	1	340 cm	
Acacia tenuissima	0.1	160 cm				
Acacia tumida var. pilbarensis	0.1	300 cm		0.1	210 cm	
Aristida holathera var. holathera	0.1	40 cm		0.1	40 cm	
Aristida pruinosa	0.1	140 cm	YAQ16-18	0.1	80 cm	YAQR16-08
Atalaya hemiglauca	0.1	280 cm		0.5	310 cm	
Bidens bipinnata				0.1	30 cm	
Boerhavia coccinea				0.1	10 cm	YAQR16-12
Bonamia erecta				0.1	30 cm	
Bothriochloa ewartiana				0.1	150 cm	
Cenchrus ciliaris	0.1	50 cm		0.5	60 cm	
Cenchrus setiger				0.1	60 cm	
Cheilanthes sieberi subsp. sieberi				0.1	10 cm	
Chrysopogon fallax	0.1	100 cm		0.1	100 cm	
Corchorus sidoides	0.1	30 cm	YAQ16-06			
Corchorus tridens				0.1	40 cm	YAQR16-10
Corymbia hamersleyana	4	900 cm		4	640 cm	
Crotalaria medicaginea var. neglecta				0.1	20 cm	
Cymbopogon ambiguus	0.1	80 cm	YAQ16-33	0.1	110 cm	
Cymbopogon obtectus	0.1	80 cm	YAQ16-10	0.1	130 cm	
Dactyloctenium radulans				0.1	5 cm	
Digitaria ctenantha				0.1	50 cm	
Duperreya commixta	0.1	50 cm		0.1	220 cm	
Enchylaena tomentosa var. tomentosa	0.1	50 cm	YAQ16-23			
Enneapogon lindleyanus	0.1	70 cm	YAQ16-25	0.1	60 cm	
Enneapogon polyphyllus	0.1	30 cm	YAQ16-26	0.1	50 cm	
Eragrostis cumingii	0.1	25 cm		0.1	30 cm	
Eragrostis eriopoda	0.1	35 cm	YAQ16-04	0.1	40 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Eriachne mucronata (typical form)				0.1	60 cm	
Eulalia aurea	0.1	80 cm	YAQ16-16	0.1	80 cm	
Eulalia sp. (Three Rivers Station, B.Forsyth AQ6789133)				0.5	70 cm	YAQR16-07
Euphorbia australis var. subtomentosa	0.1	3 cm	YAQ16-15			
Euphorbia biconvexa	0.1	20 cm	YAQ16-22	0.1	60 cm	YAQR16-02
Euphorbia tannensis subsp. eremophila	0.1	50 cm	YAQ16-09	0.1	40 cm	
Evolvulus alsinoides var. decumbens				0.1	40 cm	
Evolvulus alsinoides var. villosicalyx	0.1	20 cm	YAQ16-21	0.1	20 cm	
Goodenia microptera	0.1	30 cm		0.1	25 cm	
Goodenia muelleriana	0.1	30 cm	YAQ16-24			
Goodenia nuda				0.1	50 cm	YAQR16-06
Gossypium australe	0.1	100 cm		0.1	50 cm	
Gossypium robinsonii	0.1	400 cm		0.1	400 cm	
Hakea chordophylla	0.1	420 cm		0.1	430 cm	
Hakea lorea subsp. lorea	0.1	420 cm		0.1	300 cm	
Hibiscus sturtii var. platychlamys	0.1	20 cm	YAQ16-14	0.1	30 cm	
Indigofera colutea				0.1	20 cm	
Indigofera monophylla	0.1	50 cm	YAQ16-20			
Iseilema membranaceum				0.1	30 cm	YAQR16-05
Jasminum didymum subsp. lineare	0.1	100 cm		0.1	80 cm	
Malvastrum americanum	0.1	30 cm		0.1	60 cm	
Melhania oblongifolia	0.1	40 cm	YAQ16-19	0.1	50 cm	
Panicum effusum				0.1	70 cm	YAQR16-09
Paraneurachne muelleri	0.1	40 cm		0.1	40 cm	
Paspalidium clementii	0.1	15 cm	YAQ16-11			
Paspalidium rarum				0.1	20 cm	YAQR16-04
Polycarpaea corymbosa var. corymbosa				0.1	10 cm	
Polymeria ambigua	0.1	5 cm	YAQ16-31	0.1	30 cm	YAQR16-01
Pterocaulon sphacelatum	0.1	40 cm	YAQ16-07			
Ptilotus astrolasius	0.1	40 cm		0.1	50 cm	
Ptilotus nobilis subsp. nobilis				0.1	10 cm	
Rhynchosia minima	0.1	60 cm		0.1	20 cm	
Salsola australis	0.1	50 cm		0.1	20 cm	
Santalum lanceolatum	0.1	160 cm		0.1	240 cm	
Scaevola spinescens	2	150 cm	YAQ16-03	2	110 cm	
Senna artemisioides subsp. helmsii	0.1	80 cm		0.1	90 cm	
Senna artemisioides subsp. oligophylla (thinly sericeous form MET 15,035)	0.1	60 cm	YAQ16-13			
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.5	60 cm	YAQ16-02	1	100 cm	
Setaria dielsii	0.1	30 cm	YAQ16-27	0.1	80 cm	
Setaria verticillata				0.1	60 cm	
Sida arsiniata				0.1	30 cm	
Sida fibulifera	0.1	20 cm	YAQ16-12	0.1	20 cm	YAQR16-11
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	180 cm		0.1	160 cm	
Sida sp. verrucose glands (F.H. Mollemans 2423)	0.1	25 cm	YAQ16-29	0.1	50 cm	
Solanum lasiophyllum	0.1	50 cm	YAQ16-17	0.1	50 cm	
Streptoglossa decurrens	0.1	20 cm				
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	0.1	10 cm	YAQ16-30	0.1	30 cm	YAQR16-03
Themeda triandra	0.5	100 cm	YAQ16-08	0.5	120 cm	
Tribulopis angustifolia				0.1	10 cm	
Tribulus macrocarpus	0.1	10 cm		0.1	15 cm	
Triodia pungens	25	50 cm	YAQ16-01	40	50 cm	
Urochloa occidentalis var. occidentalis	0.1	25 cm	YAQ16-28			
Waltheria indica				0.1	60 cm	

YAQ16 Phase 1

YAQ16 Phase 2

Yandi Additional Quadrats YAQ18

Described by PLSW Date 15-Jun-12 Type Quadrat 50 x 50 m

Location 20 km SSW of Marillana, 78.7 km SE of Auski Roadhouse and 76.1 km NNW of Newman.

Central Coordinate 737600 mE, 7477813 mN.

Habitat Crest of low stony hill; sloping to northeast.

Soil Red-brown sandy loam.

Rock Type Continuous surface layer of ironstone pebbles, gravel and rocks.

Vegetation *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* scattered tall shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T wiseana*) open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Notes Elevation 498 m ASL.

Species	Cover (%)	Height	Specimen
Acacia ancistrocarpa	0.1	170 cm	
Acacia bivenosa	2	270 cm	
Acacia citrinoviridis	0.1	150 cm	
Acacia pruinocarpa	0.1	50 cm	
Amphipogon sericeus	0.1	25 cm	YAQ18-04
Aristida contorta	0.1	20 cm	YAQ18-07
Eucalyptus leucophloia subsp. *leucophloia*	0.5	500 cm	
Fimbristylis simulans	0.1	10 cm	
Goodenia stobbsiana	0.1	8 cm	
Goodenia triodiophila	0.1	30 cm	
Ptilotus astrolasius	0.1	30 cm	
Ptilotus calostachyus	0.1	40 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	15 cm	
Ptilotus rotundifolius	0.1	100 cm	
Schizachyrium fragile	0.1	5 cm	
Senna artemisioides subsp. *oligophylla*	0.1	40 cm	YAQ18-05
Senna glutinosa subsp. *pruinosa*	0.1	150 cm	
Senna glutinosa subsp. *x luerssenii*	0.1	110 cm	YAQ18-02
Solanum lasiophyllum	0.1	60 cm	YAQ18-03
Trianthema glossostigmum	0.1	1 cm	YAQ18-06
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	18	50 cm	YAQ18-01
Triodia wiseana	4	90 cm	

YAQ18

Yandi Additional Quadrats YAQ19

Described by CGSV Date 16-Jun-12 Type Quadrat 50 x 50 m

Location 20.5 km SW of Marillana, 76.2 km SE of Auski Roadhouse and 78.2 km NW of Newman.

Central Coordinate 735259 mE, 7478833 mN.

Habitat Crest and upper slopes of low stony hill.

Soil Red-brown clay loam.

Rock Type Continuous surface layer of ironstone cobbles, rocks and boulders.

Vegetation *Eucalyptus leucophloia* scattered low trees over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), (*T. wiseana*) very open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Notes Elevation 516 m ASL. *Acacia inaequilatera* scattered on hills and slopes; *Corymbia hamersleyana* just outside quadrat.

Species	Cover (%)	Height	Specimen
Abutilon sp. Dioicum (A.A. Mitchell PRP	0.1	30 cm	YAQ19-13
Acacia adoxa var. *adoxa*	0.1	30 cm	
Acacia bivenosa	0.1	210 cm	
Acacia hilliana	0.1	40 cm	
Acacia pruinocarpa	0.1	170 cm	
Amphipogon sericeus	0.1	35 cm	YAQ19-11
Aristida holathera var. *holathera*	0.1	30 cm	
Cleome viscosa	0.1	5 cm	
Clerodendrum floribundum var. *angustifolium*	0.1	5 cm	YAQ19-04
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	35 cm	YAQ19-09
Cucumis variabilis	0.1	50 cm	
Eriachne aristidea	0.1	15 cm	
Eucalyptus leucophloia subsp. *leucophloia*	2	600 cm	
Fimbristylis dichotoma	0.1	7 cm	YAQ19-05
Goodenia stobbsiana	0.1	50 cm	
Goodenia triodiophila	0.1	30 cm	
Hakea chordophylla	0.1	70 cm	
Hakea lorea subsp. *lorea*	0.1	160 cm	YAQ17-22=
Hibiscus coatesii	0.1	30 cm	YAQ19-08
Oldenlandia crouchiana	0.1	10 cm	
Ptilotus astrolasius	0.1	50 cm	
Ptilotus calostachyus	0.1	130 cm	
Ptilotus rotundifolius	0.1	140 cm	
Schizachyrium fragile	0.1	5 cm	YAQ19-03
Senna artemisioides subsp. *oligophylla x S. glutinosa* subsp. *glutinosa*	0.1	100 cm	YAQ19-07
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	40 cm	YAQ19-10
Senna glutinosa subsp. *glutinosa*	0.1	130 cm	
Senna glutinosa subsp. *pruinosa*	0.1	160 cm	
Senna glutinosa subsp. *x luerssenii*	0.1	170 cm	
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.1	60 cm	YAQ19-06
Solanum phlomoides	0.1	60 cm	YAQ19-02
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	0.1	10 cm	YAQ19-12
Tribulus suberosus	0.1	110 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	11	30 cm	YAQ19-01
Triodia wiseana	0.1	40 cm	

YAQ19

Yandi Additional Quadrats YAQ21

Described by CGSV Date 16-Jun-12 Type Quadrat 50 x 50 m

Location 19 km SSW of Marillana, 77.6 km SE of Auski Roadhouse and 77.4 km NNW of Newman.

Central Coordinate 737304 mE, 7479144 mN.

Habitat Broad floodplain on western side of major creek (Weeli Wolli Creek).

Soil Red-brown clay loam.

Rock Type Scattered ironstone and quartz pebbles and stones.

Vegetation *Eucalyptus victrix* scattered trees over *Acacia citrinoviridis* low open woodland over **Cenchrus ciliaris* open tussock grassland.

Veg Condition Poor; presence of weeds (**Cenchrus ciliaris*) and signs of cattle (scats).

Fire Age No sign of recent fire.

Notes Elevation 479 m ASL.

Species	Cover (%)	Height	Specimen
Abutilon fraseri subsp. *fraseri*	0.1	40 cm	YAQ21-14
Acacia citrinoviridis	7	800 cm	
Acacia pyrifolia var. *morrisonii*	0.1	150 cm	YAQ21-01
Aristida holathera var. *holathera*	0.1	35 cm	
Atalaya hemiglauca	0.1	450 cm	
Boerhavia coccinea	0.1	10 cm	YAQ21-02
Cenchrus ciliaris	12	80 cm	
Corchorus crozophorifolius	0.1	160 cm	
Duperreya commixta	0.1	30 cm	
Enneapogon polyphyllus	0.1	35 cm	
Eucalyptus victrix	1	1200 cm	
Euphorbia australis var. *subtomentosa*	0.1	7 cm	YAQ21-03
Euphorbia tannensis subsp. *eremophila*	0.1	40 cm	YAQ21-13
Gossypium australe	0.1	250 cm	YAQ21-09
Hakea lorea subsp. *lorea*	0.1	750 cm	
Hibiscus sturtii var. *platychlamys*	0.1	35 cm	YAQ21-11
Indigofera monophylla	0.1	50 cm	YAQ21-15
Melhania oblongifolia	0.1	30 cm	YAQ21-07
Notoleptopus decaisnei var. *orbicularis* (A.B. Craig 428)	0.1	10 cm	
Perotis rara	0.1	6 cm	
Pterocaulon sphacelatum	0.1	15 cm	YAQ21-05
Ptilotus astrolasius	0.1	40 cm	
Ptilotus obovatus	0.1	100 cm	
Rhynchosia minima	0.1	40 cm	
Senna artemisioides subsp. *helmsii*	0.1	30 cm	YAQ21-08
Sida. fibulifera	0.1	20 cm	YAQ21-04
Solanum lasiophyllum	0.1	100 cm	YAQ21-10
Streptoglossa decurrens	0.1	70 cm	
Themeda triandra	0.1	100 cm	
Tribulus macrocarpus	0.1	15 cm	
Triodia pungens	0.1	40 cm	YAQ21-06
Waltheria indica	0.1	60 cm	

YAQ21

Yandi Additional Quadrats /Yandi Billiards Level 2 YAQ23

Described by Phase 1: CGSV Phase 2: SVSW Date Phase 1: 16-Jun-12 Phase 2: 10-Mar-14

Type Quadrat 50 x 50 m

Location 18.8 km SSW of Marillana, 76.4 km NNW of Newman and 78.8 km SE of Auski Roadhouse

Central Coordinate 738465 mE, 7478772 mN.

Habitat Colluvial plain.

Soil 2.5YR 3/4 dark reddish brown sandy loam.

Rock Type Nil.

Vegetation Phase 1: *Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia pruinocarpa, A. ancistrocarpa* tall open shrubland over *Triodia basedowii*, (*T. pungens*) open hummock grassland.
Phase 2: *Eucalyptus gamophylla* scattered low mallee trees over *Corchorus tectus* scattered low shrubs over *Triodia basedowii* very open hummock grassland over *Aristida holathera* var. *holathera* scattered bunch grasses.

Veg Condition Phase 1: Very Good; signs of cattle (tracks). Phase 2: Excellent.

Fire Age Phase 1: No sign of recent fire. Phase 2: Burnt 3-5 years ago.

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. adoxa				0.1	30 cm	
Acacia adsurgens	0.1	160 cm	YAQ23-08			
Acacia ancistrocarpa	1	300 cm		0.1	30 cm	
Acacia bivenosa	0.1	250 cm				
Acacia inaequilatera	0.1	250 cm		0.1	65 cm	
Acacia pachyacra	0.1	200 cm	YAQ23-07	0.1	30 cm	YAQR23-02
Acacia pruinocarpa	1	360 cm		0.1	30 cm	
Acacia tumida var. pilbarensis				0.1	50 cm	
Aristida holathera var. holathera	0.1	40 cm		1	50 cm	
Bonamia erecta	0.1	30 cm				
Corchorus sidoides	0.1	30 cm	YAQ23-02			
Corchorus tectus				1	40 cm	YAQR23-01
Corymbia hamersleyana	0.1	400 cm		0.1	420 cm	
Cymbopogon obtectus				0.1	80 cm	
Dicrastylis cordifolia				0.1	40 cm	
Dodonaea coriacea	0.1	120 cm		0.1	20 cm	YAQR23-09
Eragrostis eriopoda	0.1	30 cm		0.1	45 cm	
Eriachne aristidea				0.1	10 cm	
Eucalyptus gamophylla	1	320 cm		0.5	210 cm	
Euphorbia australis var. hispidula				0.1	20 cm	YAQR23-06
Euphorbia biconvexa/coghlanii/trigonosperma				0.1	10 cm	
Gomphrena affinis subsp. pilbarensis				0.1	10 cm	YAQR23-07
Goodenia microptera				0.1	30 cm	
Goodenia muelleriana				0.1	30 cm	YAQR23-08
Goodenia stobbsiana	0.1	20 cm		0.1	30 cm	
Gossypium robinsonii				0.1	80 cm	
Hakea chordophylla	0.1	350 cm		0.1	350 cm	
Hakea lorea subsp. lorea	0.1	210 cm				
Heliotropium pachyphyllum				0.1	25 cm	YAQR23-04
Hibiscus leptocladus				0.1	20 cm	YAQR23-11
Hibiscus sturtii var. platychlamys	0.1	25 cm	YAQ23-10	0.1	15 cm	
Hybanthus aurantiacus	0.1	25 cm		0.1	45 cm	
Indigofera monophylla				0.1	40 cm	
Mollugo molluginea	0.1	10 cm		0.1	20 cm	
Paraneurachne muelleri	0.1	40 cm		0.1	30 cm	
Petalostylis cassioides				0.1	35 cm	YAQR23-12
Petalostylis labicheoides	0.1	200 cm				
Ptilotus astrolasius	0.1	30 cm		0.1	30 cm	
Ptilotus auriculifolius				0.1	30 cm	
Ptilotus calostachyus	0.1	120 cm		0.1	70 cm	

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Ptilotus nobilis subsp. nobilis				0.1	15 cm	
Ptilotus polystachyus				0.1	25 cm	
Rhagodia eremaea	0.1	120 cm				
Rhyncharrhena linearis	0.1	10 cm				
Scaevola parvifolia subsp. pilbarae	0.1	30 cm				
Schizachyrium fragile	0.1	7 cm	YAQ23-11			
Senna artemisioides subsp. helmsii	0.1	140 cm	YAQ23-06	0.1	30 cm	
Senna artemisioides subsp. oligophylla				0.1	30 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	50 cm	YAQ23-03			
Senna glutinosa subsp. glutinosa x S. stricta				0.1	40 cm	YAQR23-10
Senna notabilis	0.1	15 cm		0.1	12 cm	
Sida arenicola				0.1	100 cm	
Sida cardiophylla				0.1	40 cm	YAQR23-14
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	0.1	40 cm	YAQ23-09			
Solanum elatius	0.1	50 cm	YAQ23-04	0.1	60 cm	YAQR23-13
Solanum lasiophyllum	0.1	40 cm		0.1	15 cm	
Solanum phlomoides				0.1	40 cm	
Themeda triandra				0.1	60 cm	
Trianthema pilosum				0.1	10 cm	
Triodia basedowii		20	40 cm	YAQ23-01	30 cm	
Triodia pungens	0.1	50 cm	YAQ23-05			
Yakirra australiensis var. australiensis				0.1	15 cm	YAQR23-05

YAQ23 Phase 1

YAQ23 Phase 2

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ25

Described by	Phase 1: CGSV Phase 2: SVSW	Date	Phase 1: 17-Jun-12 Phase 2: 9-Mar-14
Type	Quadrat 50 x 50 m		
Location	12.9 km SW of Marillana, 77.3 km ESE of Auski Roadhouse and 80.4 km NNW of Newman.		
Central Coordinate	740425 mE, 7484458 mN.		
Habitat	Low, rocky upper hill slope.		
Soil	2.5YR 2.4/4 dark reddish brown sandy loam.		
Rock Type	Ironstone shale, cobbles, pebbles, gravel.		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *A. bivenosa, A. pruinocarpa* scattered tall shrubs over *A. hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2: Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2: No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia aptaneura	0.1	120 cm	YAQ25-06	0.1	130 cm	YAQR25-01
Acacia bivenosa				1	390 cm	
Acacia bivenosa (wispy/weeping form)	0.1	300 cm				
Acacia citrinoviridis	0.1	250 cm	YAQ25-04			
Acacia hilliana	2	60 cm		3	40 cm	
Acacia inaequilatera	0.1	150 cm		0.1	180 cm	
Acacia pruinocarpa				0.5	420 cm	
Acacia pyrifolia var. pyrifolia	0.1	160 cm				
Aristida holathera var. holathera				0.1	30 cm	
Eucalyptus leucophloia subsp. leucophloia	0.5	450 cm		2	550 cm	
Fimbristylis dichotoma	0.1	15 cm	YAQ25-03	0.1	15 cm	
Fimbristylis simulans	0.1	10 cm		0.1	15 cm	
Goodenia stobbsiana	0.1	10 cm				
Grevillea wickhamii subsp. hispidula	0.1	210 cm	YAQ25-05	0.1	420 cm	
Ptilotus calostachyus	0.1	50 cm		0.1	60 cm	
Senna artemisioides subsp. helmsii				0.1	70 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	20 cm	YAQ25-02	0.1	40 cm	YAQR25-02
Senna glutinosa subsp. glutinosa	0.1	160 cm		0.1	140 cm	
Senna glutinosa subsp. glutinosa x subsp. x luerssenii				0.1	130 cm	YAQR25-03
Senna glutinosa subsp. pruinosa	0.1	160 cm		0.1	130 cm	
Senna glutinosa subsp. x luerssenii	0.1	110 cm		0.1	70 cm	
Solanum lasiophyllum	0.1	50 cm		0.1	60 cm	
Trachymene oleracea subsp. oleracea	0.1	20 cm		0.1	3 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	11	30 cm	YAQ25-01	55	30 cm	

YAQ25 Phase 1

YAQ25 Phase 2

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ27

Described by	Phase 1: CGSV Phase 2: PLSV	Date	Phase 1: 17-Jun-12 Phase 2:19-Mar-14
Type	Quadrats 50 x 50 m		
Location	14.5 km SW of Marillana, 77.1 km ESE of Auski Roadhouse and 79.8 km NNW of Newman.		
Central Coordinate	739393 mE, 7483220 mN.		
Habitat	Crest and mid-slope of a low hill facing towards the southwest.		
Soil	2.5YR 3/3 dark reddish brown sandy clay loam.		
Rock Type	Ironstone surface plates and broken plates (continuous); cobbles (40%), pebbles (40%), and gravel (18%).		
Vegetation	Phase 1: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa* scattered tall shrubs over *A. hilliana* scattered low shrubs over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland. Phase 2: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia pruinocarpa*, *A. bivenosa* scattered tall shrubs over *A. hilliana* low open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland.		
Veg Condition	Phase 1: Excellent. Phase 2:Excellent.		
Fire Age	Phase 1: No sign of recent fire. Phase 2:No sign of recent fire.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia adoxa var. adoxa	0.1	70 cm		0.1	50 cm	
Acacia bivenosa				0.5	230 cm	
Acacia bivenosa (wispy/weeping form)	0.1	200 cm				
Acacia hilliana	2	40 cm		6	50 cm	
Acacia pruinocarpa	0.5	300 cm		1	350 cm	
Corchorus crozophorifolius				0.1	10 cm	
Eucalyptus leucophloia subsp. leucophloia	1	320 cm		2	500 cm	
Fimbristylis simulans	0.1	10 cm		0.1	15 cm	
Goodenia stobbsiana	0.1	15 cm		0.1	30 cm	
Goodenia triodiophila	0.1	30 cm		0.1	25 cm	
Grevillea wickhamii subsp. hispidula	0.1	200 cm	YAQ27-02	0.1	220 cm	
Indigofera monophylla	0.1	35 cm	YAQ27-05	0.1	40 cm	
Mollugo molluginea				0.1	25 cm	
Ptilotus astrolasius	0.1	40 cm				
Ptilotus calostachyus	0.1	120 cm				
Ptilotus obovatus var. obovatus				0.1	35 cm	
Ptilotus rotundifolius	0.1	110 cm		0.1	110 cm	
Senna artemisioides subsp. oligophylla x subsp. helmsii	0.1	60 cm	YAQ27-03	0.1	60 cm	
Senna glutinosa subsp. glutinosa	0.1	130 cm		0.1	20 cm	
Senna glutinosa subsp. glutinosa x S. stricta				0.1	170 cm	YAQR27-01
Senna glutinosa subsp. pruinosa	0.1	100 cm		0.1	110 cm	
Sida arenicola				0.1	35 cm	
Solanum phlomoides				0.1	30 cm	
Trianthema glossostigmum	0.1	1 cm				
Triodia pungens	0.1	50 cm	YAQ27-04	0.1	40 cm	
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	12	30 cm	YAQ27-01	12	30 cm	

Yandi Additional Quadrats YAQ29

Described by PLSW Date 17-Jun-12 Type Quadrat 50 x 50 m

Location 15.3 km SW of Marillana, 77.2 km ESE of Auski Roadhouse and 79.4 km NNW of Newman.

Central Coordinate 739045 mE, 7482529 mN.

Habitat Floodplain.

Soil Red-brown clay loam with some cover of cobbles and rocks.

Rock Type Not recorded.

Vegetation *Corymbia hamersleyana* low scattered trees over *Acacia pruinocarpa*, *Grevillea wickhamii* subsp. *hispidula*, *A. inaequilatera* tall open shrubland over Corc*horus tectus, Ptilotus astrolasius* scattered low shrubs over *Triodia pungens* very open hummock grassland.

Veg Condition Good; occasional **Cenchrus ciliaris*; fencing wire present in quadrat.

Fire Age Burnt 3-5 years ago.

Notes Elevation 474 m ASL. *Eucalyptus gamophylla* is present outside quadrat.

Species	Cover (%)	Height	Specimen
Abutilon otocarpum	0.1	10 cm	YAQ29-27
Acacia bivenosa (wispy/weeping form)	0.1	150 cm	
Acacia inaequilatera	0.5	280 cm	
Acacia pachyacra	0.1	160 cm	
Acacia pruinocarpa	1	260 cm	
Acacia tumida var. *pilbarensis*	0.1	200 cm	
Aristida contorta	0.1	25 cm	
Aristida holathera var. *holathera*	0.1	50 cm	
Aristida inaequiglumis	0.1	110 cm	YAQ29-09
Boerhavia coccinea	0.1	10 cm	
Cenchrus ciliaris	0.1	50 cm	
Cleome viscosa	0.1	30 cm	
Corchorus lasiocarpus subsp. *parvus*	0.1	45 cm	YAQ29-16
Corchorus tectus	1	50 cm	YAQ29-02
Corymbia hamersleyana	1	850 cm	
Cucumis variabilis	0.1	160 cm	YAQ29-17
Dicrastylis cordifolia	0.1	60 cm	
Digitaria ctenantha	0.1	40 cm	
Duperreya commixta	0.1	170 cm	
Dysphania rhadinostachya subsp. *rhadinostachya*	0.1	5 cm	YAQ29-12
Eragrostis eriopoda	0.1	40 cm	
Eremophila longifolia	0.1	110 cm	
Eriachne pulchella	0.1	10 cm	YAQ29-14
Euphorbia australis var. *erythrantha*	0.1	5 cm	YAQ29-23
Euphorbia australis var. *subtomentosa*	0.1	15 cm	YAQ29-19
Euphorbia boophthona	0.1	10 cm	
Evolvulus alsinoides var. *villosicalyx*	0.1	5 cm	
Gomphrena cunninghamii	0.1	10 cm	
Goodenia microptera	0.1	25 cm	
Goodenia stobbsiana	0.1	40 cm	
Goodenia triodiophila	0.1	50 cm	
Gossypium robinsonii	0.1	35 cm	
Grevillea wickhamii subsp. *hispidula*	0.5	300 cm	YAQ29-01
Hakea chordophylla	0.1	110 cm	
Hakea lorea subsp. *lorea*	0.1	50 cm	
Heliotropium inexplicitum	0.1	10 cm	YAQ29-22
Heliotropium pachyphyllum	0.1	25 cm	YAQ29-11
Hibiscus leptocladus	0.1	40 cm	YAQ29-15
Hibiscus sturtii var. *platychlamys*	0.1	100 cm	
Indigofera monophylla	0.1	40 cm	YAQ29-05
Polycarpaea corymbosa var. *corymbosa*	0.1	5 cm	
Polycarpaea holtzei	0.1	2 cm	
Polycarpaea longiflora	0.1	15 cm	

Species	Cover (%)	Height	Specimen
Ptilotus astrolasius	1	50 cm	
Ptilotus calostachyus	0.1	130 cm	
Ptilotus helipteroides	0.1	15 cm	
Ptilotus nobilis subsp. *nobilis*	0.1	35 cm	
Rhynchosia minima	0.1	160 cm	
Sclerolaena cornishiana	0.1	25 cm	YAQ29-24
Senna artemisioides subsp. *helmsii*	0.1	110 cm	
Senna artemisioides subsp. *oligophylla*	0.1	30 cm	YAQ29-10
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	50 cm	YAQ29-13
Senna ferraria	0.1	100 cm	YAQ29-21
Senna glutinosa subsp. *glutinosa*	0.1	130 cm	
Senna notabilis	0.1	5 cm	
Sida arenicola	0.1	160 cm	YAQ29-18
Sida cardiophylla	0.1	70 cm	YAQ29-20
Sida echinocarpa	0.1	150 cm	YAQ29-06
Sida sp. spiciform panicles (E. Leyland s.n.	0.1	250 cm	YAQ29-08
Sida sp. verrucose glands (F.H. Mollemans	0.1	50 cm	YAQ29-04
Solanum lasiophyllum	0.1	80 cm	YAQ29-03
Solanum phlomoides	0.1	110 cm	YAQ29-26
Sporobolus australasicus	0.1	15 cm	
Tribulus macrocarpus	0.1	12 cm	
Triodia basedowii	0.1	50 cm	YAQ29-25
Triodia pungens	2	40 cm	YAQ29-07
Waltheria indica	0.1	30 cm	

YAQ29

Yandi Additional Quadrats/Yandi Billiards Level 2 YAQ30

Described by	Phase 1: PLSW Phase 2: PLCA	Date	Phase 1: 17-Jun-12 Phase 2: 9-Mar-14
Type	Quadrat 50 x 50 m		
Location	11.5 km SW of Marillana, 76.9 km ESE of Auski Roadhouse and 81.4 km NNW of Newman.		
Central Coordinate	740844 mE, 7485826 mN.		
Habitat	Broad flat plain.		
Soil	Dark reddish brown silty clay loam.		
Rock Type	Scattered ironstone pebbles and gravel (10%).		
Vegetation	Phase 1: *Acacia citrinoviridis* scattered low trees over *A. pruinocarpa, A. sclerosperma* subsp. *sclerosperma* scattered tall shrubs over **Cenchrus ciliaris*, **C. setiger* open tussock grassland. Phase 2: *Acacia pruinocarpa, A. citrinoviridis, A. sclerosperma* subsp. *sclerosperma* tall open shrubland over **Cenchrus ciliaris, *C. setiger* open tussock grassland.		
Veg Condition	Phase 1: Poor; presence of weeds (**Cenchrus ciliaris*) and signs of cattle (tracks and scats). Phase 2: Poor (**Cenchrus* spp., cow scats).		
Fire Age	Phase 1: Very long unburnt. Phase 2: Very long unburnt.		

Species	Phase 1			Phase 2		
	Cover (%)	Height (cm)	Specimen	Cover (%)	Height (cm)	Specimen
Acacia citrinoviridis	1	900 cm		1	950 cm	
Acacia pruinocarpa	1	420 cm		2	500 cm	
Acacia sclerosperma subsp. sclerosperma	1	300 cm		1	300 cm	
Atalaya hemiglauca	0.1	210 cm		0.1	450 cm	
Boerhavia burbidgeana				0.1	25 cm	YAQR30-02
Boerhavia coccinea	0.1	1 cm		0.1	30 cm	
Cenchrus ciliaris	13	70 cm		15	80 cm	
Cenchrus setiger	0.5	70 cm		5	90 cm	
Cleome viscosa	0.1	40 cm		0.1	60 cm	
Duperreya commixta	0.1	190 cm		0.1	210 cm	
Heliotropium cunninghamii				0.1	20 cm	YAQR30-01
Polycarpaea longiflora	0.1	8 cm				
Ptilotus obovatus var. obovatus	0.1	50 cm		0.1	60 cm	
Salsola australis	0.1	10 cm				
Senna artemisioides subsp. helmsii	0.1	90 cm		0.1	25 cm	
Solanum lasiophyllum	0.1	30 cm	YAQ30-01	0.1	50 cm	
Trichodesma zeylanicum var. zeylanicum	0.1	15 cm				
Triodia angusta	0.1	30 cm	YAQ30-02	0.1	30 cm	
Triodia pungens	0.1	110 cm	YAQ30-03			

YAQ30 Phase 1

YAQ30 Phase 2 (no photo)

Yandi Additional Quadrats YAQ-CSRA

Described by	CGSV	Date	13-Jun-12	Type	Relevé Unbounded

Location 26.6 km SW of Marillana, 75 km NW of Newman and 77.9 km SE of Auski Roadhouse.
Central Coordinate 732770 mE, 7473142 mN.
Habitat Broad floodplain of major creek (Weeli Wolli Creek).
Soil Red-brown clay loam with some surface crusting.
Rock Type Nil.
Vegetation *Eucalyptus victrix* scattered trees over *Acacia citrinoviridis*, (*A bivenosa*) tall open shrubland over **Cenchrus ciliaris* very open tussock grassland with *Triodia wiseana, T. longiceps* scattered hummock grasses.
Veg Condition Good: presence of weeds (**Cenchrus ciliaris*) and signs of cattle.
Fire Age No sign of recent fire.

Species	Cover (%)	Height	Specimen
Acacia bivenosa	1	400 cm	
Acacia citrinoviridis	4	400 cm	YAQ-CSRA02
Acacia inaequilatera	0.1	50 cm	
Acacia pruinocarpa	0.1	600 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	100 cm	
Atalaya hemiglauca	0.1	100 cm	
Capparis spinosa var. *nummularia*	0.1	100 cm	YAQ-CSRA03
Cenchrus ciliaris	8	40 cm	
Eriachne mucronata (typical form)	0.1	50 cm	YAQ-CSRA04
Eucalyptus victrix	1	1500 cm	
Hakea lorea subsp. *lorea*	0.1	500 cm	
Ptilotus obovatus var. *obovatus*	0.1	50 cm	
Triodia longiceps	0.1	60 cm	YAQ-CSRA01
Triodia wiseana	1	50 cm	

YAQ-CSRA

Yandi Additional Quadrats YAQ-CSRB

Described by CGSV Date 13-Jun-12 Type Relevé Unbounded

Location 26.6 km SW of Marillana, 75.1 km NW of Newman and 77.8 km SE of Auski Roadhouse.

Central Coordinate 732643 mE, 7473170 mN.

Habitat Low hill; bordering western edge of floodplain of major creek (Weeli Wolli Creek).

Soil Red-brown clay loam.

Rock Type Scattered ironstone pebbles and cobbles on surface.

Vegetation *Acacia pruinocarpa, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland.

Veg Condition Excellent.

Fire Age No sign of recent fire.

Notes Elevation 508 m ASL.

Species	Cover (%)	Height	Specimen
Acacia ancistrocarpa	0.1	300 cm	
Acacia aptaneura	0.1	600 cm	YAQ-CSRB02
Acacia ayersiana	0.1	400 cm	YAQ-CSRB01
Acacia bivenosa	0.1	200 cm	
Acacia inaequilatera	1	250 cm	
Acacia pruinocarpa	1	300 cm	
Acacia synchronicia	0.1	400 cm	
Aristida holathera var. *holathera*	0.1	35 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	30 cm	YAQ-CSRB06
Corymbia hamersleyana	0.1	600 cm	
Cucumis variabilis	0.1	150 cm	
Duperreya commixta	0.1	50 cm	
Enchylaena tomentosa var. *tomentosa*	0.1	50 cm	YAQ-CSRB05
Enneapogon polyphyllus	0.1	50 cm	
Eragrostis eriopoda	0.1	50 cm	
Gossypium australe	0.1	170 cm	
Grevillea wickhamii subsp. *hispidula*	0.1	180 cm	YAQ-CSRB08
Indigofera monophylla	0.1	40 cm	YAQ-CSRB07
Paraneurachne muelleri	0.1	40 cm	
Ptilotus astrolasius	0.1	40 cm	
Sclerolaena cornishiana	0.1	20 cm	YAQ-CSRB10
Senna artemisioides subsp. *oligophylla*	0.1	30 cm	YAQ-CSRB04
Senna glutinosa subsp. *pruinosa*	0.1	210 cm	
Sida echinocarpa	0.1	30 cm	YAQ-CSRB09
Solanum lasiophyllum	0.1	30 cm	
Themeda triandra	0.1	50 cm	
Trichodesma zeylanicum var. *zeylanicum*	0.1	140 cm	
Triodia wiseana	25	50 cm	

YAQ-CSRB

Yandi Additional Quadrats YAQ-CSRC

Described by CGSV Date 17-Jun-12 Type Relevé Unbounded

Location 14.4 km SW of Marillana, 77.4 km ESE of Auski Roadhouse and 79.5 km NNW of Newman.

Central Coordinate 739681 mE, 7483146 mN.

Habitat	Floodplain.
Soil	Red-brown clay loam with pebbles and cobbles.
Rock Type	Not recorded.
Vegetation	*Eucalyptus victrix* open woodland over *Acacia tumida* var. *pilbarensis*, *A. pyrifolia* var. *pyrifolia* tall shrubland over **Cenchrus ciliaris* (**C. setiger*) open tussock grassland.
Veg Condition	Poor; presence of weeds (**Cenchrus* spp.) and signs of cattle.
Fire Age	Not recorded.
Notes	Elevation 464 m ASL.

Species	Cover (%)	Height	Specimen
Acacia pyrifolia var. *pyrifolia*	8	500 cm	
Acacia tumida var. *pilbarensis*	10	500 cm	
Androcalva luteiflora	0.1	340 cm	
Atalaya hemiglauca	0.1	350 cm	
Cenchrus ciliaris	20	50 cm	
Cenchrus setiger	1	60 cm	
Corymbia hamersleyana	0.1	550 cm	
Eucalyptus victrix	3	1500 cm	
Indigofera monophylla	0.1	50 cm	YAQ-CSRC01

YAQ-CSRC

Yandi Additional Quadrats YAQ-CSRD

Described by	CGSV	Date	17-Jun-12	Type	Relevé Unbounded

Location 13.8 km SW of Marillana, 77 km ESE of Auski Roadhouse and 80.2 km NNW of Newman.
Central Coordinate 739685 mE, 7483923 mN.
Habitat Floodplain.
Soil Red brown sandy loam.
Rock Type Not recorded.
Vegetation *Acacia tumida* var. *pilbarensis* scattered tall shrubs over **Cenchrus ciliaris* (**C.setiger*) tussock grassland.
Veg Condition Very Poor; presence of (**Cenchrus* spp.,**Aerva javanica*) and signs of cattle.
Fire Age No sign of recent fire.
Notes Elevation 467 m ASL.

Species	Cover (%)	Height	Specimen
Acacia citrinoviridis	0.1	450 cm	
Acacia pyrifolia var. *morrisonii*	0.1	350 cm	YAQ-CSRD02
Acacia tumida var. *pilbarensis*	1	400 cm	YAQ-CSRD01
Aerva javanica	0.1	70 cm	
Atalaya hemiglauca	0.1	300 cm	
Cenchrus ciliaris	30	60 cm	
Cenchrus setiger	5	60 cm	
Eucalyptus victrix	0.1	1200 cm	
Gossypium robinsonii	0.1	290 cm	
Hakea lorea subsp. *lorea*	0.1	400 cm	
Petalostylis labicheoides	0.1	310 cm	

YAQ-CSRD

Yandi Additional Quadrats YAQ-RPLA

Described by PLSW Date 15-Jun-12 Type Relevé 4 x 100 m

Location 22.7 km SW of Marillana, 76.1 km SE of Auski Roadhouse and 77.6 km NW of Newman.

Central Coordinate 733835 mE, 7477184 mN.

Habitat Gully.

Soil Sandy loam; rocky, ironstone.

Rock Type Ironstone.

Vegetation *Corymbia hamersleyana*, *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *Themeda triandra*, *Eriachne tenuiculmis*, *E. mucronata* (typical form) very open tussock grassland with *Triodia wiseana* scattered hummock grasses.

Veg Condition Excellent.

Fire Age No sign of recent fire.

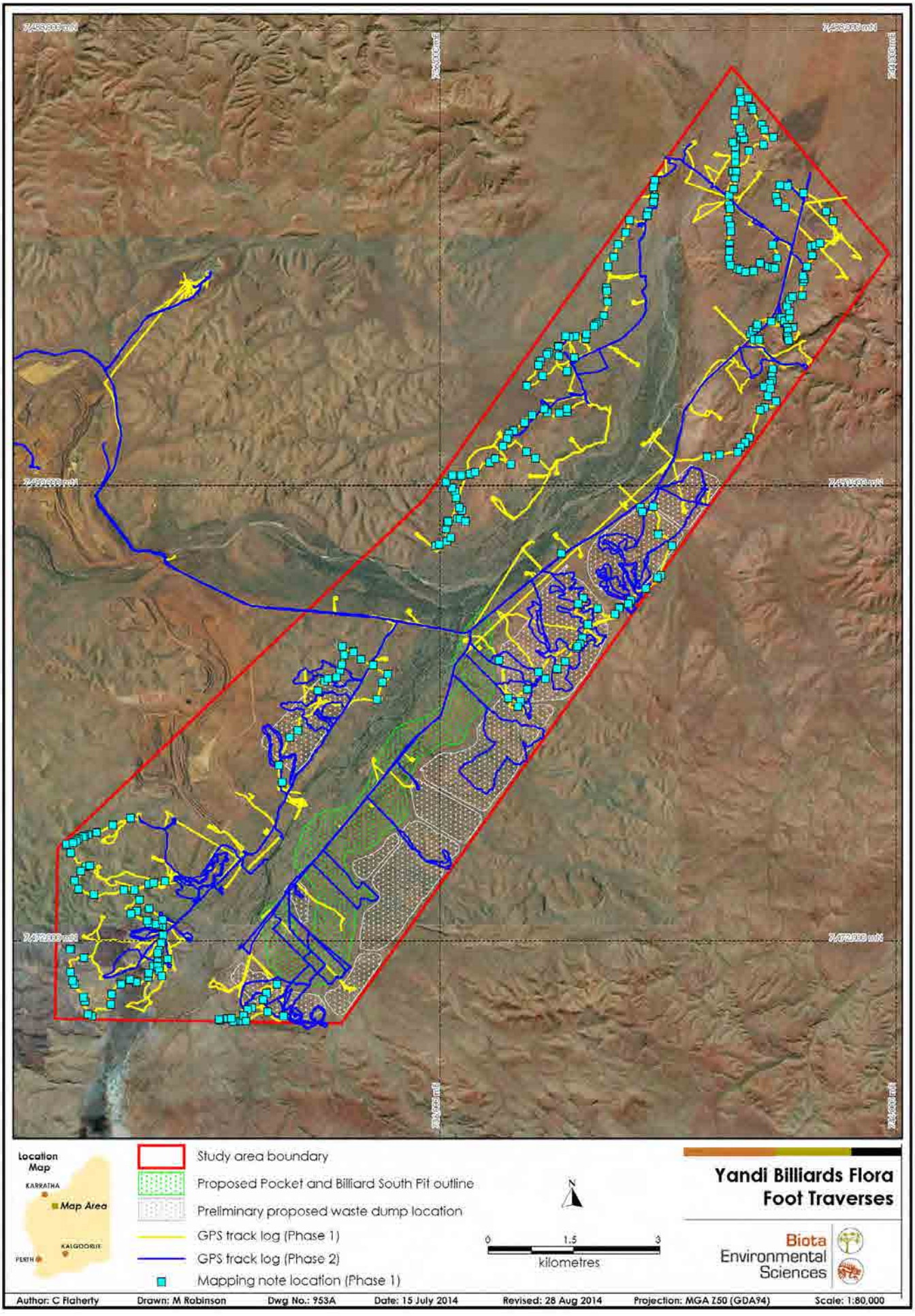
Notes Actual gully bed ~1.5-4m wide.

Species	Cover (%)	Height	Specimen
Abutilon lepidum	0.1	30 cm	YAQ-RPLA10
Abutilon sp. Dioicum (A.A. Mitchell PRP	0.1	40 cm	YAQ-RPLA11
Acacia adoxa var. *adoxa*	0.1	50 cm	
Acacia ancistrocarpa	0.1	170 cm	
Acacia bivenosa	0.1	200 cm	
Acacia pyrifolia var. *pyrifolia*	0.1	100 cm	
Acacia tumida var. *pilbarensis*	3	280 cm	
Aristida holathera var. *holathera*	0.1	40 cm	YAQ-RPLA09
Atalaya hemiglauca	0.1	220 cm	
Bulbostylis barbata	0.1	10 cm	
Cleome viscosa	0.1	20 cm	
Corchorus lasiocarpus subsp. *lasiocarpus*	0.1	40 cm	YAQ-RPLA15
Corymbia hamersleyana	0.5	800 cm	
Crotalaria novae-hollandiae subsp. *novae hollandiae* -	0.1	10 cm	YAQ-RPLA19
Cucumis variabilis	0.1	50 cm	
Cymbopogon ambiguus	0.1	140 cm	YAQ-RPLA02
Duperreya commixta	0.1	100 cm	
Eremophila longifolia	0.1	150 cm	
Eriachne mucronata (typical form)	0.5	35 cm	YAQ-RPLA03
Eriachne tenuiculmis	0.5	50 cm	YAQ-RPLA07
Eucalyptus leucophloia subsp. *leucophloia*	0.1	700 cm	
Euphorbia australis var. *subtomentosa*	0.1	6 cm	YAQ-RPLA20
Euphorbia biconvexa	0.1	25 cm	YAQ-RPLA17
Gomphrena cunninghamii	0.1	5 cm	
Goodenia muelleriana	0.1	30 cm	YAQ-RPLA08
Goodenia stobbsiana	0.1	40 cm	
Gossypium robinsonii	0.1	350 cm	
Hibiscus coatesii	0.1	40 cm	YAQ-RPLA12
Hibiscus sturtii var. *campylochlamys*	0.1	25 cm	YAQ-RPLA14
Hybanthus aurantiacus	0.1	40 cm	
Indigofera monophylla	0.1	60 cm	YAQ-RPLA04
Isotropis atropurpurea	0.1	25 cm	
Melhania oblongifolia	0.1	40 cm	YAQ-RPLA13
Notoleptopus decaisnei var. *decaisnei*	0.1	25 cm	YAQ-RPLA18
Paraneurachne muelleri	0.1	40 cm	
Polycarpaea longiflora	0.1	30 cm	
Santalum lanceolatum	0.1	200 cm	
Senna artemisioides subsp. *oligophylla x* subsp. *helmsii*	0.1	100 cm	YAQ-RPLA16
Senna glutinosa subsp. *glutinosa*	0.1	160 cm	YAQ-RPLA05
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186) PN	0.1	50 cm	YAQ-RPLA06
Themeda triandra	1	100 cm	YAQ-RPLA01
Trichodesma zeylanicum var. *zeylanicum*	0.1	20 cm	
Triodia wiseana	0.5	45 cm	

YAQ-RPLA

Appendix 7

Survey Effort – Foot Traverses and Mapping Note Locations


Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Study area boundary
Proposed Pocket and Billiard South Pit outline
Preliminary proposed waste dump location
GPS track log (Phase 1)
GPS track log (Phase 2)
Mapping note location (Phase 1)
N
0
1.5
3
kilometres
Yandi Billiards Flora
Foot Traverses
Biota
Environmental
Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 953A
Date: 15 July 2014
Revised: 28 Aug 2014
Projection: MGA Z50 (GDA94)
Scale: 1:80,000

Appendix 8

List of Flora Taxa Recorded in the Study Area

Vascular flora species (ordered by family)

Acanthaceae

Dicladanthera forrestii
Dipteracanthus australasicus subsp. *australasicus*

Aizoaceae

Trianthema glossostigmum
Trianthema pilosum
Zaleya galericulata subsp. *galericulata*

Amaranthaceae

Achyranthes aspera
**Aerva javanica*
Alternanthera angustifolia
Alternanthera denticulata
Alternanthera nana
Amaranthus cuspidifolius
Amaranthus undulatus
Gomphrena affinis subsp. *pilbarensis*
Gomphrena cunninghamii
Ptilotus aervoides
Ptilotus astrolasius
Ptilotus auriculifolius
Ptilotus calostachyus
Ptilotus clementii
Ptilotus fusiformis
Ptilotus gaudichaudii subsp. *gaudichaudii*
Ptilotus helipteroides
Ptilotus nobilis subsp. *nobilis*
Ptilotus obovatus var. *obovatus*
Ptilotus polystachyus
Ptilotus roei
Ptilotus rotundifolius

Apocynaceae

Rhyncharrhena linearis
Tylophora flexuosa

Araliaceae

Trachymene oleracea subsp. *oleracea*

Asteraceae

**Bidens bipinnata*
Blumea tenella
Calotis plumulifera
Centipeda minima subsp. *macrocephala*
Chrysocephalum apiculatum
Chrysocephalum gilesii
Chrysocephalum pterochaetum
**Flaveria trinervia*
Helichrysum luteoalbum
Ixiochlamys cuneifolia
Peripleura arida
Peripleura hispidula var. *hispidula*
Pluchea dentex
Pluchea dunlopii
Pluchea ferdinandi-muelleri

Pluchea rubelliflora
Pterocaulon sphacelatum
Rhodanthe floribunda
**Sigesbeckia orientalis*
**Sonchus oleraceus*
Streptoglossa bubakii
Streptoglossa decurrens
Streptoglossa odora

Boraginaceae

Heliotropium chrysocarpum
Heliotropium cunninghamii
Heliotropium glabellum
Heliotropium heteranthum
Heliotropium inexplicitum
Heliotropium pachyphyllum
Heliotropium tanythrix
Heliotropium tenuifolium
Trichodesma zeylanicum var. *zeylanicum*

Brassicaceae

Lepidium catapycnon (Threatened)
Lepidium oxytrichum
Lepidium pedicellosum
Lepidium phlebopetalum
Lepidium pholidogynum
**Sisymbrium orientale*

Campanulaceae

Lobelia arnhemiaca
Wahlenbergia tumidifructa

Capparaceae

Capparis lasiantha
Capparis spinosa var. *nummularia*

Caryophyllaceae

Polycarpaea corymbosa var. *corymbosa*
Polycarpaea holtzei
Polycarpaea longiflora

Chenopodiaceae

Dysphania cristata
Dysphania kalpari
Dysphania melanocarpa forma *melanocarpa*
Dysphania plantaginella
Dysphania rhadinostachya (sterile; subsp. not determined)
Dysphania rhadinostachya subsp. *inflata*
Dysphania rhadinostachya subsp. *rhadinostachya*
Dysphania sp. (juvenile; insufficient material to determine species)
Enchylaena tomentosa var. *tomentosa*
Maireana planifolia
Maireana planifolia x *villosa*
Maireana villosa
Rhagodia eremaea
Salsola australis
Sclerolaena cornishiana
Sclerolaena eriacantha

Cleomaceae

Cleome viscosa

Convolvulaceae

Bonamia erecta
Bonamia pannosa
Bonamia sp. Dampier (A.A. Mitchell PRP 217)
Convolvulus clementii
Duperreya commixta
Evolvulus alsinoides (sterile; var. not determined)
Evolvulus alsinoides var. *decumbens*
Evolvulus alsinoides var. *villosicalyx*
Ipomoea muelleri
Ipomoea polymorpha
Operculina aequisepala
Polymeria ambigua

Cucurbitaceae

**Cucumis melo* subsp. *agrestis*
Cucumis variabilis

Cyperaceae

Bulbostylis barbata
Bulbostylis turbinata
Cyperus cunninghamii subsp. *cunninghamii*
Cyperus difformis
Cyperus iria
Cyperus ixiocarpus
Cyperus squarrosus
Cyperus vaginatus
Eleocharis atropurpurea
Fimbristylis dichotoma
Fimbristylis microcarya
Fimbristylis simulans
Schoenoplectus subulatus

Euphorbiaceae

Euphorbia alsiniflora
Euphorbia australis (specimen lost)
Euphorbia australis var. *australis*
Euphorbia australis var. *erythrantha*
Euphorbia australis var. *hispidula*
Euphorbia australis var. *subtomentosa*
Euphorbia biconvexa
Euphorbia sp. (*biconvexa/coghlanii/trigonosperma*; sterile)
Euphorbia boophthona
Euphorbia coghlanii
Euphorbia drummondii
Euphorbia tannensis subsp. *eremophila*
Euphorbia trigonosperma
Euphorbia sp. (insufficient material to determine species)

Fabaceae

Acacia adoxa var. *adoxa*
Acacia adsurgens
Acacia ancistrocarpa
Acacia ancistrocarpa x *arida*

Acacia aptaneura
Acacia aptaneura x
Acacia aptaneura x *ayersiana*
Acacia aptaneura x *incurvaneura*
Acacia aptaneura x *macraneura*
Acacia arida
Acacia arida x *hilliana*
Acacia ayersiana
Acacia bivenosa
Acacia bivenosa (wispy/weeping form)
Acacia catenulata
Acacia citrinoviridis
Acacia coriacea subsp. *pendens*
Acacia dictyophleba
Acacia elachantha
Acacia hilliana
Acacia inaequilatera
Acacia kempeana
Acacia maitlandii
Acacia monticola
Acacia pachyacra
Acacia pruinocarpa
Acacia pyrifolia (var. not determined)
Acacia pyrifolia var. *morrisonii*
Acacia pyrifolia var. *pyrifolia*
Acacia sclerosperma hybrid
Acacia sclerosperma subsp. *sclerosperma*
Acacia sericophylla
Acacia sibirica
Acacia spondylophylla
Acacia synchronicia
Acacia tenuissima
Acacia tetragonophylla
Acacia trudgeniana
Acacia tumida var. *pilbarensis*
Alysicarpus muelleri
Crotalaria medicaginea var. *neglecta*
Crotalaria novae-hollandiae subsp. *novae-hollandiae*
Cullen lachnostachys
Cullen leucochaites
Cullen martinii
Glycine canescens
Gompholobium oreophilum
Indigofera colutea
Indigofera georgei
Indigofera linifolia
Indigofera linnaei
Indigofera monophylla
Indigofera rugosa
Isotropis atropurpurea
Petalostylis cassioides
Petalostylis labicheoides

Rhynchosia minima
Senna artemisioides subsp. *helmsii*
Senna artemisioides subsp. *oligophylla*
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035) x subsp. *helmsii*
Senna artemisioides subsp. *oligophylla* x *S. glutinosa* subsp. *glutinosa*
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*
Senna artemisioides subsp. x *artemisioides*
Senna ferraria
Senna glutinosa subsp. *glutinosa*
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*
Senna glutinosa subsp. *glutinosa* x *S. stricta*
Senna glutinosa subsp. x *luerssenii*
Senna glutinosa subsp. *pruinosa*
Senna glutinosa subsp. *pruinosa* x subsp. ? *glutinosa*
Senna glutinosa subsp. *pruinosa* x
Senna notabilis
Senna sericea
Senna sp. Meekatharra (E. Bailey 1-26)
Senna sp. (inadequate material to determine species)
Sesbania cannabina
Swainsona formosa
Swainsona kingii
Swainsona maccullochiana
Tephrosia oxalidea
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)
Tephrosia supina
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)
Tephrosia sp. Fortescue (A.A. Mitchell 606)
Tephrosia sp. Newman (A.A. Mitchell PRP 29)
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)
**Vachellia farnesiana*

Goodeniaceae

Dampiera candicans
Goodenia lamprosperma
Goodenia microptera
Goodenia muelleriana
Goodenia nuda (Priority 4)
Goodenia prostrata
Goodenia stellata
Goodenia stobbsiana
Goodenia triodiophila
Scaevola amblyanthera var. *centralis*
Scaevola browniana subsp. *browniana*
Scaevola parvifolia subsp. *pilbarae*
Scaevola spinescens

Gyrostemonaceae

Codonocarpus cotinifolius

Haloragaceae

Haloragis gossei (sterile specimen; var. not determined)

	Haloragis gossei var. *gossei*
Lamiaceae	
	Clerodendrum floribundum var. *angustifolium*
	Dicrastylis cordifolia
	Spartothamnella teucriiflora
Lauraceae	
	Cassytha filiformis
Loranthaceae	
	Amyema hilliana
	Diplatia grandibractea
Lythraceae	
	Ammannia baccifera
	Ammannia multiflora
Malvaceae	
	Abutilon amplum
	Abutilon cryptopetalum
	Abutilon fraseri subsp. *fraseri*
	Abutilon lepidum
	Abutilon leucopetalum
	Abutilon macrum
	Abutilon otocarpum
	Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)
	Abutilon sp. Pilbara (W.R. Barker 2025)
	Abutilon sp. (insufficient material to determine species)
	Androcalva luteiflora
	Corchorus crozophorifolius
	Corchorus lasiocarpus (subsp. not determined)
	Corchorus lasiocarpus subsp. *lasiocarpus*
	Corchorus lasiocarpus subsp. *parvus*
	Corchorus sidoides (subsp. not determined)
	Corchorus sidoides subsp. *sidoides*
	Corchorus sidoides subsp. *vermicularis*
	Corchorus tectus
	Corchorus tridens
	Corchorus sp. (insufficient material to determine species)
	Gossypium australe (two forms observed)
	Gossypium robinsonii
	Gossypium sturtianum var. *sturtianum*
	Hibiscus brachychlaenus
	Hibiscus burtonii
	Hibiscus coatesii (variation was observed within this species)
	Hibiscus goldsworthii
	Hibiscus leptocladus
	Hibiscus sturtii var. *campylochlamys*
	Hibiscus sturtii var. *grandiflorus*
	Hibiscus sturtii var. *platychlamys*
	Hibiscus sp. Mt Robinson (G. Byrne 3537)
	Hibiscus sp. (insufficient material to determine species)
	Keraudrenia nephrosperma
	Keraudrenia velutina subsp. *elliptica*
	**Malvastrum americanum*
	Melhania oblongifolia

Sida arenicola
Sida arsiniata
Sida cardiophylla
Sida echinocarpa
Sida ectogama
Sida fibulifera sens. lat. (variation was observed within this species)
Sida platycalyx
Sida sp. Barlee Range (S. van Leeuwen 1642) (Priority 3)
Sida sp. Excedentifolia (J.L. Egan 1925)
Sida sp. Pilbara (A.A. Mitchell PRP 1543)
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)
Sida sp. verrucose glands (F.H. Mollemans 2423)
Triumfetta clementii
Triumfetta maconochieana
Waltheria indica

Molluginaceae

Mollugo molluginea

Moraceae

Ficus brachypoda

Myrtaceae

Calytrix carinata
Corymbia aspera
Corymbia candida
Corymbia deserticola subsp. *deserticola*
Corymbia ferriticola
Corymbia hamersleyana
Eucalyptus camaldulensis subsp. *refulgens*
Eucalyptus gamophylla
Eucalyptus leucophloia subsp. *leucophloia*
Eucalyptus victrix
Eucalyptus xerothermica
Melaleuca argentea

Nyctaginaceae

Boerhavia burbidgeana
Boerhavia coccinea
Boerhavia gardneri
Boerhavia repleta

Oleaceae

Jasminum didymum subsp. *lineare*

Papaveraceae

**Argemone ochroleuca* subsp. *ochroleuca*

Phyllanthaceae

Notoleptopus decaisnei var. *decaisnei*
Notoleptopus decaisnei var. *orbicularis* (A.B. Craig 428)
Phyllanthus erwinii
Phyllanthus maderaspatensis

Plantaginaceae

Stemodia grossa

Poaceae

Acrachne racemosa
Amphipogon sericeus
Aristida contorta

Aristida holathera var. *holathera*
Aristida hygrometrica
Aristida inaequiglumis
Aristida ingrata
Aristida latifolia
Aristida pruinosa
Aristida sp. (insufficient material to determine species)
Bothriochloa ewartiana
Brachyachne prostrata
**Cenchrus ciliaris*
**Cenchrus setiger*
Chloris pectinata
Chrysopogon fallax
Cymbopogon ambiguus
Cymbopogon obtectus
Cymbopogon procerus
Cymbopogon sp. (sterile; insufficient material to determine species)
Dactyloctenium radulans
Dichanthium sericeum subsp. *humilius*
Digitaria brownii
Digitaria ctenantha
Enneapogon caerulescens
Enneapogon lindleyanus
Enneapogon polyphyllus
Enneapogon robustissimus
Enteropogon ramosus
Eragrostis cumingii
Eragrostis desertorum
Eragrostis dielsii
Eragrostis elongata
Eragrostis eriopoda
Eragrostis falcata
Eragrostis leptocarpa
Eragrostis pergracilis
Eragrostis setifolia
Eragrostis tenellula
Eragrostis xerophila
Eriachne aristidea
Eriachne lanata
Eriachne mucronata (form not determined)
Eriachne mucronata (arid form)
Eriachne mucronata (typical form)
Eriachne pulchella
Eriachne tenuiculmis
Eulalia aurea
Eulalia sp. (Three Rivers Station, B. Forsyth AQ6789133)
Iseilema dolichotrichum
Iseilema macratherum
Iseilema membranaceum
Iseilema vaginiflorum
Panicum effusum
Paraneurachne muelleri

	Paspalidium basicladum
	Paspalidium clementii
	Paspalidium rarum
	Perotis rara
	Schizachyrium fragile
	Setaria dielsii
	Setaria surgens
	**Setaria verticillata*
	Sorghum plumosum
	Sorghum timorense
	Sporobolus australasicus
	Themeda triandra
	Themeda sp. Mt Barricade (M.E. Trudgen 2471)
	Tragus australianus
	Triodia angusta
	Triodia basedowii (identified as *T. lanigera* in previous reporting)
	Triodia brizoides
	Triodia epactia
	Triodia longiceps
	Triodia pungens
	Triodia schinzii
	Triodia wiseana
	Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)
	Tripogon loliiformis
	Triraphis mollis
	Urochloa holosericea subsp. *velutina*
	Urochloa occidentalis var. *occidentalis*
	Urochloa piligera
	Urochloa subquadripara
	Yakirra australiensis var. *australiensis*
Polygalaceae	
	Polygala glaucifolia
Polygonaceae	
	**Acetosa vesicaria* (recorded by Pilbara Iron, unpublished data; GHD 2009)
Portulacaceae	
	Calandrinia ptychosperma
	Calandrinia sp. (insufficient material to determine species)
	Portulaca filifolia
	Portulaca intraterranea
	Portulaca pilosa
	Portulaca sp. *(oleracea/intraterranea)*
Proteaceae	
	Grevillea berryana
	Grevillea pyramidalis subsp. *leucadendron*
	Grevillea wickhamii subsp. *hispidula*
	Hakea chordophylla
	Hakea lorea subsp. *lorea*
Pteridaceae	
	Cheilanthes brownii
	Cheilanthes contigua
	Cheilanthes sieberi subsp. *pseudovellea*
	Cheilanthes sieberi subsp. *sieberi*

Rubiaceae
- *Oldenlandia crouchiana*
- *Psydrax latifolia*
- *Psydrax suaveolens*
- *Spermacoce brachystema*
- *Synaptantha tillaeacea* var. *tillaeacea*

Santalaceae
- *Anthobolus leptomerioides*
- *Santalum lanceolatum*
- *Santalum spicatum*

Sapindaceae
- *Alectryon oleifolius* subsp. *oleifolius*
- *Atalaya hemiglauca*
- *Dodonaea coriacea*
- *Dodonaea lanceolata* var. *lanceolata*
- *Dodonaea petiolaris*
- *Dodonaea viscosa*

Scrophulariaceae
- *Eremophila forrestii* subsp. *forrestii*
- *Eremophila forrestii* x *latrobei*
- *Eremophila fraseri* subsp. *fraseri*
- *Eremophila jucunda* subsp. *pulcherrima*
- *Eremophila lanceolata*
- *Eremophila latrobei* subsp. *filiformis*
- *Eremophila latrobei* subsp. *latrobei*
- *Eremophila longifolia*

Solanaceae
- **Datura leichhardtii*
- *Nicotiana benthamiana*
- *Nicotiana occidentalis* subsp. *obliqua*
- *Nicotiana occidentalis* subsp. *occidentalis*
- *Nicotiana rosulata*
- *Nicotiana simulans*
- *Solanum cleistogamum*
- *Solanum elatius*
- *Solanum horridum*
- *Solanum lasiophyllum*
- **Solanum nigrum*
- *Solanum phlomoides*
- *Solanum* sp. (insufficient material to determine species)

Surianaceae
- *Stylobasium spathulatum*

Typhaceae
- *Typha domingensis*
- **Typha orientalis* (recorded by GHD 2009)

Violaceae
- *Hybanthus aurantiacus*

Zygophyllaceae
- *Tribulopis angustifolia*
- *Tribulus astrocarpus*
- *Tribulus hirsutus*
- *Tribulus macrocarpus*

Tribulus platypterus
Tribulus suberosus
**Tribulus terrestris*
Tribulus sp. (insufficient material to determine species)
Zygophyllum eichleri

Fungi species (ordered by family)	
Agaricaceae	
	Podaxis pistillaris
Polyporaceae	
	Pycnoporus coccineus

Appendix 9

Selected PRIMER Inputs and Outputs

List of quadrats and relevés included in the floristic analysis

Site:	Site Type	Sampled By	Inside/Outside Study Area	Veg Code
BIL01	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H3
BIL02	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	C2
BIL03	Quadrat	Current survey (Ph 1)	Inside	H2
BIL04	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H4
BIL05	Quadrat	Current survey (Ph 1)	Inside	H1
BIL06	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H3
BIL07	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P2
BIL08	Quadrat	Current survey (Ph 1)	Inside	P2
BIL09	Quadrat	Current survey (Ph 1)	Inside	P2
BIL10	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P2
BIL11	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F4
BIL12	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P9
BIL13	Quadrat	Current survey (Ph 1)	Inside	P9
BIL14	Quadrat	Current survey (Ph 1)	Inside	F4
BIL15	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H2
BIL16	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F1
BIL17	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H1
BIL18	Quadrat	Current survey (Ph 1)	Inside	P5
BIL19	Quadrat	Current survey (Ph 1)	Inside	H1
BIL20	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H1
BIL21	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F5
BIL22	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P8
BIL23	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F2
BIL24	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F2
BIL25	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P7
BIL26	Quadrat	Current survey (Ph 1)	Inside	H2
BIL27	Quadrat	Current survey (Ph 1)	Inside	H2
BIL28	Quadrat	Current survey (Ph 1)	Inside	H1
BIL29	Quadrat	Current survey (Ph 1)	Inside	H2
BIL30	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	C3
BIL31	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	C2
BIL32	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P6
BIL33	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P5
BIL34	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H1
BIL35	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F3
BIL36	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F3
BIL37	Quadrat	Current survey (Ph 1)	Inside	H1
BIL38	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P1
BIL39	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	H2
BIL40	Quadrat	Current survey (Ph 1)	Inside	H2
BIL41	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P9
BIL42	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P8
BIL43	Quadrat	Current survey (Ph 1)	Inside	H1
BIL44	Quadrat	Current survey (Ph 1)	Inside	H2
BIL45	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	P9
BIL46	Quadrat	Current survey (Ph 1 and Ph 2)	Inside	F4
BIL47	Quadrat	Current survey (Ph 1)	Inside	F5
BIL48	Quadrat	Current survey (Ph 1)	Inside	P7
BIL49	Quadrat	Current survey (Ph 1)	Inside	P1
BIL-RCFA	Relevé	Current survey (Ph 1)	Inside	H2
BIL-RCFB	Relevé	Current survey (Ph 1)	Inside	H5
BIL-RCFC	Relevé	Current survey (Ph 1)	Inside	F1
BIL-RCFD	Relevé	Current survey (Ph 1)	Inside	H5
BIL-RPCA	Relevé	Current survey (Ph 1)	Inside	H3
BIL-RSPA	Relevé	Current survey (Ph 1)	Inside	P6
BIL-RSWA	Relevé	Current survey (Ph 1)	Inside	F1
H050	Quadrat	Biota (2002), Current survey (Ph 1)	Inside	C4

Site:	Site Type	Sampled By	Inside/Outside Study Area	Veg Code
H051	Quadrat	Biota (2002)	Inside	C4
HDA07	Quadrat	Biota (2004b)	Inside	P4
HDA08	Quadrat	Biota (2004b), Current survey (Ph 1)	Inside	P6
HDA09	Quadrat	Biota (2004b), Current survey (Ph 1)	Inside	C4
HDA12	Quadrat	Biota (2004b)	Inside	P5
HDA13	Quadrat	Biota (2004b)	Inside	P6
HDA14	Quadrat	Biota (2004b)	Inside	P3
HDA15	Quadrat	Biota (2004b)	Inside	P4
HDA16	Quadrat	Biota (2004b)	Inside	H2
HDA24	Quadrat	Biota (2004b), Current survey (Ph 1)	Inside	H2
OXB01	Quadrat	Biota (2010)	Outside	H1
OXB02	Quadrat	Biota (2010)	Outside	H2
OXB03	Quadrat	Biota (2010)	Outside	Hc
OXB04	Quadrat	Biota (2010)	Outside	F1
OXB05	Quadrat	Biota (2010)	Outside	H1
OXB06	Quadrat	Biota (2010)	Outside	C1
OXB09	Quadrat	Biota (2010)	Outside	P1
OXB10	Quadrat	Biota (2010)	Outside	H1
OXB11	Quadrat	Biota (2010)	Outside	H1
OXB13	Quadrat	Biota (2010)	Outside	Hd
OXB16	Quadrat	Biota (2010)	Outside	C2
WW30	Quadrat	Halpern Glick Maunsell (2000)	Inside	P5
YAQ01	Quadrat	Biota (2014b)	Outside	H1
YAQ02	Quadrat	Biota (2014b)	Outside	H2
YAQ03	Quadrat	Biota (2014b)	Outside	F1
YAQ04	Quadrat	Biota (2014b)	Outside	H2
YAQ05	Quadrat	Biota (2014b)	Outside	F1
YAQ06	Quadrat	Biota (2014b)	Outside	H2
YAQ07	Quadrat	Biota (2014b)	Outside	H1
YAQ08	Quadrat	Biota (2014b)	Outside	H2
YAQ09	Quadrat	Biota (2014b)	Outside	H1
YAQ10	Quadrat	Biota (2014b)	Outside	H1
YAQ11	Quadrat	Biota (2014b)	Outside	H1
YAQ12	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	C4
YAQ13	Quadrat	Biota (2014b)	Outside	C4
YAQ14	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	H1
YAQ15	Quadrat	Biota (2014b)	Outside	H2
YAQ16	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	P2
YAQ17	Quadrat	Biota (2014b)	Outside	Ha
YAQ18	Quadrat	Biota (2014b)	Inside	H2
YAQ19	Quadrat	Biota (2014b)	Inside	H2
YAQ20	Quadrat	Biota (2014b)	Outside	F1
YAQ21	Quadrat	Biota (2014b)	Inside	C4
YAQ22	Quadrat	Biota (2014b)	Outside	C1
YAQ23	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	P5
YAQ24	Quadrat	Biota (2014b)	Outside	P2
YAQ25	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	H1
YAQ26	Quadrat	Biota (2014b)	Outside	C3
YAQ27	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	H1
YAQ28	Quadrat	Biota (2014b)	Outside	P5
YAQ29	Quadrat	Biota (2014b)	Inside	P2
YAQ30	Quadrat	Biota (2014b), Current survey (Ph 1)	Inside	F2
YAQ-CSRA	Relevé	Biota (2014b)	Inside	C4
YAQ-CSRB	Relevé	Biota (2014b)	Inside	P4
YAQ-CSRC	Relevé	Biota (2014b)	Inside	F2
YAQ-CSRD	Relevé	Biota (2014b)	Inside	F2
YAQ-RPLA	Relevé	Biota (2014b)	Inside	F3
YAQ-RPLB	Relevé	Biota (2014b)	Outside	F2
YBI01	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	C3

Site:	Site Type	Sampled By	Inside/Outside Study Area	Veg Code
YBI02	Quadrat	Biota (2009b)	Inside	C4
YBI03	Quadrat	Biota (2009b)	Inside	C4
YBI04	Quadrat	Biota (2009b)	Inside	C4
YBI05	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	H2
YBI06	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P5
YBI07	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P5
YBI08	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	C4
YBI09	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P5
YBI10	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P2
YBI11	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P3
YBI12	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P6
YBI13	Quadrat	Biota (2009b)	Inside	P6
YBI14	Quadrat	Biota (2009b)	Inside	P5
YBI15	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P6
YBI16	Quadrat	Biota (2009b)	Inside	P5
YBI17	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P3
YBI18	Quadrat	Biota (2009b)	Outside	H2
YBI19	Quadrat	Biota (2009b)	Inside	P4
YBI20	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	F1
YBI21	Quadrat	Biota (2009b)	Inside	P5
YBI22	Quadrat	Biota (2009b)	Inside	P5
YBI23	Quadrat	Biota (2009b)	Inside	C1
YBI24	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	H4
YBI25	Quadrat	Biota (2009b)	Inside	F1
YBI26	Quadrat	Biota (2009b)	Inside	P2
YBI27	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	P5
YBI28	Quadrat	Biota (2009b)	Inside	P5
YBI29	Quadrat	Biota (2009b)	Inside	P5
YBI30S	Quadrat	Biota (2009b)	Inside	C1
YBI31S	Quadrat	Biota (2009b)	Inside	H1
YBI32S	Quadrat	Biota (2009b)	Inside	H2
YBI33S	Quadrat	Biota (2009b)	Inside	H1
YBI34S	Quadrat	Biota (2009b)	Inside	P5
YBI35S	Quadrat	Biota (2009b)	Inside	F1
YBI36	Quadrat	Biota (2009b), Current survey (Ph 1)	Inside	H2
YEX01	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	H1
YEX02	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	C4
YEX03	Quadrat	Biota (2004a)	Inside	P4
YEX04	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	P4
YEX05	Quadrat	Biota (2004a)	Inside	P1
YEX06	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	H1
YEX07	Quadrat	Biota (2004a)	Inside	F3
YEX08	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	F3
YEX09	Quadrat	Biota (2004a)	Inside	P6
YEX10	Quadrat	Biota (2004a)	Outside	H1
YEX11	Quadrat	Biota (2004a)	Outside	F3
YEX12	Quadrat	Biota (2004a)	Outside	P1
YEX13	Quadrat	Biota (2004a)	Outside	H1
YEX14	Quadrat	Biota (2004a)	Outside	P1
YEX15	Quadrat	Biota (2004a)	Outside	P5
YEX16	Quadrat	Biota (2004a)	Outside	C1
YEX17	Quadrat	Biota (2004a)	Outside	C4
YEX18	Quadrat	Biota (2004a)	Outside	H1
YEX19	Quadrat	Biota (2004a)	Outside	P2
YEX20	Quadrat	Biota (2004a)	Outside	P2
YEX21	Quadrat	Biota (2004a)	Outside	C1
YEX22	Quadrat	Biota (2004a)	Outside	H2
YEX23	Quadrat	Biota (2004a)	Outside	P2
YEX24	Quadrat	Biota (2004a)	Outside	H1

Site:	Site Type	Sampled By	Inside/Outside Study Area	Veg Code
YEX25	Quadrat	Biota (2004a)	Outside	C2
YEX26	Quadrat	Biota (2004a)	Outside	F3
YEX27	Quadrat	Biota (2004a)	Outside	P2
YEX28	Quadrat	Biota (2004a)	Outside	C3
YEX29	Quadrat	Biota (2004a)	Outside	C4
YEX30	Quadrat	Biota (2004a)	Outside	H1
YEX31	Quadrat	Biota (2004a)	Outside	P5
YEX32	Quadrat	Biota (2004a)	Inside	P4
YEX33	Quadrat	Biota (2004a)	Inside	P5
YEX34	Quadrat	Biota (2004a)	Outside	F3
YEX35	Quadrat	Biota (2004a)	Outside	H1
YEX36	Quadrat	Biota (2004a)	Outside	H1
YEX37	Quadrat	Biota (2004a)	Inside	H1
YEX38	Quadrat	Biota (2004a), Current survey (Ph 1)	Inside	F2
YEX39	Quadrat	Biota (2004a)	Outside	C1
YEX-G	Relevé	Biota (2004a)	Outside	F3
YEX-M	Relevé	Biota (2004a)	Outside	C4
YEX-N	Relevé	Biota (2004a)	Outside	P5
YSW01	Quadrat	Biota (2010)	Outside	C2
YSW02	Quadrat	Biota (2010)	Outside	Hb
YSW03	Quadrat	Biota (2010)	Outside	H1
YSW04	Quadrat	Biota (2010)	Outside	C2
YSW05	Quadrat	Biota (2010)	Outside	F1
YSW06	Quadrat	Biota (2010)	Outside	H1
YSW07	Quadrat	Biota (2010)	Outside	P1
YSW08	Quadrat	Biota (2010)	Outside	C1
YSW09	Quadrat	Biota (2010)	Outside	He
YSW11	Quadrat	Biota (2010)	Outside	P1
YSW12	Quadrat	Biota (2010)	Outside	P1
YSW13	Quadrat	Biota (2010)	Outside	H1
YSW14	Quadrat	Biota (2010)	Outside	Hf
YSW15	Quadrat	Biota (2010)	Outside	H1
YSW16	Quadrat	Biota (2010)	Outside	He
YSW17S	Quadrat	Biota (2010)	Outside	H2
YSW18S	Quadrat	Biota (2010)	Outside	F1
YSW19S	Quadrat	Biota (2010)	Outside	Ca
YSW20S	Quadrat	Biota (2010)	Outside	Hd
YVI01	Quadrat	Biota (2014c)	Outside	H2
YVI02	Quadrat	Biota (2014c)	Outside	H2
YVI03	Quadrat	Biota (2014c)	Outside	P1
YVI04	Quadrat	Biota (2014c)	Outside	P1
YVI05	Quadrat	Biota (2014c)	Outside	He
YVI06	Quadrat	Biota (2014c)	Outside	C1
YVI07	Quadrat	Biota (2014c)	Outside	H1
YVI08	Quadrat	Biota (2014c)	Outside	P1
YVI09	Quadrat	Biota (2014c)	Outside	C2
YVI10	Quadrat	Biota (2014c)	Outside	P1
YVI11	Quadrat	Biota (2014c)	Outside	F1
YVI12	Quadrat	Biota (2014c)	Outside	F1
YVI13	Quadrat	Biota (2014c)	Outside	F1
YVI14	Quadrat	Biota (2014c)	Outside	H1
YVI15	Quadrat	Biota (2014c)	Outside	Ca
YVI16	Quadrat	Biota (2014c)	Outside	He
YVI-RMMA	Relevé	Biota (2014c)	Outside	H1

Table 2: Summary details for the 36 floristic groups identified using the SIMPROF test for sites in the Yandi locality based on percent cover of perennial species only.

† Vegetation type not mapped in current study area.

Floristic Group (No. of Sites in Group)		Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group (Sites within Current Study Area)
17 group level	36 group level		
FG1 n=1)	FG1 (n=2)	*Eriachne mucronata* (23.68%) *Corymbia ferriticola* (13.67%) *Cymbopogon ambiguus* (13.67%) *Eucalyptus leucophloia* subsp. *leucophloia* (13.67%)	H5 (BIL-RCFB, BIL-RCFD)
FG2 (n=64)	FG2 (n=1)	Not calculated (only one site in floristic group); appears to be separated from sites in FG06 by the presence of a number of species that are absent from FG06 (including 2% cover of *Indigofera monophylla*) and the lack of *Acacia hilliana*.	H2 (BIL15)
	FG3 (n=3)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (33.61%) *Acacia inaequilatera* (7.05%) *Acacia adoxa* var. *adoxa* (5.12%) *Acacia hilliana* (5.12%)	H1 (nil)
	FG4 (n=2)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (47.73%) *Triodia wiseana* (18.04%) *Acacia bivenosa* (5.70%) *Acacia inaequilatera* (5.70%)	H1 (nil) H2 (BIL03)
	FG5 (n=6)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (40.50%) *Grevillea wickhamii* (10.66%) *Acacia ancistrocarpa* (4.44%) *Goodenia stobbsiana* (3.70%)	H1 (nil) P1 (YEX05)
	FG6 (n=4)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (47.51%) *Triodia wiseana* (29.31%) *Grevillea wickhamii* (2.61%) *Solanum lasiophyllum* (2.61%)	H2 (YBI32S) Hf † P1 (nil)
	FG7 (n=4)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (33.09%) *Triodia wiseana* (9.01%) *Eucalyptus leucophloia* subsp. *leucophloia* (8.37%) *Triodia pungens* (7.27%)	F3 (nil) H1 (nil) P1 (BIL38, BIL49)
	FG8 (n=44)	*Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) (57.89%) *Eucalyptus leucophloia* subsp. *leucophloia* (7.95%) *Acacia hilliana* (5.63%) *Goodenia stobbsiana* (3.14%)	H1 (BIL05, BIL17, BIL20, BIL28, BIL34, BIL37, BIL43, YAQ14, YAQ19, YAQ25, YAQ27, YBI31S, YBI33S, YEX01, YEX06, YEX37) H2 (BIL19, BIL29, BIL39, HDA16, HDA24, YAQ18, YBI36) H3 (BIL01, BIL06, BIL-RPCA) H4 (BIL04, YBI24)
FG3 (n=27)	FG9 (n=2)	*Triodia wiseana* (45.97%) *Acacia bivenosa* (16.25%) *Acacia pruinocarpa* (4.20%) **Cenchrus* spp. (4.20%)	P7 (BIL43) P4 (YEX03)
	FG10 (n=25)	*Triodia wiseana* (68.22%) *Acacia inaequilatera* (7.09%) *Paraneurachne muelleri* (1.67%) *Solanum lasiophyllum* (1.59%)	H2 (BIL26, BIL27, BIL40, BIL44, YBI05) Hd, He † P1 (nil) P4 (HDA07, HDA15, YAQ-CSRB, YBI19)

Floristic Group (No. of Sites in Group)		Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group (Sites within Current Study Area)
17 group level	36 group level		
FG4 (n=2)	FG11 (n=2)	*Triodia schinzii* (59.47%) *Eucalyptus gamophylla* (16.89%) *Acacia dictyophleba* (3.38%) *Acacia pachyacra* (3.38%)	P8 (BIL22, BIL42)
FG5 (n=1)	FG12 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG14 and FG15 due to the particularly high cover of *Eucalyptus victrix* (65%) and also *Cyperus vaginatus* (25%)	C1 (YBI23)
FG6 (n=15)	FG13 (n=5)	*Eucalyptus victrix* (25.50%) *Acacia citrinoviridis* (13.11%) *Corchorus crozophorifolius* (7.24%) **Cenchrus* spp. (5.95%)	C1 (nil) C3 (BIL30, YBI01)
	FG14 (n=10)	*Eucalyptus camaldulensis* subsp. *refulgens* (15.11%) *Melaleuca glomerata* (8.68%) *Eucalyptus victrix* (7.58%) *Acacia coriacea* subsp. *pendens* (6.61%)	C1 (YBI30S) C2 (nil)
FG7 (n=20)	FG15 (n=20)	**Cenchrus* spp. (47.93%) *Acacia citrinoviridis* (21.68%) *Eucalyptus victrix* (4.58%) *Atalaya hemiglauca* (3.99%)	C4 (H050, H051, HDA09, YAQ12, YAQ21, YAQ-CSRA, YBI02, YBI03, YBI04, YEX02) F2 (BIL23, BIL24, YAQ30, YAQ-CSRC, YAQ-CSRD) P9 (BIL12)
FG8 (n=23)	FG16 (n=2)	*Triodia basedowii* (30.03%) *Triodia wiseana* (13.43%) *Acacia bivenosa* (9.49%) *Eucalyptus leucophloia* subsp. *leucophloia* (6.71%)	P5 (YBI29, YBI34S)
	FG17 (n=2)	*Triodia basedowii* (40.64%) *Paraneurachne muelleri* (9.71%) *Petalostylis cassioides* (9.71%) *Acacia dictyophleba* (3.07%)	P5 (YBI14, YBI28)
	FG18 (n=2)	*Triodia basedowii* (27.86%) *Acacia ancistrocarpa* (24.13%) *Paraneurachne muelleri* (16.48%) *Acacia adsurgens* (1.97%)	P5 (YBI07, YBI21)
	FG19 (n=17)	*Triodia basedowii* (49.33%) *Acacia pruinocarpa* (3.43%) *Acacia inaequilatera* (3.38%) *Acacia ancistrocarpa* (3.17%)	P5 (BIL08, BIL18, BIL33, YAQ23, YBI06, YBI09, YBI16, YBI22, YBI27, YEX33) P9 (BIL13, BIL41, BIL45)
FG9 (n=1)	FG20 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG22 and FG23 due to the relatively high cover of *Senna artemisioides* subsp. *oligophylla* (15%) and *Triodia epactia* (5%).	F1 (BIL-RSWA)

Floristic Group (No. of Sites in Group)		Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group (Sites within Current Study Area)
17 group level	36 group level		
FG10 (n=1)	FG21 (n=1)	Not calculated (only one site in floristic group); appears to be separated from neighbouring FG22 and FG23 due to the relatively high cover of *Cymbopogon ambiguus* (15%) and *Enneapogon lindleyanus* (10%), and probably the lack of species such as *Acacia aneura* and *A. pruinocarpa*	H2 (BIL-RCFA)
FG11 (n=2)	FG22 (n=2)	*Acacia bivenosa* (14.94%) *Eucalyptus victrix* (14.94%) *Eriachne tenuiculmis* (9.45%) *Acacia ancistrocarpa* (6.68%)	Ca †
FG12 (n=1)	FG23 (n=1)	Not calculated (only one site in floristic group); the small amount of *Triodia wiseana* (0.1%) appears to separate this site from BIL48 in FG2, leading to clustering with FG25-FG27; FG24 appears to be separated due to the relatively high cover of *Eremophila fraseri* (20%) and *Eragrostis eriopoda* (7%)	P7 (BIL25)
FG13 (n=14)	FG24 (n=4)	*Triodia longiceps* (38.48%) **Cenchrus* spp. (11.23%) *Acacia pruinocarpa* (4.20%) *Corymbia hamersleyana* (3.51%)	F2 (YEX38) P3 (YBI11, YBI17) P6 (YBI13)
	FG25 (n=2)	*Triodia wiseana* (19.42%) *Paraneurachne muelleri* (17.91%) *Acacia "aneura"* (all Mulga taxa merged) (8.69%) *Triodia pungens* (8.69%)	P4 (YEX04, YEX32)
	FG26 (n=8)	*Acacia "aneura"* (all Mulga taxa merged) (33.81%) *Acacia pruinocarpa* (10.40%) **Cenchrus* spp. (4.20%) *Eremophila forrestii* subsp. *forrestii* (2.89%)	P5 (HDA12) P6 (BIL32, BIL-RSPA, HDA08, HDA13, YBI12, YBI15, YEX09)
FG14 (n=1)	FG27 (n=1)	Not calculated (only one site in floristic group); appears to be separated due to the combination of a reasonable cover of *Eremophila fraseri* and *Triodia pungens*, together with negligible cover of *T. wiseana*	Ha †
FG15 (n=9)	FG28 (n=9)	*Acacia tumida* var. *pilbarensis* (27.34%) *Triodia pungens* (8.06%) *Corymbia hamersleyana* (5.25%) *Grevillea wickhamii* (4.45%)	F1 (BIL-RCFC, YBI20, YBI25) F3 (YAQ-RPLA) C2 (BIL02)

Floristic Group (No. of Sites in Group)		Top Four Species with Greatest Contribution to Site Similarity according to SIMPER Test (% contribution)	Vegetation Types with Sites in this Floristic Group (Sites within Current Study Area)
17 group level	36 group level		
FG16 (n=46)	FG29 (n=3)	*Triodia pungens* (19.00%) *Eulalia aurea* (12.62%) *Paraneurachne muelleri* (12.11%) *Ptilotus astrolasius* (4.65%)	P2 (nil) P3 (HDA14)
	FG30 (n=3)	*Petalostylis cassioides* (9.95%) *Triodia basedowii* (7.06%) *Triodia pungens* (6.59%) *Acacia tumida* var. *pilbarensis* (5.57%)	F4 (BIL11, BIL14, BIL46)
	FG31 (n=7)	*Themeda triandra* (23.34%) *Triodia pungens* (12.93%) *Acacia tumida* var. *pilbarensis* (6.79%) *Corymbia hamersleyana* (5.60%)	C4 (nil) F1 (BIL16) F3 (BIL35, YEX07, YEX08) P2 (nil)
	FG32 (n=17)	*Triodia pungens* (23.84%) *Corymbia hamersleyana* (8.99%) *Acacia pyrifolia* (3.97%) **Cenchrus* spp. (2.82%)	C2 (BIL31) F1 (YBI35S) F3 (BIL36) F5 (BIL21, BIL47) P1 (nil) P2 (YAQ16, YAQ29)
	FG33 (n=2)	**Cenchrus* spp. (27.64%) *Triodia pungens* (20.23%) *Acacia citrinoviridis* (18.10%) *Acacia pruinocarpa* (13.82%)	C4 (YBI08) P2 (YBI10)
	FG34 (n=4)	*Triodia pungens* (41.46%) **Cenchrus* spp. (18.40%) *Acacia pruinocarpa* (6.91%) *Acacia sclerosperma* subsp. *sclerosperma* (5.32%)	P2 (BIL07, BIL09, BIL10, YBI26)
	FG35 (n=10)	*Triodia pungens* (64.49%) *Acacia dictyophleba* (3.29%) *Triodia wiseana* (3.10%) *Acacia inaequilatera* (2.81%)	Hb, He † P1 (nil) P2 (nil) P5 (WW30)

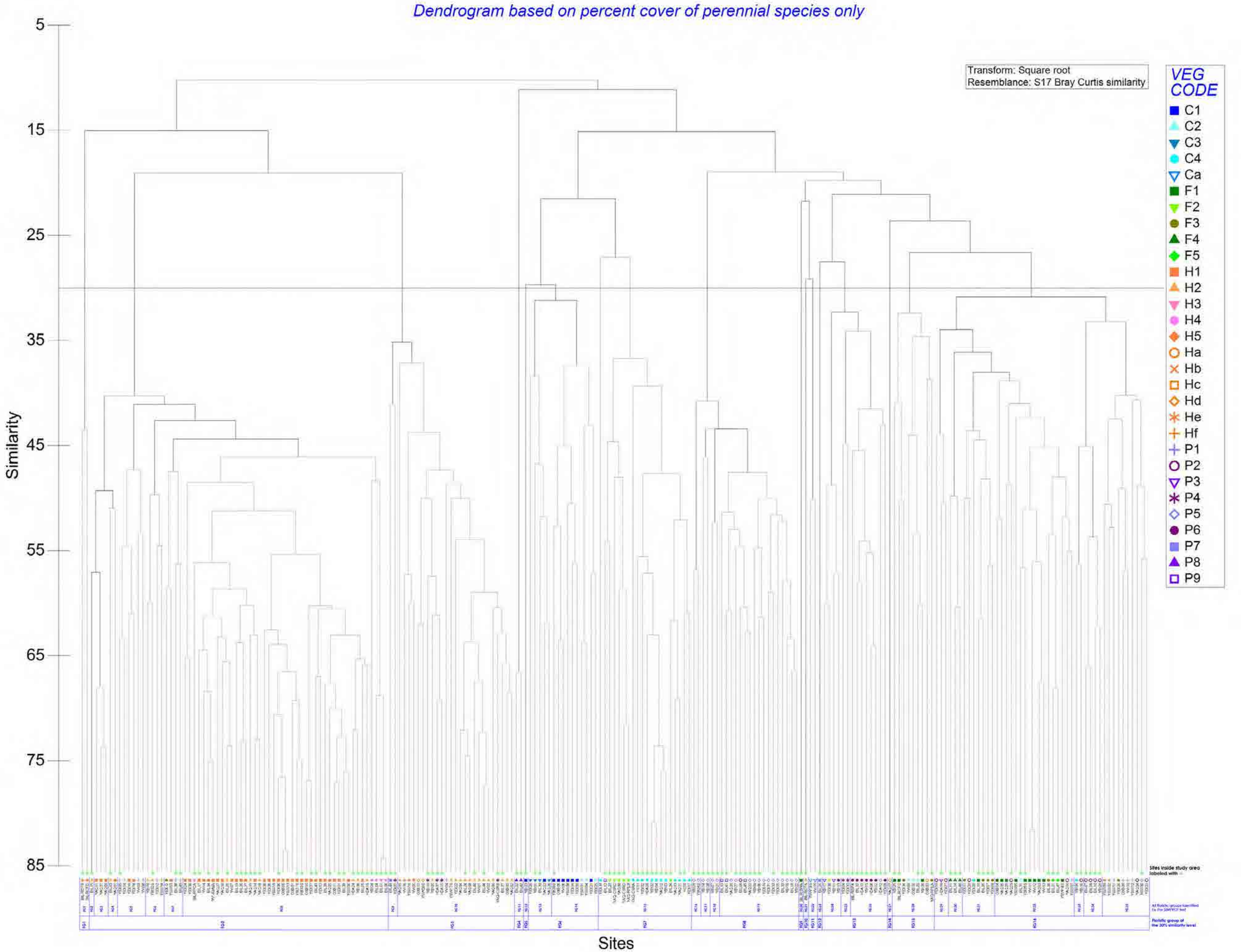


Figure 1: Dendrogram based on percent cover of perennial species in sites from the Yandi locality.
Adjacent sites connected by red lines are not significantly floristically different, as determined by the SIMPROF test.

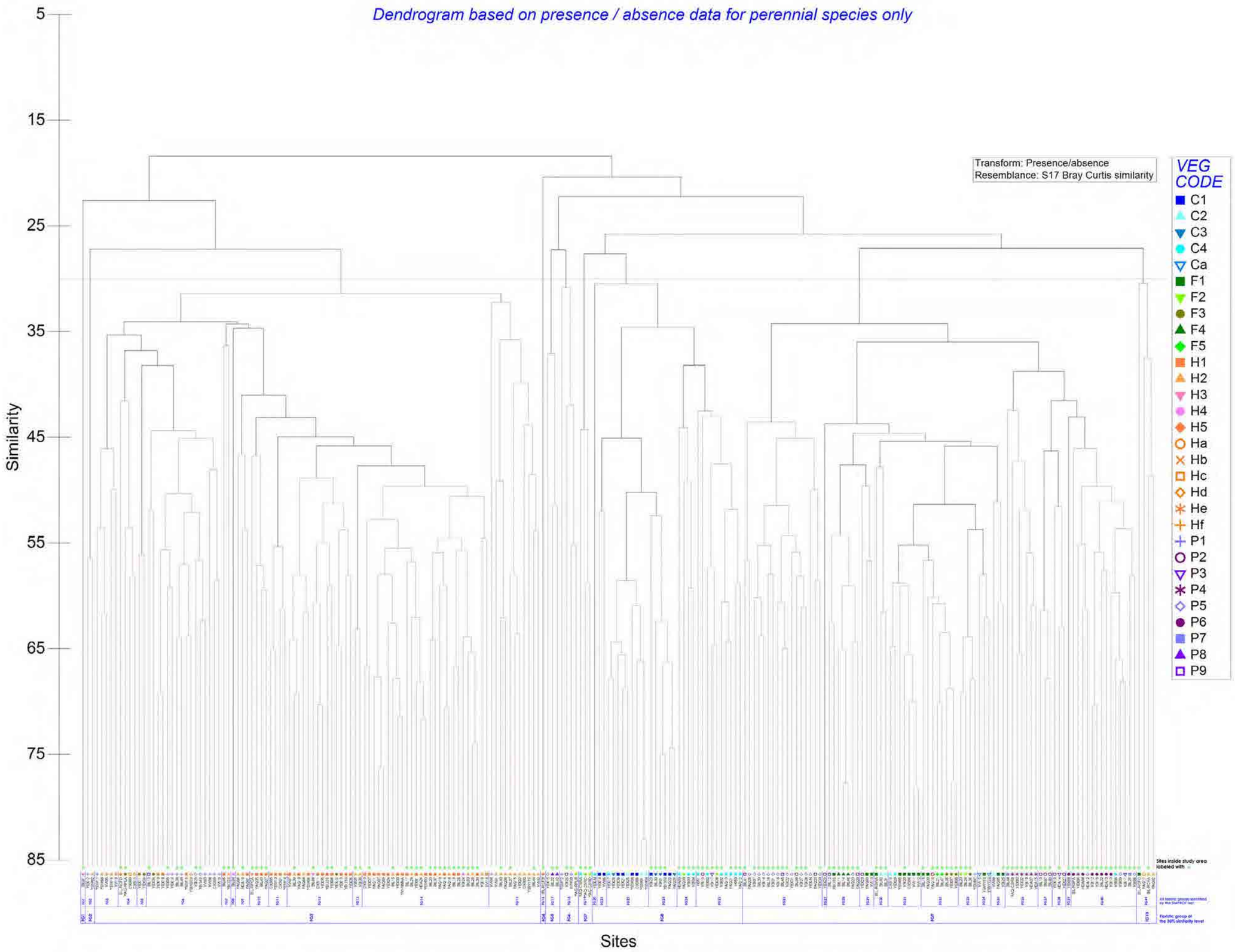


Figure 2: Dendrogram based on presence / absence of perennial species in sites from the Yandi locality.
Adjacent sites connected by red lines are not significantly floristically different, as determined by the SIMPROF test.

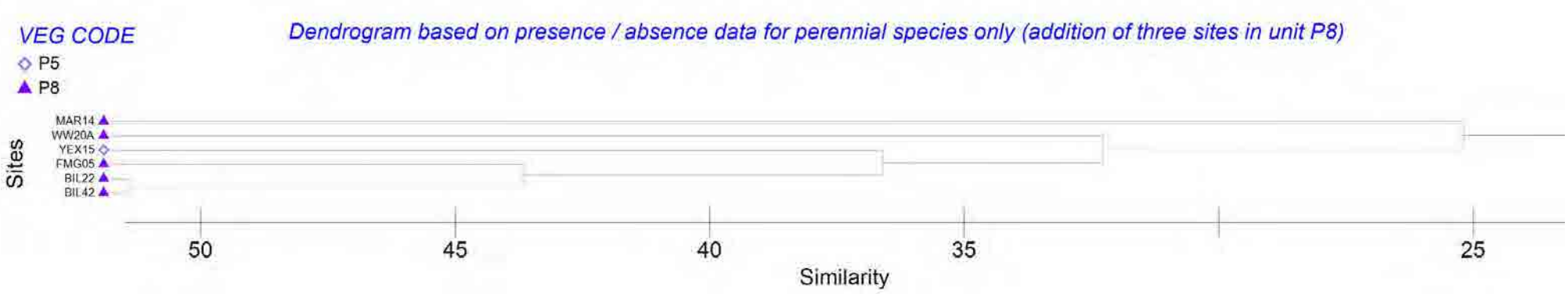


Figure 3: Extract from dendrogram showing clustering of sites from the original FG11 (BIL22 and BIL22) together with three additional sites from equivalent vegetation (unit P8) outside the study area.

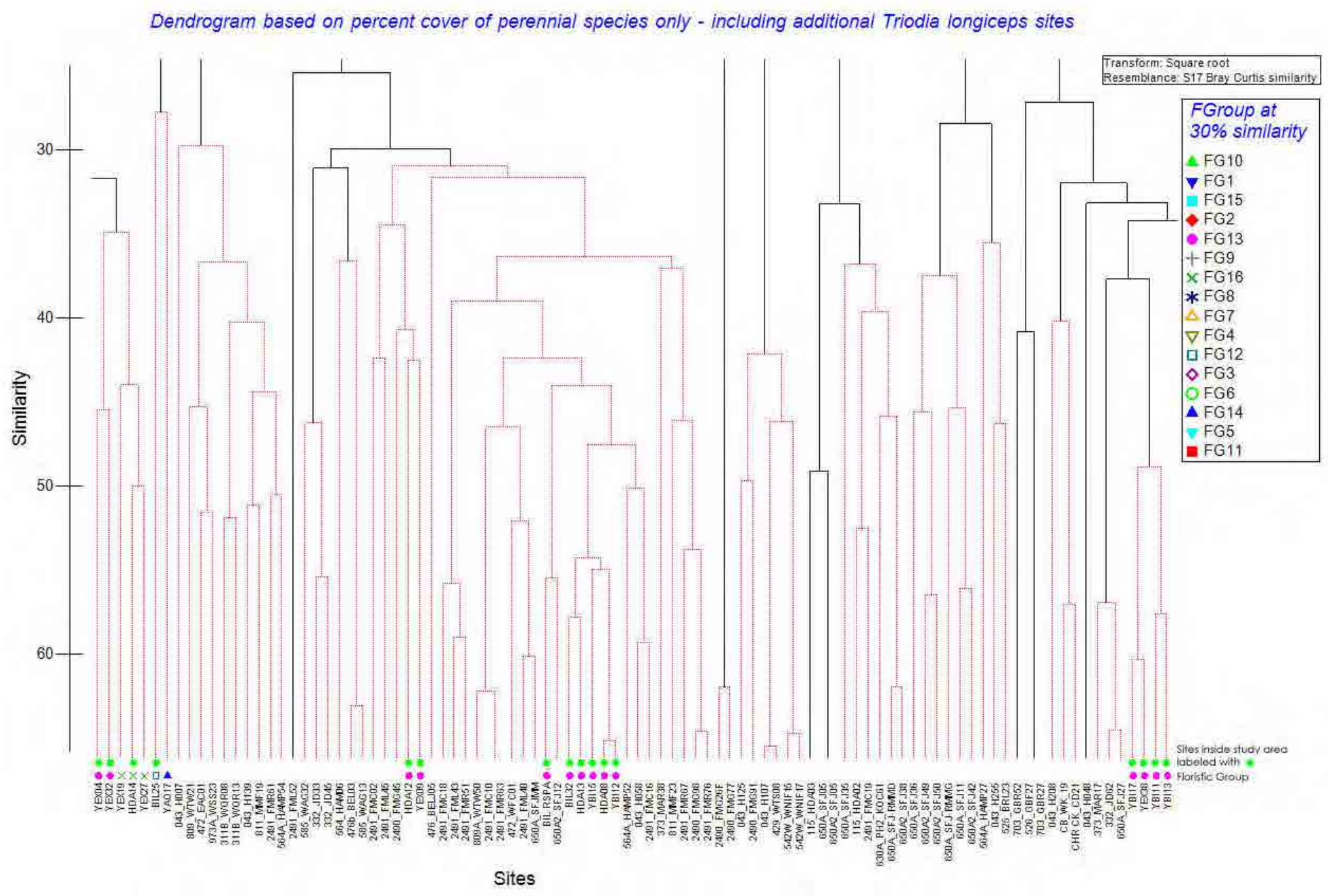


Figure 4: Extract from dendrogram showing clustering of sites from the original FG13 together with other sites from outside the study area.

Appendix 10

Poorly Collected, Variable or Incompletely Resolved Taxa

1. Poorly Collected Taxa

- *Euphorbia australis* var. *australis*
  The current vouchered specimens of this taxon are predominantly from coastal locations, with only one vouchered record from the central Pilbara. Two specimens keying to *Euphorbia australis* var. *australis* were collected from the study area. These specimens were confirmed by Andrew Perkins (a taxonomist at the WA Herbarium), and will be submitted to the WA Herbarium for lodgement.

- *Heliotropium glabellum*
  A single specimen keying to *Heliotropium glabellum* was collected from the study area during the Phase 1 survey, and four additional specimens were collected during Phase 2. Two of these specimens were confirmed by Andrew Perkins, and vouchers have subsequently been submitted to the WA Herbarium. Although this species is widespread through the Kimberley, it is uncommon in the Pilbara, with only a few voucher records from the far east of the region.

- *Peripleura hispidula* var. *hispidula*
  A single specimen keying to *Peripleura hispidula* var. *hispidula* was collected from the study area, however this taxon had not previously been considered to occur in WA. The specimen was sent to Andrew Perkins, who confirmed the identification as *P. hispidula* var. *hispidula.* This specimen will be submitted to the WA Herbarium as a voucher. Equivalent material has been recorded from other survey areas in the Pilbara, including near West Angelas (Biota 2014e), and will similarly be vouchered.

2. Variable Taxa

- *Abutilon lepidum*
  Three apparently undescribed entities in this species were identified by Malcolm Trudgen (M.E. Trudgen and Associates) in material from the study area, all of which are widespread and not believed to be of conservation significance: *Abutilon* aff. *lepidum* (1) (MET 15352), *A.* aff. lepidum (2) (MET 15970) and *A.* aff. *lepidum* (4). For the purpose of this report, they are recognised as one entity: *Abutilon lepidum* sens. lat.

- *Eriachne mucronata*
  Two forms of *Eriachne mucronata* were present in the study area: the 'typical form' (culms with sparse erect hairs), and one designated as 'arid form' (which has white woolly hairs on the culms). Both forms are widespread in the Pilbara bioregion and commonly collected. Although not formally recognised, they have been treated as separate entities for this report since they are clearly distinguishable.

- *Gossypium australe*
  Two apparently undescribed forms of *Gossypium* were recorded from the study area: *G. australe* (Burrup Peninsula form) and *G. australe* (Whim Creek form). These entities are widespread in the Pilbara. For the purpose of this report they have been recognised as a single entity: *Gossypium australe*.

- *Hibiscus coatesii*
  Considerable variation is observed within Pilbara specimens of this taxon. Two apparently undescribed entities were identified from the study area during past surveys, both of which are widespread: *Hibiscus* aff. *coatesii* (MET 16,542) and *H.* aff. *coatesii* (site 664). For the purpose of this report, they are recognised as a single entity: *Hibiscus coatesii.*

- *Indigofera monophylla*
  Several forms of *Indigofera monophylla* were identified by Malcolm Trudgen (M.E. Trudgen and Associates) amongst the specimens from the study area. All forms are considered to be widespread in the Pilbara. For the purpose of this report, the different forms of *Indigofera monophylla* have not been distinguished and they are referred to as a single entity.

- *Senna artemisioides* subsp. *oligophylla* (thinly sericeus form MET 15,035)
  This taxon is a form of *Senna artemisioides* subsp. *oligophylla* recognised by Malcolm Trudgen (M.E. Trudgen and Associates), which can be distinguished by the very appressed hairs on the leaflets. Although not formally recognised, this taxon has been included in this report because

it appears distinctly different from *S. artemisioides* subsp. *oligophylla* and is easily recognised. It also occurred in the study area as a hybrid with *Senna artemisioides* subsp. *helmsii*.

- *Sida fibulifera*
  Sida fibulifera is a very variable taxon. In past surveys, six apparently undescribed entities were identified from the study area: *Sida* aff. *fibulifera* (FMG 125-20), *S.* aff. *fibulifera* (HD12-39), *S.* aff. *fibulifera* (HD237-9), *S.* aff. *fibulifera* (oblong; MET 15 220), *S.* aff. *fibulifera* (site 1394) and *Sida* aff. *fibulifera* (prostrate A.A. Mitchell 3 572). None of these taxa are considered to be rare, and it is likely that more entities exist within this group. For the purpose of this report, all entities have been assigned to *Sida fibulifera* sens. lat.
- *Triodia basedowii*
  Following discussion with Dr Matthew Barrett (Kings Park and Botanic Garden), all specimens of *Triodia lanigera* collected from the study area during both the current survey and previous surveys have been redetermined as *T. basedowii*. A relevant specialist taxonomist will be consulted for further confirmation.

3. Incompletely Resolved Taxa

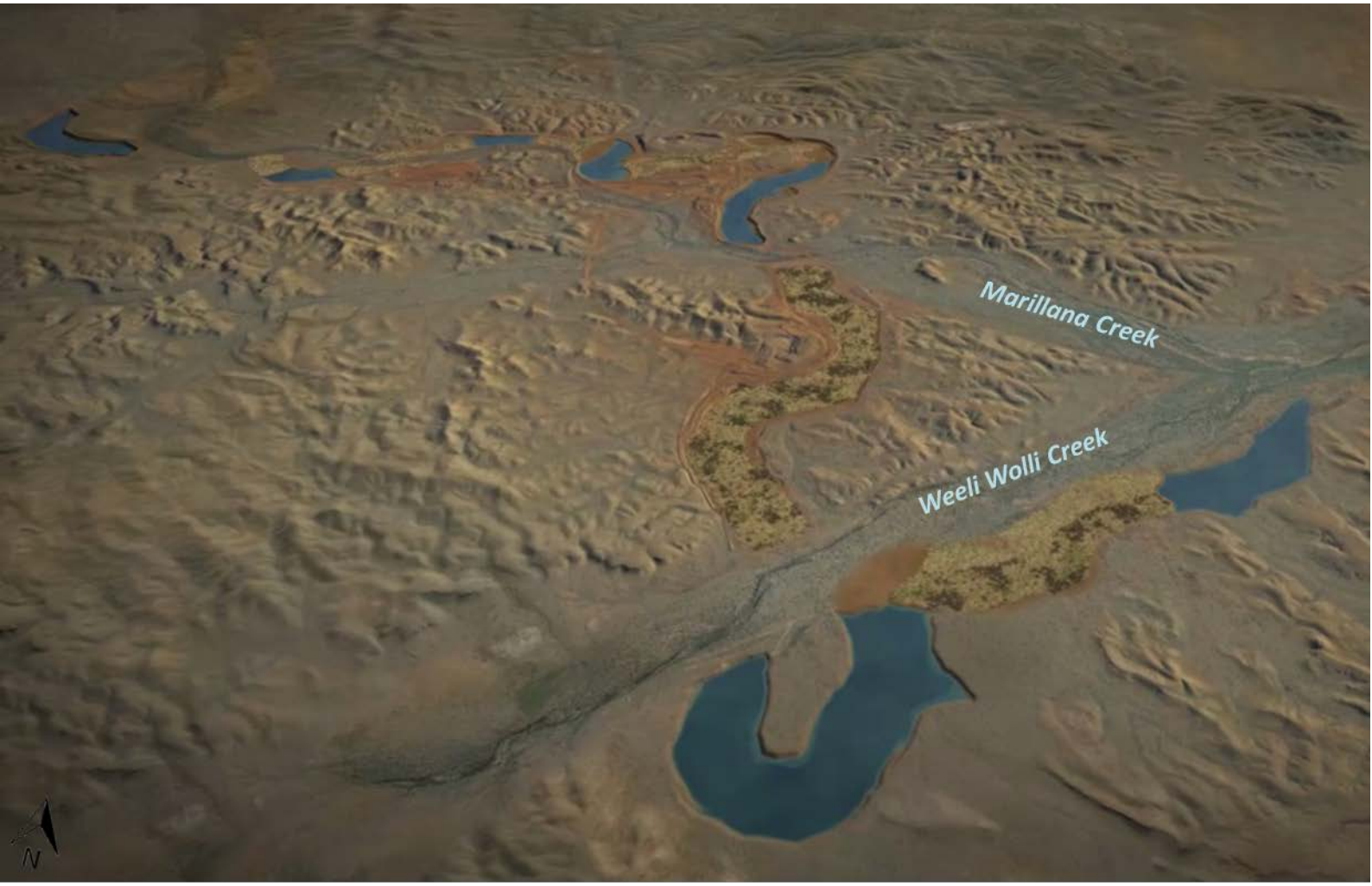
- *Portulaca oleracea/Portulaca intraterranea*
  The taxonomy of "*Portulaca oleracea*" in the Pilbara is currently unresolved. It is not clear whether specimens from this region with weakly developed tubercles on the seeds belong to *Portulaca oleracea, P. intraterranea* and/or one or more undescribed taxa (S. Dillon, WA Herbarium, pers. comm. 2012). For the purposes of this report, all specimens have been allocated to "*Portulaca oleracea/P. intraterranea*", with the exception of a single specimen that was confirmed as *P. intraterranea* by Andrew Perkins (WA Herbarium taxonomist). The latter specimen was conspicuously different to the other specimens designated as "*Portulaca oleracea/intraterranea*", having seeds with very prominent elongated tubercles with star-shaped bases.

Hamersley Iron – Yandi Pty Limited

Yandicoogina mine closure plan

13 August 2015

RTIO-HSE-0208486
Mineral field 47 – West Pilbara



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CORPORATE CLOSURE PLANNING STATEMENT

Hamersley Iron – Yandi Pty Limited (**HIY**) is a wholly owned member of the Rio Tinto Group and part of Rio Tinto's global iron ore business. Rio Tinto's iron ore group (**Rio Tinto**) considers closure planning to be an integral part of its business. The process of preparing for closure begins in the early stages of project development, and continues throughout the life of the mine.

A team of in-house rehabilitation and closure planning specialists has been established within Rio Tinto to manage this aspect of our operations. A Rehabilitation and Closure Working Group has been established to facilitate integration of closure planning into the broader mine planning framework, and to oversee the research and improvement projects recommended in each closure plan. In this way, Rio Tinto aims to continually improve both its understanding of closure risks, and the strategies employed to mitigate them.

This plan documents the current closure knowledge base for Yandicoogina. It outlines the objectives that need to be met at closure, the strategies and plans to be employed to achieve them, and provides an indication of the criteria that will be used to assess closure success.

However, this is not a static document. Rio Tinto will continue to revisit its closure plans on a regular basis to ensure that the objectives to which it is working towards remain relevant and aligned to stakeholder expectations, and to revise its strategies and plans where appropriate to achieve improved closure outcomes.

EXECUTIVE SUMMARY

Overview

HIY's Yandicoogina channel iron deposits (**CID**) are located near the junction of Marillana Creek and Weeli Wolli Creek, approximately 90km northwest of Newman in the Pilbara region of Western Australia. The CID is a local aquifer, located adjacent to and under the current creek system. The CID is dewatered then removed using open cut, conventional drill-and-blast and load-and-haul mining methods. Waste generated through mining is deposited in temporary stockpiles adjacent to the pit, until sufficient void space becomes available for the material to be returned to the void. The mine has been operating continuously since 1998.

Scope

This closure plan has been prepared to support the Yandicoogina Iron Ore Project - Pocket and Billiard South (**PBS**) referral under Part IV of the *Environmental Protection Act* 1986 (**EP Act**). PBS will utilise infrastructure at the existing Yandicoogina operations (**Yandicoogina**). Consequently, this closure plan has been designed to address the closure requirements for Yandicoogina inclusive of the PBS decommissioning and rehabilitation requirements. This closure plan also includes reference to Oxbow East, also currently under referral under Part IV of the EP Act. Closure is assumed to include progressive rehabilitation that will occur throughout the life of the mine. The goal of mine closure at Yandicoogina is to relinquish the site to the Government.

This closure plan has been developed to meet the requirements of the joint Office of the Environmental Protection Authority / Department of Mines and Petroleum Guidelines for Preparing Mine Closure Plans (2015) [1] (**Closure Guidelines**). As such, this closure plan includes closure approaches for prospective areas that are not intended for regulatory approval at this time[2], namely Billiard North and Braid. Closure options presented for Billiard North and Braid deposits are provided solely for the purpose of facilitating discussions with key stakeholders, as part of an integrated closure plan.

Primary obligations and commitments

Yandicoogina is subject to the *Iron Ore (Yandicoogina) Agreement Act 1996* and Ministerial Statement 914 under the EP Act. It is recognised that additional obligations may arise associated with the proposal to mine PBS and Oxbow East.

Post-mining land use

The pre-mining land use of cattle grazing pastoral activities is not considered to be compatible with basic landforms that will be left as a consequence of mining, e.g. waste dumps, pit voids and pit lakes. Alternative land use options are continuing to be investigated in consultation with the local pastoral stations, local communities and Traditional Owners.

Until an alternate land use is agreed, the closure and rehabilitation strategy focuses on the following, to ensure the system remains compatible with general Pilbara land uses:

- create landforms that are stable for access by humans and native fauna;
- ensure water systems support existing riparian vegetation and are compatible with the natural system dynamics; and
- establish ecosystems with similar biodiversity and cultural heritage values as surrounding reference sites.

Closure objectives

The following closure objectives have been developed for Yandicoogina:

- rehabilitated landforms are stable and designed to manage floodwater appropriately;
- the environmental and cultural heritage values associated with creek flows and function are maintained post-closure;
- environmental values of Fortescue Marsh are not compromised;
- water quality within pit lakes support natural ecosystems and are compatible with post-mining land use;
- alluvial groundwater systems support remnant phreatophytic vegetation;
- final landforms are rehabilitated to be compatible with post-mining land use; and

[1] Department of Mines & Petroleum and Office of the Environmental Protection Authority (2015) Guidelines for Preparing Mine Closure Plans, June 2015.

[2] refer to Closure Guidelines Section 3.1, page 12, "…closure planning should start in the project feasibility stage (before project approvals)."

- public safety hazards have been addressed.

Note that these objectives do not represent the full range of closure issues that may be present at the site. Rather the objectives reflect key issues against which closure performance will be assessed by government regulators.

Indicative completion criteria have been proposed within this closure plan, however further work is required to clarify and quantify the completion criteria.

Anticipated closure outcome

Due to the limited volume of mineral waste generated by the mining operation, the legacy of below water table mining at Yandicoogina will be the creation of a series of groundwater-dependent pit lakes.

The closure approach returns mineral waste to the pit voids and preferentially places the material against pit walls that are adjacent to creeks, to stabilise the walls and prevent the creeks from collapsing into the mine voids post-closure. As a result, Marillana Creek and Weeli Wolli Creek are expected to continue to function without assistance and with no long term impact to Fortescue Marsh (located downstream of the operation).

The in pit closure landform has, subsequently, been designed to minimise the future lake surface areas. By minimising the lake area, evaporation will be minimised. This will, in turn, retard lake salinity and facilitate groundwater recovery levels to pre-disturbance[3] groundwater levels. This is expected to lead to better groundwater conditions (than other closure alternatives) within the adjacent alluvial groundwater aquifers that support groundwater dependent (phreatophytic) ecosystems.

All areas disturbed by mining activities, with the exception of the pit walls, will be rehabilitated. Away from the lakes, the disturbed land will be revegetated to provide habitat similar to the pre-mining conditions. Habitat requirements for species of biodiversity value will be integrated into the rehabilitation design, where appropriate. Surface water will be managed in a manner sympathetic to the habitat.

The lake fringes will be dynamic environments. The lake fringe will be rehabilitated to be compatible with the post-mining soil, landform and water conditions. Lake levels are expected to rise and fall over 10 m due to the strong links between creek flows, creek bed infiltration / groundwater recharge and subsequent groundwater rise. Bore observations suggest the rapid rise in groundwater level, and slow decline, will occur regardless of whether the lake is connected to a creek or catchment area. This dynamic lake environment is commonly associated with wetlands, but is not readily identified with existing Central Pilbara ecosystems. Consequently, the characteristics and completion criteria that will define a stable, self-sustaining ecosystem in the lake fringe habitat zones will be different from those used to define rehabilitation success elsewhere, and are subject to further study and validation.

Water quality is expected to vary from one lake to another, as groundwater moves through one lake system to another, depending on whether the lake behaves as a groundwater through-flow or sink system, and is expected to change over time. Groundwater modelling suggests the Oxbow West and JC lakes will act as groundwater sinks, that is, most of the water entering these voids will leave via evaporation. As a result, the lake water salinity within these lakes is expected to steadily increase over the long term. All of the other pit lakes are expected to behave as groundwater through flow lake systems.

Unfortunately, the interactions between the closure landform, surface water and groundwater systems at Yandicoogina are very complex. Computer programs commonly used to model and / or simulate groundwater and lake conditions struggle to define how water will move and how water quality may change over time; especially at spatial and temporal scales that enable environmental impacts to the groundwater dependent ecosystems to be conclusively resolved. Ongoing review and update of the water models is required throughout the life of the operation to improve the model predictions and during the post-mining period to validate the outcomes.

[3] “Pre-disturbance” is defined as period prior to any mining activities taking place within the catchment.

CLOSURE GUIDELINES CHECKLIST

Q	Mine Closure Plan (MCP) Checklist	Y/N/ NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
1	Has the Checklist been endorsed by a senior representative within the operating company?	Y			NA		
2	Are you aware that from 2015 all MCPs will be made publically available?	Y			NA		
3	Is there any information in this MCP that should not be publicly available?	N			NA		
4	If “Yes” to Q3, has confidential information been submitted in a separate document / section?	NA			NA		
5	Does the MCP cover page include: Project Title, Company Name, Contact Details (including telephone numbers and email address) Document ID and version number, Date of submission (needs to match the date of this checklist)	Y			Y		Contact changed
6	State why the MCP is submitted (e.g. as part of a Mining Proposal, a reviewed MCP or to fulfil other legal requirement)			Referral under Part IV EP Act	Y		
7	Does the project summary include land ownership details, location of the project, comprehensive site plans and background information on the history and status of the project?	Y			Y		HIY referenced instead of RTIO
8	Does the MCP include a consolidated summary or register of closure obligations and commitments been included?	Y	22		Y		New register generated
9	Have all stakeholders involved in closure been identified?	Y	24		N		
10	Does the MCP included a summary or register of historic stakeholder engagement been provided, with details on who has been consulted and the outcomes?	Y	24		Y		Updated
11	Does the MCP include a stakeholder consultation strategy to be implemented in the future?	Y	23		N		
12	Does the MCP include agreed post-mining land use, closure objectives and conceptual landform design diagram?	Y	30		Y		New landform design image
13	Does the MCP identify all potential (or pre-existing) environmental legacies which may restrict the post mining land use (including contaminated sites)?	Y	34		N		
14	Has any soil or groundwater contamination that occurred, or is suspected to have occurred, during the operation of the mine, been reported to DER as required under the Contaminated Sites Act 2003?	NA			N		

Q	Mine Closure Plan (MCP) Checklist	Y/N/ NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
15	Does the MCP include an appropriate set of specific completion criteria and closure performance indicators?	Y	32		Y		pH of lake water added
16	Does the MCP include baseline data (including pre-mining studies and environmental data)	Y	34		N		
17	Has materials characterisation been carried out consistent with applicable standards and guidelines (e.g. GARD Guide)?	Y	46		N		
18	Does the MCP identify applicable closure learnings from benchmarking against other comparable mine sites?	Y		See Appendix B & C	Y		New review included
19	Does the MCP identify all key issues impacting mine closure objectives and outcomes (including potential contamination impacts)?	Y	84		Y		Updated
20	Does the MCP include information relevant to mine closure for each domain or feature?	Y	93		N		
21	Does the MCP include a gap analysis / risk assessment to determine if further information is required in relation to closure of each domain or feature?	Y	85		N		
22	Does the MCP include the process, methodology and has the rationale been provided to justify identification and management of the issues?	Y	84		Y		Risk assessment process clarified
23	Does the MCP include a summary of closure implementation strategies and activities for the proposed operations or for the whole site?	Y	89		N		
24	Does the MCP include a closure work program for each domain or feature?	N		To be developed prior to closure	NA		
25	Does the MCP contain site layout plans to clearly show each type of disturbance as defined in Schedule 1 of the MRF Regulations?	N		State agreement site not subject to MRF	NA		
26	Does the MCP contain a schedule of research and trial activities?	Y	89		Y		Updated
27	Does the MCP contain a schedule of progressive rehabilitation activities?	N		Indicative closure schedule provided. Opportunities for rehab assessed annually	NA		
28	Does the MCP include details of how unexpected closure and care and maintenance will be handled?	Y	94		Y		Updated
29	Does the MCP contain a schedule of decommissioning activities?	N		To be developed prior to closure	NA		
30	Does the MCP contain a schedule of closure performance monitoring and maintenance activities?	N		To be developed prior to closure	NA		
31	Does the MCP contain a framework, including methodology, quality control and remedial strategy for closure performance monitoring including post-closure monitoring and maintenance?	Y	97		N		

Q	Mine Closure Plan (MCP) Checklist	Y/N/ NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
32	Does the MCP include costing methodology, assumptions and financial provision to resource closure implementation and monitoring?	Y	101	Financial provision not included	N		
33	Does the MCP include a process for regular review of the financial provision?	Y	101		N		
34	Does the MCP contain a description of management strategies including systems and processes for the retention of mine records?	Y	102		N		

I hereby certify that to the best of my knowledge, the information within this closure plan is true and correct and addresses the relevant requirements of the *Guidelines for Preparing Mine Closure Plans* approved by the Director General of Mines.

David Bloor
General Manager - Health, Safety and Environment

MINISTERIAL STATEMENT COMPLIANCE CHECKLIST

The Yandicoogina Closure Plan has been prepared to satisfy multiple objectives, including compliance with obligations arising from environmental approvals.

This checklist has been provided to facilitate audits of compliance against Ministerial Statement 914 Condition 9-3, which specifies: "*The Yandicoogina Decommissioning and Rehabilitation Plan required pursuant to Condition 9-1 shall set out procedures to:*" (as follows)

Clause		Relevant sections	Page
(1)	manage long-term hydrogeological impacts of mining the channel iron deposit	Section 17	68
(2)	model the long-term hydrological impacts, particularly the water levels and quality both in the pit void and downstream of waste material landforms	Section 17	68
(3)	manage over the long-term the surface water systems affected by the open pit	Section 16 and 17	63
(4)	progressively rehabilitate all disturbed areas to a standard suitable for the agreed end land use(s), with consideration and incorporation of:		
	(a) the characteristics of the pre-mining ecosystems within the project area (through research and baseline surveys)	Section 14	48
	(b) the performance of previously rehabilitated areas within the mining lease	Section 14	60
	(c) the performance of rehabilitation areas at the proponent's other operations in the Pilbara	Appendix B & C	
	(d) best practice rehabilitation techniques used elsewhere in the mining industry	Appendix C	
(5)	develop and identify completion criteria	Section 11	32
(6)	monitor rehabilitation to assess the performance of all rehabilitated areas against the completion criteria	Section 23	97
(7)	report on the rehabilitation and monitoring results	Section 14	60
(8)	remove all infrastructure	Section 15	62
(9)	develop management strategies and/or contingency measures in the event that operational experience and/or monitoring identify any significant environmental impact as a result of the proposal	Section 22	94
(10)	manage and monitor mineral waste including physical characteristics and acid or neutral metalliferous drainage using national and international standards and updates	Section 13.5	45
(11)	develop a 'walk away' solution for the decommissioned mine site	Section 16.1 *Discussion also in Appendix D*	63

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INTRODUCTION TO CLOSURE PLANNING

1. What is a closure plan?

A closure plan documents strategies to achieve the desired post-closure landform and avoid or mitigate potential social and environmental impacts associated with site closure, to an extent that is fiscally appropriate. As such, closure plans provide the framework for planning and implementing mine. Closure plans also document tasks the HIY has committed to undertake to improve closure outcomes.

Closure plans are intended to be used by site personnel to inform on-going planning decisions, and to ensure closure is integrated into operational activities. Closure plans are also one of the methods used by the business to communicate its closure strategy to stakeholders, including regulators.

2. The closure planning process

Closure plans are regularly updated to account for changes resulting from:

- amendments to the mine plan;
- improvements of the site closure knowledge base (e.g. through daily activities, technical studies and research actions, progressive rehabilitation);
- new or amended regulation;
- changes to surrounding land uses; and
- evolving stakeholder expectations.

Review processes bring experts together to discuss current performance, proposed mine changes and opportunities to improve closure outcomes. At the end of the review process, improvement actions are assigned and the closure plan is updated.

A key output of closure planning is the development of a closure cost estimate. Closure provisions are subsequently integrated into our business planning processes to ensure funds will be available to close the site effectively.

The detail of each closure plan increases as the knowledge base develops. When the site moves to within five years of scheduled closure, studies will be completed to define how infrastructure, decontamination, rehabilitation, the workforce and communications will be managed throughout the mine closure period (and beyond), specific to the site conditions at the end of mining. Stakeholder engagement and endorsement of the final completion criteria is facilitated at this time.

In the final closure plan update (also referred to as the Decommissioning Plan), location specific management plans are provided for each closure domain. These detailed plans cover the physical closure, dismantling and subsequent rehabilitation implementation requirements. The supporting technical reports that have been used within the closure plan to predict the post-closure outcomes are also appended to the final closure plan.

3. Closure terminology

This closure plan is accessed by various groups within Rio Tinto as well as external stakeholders, including Western Australian State Government regulator and advisory departments and Traditional Owner groups. The following clarification is provided to define how the following terms are used within this closure plan:

- A mine void refers to the cavity created in the natural geology in order to mine ore, which extends below the natural surface.

- A pit refers to total area from which material was removed. A pit may include shallow depressions, where material is removed for construction purposes e.g. a borrow pit, and / or quarries where no surface depression is created, but instead part of a rock outcrop is removed.

- Post-mining landform refers to the shape of the land that would be generated as a result of implementation of the current operational mine plan and standard operating practice. Issues that could potentially arise from this scenario, and strategies to manage them, are the focus of this closure plan.

- Final landform designs refer to the individual feature or domain-based landform shaping requirements required to achieve the closure objectives.

- Closure landform refers to the overall shape of all the land disturbed by mining activities after rehabilitation earthworks are complete.
- Post-closure landform encompasses the closure landform and the surrounding undisturbed land, to describe the wider catchment conditions.
- Pre-mining refers to the condition of the environment immediately prior to ground disturbance activities.
- Pre-disturbance refers to the general condition of the environment prior to any mining activities, including the Yandicoogina operation, commencing in the catchment. Within the context of this closure plan pre-disturbance conditions are inclusive of impacts associated with pastoral use.

PURPOSE AND SCOPE

4. Purpose

Planning for closure of a site is a critical business process that demonstrates HIY's commitment to sustainable development. The report follows the format and content requirements for mine closure plans as recommended in the Closure Guidelines and Ministerial Statement 914 Condition 9 *Decommissioning and Rehabilitation*.

This closure plan has been prepared to support the Yandicoogina Iron Ore Project PBS and Oxbow East referrals under Part IV of the EPA Act.

This update also includes information developed as part of ongoing closure plan revisions and information developed in response to key stakeholder feedback, including:

- improvements to the visual presentation of the closure landform designs;
- additional water balance information developed for proposed pit lakes at PBS;
- revision of the end of mine life date, such that the final deposit is listed as PBS;
- inclusion of conceptual closure options for prospective areas. These options are presented for consideration in cumulative impact, integrated mine planning and to facilitate discussion with key stakeholders and are not intended to be approved by regulators for implementation;
- change of the pit naming convention from Oxbow to Oxbow West; and
- inclusion of the proposed Oxbow East.

This closure plan supersedes all previous closure, decommissioning and rehabilitation plans for Yandicoogina.

5. Scope

This plan covers the closure, rehabilitation and decommissioning of facilities and disturbed areas associated with mining activities at Yandicoogina, including:

- open cut pits, mineral waste dumps, haul roads and associated ground disturbance;
- dewatering borefield, pipelines, discharge outlets and associated infrastructure;
- processing facilities, conveyor infrastructure, and associated facilities and infrastructure; and
- administration buildings, camp, associated facilities and infrastructure, sealed and unsealed roads.

Decommissioning and removal of the rail network has been specifically excluded from this closure plan in accordance with *Iron Ore (Yandicoogina) Agreement Act 1996*, clause 39 (2) (refer to Appendix A). This exclusion is subject to review with each revision and update of the closure plan.

This mine closure plan update has been developed using information current as at March 2015.

PROJECT SUMMARY

6. Description of operation

6.1 Overview

Yandicoogina (Figure 1) is located in the Shire of East Pilbara, approximately 90km northwest of Newman within the Weeli Wolli Creek catchment. The mine is sufficiently remote that mining is operated on a fly-in fly-out (**FIFO**) basis.

The mine is one of several operations within a localised area along a CID (Figure 2). The CID is characterised by continuous iron mineralisation along a palaeochannel in the lower reaches of the Weeli Wolli Creek catchment. The CID snakes over 100km from the Munjina Claypan in the west down Marillana Creek and its tributaries and into Weeli Wolli Creek, terminating somewhere under Fortescue Marsh.

The first mine in the catchment to be developed, commencing in 1991, was the BHP Billiton Iron Ore Yandi mine (also known as Marillana Creek) located approximately 12 km west and immediately upstream of Yandicoogina on Marillana Creek. BC Iron Limited (formerly Iron Ore Holdings) with Mineral Resources operate Phils Creek Iron Ore Mine, located immediately north and upstream of Yandicoogina on Phils Creek. Other iron ore mining companies seeking to establish operations in the immediate vicinity of Yandicoogina include:

- BC Iron Limited Iron Valley project, situated approximately 5km to the north-east, adjacent to Fortescue Metals Group (**FMG**) Nyidinghu project;
- FMG Nyidinghu project, located immediately downstream of the Yandicoogina mining lease (M274SA) adjacent to Weeli Wolli Creek; and
- Brockman Mining Limited Marillana Iron Ore Project, located approximately 20km to the north of Yandicoogina and downstream of the BC Iron Limited Iron Valley and FMG Nyidinghu projects.

Due to the proximity of the mines, mining and closure activities at Yandicoogina are expected to influence the mine and closure strategies at the BHP Billiton Iron Ore Yandi mine, the BC Iron Limited Iron Valley project and the FMG Nyidinghu project.

Other major mines within the Weeli Wolli Creek catchment, upstream of Yandicoogina and adjacent to Weeli Wolli Creek, include:

- BHP Billiton Iron Ore Mining Area C mine and Jinidi expansion project, located approximately 32 km to the south-east of Yandicoogina; and
- Hamersley HMS Hope Downs 1 mine, located approximately 22 km to the south of Yandicoogina.

Rio Tinto group companies also hold leases over the Snooker and Meander deposits, located upstream of the BHP Billiton Iron Ore Yandi mine. As Yandicoogina is located downstream and outside the influence of these areas, closure is not expected to impact these areas. However, activities at these mines and at BHP Billiton Iron Ore Yandi mine may influence the Yandicoogina’s mine and closure strategies.

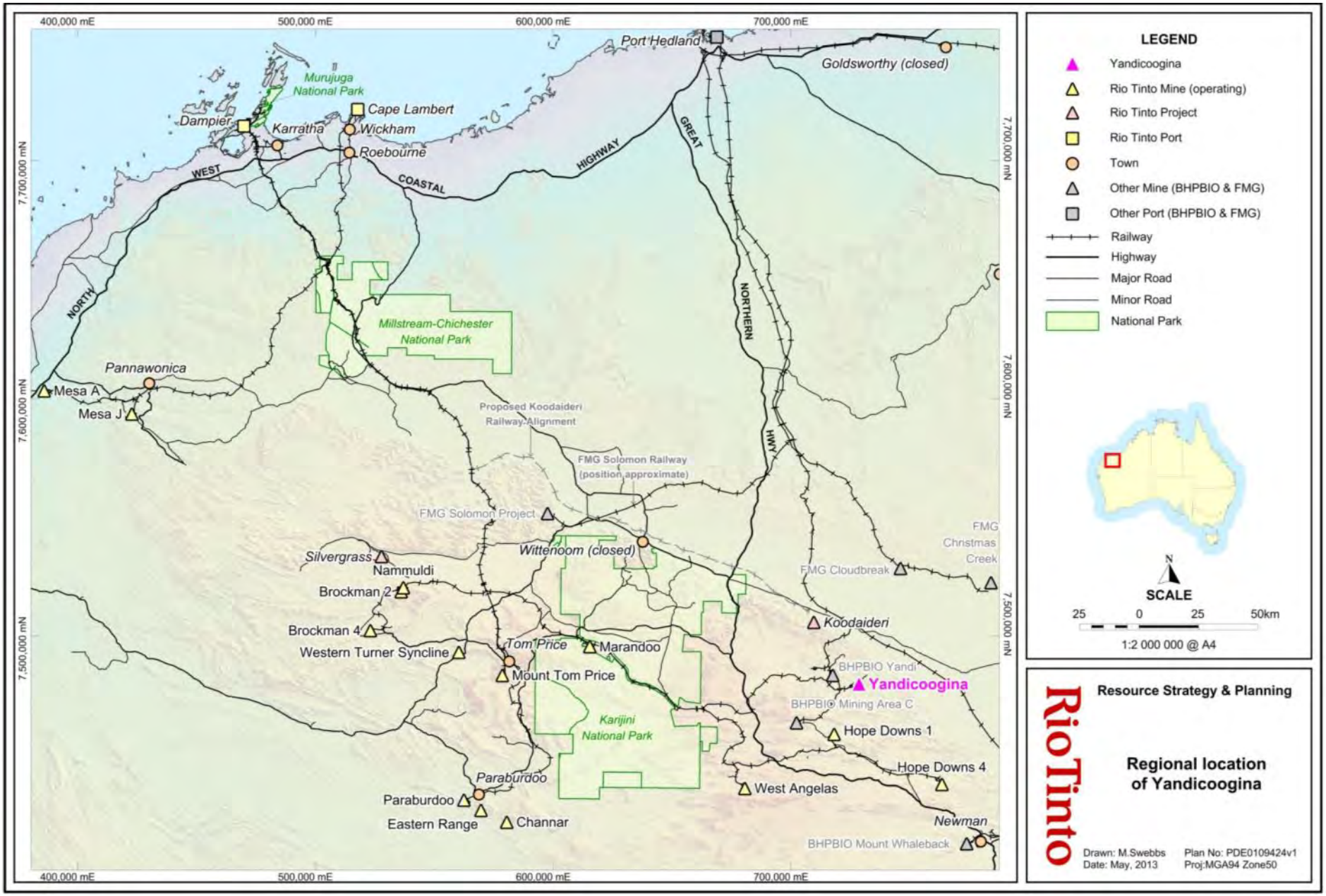


Figure 1: Location of Yandicoogina mine.

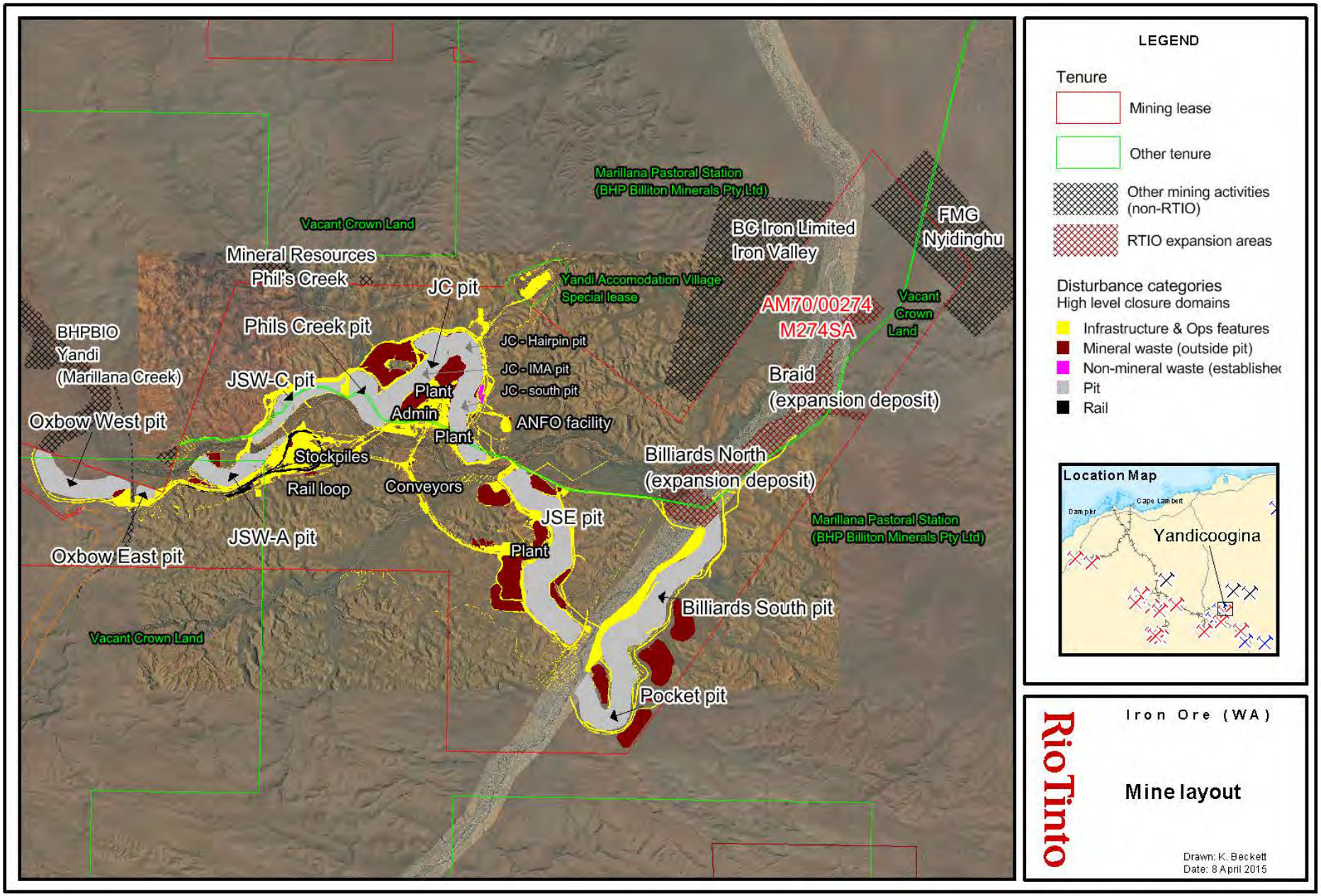


Figure 2: Yandicoogina mine layout.

6.2 Closure plan development history

The initial Yandicoogina mine proposal, which covered the western half of the Junction Central deposit, was approved under Part IV of the EP Act in 1996. The resulting Ministerial Statement, 417, identified long term management of water and associated vegetation as key closure issues. The proposal to extend the mining area to the east (over the Junction Central Hairpin and Waterstand areas) was approved in 1999 as an amendment to Ministerial Statement 417, Ministerial Statement 523.

In these initial proposals, it was identified that Yandicoogina was unlikely to have sufficient mineral waste to cover the exposed groundwater table, such that the creation of pit lakes at Yandicoogina was required. This requirement was acknowledged in the initial Yandi Operations Closure Statement in 1999. A closure plan for Yandicoogina was subsequently approved by OEPA in August 2000. The plan was then updated for internal use in 2001.

The Yandicoogina closure plan was significantly updated in 2003 and provided as part of the 2005 Junction South East (**JSE**) referral that resulted in Ministerial Statement 695. In the 2005 Yandicoogina closure plan, HIY suggested that an adjacent hill could be mined to fill the JSE mine void to the 490mRL to prevent the formation of a permanent pit lake. Ministerial Statement 695 included Condition 6 *Post-closure Backfill Source* requiring HIY to address issues other than water management associated with this closure strategy, including Aboriginal ethnographic and archaeological, vegetation, flora and fauna values. This condition provided a turning point for the closure planning strategy for Yandicoogina, which until this point had been focused on the protection of groundwater quality values over all other environmental and social values.

In 2008, a closure management study for Yandicoogina was reviewed by the Department of Industry and Resources (now DMP), in accordance with Ministerial Statement 695 Condition 5-1. The Department of Industry and Resources' review stated the closure management study did not meet the requirements of condition 5.1[4].

A closure plan for Yandicoogina was subsequently included in a revised proposal submitted under Part IV of the EP Act for the Junction South West (**JSW**) and Oxbow referral. Ministerial Statement 914 issued in 2012 encompassing the entire Yandicoogina operation, superseding Ministerial Statements 417, 523 and 695 for the Yandicoogina Operations, in accordance with section 45B of the EP Act. This 2012 Yandicoogina closure plan acknowledged that mining neighbouring hills to suppress the groundwater table would require significant additional clearing, and was no longer consider to be the preferred closure strategy.

Ministerial Statement 914 Condition 7-3 introduced a new requirement for closure planning, to ensure "there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems" along both Marillana and Weeli Wolli Creeks. Compliance with this condition had the potential to conflict with some proposed closure strategies presented in the 2012 Yandicoogina Closure Plan.

The 2014 Yandicoogina Closure Plan was submitted to the OEPA, in accordance with Ministerial Statement 914 Condition 9-1, on 31 March 2014 and approved on 23 January 2015. Areas for improvement identified by regulators in the 2014 review have been addressed in this closure plan.

6.3 Mine layout

Yandicoogina utilises standard truck and shovel methods to develop open pit iron ore deposits. The deposits include (from upstream to downstream): Oxbow West, Oxbow East, JSW areas A (**JSW-A**) and C (**JSW-C**), Junction Central (**JC**), Junction South East (**JSE**) and PBS. Prospective areas include the Billiard North and Braid.

At the point of closure Yandicoogina will include:

- open cut pits developed to depths below the natural groundwater table;
- temporary out-of-pit mineral waste dumps and in-pit backfilling of exhausted mine areas;
- topsoil and subsoil stockpiles for mine site rehabilitation;
- a dewatering system including groundwater bores, pipelines, water storage areas and discharge outlets;
- roads including light vehicle / heavy vehicle access and haul roads, and several floodways;
- flood protection infrastructure, including levees along Marillana Creek and Weeli Wolli Creek, diversion of Phils Creek, minor creek diversions levees and drains. Some levee and diversion structures will be retained on closure;

[4] Letter from Ross Atkin, Project Manager Investment Facilitation (DOIR), dated 8 October 2008, available at RTIO-HSE-0071273

- infrastructure associated with ore haulage to processing facilities at JC and JSE, and rail load out facilities south-east of JSW;
- power and communications infrastructure; and
- other supporting infrastructure including accommodation village, administration buildings, maintenance workshops and associated utilities and services.

Key aspects of the post-mining landform include:

- 8 mine voids that extend below the water table;
- 7 or more waste dumps located within the mine voids. The toe of each dump will extend to the base of the pit, below the natural groundwater table. In some locations the toe of the dump may already be underwater due to recovery of the groundwater table;
- over 10 temporary stockpiles of mineral waste (waste dumps) located external and adjacent to the mine voids, which will need to be transported back into the mine void prior to rehabilitation;
- 3 in pit waste fines cells in JC and a network of waste fines cells in JSE; and
- a specially designed and constructed land bridge that connects Phils Creek back to Marillana Creek along the original flow path.

Note, a full site inventory is included in closure cost estimate reports for the site and is not reproduced in this report.

6.4 Mine development and schedule

JC was the first deposit to be developed at Yandicoogina and has been operating continuously since 1998. Mineral waste (overburden) was deposited outside of the pit area to the north of the operations adjacent to Phils Creek and topsoil was stockpiled immediately south of the mine area, where they remain today. As void space became available, mineral waste was deposited directly into the mined out sections of the void (backfilled). Mined out areas of the JC mine void have also been converted into waste fines storage areas for the benign waste residue generated by wet processing of the iron ore. Mineral waste will be continually deposited back into the JC mine void until the deposit is exhausted.

Development of JSE commenced in 2006. Dewatering challenges prevented the full vertical extent of the deposit from being mined simultaneously; and as a result, the mineral waste from JSE has had to be placed in temporary stockpiles external to the pit. The JSE mine void has also been converted into a waste fines storage area.

Development of JSW commenced in 2013. The JSW ore body extends under Marillana Creek, although mining is limited to areas outside the 100 year floodplain. The last 800 m of Phils Creek has been diverted, temporarily, to facilitate mining under Phils Creek. This section of Phils Creek is expected to be reinstated prior to closure. Mineral waste from JSW is deposited into existing mine voids in JC and JSW.

Oxbow West, Oxbow East and PBS are expected to be developed after 2017. Mineral waste from Oxbow West and Oxbow East will be deposited into the JSW mine voids. Mineral waste from PBS will be placed external to the mine void until areas of the PBS pit are exhausted, at which time the mineral waste will backfilled directly into the PBS mine void.

The major development milestones, based on the current mine plan, are presented in Table 1. It should be noted that the mine plan is subject to constant review and modification, and these timeframes may differ in future closure plan updates.

Table 1: Pit development schedule

Deposits	Commence	Ore exhausted
Oxbow West	2018	2025
Oxbow East	2017	2020
JSW-A	Underway	2020
JSW-C	Underway	2018
JC	Underway	2017
JSE	Underway	2019
PBS	2017	2032

CLOSURE OBLIGATIONS AND COMMITMENTS

7. Legal obligations

A closure obligations register is presented as Appendix A, in accordance with the format prescribed in the Closure Guidelines. It contains a list of obligations from the following instruments:

- *Iron Ore (Yandicoogina) Agreement Act 1996*;
- Ministerial Statement 914 (Yandicoogina Iron Ore Project – Expansion to Include Junction South West and Oxbow Deposits);
- EPBC Decision Notice 2011/5815;
- relevant Native Vegetation Clearing Permits; and
- relevant leases held pursuant to *Land Administration Act 1997*.

The register also identifies legislation, standards and guidelines that may not apply to Yandicoogina specifically, but that may be relevant to closure of mine sites generally.

This closure plan has been prepared to support the Yandicoogina Iron Ore Project PBS and Oxbow East referrals under Part IV of the EPA Act, and additional specific obligations may arise through these processes. These will be documented in the next update of the Yandicoogina closure plan.

STAKEHOLDER CONSULTATION

8. Stakeholder consultation

8.1 Consultation process

Stakeholder consultation is undertaken to ensure all stakeholders have their interests considered during closure planning. HIY has established processes and protocols for consultation with each of its key stakeholders. This work expands on the principles established by HIY's approach to Communities and Social Performance. Most closure consultation is conducted within this existing framework.

Consultation is commenced in the early stages of the closure planning process, and continues through to site relinquishment. The consultation strategy used by HIY is designed to:

- identify stakeholders and interested parties;
- develop a targeted consultation plan to reflect the needs of the stakeholder groups and interested parties;
- integrate the consultation plan into the mine planning/closure planning process; and
- where practicable, work with communities to manage the potential impacts of mine closure.

Closure consultation is usually conducted within a broader consultation framework, as a component of on-going consultation forums. For example, consultation with State and Local Government stakeholders occurs as part of regular meetings held with individual agencies. Consultation on specific issues is also undertaken outside of these regular meetings as the need arises. Consultation with other stakeholders is conducted in a manner that is appropriate to the stakeholder and the specific issues requiring discussion.

The timing of discussions and discussion focus will change as the project matures or new deposits are discovered and developed. The focal areas for discussion are illustrated in Table 2.

Table 2: Closure discussion framework

Stage	Focus
Prior to deposit development	Undertake stakeholder identification and stakeholder mapping. Commence closure-specific discussions with key stakeholders. Discuss and agree (where relevant) key environmental, cultural and social values and closure objectives. (Usually undertaken in conjunction with environmental approval discussions.) Review public comments provided though public environmental review processes to identify additional stakeholders and / or concerns.
During operations	Ensure closure objectives and indicative closure criteria remain relevant and appropriate. Communicate outcomes of studies undertaken to improve the closure knowledge base, reduce closure risks or improve closure strategies, as part of the closure plan review process. Include closure in Traditional Owners liaison forums, established under the terms of Indigenous Land Use Agreements with relevant groups.
In the lead up to closure (development of Decommissioning Plan)	Undertake communication campaign to finalise completion criteria through key stakeholder consensus. Discussion future uses for infrastructure with other parties, i.e. for sale of equipment. Commence workforce communication strategy.
Post-closure	Establish a public awareness campaign to demonstrate progress of closure against completion criteria.

8.2 Communication register

Key stakeholders in the closure of Yandicoogina are listed in Table 3. This list is dynamic and is expected to evolve over time. The communications register (Table 4) summarises the discussions that have been held with stakeholders with respect to closure.

Table 3: Key stakeholders

Category	Stakeholder
Commonwealth Government	Department of the Environment
State Government	Department of State Development (**DSD**)
	Department of Aboriginal Affairs (**DAA**)
	Department of Mines and Petroleum (**DMP**)
	Office of the Environmental Protection Authority (**OEPA**)
	Department of Parks and Wildlife (**Parks and Wildlife**)
	Department of Environment Regulation (**DER**)
	Department of Water (**DOW**)
	Department of Regional Development and Lands (**RDL**)
	Department of Agriculture and Food WA (**DAFWA**)
	Main Roads WA (**MRWA**)
	Pastoral Lands Board
Local Government	Shire of East Pilbara
Community	Banjima people
	Nyiyaparli people
	Yinhawangka (formerly Innawonga) people
	Marillana Pastoral Station
	Fortescue Metals Group (**FMG**)
	BC Iron Limited
	BHP Billiton Iron Ore
	Brockman Mining Limited
	Mineral Resources
	Hamersley HMS Pty Limited

Table 4: Stakeholder engagement (communications) register

Date(s)	Title of communication	
Stakeholders	**Outcomes**	**Resolution and related actions**
1996	Junction Central environmental approvals	
EPA public process, public submissions from: Conservation Council, Dept Aboriginal Affairs, Dept Conservation & Land Management, Dept Minerals & Energy, Dept Resources Development	The main closure concerns identified by stakeholders were: • salinity of any remaining pit voids; and • aquifer rebound, and vegetation stress caused by depressed groundwater levels. A commitment was made to develop a decommissioning plan at least 2 years prior to closure: the EPA considered this to be insufficient, and imposed a condition requiring the plan to be developed within 5 years of commissioning.	Commitment to develop a decommissioning plan at least 5 years prior to closure was adopted.
1998	Agreement on key environmental criteria	
Department of Environment, Water & Rivers Commission	Closure performance criteria agreed as part of the 1998 closure planning process. Agreed criteria were: • maintain beneficial use (stock watering) water quality in Weeli Wolli braided area; • limit extent and intensity of impact of drawdown on creek and phreatophytic vegetation to within 1 to 2 km of the pit; and • limit the potential for saline development of in-pit water to less than 15,000mg/L.	These criteria were re-affirmed in the 2003 closure plan update and approved by the DEC in 2005. Note, the FMG Nyidinghu project is now located within the Weeli Wolli braided area. The potential mining influence on this location suggests the Weeli Wolli braided area is no longer a suitable measurement location.
2005	Junction South East environmental approvals	
EPA public process. Consultation was undertaken in preparation of Environmental Protection Statement with: Environmental Protection Authority, Dept Environment, Dept Conservation & Land Management, Conservation Council, Wildflower Society, Gumala Aboriginal Corporation, BHP Billiton Iron Ore, Hope Downs Management Services.	Closure related issues raised by stakeholders related to the following issues: • Salinity of mine void lakes; • Surveys and rehabilitation plans for 'Backfill Hill' prior to mining for backfill material; • Mechanisms for development of completion criteria; • Undertaking closure planning as a component of operational mine planning; • Minimisation of the time between mining and rehabilitation. The final proposal approved by the EPA included the following closure strategy (developed after stakeholder consultation, and not questioned during the public appeal period): "*Use out of pit waste dumps and ROM pad, plus additional mined fill, to backfill the final pit void to at least 490mRL. Rehabilitation of backfilled material to commence once final landforms are constructed and stable*."	A closure plan was submitted in 2008 to comply with the commitment to revise the 2003 Closure Plan to include JSE within 12 months of commissioning.

Date(s)	Title of communication	
Stakeholders	**Outcomes**	**Resolution and related actions**
2010	Junction South West and Oxbow expansion	
Office of the Environmental Protection Authority, Department Environment & Conservation, Department of Water, Department of Mines & Petroleum	Several meetings were held with Government agencies concurrent with Junction South West and Oxbow expansion proposal, including a one day workshop 28 May 2010 where closure objectives and options were discussed. Departmental officers agreed that it may be appropriate to review existing objectives, but indicated that such decisions would need to be made by the OEPA. Efforts to engage discussion with the OEPA during the course of the study were unsuccessful. A formal letter was sent to the OEPA on 18 June 2010[5], with no response. DMP officers suggested that an objective be included that relates to erosion management. Departmental officers agreed that the existing closure strategy (partial backfill) is likely to be inappropriate, but indicated that formal endorsement of alternative strategies would need to be made by the OEPA. Departmental officers did not endorse any particular alternative closure strategy on the basis that further information is required to enable reasonable assessment. However; there was some qualified support for the 'channel' and 'pit void' options.	An indicative completion criteria relating to landform stability has been included in the closure plan.
Gumala Aboriginal Corporation	Half day workshop 24 March 2010 to discuss ethnographic values relevant to closure, to introduce closure options, and obtain feedback on options[6]; and Attendance at the Gumala elders meeting 20 August 2010 to discuss issues specific to the 'channel final landform configuration' (the preferred landform scenario presented in this study report). Concerns were initially raised that the final landform would be different to the pre-mining landscape. No specific ethnographic values that may affect closure planning were identified in the discussions. It was clear at this stage that the Traditional Owners did not wish to provide definitive answers regarding the project, as the options discussed were at a broader strategic level. With respect to the channel configuration, the following issues were identified: • Any standing water should be of suitable quality to maintain a functional ecosystem; • The channel should be constructed in such a manner that enables egress to people or animals that enter; • Heritage surveys conducted to date are not sufficient to identify impacts. Surveys of	Concerns raised by Gumala have been discussed in the closure plan. Engagement with Traditional Owners is proposed to continue via the regular GAC Monitoring and Liaison Meetings

[5] Correspondence to Office of the Environmental Protection Authority dated 18 June 2010, RTIO-CR-0022848

[6] Workshop outcomes are documented in memo RTIO-CR-0024696. The summary of outcomes was also forwarded to Gumala Aboriginal Corporation on 26 March 2010

Date(s)	Title of communication	
Stakeholders	**Outcomes**	**Resolution and related actions**
	additionally impacted areas would be required; • Consideration should be given to maintaining access from one side of the channel to the other; and • Further discussions will be required with Traditional Owners when more specific closure plan details have been established.	
2013	Traditional Owner liaison meetings	
Gumala Aboriginal Corporation	At the June 2013 Yandicoogina Land Use Agreement Monitoring and Liaison Committee an overview of the mine closure process was presented to the GAC board members. It was agreed at the meeting to form a sub-committee / working group to address issues relating to closure and land management. The terms of reference for the sub-committee / working group are yet to be resolved.	HIY subsequently (October 2013) met with the Gumala Aboriginal Corporation Lore and Culture Committee to discuss participation of Elders in the closure working group. A decision on Elder's participation and representation is still pending.
2014	Pocket and Billiard South expansion	
Elders representing the Banjima, Nyiyaparli and Yinhawangka peoples	At this forum, HIY presented the key outcomes of heritage, environment and closure associated with the proposed Pocket and Billiard South expansion project at Yandicoogina. The closure objectives were reaffirmed with the Elders, and clarification of the predicted outcomes for closure of the Yandicoogina site as approved today and including outcomes should expansion continue through to the Billiard North area were discussed.	Water quality was a primary concern for the participants. HIY committed to continue to apprise the community on updates to water quality predictions through the Gumala Monitoring and Liaison Committee.
OEPA, DMP, DoW, Parks and Wildlife	HIY presentation of the Pocket and Billiard South expansion proposal at various forums.	No closure specific actions identified.
2015	Pocket and Billiard South expansion	
OEPA, DMP, DoW and Gumala Aboriginal Corporation	HIY presentation of the Pocket and Billiard South expansion proposal at various forums.	No closure specific actions identified.
2015	Yandicoogina Closure – BHPB & RTIO	
BHP Billiton Iron Ore	HIY presented the Yandicoogina closure plan. BHP Billiton advised they are starting a major update to the Yandi closure plan, including design of Marillana Creek realignment. General discussion between subject matter experts regarding modelling of pit lakes, groundwater movement and surface water – approaches and boundary condition controls. HIY emphasised that current modelling predictions are based on BHP Billiton's published closure outcomes, and expectation that Marillana Creek hydrological regime will not be changed by BHP Billiton realignment activity. It was established that surface water connectivity to groundwater system was different at each site.	No closure specific actions identified.

8.3 Ongoing consultation synopsis

8.3.1 Regional community and local government

Yandicoogina is a remote mine site. The workforce is FIFO, housed in purpose built accommodation areas, with a small proportion (10%) of staff working permanently from the Perth main office. The majority of the FIFO personnel are permanent employees that live in Perth. The nearest town to Yandicoogina, Newman, is located 90km south-east. Newman is ostensibly linked to BHP Billiton Mt Newman iron ore mine, located on the outskirts of the town. Yandicoogina has negligible interaction with Newman or any other local towns. Closure of Yandicoogina has not been discussed with the regional community or Shire of East Pilbara.

No significant non-Indigenous cultural heritage values have been identified through the broader consultation and research activities undertaken to date. It is recognised that locations along Weeli Wolli Creek are opportunistically accessed by the general public for camping, fishing and other associated recreation activities.

Community engagement with respect to closure is expected to commence approximately 5 years from scheduled closure.

8.3.2 Aboriginal groups

Yandicoogina straddles the native title boundary between Banjima land (west) and Nyiyaparli land (east) (Figure 3). The Yinhawangka people, who share a common language (Banjima) with the Banjima and Nyiyaparli peoples, were heavily involved in development of the Yandicoogina Land Use Agreement and are also closely linked to the mine development. Members of these language groups are geographically dispersed with key locations being Wakathuni and Bellary near Tom Price, Onslow, Roebourne, Karratha and Port Hedland.

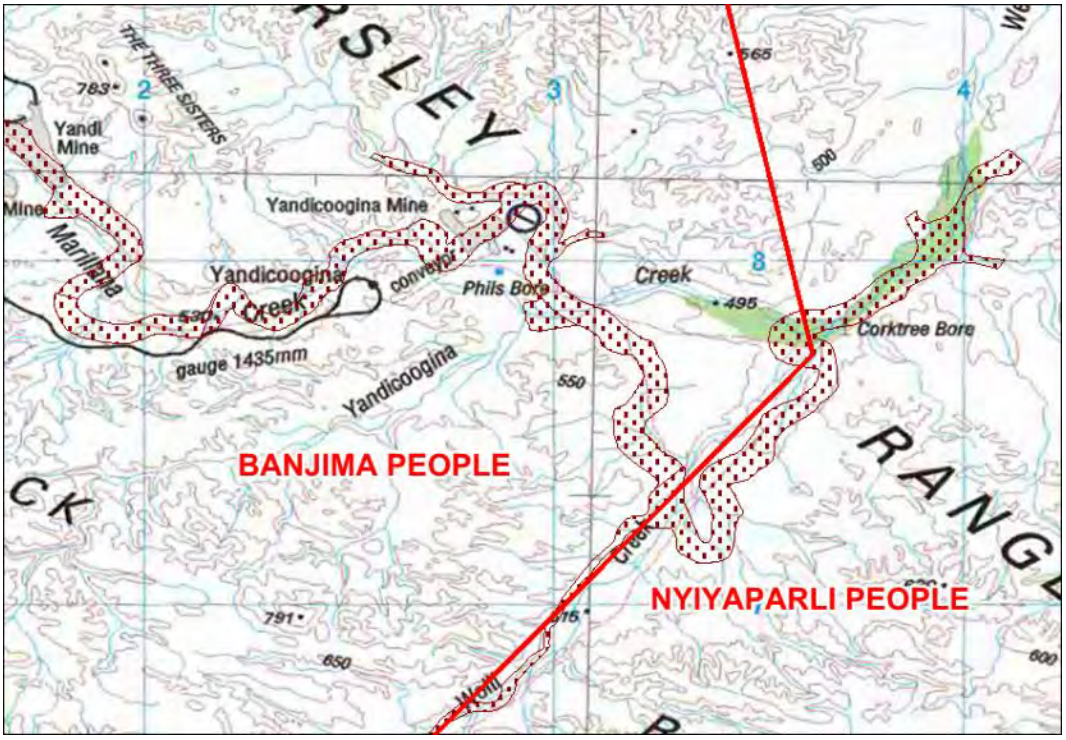


Figure 3: Native Title boundaries.

Consultation with Banjima, Nyiyaparli and Yinhawangka on life of mine planning aspects, including closure, is undertaken through regular Monitoring and Liaison Committee Meetings. This committee is a joint forum of HIY senior leaders and Gumula Aboriginal Corporation who represent the interests of the Banjima, Nyiyaparli and Yinhawangka people. Extensive archaeological and ethnographic surveys have been undertaken within the Yandicoogina locality, principally in association with mining activities in the area. Closure aspects are also raised and discussed, when appropriate, during ethnographic surveys and similar forums. Where appropriate, this engagement is documented as part of the Cultural Heritage Management System. The outcomes of these sessions and surveys are used to inform the development of closure strategies.

Closure consultation with Traditional Owners, to-date, has focused on landscape-scale changes. Topics discussed with Traditional Owners and their representatives include:

- Preservation of remaining ecosystems and protection for creek banks;
- Lake water quality;
- Ongoing importance of ethnographic and archaeological surveys;
- Role of Gumala Aboriginal Corporation in closure planning;
- Importance of including elders and young people in consultation;
- Management of artefacts at closure;
- Potential community use of site infrastructure after closure; and
- Access through and around the mine and into the lake areas.

Water is a highly valued resource in the Pilbara, and water has high significance for Pilbara Indigenous communities generally[7]. The views represented by the Banjima, Nyiyaparli and Yinhawangka peoples are consistent with those of other Indigenous people of the Pilbara and regions across Australia. Rumley and Barber (2004) explain, '…*that in Indigenous belief systems water is perceived as an elemental part of the broader cultural landscape, held and managed under customary systems of law. Water sources are derived from the actions of mythic beings during the Dreaming and are the most important features in the Pilbara cultural landscape. Sustaining and protecting country, including the relationships Traditional Owners have with particular places, was found to be the primary obligation for people*'.

Marillana Creek, Yandicoogina Creek, Weeli Wolli Creek and Phils Creek have all been identified as places of high cultural significance. Cultural values at Yandicoogina are generally associated with camping, ceremonies and other cultural activities, which are generally undertaken adjacent to these creek systems. Consequently, any proposed long-term alteration to the creeks is of interest to Traditional Owners. Traditional Owners have suggested, however, that pit lakes may be beneficial, e.g. for camping, fishing etc., if the water is of a suitable quality to support natural ecosystems.

Numerous Aboriginal archaeological sites have been recorded in the mine area including artefact scatters, quarries, skeletal material / burial, rock shelters, engraving sites and scarred trees. These sites range from low to high archaeological and cultural significance. At closure, repatriation of cultural artefacts to the Yandicoogina area is anticipated, and thus sustained access to existing heritage sites and agreed repatriation sites will need to be included in the closure landform design.

[7] Rumley & Barber (2004) We Used to Get Our Water Free – Identification and Protection of Aboriginal and Cultural Values of the Pilbara Region, April 2004, Study report prepared for the Water & Rivers Commission

POST-MINING LAND USE AND CLOSURE OBJECTIVES

9. Post-mining land use

The Pilbara is classified as an Extensive Land Use Zone. The majority of the development area overlies the Pastoral Lease L3114 984, owned by BHP Billiton Iron Ore and operated as Marillana Station. (JSW-A and Oxbow partially overlay Vacant Crown Land.) Prior to mining, the land was heavily grazed by cattle.

Traditional Owners, the Banjima and Nyiyaparli peoples, regularly access culturally significant areas in the local area, to maintain traditional law and connection to country. This connection to land is the basis for the formal recognition of Traditional Owner native title rights and interests.

Mining and pastoralism are the only industries that have historically proven viable in the Pilbara. Inland regions are sparsely populated, with the largest inland towns, such as Tom Price, Paraburdoo and Newman, established specifically to support the mining industry.

Pit lakes and the associated lake fringe that will be created on closure (Figure 4) are not expected to be compatible with cattle grazing, but may provide alternate land-use opportunities, including recreation / camping grounds and / or fauna refuge (due to the permanent water supply). These opportunities are subject to further discussion with relevant key stakeholders.

Until the post-mining land use is agreed, the closure and rehabilitation strategy will focus on the following, to ensure the system remains compatible with general Pilbara land uses:

- create landforms that are stable for access by humans and native fauna;
- ensure water systems support existing riparian vegetation and are compatible with the natural system dynamics; and
- establish ecosystems with similar biodiversity and cultural heritage values as surrounding reference sites.

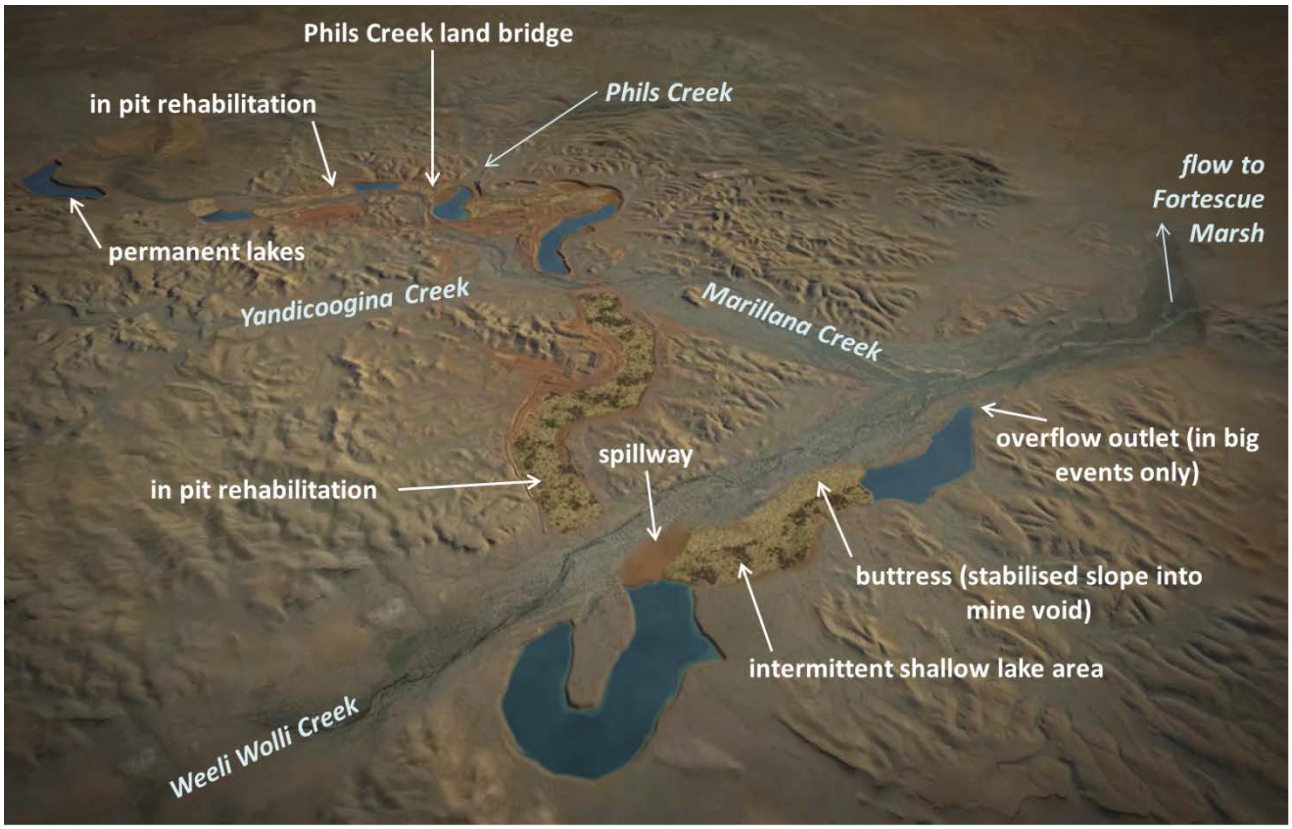


Figure 4: Conceptual landform design for Yandicoogina.

10. Closure objectives

10.1 HIY's vision for closure in the Pilbara

Closure objectives for Yandicoogina have been developed with consideration of HIY's general vision for closure, to:

- relinquish its mining leases to the Western Australian State Government;
- preserve, protect and manage the cultural heritage values of the area in cooperation with the Traditional Owners and other stakeholders;
- develop and implement strategies for closure which consider the implications on local communities;
- achieve completion criteria which have been developed with stakeholders and agreed with Government;
- develop landforms that are safe and stable and compatible with the surrounding environment and post-mining land use;
- achieve environmental outcomes that are compatible with the surrounding environment;
- implement a workforce strategy which addresses the impacts of closure on employees and contractors; and
- achieve successful closure in a cost effective manner.

10.2 Yandicoogina closure objectives

The ultimate goal of mine closure at Yandicoogina is to relinquish the site to the Government. This goal will be achieved once the key stakeholders agree that the condition of the site is compatible with the agreed post-mining land use(s). Table 5 lists the closure objectives developed in consideration of the key stakeholder expectations for mine closure.

Table 5: Yandicoogina closure objectives

	Objective
1	Rehabilitated landforms are stable and designed to manage floodwater appropriately
2	The environmental and cultural heritage values associated with creek flows and function are maintained post-closure
3	Environmental values of Fortescue Marsh are not compromised
3	Water quality within pit lakes support natural ecosystems and are compatible with post-mining land use
4	Alluvial groundwater systems support remnant phreatophytic vegetation
5	Final landforms are rehabilitated to be compatible with post-mining land use
6	Public safety hazards have been addressed

COMPLETION CRITERIA

11. Completion criteria

Completion criteria can be defined as the indicators used to determine whether closure objectives have been met. They are used to measure the success of closure implementation against objectives, and to facilitate relinquishment of mining tenure.

The completion criteria, presented in Table 6, have been developed following consultation with stakeholders and in consideration of the predicted closure outcomes. Measurement processes, and the associated supporting data (evidence and / or metrics), that will be used to calculate or otherwise define the conditions at Yandicoogina are also described in Table 6.

The completion criteria are subject to ongoing review and update, informed by the outcome from studies identified in the closure task list (Table 20) and ongoing stakeholder consultation. As the site approaches scheduled closure the completion criteria will contain more measurable and time-bound parameters.

Table 6: Indicative completion criteria.

Objective	Indicative completion criteria	Process	Evidence or metrics / data
1. Rehabilitated landforms are stable and designed to manage floodwater appropriately	1a. Erosion does not threaten the long term stability of the landform	Visual and measured assessment of erosion from rehabilitated areas for comparison of trends Post-closure evaluation of long-term erosion due to flooding	Rill and gully frequency Gully depth and width Water monitoring: • volumes, flows, levels • quality / chemistry Weather data and climate trends
2. The environmental and cultural heritage values associated with creek flows and function are maintained post-closure	2a. Surface water remains at a level and quality that ensures retention of ecological function and cultural value	Post-closure evaluation of surface water conditions against baseline (pre-mining) conditions and / or reference site trends over time. Post-closure evaluation of ecological values (vegetation and fauna) against baseline (pre-mining) conditions and / or reference site trends over time.	Photographic evidence that: • a disturbance buffer has been maintained • water is present post-closure Ecological survey(s) to determine: • fauna diversity / richness • vegetation, habitat • tree health monitoring Water monitoring: • volumes, flows, levels • quality / chemistry Weather data and climate trends
3. Environmental values of Fortescue Marsh are not compromised	3a. The frequency of large flood events is maintained at the downstream tenement boundary	Post-closure evaluation of flood conditions against baseline (pre-mining) conditions.	Water monitoring: • volumes, flows, levels • quality / chemistry Weather data and climate trends

Objective	Indicative completion criteria	Process	Evidence or metrics / data
4. Water quality within pit lakes support natural ecosystems and are compatible with post-mining land use	4a. Groundwater salinity is not predicted[8] to exceed 2,500mg/L at the downstream tenement boundary. 4b. Lake salinity is not predicted to exceed 4,500mg/L or pH <8.5.	Post-closure evaluation of groundwater recovery conditions against model predictions. Post-closure evaluation of lake water quality recovery conditions against model predictions.	Water monitoring: • volumes, flows, levels • quality / chemistry Weather data and climate trends
5. Alluvial groundwater systems support remnant phreatophytic vegetation	5a. Tree deaths more than 2km from the edge of each pit do not result from water quality or drawdown impacts stemming from the post-closure landform.	Post-closure evaluation of phreatophytic vegetation against post-mining conditions and / or reference site trends over time.	Ecological survey(s) to determine tree health Water monitoring: • volumes, flows, levels • quality / chemistry Weather data and climate trends
6. Final landforms are rehabilitated to be compatible with final land use	6a. Vegetation on rehabilitated land is native and self-sustaining 6b. Habitat for native fauna is provided in appropriate rehabilitated areas 6c. The prevalence of invasive species (weeds, feral animals) is similar to or less than that in nearby reference sites.	Field vegetation monitoring for comparison of trends Field monitoring of fauna habitat indicators for comparison of trends	Vegetation monitoring including: • Species richness • Species diversity • Percentage cover Records of seed provenance Fauna habitat monitoring (may include): • spinifex cover • shrub cover • evidence of scats/tracks • litter cover • indicator species (e.g. ants) Feral animal management records
7. Public safety hazards have been addressed	7a. Measures to eliminate or mitigate public safety hazards have been agreed with stakeholders and have been implemented.	Identification of potential hazards to the public in the decommissioned area. Audit(s) to confirm that hazard mitigation measures have been implemented.	Reports: • Geotechnical evaluation • Fibrous materials audit • Contaminated sites audit • Electrical safety inspection • Public access evaluation • Traditional Owner cultural access requirements

[8] The reference to predicted values reflects the fact that equilibrium conditions may not be reached prior to relinquishment.

COLLECTION AND ANALYSIS OF CLOSURE DATA

The closure knowledge base (Appendix B) is a collection of baseline studies, models and interpretations, which are used to inform the closure planning process presented in this closure plan. The knowledge may be specific to the site or generally applicable to the Pilbara region; and includes information on the performance of closure-related trials completed at other Pilbara mining operations (when appropriate). At this stage of the closure plan development, only summaries of these reports are provided and the relevant information is summarised below. The relevant knowledge base reports will be included in the final closure plan.

12. Climate

Climate, particularly rainfall, rainfall intensity, cyclone frequency and evaporation, influence closure planning aspects such as landform stability and erosion rates, pit lake modelling, and revegetation success.

The climate in the Yandicoogina area can be characterised as arid tropical with two distinct seasons: hot wet summers and cool dry winters. Mean daily maxima temperatures range from 39°C in summer to 24°C in winter. Daily temperature can rise up to 50°C during the summer and drop to 0°C in winter.

Evaporation is the most important factor for biological water use in the region, influencing both plants and animals[9]. Throughout the Pilbara, potential evaporation, estimated to be around 3500mm to 3700mm[10] per year, exceeds average annual rainfall by a factor of at least eight and by up to twenty fold in the south-east (near Yandicoogina).

12.1 Rainfall and significant weather events

Rainfall in the Pilbara averages from 200mm to 400mm per year. The majority of rain falls in the three months from January to March, each typically averaging more than 50mm per month and often falling in heavy rainfall events associated with tropical lows. The period between May and November is practically dry, with average rainfalls of less than 20mm per month.

HIY has maintained a meteorological monitoring station at Yandicoogina since commissioning the mine in 1998. In addition, there are a number of other gauging stations managed by Government departments in the area[11]. However, the climate records are inconsistent, with numerous gaps in the datasets as a result of equipment malfunctions, often during extreme weather events.

From data recorded at Yandicoogina, and augmented by neighbouring stations to create a longer historic record, the average rainfall over the past 20 years at Yandicoogina is approximately 390mm to 400mm per annum. Annual rainfall is highly varied, with recorded rainfall ranging from 148mm to 890mm over a calendar year[12]. The highest recorded monthly rainfall was 480mm during December 1974, which was associated with Tropical Cyclone Joan. This system brought wide spread and, in many locations, unprecedented flooding to the Pilbara. For comparison, a single rainfall event which produces between 200mm and 370mm within 24 to 72 hours over the Marillana Creek Catchment is classified by Engineers Australia (2001)[13] as a 1 in 100 year annual recurrence interval (ARI) rainfall event. An event of this magnitude was recorded at Yandicoogina during January 2003.

[9] N.L. McKenzie, S. van Leeuwen and A.M. Pinder (2009) Introduction to the Pilbara Biodiversity Survey, 2002–2007. Records of the Western Australian Museum, Supplement 78: 3–89, 2009.

[10] Mean annual pan evaporation from Newman. Average annual evaporation rate as measure from Yandicoogina dry bulb data is around 1800mm per year, which more closely approximates actual evaporation from dam situations.

[11] Rainfall records for the Weeli Wolli Creek Catchment include: Australian Bureau of Meteorology (BOM) Rhodes Ridge 007169 (Feb 1971 to Oct 2011), Packsaddle Camp 005089 (Jan 1989 to Jun 2002), and Western Australian Department of Water (DoW) Wonmunna 11247 (Nov 1984 still open), Tarina 11220 (May 1985 still open), Munjina 11186 (Jan 1969 still open), Packsaddle 11196 (Jun 1970 to Sep 1999), Flat Rock 11193 (Mar 1970 still open), Yandicoogina 11217 (Dec 1979 to Apr 1986) and Waterloo Bore 11221 (May 1985 still open). Immediately downstream of Weeli Wolli Catchment in Fortescue Marsh gauges of relevance include BOM Marillana 005009 (Dec 1936 still open) and Sand Hill 005064 (May 1971 to Jul 1984). There are no open, publically available gauges with the Weeli Wolli Creek Catchment for other climate aspects. The closest gauges are approximately 100km away and include: Newman Aero 007176 (1971 still open) and Newman Town 007151 (1965 to 2001) to the east, Wittenoom 005026 (1949 still open) to the west, and Redmont 004043 (1925 still open) to the north. Note most of these records are incomplete.

[12] Using a season split from October to September to encompass the entire wet season, rainfall extremes range from 124mm to 1060mm over 12 months with an average of 390mm.

[13] Institution of Engineers Australia (2001*) Australian Rainfall and Runoff*. Editor-in-chief D.H. Pilgrim, Barton, ACT. This report defines the standards for engineering surface water control structures in Australia.

The north / north-western coastline of Australia has experienced more tropical cyclones than anywhere else on mainland Australia. In this region most tropical cyclones are observed during the late summer, occurring anytime from November through to May with their maximum frequency during January and February. On average, five tropical cyclones are expected off the Pilbara coast each year, with two expected to make landfall. Tropical cyclones and tropical lows commonly produce damaging wind gusts in excessive of 150km per hour, heavy rains and regional flooding.

12.2 Climate change

Our understanding of how climate will change in the future in the Pilbara is guided by the outcomes of climate modelling, commissioned privately by Rio Tinto and other Australian government agencies.

From modelling completed to date, our understanding of Pilbara climate change suggests the region will experience the following climate trends.

- A shift in the historical tropical cyclone season, with an earlier start and potentially later finish.
  - For the period from 2051 to 2099, compared to present day, tropical cyclone frequency could decrease by half while the duration of a given tropical cyclone could decrease by 0.6 days on average when compared to present day. Projections also suggest, however, that tropical cyclones could increase in size and intensity
- Continuation of the highly variable multi-decadal scale rainfall trends.
  - Projected rainfall reductions range from 1 to 24% for mid-century, and 9 to 24% for the end of the century
- A significant warming trend, influencing maximum temperatures, with the largest changes during the January to March period.
  - On average, maximum temperatures are expected to increase by 2.1 to 3.2 ˚C by mid-century and by a total range of 3.8 to 4.6 ˚C by the end of the century. For minimum temperatures the corresponding averaged increases are 1.9 to 2.4 ˚C (mid-century) and 4.1 to 4.6 ˚C (end of the century).

The main climate drivers for the Pilbara are the El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) ocean currents. However, these ocean currents are not well represented in most global climate models, and as a result, climate predictions for the northwest of Western Australia can vary significantly. The ENSO and IOD ocean currents are currently being researched by CSIRO. At the same time, modelling is being progressively improved by various Australian Government agencies to expand our understanding of the climate drivers in the southern hemisphere, our understanding the associated impacts on water availability and to predict changes to existing ecosystems.

Consequently, at present, there is insufficient agreement on climate change within the scientific community at the level of detail that is required to inform a detailed assessment of climate change impacts on weather, stream flow, water availability and vegetation response at Yandicoogina. This position will be reviewed periodically and new knowledge will be incorporated into studies as appropriate.

12.3 Climate and landform stability

The heavy, intense rainfall experienced in the Pilbara makes rainfall the key climatic factor that influences surface stability in the Pilbara. Rainfall erosivity (measured in megajoule millimetre per hectare per hour per year - MJ.mm/ha/hr/yr) is the term used to describe the erosive force of rain. For Pilbara sites, long-term annual erosivity values range from ~1,000-1,600 MJ.mm/ha/hr/yr. Rainfall in the Pilbara is typically more erosive than Perth's rainfall, even though it only receives on average half the rainfall that Perth receives on an annual basis. For comparison, average annual erosivity values for Perth are ~1000 MJ.mm/ha/hr/yr from an average of 780 mm of rain a year.

Rainfall erosivity is highly variable from year to year, or even from event to event. Studies of Pilbara rainfall concluded that at Tom Price, for example, erosivity for the period 1998 to 2009 ranged from 212 – 6,349 MJ.mm/ha/hr/yr. The most erosive year recorded was 2007 at Channar, where 421mm fell during February (704mm fell over the whole year). This singular rain period embodied 11,994 MJ.mm/ha/hr/yr of erosive force, or 89% of the entire erosivity of rain for that year. Given the pattern of intense and infrequent rainfall events in the Pilbara, it can be expected that only a few events every year (~1-3 events) will generate the majority of runoff and erosion of that occurs each year.

The studies showed a rapid decline in erosion or sediment yield occurs when annual rain decreases below about 300mm per year due to a corresponding decline in rainfall volumes and rainfall erosivity. However, when annual rainfall increases above ~300mm, vegetation growth increases and becomes increasingly effective in controlling soil erosion. Hence, there is a point of maximum erosion potential at an annual rainfall

value of ~200-400 mm such that surface (vegetation) cover is low due to lack of rain and ineffective for controlling erosion, yet rainfall erosivity is sufficiently high to cause erosion, as observed in the Pilbara.

Outcomes from these studies have informed development of the Rio Tinto Iron Ore (WA) Landform Design Guidelines for achieving stable waste dumps.

12.4 Climate in water models

As a key component of all water models, climate, and the accuracy of future climate predictions, is a major influence in groundwater and surface water predictions.

Most regional groundwater models in the Pilbara, for example, are innately attuned to current climate conditions as they are calibrated to observed groundwater levels. A groundwater level, as measured at a single bore, represents the result of rainfall that has infiltrated through the soil and possibly been subjected to evaporation / evapotranspiration processes. If the water is relatively young and within an unconfined aquifer, as at Yandicoogina, then the groundwater level today is a reflection of the immediate past climate; notably rainfall volumes and flood frequency. As seen in the bore logs, a few years of dry weather results in a drop in the groundwater levels while a few wet years and the levels rise.

As the reaction of a groundwater table to rainfall is not a linear relationship, if climate shifts beyond the observed climate range the model has no guidance as to how the groundwater should behave. As a consequence, the results of these deterministic models may not provide accurate predictions as the climate changes.

To overcome these limitations, work has commenced on the use of stochastic models to examine the interactions between creek and groundwater systems. Stochastic models can calculate the outcome of thousands of different theoretical climate sequences to provide guidance on the probability of certain conditions occurring. At present, the use of stochastic models is limited to simple models due to the computer processing capacity and time required to compute simple situations. However, as technology improves it is anticipated that this constraint may be overcome.

12.5 Climate and vegetation growth

Water is generally the limiting factor for plant growth in the Pilbara’s arid environment. As a consequence of the hot temperatures, high evaporative demand and infrequent and irregular rainfall, much of the vegetation displays xeromorphic adaptations (plant structural adaptations for survival in dry conditions). These adaptations include the ability to regulate water loss from leaves, extract water from very dry soils and match reproductive strategies with wetter periods. Many species are ephemeral and persist in soil banks in between wetter periods.

The adaptive capacity of Pilbara species implies a degree of resilience to changes to hydrological regimes. However, the impacts to Pilbara vegetation as a consequence of climate change are not clear. Changes in vegetation density and water use will alter the amount of runoff that occurs after a rainfall event, which in turn will alter creek flows and groundwater recharge.

Some initial studies within the wider Weeli Wolli Creek catchment are underway to understand how the presence and absence of water affects vegetation growth within riparian corridors. The outcomes from these studies and other evolving research on climate change will be monitored and integrated into Yandicoogina closure studies to inform assumptions on climate influences and impacts.

13. Land

13.1 Geographical overview

Yandicoogina is located near the eastern edge of the Hamersley sub-region, adjacent to the Fortescue Plains sub-region, of the Pilbara biogeographic region[14]. As described in Table 7, the majority of the landscape within the project area is considered typical of the Hamersley sub-region, while the creek systems have affinities with the Fortescue Plains sub-region.

Table 7: Important biogeographic zones

Zone	Description
Hamersley	Mountainous area of Proterozoic ranges and plateaus of mulga woodland bunch grasses on fine textured soils and snappy gum over *Triodia brizoides* on skeletal soils.
Fortescue Plains	Alluvial plains and river frontages, salt marsh, mulga bunch grass and short grass communities on alluvial plains. River Gum woodlands fringe drainage lines. Northern limit of the *Acacia aneura* complex (Mulga).

The topography of the locality is provided Figure 5. The surface topography at Yandicoogina has been shaped by alluvial processes with the existing streams winding between low lying mesas and hills. The dominant landscape features are the ephemeral watercourses that drain to the northeast to Fortescue Marsh. The creek lines follow a surface gradient sloping downwards from west to east (~520mRL at Oxbow to ~480mRL near the Marillana Creek and Weeli Wolli Creek confluence).

A row of small hills rising 800mRL to 900mRL extends from JC to the northwest with a line of slightly higher hills (900 to 1,000mRL) oriented in an east-west direction to the south of the current mining operations. The area immediately south of JSW and Oxbow rises to around 600mRL.

The Yandicoogina ore body is a specific type of paleochannel[15] known as a Channel Iron Deposit (CID). This ancient creek channel is located adjacent to the current Marillana and Weeli Wolli Creeks and crosses underneath these modern day creek channels in various locations, as shown in Figure 5.

The CID mined at Yandicoogina consists of three main layers:

- Overburden material. A mixture of lateritic pisolite, poorly sorted angular to sub-rounded banded iron formation (BIF), chert and dolomite gravels in a sandy matrix. Discontinuous kaolin clay in bands and pods are common in the overburden (occurring less frequently in the iron deposits).
- Iron deposits. Mostly pisolite (iron oxide spheroids) with minor components of clay minerals (mainly kaolinite) and petrified wood mixed through the profile. The iron deposit is up to 70m thick. Once the high quality (economic) iron deposit is removed, a thin layer of clay and non-economic iron is left behind; and
- Basement rocks and altered basement rocks. The basement rocks (Weeli Wolli Formation) are what is left of the original geology that was eroded during the formation of the channel. The basement rocks have fewer fractures, gaps and pore spaces than the overlying iron deposits or overburden, such that groundwater that is accumulated within the channel tends to flow along the channel.

[14] As defined by the Interim Biogeographic Regionalisation for Australia (IBRA) which recognises 85 bioregions across Australia: defined on the basis of climate, geomorphology, landform, lithology, and characteristic flora and fauna attributes (Environment Australia 2000).

[15] Paleochannels are remnants of ancient streams cut into old rocks and filled with sediments from younger rocks; such that they reflect historical drainage lines. The contemporary equivalent is called an alluvial channel.

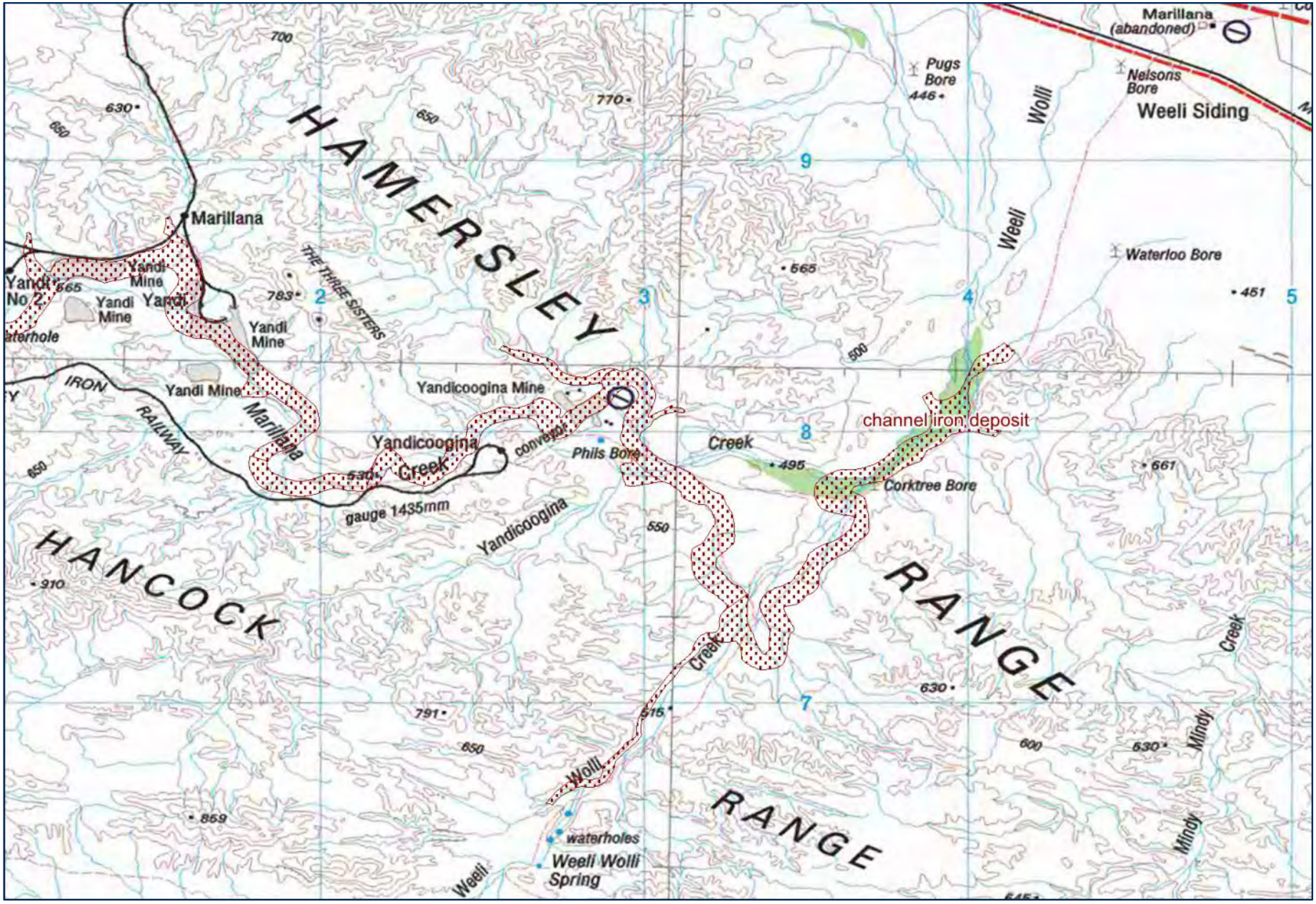


Figure 5: Topographical features including location of the channel iron deposit (CID) palaeochannel.

13.2 Surface water

13.2.1 Creeks

As shown in Figure 5, Yandicoogina is located near the intersection of Marillana Creek and Weeli Wolli Creek. The deposits of Junction Central, Junction South West and Oxbow are located adjacent to Marillana Creek. Junction South East straddles the catchment divide, bound by Marillana Creek to the north and Weeli Wolli Creek to the south, and the proposed expansion deposits of Billiard are located under and adjacent to Weeli Wolli Creek. Marillana Creek is a tributary to the Weeli Wolli Creek system, as part of the regional water catchment known as Weeli Wolli Catchment.

The Marillana Creek system has a total catchment area of 2,250km^2. The headwaters rise from the high relief areas of Hamersley Range where the Creek drains in an east and north easterly direction into the Munjina Claypan. The Claypan has an internally draining catchment area of approximately 274km^2. It is subject to periodic inundation following rainfall events and has the potential to retain surface water flows for lower flood events (≤1 in 10 year annual recurrence interval (ARI)). Water stored in the Claypan is believed to infiltrate and recharge the alluvial systems of Marillana Creek including the CID, and subsequently sustains creek bed (subsurface) flows for longer than (Pilbara) normal periods after flood events.

Water in excess of the basin's holding capacity flows southeast; past Flat Rocks gauging station, BHP Billiton Iron Ore's Yandi mine, Yandicoogina and into Weeli Wolli Creek. Named tributaries of Marillana Creek include Lamb Creek, Iowa Creek, Phils Creek and Yandicoogina Creek.

The Weeli Wolli Creek system, excluding the Marillana Creek catchment area, has a catchment area of 1,750km^2. The headwaters rise from over 50km to the south of the Yandicoogina area, with Weeli Wolli Creek flowing northwest, past the Hamersley HMS Hope Downs 1, BHP Billiton Iron Ore Mining Area C and Jinidi operations, before merging with Marillana Creek (the largest tributary).

As for most parts of the Pilbara, the normal condition for these watercourses is dry. Runoff is ephemeral, occurring only after significant and intense rainfall events. Flow depths in both Marillana and Weeli Wolli Creeks can exceed 5m with velocities through the majority of the channel ranging from 2m/s to 3.5m/s. Large stream flows are generally associated with rain bearing depressions or high intensity cyclonic rainfall that brings heavy rain over a large areas of the catchment.

The flows terminate in Fortescue Valley, north of the Hamersley Range, contributing to Fortescue Marsh; an extensive, intermittent wetland.

Background surface water quality measurements at Yandicoogina are complicated by the discharge of groundwater to Marillana Creek from the BHP Billiton Iron Ore Yandi operation and to Weeli Wolli Creek from Hope Downs 1 operation, both immediately upstream of the Yandicoogina. In one sampling campaign, the chloride concentration 800m down gradient of the BHP Billiton Iron Ore Yandi discharge point was ~125mg/L and increased to ~150mg/L approximately 6km down gradient, towards the terminus of Marillana Creek. Further downstream, in Weeli Wolli Creek, the chloride concentration was observed to decrease to less than 100mg/L as relatively fresh discharged groundwater from the Yandicoogina and the Hope Downs 1 operations mixed with very fresh alluvial water which naturally[16] discharges to the surface.

The background quality of surface water during flood events is undefined, due to the complexity of the sampling requirements and issues around work place safety. However, methodologies to safely sample water during flood events across the Pilbara are being considered; such that samples will be taken once health, safety and environmental protocols can be met.

13.2.2 Pools

Although historically, there have been no permanent surface water bodies present in the local area around Yandicoogina (the closet being Weeli Wolli Spring), discharge from the Yandicoogina and Hope Downs 1 operations has resulted in permanent creek flow and the formation of local semi-permanent pools within Weeli Wolli Creek.

[16] Groundwater that expresses without assistance is called discharge. This should not be confused with water that is released into a creek to manage surplus water which is also referred to as discharge. Natural discharge occurs when the groundwater aquifer is "full", such that slight changes in topography or subsurface changes in hydraulic parameters mean that the volume of water travelling below the ground cannot be sustained, and the water is released to create surface water flows. Depending on the location and frequency of the event, these surface water flows may also be referred to as seeps or springs.

Around a quarter of pools found in the Pilbara's major rivers are naturally semi-permanent to permanent[17]. The pools are sustained by a combination of regular flooding, pool depth (storage exceeding evaporation), groundwater discharge via springs or seepage through porous sediments, and impedance of subsurface flow by bedrock structures at the downstream ends of pools.

Some of these pools are considered fresh (salinity less than 1500mg/l) even though Pilbara evaporation rates significantly exceed rainfall. Different environmental factors naturally manage or offset evapoconcentration (the process whereby salinity increases as water is removed via evaporation) of salts in these pools, including:

- interactions with creeks and creek infiltration, such that flushing removes salts from the pools;
- high groundwater flow rates (i.e. springs or seeps), where the exposure time of water within the pool is reduced, e.g. water quickly infiltrates back into porous sediments;
- wind sheltering, by vegetation or topography, which reduces evaporation rates; and
- shading influence from trees or topography which reduce evaporation rates.

Normally, however, salinity increases between flood events, until pools are completely dry; leaving salts in the base of pools. These salts are subsequently flushed from the pools with each flood event, but can successively contribute to pool salinity prior to a flushing event.

Pools that sustain brackish water qualities (for example, are of stock drinking water quality, up to 4000mg/l) are usually associated with groundwater springs and seeps. These fresher pools provide an important ecological function, especially through periods of drought[17]. In these fresher pools, the groundwater discharge rates usually exceed the evaporation rates and the pools are positioned in the landscape such that the pools maintain a connection to a creek and / or a creek alluvial groundwater aquifer (e.g. within the floodplain). This connection enables salty water and sediments to be flushed from the pool, to be replaced by fresh surface water or fresher groundwater. For this reason, pools with this type of connection to groundwater systems can be considered groundwater dependant ecosystems[18]. These type of pools are noted to occur upstream (e.g. Weeli Wolli Spring) of Yandicoogina, but have not been identified within or downstream of the mine area.

13.2.3 Cumulative effect of landform changes on catchment hydrology

There are a number of reasons why closure strategies permanently alter the local catchment hydrology and change local surface water movement. The principal reason termination or capture of surface water flows is employed is to manage groundwater or pit lake water quality. Diverting runoff, creek flows and / or syphoning a proportion of flood water mine void post closure has been referenced as a water management solution to, for example, "flush" salts out of lakes and into the groundwater system, to flush salts from soils when the groundwater table is very near but not exposed on the surface (subject to groundwater capillary rise) or to add nutrients and aquatic flora / fauna to rejuvenate / sustain aquatic ecosystems. In other closure strategies, the capture of local runoff and creeks is simply a result of the slow, inevitable collapse of local surface water control structures.

Removal of these small volumes of water, when considered on a pit by pit basis, is unlikely to change the flow dynamics of the larger creek systems. However, by examining the catchment as a whole, it was recognised that the cumulative effect of terminating small runoff and flows as a consequence of mining activities across the Marillana / Weeli Wolli Creek catchment could alter the flood regime; and that these changes could have an impact on riparian communities adjacent to Yandicoogina.

A simple study was conducted in 2010 to quantify the potential magnitude of changes to flood frequency in Marillana Creek. The study assumed a worst case scenario whereby all local tributaries that flow over the mapped CID were subject to mining activities and would result in surface water flow entering the mine voids post-closure. These conditions align roughly with the proposed, externally released BHP Billiton Iron Ore Yandi[19] closure strategy and closure options presented by HIY for the 2011 public environmental review of Yandicoogina.

[17] Pinder, A and Leung, A (2009) Conservation status and habitat associations of aquatic invertebrates in Pilbara coastal river pools, Report to the Western Australian Department of Water from Science Division Department of Environment and Conservation, August 2009.

[18] Boulton, A. and Hancock, P.J. (2006). Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications. Australian Journal of Botany 54: 133-144.

[19] BHP Billiton (2004) Marillana Creek (Yandi) Mine : decommissioning and final rehabilitation plan, January 2004

The results showed that at the terminus of Marillana Creek the frequency of overbank flow would reduce from a 10% annual exceedance probability to a 5 % annual exceedance probability. This means that in the future there will only be a five percent chance of overbank flooding occurring in any year, instead of a 10 percent chance. This flood regime change would affect sections of the creek otherwise unaffected by mining activities that support flood plain ecologies, such as *Eucalyptus camaldulensis* (River Red Gum), by reducing the volume of water stored in the floodplain alluvial soils.

It is difficult to implement actions based on theoretical cumulative impact outcomes such as those discussed above. New systems for managing cumulative effects are expected to be developed by regulators in Western Australia following the release of the new Western Australia Government Water Resources Management legislation[20]. Cumulative effect considerations will need to be resolved and integrated into the closure plan once these new systems are in place.

13.3 Groundwater

13.3.1 Aquifers

Groundwater moves principally within two aquifer systems at Yandicoogina, namely through the CID (historical drainage) and alluvial (current drainage) aquifers (Figure 6). The CID and alluvial aquifers are inter-connected and recharged from infiltration generated by water flowing along the creeks. As a result, water quality in the CID and alluvial aquifers is relatively fresh (predominantly <600 mg/L).

The CID and alluvial aquifers are bound by the Weeli Wolli Formation basement rocks, which acts as the regional aquifer. Water moves through this regional aquifer in secondary porosity, associated with, for example, dissolution features in weathered rocks and fractures. As a result, the hydraulic conductivity of the Weeli Wolli Formation at Yandicoogina is significantly lower than the CID and alluvial aquifers and has been described as “relatively impermeable”.

Hydrogeological characterisation of the area has been undertaken since mining first began in the area. Historically, characterisation has focused on the CID. Water flow (through-flow) along the CID is estimated between 1500 m^3/day and 3000m^3/day, depending on the width of the CID channel. Usually the lower through-flow rates are observed at distances furthest from the main creeks. For example, in the mined out CID at JC Hairpin area, where the CID has no direct connection to the creek alluvial system, through-flow was measured to be around 1000m^3/d. The hydraulic conductivity in the CID ranges between 3m/d and 25m/d, with an average of roughly 9m/d.

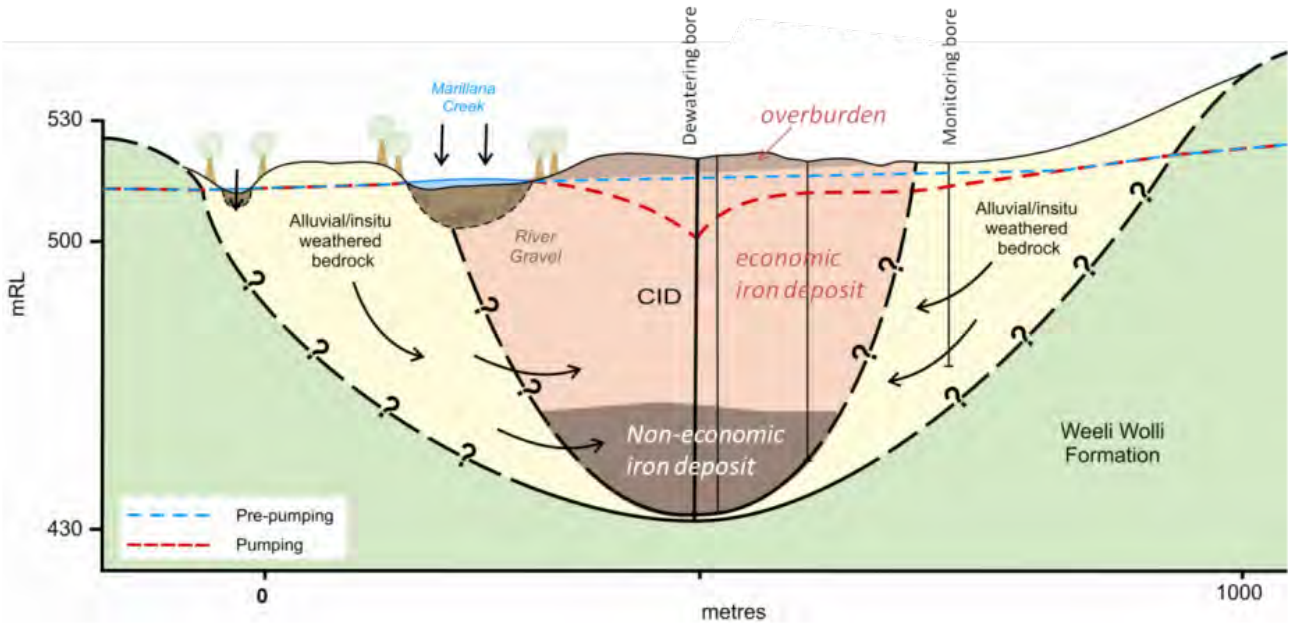


Figure 6: Schematic presentation of groundwater aquifers at Yandicoogina.

The pre-disturbance groundwater contours are illustrated in Figure 7. The groundwater table is located around 2m below the surface of Marillana Creek. This translates to a depth of 20m to 30m below the surface

[20] http://www.water.wa.gov.au/Future+water/Water+reform/default.aspx

in areas of mine away from the creek system in JC. Along the length of the CID, from Oxbow West to Billiard South, the pre-disturbance groundwater elevation changed by around 100m. This represents a groundwater gradient of 0.002 or a 2m decrease in groundwater level for every kilometre along the CID.

The gradient is relatively uniform along the length of the CID, suggesting the CID has a relatively uniform width with no barriers to subsurface flow. It was noted, however, that in the JC Hairpin area, where the CID bends around on itself, the low through-flow rates may indicate a "bottleneck" which could have caused groundwater levels to naturally back up following rainfall/recharge events. This may have led to an increase in preferential flow through the alluvial aquifer system, bypassing the current mining area, and elevating groundwater levels in the CID and alluvial aquifers in the JSW area.

The water table is observed to fluctuate considerably in response to significant rainfall events. For example, groundwater levels increase by around 10m following substantial rainfall events associated with ex-tropical cyclones Claire, Emma, Glenda and Hubert in January to April 2006, and in December 1999 as a result of rainfall Tropical Cyclone John. Over the long term, however, a noticeable trend of increasing groundwater levels has been observed across the region. At monitoring bore YM119 located in the Billiard deposit, for example, a change in average water level from 465mRL in 1991 to an almost steady state level of around 476mRL has been observed. The steady state is interpreted as the aquifer being “full”; a consequence of higher than average rainfall, more than 25 percent over the short term average, between 1995 and 2006 (prior to the establishment of the Yandicoogina reinjection bore and before any influence from the Hope Downs 1 mine discharge). Since 2006, rainfall has remained high and, combined with the dewatering influences from the Yandicoogina and Hope Downs 1 operations, the aquifers in the Billiard areas remain full.

As mining operations have moved closer to the active creek systems, characterisation of the alluvial aquifer has had renewed focus. A comprehensive field campaign was undertaken in 2009 to address knowledge gaps and strengthen the conceptualisation for groundwater model predictions. This work demonstrated that the alluvial aquifers, which were previously assumed to be shallow and poorly connected to the CID, consist of both unconsolidated alluvium and in situ weathered Weeli Wolli Formation bedrock. The alluvial aquifers can extend to depths similar to the CID and have a much higher hydraulic transmissivity and storage capacity than previously thought.

Based on results from the field campaign, horizontal hydraulic conductivity of the alluvial aquifers has been revised to 5 m/day to 10m/day in the upper alluvium and creek bed gravels. It has been estimated that the volume of recharge generated by one large flood event over a 25km length of Marillana Creek is equivalent to approximately 16GL of water and can be as high as 30GL depending on the duration of the event. As a result of this strong connection to the creek system, it has been theorised that a fully dewatered CID could recover to 90 percent of its original groundwater elevation in as few as 10 to 20 years.

Within the groundwater, chloride concentration ranges from 15mg/l (in a CID sample) to a maximum of 280mg/L (in an alluvium sample). The average chloride concentration in the CID is ~120mg/L, roughly 30 percent lower than that of alluvium water. This difference is attributed to the processes of direct evaporation and evapotranspiration by native vegetation along Marillana Creek that act to concentrate salts in the upper profile of the alluvial aquifer.

Total dissolved ions (TDS) of groundwater range from 100mg/l to 1,290mg/l, averaging around 550mg/l in the CID and 600mg/l in the alluvium, but without clear segregation. Groundwater from both aquifers is dominated by bicarbonate anions, contributing to pH conditions ranging from 6.7 to 8.3. Sodium constitutes a higher portion of the major cations, followed by calcium and magnesium.

No significant water quality changes have been detected in the aquifers since the start of routine water quality monitoring at Yandicoogina.

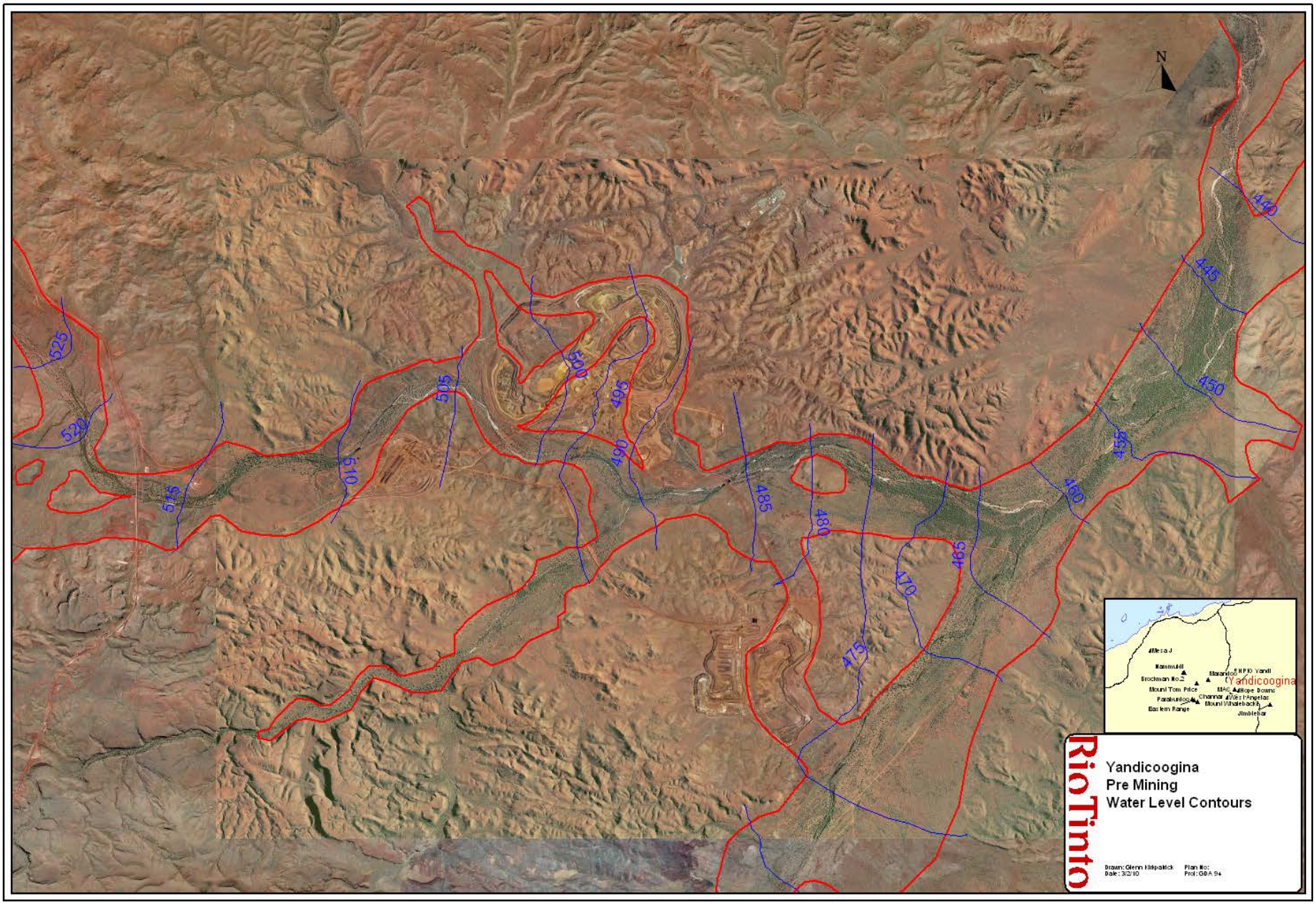


Figure 7: Groundwater pre-disturbance contour map.

13.3.2 Effects of evaporation on water quality

Conceptual water balance models indicate that some landform configurations create highly saline lake waters. Very conservative geochemical modelling was undertaken to understand the effects of trace element leaching from backfill materials and evaporation. The model used measured groundwater quality parameters from Yandicoogina area (highest values ever recorded in any literature), assumed an evaporation rate of 90 percent in an open system (reflecting final salinity concentration in excess of 10,000mg/l) and only allowed hydroxide and carbonates to precipitate.

The geochemical model results indicate the groundwater is supersaturated with respect to carbon dioxide (CO_2). Thus degassing of CO_2 was modelled to occur as the groundwater equilibrates with the atmosphere and mixes with pore waters from backfill materials. Degassing of CO_2 increases the pH of the system from ~7.4 to ~8.6. Equilibrium with the atmosphere and the increase in pH resulted in the precipitation of minerals including calcite and ferrihydrite.

Evaporation of the resulting model fluid caused an increase in the saturation states of many minerals, and resulting precipitates including ferrihydrite, calcite, sepiolite, manganite, tenorite and smithsonite. Subsequent reactions modelled included increased precipitation, element depletion and further degassing of CO_2 due to evapoconcentration, leading to a further reduction in pH and additional precipitation.

Sorption / desorption processes were not considered as part of this modelling. It is recognised, however, that if high pH (alkaline) conditions develop, elements that are present as sorbed species in minerals such as hematite or goethite, but currently below detection limits, could mobilise. Elements of concern that could be mobilised under alkaline conditions include arsenic, selenium and antimony. Alkaline conditions may also mobilise amphoteric elements such as aluminium, which would be otherwise fixed in the system as gibbsite or other minerals.

It is important to note that mineral precipitation predicted by modelling may be reversible in the field if flushing with neutral or slightly acidic water occurs, for example from a rain event or from surface water runoff. Thus, remobilisation of solutes such aluminium, iron, manganese, copper and zinc could occur during rain events. Desorption on the other hand, may not be reversible. Once arsenic, selenium or antimony are mobilised, they may remain in solution even after rain events.

Physical modelling (i.e. evaporation trials) will be required to validate the input parameters before further geochemical modelling of lake specific conditions is undertaken.

13.4 Soil

13.4.1 Local soil

Soils in disturbed areas at Yandicoogina are dominated by alluvium and colluvium materials associated with low slopes and sheetwash areas, presenting as red-brown sandy and clayey loam soils. Along the banks of the Weeli Wolli Creek, and in some drainage lines, calcrete is visible within the soil, creating stony loam soils.

Subsoil has physical properties suitable for plant growth and generally has chemical properties amenable to plant growth, although it does lack the nutrient content, organic matter, soil seed bank and mychorrhizal fungi properties of topsoil.

13.4.2 Soil inventory

The availability of topsoil significantly improves the potential for rehabilitation success. The Rio Tinto Iron Ore Soil Resource Management Work Practice provides guidance on soil collection and appropriate management during the operation of the mine. The procedure aims to maximise topsoil recovery and retaining soil viability and productivity to improve future success of rehabilitation programs.

The Rio Tinto Iron Ore Soil Resource Management Work Practice implemented at Yandicoogina includes:

- stockpiling grubbed surface vegetation to provide a supply of additional seeds and organic matter for the soil;
- collecting more than the minimum 200mm mandated quantity of topsoil where available;
- storage of topsoil in stockpiles no more than 2m high (or one truck paddock dumped tip height, when using larger trucks) in sign posted, restricted access areas;
- collection of subsoil up to 600mm where available;
- collecting additional subsoil where practicable / available;
- maintaining a soil inventory; and

- regularly reconciling the available and project soil requirements to the projected life of mine disturbance areas.

The soil inventory, provided in Table 8, shows that Yandicoogina is not expected to recover sufficient topsoil in order to meet the rehabilitation requirements for the site. This assessment is based on a total disturbance area of approximately 40,600,000m^2, of which 35,900000m^2 is expected to require revegetation (includes areas above the groundwater recovery water table and excluded pit walls and associated geotechnical zones of instability that will not be revegetated), applying soil (a combination of topsoil and subsoil) at a uniform depth of 200mm. It is currently assumed, based on the rehabilitation success at other Pilbara mine sites, that biodiversity can be restored without the need to reconstruct soil horizons.

This inventory will be updated throughout the life of the mine to reconcile closure requirements with soil stockpiles.

Table 8: Soil stockpile volumes (as of 2014).

Material Type	Volume (Mm^3)
Existing stockpiled soil	
Topsoil recovered	*1.1*
Subsoil recovered	*2.3*
Planned (future) soil recovery (JSW, Oxbow, Billiard South only)	
Anticipated topsoil recovery	*3.7*
Anticipated subsoil recovery	*10.9*
Volume required for rehabilitation (disturbance area[21] x 200mm)	7.2
Soil balance (stockpile + planned recovery – rehabilitation requirement)	**+7.4 (surplus subsoil)**

Figure 8: Topsoil stockpile at Yandicoogina, 2013.

13.5 Mineral waste characterisation

13.5.1 Physical properties

Mineral waste generated at the site consists largely of overburden material and CID fines. Characteristics of the material are summarised in Table 9 and Table 10.

Table 9: General properties of the alluvial overburden material at Yandicoogina.

pH	EC1:5	EC1:2	ESP	Potentially dispersive	Exchangeable cations (m.eq./100g)					ECEC
(-)	(dS/m)	(dS/m)	(%)		K	Ca	Mg	Na	Al	
6.5	0.02	0.04	3.1	No	0.42	1.85	0.82	0.1	0	3.2

[21] The disturbance area requiring soil application is assumed to be the total disturbance footprint at the end of the mine life minus pit areas that do not require rehabilitation. Rehabilitation area has been assessed as a three-dimensional surface.

Table 10: Particle size distribution of the alluvial overburden material at Yandicoogina.

Rock >45mm (%)	Pebbles 22-45mm (%)	Gravel 2-22mm (%)	Fine Fraction <2mm (%)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
1	0	18	81	40	44	4	12

The majority of the mineral waste (386Mm^3) is expected to be of high erodibility, and will require conservative landform design parameters to be used in order to create stable slopes. A small volume (2 Mm^3) of low erodibility mineral waste may be mined; however there is no plan to segregate this material for use at closure at this stage.

Mineral waste has been used at other Pilbara mining operations as an alternative growth media to topsoil. In general, the soil structure created using inert mineral waste has been shown to be relatively stable, with only slight or no dispersion upon re-moulding and was not prone to hardsetting. This indicates that the mineral waste creates a relatively stable soil structure that is not easily degraded. Similar outcomes are expected from the Yandicoogina mineral waste, and will be tested as part of site rehabilitation trials.

13.5.2 Geochemical properties

HIY has implemented an extensive program of geochemical testing, over several years, to understand the potential for acidification and / or metal enrichment to occur as a result of the various waste types. Static tests have been conducted on all waste types, with more comprehensive sequential leach and kinetic tests undertaken on materials with uncertain test results or considered to pose significant geochemical risk. The sequential leach and kinetic testing regimes also included samples of materials which were identified as low risk in order to confirm that this is indeed the case. All tests were conducted in accordance with the *Global Acid Rock Drainage (GARD) Guide.*

No sulphides, the primary source of acid drainage issues, have been identified in the host geology or mineral waste at Yandicoogina. Although it is recognised that some minerals, such as alunite and jarosite, that contain sulphates and pose a low geochemical risk, due to self-limiting chemical processes, may be present in small quantities at Yandicoogina in the alluvium, weathered channel alluvial material and to a lesser extent the Weeli Wolli formation. The total sulphur concentration of the 99th percentile of all sampled processed ore and waste at Yandicoogina is less than 0.02%, suggesting the overall acid rock drainage risk is low to nil.

Neutral mine drainage and saline drainage are characterised by pH levels of above 6. Neutral mine drainage is generally characterised by a sulphate concentration of more than 1,000mg/L, while saline drainage is characterised by a total dissolved salt concentration of more than 1,000mg/L. Elevated concentrations of elements of interest may be present under neutral or saline drainage conditions because:

- there was an excess of neutralization potential (NP) from in situ rock or waste rock that reacted with and consumed acid in the waters. As a result no acidic conditions are observed or ex situ downstream, or
- elements, i.e. antimony, arsenic, cadmium, molybdenum, selenium and zinc, remain relatively soluble under neutral pH conditions, or
- elements are released through rapid or accelerated weathering.

Mineral wastes were classified as non-saline and non-sodic, with no sample presenting above the 15% threshold for exchangeable sodium percentage (ESP), the indicator of high sodicity. Mineral waste and ore lithologies were shown to be enriched in iron, arsenic and tin against the crustal abundance index.

Sequential extraction test work demonstrated that iron, arsenic and tin are incorporated in the crystalline iron oxides and silicates which reduce the potential for the minerals to be released. However, the potential for contaminant release still exists under slightly alkaline and saline environments. Thus saline drainage, and not neutral mine drainage, conditions are anticipated to evolve at Yandicoogina post-closure. The release of contaminants is limited, however, due to the combined effects of sorption and low mineral solubility under neutral pH conditions.

Leach tests conducted on waste rock and waste fines presented circum-neutral pH values between 6.5 to 8.5 and EC values of around 650µS/cm for waste rock and 70µS/cm for waste fines, regardless of test conditions.

Readily detectable elements within the waste rock included the major elements Ca, Mg, Na, K, Cl, Si and SO4 and the trace elements Al, B, Ba, F, Fe, Sr and Zn. The highest concentrations of elements were recorded in the low contact ratio leach tests. The majority of the elements were source term limited, such that low masses were present in the samples and would be completely dissolve during the test. The test work also indicated that elements Al, Ba, F and Si may be solubility controlled.

The characteristics of the waste fines materials are similar to the waste rock, with the exception that low contact ratio leach tests contained low but detectable concentrations of Cd, Cr, Cu, Pb, Mn and Ni. These elements were not detected in the 2:1 L:S leach.

Selenium, a non-metallic chalcogen, has also been identified by the EPA as an element of concern in some Pilbara iron ore lithologies. Studies in the JSW and Oxbow deposits found that selenium does not occur at elevated concentrations compared with background materials. Gardiner (2003)[22] reported dissolved selenium concentrations of up to 2.94 µg/L in pre-mining groundwater measurements within the Yandicoogina CID aquifer. These concentrations are below the ANZECC/ARMCANZ Guidelines[23] for selenium trigger values for freshwater aquatic ecosystems (trigger value <5 µg/L for protection of 99% of species).

Iron mineralogies are often associated with low mobility of metalliferous and other elements. Iron oxy-hydroxides have high sorption capacities for arsenic and selenium[24] [25], and consequently these materials have been used around the world for treating water enriched in these elements (via adsorption to the hydrated iron hydroxide surface). The overall risk posed by selenium release to the surface environment from mineral wastes is considered to be negligible. The oxidation state of the iron-rich lithologies would prevent major chemical change from mining and storage activities.

13.5.3 Fibrous materials

Naturally occurring silicate minerals can have fibrous habitats that can pose a health risk if the fibres are of a respirable size, become airborne and are inhaled. The fibrous silicate minerals crocidolite and actinolite have been encountered in the Yandicoogina region. Crocidolite has been encountered in alluvial/colluvial material that overlies the CID. This material has been transported from weathered crocidolite seams located in the hills surrounding the deposits. Discontinuous actinolite seams have been encountered in Dolerite during excavation for rail cuttings, the F5 canyon and a number of areas in proximity to the loop. This material was encapsulated in the fibrous waste dump highlighted in Figure 9.

Figure 9: Fibrous materials intersected during construction of the rail loop are encapsulated within this mineral waste dump inside the rail loop. Waste dumps containing fibrous materials will be rehabilitated in situ on closure.

When fibrous materials are encountered, management of the material is guided by the Rio Tinto Iron Ore (WA) Fibrous Mineral Management Plan. The plan includes:

- undertaking risk assessments prior to entering or disturbing areas with potential fibrous risk, to ensure appropriate personal protection equipment is worn as well as personal dust monitoring; and

[22] Gardiner SJ (2003) Impacts of mining and mine closure on water quality and the nature of the shallow aquifer, Yandi iron ore mine, Master of Science Thesis, Curtin University of Technology, Perth.

[23] ANZECC/ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* Agriculture and Resource Management Council of Australia and New Zealand and Australian and New Zealand Environment and Conservation Council, Canberra.

[24] Zhang W, Singh P, Paling E & Delides S (2004) Arsenic removal from contaminated water by natural iron ores, *Minerals Engineering*, Vol. 17, pp: 517-524

[25] Rovira M, Gimenez J, Martınez M, Martınez-Llad X, de Pablo J, Martı V & Duro L (2008) Sorption of selenium(IV) and selenium(VI) onto natural iron oxides: Goethite and hematite, *Journal of Hazardous Materials*, Vol. 150, pp:279–284

- encapsulating intersected / identified fibrous mineral waste in 2 m thickness of non-fibrous mineral waste, in a location where the material will not be disturbed on closure.

If fibrous minerals are confirmed to be present in the alluvial / colluvial materials immediately adjacent to disturbed areas, there is a potential for these materials to be disturbed as part of rehabilitation activities, i.e. grading. In which case, following a risk assessment, fibrous mineral management will be integrated into the decommissioning and rehabilitation implementation plans for affected areas.

13.6 Other potential contamination

A preliminary site investigation was carried out at Yandicoogina to establish potential sources of contamination resulting from the current and historical site activities. The main sources of contamination present at Yandicoogina today are at the hydrocarbon (mainly diesel) storage / handling facilities and fuel pumps facilities. No locations have currently triggered reporting thresholds under the *Contaminated Sites Act 2003.* Other potential sources of contamination include vehicle wash-down and maintenance facilities, waste oil handling facilities, liquid waste storage facilities, ammonium nitrate and fuel oil, equipment laydown, landfill, wastewater treatment and land farm facilities.

HIY manages contaminated sites in accordance with a Contaminated Sites Management Plan (**CSMP**), and relevant contaminated sites and environmental legislation. The CSMP outlines how HIY will manage all potentially contaminated sites, on a site-by site basis. It provides for internal management, whilst also adhering to relevant regulatory requirements. The CSMP applies to all Rio Tinto facilities and assets, including mine sites, exploration / evaluation projects, port and rail facilities and pastoral stations.

Site closure will undoubtedly involve a change in land use, as such; the significance of any site contamination may change. A contaminated sites assessment will therefore be undertaken prior to closure, and specific plans developed, as part of the decommissioning process, to remove or manage contamination where appropriate.

14. Biodiversity

14.1 Flora, fauna and vegetation

Baseline surveys were undertaken prior to mining disturbance and environmental reviews have been undertaken regularly throughout the life of the mine to verify environmental condition and track changes to the environment as a consequence of mining.

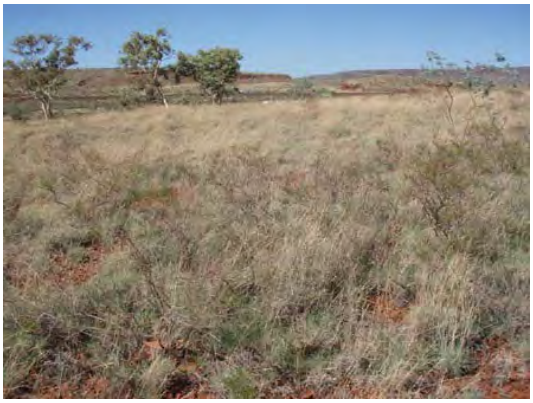
As captured in Appendix B, surveys and environmental reviews cover:

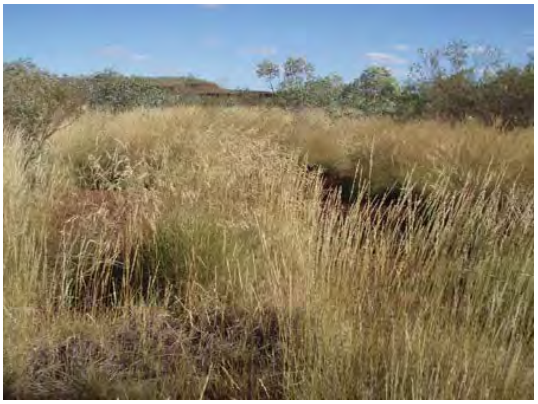
- terrestrial vegetation and flora;
- terrestrial and subterranean fauna (including Short-Range Endemic (SRE) invertebrates, troglofauna and stygofauna);
- riparian vegetation and flora; and
- aquatic fauna.

14.1.1 Terrestrial habitat

Six broad habitats types have been identified across the Yandicoogina area. These habitats include hilltop, gullies, slopes, plains, creeks and drainage lines. Characteristics of these habitat types are provided in Table 11. On closure, the characteristics of the landscape will be altered to introduce terminal (internal draining) basins, permanent pit lakes, and wetland areas with direct connection to the existing creek systems. Table 11 describes the characteristics typical of these different drainage habitat types, based on similar landscape features located elsewhere in the Pilbara.

Table 11: Habitats considered in closure planning.

Habitat	Description
Hill habitats	
Hilltop	 Hills, ridges, plateaux remnants and breakaways of varied geological origin. Soil is generally skeletal sandy clay loams with greater than 80% stony detrital material. Under natural conditions this habitat zone is characterised by a scattered overstorey of Snappy gum *Eucalyptus leucophloia*, Bloodwood *Corymbia hamersleyana*, Kanji *Acacia inaequilatera* and/or *Hakea chordophylla* over moderately dense spinifex, predominantly *Triodia* aff. *basedowii*, with some *T. wiseana* on slopes. Rocky, sheltered ridges and breakaways provide a suite of specialist plants or species more typical of lowlands. This habitat is characterised by a low diversity of microhabitats. In general there are few to no logs, little woody debris, and very few hollows in trees. The shallow soil is often hard and unsuitable for burrowing fauna. Although the exposed bedrock can provide a few niche habitats in the form of cracks and crevices. This habitat zone will be present in undisturbed areas around the mine and may evolve around the edge of the disturbed mine area, especially where the pit shell intersects local hills. However this habitat type will not be restored or rehabilitated as part of the closure plan.
Gullies	 Small gullies in upper hills with small, stony creeks. Under natural conditions gully habitats are only marginally different from the community that happened to surround them. Usually species poor, with occasional eucalypts over *Triodia* aff. *basedowii* and *T. wiseana*. This habitat creates a diverse array of microhabitats. The habitat often contains rock shelters in the form of overhangs, cracks, crevices, caves and areas for water to pool during the wet season. Vegetation provides microhabitats in the form of logs, debris and hollows. This habitat zone will be present in undisturbed areas around the mine. However this habitat type will not be restored or rehabilitated as part of the closure plan.

Habitat	Description
Valley habitats	
Slopes	 Stony lower slopes with quaternary colluvium and situated below the surrounding hill systems. Under natural conditions major soil types include red loamy earths and red shallow loams. Vegetation is characterised by hard and soft spinifex grasslands and scattered mulga (*Acacia aneura*) shrublands, as seen in the western half of the Oxbow area and in the JSW-A area pre-mining. This habitat is characterised by a low diversity of microhabitats with few logs and woody debris, and very few tree hollows. The soil is usually hard and unsuitable for burrowing fauna. The Western Pebble-mouse traditionally inhabits this habitat zone as it creates its Pebble mounds on the rocky scree. This habitat zone will be present in undisturbed areas outside of the mine. Opportunities for successful rehabilitation of this habitat are limited to areas where soils remain stony after disturbance.
Plains	 Undulating, low stony plains and alluvial flats. Under natural conditions soils vary from relatively deep, stony, skeletal red clay loams on low undulating plains to deep red clay loam soils with massive clay substrates on Mulga flats. Vegetation is characterised by scattered low trees over sparse mixed shrubs i.e. *Acacia* spp. and *Grevillea* sp. and various species of spinifex. Alluvial soils may also support Mulga *Acacia aneura* and other Acacia communities over a moderately rich assemblage of shrubs, herbs and tussock grasses. Spinifex is less conspicuous in this community than most other habitats; however *Triodia wiseana* and *T. pungens* are frequently present. This habitat type contains limited microhabitats with the dominant Acacia species providing no tree hollows, few logs, limited leaf litter and sparse vegetation. This habitat zone will be present in undisturbed areas outside of the mine and has the most potential for successful rehabilitation, for example in low disturbance areas where topsoil is available and the substrate has not been disturbed.

Habitat	Description
Drainage habitats	
Creeks	 A linear habitat characterised by regular surface water flows, defined banks and associated riparian vegetation corridor. The creek habitat includes areas that are periodically flooded due to high surface water flow volumes (floodplains) and are usually associated with accessible groundwater and increased soil water (bank) storage potential. Creeks in the Yandicoogina area include Weeli Wolli Creek, Marillana Creek, Phils Creek and Yandicoogina Creek. Vegetation is characterised by a mixture of woodlands (including River Red Gum *Eucalyptus camaldulensis*, Coolibah *E. victrix* and other tree species), shrublands and hummock grasslands, including riverine fringing vegetation of grasslands and herbs. Spinifex was comparatively sparse in drainage lines, and usually comprised *Triodia pungens* or *T. longiceps*. Creek habitats act as wildlife corridors that help flora and fauna disperse across the landscape. There is a high diversity of microhabitats including logs, debris, tree hollows and soft soils, as well as temporary and permanent pools. This habitat zone will be present in undisturbed areas outside of the mine. Disturbed creek habitat will be rehabilitated to restore creek functionality.
Drainage line	 A linear habitat that begins at the top of hills and runs to the surrounding plains, or encompasses small tributaries that eventually flow into larger river and creek habitat types. Vegetation composition is usually similar to the neighbouring habitat but with increased vigour and density due to sustained, elevated soil moisture following rainfall events. Drainage line habitat act as wildlife corridors that help flora and some fauna disperse across the landscape. There is a moderate diversity of microhabitats with some logs, debris, occasional tree hollows and isolated pods of soft soils. Surface water is more likely to persist in this habitat after it has evaporated elsewhere, providing a refuge for fauna. This habitat zone will be present in undisturbed areas outside of the mine. Drainage line habitat will be rehabilitated / created as part of local drainage controls. Where drainage line habitat is created, erosion control mechanism will need to be integrated into the drainage line rehabilitation design.

Habitat	Description
Terminal basin	 Land that due to its shape captures and holds surface water runoff. The landform shape facilities the settling of silts and sediments, often creating a clay pan or hard pan over time. Vegetation communities are designed to accommodate periodic, sustained flooding as well as periods of drought. As few vegetation species are capable of withstanding the extreme conditions, species diversity within and coverage across the habitat may be low. This habitat type can contain limited opportunity for fauna re-colonisation if the ground becomes a hard pan, preventing trees from establishing and thereby limiting log and leaf litter generation. This habitat zone will be introduced in constructed low lying topography within backfilled pit landforms, e.g. above existing waste fines cells, as part of the surface water management design. The terminal basin areas will capture and contain rainfall within the former pit areas, to minimise runoff and subsequent erosion across the backfilled landform.
Pit lake	 A water body created through the process of mining below the water table. Water within the mine void is sustained by the local groundwater system. Water quality may vary over time, and could become unpalatable or highly saline over time. Landforms will not be specifically engineered for long-term landform stability, with the exception of the creation of safe egress areas. Scree slopes are likely to form over time as the pit walls erode. The pit walls and floor will not be revegetated, although vegetation and weeds may opportunistically colonise the evolving scree slopes. This habitat may attract fauna and is susceptible to weeds. Intensive monitoring and management may be required to ensure that the resulting environmental conditions are within an established, acceptable range. This habitat zone will be introduced at Oxbow East and Oxbow West.

Habitat	Description
Wetland	 Habitat created through the process of mining below the water table where mine voids are rehabilitated to function as a lake system. The water body is readily accessible to fauna and humans, and the quality of the water is anticipated to be suitable for the proposed function of the lake. The fringe of the lake may be vegetated to ensure an adequate diversity of species is present to support a self-sustaining ecosystem. However, all of the pit walls surrounding the lake may not be stabilised, such that some minor pit wall erosion may occur. Aquatic fauna and aquatic fauna habitat are not anticipated to be included in the rehabilitation process, but are expected to develop over time through natural recovery processes. This habitat zone will be introduced to create wetlands in the JSW-A, JSW-C, Phils, JC, Pocket and Billiard South mine voids.

The key characteristics for three common habitat types at Yandicoogina, plains, slope and hilltop habitats, are presented in . These statistics were established in 2009 based on the anticipated rehabilitation requirements at Yandicoogina. Further work is required to define metrics and key values associated with the proposed terminal basin, drainage line and wetland habitats.

Table 12: Yandicoogina reference site vegetation statistics.

	Lower slopes / flat - Plains habitat	Midslopes - Slope habitat	Upper slopes - Hilltop habitat
Bare ground (%)	20.8 ± 4.2 (std error)	10.8 ± 2.1 (std error)	12.1 ± 2.5 (std error)
Live plant density (plants/m^2)	Range 2.3 – 2.6	Range 2.6 – 6.0	Range 4.2 – 10.9
Foliage cover (%)	Range 27.3 – 31.9	Range 32.1 – 33.2	Range 18.7 – 29.0
Species richness (per m^2)	Range 0.7 – 1.1	Range 0.4 – 1.0	Range 0.5 – 0.85
Dominant plants (average alive plants/m^2)	Perennial grasses (1.65) Shrubs (0.6) Perennial herbs (0.2)	Perennial grasses (3.5) Shrubs (0.2) Perennial herbs (0.04)	Perennial grasses (5.8) Sedge (2.0) Shrubs (0.1)
Dominant plants (alive % foliage cover)	Perennial grasses (21.4) Shrubs (5.8) Trees (2.0)	Perennial grasses (26.6) Shrubs (4.5) Trees (1.5)	Perennial grasses (23.0) Shrubs (1.9) Trees (0.2) Sedge (0.1)

Figure 10: Example of existing ridge habitat from C1 transect on hill tops (2009).
Hummock grassland of *Triodia wiseana* with *Eucalyptus leucophloia* and *Senna glutinosa* subsp. *pruinosa*.

Figure 11: Example of existing slope habitat from C6 transect on mid slopes (2009).
Hummock grassland of *Triodia basedowii* and *Triodia wiseana* with *Eucalyptus gamophylla* and Acacia spp.

Figure 12: Example of existing plain habitat from C5 transect on low slopes (2009).
Hummock grassland of *Triodia pungens* with *Eucalyptus gamophylla*, *Corymbia hamersleyana*, *Hakea lorea*, and Acacia sp.

Table 13 and Table 14 list the significant fauna and flora (respectively) that are likely to occur or have been found at Yandicoogina, and their habitat relationships.

Table 13: Significant fauna with potential to occur within the local Yandicoogina area, and its relationship to habitat types.

Fauna species	Conservation status	EPBC Act status	Habitat occurrence	Comments
Dasyurus hallucatus (northern quoll)	Schedule 1	Endangered	Gullies Disturbed	Habitat for this species is rocky ridgelines and rocky gorges.
Pezoporus occidentalis (night parrot)	Schedule 1	Endangered	Plains	Prefers dense, low vegetation for day shelter. Most records come from hummock grasslands with spinifex (Triodia), from areas dominated by samphire, or particularly, where these two habitats are juxtaposed
Rhinonicteris aurantia (Pilbara orange leaf-nosed bat)	Schedule 1	Vulnerable	Gullies Hilltop	Caves near water provide suitable roosts. Caves near Oxbow area provides only potential habitat.
Liasis olivaceus barroni (olive python)	Schedule 1	Vulnerable	All hill habitats	Widespread in rocky areas, showing a preference for rocky habitats near water, particularly rock pools
Falco hypoleucos (grey falcon)	Schedule 1	Vulnerable	Acacia woodland Mulga woodland Drainage habitats	Ranges across habitats in search of food. Prefers lightly wooded coastal and riverine plains.
Falco peregrinus (peregrine falcon)	Schedule 4	-	All habitats	Ranges across habitats in search of food
Ramphotyphlops ganei	Priority 1	-	All habitats	Prefers moist gorges.
Pseudomys chapmani (western pebblemound mouse)	Priority 4	-	All hill habitats	Recorded in area. Habitat for this species is rocky, hummock grasslands, with little or no soil. The western pebble-mound mouse occupies burrows beneath mounds of pebbles. Mounds are most common on the spurs and lower slopes of ridges
Macroderma gigas (ghost bat)	Priority 4	-	Gullies Hilltop	Roost in caves, rock piles and abandoned mines. Will travel 2 km from roost to hunt. Caves near Oxbow area provides only potential habitat
Ardeotis australis (Australian bustard)	Priority 4	-	Plains	Recorded in area. Habitat preferred by this species lightly wooded country next to daytime shelter of thickets or long grass.
Burhinus grallariuss (bush stone-curlew)	Priority 4	-	All valley habitat	Habitat preferred by this species is tussock grassland, Triodia hummock grassland, grassy woodland and low shrublands
Merops ornatus (rainbow bee eater)		Migratory	All valley habitats	Found within open forests, woodlands and shrublands, and cleared areas. Open pit walls may be utilised to build nesting tunnels
Neochmia ruficauda subclarescens (star finch)	Priority 4			Recorded in area. Typically confined to reedbeds and adjacent vegetation communities along permanent waterways

Table 14: Significant flora and its relationship to habitat across Yandicoogina.

Flora taxon	Conservation status	EPBC Act status	Habitat occurrence	Habitat comments
Lepidium catapycnon	Threatened*	Vulnerable*	Hilltop	Skeletal soils. Break of slope topography, hillsides
Rhodanthe ascendens	Priority 1		Plains	Clay soils
Stylidium weeliwolli	Priority 2		Drainage	Occurs mainly along major water courses in seasonally damp or wet areas, including root mats of Melaleuca, on floodplains and in seepages around granite rocks.
Rostellularia adscendens var. *latifolia*	Priority 3		Hill	Ironstone soils. Near creeks, rocky hills
Sida sp. Barlee Range (S. van Leeuwen 1642)	Priority 3		Hill	Skeletal red soils pockets. Steep slope.
Themeda sp. Hamersley Station (M.E. Trudgen 11431)	Priority 3		Plains	Red clay. Clay pan, grass plain
Rhynchosia bungarensis	Priority 4		Hill	Pebbly, shingly coarse sand amongst boulders
Goodenia nuda	Priority 4		Plains	Wide alluvial plain or creek beds. Red brown clay loam, ironstone.

*Currently subject to re-evaluation of conservation status.

The surveys show that most of the vegetation communities found at Yandicoogina and the fauna habitat they support are widespread and well represented regionally. Riparian vegetation along Marillana and Weeli Wolli Creeks is considered locally significant, due to the relatively limited extent of this vegetation type compared with other locally occurring vegetation types and the ecological services that it provides in the local area. These services include:

- provision of structural habitat elements, such as tree hollows;
- protection of creek banks from erosion;
- protection of water quality through sediment trapping and nutrient stripping, and
- transfer of subterranean water and nutrients to the surface environment by some of the dominant tree species.

Consequently, creek and wetland habitat is considered to be of elevated value due to the diversity of microhabitats and potential to support conservation significant fauna species. Drainage line and gully habitats are considered to have moderate habitat value, due to the number of fauna that may utilise the area; while slopes, plain, hilltop, pit lake and terminal basin habitats have low habitat value.

Impacts to the riparian systems are anticipated during mining operations. The Yandicoogina Environmental Management Plan has been implemented (in accordance with MS 914 Conditions 7 and 8) to ensure adequate protection of the waterways and associated riparian vegetation.

The operation is not expected to impact the conservation status of any flora or fauna species, populations or fauna habitat. This includes changes to fauna and flora abundance, species diversity, geographic distribution and / or productivity at species or ecosystem levels.

As Yandicoogina is not predicted to impact the conservation significance of any species, ecosystem restoration activities and reintroduction of fauna are not planned as part of the rehabilitation activities.

14.1.2 Subterranean habitat

Subterranean fauna are animals that inhabit underground habitats and include:

- stygofauna - obligate, groundwater dwelling aquatic fauna, and
- troglofauna - obligate, subterranean dwelling fauna occurring in the unsaturated profile above the water table.

Stygofauna and troglofauna are known to occur in a range of habitats in the Pilbara region, but can potentially have restricted distributions based on their evolutionary history and specialised habitat requirements. The CID at Yandicoogina does not provide ideal troglofauna habitat due to frequent inundation during periods of heavy rainfall. Three potentially troglobitic species have been collected, none of which are endemic to the area.

At least 150 species of stygofauna have been recorded in the Pilbara[26] with 500–550 taxa[27] estimated to remain undescribed. Prior to 2011, 15 new (undescribed) taxa, currently only known to be present within Marillana and Weeli Wolli Creeks, had been identified. For this reason, subterranean fauna habitat is considered to have biodiversity value.

A subterranean fauna management plan was implemented at Yandicoogina to address possible direct and indirect impacts to subterranean fauna affected by mining. The plan included regular sampling and morphological analysis, identification of species whose long-term survival is at risk and procedures to avoid or minimise the impacts on these species, and analysis of physical environmental (habitat) data.

Work, completed in accordance with the plan, demonstrated that the taxonomic composition of the stygobitic fauna recorded at Yandicoogina remained similar over multiple recording campaigns. These results suggest that an abundant and diverse stygal community remains within the aquifers of the Yandicoogina creek systems, years after the commencement of the dewatering at the operation, and shows that impacts to subterranean fauna are localised to the immediate mine areas. Consequently, targeted creation of stygofauna habitat is not considered to be required for the closure of this site.

Closure and post-closure impacts to the stygofauna populations may arise as a consequence of predicted changes to groundwater quality (salinity and / or pH). The potential response of remnant stygofauna populations at Yandicoogina to potentially altered groundwater conditions is currently unknown; although stygal communities are known to be present in the brackish water condition of the Fortescue Marsh[28].

14.2 Local environmental values

Creek systems in the Yandicoogina area offer deeper soil types (alluvium), with capacity to store water in between rainfall events. This stored soil water is used to sustain plant growth through dry periods. Some of the larger tree species have root systems that enable access to water stored deep within the alluvium, and in some cases are able to access the groundwater table on an ongoing or transient basis. The key tree species are *Eucalyptus victrix* (Coolibah), *Eucalyptus camaldulensis* (River Red Gum) and *Melaleuca argentea* (Silver Cadjeput).

The paperbark species *Melaleuca argentea* occurs in areas of shallow groundwater and is regarded as being dependent on groundwater to meet its ecological water requirements[29][30] *Eucalyptus camaldulensis* and *E. victrix* occur extensively along Marillana and Weeli Wolli Creeks. These species are known to use a range of mechanisms to regulate their water use in response to changes to water availability, such as: stomatal control[31], cell-wall elastic adjustment and osmotic adjustment[32], leaf area equilibration[33], and self thinning[34].

[26] Eberhard SM, Halse SA, Scanlon MD, Cocking JS & Barron HJ 2005, „Assessment and conservation of aquatic life in the subsurface of the Pilbara region, Western Australia", *Proceedings of the Symposium on World Subterranean Biodiversity*, Universté Claude Bernard Lyon, November 2005.

[27] Eberhard SM, Halse SA, Scanlon MD, Cocking JS & Barron HJ 2009, „Exploring the relationship between sampling efficiency and short-range endemism for groundwater fauna in the Pilbara region, Western Australia", *Freshwater Biology*, vol. 54, pp: 885–901.

[28] Bennelongia (2010) Christmas Creek Project Water Management Scheme: Stygofauna Assessment, prepared for Fortescue Metals Group Ltd, Report 2010/96, September 2010.

[29] Graham J (2001) The root hydraulic architecture of *Melaleuca argentea'*, Honours Thesis, Department of Botany, University of Western Australia, Perth

[30] O'Grady AP, Eamus D, Cook PG & Lamontagne S (2005) Comparative water use by the riparian trees *Melaleuca argentea* and *Corymbia bella* in the wet–dry tropics of northern Australia, *Tree Physiology*, vol. 26, pp: 219–228

[31] For example White DA, Turner NC & Galbraith JH (2000) Leaf water relations and stomatal behaviour of four allopatric Eucalyptus species planted in Mediterranean southwestern Australia, *Tree Physiol* , vol. 20, pp: 1157-1165

These adaptations and the ability to extract water variably through deep tap roots or shallow lateral roots, depending on relative water availability, make the Eucalypt species relatively resilient to water table fluctuations; although they will still exhibit stress when soil water content goes above or below an optimal level.

Downstream of Yandicoogina, the Fortescue Marsh area has important conservation values[35] and has been recognised by the Western Australian Department of Parks and Wildlife as a Priority Ecological Community[36] (PEC) Priority 1. The marsh is rich in plant and animal species of high conservation value and is part of an ancient and complex array of alluvial aquifers and groundwater systems. It is sustained by floodwater from the upper Fortescue River catchment[37], of which the Weeli Wolli catchment comprises around half the source catchment, and local rainfall. Regular flooding of the fringing vegetation around the wetland is required to flush salts from the soil into the underlying groundwater table. This flushing is necessary to periodically reduce the stress on the samphire and halophytic vegetation[38], providing the ecosystem with a period of rejuvenation. It is recognised that changes to the large flood regime of Marillana or Weeli Wolli Creek could potentially have an impact on the health of the Fortescue Marsh.

Upstream of Yandicoogina PBS deposit, on Weeli Wolli Creek, the Weeli Wolli Spring riparian woodland and forest associations (approximately 15km upstream from the Marillana and Weeli Wolli Creek confluence) have been identified as a PEC (Priority 1). There is no evidence of an environmental connection between conditions at Weeli Wolli Spring and Yandicoogina, such that no impact on the Weeli Wolli Spring community is expected as a consequence of the Yandicoogina development.

Upstream of the Yandicoogina Oxbow West deposit, on Marillana Creek, the BHP Billiton Iron Ore operates the Yandi (also known as Marillana Creek) mine. The dewatering and closure activities at the BHP Billiton Iron Ore Yandi mine have and will continue to have an impact on the environmental conditions in Marillana Creek. Environmental factors that are influenced by BHP Billiton Iron Ore Yandi activities and in turn influence environmental conditions at Yandicoogina include groundwater levels, groundwater quality, surface water flows and surface water quality.

[32] For example Lemcoff JH, Guarnaschelli AB, Garau AM & Prystupa P (2002) Elastic and osmotic adjustments in rooted cuttings of several clones of *Eucalyptus camaldulensis* Dehnh. from southeastern Australia after a drought, *Flora - Morphology, Distribution, Functional Ecology of Plants*, vol 97, pp: 134-14

[33] For example O'Grady AP, Cook PG, Eamus D, Duguid A, Wischusen JDH, Fass T & Worldege D (2009) Convergence of tree water use within an arid-zone woodland, *Oecologia*, vol. 160, pp: 643-655

[34] Horner GJ., Baker PJ, Macnally R., Cunningham SC, Thomson JR & Hamilton (2009) Mortality of developing floodplain forests subjected to a drying climate and water extraction, *Global Change Biology*, vol. 15, pp: 2176–2186

[35] Environmental Protection Authority (2013) Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area, Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986, Report 1484, July 2013.

[36] Priority Ecological Communities (PECs) are poorly understood ecological communities, which potentially have high conservation values and may be subject to threatening processes. They are classified as either priority 1, 2 or 3; ranked in order of priority for survey and/or definition of the community, and evaluation of conservation status. It is noted that areas of Fortescue Marsh will change to conservation tenure following the renewal of Western Australian pastoral leases in 2015.

[37] Skrzypek G., Dogramaci S., Grierson P.F. (2013) Geochemical and hydrological processes controlling groundwater salinity of a large inland wetland of northwest Australia. *Chemical Geology* 357: 164–177. RTIO-HSE-0198428

[38] Huxtable, D. (2013) Perspectives on ecological water requirements for plant communities of the Fortescue Marsh, in Proceedings of the Fortescue Marsh workshop, 26 March 2013.

14.3 Weeds

A total of 21 introduced flora species (weeds) were recorded in the Yandicoogina area prior to disturbance (Table 15). None of these species are listed as Declared Plants for the Pilbara region under the *Agriculture and Related Resources Protection Act 1976*.

Table 15: Weeds identified within the project envelope

Scientific Name	Common Name	Priority Classification
Acetosa vesicaria	Ruby Dock	Moderate
Aerva javanica	Kapok Bush	Low
Argemone ochroleuca subsp. Ochroleuca	Mexican Poppy	Low
Bidens bipinnata	Bipinnate Beggartick	Low
Cenchrus ciliaris	Buffel grass	Low
Cenchrus setiger	Birdwood Grass	Low
Citrullus colocynthis	Colocynth	Low
Cucumis melo subsp. Agrestis	Ulcardo Melon	Low
Cynodon dactylon	Couch	Low
Datura leichhardtii	Native Thornapple	Low
Helichrysum luteoalbum	Jersey Cudweed	Low
Malvastrum americanum	Spiked Malvastrum	Negligible
Portulaca oleracea	Purslane	Low
Setaria verticillata	Whorled Pigeon grass	Low
Sigesbeckia orientalis	Indian Weed	Low
Sisymbrium irio	London Rocket	Low
Sisymbrium orientale	Indian Hedge Mustard	Low
Solanum nigrum	Black Berry Nightshade	Low
Sonchus oleraceus	Common Sowthistle	Negligible
Tribulus terrestris	Caltrop	Low
Vachellia farnesiana	Mimosa Bush	Low

Buffel grass (*Cenchrus ciliaris*) was widespread and abundant prior to mining as a result of pastoral activities. Other species generally occurred as scattered individuals or in isolated patches. Mesic habitats such as creeklines and floodplains are particularly susceptible to weed invasion, and comprise the main areas around the mine supporting significant weed infestations.

Procedures to identify, control and eradicate target weeds and monitor weed control measures are in place to minimise the spread of weed species, prevent the introduction of new weeds and control and/or eradicate both noxious and environmental weeds in the mine area. Weed eradication programmes at Yandicoogina currently target *Acetosa vesicaria* (Ruby dock), *Aerva javanica* (kapok bush), *Malvastrum americanum* (spiked malvastrum), *Ricinus communis* (castor oil plant), *Setaria verticillata* (whorled pigeon grass) and *Vachellia farnesiana* (mimosa bush).

14.4 Progressive rehabilitation activities

Opportunities to undertake progressive rehabilitation at Yandicoogina have been limited as the majority of the disturbed area is still being used to support mining activities. Some rehabilitation of borrow areas has been undertaken, as discussed below. A review of standard rehabilitation practice performance was undertaken in 2015. This review (Appendix C) assessed the performance of rehabilitation undertaken on landforms similar to those that are expected to be present at Yandicoogina. The review indicates that standard rehabilitation practice is expected to achieve the required rehabilitation results for valley and hill type habitats associated with general landforms, long-term and short-tern disturbance areas; however, further research is required to develop rehabilitation strategies for drainage habitats.

14.4.1 Borrow pits

Borrow pits associated with the railway at Yandicoogina were rehabilitated in the second half of 1998. Rehabilitation monitoring commenced in 1999 and continues today. Monitoring results suggest that vegetation communities, in general, are similar to that of reference sites (Figure 13), while classification analysis showed there was no clear difference between the rehabilitated and reference sites in terms of their overall species composition.

Burning has occurred in both control sites and rehabilitation areas. The density and numbers of species present at control sites was observed to change after burning, often resulting in significant increases in plant species and resulting increased vegetation cover and diversity. However, analysis suggests rehabilitated sites do not respond to burning in the same manner, such that burning of rehabilitated sites does not result in long-term differences in vegetation composition.

Figure 13: Comparison of reference site 434 (left) and rehabilitated borrow pit area 434 (right) in 2013, 15 years after rehabilitation.

Figure 14 illustrates the difference in rehabilitation performance five years and 12 years after rehabilitation. After 12 years a small number of species present in reference sites have yet to be recorded in rehabilitation areas or are present only in lower numbers. However, there is a trend to gradual increase in species diversity. For example, in 2007, 20 species were recorded in reference sites that were not present in rehabilitation areas. By 2010 the number of species not identified in rehabilitation areas had reduced to 10, two of which were only recorded as a single plant across all reference sites.

Species found to be present in rehabilitated borrow pits at densities lower than in their reference sites comprise *Acacia aneura, Acacia dictyophleba*, *Acacia atkinsiana*, *Triodia pungens* and *Triodia wiseana*. Reasons for the lower abundance of some species in rehabilitation may include influence of fires, different densities prior to clearing and topsoil handling techniques.

Figure 14: Borrow Pit 417, with *Triodia* ground cover and *Acacia ancistrocarpa* and *A. atkinsiana* upper storey in 2003 (left) five years after rehabilitation, and in 2010 (right) 12 years after rehabilitation was completed.

14.4.2 Drainage shadow

Drainage shadow monitoring on Hamersley Iron's Yandicoogina railway commenced in 1998 and was completed in 2004. The monitoring program was designed to assess whether construction and operation of the railway had any indirect impact on the survival and health of Mulga, *Acacia aneura*. It was postulated that downslope impacts in the drainage shadow area might occur, with limited upslope impacts due to flooding also considered.

The results showed that although numbers of all mulga age classes and dead mature mulga appeared to be higher in some upslope transects, over time there was no clear statistically significant difference between the upslope and downslope transects.

CLOSURE RELATED DATA AND ANALYSIS

15. Removal of infrastructure

Decommissioning is anticipated to commence at the cessation of mining activities, as most areas of the mine, mine equipment and infrastructure will be fully utilised until the end of the mine life. However, as with progressive rehabilitation, opportunities to decommission areas in advance and facilitate rehabilitation will be reviewed through the mine planning process.

HIY has generic strategies for the removal of infrastructure, and develops location specific decommissioning plans as part of the decommissioning study, which will be undertaken 5 years prior to closure. Strategies involve:

- negotiating with Government prior to the removal of infrastructure as required under State Agreement requirements;
- actively seeking opportunities to recycle or reuse infrastructure that is to be removed;
- removing any environmentally hazardous materials in accordance with Controlled Waste Regulations; and
- where recycling and reuse opportunities are not available or viable, demolishing inert infrastructure and burying it onsite.

The decommissioning requirements for infrastructure at Yandicoogina are outlined in Table 16.

Table 16: Decommissioning requirements for Yandicoogina.

Category	Strategy
General	• Any equipment, steel structures or material that is not suitable for reuse are to be completely removed to an approved disposal site. • If encountered, any asbestos-containing building product or pipe work is to be disposed appropriately.
Above ground structures (e.g. buildings, tanks, rail)	• Brick, block work and steel frame structures are to be dismantled and salvaged or appropriately disposed. • Any container or tank that has held hazardous materials is to be drained/emptied and then disposed. • Bullet tanks and storage tanks 4 m diameters and less will be disposed of whole. Bins and storage tanks greater than 4 m diameter will be cut into transportable sizes for removal.
Reinforced soil walls	• Remove any structures, footings, slabs and equipment supported by the wall and its backfill. • Dismantle wall and remove backfill back to a natural surface profile. Any part of the wall that will be more than 1m below the finished ground surface can remain in place.
Concrete or sleeper-type retaining walls	• Remove any structure, footings, slabs and equipment supported by the wall. • Excavate soil from back of wall to a depth sufficient to allow the next two steps to be safely accomplished. • Remove any tiebacks and associated infrastructure that are within 1 m of the finished ground level.
Ground slabs	• Remove all attached steelwork, block work, services and equipment. • Break up and dispose of the concrete and full removal is practicable / required. • Otherwise leave the slab in place and cover with earth to a natural profile, and with minimum cover of 1 m.
Footings and associated pedestals	• Remove all attached steelwork and equipment. • If the footing and associated pedestals are less than 2 m^3, remove and dispose of them. • Otherwise cut and remove pedestals if required, and cover with earth to a natural profile, and with minimum cover of 1 m.
Above-ground concrete plinths (e.g. pump plinths) and structures (e.g. crusher blocks)	• Remove all attached steelwork and equipment. • Where practicable, remove concrete intact to disposal. • Otherwise, break concrete items and remove to disposal.
Culverts	• Remove all fill back to natural surface profile. • Remove culvert.

Category	Strategy
Sedimentation basins, ponds and reservoirs	• Dispose of liquid and sediments prior to deconstruction. • Break up and remove all concrete.
Roads and hardstand areas	• Remove any bituminous material to a disposal pit. • If roads were treated with salt or an acid based dust suppressant then clean fill maybe required over the road so that plant germination is not suppressed
Below ground infrastructure	• Services and infrastructure less than 1 m below ground level to be removed. • Services and infrastructure greater than 1m below ground level to be left in situ.
General areas	• Dispose of rubbish and any other decommissioning debris in an appropriate manner. • Remove any contaminated soil or designated hazardous materials that area to be remediated separately.

16. Landform design

16.1 Landform design strategy

HIY aims to create landforms that are safe and stable, considered aesthetically compatible with the surrounding landscape, supportive of native vegetation, and are non-polluting. It was recognised that integration of pit lakes into the closure landform for Yandicoogina was a necessity as there was not enough mineral waste generated by the mining process to backfill the voids to above the groundwater recovery levels. In consideration of how topography can influence water systems, six different landform combinations, using mineral waste volumes generated through mining to create landforms and control water movement, were investigated at Yandicoogina. Each closure scenario investigated was selected because it influenced the surface and ground water systems differently, and had the potential to achieve different environmental and social closure outcomes.

The six scenarios investigated, presented and illustrated in Appendix D, were:
1. No backfill (all voids become lakes);
2. Backfill to pre-mining water table (material would be mined, removing adjacent hills to achieve this scenario);
3. Maintaining creek flows (with lakes);
4. Multiple small, deep lakes (Weeli Wolli Creek captured);
5. One permanent lake (large lake captures Weeli Wolli Creek); and
6. Continuous channel (large lake in palaeo valley, all creeks captured).

Scenario 3, to maintain creek flows, was considered by HIY to provide the optimal closure outcome for the Yandicoogina area, based on the currently proposed life of mine plan (including development of the potential future expansion Billiard North and Braid deposits). The landform design for Yandicoogina considered different stakeholder / environment needs and the post-closure land-use options. Key drivers for the design of the post-closure landform were, in order of priority:
- safe, stable, non-polluting landforms;
- preservation of creek ecosystems, including riparian habitat;
- minimum impact to surface water flow paths, volumes and levels;
- achieving the lowest lake water salinity, preferably stock drinking water quality (4000mg/l) or lower; and
- minimum rehandle of mineral waste.

However, it is recognised that the mine plan may change in the future, for example, if new ore deposits are identified or if restrictions to the mine plan occur (i.e. for environmental or heritage reasons). Rio Tinto will continue to evaluate the impact of mine plan changes on closure outcomes, and this could result in a need to modify the closure landform in the future.

The “maintaining creek flows” scenario prioritises the use of available mineral waste to stabilise the pit walls, strengthen flood bunds and thereby preserves the creek systems as far as practicable. No attempt to suppress the groundwater table is made. Instead deep lakes are encouraged to form in the all pits except JSE, and excess mineral waste not required to support the creek system is placed to reduce the surface area of the lakes, rather than reduce the depth of the lake.

A conceptual landform was generated by prioritising mineral waste placement into the following locations:
- Phils Creek reconstruction. Phils Creek is removed as part of the JSW pit development. Additional mineral waste would be used to strengthen the land bridge (constructed during operations) by increasing the

buttressing either side of the land bridge. This configuration would minimise the potential for pit walls to collapse and increase resilience to large flood events.

- Marillana Creek between the JSW A and C areas. The area where Marillana Creek divides the JSW –A (southern) deposit from the JSW-C (northern) deposit restricts surface water flows between two flood bunds. Once the ore is removed, the bridge of CID ore and alluvium that remains under Marillana Creek has the potential to collapse into the void. Mineral waste would be used here to strengthen the pit walls and, leaving the flood bund in place, strengthen the flood bund. This configuration would increase resilience to large flood events.
- JSW-A adjacent to Marillana Creek. Mineral waste would be used at the southern end of the deposit to strengthen the pit wall adjacent to the Marillana Creek floodplain. The flood bund would be left in place and waste would be built up behind it to strengthen flood bund. This configuration would increase resilience to large flood events.
- Billiard South adjacent to Weeli Wolli Creek. Mineral waste would be used along the length of the deposit located within the Marillana Creek flood plain to strengthen the pit wall. An additional ramp area would be constructed to provide a controlled entry point and to convey floodwater from Weeli Wolli Creek into base of the pit. The entry point is expected to be towards the centre of the pit, such that the ramp would need to extend north and south across the width of the mine void into pit lakes created at either end of the mine void.
- JSE pit. Mineral waste would be used to suppress the groundwater table at JSE. This would prevent the permanent drawdown of the groundwater table under Weeli Wolli Creek adjacent to the JSE deposit.

With this landform configuration, a conceptual water balance model was compiled. The model suggested the groundwater table would recover to approximately pre-disturbance levels, in spite of the creation of several lakes.

16.2 Mineral waste management

The majority of the mineral waste is expected to be inert and highly erodible. Mineral waste dumps have been constructed in pit where possible; however a number of external waste dumps will be constructed throughout the mine life. These waste dumps will be removed and rehandled at closure (and opportunistically during the mine life), to place the mineral waste in strategic locations as illustrated in Figure 17.

This will include the use of mineral waste to:

- backfill and suppress the groundwater table. This mineral waste landform will construct a mostly flat surface, below the level of the original topography. Where the mineral waste landform ends, and the future pit lakes will form, (Figure 15) the mineral waste will be shaped to create a stable slope. Backfill elevations are shown in Figure 17.
- buttress pit walls located adjacent to creeks, as illustrated in Figure 16. These support structures are constructed as an in pit waste dump which merges into the natural land / levee (adjacent to the creek) and is rehabilitated to create a stable slope inside the mine void.

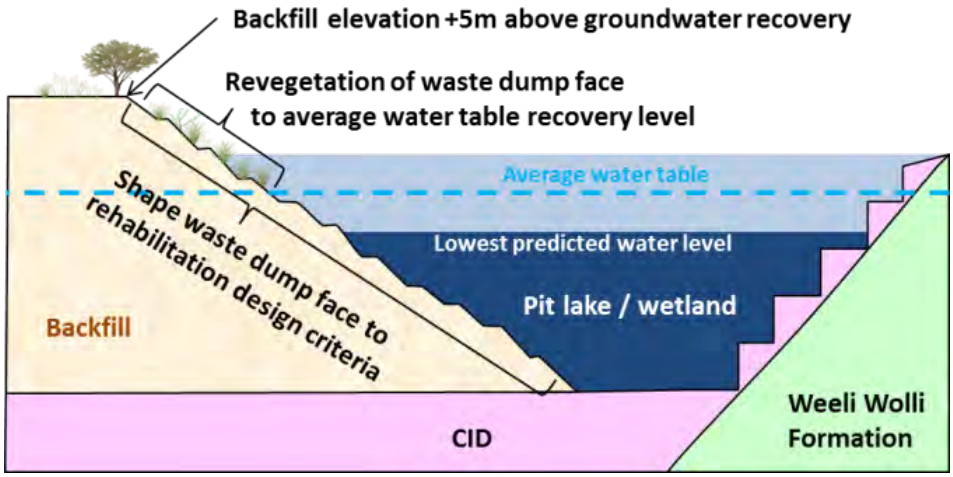


Figure 15: Schematic representation of mineral waste adjacent to future lake area.

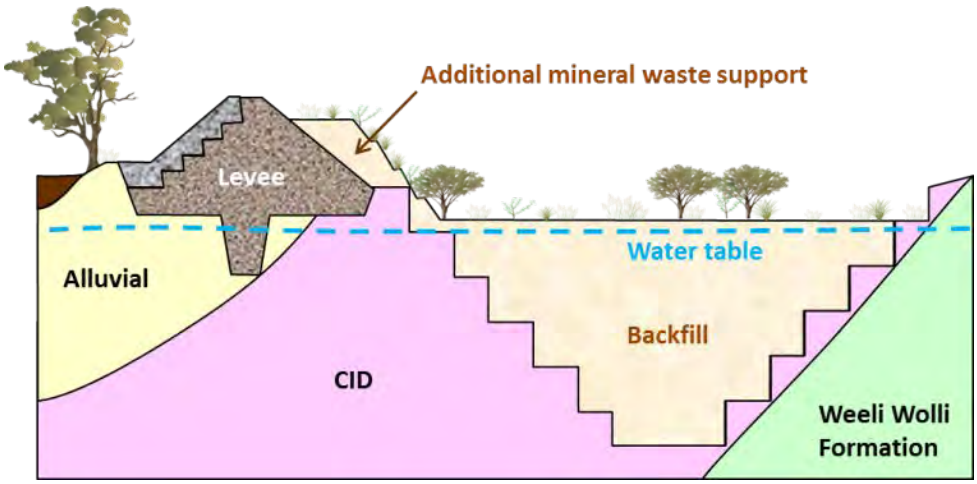


Figure 16: Schematic representation of mineral waste supporting the pit wall adjacent to a creek.

All of the mineral waste will be rehabilitated in accordance with waste dump design criteria described in Table 17.

Table 17: Rehabilitation landform design for mineral waste.

Waste dump	Slope angle (degrees)	Lift height (m)	Berm width (m)	Back slope angle (degrees)	Comments
All mineral waste	20	5	10	5	Additional erosion protection may be required for drainage and surfaces at lake fringe. To be resolved during detailed rehabilitation planning.

The rehabilitation waste dump design criteria (Table 17) conform to the internal guidelines, which outline a process for developing waste dump designs to take into account:

- specific mineral wastes present in each dump;
- climatic conditions present at the site;
- location, including in pit disposal / backfill and surface water considerations;
- maximum dump height and footprint constraints;
- shape of waste dump, preferably to minimise surface area to volume ratio;
- shaping options for the top of the waste dump.

Slope angles that conform to the guidance are predicted to have an average erosion rate (averaged over the entire slope length) of <5 t/ha/y, together with a predicted maximum erosion rate at any point on the slope of <10 t/ha/y, such that rilling, and consequently gullying potential will be minimised. Erosion rates on the final landforms may differ from these values, due to variations in waste types, surface treatments, plant growth and drainage controls.

The final landform design is reviewed by a multi-disciplinary team and includes lift height, slope angle, minimum berm width and supplementary measures, i.e. selective material management, surface treatment and drainage management, for factors that cannot be resolved through landform shaping alone.

Rehabilitation trials have commenced at the base of the Phil's Pit, where the groundwater table is exposed across the pit floor, to investigate how mineral waste stability performs under saturated conditions, similar to those that will be present at the lake fringes. Two slope angles have been created, a conservative 10 degree slope and the standard 20 degree slope. Performance of these slopes angles, slope lengths and associated lift heights will be evaluated over time to identify any structural issues that may develop due to the future lake (saturated mineral waste) conditions.

Waste dump specific implementation plans, including drainage controls resulting (discussed below) from run on and incident rainfall, will be developed prior to rehabilitation. No implementation plans have been developed to date.

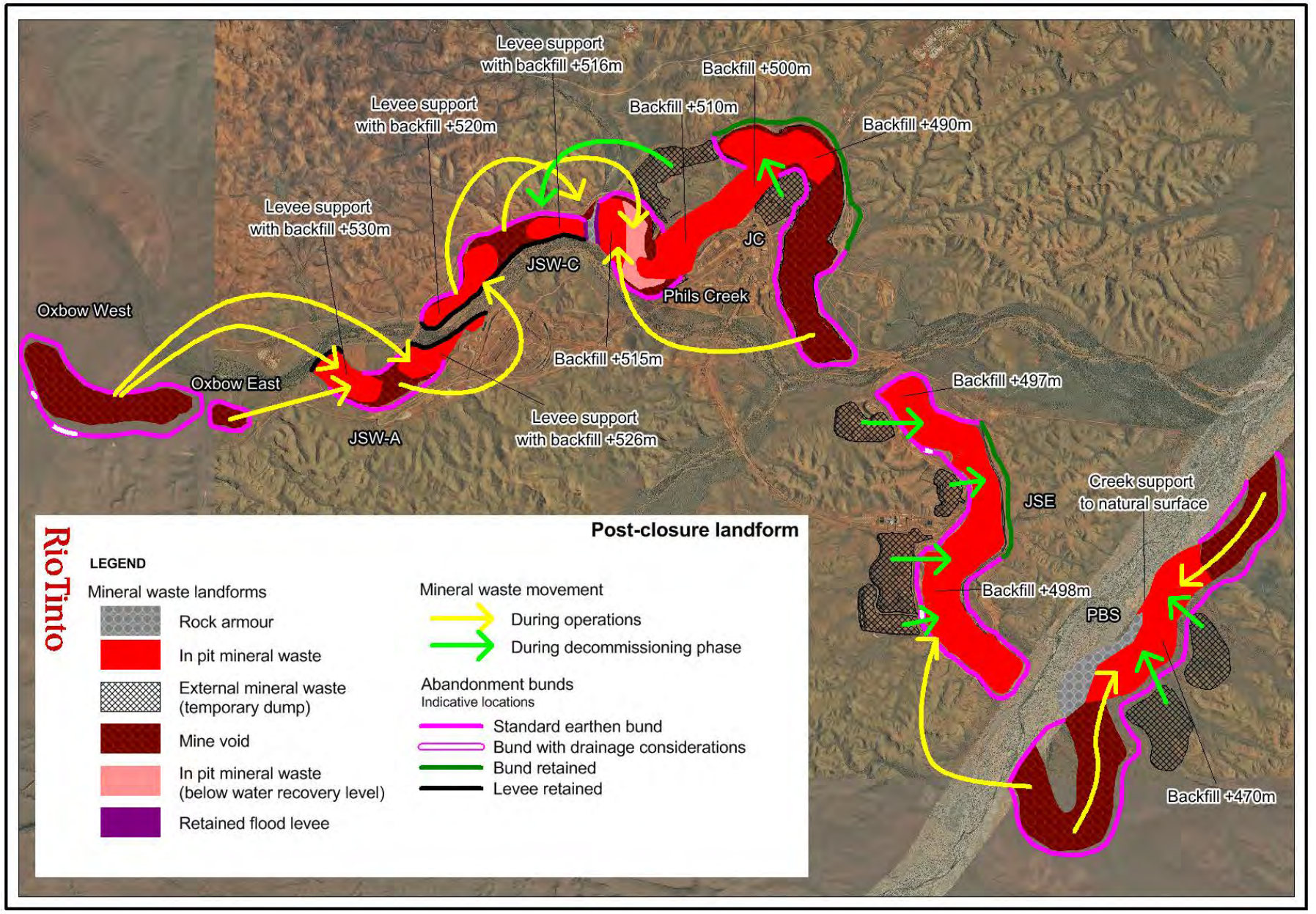


Figure 17: Yandicoogina mineral waste proposed rehandle / reclamation strategy.

16.3 Waste fines cell

Two waste fines cells have been created in the JC pit and a third waste fines cell has been established in the centre of the JSE pit. Another waste fines cells is expected to be established within the JC void before the end of the mine life.

Hydrogeological studies have been completed which demonstrate that the waste fines cells are not an impediment to groundwater flow. This is because the 10m to 15m thick continuous, non-economic geological units left intact at the base of the Yandicoogina CID have demonstrated, in the field and through modelling, that they have the capacity to sustain groundwater flow of around 10m/day.

The established waste fines cells in the JC pit will be rehabilitated to integrate into the JC in-pit landform. This will include:

- review of the landform elevation, to confirm if the elevation of the final lift on the waste fines cells is above the long-term projected groundwater. Where the final lift is below the long term groundwater elevation mineral waste will be used to cover the waste fines cell and raise the surface to above the long-term projected groundwater elevation;
- review of the surface conditions on the waste fines cells, to confirm if, on drying, the surface materials would be subject to wind erosion on drying. If wind erosion is likely to occur, mineral waste or subsoil will be blended into the surface material or placed as a cap to create a competent surface layer; and
- landform shaping, including battering of slopes to appropriate angles, to blend the location into the surrounding in-pit landform.

This approach would also be employed as part of the rehabilitation for the JSE waste fines cell. The future JC waste fines cell, however, is expected to be fully submerged beneath the recovered water table (JC pit lake) and would not be rehabilitated.

As the waste fines cells have been constructed below the long-term projected groundwater elevation, the waste fines materials are expected to remain relatively ‘wet’ (i.e. will not dry out). Consequently, surface subsidence, often associated with the drying of waste fines cells, is not expected to be a significant issue at Yandicoogina.

16.4 Flat and undulating areas

The majority of the infrastructure areas can be described as flat or undulating areas. This includes areas such as laydown areas, haul roads, building sites and bitumen roads. Rehabilitation of these areas is subject to detailed design during the decommissioning study in accordance with the following guidelines:

- Any steep slopes that have been artificially constructed will be dozed or shaped to less than 20 degrees or rock armoured to prevent erosion, unless it can be demonstrated that the structures are stable in the long term. (High disturbance areas)
- Areas with less than 1m relief will be re-contoured, to control runoff and so that the landform blends in with the surrounding landscape. If the area is large with a slight slope, then shallow windrows may be constructed on the contour approximately every 50m to prevent erosion from large sheet water flows. (Moderate disturbance)
- Where practical, areas will be ripped or scarified to remove compaction and encourage water infiltration and plant growth. On slopes, areas will be ripped parallel to the topographic contours. Roads are usually ripped along their length if they are not wide enough for contour ripping. Compacted areas such as haul roads require deep ripping.

17. Water management

17.1 Minor drainage works

Minor drainage works will be required to reinstate natural flow paths through disturbed areas prior to revegetation. This includes, following the removal of infrastructure:

- removing culverts and diversions;
- reinstating minor drainage lines / surface water flow systems, preferable along pre-disturbance flow paths;
- undertaking minor landscaping to recreate appropriate creek bed slopes and banks; and
- implementing localised surface water controls on large flat disturbed areas, to manage incident rainfall and local catchment run-on / run-off.

Minor drainage design works require a comprehensive understanding of the local long-term landforms. As a result closure drainage designs cannot be effectively generated until the future landform is known and no further land disturbance is proposed. Figure 18 illustrates some of the basic minor drainage works that are expected to be required as part of the minor drainage design activities.

In general, re-instated and constructed drainage will be designed in accordance with the following guidelines:

- The final profile of the constructed drainage line will consist of a flat base and sloped banks to allow for free drainage. Depth should not exceed 0.5m.
  The channel width will be determined based on the estimated volume of water that is anticipated to flow down the channel. In areas where friable, easily erodible material exists, or where there is the potential for high flow velocities, it may be necessary to cover the base of the constructed channel with competent rock .
- Where possible, the channel will be designed to meander such that the constructed channels have characteristics similar to the surrounding region, e.g. are not all linear features.
- The constructed channel will be blended in with any natural drainage lines.

Minor drainage design activities will be undertaken as part of progressive rehabilitation activities or during the decommissioning study.

17.2 Creek management

Major drainage works will be required to reconstruct sections of major creeks significantly altered through the act of mining. This includes:

- removal of the Phils Creek diversion and reconstruction of the Creek along its original alignment;
- repair of the Marillana Creek floodplain, including removal of the flood levee, and construction of the Marillana Creek to PBS pit lake spillway; and
- (potentially) modification to levee locations to expand the floodplain width between the JSW-A and JSW-C mine voids.

Physical design and construction of major surface water management structures is guided by the Rio Tinto Environmental Design Principles for Permanent Facilities. These principles aim to:

- ensure the long term safety and stability of engineered landforms e.g. considering local climate and climate change;
- ensure local drainage is reinstated in such a way that impacts on local hydrology is limited e.g. maintain flows, minimise erosion and sedimentation; and to
- ensure the latest design practice and monitoring evidence are used to guide design.

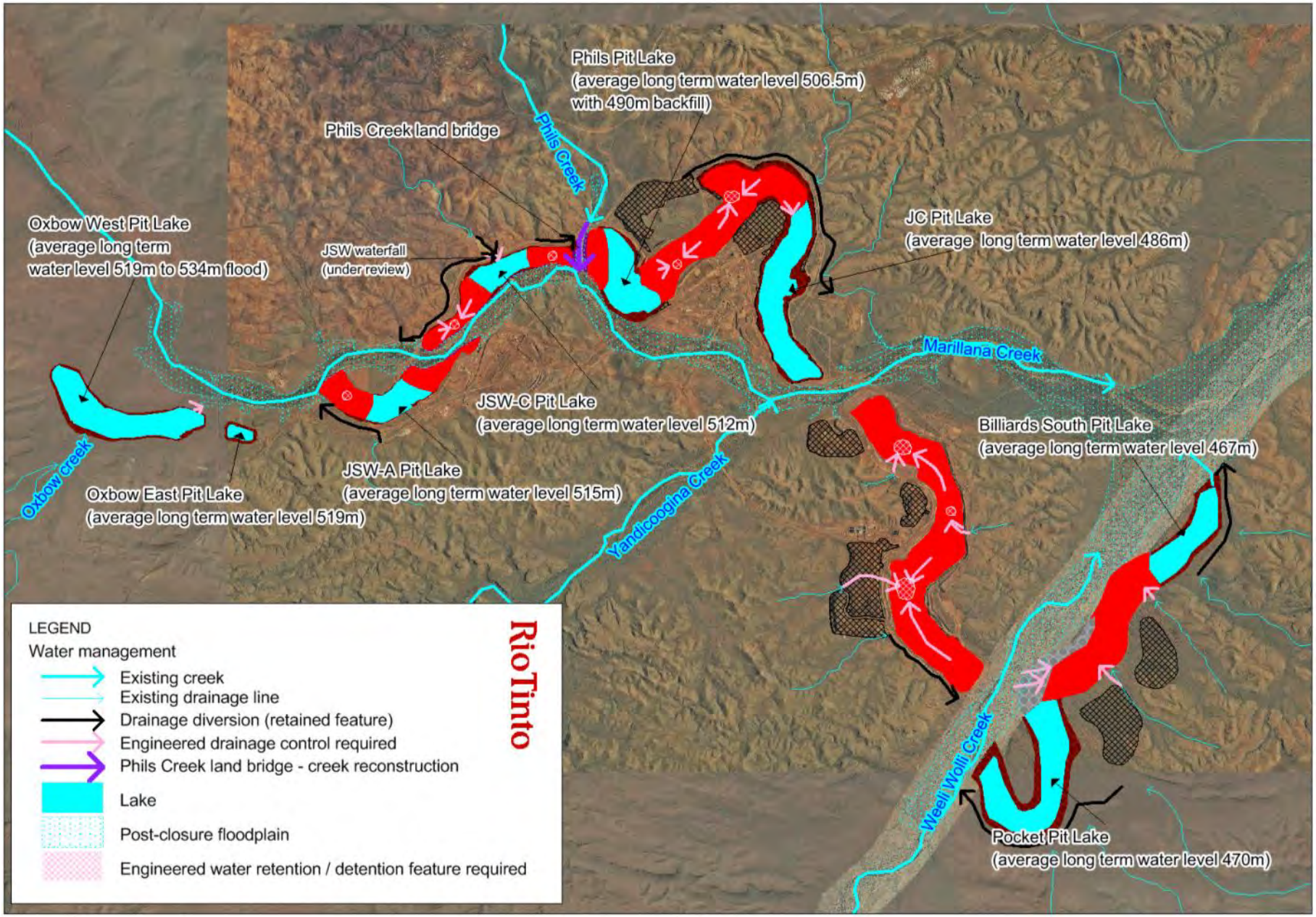


Figure 18: Post-closure landform water conditions. Proposed drainage works are shown in pink.

17.2.1 Phils Creek reconstruction

Phils Creek has been temporarily diverted through the active mine area while ore from beneath Phils Creek is mined. During the operation of the mine, a land bridge will be constructed across the mined void, using mineral waste and specialised compaction techniques to reinstate the original Phils Creek flow path to Marillana Creek. The width of the flood plain will not be reinstated during this initial build; instead, flood levees and appropriately sized rock armour will be used to contain the flood water and prevent erosion.

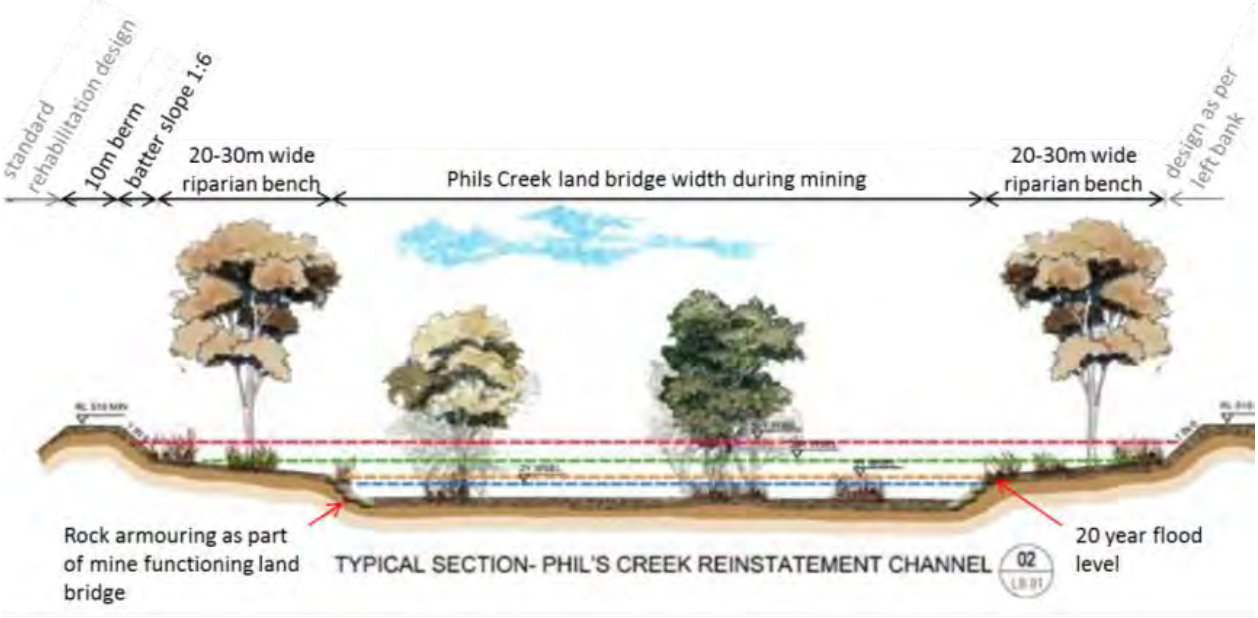


Figure 19: Conceptual design of the Phils Creek closure landform (profile view).

The performance of the Phils Creek land bridge will be extensively monitored during the operation of the mine, to ensure any early settlement, subsidence or erosion is appropriately managed.

The design of the Phils Creek land bridge will be altered at closure to facilitate larger flood events (Figure 19 and Figure 20). This will involve widening the distance between the top half of the levees to create an artificial flood plain. The flood plain will help to reduce the flood flow velocities and thereby reduce the potential for erosion. The levee thickness will also be increased, to strengthen the structures and allow for redundancy, such that erosion of the levee landforms does not result in the collapse of the levee into the foreseeable future.

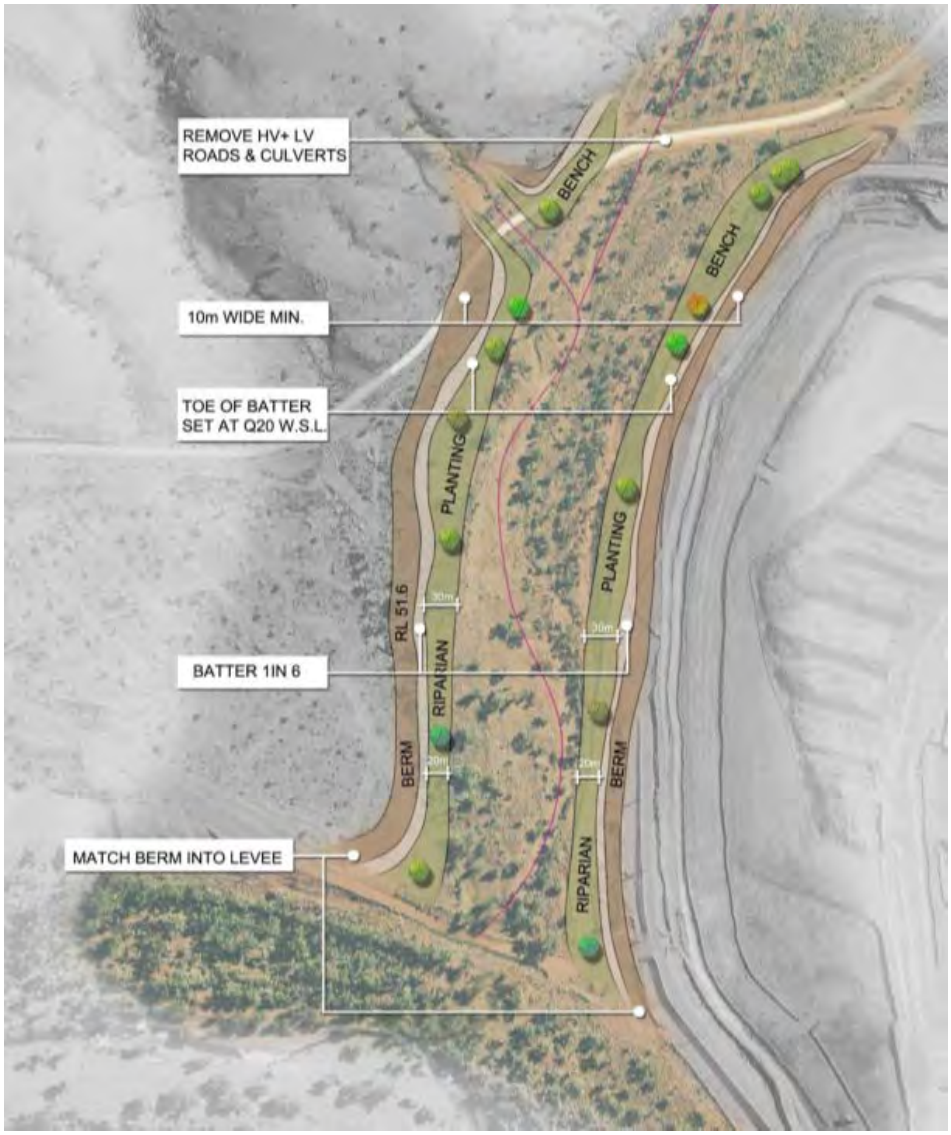


Figure 20: Conceptual design of the Phils Creek closure landform (plan view).

17.2.2 PBS pit lake spillway

Conceptual design of the PBS pit lake flood spillway will be undertaken following confirmation of the PBS pit design and associated geotechnical and hydrogeological studies. The design is expected to utilise mineral waste and the PBS pit wall buttress to create a ramp of appropriate gradient and erosion protection to convey flood water from the Marillana Creek floodplain to the pit lakes, without creating erosion (or head cut) in the Marillana Creek floodplain.

17.2.3 JSW-A and JSW-C floodplain

The levees adjacent to JSW-A (Figure 21) and JSW-C on the edge of the Marillana Creek floodplain, are proposed to remain and be strengthened at closure, to prevent large events from eroding the in-pit mineral waste wall buttresses.

A preliminary review of the hydraulic performance of Marillana Creek identified that high flow velocities were evident in the creek bed between JSW-C and JSW-A during large flood events; such that over the very long term bed erosion could occur.

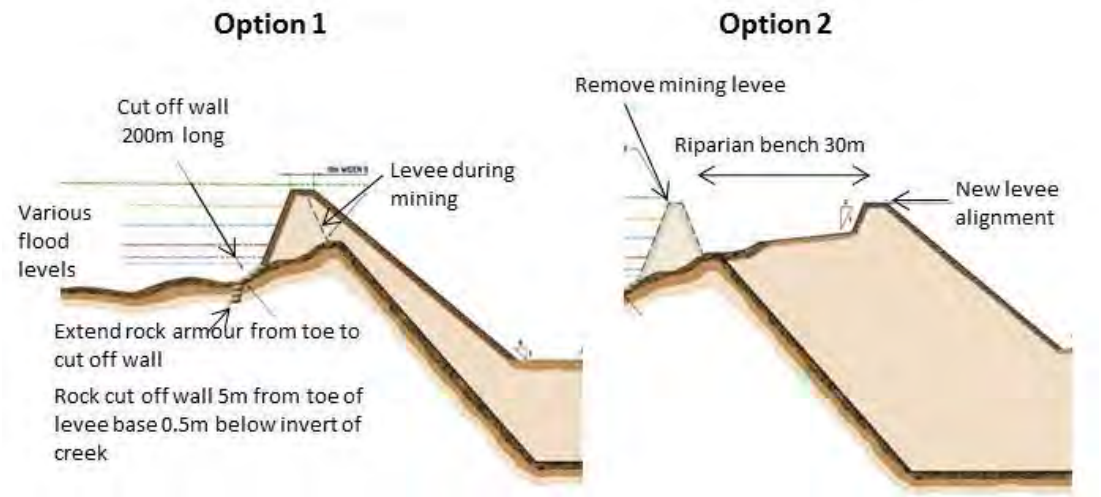


Figure 21: Design concepts for the JSW-A flood levee, retained as constructed during operations (left) or modified to reduced stresses incurred during large flood events (right).

Further hydraulic modelling is required to verify if the retention of the levees has the potential to increase that rate of bed erosion in Marillana Creek between JSW-C and JSW-A, considering changes to future climate and future catchment hydrology. Alteration to the levee configuration (Figure 21 Option 2 and Figure 22), including increasing the width of the floodplain by removing and relocating the levees at closure may need to be considered to mitigate the erosion.

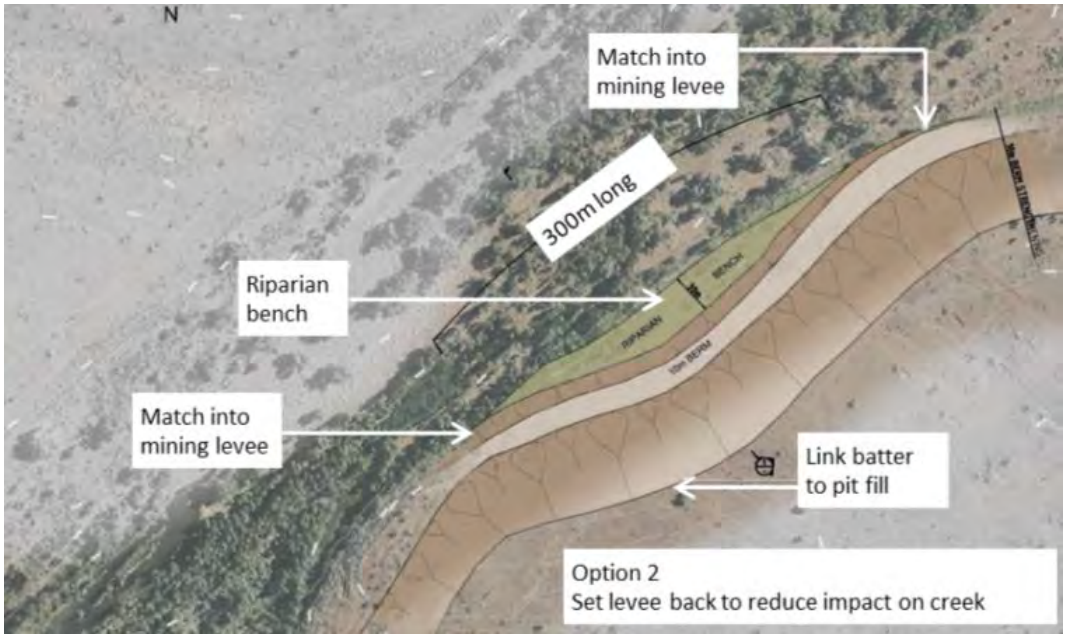


Figure 22: Design concepts for the modified JSW-A flood levee (plan view).

17.3 Groundwater and pit lake formation

17.3.1 General groundwater recovery

Groundwater levels at Yandicoogina have been suppressed over a long period of time, decades in some location, to facilitate mining. When groundwater dewatering ceases, however, the groundwater system is not expected to behave as it did prior to mining, due to changes in the CID aquifer, including:

- removal of large sections of the CID aquifer as economic ore;
- return of mineral waste fines and coarse (normal) mineral waste to the mine voids; and
- inability to suppress the entire length of the groundwater table, which will enable pit lakes to develop.

Groundwater models have been developed to simulate groundwater recovery and post-mining groundwater movement (Figure 23).

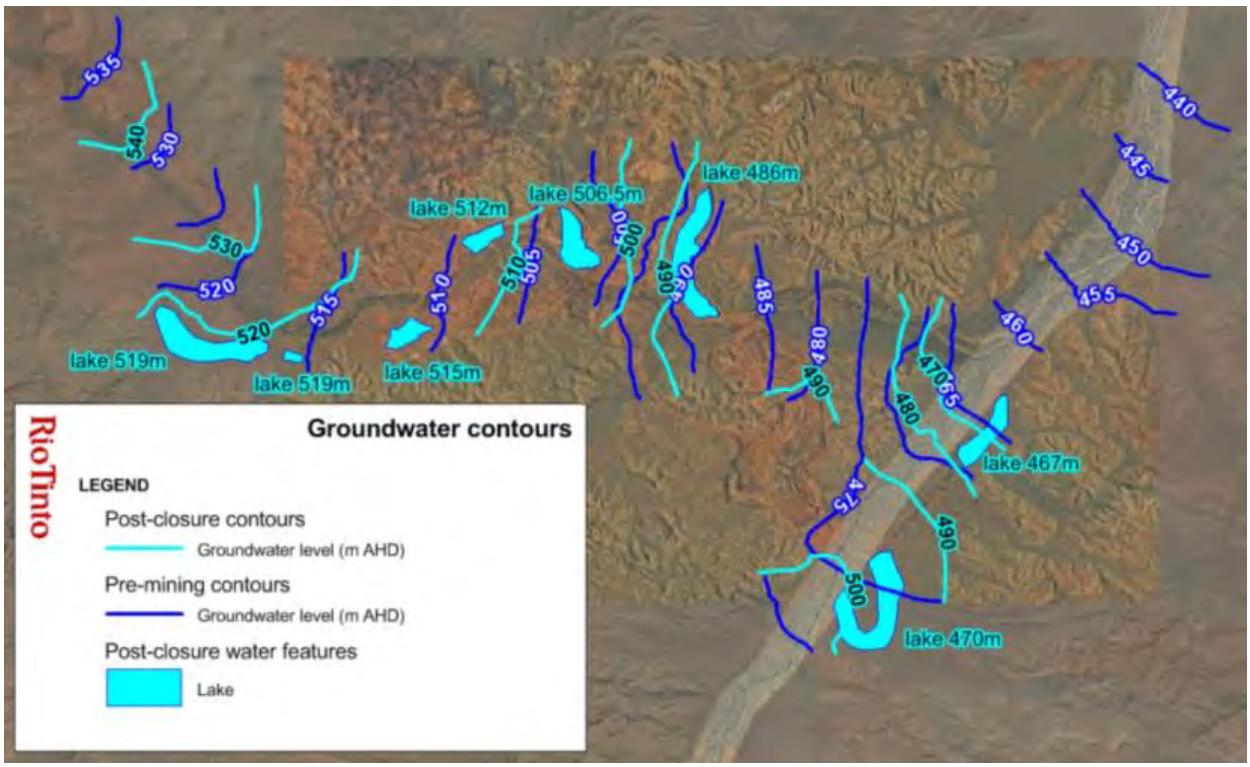


Figure 23: Groundwater recovery contour map.

The latest groundwater recovery model considered the interaction of surface water flows, groundwater aquifers and lake storage and utilises the latest surface water flow predictions for the Marillana and Weeli Wolli Creek catchment areas and rainfall predictions for the region.

The modelling suggests that:

- Groundwater flow rates will change, due to the different properties of the material within the CID (around 15m/d for coarse mineral waste and <1m/d for waste fine cells).
- Groundwater levels will return to approximate pre-mining groundwater levels (Figure 23), with the exception of JC pit lake, where the groundwater table will be permanently suppressed for a radius of 1km - 2km due to evaporation processes. This impact equates to a 1m - 2m permanent reduction (within the natural observed seasonal variation) in the alluvial groundwater aquifer levels beneath Marillana Creek, along a kilometre stretch of Marillana Creek within the Zone 2a[39] riparian reach, adjacent to JC pit lake. (Note the extent of the depressed groundwater is predicted to be similar in extent to the existing mine dewatering cone of depression, although substantially shallower.)
- Groundwater flow directions will reverse (compared to pre-mining conditions) through the JSE section of the CID, due to the suppression of the groundwater table at JC pit lake.

Monitoring evidence suggests that large flood events will rapidly recharge depleted groundwater aquifers, such that, once dewatering stops, groundwater systems can substantially recover (over 80 percent recovery) in as little as 10 years at JSW, although water levels could take up to 40 years to stabilise at JC.

This groundwater recovery model will be reviewed and updated intermittently, during the life of the operation, as more information and improved software capabilities are available.

Due to the complexity of the creek, groundwater and lake interactions at Yandicoogina, existing computer programmes struggle to model how water will move and the quality change at spatial and temporal scales that enable environmental impacts, especially the effects on groundwater dependent ecosystems, to be conclusively resolved.

This issue is currently managed by sequential modelling, using the results from the regional groundwater model as control or seed conditions within detailed, local water balance models. Results from the individual JSE, Oxbow West and PBS mine voids are described below. Models for the JC and JSW areas will be developed following the next update to the groundwater recovery model.

[39] Commensurate with impact Zone 2a as defined within the Report and recommendations of the Environmental Protection Authority, Yandicoogina Iron Ore Project - Expansion to include Junction South West and Oxbow Deposits, Report 1448 August 2012.

From the groundwater recovery models, basic lake water depths to lake area relationships suggest that the water column within all of the pit lakes will be mixed once a year (monomitic). Consequently, it is appropriate to assume that the lake water within the water balance models will be fully mixed, of equal salinity down the water column, and oxygenated.

17.3.2 JSE water conditions

On closure, the JSE mine void will be backfilled to supress the groundwater table and prevent the formation of a permanent lake. As the void will not be backfilled to surface, it will be the lowest point in the local catchment; and as such, surface water runoff will naturally flow into and be trapped within the void.

With a limited supply of mineral waste material available, to ensure that the combination of natural groundwater variations, incident rainfall and surface water run-on did not create a permanent lake, the minimum cover depth for the JSE void was calculated using an ecological water balance.

For the purpose of this water balance, a permanent lake was defined as: the presence of more than 10cm of water for more than 30 days on average each year. It was also assumed that waste fines cells would extend through the majority of the JSE mine void as a series of cells, filled from south to north to the 495mRL and separated by walls constructed from coarse mineral waste.

The model was calibrated to the regional groundwater recovery model, such that groundwater was sourced from the beneath Weeli Wolli Creek, tracked through different waste fines cells and backfilled coarse mineral waste (new aquifers), and returned to the Marillana Creek CID / alluvial aquifer. This regional recovery water level varied from 497.3m RL under Weeli Wolli Creek to 490.9m RL under Marillana Creek.

Inputs were also received via surface water runoff from the adjacent catchments and rainfall, and removed via evaporation (when present as a lake / pond) and evapotranspiration (based on a specified vegetation profile).

The water balance used a three layer model to simulate potential water conditions including ponding on the surface, the water content of coarse mineral waste backfill and the water content in the waste fines cells. The depth of the coarse mineral waste was subsequently minimised to determine the thickness (Figure 24) necessary to ensure that 10cm of water was not present for more than 30 days on average each year.

(Note these landform design requirements to suppress the groundwater table at JSE have been incorporated into the mineral waste management backfill / landform design, as presented in Figure 17.)

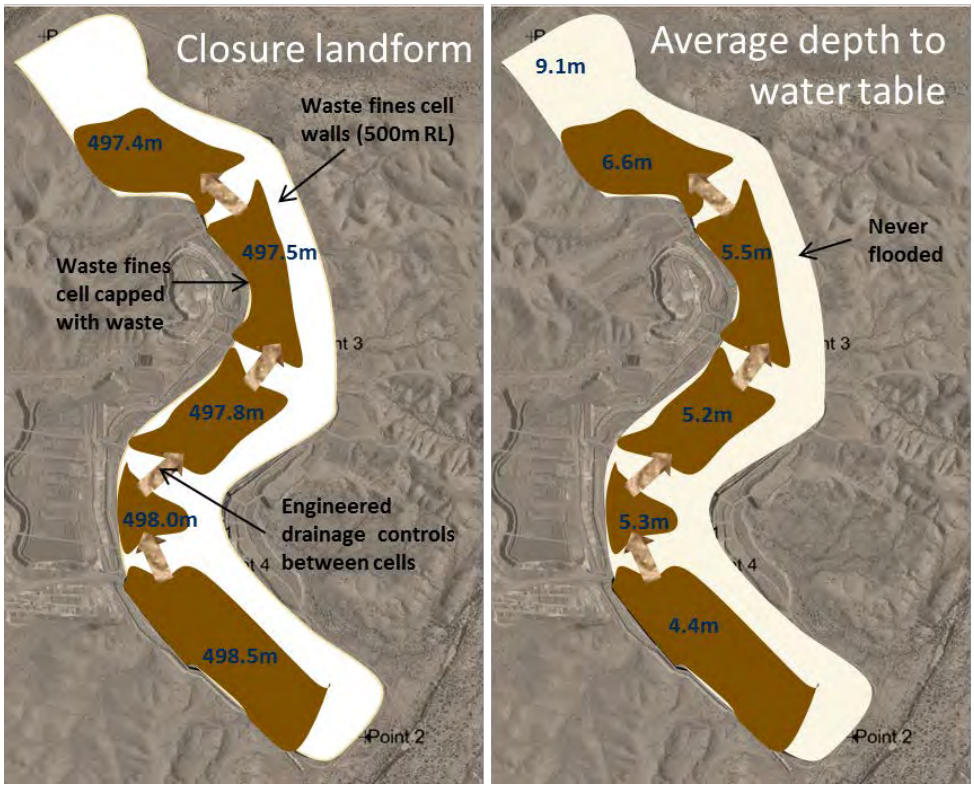


Figure 24: Junction South East (JSE) landform design requirements to suppress water table.

Due to the sloping groundwater table, the resolved landform surface of the coarse mineral waste (over the waste fines cells) was also sloped. Surface water trapped within the mine void is subsequently expected to flow from south to north following large storm events, creating a temporary pond at the northern tip of the void (Figure 25). This configuration had the additional advantage of applying recharge directly into the groundwater depression created by the presence of the JC lake, which may assist in reducing the impact of the JC pit lake cone of depression.

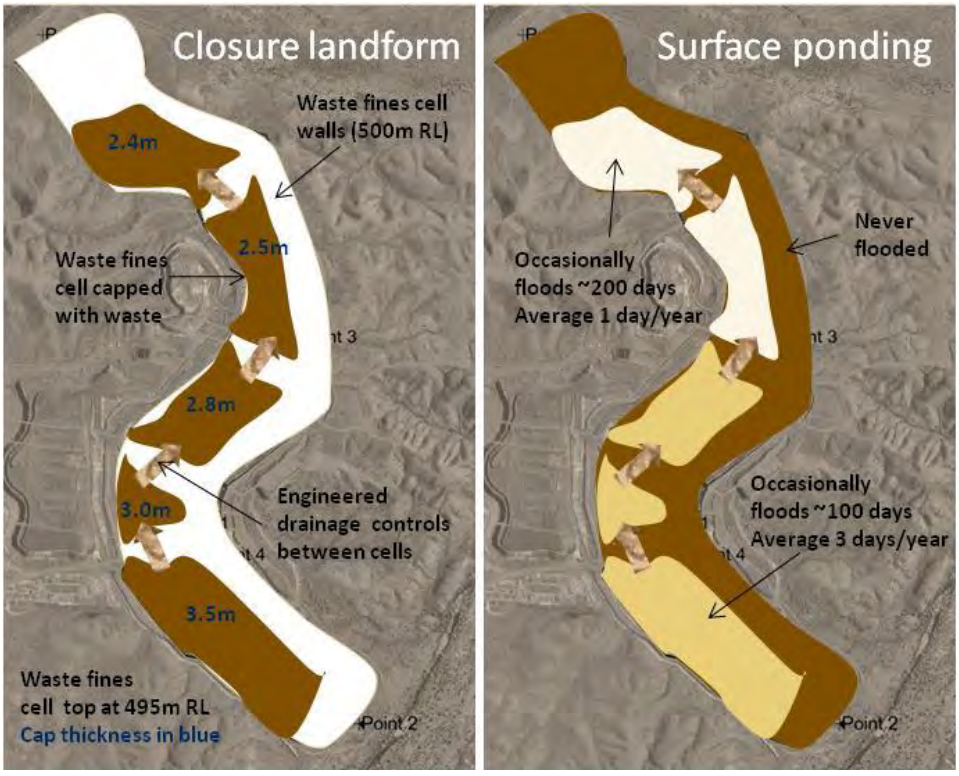


Figure 25: Surface water conditions anticipated to occur in the JSE closure landform.

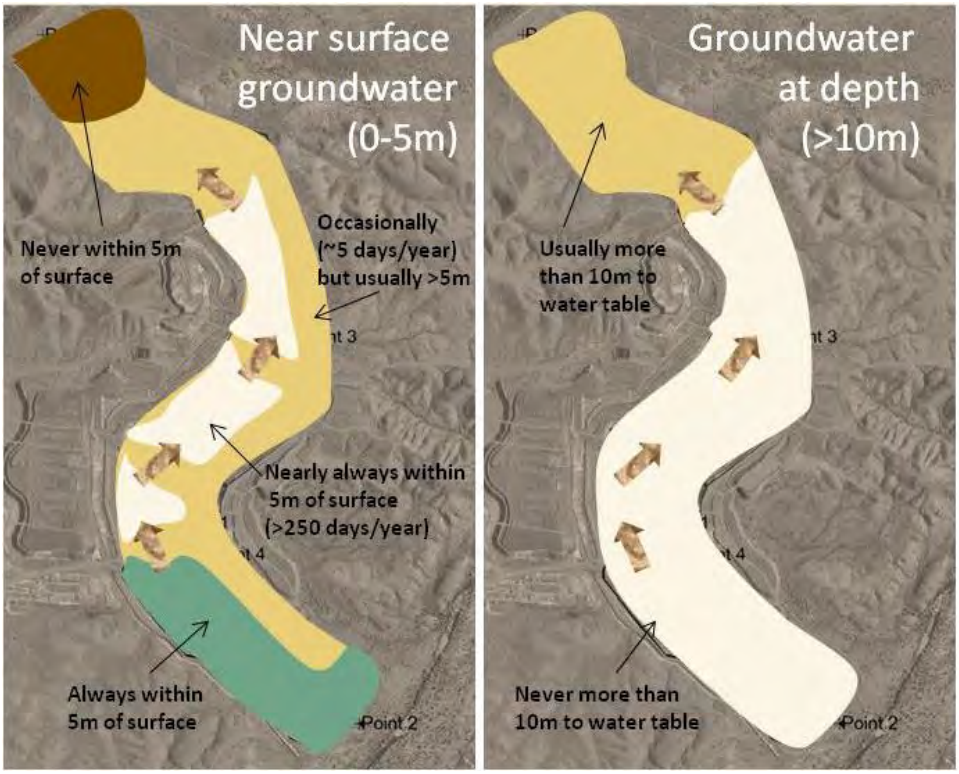


Figure 26: Groundwater conditions anticipated to occur in the JSE closure landform.

The model also enabled the spatial variability in water availability to be resolved across the JSE backfilled void. As illustrated in Figure 26, in the southern end of the void groundwater will be constantly near to the surface, providing access to water through prolonged droughts. In the southern tip, the lowest point within

the void, the area is expected to experience prolonged water logging after heavy rains. While the centre of the mine void will receive only incident rainfall. It is expected that this water availability guidance will be used assist with the selection of appropriate in-pit vegetation, as part of wider rehabilitation plans.

17.3.3 Oxbow West lake model

A simple water balance model was developed for Oxbow West lake to characterise salinity and water levels. The model used the same parameters as employed in the groundwater recovery model: groundwater, surface water flows from the oxbow catchment and climate sequences to calibrate the water balance, then simulated alternate evaporation and rainfall sequences through a Monte Carlo process to determine salinity and water levels. This modelling approach enabled detailed daily and monthly variability, i.e. temporal peaks in water levels created by minor flood events, to be resolved which cannot be achieved using the groundwater recovery model alone. As with the groundwater recovery model, this model used the latest information available, such that the results supersede previous water level and quality predictions for Oxbow West.

The water balance results aligned with the groundwater model predictions, estimating that water levels would recover to around 514mRL (±1m with 25% certainty), approximating the pre-mining groundwater level. This water level was sustained by a combination of groundwater, surface water and rainfall inflows. For example, nearly half of the water presenting in the lake each year was due to groundwater inflows, another 30 percent was due to runoff from the catchment above the lake and the remainder was from direct rainfall. The water level never reached the top of the pit and it was found that the lake never received sufficient water so as to over top the pit wall.

Although the lake levels reached approximate pre-mining levels, the additional detail provided by the water balance revealed the lake was most likely to behave as a sink.

The detailed outputs from the new Oxbow West water balance model suggest that groundwater levels in the adjacent Marillana Creek alluvial aquifer will be slightly higher than Oxbow West lake, which although subject to flooding is also subject to continual evaporation. This balance will prevent water from Oxbow West pit lake from flowing back into the Marillana Creek alluvial aquifer and is likely to terminate longitudinal flow down the CID, in favour of infiltration from the overlying Marillana Creek alluvials. As a consequence, salts, delivered through the CID groundwater system (via the BHP Billiton Iron Ore Yandi mine), were predicted to build up in the lake in perpetuity. When inflow salinity was set at 1100mg/l[40], after 300 years the salinity was predicted to exceed 10,000mg/l.

It was observed as part of the water balance modelling that, due to the coarse grid cell size required to run the groundwater model, the groundwater model over-estimates the storage capacity of Oxbow West's lake by roughly 30 percent. A separate water balance was subsequently run, using the same input parameters, to quantify the sensitivity of the lake water levels and salinity to the geometry of the void.

With a smaller mine void, a more accurate reflections of the mine void Rio Tinto are expected to build, the water level recovered to a higher level, 528mRL (±1m with 25% certainty), due to the smaller lake surface area and associated lower annual evaporative volume. If the water levels recover to 528mRL, it is possible for the lake to overtop and for water from the lake to return to Marillana Creek. Under these conditions the salinity was predicted to stabilise at 2,700mg/L after 2000 years, remaining fresh (below 1,500mg/l) for the first 500 years.

The large difference in water salinities and water levels resolved in these two models show that the water balance in this location is very sensitive to the closure landform design. At present, the void modelled water balance for Oxbow West has not considered the development of the small, neighbouring Oxbow East (future) pit lake or how the adjacent tenure holder, BHP Billiton Iron Ore, plan to develop the CID adjacent to Oxbow West[41]. However, it would be reasonable to assume that development of the adjacent BHP Billiton Iron Ore tenure CID would result in the creation of another pit lake. Consequently, the annual evaporative losses are more likely to increase, reflecting the modelling outcomes from the larger mine void – the development of highly saline (sink) lake that is not connected (downstream) to Marillana Creek or the

[40] This value is the estimated groundwater salinity at Oxbow as a result of mining activities at BHP Billiton Iron Ore Yandi, as published in BHP Billiton (2004) Marillana Creek (Yandi) Mine: decommissioning and final rehabilitation plan, January 2004.

[41] Rio Tinto is not privy to the proposed mine development activities or strategies of BHP Billiton Iron Ore, which would constitute the release of commercially sensitive information to a competitor, and could breach antitrust laws. A legal framework has yet to be identified that will enable the exchange of commercially sensitive information between Rio Tinto and its competitors. As a consequence, Rio Tinto is not in a position to resolve cumulative catchment impacts that are sensitive to mine development strategies i.e. final landform designs.

associated Marillana Creek alluvial aquifer. On this basis, further management planning will assume the worst case scenario, where saline conditions evolve, until future modelling is able to demonstrate otherwise.

17.3.4 PBS lake model

Employing the same methodology used to generate the Oxbow West lake model, a water balance model was developed for the PBS lakes to characterise salinity and water levels. The schematic water balance used for this analysis is presented in Figure 27.

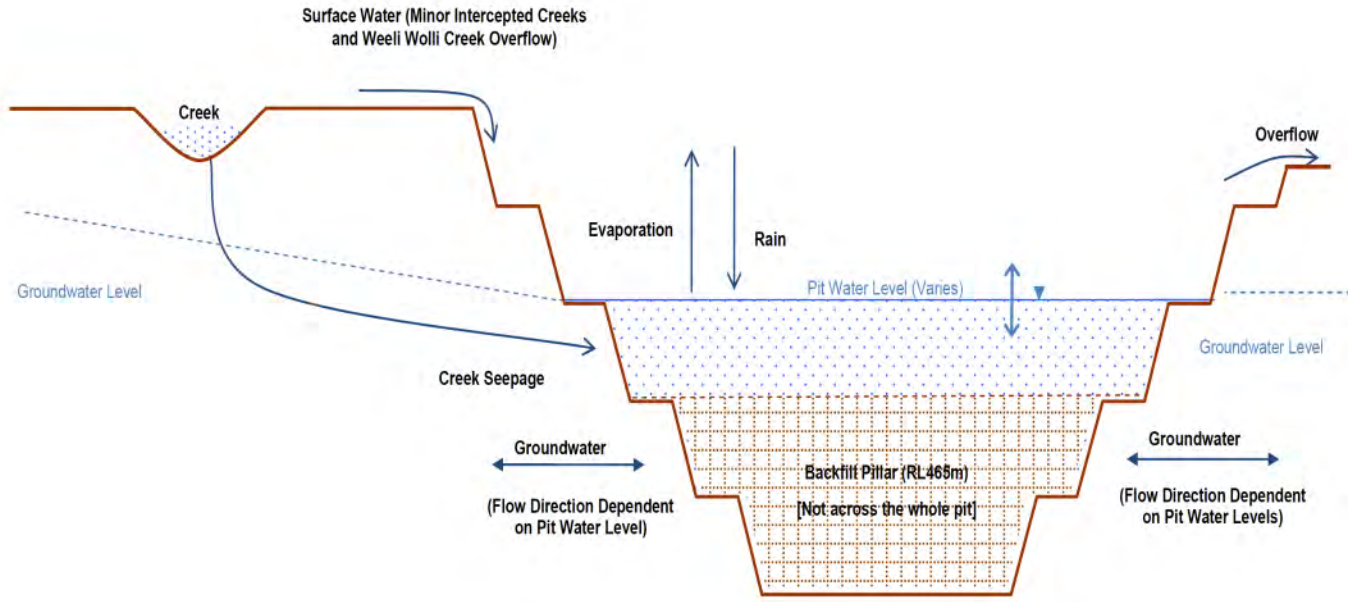


Figure 27: Schematic of the water balance used to simulate lake salinity and water level changes in the PBS mine void over the next 1000 years.

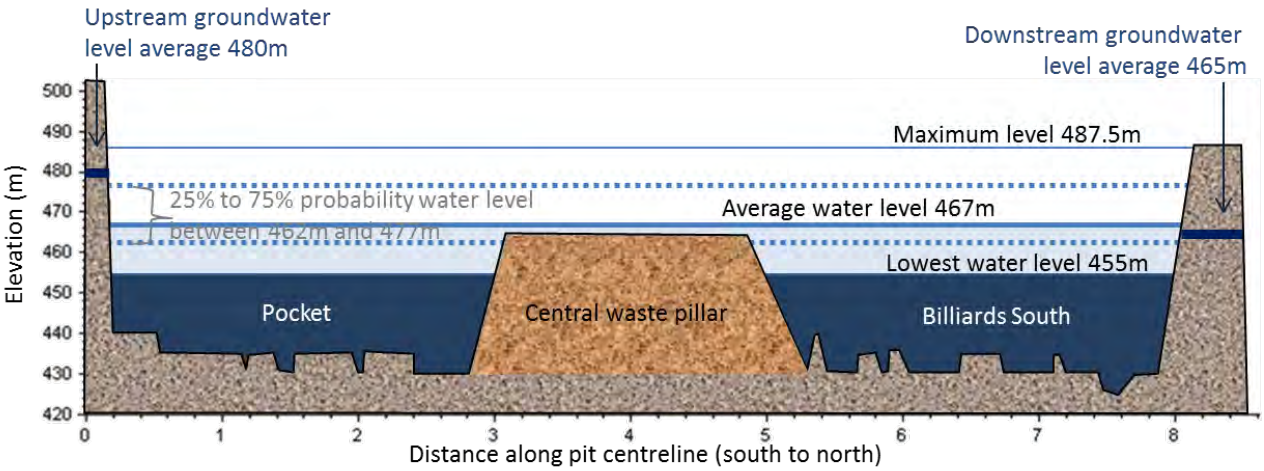


Figure 28: Long section through the PBS pit, presenting the statistical water level results from the water balance model.

The model results suggest:

- There is an eighty percent chance that flood water volumes from Weeli Wolli Creek in excess of 1000m^3 will flow into the void each year. The inflows contribute to a reduction in the pit lake salinity and are expected to deliver nutrients and aquatic fauna / flora to the lakes.
- An average of 10% of the flood water volume from Weeli Wolli Creek could be captured in the PBS mine void with each flood event.
- The void would overtop approximately 1.5 times every 100 years due to very large flood events in Weeli Wolli Creek. These very large floods would remove a substantial portion of the salts that have built up in the PBS lake.
- Removal of the PBS lake water through overtopping is expected to increase the salinity Weeli Wolli Creek flood water to a maximum of 300mg/l. This water quality is within the natural range observed in pools following flood events and as such is not expected to have an impact on the downstream environment.

- Lake levels (Figure 28) would average approximately 2m above the downstream recovered groundwater level of 465m RL, with median lake levels ranging between 1m and 6m above the downstream recovered groundwater level, creating a through flow lake system.
- During extreme drought periods the water could drop to as low as 8m below the downstream recovered groundwater level. The lake would cease to be a through flow system during these periods and the lake salinity would increase significantly.
- Salinity would be highly variable with time. One large inflow event which restored through flow conditions could reduce lake salinity by 1000mg/l. One large inflow event resulting in an overtopping event could reduce lake salinity by 3000mg/l.
- After 75 years there was a 50 percent probability that the salinity would still be fresh (<1000mg/l) and after 1000 years there was a 50 percent probability that the salinity would be 3000 mg/l, with extreme outcomes from the Stochastic modelling ranging from 200mg/l to 13,000 mg/l after 1000 years.

18. Plant and soil development

18.1 Habitat planning

A habitat is made up of physical factors such as soil, moisture, range of temperature, shelter and availability of light as well as biotic factors such as vegetation, availability of food and the presence of predators. Habitats provide a simple method of dividing the land into areas with common characteristics.

On closure, the land will be returned to self-sustaining ecosystems using native species of local provenance. The physical factors associated with the closure landform provide a starting point to identify which habitat units could best be reinstated across the mine area, given the changes to the land resulting from mining activities, in order to establish native self-sustaining ecosystems.

Flora, fauna and vegetation survey (baseline) data has been used to understand and group the area's pre-mining biodiversity / ecosystem values. When disturbed areas are no longer required to support mining activities, the areas may be progressively closed and rehabilitated. The habitat plans, as illustrated in Figure 29 (JSE in isolation) and Figure 30 (the entire area), provide the strategic vision to assist with the local planning activities.

Figure 29: Rehabilitation strategy for the JSE closure landform.

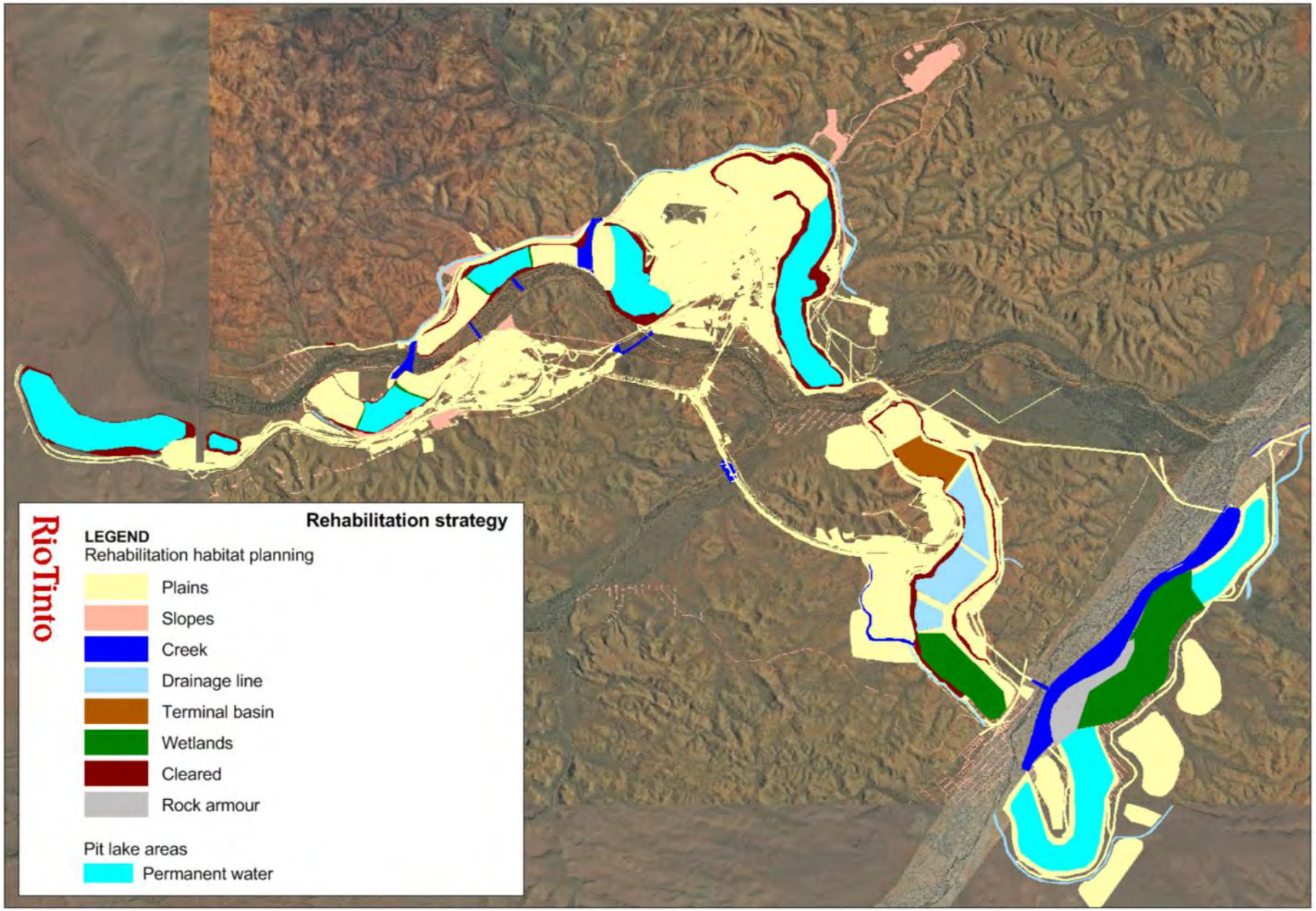


Figure 30: Rehabilitation strategy for the Yandicoogina closure landform.

The habitat units are expected to reflect the pre-mining biodiversity / ecosystem values through the habitat characteristics described in Table 11.

Habitat elements that are considered as part of the rehabilitation, including progressive rehabilitation, design include:

- selection of vegetation characteristics of the desired habitat unit e.g. known to provide preferred food or shelter preference;
- ability to reuse retained woody debris, to provide fauna refuge and microhabitats;
- ability to integrate rocky features, i.e. oversized waste burden or scree slopes, into the design for aesthetics and fauna use;
- requirements for rapid generation and retention of leaf litter using small-scale topography (e.g. furrows created from ripping);
- establishing soil depth and considering opportunities to use subsoil or inert mineral waste to build habitat for burrowing fauna;
- preserving connectivity with unmined areas, and maintaining the quality of these habitats; and
- managing feral predators and herbivores across both reference and rehabilitated areas.

If only a low level of land disturbance has occurred, the land can usually be returned to a standard similar to the pre-mining habitat. However, some mine related activities, such as the termination or modification of drainage flow paths and the introduction of new topographical features (waste dumps, tailing dam, mine voids etc.), can substantially change the physical habitat characteristics of the land.

In these situations, alternate habitat types have been selected. These alternatives have been drawn from the pre-mining habitats in the surrounding area. For example, a laydown area built up with inert mineral waste over a former hill habitat area is proposed to be revegetated to mimic the adjacent plains habitat as the land is now flat and is more likely to evolve a soil profile similar to the plains habitat units. Figure 31 illustrates the pre-mining habitat distribution and how alternative habitats are proposed to be introduced as part of rehabilitation activities, based on the different material and water conditions that will be present at closure. The planned rehabilitation habitats are usually located adjacent to undisturbed habitat of the same habitat type, in order to provide a means for natural migration of flora and fauna.

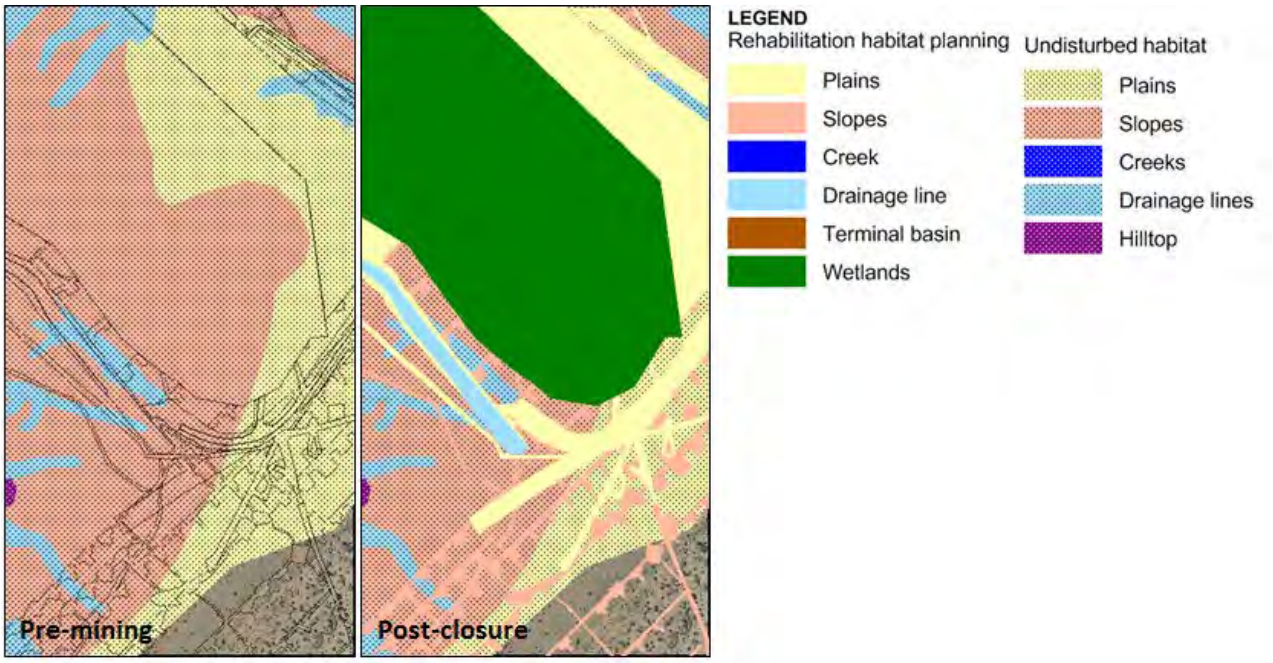


Figure 31: Comparison of pre-mining habitat areas and proposed closure habitat areas at the southern end of JSE.

The presence of permanent standing water (lakes) at Yandicoogina as part of the closure landform introduces new physical characteristics to the landscape: the potential for high soil water availability, littoral zone development around the edge of lakes, and the water bodies themselves. At this stage of the closure plan development, the wetland and pit lake habitat units represent undifferentiated water body of unknown ecosystem function. It is expected that these units will be split into different management units based on water quality and potential land-use / ecosystem viability following rehabilitation trials when more detailed information on vegetation and landform performance is available.

Through the act of mining, there will also be areas associated with the pit development that cannot be rehabilitated due to safety and access issues. This usually includes the pit high walls and benches, within the geotechnical zone of instability, and areas above the high wall where access is cut off as ore is mined. These areas are demarcated as cleared habitat units. Usually these areas have little to no soil cover, and are subject to erosion over time.

It is expected that the majority of the site will be rehabilitated as part of mine closure, with the rehabilitation design developed as part of the decommissioning plan.

18.2 Revegetation

Topsoil will be spread over reconstructed landforms and deep ripped to enhance seed establishment. Stockpile vegetation is then returned to the area.

Monitoring has shown that in small disturbed areas adjacent to existing vegetation or in areas where fresh topsoil can be utilised (e.g. borrow pits), appropriate species are generally re-established without the need for additional seed. This is because the seed bank in the fresh topsoil remains viable, resulting in good germination and growth, and in very small areas seeds can ingress from surrounding vegetation.

In most cases, however, locally collected seed is needed to assist in revegetation and the creation of a self-sustaining ecosystem. Over time the viability of seeds in stockpiled topsoil decreases, and thus the quality of the topsoil deteriorates. In addition the topsoil that was salvaged prior to disturbance may not contain seeds of all the target species of its new location / habitat.

Revegetation activities and replacement of topsoil should ideally be timed so that rehabilitated areas are completed prior to the summer wet season, usually commencing in November. This should give the seeds in the rehabilitation area the best chance of germination and survival.

Seed mixes for rehabilitation are preferentially of local provenance. Specific seed mixes are selected to provide a range of species appropriate to the desired habitat (Table 11), taking into consideration landscape position and slope. In areas where erosion risks are identified, seed mixes may be modified to include or increase the portion of species that provide rapid cover.

Seeds will be purchased from commercial seed suppliers immediately prior to rehabilitation. Seed mixes will, preferentially, be sourced for local provenance and will be selected to provide a range of species appropriate to the desired habitat, taking into consideration landscape position and slope. In areas where erosion risks are identified, seed mixes may be modified to include or increase the portion of species that provide rapid cover.

Seed mixes may also include species of cultural significance to Traditional Owners, such as bush tucker and medicinal plant, if and when identified through ongoing consultation with Traditional Owners.

The inclusion of rare and threatened species in rehabilitation programmes is limited by:

- habitat preference (preference for drainage lines, gullies, calcretes or other habitat not suitable or similar to those likely to be present in the rehabilitation landscapes);
- abundance – very few populations or small populations from which to source seed;
- difficult taxonomy / unresolved taxonomy issues and thus status of species highly uncertain; and / or
- growth form – e.g. short lived annual species with preference for growth under woodland canopies;

Other issues include the availability of seed at the time when rehabilitation occurs and seed dormancy.

In consideration of these issues, only three species from the significant flora list (Table 14) have been identified that could be considered in future rehabilitation programmes at Yandicoogina:

- *Lepidium catapycnon* in hill habitat rehabilitation;
- *Sida* species Barlee Range in valley floor habitat rehabilitation; and
- *Themeda* species Hamersley Station in valley floor habitat rehabilitation.

Research undertaken into rehabilitation of the *Lepidium catapycnon* [42] found that the use of the growth hormone gibberellic acid enabled germination rates approaching 90 percent in the laboratory and concluded that good germination results are likely to be possible in the field. Test and transplant work for this species is

[42] Department of Conservation and Land Management (now DEC), The germination requirements of seeds of the rare Hamersley *Lepidium catapycnon* (Brassicaceae), February 2000, report to BHP Iron Ore Pty Ltd.

ongoing; however, the availability of seed and habitat requirements may limit the re-introduction of this species at Yandicoogina.

Inclusion of *Sida* species Barlee Range in rehabilitation is currently limited due to seed collections issues and potential seed dormancy, but is otherwise expected to be suitable for inclusion in the rehabilitated habitat zone seed mix.

Themeda species Hamersley Station has a preference for heavy, clay soils. This restricts potential use of this species to areas with a high soil fine fraction. These conditions may develop in the closure landform at the waste fines cell areas. However, conditions will need to be verified in the field, after landform shaping, to confirm suitability for rehabilitation purposes.

18.3 Creek (discharge) recovery

Dewatering discharge undertaken during operations extends the duration of creek flow within the naturally ephemeral Yandicoogina creek systems. This activity has created water logged areas and permanent pools within the Marillana and Weeli Wolli Creeks. As mining activities draw to a close, the volume of discharge will taper then cease at the end of mining, returning the creeks to their pre-existing ephemeral regime. Water will not be artificially sustained to the creeks after the cessation of mining.

Environmental management plans have been implemented at Yandicoogina to respond to any impacts relating to the modification of major creek system or associated riparian vegetation communities. This includes potential impacts and mitigation associated with creek discharge.

From our current understanding and observations during operations, riparian vegetation is expected to achieve a new equilibrium without human assistance. Examples of the natural progression and re-establishment of a new equilibrium can be observed in the understorey surrounding around former permanent discharge sites i.e. D03.

Monitoring of creek ecosystem health will continue throughout the operation of Yandicoogina, in accordance with the site environmental management plans. Contingency plans, to mitigate or remediate areas of the creek that have been substantially degraded as a consequence of the cessation of the dewatering activities, will be discussed with key stakeholders and developed, if required, as part of the Decommissioning Study.

18.4 Fauna colonisation

Fauna species are not proposed to be introduced to the area on closure. Natural migration of fauna species into rehabilitated land will be encouraged by selecting seed mixes that produce vegetation communities that are linked to pre-mining habitat units. Most post-mining habitat units are also connected to similar undisturbed habitat, which helps fauna to migrate.

Ridges, outcropping, caves and gorges represent preferred habitat for the Northern Quoll (*Dasyurus hallucatus*), Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*) and Pilbara Olive Python (*Liasis olivaceus barroni*) will remain post-closure in areas adjacent to current mining activity. However, no habitat reconstruction or artificial micro-habitats construction to support colonisation of these species is proposed as part of this closure plan.

Australian Bustard (*Ardeotis australis*), Rainbow Bee-eater (*Merops ornatus*) and Star Finch (*Neochmia ruficauda subclarescens*) prefer tussock grassland, Triodia hummock grassland, grassy woodland, and low shrublands, associated with Valley habitats. Rehabilitated plains and slope habitats are expected have characteristics similar to those preferred by these avifauna species.

The creation of pit lakes and wetlands represents a departure from the pre-mining environment. The nearest permanent water bodies are located 10km upstream (Weeli Wolli Springs) and 40km downstream (Fortescue Marsh). These water bodies present dramatic differences in water quality, with the former being fresh and the latter ranging from sub-potable to hypersaline (depending on the length of time since last rainfall). This suggests aquatic fauna in the local area can be sustained in and around water bodies of varying salinity.

All sites of permanent water (whether saline or fresh) are considered significant refuges for fauna during years with below average rainfall. It is expected that wetland habitats introduced at Yandicoogina will be capable of supporting a variety of fauna, including fish, birds, tortoises and frogs. However, further study and field trials are required to validate this assumption.

19. Post-closure safety features

19.1 Abandonment bunds

Abandonment bunds will be constructed around the perimeter of mine voids to prevent inadvertent access to the zone of geotechnical instability around the mine voids. Indicative locations for abandonment bunds have been included in Figure 17. The abandonment bunds are expected to include a combination of earthen bunds, retained levee structures (as described previously) and retained earthen bunds (already present on site, usually associated with existing drainage controls).

The earthen bund will be constructed from inert mineral waste. The dimensions of the abandonment bund will be with a height of at least 2m and width of at least 5m at the base, with side slopes greater than 15 degrees (depending on the material type characteristics). This design will be modified at select locations, indicated in Figure 17, where to accommodate surface water. These design modification will be developed as part of the rehabilitation design and discussed with key stakeholder prior to implementation, to ensure the proposed barricades achieve the required safety performance,

19.2 Access to heritage sites

Traditional Owners require ongoing access to sites of cultural significance. Safe access to locations of cultural significance will be discussed with Traditional Owners prior to closure, with consideration given to neighbouring land users' activities (i.e. other mine developments) and other land-use conflicts that may restrict access to the culturally significant sites over the long term.

19.3 Signage

Signage will be developed in consultation with the relevant authorities immediately prior to closure. This includes signage of an appropriate size, colour and font, and safety symbols, where appropriate.

IDENTIFICATION AND MANAGEMENT OF CLOSURE ISSUES

20. Issue evaluation

A closure risk assessment was completed on the proposed closure strategy for Yandicoogina. The assessment was completed by a panel of multi-disciplinary subject matter experts with the aim of:

- identifying hazards, aspects and opportunities that could influence the successful closure of the site;
- evaluating the resulting risks to people, property and the environment; and
- defining the actions required to reduce the risk to below the risk acceptance threshold.

20.1 Hazard / aspect identification

The context and acceptability criteria for the risk analysis was established by reviewing baseline studies, stakeholder consultation, learnings from work undertaken at other sites, and research etc. to identify any knowledge gaps.

Controls and commitments that are currently in place to manage each hazard were subsequently identified. This identification process included a review of the effectiveness of current management plans, procedures, work practice guidelines etc. to identify any management gaps.

summarises the topics raised / discussed during the evaluation session(s). Aspects reviewed as part of the closure risk evaluation included:

- mineral waste characterisation;
- pit lakes and ground water;
- landform stability;
- surface water implications;
- decontamination;
- biodiversity;
- visual amenity;
- cultural heritage; and
- local communities, communication and consultation.

Table 18: Closure context for Yandicoogina risk evaluation process.

Aspect	Current status
Landform	• Mineral waste is highly erodible, but will be returned to mine voids for rehabilitation. Will still need to construct stable landforms from mineral waste within mine void and requires incident rainfall management. • Mineral waste proposed to be used to ensure long term stability of Phils Creek land bridge and pit wall sections in / adjacent to creeks. • Pit lakes will be established in all former pits. Stability of waste on pit lake fringes to be investigated as part of rehabilitation trial.
Water	• Surface water flood regimes to be maintained post-closure. • Some peak flood water volume from Weeli Wolli Creek will enter PBS pit lakes. Local creek above Oxbow West pit will flow into void. All other lakes are disconnected from creek systems. • Groundwater system will be depleted through mining but will recover quickly due to strong creek flow recharge relationship. • All pit lakes will be groundwater dependent. • Groundwater and pit lake water levels and water quality strongly influenced by landform design.
Contamination	• Low risk of mining designated hazardous fibres. • Some historic now encapsulated problematic fibres. Fibres could also be encountered in alluvial materials during rehabilitation implementation. • Low risk of acid drainage. No significant contamination or hazardous waste issues identified. • Evidence emerging of potential alkalinity increases from extreme evapoconcentration of groundwater, could affect mobilisation of trace elements in mineral waste post-closure.
Biodiversity	• No impact to conservation status of any flora or fauna species, populations or fauna habitat expected from closure implementation. • Rehabilitation techniques for new habitats i.e. evaporation basins and permanent deep lakes, is untested, requires extensive research. • Control of invasive species critical to rehabilitation success.

Aspect	Current status
Community	• Interaction and potential impacts of post-mining landform to / on cultural heritage values to be investigated. • Roads / paths through the closure landform to access cultural sites to be incorporated into closure landform design. • Minimal community financial impact expected as 100% FIFO site.

20.2 Risk evaluation

Risk was evaluated on the basis of the maximum reasonable outcome consequence and the likelihood of that consequence occurring, e.g. rare, unlikely, possible, likely or almost certain. Risks were evaluated inclusive of current management and commitments, and represent current residual risk. The risk register developed for Yandicoogina is included in Appendix E. A summary of the risk titles and evaluated risk class are provided in Table 19.

Consequences included in the evaluation were:

- Health: reversible health effects of little concern (very low) to multiple fatalities (very high);
- Personal safety: inconvenient first aid treatments (very low) to multiple fatalities (very high);
- Environment: reversible impact (very low) to widespread, long-term impacts (very high). As some environmental impacts can escalate if immediate identification and remediation is not possible, environmental consequences are also evaluated by:
  - On-site: referring to impacts that occur during the pre-closure and decommissioning phases, when staff are able to utilise site equipment and quickly react to remediate impacts; and
  - Off-site: referring to impacts that occur during the post-closure phase, when remediation may not immediately follow impact identification, due to a need to bring equipment and experts back to site to remediate.
- Community trust: mistrust amongst a small section of the wider community (very low) to widespread mistrust with key stakeholders (very high); and
- Compliance: non-conformance to internal requirements (very low) to prosecution for breach of regulatory licence(s) (very high).

Risks resolved from the evaluation were classified as follows:

- Low (Class I): Risks that are below the risk acceptance threshold and do not require further management.
- Moderate (Class II): Risks that lie on the risk acceptance threshold and require regular review to ensure management remains adequate and fit-for-purpose.
- High (Class III): Risks that, based on the current level of knowledge, could exceed the risk acceptance threshold and require proactive management and / or resolution of knowledge gaps.
- Critical (Class IV): Risks that, based on the current level of knowledge, will exceed the risk acceptance threshold and need urgent and immediate attention to develop an alternative approach.

Actions were assigned to risks that exceeded the risk acceptance threshold. Actions were also assigned to address knowledge gaps and assigned where subject matter experts requested the performance of existing controls and commitments be re-evaluated at some later date.

Table 19: Summary of closure risks at Yandicoogina.

Risk title	Maximum reasonable consequence evaluation		Risk
	Likelihood	Consequence	
Under-estimated general contaminant clean up requirements	Rare	Low	Class I
Under-estimated acid and / or metalliferous drainage management requirements during operations (pre-closure) & decommissioning phase	Rare	Low	Class I
Acid and / or metalliferous drainage generation (after closure) creates a contaminated site	Possible	Low	Class II
Human health impacts from in situ fibrous material exposures	Rare	Moderate	Class II
Lake and / or lake fringe habitat has undesirable impacts on general ecosystem function.	Unlikely	Moderate	Class II
Lake poses public liability and / or health risk	Rare	Low	Class II
Degradation of regional groundwater quality or levels	Rare	Moderate	Class II

Risk title	Maximum reasonable consequence evaluation		Risk
	Likelihood	Consequence	
Wall failure within mine void compromises closure outcomes	Unlikely	Moderate	Class II
Built landforms (excluding mine void areas) erode and / or collapse	Unlikely	Low	Class II
Surface treatment on landforms limits vegetation growth	Unlikely	Moderate	Class II
Vegetation is not self-sustaining (due to cattle grazing impacts)	Unlikely	Moderate	Class II
Access through area post-closure poses public liability risk	Unlikely	Moderate	Class II
General environment outside of approved mine disturbance areas is adversely impacted	Possible	Low	Class II
Adverse impact to flora or fauna with conservation status or wider regional impact to high value environment	Unlikely	High	Class III
Heritage site condition / cultural value is degraded as a result of implementing the closure plan	Possible	Low	Class II
Consultation fails to identify stakeholder concerns	Rare	Moderate	Class II
Closure outcomes do not meet stakeholder(s) / community expectations	Unlikely	Moderate	Class II
A stakeholder's expectations conflict with that of another stakeholder, causing delays to plan approval and / or closure	Unlikely	Moderate	Class II
Closure strategy prevents or limits future exploitation of resources	Likely	Low	Class I
Mine closure has a significant, long-term detrimental impact on local communities	Rare	Very low	Class I
Closure is not implemented in accordance with the approved closure plan	Rare	Moderate	Class II

20.3 Key risks

Of the 21 risks evaluated, one risk was identified that exceeded the risk acceptance threshold. This high (Class III) risk was associated with adverse impact to significant fauna. Studies will be undertaken required to assess the impact of closure implementation on significant fauna, including species of conservation value, in order the develop actions to reduce the risk to below the acceptable risk threshold.

Other risks that were assessed to have been adequately managed, yet still require significant additional work prior to closure, include risks associated with land form stability, water management and water quality, and stakeholders (i.e. post-mining land-use). A summary of these risks and required actions is provided below.

20.3.1 Closure landform

Yandicoogina's mineral waste is dominated by highly erodible alluvial and colluvial material. The challenges associated with managing highly erodible waste are reduced by utilising, where ever possible, mined out void to store waste during operations and the return of waste to the void during closure. Rehabilitation designs for in pit waste dumps have accounted for the erodibility properties of the material, regardless of whether the mineral waste dump is located above or below the water table, e.g. will eventually be underwater as part of the lake edge.

It is recognised, however, that additional erosion management may be required in locations that receive surface water runoff or creek flows. Management of these aspects will be guided by waterway design principles. Detailed hydrological and engineering assessment will be undertaken during the decommissioning study to design structures, sympathetic to the natural environment, to control erosion. It is recognised that some rocky capping material may be required to assist in erosion control; however a review of the site material inventory has shown that the required material will not be mined as part of the normal development process and will need to be sourced from elsewhere once the exact specifications are understood.

Walking tracks will be required through the Yandicoogina area to facilitate specific Traditional Owner land-use requirements, e.g. to access to repatriated cultural artefacts and culturally significant sites. Due to the high potential for tracks to erode or cause erosion, detailed landscape design studies during the

decommissioning study will be undertaken to ensure the tracks do not facilitate additional erosion of built structures.

Historically, mining at Yandicoogina has minimised interactions with creek systems. The Yandicoogina life of mine plan, on which this closure plan is based, anticipates mining activities to occur closer to and within some the flood plain of major creeks. Investigations are currently underway to review the geotechnical stability of the geology left in situ adjacent to the creeks, to understand how to best construct mineral waste pillars / buttress that will be used to stabilise pit walls adjacent to creek systems and to return Phils Creek to its original alignment.

Closure landforms approved by the OEPA, in accordance with MS 914 Condition 9-1, have been developed based on approved deposits and subsequent mineral waste generation. This landform aims to stabilise creek systems and achieve a closure landform that minimises evapotranspiration. Variations to the closure landforms have been developed based on various expansion cases, to inform future mine plan develops and to assist with cumulative impact assessments.

20.3.2 Water

The hydrology of the creeks in the Yandicoogina area is well understood, and with the exception of the PBS deposit, the creek hydrology is expected to be unaffected by the closure landform. Data will continue to be collected during operations to verify and improve our understanding of surface and subsurface water interactions within the creeks. Mining through Phils Creek, for example, is expected to provide an opportunity to verify the geometry of the alluvial systems used in various models, as well as providing an opportunity to validate preferential flow movement along and between layers exists within the alluvial aquifer.

The process of mining the Yandicoogina CID will not produce enough mineral waste to backfill the areas excavated below the water table. As a consequence the closure landform must incorporate pit lakes. Basic water balance modelling has shown that water quality, lake levels and the associated groundwater system will evolve differently under different closure landform designs, e.g. the positioning of large pit lakes can create local groundwater depressions, which in turn control groundwater movement through the CID and former mining areas. The closure landform for Yandicoogina has been designed in consideration of these interrelationships, including the development of local groundwater sinks at Oxbow West and JC. Consequently, through implementation of this closure landform, the groundwater model predicts that outside of the mining disturbance areas and more than 2km from the Oxbow and JC mine voids, water levels will be largely predicted to return to pre-disturbance levels.

A groundwater sink will be established at Oxbow West by leaving the entire pit shell as a lake area, maximising potential evaporation. The resulting Oxbow West (pit) Lake will be dependent on groundwater inflows, which are expected to be impacted by the closure landforms implemented at BHP Billiton Iron Ore Yandi Mine, with a minor surface water flow contribution from a truncated local creek (a former small tributary to Marillana Creek). As a groundwater sink, the salinity of the lake is expected to increase over time to create a saline lake. However, the lake is disconnected from Marillana Creek proper, and, as a groundwater sink, saline groundwater is not expected to interact with Marillana Creek or its associated groundwater aquifers.

Consultation with the BHP Billiton Iron Ore Yandi mine is required to ensure the groundwater quality and level assumptions used in the models, based on predicted outcomes from the BHP Billiton Iron Ore Yandi mine closure, are accurate. Further refinement of the Oxbow West water balance water quality modelling is also required, integrating the additional evaporation from proposed Oxbow East pit and latest pit shell produced for the Oxbow West deposit, to update the water quality predictions.

The groundwater model suggests that, due to the groundwater sink in Oxbow West, the groundwater aquifers downstream of Oxbow East, including JSW-A, JSW-C and JC, will receive groundwater sourced from the adjacent Marillana Creek alluvial aquifer system. The water quality of the Marillana Creek alluvial system is relatively fresh. Consequently, the JSW-A and JSW-C groundwater though flow pit lakes are expected to contain freshwater. As a groundwater sink, the salinity in JC will also increase over time. However, as the incoming groundwater quality is relatively fresh, the lake water quality is expected to remain fresh to brackish for a significant period of time (several hundreds of years). Further work is required to understand updates to the groundwater model, following development of the Oxbow area, to ensure these conclusions remain valid. Water quality, including evolution over time, will also need to be developed.

The Pocket and Billiard South deposit requires a small encroachment of mining to occur within the Weeli Wolli Creek floodplain. Based on the current closure design, there is an eighty percent chance that some water from Weeli Wolli Creek will flow into the void each year, delivering nutrients and aquatic fauna / flora to the lakes. By design, only the peak of flows would overtop the pit wall and enter the mine void via an

engineered spillway, such that water flow down the low flow channel of Weeli Wolli Creek will remain unchanged. Further work is required to review the spillway design and siting, based on the as built conditions around the pit.

Occasionally, e.g. 3 times in every 200 years, the volume of water entering the PBS mine void will be sufficient to flush the area, allowing water to exit the area at the northern tip of the pit. A large proportion of the accumulated lake salts are expected to be removed from the system during these events, which will reset the salinity in the lake chain. This behaviour will be similar to the hydrological flood regime system observed in Fortescue Marsh. Although the ratio of outflow to Weeli Wolli Creek flood water is very low, suggesting dilution of the salts in the flood water would not have an effect on the Weeli Wolli Creek ecosystem, further work is required to validate this assumption.

The closure landform design will be refined through stakeholder feedback and in consideration of mine activities, evolving knowledge and monitoring data. Further monitoring and modelling is required to resolve the water quality evolution within the lakes and to continue to refine the groundwater model (including surface and groundwater interactions). Opportunities to enhance the recovery of the groundwater will be investigated.

Recent investigation into the effect of evapoconcentration processes on Yandicoogina groundwater showed there is the potential for alkaline water conditions to affect mobilisation of trace elements. Further investigations are required to determine if any problematic trace elements are present in natural background water and / or could be desorbed / released under future water conditions. Further studies may also be required to determine the frequency of potential water quality issues and the interaction with the local environment.

The cumulative effects of mining in the Weeli Wolli catchment and the influence of climate change are poorly understood with respect to the changes to water conditions after closure. This situation is mainly driven by regional unknowns, i.e. what other mines will develop, when will they develop, what impact will they have on the environment and how will their changes affect water quality and quantity. Within the existing modelling, a basic assumption for increased groundwater salinity has been used as an input, based on published literature. However, this condition is not expected to accurately reflect post-mining or climate changes to water quality, and will need to be reviewed and revised as further literature becomes available.

During the closure modelling processes, it was noted by water modelling experts that it is not possible to simultaneously model the water quality and level information using normal commercial software. This is due to the complexity of the surface water, groundwater and multiple lake interactions at Yandicoogina combined with the size of the model and (grid) resolution at which environmental impacts should be assessed. To achieve the current results, different water model programmes have been employed. It is anticipated that as technology improves, more advancements in water modelling software will improve modelling capabilities.

During operations, the groundwater table will be suppressed within all pits until rehabilitation and closure activities have been completed, in order to maintain a safe working environment within the mine voids. This could mean that dewatering could occur across a large proportion of the entire site, including exhausted pits, for many decades to come. An opportunity to reduce the dewatering requirements through large, progressive rehabilitation campaigns has been identified and will be investigated over the next few years, to ensure the solution does not sterilise future resources. By reducing the dewatering requirements, the groundwater table will recover earlier than the groundwater recovery model predictions.

Furthermore, given the long mine life estimated for the Yandicoogina deposits, it may be possible to utilise surplus water generated from active mine areas to enhance groundwater recovery. For the most part, this could be achieved through the creation of pit lakes, by discharging surplus water into the landscaped mine voids, whereby the water will dissipate into waste material located within the pits and eventually link up with the in situ groundwater aquifers.

Further investigations, modelling and stakeholder engagement will be undertaken to understand if enhanced groundwater recovery may be pursued without compromising safety, the environmental or social values in the region.

20.3.3 Biodiversity

The closure landform will be rehabilitated to a wide variety of habitats, ranging from exposed bare rock areas associated with the pit walls, to Acacia dominated plains-style habitat similar to the pre-disturbance habitat, to the creation and introduction of wetland habitats surrounding the pit lakes. Standard landform design and revegetation practices are considered sufficient to establish an appropriate degree of biodiversity in areas that will be revegetated for non-water related habitats.

However, in recognition of the limited experience in rehabilitating habitats associated with water, Rio Tinto has commenced research programmes and rehabilitation trials are underway and are expected to be completed prior to decommissioning to provide informed instruction for water related habitats. These studies include how seeds collected from the local creeks systems respond to groundwater and generic mineral waste (growth media), whether these species thrive post-germination with variable access to the groundwater table, which plant species combination(s) ensure wetland and floodplain vegetation communities are self-sustaining, what landform shapes support lake littoral zone development and what management is required to ensure water quality in the recovering lakes remain non-toxic and promotes ecosystem development.

Studies are ongoing to integrate Priority flora species into rehabilitation programmes. There is also an opportunity to integrate habitat preferences for the Northern Quoll and Pilbara Olive Python into the rehabilitation design, if such information becomes available.

It is hypothesised that stygofauna populations may be impacted by changes to groundwater quality, as predicted by groundwater modelling and as a consequence of other mining activities and / or climate change. Further study is required to review the impact of closure on the local stygofauna populations and to identify any potential mitigation strategies that may be implemented as part of rehabilitation programmes.

It is also recognised that invasive species management will be a critical factor in the successful rehabilitation of Yandicoogina. However, this management plan will not be required or developed until the decommissioning phase, five years prior to closure.

20.3.4 Stakeholders

Mining activities and by extension closure activities, often occur in close proximity to areas of cultural significance to Traditional Owners. Archaeological and ethnographic surveys are undertaken as required across Yandicoogina to identify and catalogue important features and salvage artefacts (where appropriate).

The extensive cultural heritage work associated with the expansion of the site has constrained engagement on closure with Traditional Owners, and it is recognised further consultation and engagement is required to ensure Traditional Owners values are respected and integrated (where appropriate) into the closure plan.

Post-mining land use has yet to be discussed with key stakeholders. Rio Tinto will continue to investigate the legal processes required to be observed to established post-mining land use.

It has been noted with regards to several aspects of closure that the cumulative effects of mining within the Weeli Wolli catchment and their respective closure landforms could have unforeseen consequences for the closure success at Yandicoogina. At present no formal, legal avenues exist to share information with mining competitors operating in the Pilbara regarding their anticipated closure outcomes and impacts on the environment. As a consequence inputs into the closure plan are limited to externally published reports generated through, for example, public environmental reviews.

20.4 Task list

summarises the actions identified through the risk evaluation process that require research or form part of significant ongoing investigations. It is not expected that this list includes all of the mine activities undertaken that relate to closure, only the key activities that are necessary to manage or prevent high or critical closure risks.

Table 20: Yandicoogina closure research and ongoing investigation task list.

Aspect	Ref	Detailed action descriptions	Due date
Contaminants	YA-43	Complete Phase 1 and Phase 2 (where required) contaminated sites investigations and required actions to remediate contamination.	2027
	YA-29.	Undertake alkaline leach tests on Yandicoogina waste materials.	2016
	YA-44	Update groundwater recovery (level) model to include latest data, Oxbow East and PBS lake scenarios.	2018
	YA-45	Develop local scale groundwater model and associated water quality model for JSW through to JC. (Assumes water divide after Oxbow West still exists after groundwater recovery model is updated.) Confirm that JC has no hypersaline (as an indicator of potential contamination) water quality risk.	2020

Aspect	Ref	Detailed action descriptions	Due date
	YA-46	Develop local scale (joint) groundwater model and associated water quality model for Oxbow East and Oxbow West. Investigate if surface water flow will reduce / eliminate pH 9 conditions or control aqueous metal / metalliod conditions	2020
	YA-47	Before ground disturbance, review potentially hazardous fibrous materials status to resolve areas of hazardous materials.	2032
	YA-48	Implement Fibrous Materials Management Plan in designated hazardous fibrous areas as part of progressive rehabilitation / decommissioning activities	2032
Void management	YA-34	Review the available water balance model technology to enable improved prediction of pit lake water levels.	annual
	YA-49	Update local scale groundwater model and associated water quality model for PBS. Confirm water quality of contributions to Weeli Wolli Creek	2022
	YA-19	Assess the impacts of flood water flushing of PBS lake on downstream vegetation and fauna (towards Fortescue Marsh)	2024
	YA-50	Consider early development of pit lake at Yandicoogina to study chemical / geochemical / biogeochem water quality evolution / behaviour and use to calibrate models for other lakes	2018
	YA-13	Undertake research to improve knowledge of rehabilitation of new landforms / habitats, including the best methods for restoration of Pilbara creek habitats / establishment of novel lake fringe ecosystems.	2018
	YA-38	Undertake rehabilitation trials for different landform and substrate types to inform restoration / rehabilitation plans	annual
	YA-51	Integrate results from aquatic fauna heavy metal studies into closure plan	2018
	YA-17	Assess the ability of pit lake water to sustain aquatic flora and fauna, and support other species.	2027
	YA-52	Investigate means to deter feral / unwanted predator species from lake areas	2021
	YA-53	Understand which characteristics of lake ecosystem health also address / minimise public health risks	2018
	YA-54	Predict how the lake ecosystem will evolve, consider timeframe and biodiversity over time	2021
	YA-32	Complete drilling required to improve hydrogeological conceptual model relevant to the closure plan	2021
	YA-33	Undertake program (i.e. drilling) to develop a better understanding of surface water and groundwater interactions.	2024
	YA-37	Review the behaviour of Phils Creek during mining to understand the amount of leakage, to inform the water modelling	2024
	YA-55	Investigate the long term implications of groundwater quality changes on stygofauna populations	2027
	YA-39	Review the geotechnical stability of pit walls and design requirements for creek supporting structures	2022
	YA-41	Assess the stability of pit walls adjacent to the BHP Billiton Iron Ore rail and identify a management strategy to ensure continuity of the rail post-closure.	2022
	YA-56	Identify and manage location for flow of surface water flow into the Oxbow pits.	2025
	YA-57	Identify and manage location for flow of surface water flow into the PBS pit.	2027
Landforms	YA-58	Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion at JC.	2017
	YA-59	Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion at JSW.	2024

Aspect	Ref	Detailed action descriptions	Due date
	YA-60	Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion at Oxbow.	2025
	YA-61	Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion at JSE	2027
	YA-62	Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion at PBS	2027
	YA-35	Identify sources of backfill material and capping material to achieve closure landform.	2027
	YA-63	Undertake regular reviews of the Phils Creek landbridge performance to understand any potential implications to closure, and modify / complete detailed closure design as appropriate.	annual
	YA-64	Complete rehabilitation designs for large process / crusher facilities.	2027
	YA-65	Investigate and implement opportunities for rehabilitation trials	annual
	YA-09	Develop (and maintain) a progressive rehabilitation schedule.	annual
	YA-14	Investigate creek rehabilitation requirements, considering landform pre-preparation, topsoil application and if tube stock is necessary to achieve required outcomes.	2017
	YA-66	Engage with key stakeholders to define post-closure land use	2020
	YA-67	Identify what mine features key stakeholders want to be retained, including access roads.	2027
	YA-68	Review liability of retention of mine features and agree where ownership of liability for retained features will be transferred.	2027
	YA-36	Consider the landscape design requirements for the repatriation of cultural artefacts back into the closure landform.	2021
	YA-69	Review the design of retained featured, i.e. roads, to ensure they are fit for purpose.	2027
	YA-70	Investigate and implement infrastructure options to prevent / discourage access use of retained access routes, i.e. for monitoring, where appropriate.	2027
Regional aspects	YA-18	Assess the impacts of closure implementation on groundwater dependent vegetation.	2024
	YA-12	Assess impacts of closure implementation on stygofauna populations.	2027
	YA-71	Assess impacts of closure implementation on species of conservation significance.	2024
	YA-21	Finalise the Yandicoogina Cultural Heritage Management Plan (to include closure strategies) and implement it as a working document.	annual
	YA-23	Undertake a gap analysis to identify areas requiring heritage survey and areas of significance which should be avoided and managed.	annual
	YA-24	Undertake heritage surveys as required (ethnographic and archaeological) with the traditional owners.	annual
	YA-27	Consult with the traditional owner group regarding specific water values.	2021
Stakeholders	YA-72	Review regulatory advice regarding pit lakes, identify any gaps in plan and update accordingly	2016
	YA-25	Maintain regular communication with Gumala and wider TO stakeholders through directed, closure specific engagement sessions.	annual
	YA-73	Engage Local Government to understand their requirements for mine closure.	2024
	YA-42	Conduct & communicate visual amenity assessment of final landform options	2018

Aspect	Ref	Detailed action descriptions	Due date
	YA-07	Consult with BHP Billiton Iron Ore to ascertain compatibility of closure strategies with the BHP Billiton Iron Ore Yandi mine.	2016
	YA-74	Consult with BHP Billiton Iron Ore to ascertain compatibility of closure strategies with the Marillana Station (owned by BHP Billiton Iron Ore).	2018
	YA-75	Consult with DSD with regards to wider development expectations for post-mining land-use.	2018
	YA-76	Refine closure strategy to include Billiard North and other deposits during Billiard North mining studies	2024
	YA-77	Review impact of closure on local communities (part of decommissioning scope)	2027
	YA-78	Review closure aspects with each Life of Mine plan update, to ensure implementation aligns with agreed strategy.	annual
	YA-79	Update the closure plan and seek approval for an alternative or modified closure strategy when significant changes are anticipated to occur on site	annual
	YA-80	Send closure plan to regulators for review every three years.	2018
Opportunities for improvement	YA-40	Identify opportunities to enhance aquifer recovery	2016
	YA-10	Research Northern quoll habitat requirements to enhance habitat potential in final landforms.	2024
	YA-11	Research Pilbara Olive Python habitat requirements to enhance habitat potential in final landforms.	2024

CLOSURE IMPLEMENTATION

21. Closure domains

Closure domains are used to group areas with common features, rehabilitation and decommissioning requirements. Closure domains that have been established for Yandicoogina include:

- generic site areas, as described in Table 21, that may be rehabilitated on an ad hoc basis, when the disturbed area is no longer required to support the operations. No rehabilitation schedule is available for these areas, with the majority of the rehabilitation expected to be undertaken at the end of the mine life in 2032; and
- constructed landforms, as described in Table 22, that have the potential to be rehabilitated once mining ceases in the local area. An indicative schedule indicating when the associated subdomains would be available for rehabilitation is provided.

Refinement of the closure domains and associated detailed plans for the rehabilitation and decommissioning of these areas will be developed as areas become available or alternatively during the decommissioning study.

Table 21: Yandicoogina general area implementation strategies by closure domain.

Domain	Implementation strategy	Relevant indicative completion criteria
Borrow pits	• No backfill required • Reshape to a self-draining landform and contour to blend with local landscape. • Respread topsoil windrows and stockpiled vegetation onto disturbed area. Deep rip and seed, if required.	1a, 2a, 6a, 6b, 6c, 7a
Landfill	• Cap with at least 2m of competent inert material. • Respread topsoil windrows and stockpiled vegetation onto disturbed area. Deep rip and seed.	1a, 2a, 6a, 6b, 6c, 7a
Highly disturbed area	• Demolish or dismantle built structures to footing level. Remove bitumen and concrete. Dispose of demolition material to an appropriate waste site. • Undertake extensive earthworks and reshaping of areas to create a compatible landform consistent with the surrounding natural relief and landforms. • If the area is very compacted additional ripping may be required • Natural drainage lines to be re-established where practicable. • Topsoil, deep rip, seed treatment and spread stockpiled vegetation	1a, 2a, 6a, 6b, 6c, 7a
Moderately disturbed area	• Demolish or dismantle built structures to footing level. Remove bitumen and concrete. Dispose of demolition material to an appropriate waste site. • Contour to either return the area to natural relief or create a compatible landform consistent with the surrounding natural relief and landforms. • Natural drainage lines to be re-established where practicable. • Topsoil, deep rip, seed treatment and spread stockpiled vegetation	1a, 2a, 6a, 6b, 6c, 7a
Low level disturbance	• Scatter any dead vegetation or rocks over the rehabilitated surface to increase habitat diversity and reduce wind and water erosion. • Natural drainage lines to be re-established where practicable. • Where topsoil has not been removed and compaction is limited to two wheel tracks the area will be left to rehabilitate naturally. Other tracks should be ripped. • On slopes, rip parallel to contours. • Topsoil (as required), deep rip, seed treatment and spread stockpiled vegetation.	1a, 2a, 6a, 6b, 6c, 7a

Table 22: Yandicoogina void and waste dump implementation strategies and schedule by closure domain.

Domain	Implementation strategy	Area	Relevant indicative completion criteria	Indicative closure schedule
Temporary waste dumps	• Rehandle mineral waste into strategic locations to achieve closure landform (Figure 17) • Rehabilitate footprint in accordance with the Highly disturbed area domain.	All external waste dumps ROM pad	1a, 2a, 6a, 6b, 6c, 7a	2032
Pit areas	• Backfill ~10m above groundwater recovery level, in accordance with closure landform design strategy (Figure 18). • Shape open faces of mineral waste materials according to design requirements (Table 17). • If waste fines cells are present and above water table, cap with 2m layer of inert waste or as otherwise defined, in accordance with the JSE landform design strategy (Figure 24). • Landscape surface to include surface drainage and erosion controls, as appropriate. Refer to specific closure design for the Phils Creek landbridge area. • Identify and stabilise, where required, safe egress routes to future lake areas. • Considering surface water requirements, construct abandonment bund (or similar) around the perimeter of exposed high wall and open faces, unless bound by steep topography, outside zone of geotechnical instability. Shrub and/or tree planting at the outside edge of bund to lessen visual impact (where possible). • Rehabilitate areas in accordance with habitat planning strategy (Figure 29 and Figure 30). Includes topsoil and mulch spread over the mineral waste surface to a maximum depth of 200mm, deep rip and seed. No revegetation undertaken in areas that will be under water • Identify and implement means to declare public safety risk and restrict public access.	Oxbow West pit Oxbow East pit JSW-A pit JSW-C pit Phils Creek reconstruction Phils Creek pit JC IMA pit JC central pit JC south pit JSE pit Pocket pit Billiard South pit	1a, 2a, 3a, 4a, 4b, 5a, 6a, 6b, 6c, 7a	2026 2026 2027 2025 2026 2024 2018 2018 2019 2032 2032 2032

22. Premature closure and other factors

The closure implementation schedule may be influenced by factors outside of the current mine plan. These factors include:

- suspension of operations under care and maintenance; this could occur if production costs exceed product value, e.g. due to commodity price changes;
- unexpected closure; this could occur if there was major change in global demand for iron ore; and
- future proposals; these could occur if iron ore deposits of appropriate quality are identified adjacent to the existing deposits.

22.1 Care and maintenance

In the event of temporary closure, measures will be undertaken to transfer the site from operations into a care and maintenance regime and relevant authorities notified. A Care and Maintenance Plan will be developed prior to the care and maintenance period which demonstrates how on-going environmental obligations associated with the site will continue to be met during the period of care and maintenance. Social obligations and responsibilities will also be addressed in this plan.

22.2 Unexpected closure

Whilst HIY considers the risk of unexpected closure to be minimal, there are numerous factors that could force early closure of one or several sites. Even if some level of contraction were to occur, it is reasonable to assume that Rio Tinto would continue to operate in the Pilbara and that it could continue to manage closure of Yandicoogina.

This closure plan has been produced to support the application to expand mining at Yandicoogina. If no further approval for mining is granted, the site would need to close ahead of the current schedule.

At the current stage of development, closure of the site is expected to generate the closure landform concept illustrated in Figure 32. Without further approval to mine, there is likely to be a deficit of mineral waste material available to suppress the groundwater table within the JSE mine void. These lakes are expected to act as groundwater sinks and will draw water from the aquifers beneath the Weeli Wolli and Marillana Creeks. As groundwater sinks, it is expected that salts derived from the groundwater supply would build up in the lakes over the long term, leading to highly saline lake water. It is also possible that the highly saline water could periodically have high pH levels. The high pH could result in the release trace metals into the lake water with the potential for bioaccumulation of metals within the fringing vegetation.

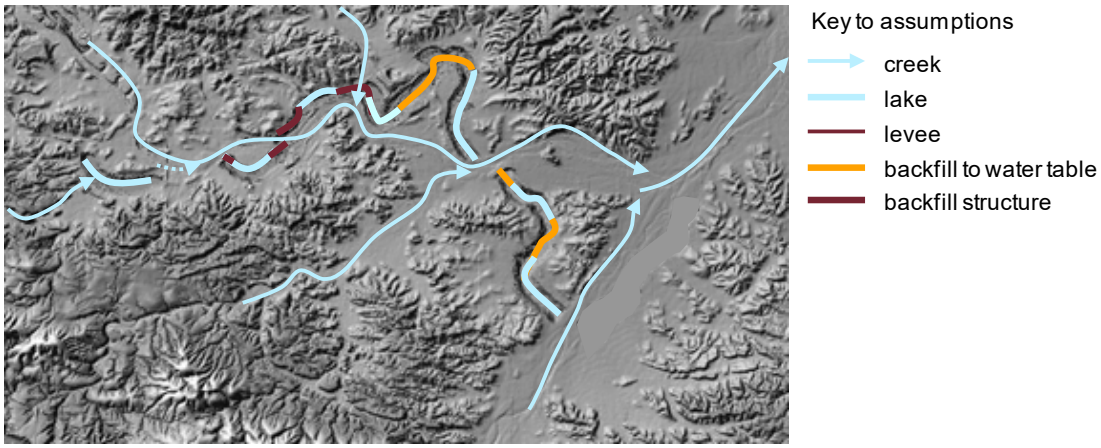


Figure 32: Contingency plan illustrating a closure landform if no further approvals are granted.

In the event of unplanned or sudden closure, HIY will notify all relevant authorities including the DMP. The existing closure plan for the site would then be revised and a Decommissioning Plan prepared and submitted to the DMP and other relevant authorities within three months of notification of closure. The Decommissioning Plan will include undertaking detailed consultation with stakeholders. Once the plan is approved by the relevant authorities, work will commence on closure implementation activities.

22.3 Prospective areas

There are several deposits, including Billiard North and Braid, which are reported as part of the ore reserves for the Yandicoogina operations. Closure information relevant to these expansion deposits is provided in this section in order to facilitate discussions with key stakeholders, and is not intended for regulatory approval at this time. Detailed closure plan information for these expansion deposits will be developed as and if mining studies progress, prior to regulatory approval to mine these deposits being requested.

22.3.1 Billiard North deposit

The Billiard North deposit is located to the north of the Billiard South deposit and is located beneath Weeli Wolli Creek. Mining of this deposit will necessitate the alteration of Weeli Wolli Creek in order to access the ore. There will not be sufficient mineral waste generated through the mining of this deposit to facilitate the reinstatement of Weeli Wolli Creek. Instead it is proposed to flood the mine void and create a sustainable, freshwater lake ecosystem in the Weeli Wolli Creek.

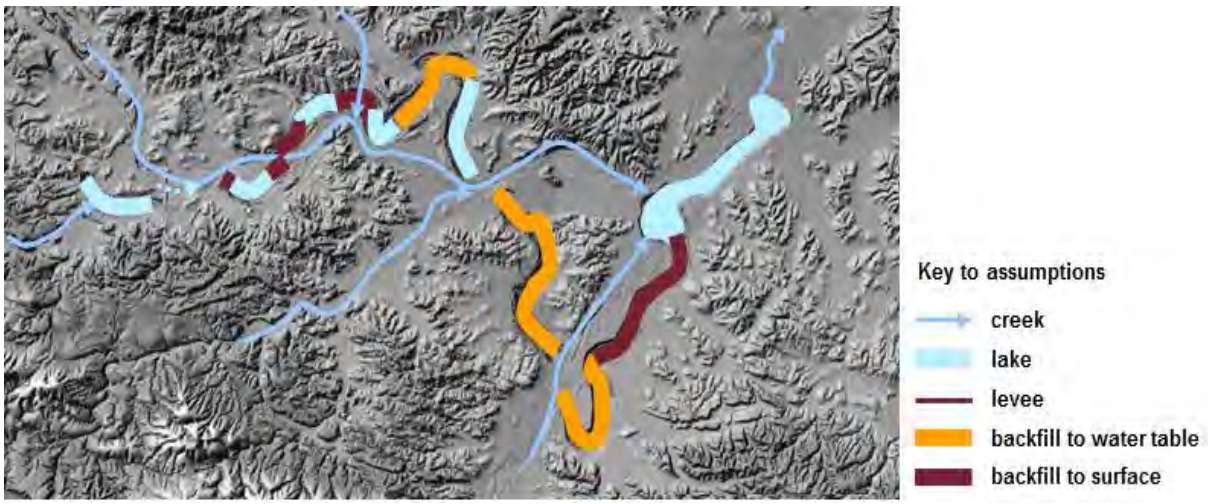


Figure 33: Closure concept for Yandicoogina incorporating the expansion development at Billiard North.

In this concept (Figure 33), mineral waste generated through the mining of the Billiard North deposit would be used to backfill the Billiard South and Pocket mine voids to the pre-mining level. Vegetation and topsoil cleared from the Billiard North area would be used to re-establish and potentially expand the Weeli Wolli Creek flood plain vegetation communities across the Billiard South deposit.

22.3.2 Braid deposit

The Braid deposit is located to the north of the Billiard North deposit. The same closure landform concept discussed for Billiard North is expected to be employed, placing mineral waste generated through the mining of Braid into the void generated by Billiard North, such that areas of Weeli Wolli Creek could be re-established (Figure 34).

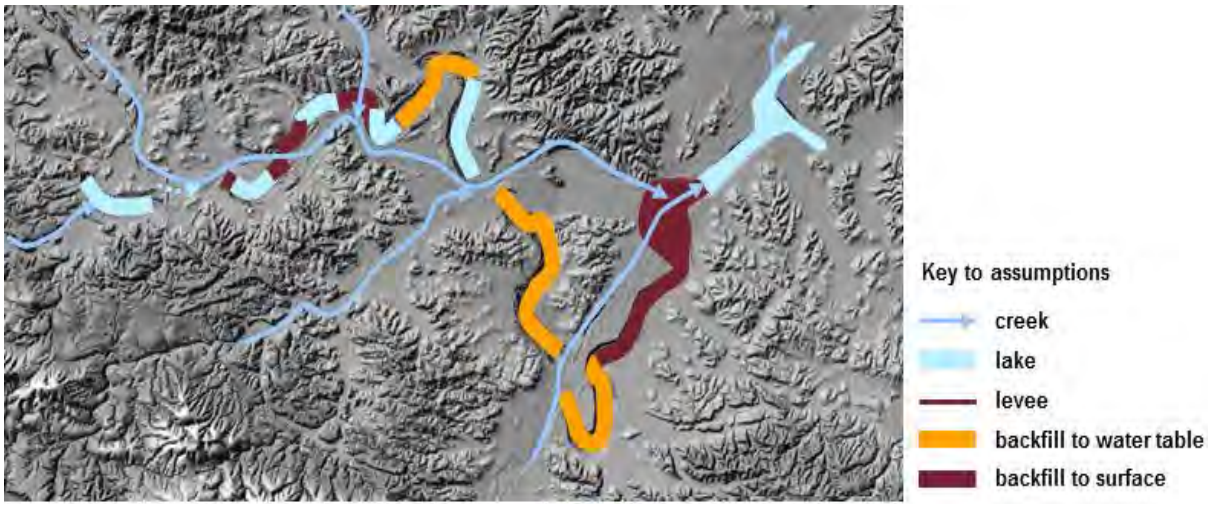


Figure 34: Closure concept for Yandicoogina incorporating the continuing expansion development at Braid.

CLOSURE MONITORING AND MAINTENANCE

23. Closure monitoring programs

An extensive environmental monitoring program is underway at Yandicoogina to track the performance of the operation, identify potential environmental impacts and to better understand the environment surrounding the mine in order to avoid or minimise future environmental impacts. This includes:

- Baseline monitoring, which is conducted as operations expand into new mining areas; and
- Operational monitoring, which occurs throughout the life of the mine, in line with regulatory requirements and the operational standards.

A summary of the information currently collected by the operation and used to inform the closure plan is listed in Table 23. Note the frequency of data collection is indicative only, with monitoring frequency (and some parameters) adapted to reflect the changing certainty (increasing and decreasing) of various aspects as the mine develops.

Table 23: Existing monitoring programmes

Aspect	Location	Frequency	Parameters measured
Soil quality	Land farm	Quarterly	TRH, pH, Total N, Total P, Soil Moisture, C:N:P Ratio, BTEX, PAH , heavy metals
Riparian vegetation	Yandicoogina	Annually	Aerial photography, DMSI
Riparian vegetation	Weeli Wolli and Marillana Creeks	Quarterly 6 monthly	Digital Cover Photography (DCP) Community structure, species diversity and abundance
Riparian vegetation	Whole site	Annually	Sum of approved clearing areas within riparian vegetation communities
Weeds	Whole site	Ongoing	Visual with annual eradication programme
Meteorological	Yandicoogina Weather Station	Monthly	Monthly rainfall total
Groundwater quantity	Abstracted water	Continuous	Volume abstracted
Groundwater quality / quantity	Mine aquifers	Monthly	pH, EC, Temperature, Run Hours, Cumulative Flow, Instantaneous Rate Flow, Water Level Elevation
Groundwater quality / quantity	Mine aquifers	Annually	pH, EC, TDS calculated, Na, K, Ca, Mg, CL, CO3, HCO3, SO4, NO3
Groundwater level	Whole site	Monthly	Water level elevation
Surface water quantity	Discharge outlets	Monthly	Cumulative volume discharged (m3)
Surface water quantity	Weeli Wolli Creek	Ongoing	Extent of the saturated creek bed
Discharge quality	Discharge outlets and creek alluvium water	Quarterly 6 monthly	TDS, TSS, EC, pH, Total P, Total N, NO3, NH3, Se, Hg, pH, EC, TDS, TSS, Al, Ca, Mg, Na, K, SO4, Pb, Cu, Fe, Mn, Mo, Zn, As, Cd, Cr
Aquatic invertebrates	Weeli Wolli Creek	6 monthly	Aquatic invertebrate abundance and diversity
Subterranean fauna/habitat	Yandicoogina	Opportunistic	Stygofauna assemblages (with groundwater quality)
Geomorphology / bathymetry	Discharge outlets	6 monthly & after flood events	Inspection and photographic records to monitor for erosion

Aspect	Location	Frequency	Parameters measured
Geomorphology / bathymetry	Marillana Creek (select locations)	6 monthly	Channel cross sectional area

Results from the operational environmental monitoring program that are relevant to closure are summarised in the *Collection and analysis of closure data* section of this report.

A phased approach to closure monitoring is proposed for Yandicoogina:
- Pre-closure monitoring: occurs as the site approaches closure to establish post-mining baseline conditions (where required). Aspects that may need to be collected to establish the post-mining conditions include water levels outside the active mine area, riparian vegetation condition, and potentially terrestrial fauna;
- Decommissioning monitoring: conducted during the period of active site decommissioning and rehabilitation. This monitoring plan will be developed as part of the Decommissioning Plan, to ensure the activities do not adversely impact the environment; and
- Post-closure monitoring: conducted on a scheduled basis until the completion criteria have been met. This monitoring plan will be developed as part of the Decommissioning Plan.

The monitoring aspects expected to be undertaken at each phase of monitoring are listed in Table 24. This monitoring is undertaken to inform Rio Tinto internal quality control and assurance processes as well as to demonstrate that closure objectives have been met. It is expected that the monitoring programmes will be sufficiently flexible to enable adjustments to be made if results indicate that more or less monitoring is warranted at any particular phase. Completion criteria monitoring will continue until stakeholders agree that the completion criterion has been achieved.

Table 24: Expected components of the closure monitoring program

	Phase		
Monitoring aspect	Pre closure	Decommissioning	Post closure
Vegetation (rehabilitation) #	✓	✓	✓
Erosion #	✓	✓	✓
Weeds #	✓	✓	✓
Fauna #	✓	✓	✓
Stygofauna	✓		✓
Feral animal	✓	✓	✓
Ecological function	✓		✓
Water quality and contaminants	✓	✓	✓
Groundwater levels and quality	✓	✓	✓
Heritage	✓	✓	

These monitoring activities also part of the Rio Tinto Iron Ore Rehabilitation Monitoring Procedure.

23.1 Vegetation

Rehabilitation monitoring tracks the progress and evaluates successional development of rehabilitation areas. This information is used to assess progress towards long term rehabilitation objectives and to improve rehabilitation techniques.

The Rio Tinto Iron Ore Rehabilitation Monitoring Procedure details the monitoring methodology for recording and assessing vegetation development. In the current procedure, characteristics as listed below are recorded by quadrat at intervals along transects at established rehabilitation and associated reference sites:
- number of plants by species;
- percentage cover by species;
- bare areas in quadrat;
- percentage of perennial cover;
- percentage of spinifex cover;
- percentage of grass cover (excluding spinifex);
- percentage of native perennial shrub cover (0.5m to 2m);
- percentage of litter cover;

- percentage of tree cover >2m;
- presence of annuals;
- presence of weeds species; and
- if burnt since last monitoring.

Qualitative assessment of erosion, soil surface, perennial vegetation cover, species richness, weeds and general condition is also recorded.

Monitoring of rehabilitation and reference sites is generally scheduled annually for the first three years after establishment, biennially from years five to nine and (approximately) triennially thereafter, until sufficient information is gathered to validate the performance of the rehabilitation.

Analysis of the trends observed at rehabilitation sites over time and in comparison to reference sites is being studied to develop an understanding of rehabilitation quality and successional processes in our rehabilitation.

23.2 Erosion

Erosion monitoring will involve the examination of transects for the number of rills and gullies, recording their width and depth. These measurements are compared over time to determine if the landform has stabilised; for example erosion rates are within the accepted completion criteria range or rill and gully geometry is similar to the surrounding landscape. If a landform fails to stabilise, further management / intervention will be applied.

23.3 Weeds

Weed management programs will be developed for each phase of closure during the decommissioning study, to reflect the different work programmes and associated risks. These programs will define procedures to identify, control and eradicate target weeds and monitor weed control measures to minimise the spread of weed species, prevent the introduction of new weeds and control and/or eradicate both noxious and environmental weeds across the rehabilitated area.

For example, the pre-closure weed management program will focus on annual weed eradication and control, as mining and associated disturbance activities will still be occurring in the area. During the decommissioning phase, weed management will emphasise weed hygiene, in order to minimise the spread of weeds with the significant increase in vehicle and earth movement activities. During the post-closure phase, weed management will focus on monitoring, which will be undertaken as part of the rehabilitation monitoring activities, with inspection and trigger / response remediation actions.

23.4 Fauna

Invertebrates have a major role in the success of rehabilitation efforts because they facilitate a variety of ecosystem processes, such as litter decomposition and nutrient cycling, herbivory, seed dispersal, soil aeration and drainage, pollination and provision of a source of food for vertebrate predators.

Invertebrates can be encouraged by providing areas of thick, widespread litter cover over part of the area, logs and standing dead wood. Vertebrates are usually the last to recolonise, once complex vegetation assemblages and invertebrate prey are established.

The Rio Tinto Iron Ore Rehabilitation Monitoring Procedure details the monitoring methodology for recording and assessing fauna re-colonisation and habitat development. The current monitoring procedure includes the following fauna habitat and utilisation indicators:

- number of logs (>10cm diameter and >30cm long);
- number of rocks (>15cm diameter);
- presence of scat;
- presence of ants;
- general animal sighting (including tracks, burrows and nests);
- flowering and fruiting species; and
- extent of grazing.

Fauna monitoring is completed concurrently with vegetation monitoring and is continued until sufficient information is gathered to validate the performance of the rehabilitation.

23.5 Stygofauna

Targeted studies of stygofauna assemblages will be undertaken during the post-closure monitoring to quantify and validate impacts to and / or expansion of stygofauna populations following the recovery of the groundwater system at Yandicoogina. The study scope will be resolved with key stakeholders during the decommissioning study.

23.6 Feral animal management

Feral carnivores (e.g. cats, dogs, foxes) can create locally increased predation pressure on native fauna as well as increase competition with native species for resources such as space (territory), water and food.

Feral herbivores (e.g. cattle, camels, donkeys) can also have a significant impact in Rangeland areas, such as the Pilbara. In dry times, grazing pressure reduces the abundance of palatable native species, impacting biodiversity and can create conditions that encourage weeds to grow. Foot traffic impacts the soil conditions, and in combination with over grazing, can encourage erosion. Foot traffic has also been the cause of damage to cultural landmarks and Aboriginal sites. Overgrazing and damaged soils has a low-on effect to native fauna species that rely on this vegetation for food and shelter.

Feral animals will continue to be managed in accordance with the existing site Feral Animal Management Plan during the pre-closure and decommissioning phases. The Feral Animal Management Plan conforms to meets current national guidelines, i.e. Codes of Practice for the humane control of invasive species published by the Department of Environment.

23.7 Ecological function

Targeted monitoring of select ecological functions may be required to ensure that biological, geological and chemical interactions associated with lake water quality and lake fringe vegetation have evolved as predicted. Monitoring requirements for validating these ecological functions will be resolved with key stakeholders during the decommissioning study.

23.8 Water quality and contaminants

Water monitoring networks will be established during the life of the mine and during the decommissioning phase to validate surface water and lake model predictions. It is expected that monitoring for water level, pH, EC, TSS, alkalinity/acidity, major cations and anions (including key nutrient indicators) will be undertaken every six months until sufficient information is gathered to validate the water recovery and quality predictions.

23.9 Groundwater levels and quality

Water monitoring networks will be established during the life of the mine and during the decommissioning phase to validate groundwater modelling predictions. It is expected that monitoring for water level, pH, EC and temperature will be undertaken every six months until sufficient information is gathered to validate the water recovery and quality predictions.

23.10 Heritage

Heritage will continue to managed and monitored in accordance with the Cultural Heritage Management System until the land tenure is relinquished to the State Government. This process ensures that significant Aboriginal and environmental sites are not disturbed without authorisation.

FINANCIAL PROVISION FOR CLOSURE

24. Principles of cost estimation

Closure cost estimates are determined in accordance with internal accounting policy methods, with the level of accuracy increasing as the site approaches closure. During the life of the operation, two closure costs will be developed:

- A Present Closure Obligation (**PCO**) which is indicative of costs associated with closure of the mine given its current footprint; and
- A Total Projected Closure (**TPC**) cost which predicts the cost (in current terms) associated with closure at the end of the life of the mine. The TPC includes areas that are not currently approved, but that feature within the life of mine plan and that are considered likely to be developed in the future

The cost estimates consider the following components:

- Decommissioning (i.e. removal of infrastructure)[43];
- Final landform construction;
- Rehabilitation and biodiversity management;
- Heritage management;
- Workforce management (i.e. training costs and redundancy payments)[44];
- Monitoring costs;
- Costs associated with the development of a Final Decommissioning Plan;
- Costs associated with undertaking a final shutdown of operations;
- Allowance for failed rehabilitation or pollution that may necessitate rework of rehabilitation areas;
- Assignment of indirect costs in accordance with Rio Tinto Accounting Policy; and
- A contingency allowance.

The amount recognised for closure at any given time will be determined by using the best and most recent estimate of the expected cost at that time.

The PCO estimate for each site is revised on an annual basis, whilst the TPC estimate is revised whenever a formal closure plan review is conducted. Note that for commercial reasons the actual estimate is not documented in this closure plan.

[43] The decommissioning cost estimate assumes that infrastructure will be demolished and buried on site. However; opportunities for salvage and recycling will be sought as the site approaches closure.

[44] Workforce management costs are only included in the TPC.

MANAGEMENT OF INFORMATION AND DATA

25. Data and information management

25.1 Iron Ore Document Management System (IODMS)

HIY operates a comprehensive document management system, with electronic records of all key information and data. The document system, known as Iron Ore Document Management System (IODMS) is linked to other business units within the Rio Tinto group of companies, and processes are in place to ensure that the data contained within this system is appropriately backed up and protected. Each document stored within this system is given a unique document number which identifies the document and enables it to be accessed. This system will continue to operate following site closure, and all relevant data will be retained accordingly.

An audit will be conducted prior to closure to ascertain whether there is any additional information stored in hard copy form at the site. Such data will be scanned and entered into IODMS to ensure that it is appropriately retained post-closure.

Hard copies of confidential information stored at the site (such as employee records) will be destroyed at the time of closure.

25.2 Closure knowledge base

The closure knowledge database is a knowledge management process designed to bring closure related research and monitoring outcomes together into one searchable location. Key characteristics stored in the knowledge base include where the report is housed and how the report outcomes can be applied to closure.

25.3 EnviroSys

EnviroSys is a desktop application, with a web based interface, that manages environmental and hydrogeological parameters collected in the field and their logical context. The tool is used to store, monitor and analyse those parameters and report trends on data collections.

Data collected includes:

- groundwater – biological, chemical, field, levels, production;
- marine water – biological, chemical, field;
- soil chemistry;
- surface water – biological, chemical, field, levels, production;
- tonnes and moisture;
- water meters; and
- weather (rainfall, temperatures etc.).

EnviroSys is used to support the building of closure knowledge bases, as well as ensure compliance with operating licenses pertaining to data management.

25.4 Legal and other requirements system

The Legal and Other Requirements System (LAORS) is used by HIY to manage the following:

- Approval and Legislation Reports which provide a high level snapshot of approvals and legislation and is used to check the status and expiry dates of approvals.
- Approval and Legislative Requirements Reports which lists
  - accountabilities for specific conditions within approvals and clauses within legislation;
  - required actions to comply with approvals and or legislation; and
  - due dates for specific requirements.
- Statutory Position Appointed Persons reports which list individuals appointed to a statutory position.
- Statutory Position Accountabilities Reports which identify clauses of legislation that the statutory position is accountable for.

APPENDIX A

26. Appendix A Yandicoogina legal obligations

YANDICOOGINA CLOSURE OBLIGATIONS REGISTER

Legal Obligations

Ministerial Statement 914	
Condition No.	**Closure conditions**
6-1	The proponent shall ensure that the discharge of excess water from the Yandicoogina Iron Ore Project - Expansion to Include Junction SouthWest and Oxbow Deposits as a result of mining does not cause long term impacts to environmental values of the Weeli Wolli Creek System.
6-2	To verify that condition 6-1 is being met, the proponent shall develop an Environmental Values Statement for the Weeli Wolli Creek System that defines the environmental values of the Weeli Wolli Creek System to the satisfaction of the CEO in consultation with the DEC.
7-3	The proponent shall manage the proposal in a manner that ensures there is no irreversible impact to riparian vegetation or groundwater dependent ecosystems within Zones 1, 2, 2a, 3, 3a, 4 and 5.
9-1	Within 12 months following commissioning of the Junction South West or Oxbow pits, whichever is first, the proponent shall prepare and implement a Yandicoogina Decommissioning and Rehabilitation Plan in accordance with the Guidelines for Preparing Mine Closure Plans, June 2011 and any updates to the requirements of the CEO on advice of the Department of Mines and Petroleum.
9-2	The Yandicoogina Decommissioning and Rehabilitation Plan required pursuant to condition 9-1 shall ensure that closure planning and rehabilitation are carried out in a coordinated, progressive manner and are integrated with development planning, consistent with current best practice, and the agreed land uses.
9-3	The Yandicoogina Decommissioning and Rehabilitation Plan required pursuant to condition 9-1 shall set out procedures to: (1) manage long-term hydrogeological impacts of mining the channel iron deposit; (2) model the long-term hydrological impacts, particularly the water levels and quality both in the pit void and downstream of waste material landforms; (3) manage over the long-term the surface water systems affected by the open pit; (4) progressively rehabilitate all disturbed areas to a standard suitable for the agreed end land use(s), with consideration and incorporation of: (a) the characteristics of the pre-mining ecosystems within the project area (through research and baseline surveys); (b) the performance of previously rehabilitated areas within the mining lease; (c) the performance of rehabilitation areas at the proponent's other operations in the Pilbara; and (d) best practice rehabilitation techniques used elsewhere in the mining industry. (5) develop and identify completion criteria; (6) monitor rehabilitation to assess the performance of all rehabilitated areas against the completion criteria; (7) report on the rehabilitation and monitoring results; (8) remove all infrastructure; (9) develop management strategies and/or contingency measures in the event that operational experience and/or monitoring identify any significant environmental impact as a result of the proposal; (10) manage and monitor mineral waste including physical characteristics and acid or neutral metalliferous drainage using national and international standards and updates; and (11) develop a 'walk away' solution for the decommissioned mine site.
9-4	The proponent shall review and revise the Yandicoogina Decommissioning and Rehabilitation Plan required by condition 9-1 at intervals not exceeding three years.
9-5	The proponent shall make revisions of the Yandicoogina Decommissioning and Rehabilitation Plan required by condition 9-1 publicly available.

YANDICOOGINA CLOSURE OBLIGATIONS REGISTER

Legal Obligations

EPBC Decision Notice 2011/5815	
Condition No.	**Closure conditions**
13	The person taking the action must rehabilitate all potentially suitable habitat for EPBC Act listed threatened species that is disturbed during construction and operation. The rehabilitation must be developed in consultation with a suitably qualified expert and must include, but not necessarily be limited to: a) baseline data of the characteristics of the pre-mining ecosystems within the development footprint; b) use of plant species of local provenance that are compatible with land system units that provide suitable habitat for EPBC Act listed threatened species; and c) monitoring and evaluation annually for three years or until establishment.

Iron Ore (Yandicoogina) Agreement Act 1996	
Clause No.	**Closure obligations**
6(1)(l)	Subject to the provisions of this Agreement the Company shall on or before 31 December 1997 submit to the Minister to the fullest extent reasonably possible its detailed proposals (including plans where practicable and specifications where reasonably required by the Minister) with respect to the production of up to 15,000,000 tonnes of iron ore per annum for transportation from the mining lease and transport and shipment of iron ore produced which proposals shall make provision for the Company's workforce and associated population required to enable the Company to mine and recover iron ore from the mining lease and transport and ship the iron ore and shall include the location, area, lay-out, design, quantities, materials and time programme for the commencements and completion of construction or the provision (as the case may be) of each of the following matters, namely: (l) an environmental management programme as to measures to be taken, in respect of the Company's activities under this Agreement, for rehabilitation and protection and management of the environment.
9(1)	Subject to clause 10, if the Company at any time during the continuance of this Agreement desires to signficantly modify, expand or otherwise vary its activities carried on pursuant to this Agreement (other than under clause 12C) beyond those activities specified in any approved proposals it shall give notice of such desire to the Minister and within 2 months thereafter shall submit to the Minister detailed proposals in respect of all matters covered by such notice and such of the other matters mentioned in subclause (1) of Clause 6 as the Minister may require.
13(1)	The Company shall in respect of the matters referred to in paragraph (1) of the subclause (1) of Clause 6 which are the subject of approved proposals, carry out a continuous programme of investigation research and monitoring to ascertain the effectiveness of the measures it is taking both generally and pursuant to such approved proposals as the case may be for rehabilitation and the protection and management of the environment.

13(2)(a) and (b)	The Company shall during the currency of this Agreement submit to the Minister: (a) not later than the 30th day of June, 1998 and the 30th day of June in each year thereafter (except those years in which a comprehensive report is required to be submitted pursuant to paragraph (b) of this subclause) a brief report concerning investigations and research carried out pursaunt to subclause (1) and the implementation by the Company of the elements of the approved proposals relating to the rehabilitation, protection and management of the environment in the year ending the 30th day of April immediately preceding the due date for the brief report; and (b) not later than the 30th day of June 2000 and the 30th day of June in each year thereafter if so requested by the Minister from time to time, a comprehensive report on the result of such investigations and research and the implementation by the Company of the elements of the approved proposals relating to the rehabilitation, protection and management of the environment during the three year period ending the 30th day of April immediately preceding the due date for the detailed report and the programme proposed to be undertaken by the Company during the following three year period in regard to investigation and research under subclause (1) and the implementation by the Company of the elements of the approved proposals relating to the rehabilitation protection and management of the environment.
39(2)	Except as otherwise determined by the Minister and subject to the provisions of subclause (3), upon the cessation or determination of this Agreement all buildings, erection and other improvements erected on the land then occupied by the Company under the mining lease or any other lease, licence easement or other title made under or pursuant to this Agreement or held pursuant hereto shall become and remain the absolute property of the State . . .
39(3) (a) and (b)	(a) In the event of the Company immediately prior to the cessation or determination of this Agreement or within 3 months therefrom desiring to remove any of its fixed or movable plant and euipment or any part thereof from any part of the land occupied by it at the date of such cessation or determination it shall give to the State notice of such desire and thereby shall grant to the State the right or option excercisable within 3 months thereafter to purchase in situ such fixed or moveable plant and equipment at a fair valuation to be agreed between the State and the Company or failing agreement determined by arbitration under this Agreement. (b) If the State does not exercise the right or option referred to in paragraph (a) the Company may on the expiry of the 3 month period referred to, or sooner with the consent of the Minister, remove the fixed or movable plant and equipment to which the right or option refers.

Mining Act 1978	
Mining Lease 254SA	
Condition No.	**Closure conditions**
n/a	n/a

Native Vegetation Clearing Permit	
Permit No. 4716/2 (Transmission line)	
Condition No.	**Closure conditions**
10	Retain and spread vegetative material and topsoil The Permit Holder shall: (a) retain the vegetative material and topsoil removed by clearing authorised under this Permit and stockpile the vegetative material and topsoil in an area that has already been cleared. (b) within 12 months following clearing authorised under this permit, revegetate and rehabilitate the areas that are no longer required for the purpose for which they were cleared under this Permit by: (i) ripping the ground on the contour to remove soil compaction; (ii) re-shaping the surface of the land so that it is consistent with the surrounding 5 metres of uncleared land; and (iii) laying the vegetative material and topsoil retained under Condition 10(a). (c) within 4 years of laying the vegetative material and topsoil on the cleared area in accordance with Condition 10(b) of this Permit: (i) engage an environmental specialist to determine the species composition, structure and density of the area revegetated and rehabilitated; and (ii) where, in the opinion of an environmental specialist, the composition structure and density determined under Condition 10(c)(i) of this Permit will not result in a similar species composition, structure and density to that of pre-clearing vegetation types in that area, revegetate the area by deliberately planing and/or direct seeding native vegetation that will result in a similar species composition, structure and denisty of native vegetation to pre-clearing vegetation types in that area and ensuring only local provenance seeds and propogating material are used.
Permit No. 4914/1 (Pipeline)	
Condition No.	**Closure conditions**
n/a	n/a

Land Administration Act 1997	
Lease L21122. The installation or construction and the use, operation and maintenance of fibre-optic cables and associated repeater stations for rail radio communications and for ancillary and incidental purposes thereto in accordance with the Approved Proposals.	
Condition No.	**Closure conditions**
10.3 Yielding up	(a) On the expiration or earlier determination of the Term the Lessee must: (i) surrender peaceably and yield up the Land (and subject to clause 10.4 all improvements on the Land) to the Minister clean, free from rubbish and in a state of repair and condition as shall be consistent with the Lessee's covenants and obligations under this Lease, the Agreement and the Approved Proposals to the absolute satisfaction of the Minister; (h) The Minister, in the Minister's own name or as the attorney of the Lessee in the name of the Lessee, is entitled to institute all proceedings against any office or company which issues a policy of insurance required by other money payable under any indemnity in favour of the Lessor or the Minister. The Lessee appoints the Minister the attorney of the Lessee for that purpose.
10.4 Ownership of improvements upon determination of Term	(a) Except as otherwise determined by the Agreement Minister and subject to clause 10.4(b), when the Term expires or determines upon the cessation or determination of the Agreement all buildings erections and other improvements erected on or below the Land shall become and remain the absolute property of the Lessor without the payment of any compensation or consideration to the Lessee or any other party and free and discharge from all mortgages and other encumbrances. The Lessee shall do and execute and cause to be done and executed all such deeds, documents and other acts, matters and things (including surrenders) as the Lessor may reasonably require to give effect to the provision of the subclause. (b) In the event the Lessee immediately prior to the expiration or determination of the Term upon the cessation or determination of the Term upon the cessation or determination of the Agreement or within the following 3 months wishes to remove all or any of its fixed or moveable plant and equipment from any part of the Land the Lessee must give to the Lessor notice of such wish and must grant to the Lessor the right or option exercisable within the following 3 months to purchase in situ such fixed or movable plant and equipment at a fair valuation to be agreed between the Parties or failing agreement as determined by arbitration under the Agreement. If the Lessor does not exercise that right or option the Lessee may on the expiration of the 3 month period, or sooner with the consent of the Agreement Minister, remove the fixed or moveable plant and equipment to which the right or option relates.

Lease L21123. The construction, provision, extension, use, operation and maintenance on the Land of an accommodation village and for ancillary and incidental purposes thereto in accordance with the Approved Proposals.	
Condition No.	**Closure conditions**
10.3 Yielding up	(a) On the expiration or earlier determination of the Term the Lessee must: (i) surrender peaceably and yield up the Land (and subject to clause 10.4 all improvements on the Land) to the Minister clean, free from rubbish and in a state of repair and condition as shall be consistent with the Lessee's covenants and obligations under this Lease, the Agreement and the Approved Proposals to the absolute satisfaction of the Minister; (ii) undertake a program of rehabilitation of disturbed land (including making the land surface safe, stable and able to support a self-regenerating ecosystem) as shall be consistent with the Lease, the Agreement and the Approved Proposals to the satisfaction of the Minister; and (iii) remove and fixtures, fittings or any other property on the Land (other than casings for bores constructed in accordance with the Approved Proposals) as may be required by the Minister and the Agreement Minister (and whether before or after the expiration of any option period as referred to in clause 10.4(b)) to those Minister's absolute satisfaction; and (iv) promptly make good to the satisfaction of the Minister or the Agreement Minister (as the case requires) any damage caused by the removal in clause 10.3(a)(iii). (b) The Lessee's obligations under clause 10.3(a) shall survive the expiration or earlier determination of the Term.
10.4 Ownership of improvements upon determination of Term	(a) Except as otherwise determined by the Agreement Minister and subject to clause 10.4(b), when the Term expires or determines upon the cessation or determination of the Agreement all buildings erections and other improvements erected on or below the Land shall become and remain the absolute property of the Lessor without the payment of any compensation or consideration to the Lessee or any other party and free and discharge from all mortgages and other encumbrances. The Lessee shall do and execute and cause to be done and executed all such deeds, documents and other acts, matters and things (including surrenders) as the Lessor may reasonably require to give effect to the provision of the subclause. (b) In the event the Lessee immediately prior to the expiration or determination of the Term upon the cessation or determination of the Term upon the cessation or determination of the Agreement or within the following 3 months wishes to remove all or any of its fixed or moveable plant and equipment from any part of the Land the Lessee must give to the Lessor notice of such wish and must grant to the Lessor the right or option exercisable within the following 3 months to purchase in situ such fixed or movable plant and equipment at a fair valuation to be agreed between the Parties or failing agreement as determined by arbitration under the Agreement. If the Lessor does not exercise that right or option the Lessee may on the expiration of the 3 month period, or sooner with the consent of the Agreement Minister, remove the fixed or moveable plant and equipment to which the right or option relates.

Lease L21124. In accordance with the Approved Proposals, the construction, provision, extension, use, operation and maintenance of a railway and associated access road to extend the Lessee's Hamersley railway line from Marandoo to Yandi via Homestead Junction and for ancillary and incidental purposes thereto including to the extent permitted by Approved Proposals the construction, use, operation and maintenance of borrow pits and water bores.	
Condition No.	**Closure conditions**
10.3 Yielding up	(a) On the expiration or earlier determination of the Term the Lessee must: (i) surrender peaceably and yield up the Land (and subject to clause 10.4 all improvements on the Land) to the Minister clean, free from rubbish and in a state of repair and condition as shall be consistent with the Lessee's covenants and obligations under this Lease, the Agreement and the Approved Proposals to the absolute satisfaction of the Minister; (ii) undertake a program of rehabilitation of disturbed land (including making the land surface safe, stable and able to support a self-regenerating ecosystem) as shall be consistent with the Lease, the Agreement and the Approved Proposals to the satisfaction of the Minister; and (iii) remove and fixtures, fittings or any other property on the Land (other than casings for bores constructed in accordance with the Approved Proposals) as may be required by the Minister and the Agreement Minister (and whether before or after the expiration of any option period as referred to in clause 10.4(b)) to those Minister's absolute satisfaction; and (iv) promptly make good to the satisfaction of the Minister or the Agreement Minister (as the case requires) any damage caused by the removal in clause 10.3(a)(iii). (b) The Lessee's obligations under clause 10.3(a) shall survive the expiration or earlier determination of the Term.
10.4 Ownership of improvements upon determination of Term	(a) Except as otherwise determined by the Agreement Minister and subject to clause 10.4(b), when the Term expires or determines upon the cessation or determination of the Agreement all buildings erections and other improvements erected on or below the Land shall become and remain the absolute property of the Lessor without the payment of any compensation or consideration to the Lessee or any other party and free and discharge from all mortgages and other encumbrances. The Lessee shall do and execute and cause to be done and executed all such deeds, documents and other acts, matters and things (including surrenders) as the Lessor may reasonably require to give effect to the provision of the subclause. (b) In the event the Lessee immediately prior to the expiration or determination of the Term upon the cessation or determination of the Term upon the cessation or determination of the Agreement or within the following 3 months wishes to remove all or any of its fixed or moveable plant and equipment from any part of the Land the Lessee must give to the Lessor notice of such wish and must grant to the Lessor the right or option exercisable within the following 3 months to purchase in situ such fixed or movable plant and equipment at a fair valuation to be agreed between the Parties or failing agreement as determined by arbitration under the Agreement. If the Lessor does not exercise that right or option the Lessee may on the expiration of the 3 month period, or sooner with the consent of the Agreement Minister, remove the fixed or moveable plant and equipment to which the right or option relates.

YANDICOOGINA CLOSURE OBLIGATIONS REGISTER

Formal Commitments

Date	Commitment
n/a	No further formal commitments relevant to closure identified

YANDICOOGINA CLOSURE OBLIGATIONS REGISTER
Relevant Legislation

Closure planning and implementation requires consideration of general legislative requirements beyond those that apply to a specific site. A list of potentially relevant legislation is provided below, but is not necessarily exhaustive. A comprehensive legal review will be required as closure approaches to ensure that all relevant legislative requirements are identified.

Australian Commonwealth Legislation

Environmental Protection and Biodiversity Conservation Act 1999
Native Title Act 1993
Aboriginal and Torres Strait Islander Heritage Protection Act 1984
Workplace Relations Act 1996

Western Australian State Legislation

Environmental Protection Act 1986
Environmental Protection Regulations 1987
Environmental Protection (Controlled Waste) Regulations 2004
Environmental Protection (Unauthorised Discharges) Regulations 2004
Contaminated Sites Act 2003
Contaminated Sites Regulations 2006
Conservation and Land Management Act 1984
Mining Act 1978
Mining Regulations 1981
Parks and Reserves Act 1895
Rights in Water and Irrigation Act 1914
Wildlife Conservation Act 1950
Aboriginal Heritage Act 1972
Aboriginal Affairs Planning Authority Act 1972
Mines Safety and Inspection Act 1994
Mines Safety and Inspection Regulations 1995
Occupiers Liability Act 1985
Criminal Code Compilation Act 1913

YANDICOOGINA CLOSURE OBLIGATIONS REGISTER

Relevant Guidelines and Standards

Closure planning and implementation requires consideration of relevant guidelines and standards, some of which may have regulatory consequence through being referenced in regulatory documents. A list of key guidelines and standards that are routinely considered is provided below, but is not exhaustive due to the breadth of the closure planning discipline. This closure plan has been prepared so as to be considered with relevant content of these guidelines and standards.

Guideline or Standard	**Author**
Guidelines for the Preparation of Mine Closure Plans (2015)	Western Australian Department of Mines and Petroleum and Environmental Protection Authority
Leading Practice Sustainable Development Program for the Mining Industry - Mine Closure and Completion (2006)	Commonwealth Department of Industry Trade and Resources
Mine Rehabilitation Handbook (1998)	Minerals Council of Australia
Guideline for the Assessment of Environmental Factors: Rehabilitation of Terrestrial Ecosystems (2006)	Western Australian Environmental Protection Authority
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)	Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council
Mine Void Water Resource Issues in Western Australia (2003)	Western Australian Water and Rivers Commission
Contaminated Sites guideline series	Western Australian Department of Environmental Regulation
Environmental Notes on Mining: Acid Mine Drainage (2009)	Western Australian Department of Mines and Petroleum
Environmental Notes on Mining: Waste Rock Dumps (2009)	Western Australian Department of Mines and Petroleum
Safety Bund Walls Around Abandoned Open Pit Mines (1997)	Western Australian Department of Industry and Resources
Global Acid Rock Drainage Guide (2014)	International Network for Acid Prevention
Australian Standard 2601: The Demolition of Structures (2001)	Standards Australia
Australian Standard 4976: The Removal of Underground Petroleum Storage Tanks (2008)	Standards Australia
Demolition Work Code of Practice (2015)	Safe Work Australia

APPENDIX B

27. Appendix B Closure knowledge database report summaries

Rio Tinto Yandicoogina closure knowledge database

The closure knowledge database is a summary of the technical reports that directly or indirectly contribute to the development of the closure plan. These documents do not form part of the report and are for indicative purposes only.

The knowledge and understanding of closure issues and management strategies evolve and improved over time, coincident with the development of the mining operation. As a result, some components of some reports and studies may be superseded by new research or studies. While the closure plan addresses the current state of understanding and strategy for closure, the closure knowledge database captures the historical development of closure knowledge, and demonstrates how experience and knowledge developed at other Rio Tinto sites has been considered during the development of the closure plan and across the life of the operation. Accordingly, some information presented in the closure knowledge database may be obsolete.

Technical reports supporting the closure of the operation will be presented as part of the last plan produced prior to the implementation of closure (also known as the Decommissioning Plan).

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Geochemical characterisation

Review of Waste Rock Geochemistry a.General Overview of Acid Base Accounting — **2006**

This report contains a general overview of acid base accounting and a summary of the geochemical test work that has been previously completed for various sites and lithologies.

Internal reference: RTIO-PDE-0021130

There are large discrepancies in the total sulfur concentration measured using XRF and LECO machines. The XRF machine underestimates the sulfur concentration at values greater than 2%. Materials with total sulfur concentrations less than 0.1% can contain low capacity PAF material, however, it is considered only to be low additional acid and metalliferous risk if the boundary for inert material and potentially acid forming material is shifted from 0.02%S to 0.1%S. A paste pH result of less than 7 should be sent to the black shale dump and a paste pH result of greater than 7 can be sent to an inert material waste dump.

Yandicoogina Mineral Waste Risk Assessment: Acid Rock Drainage Potential — **2007**

Potential for acid and metalliferous drainage has been assessed for the Yandicoogina mine site.

Internal reference: RTIO-PDE-0033672

For all processed ore and waste at Yandicoogina Junction Central the overall acid and metalliferous drainage (AMD) risk is low to nil. Specifically, the AMD risk at Junction Central, Junction South East and Billiards deposits is considered low and the risk at Junction South West deposit is low to nil. The acid and metalliferous drainage risk is slightly greater (low to medium) at the Yandicoogina Snooker and Meander deposits. Elevated sulfur concentrations were found in the alluvium, weathered channel, alluvials and to a less extent in the Welli Wolli formation. The enriched elements for the various deposits mostly included Fe, As and Sn.

Mineralogical Analysis of Potentially Acid Forming Materials — **2008**

Quantitative mineralogy (QEM-Scan) for samples of rock collected from Tom Price, Channar, West Angelas, Brockman, Paraburdoo, East Extension, Western Turner Syncline and Hope Downs 1 North was undertaken. Comparisons were made between two methodologies use to characterise potentially acid forming materials; acid base accounting and mineralogical analysis.

Internal reference: RTIO-PDE-0053725

All samples contained elevated total sulfur concentrations and the lithologies were either shale, banded iron formation or dolomite. Pyrite was the dominant mineral contributing to acidity and the dominant sulfate secondary mineralisation consisted of alunite and jarosite.

Determination of ARD potential of Rio Tinto Iron Ore (WA) Waste Rock Samples — **2008**

This report investigates the use of mineralogy to predict acid and metalliferous drainage potential. Analysis of numerous rocks was undertaken using QEM-SCAN.

Internal reference: RTIO-PDE-0051613

Areas of waste rock which have underdone oxidation can be identified where sulfur-bearing minerals vary between samples in the form of pyrite, alunite and jarosite. The variability of gangue mineral phases suggest that some areas of composite waste rock pile may provide some neutralising potential while other areas will have no neutralising potential. Variable textural and mineralogical controls on sulfide mineral occurrence result in decreased accessibility of pyrite to oxidising fluids.

Contaminant Leaching from Non-Sulfidic Waste Material — **2011**

The available leach extract data and information pertaining to the distribution of metals and metalloids in non sulfur materials at neutral pH was reviewed. Based on this review conceptual models for controls on their leaching and mobility were developed.

Internal reference: RTIO-HSE-0145041

The review found that contaminant leaching from non-sulfidic materials was generally very limited. Usually the pH in leach tests was near-neutral (pH 6 to 8), and dissolved contaminant concentration were at or below detection limits. It is believed that a primary leachable contaminant source is the oxidation of sulfide minerals. Release from oxidising sulfides leads to release of soluble reaction products. Under neutral pH conditions, there is the potential for release of these contaminants when those products dissolve.

Environmental Status of Selenium (Se) in the Pilbara Region of Western Australia – Potential Risk from Iron Ore Mining **2011**

Internal reference: RTIO-PDE-0103857

This report includes information about Selenium geochemistry, distribution in the environment, occurrence in rocks in the Pilbara and potential risks to the environment.

The Selenium (Se) content of shales containing significant pyrite should be recorded as part of the overall risk assessment for acid and metalliferous mine drainage. However, it should also be noted Se solubility is far less constrained by pH than in the case of metals and near neutral drainage may contain significant Se concentrations in solution. It would be most useful to study the Selenium budget of the wetlands in the Pilbara as, apart from the chance poisoning of livestock from the consumption of plants that have taken up high concentrations of Selenium, impacts are most likely to be felt in wetlands receiving mine site drainage.

Contaminant Leaching from Low-Sulphur Waste Minerals (Summary) **2011**

Internal reference: RTIO-PDE-0090689

RTIO's Geochemical Database was reviewed and based upon this data, conceptual models for controls on the leaching and mobility of a range of metals and metalloids were developed. This summary also describes potential controls on the amount of dissolved element that may be released. This is a summary of a comprehensive report RTIO-PDE-0100104.

For most contaminants, dissolved concentrations at circum neutral pH (pH 6 to 8) were very low, typically at or below detection limit. Geochemical modelling indicates that water-rock interactions are controlled by equilibrium, for salt, carbonates and sulphates this equilibrium is often source term limited whilst hydroxyl-sulphates and hydroxides are solubility controlled. Results also indicate that sorption plays an important role in solute concentration; weak (but detectable) sorption occurred for selenium and zinc whilst the strongest sorption was evident for cobalt. The review suggested that storage waste facilities containing low-sulfur materials pose a low level of environmental risk however, there is a small risk of increased in mobility of some contaminants if acidic conditions arise. Acidic conditions can sometimes arise from the interactions between iron and aluminium hydroxyl-sulphates and hydroxides.

Preliminary results of geochemical characterisation of Yandicoogina samples **2012**

Internal reference: RTIO-PDE-0109618

This memo summarises the results of preliminary solid extra element analysis, short term liquid extract/leach testing and phase 1 acid base accounting (ABA) completed on samples obtained from the Yandi Junction South West (JSW) drilling programme completed in June 2011 and grab samples selected by mine geology in 2009 and 2011 from Junction Central (JC) and Junction South East (JSE).

The results indicate that soluble metals/metalloids are generally below the trigger values outlined in the ANZECC water guidelines and Yandi background water values. Where there are exceedances, the trigger values (normally associated with ANZECC water guidelines for 95% protection of freshwater species) were lower than the detection limits used in the analysis. All samples were above drinking water trigger values and stock water guideline trigger values.

RTS058 Geochemical testwork on Low Sulfur samples from Yandi (Phase 1 and 2) **2012**

Internal reference: RTIO-PDE-0099036

This testwork undertakes geochemical characterisation (ABA and leach testing) on Yandicoogina samples (RC, Grab, tailings) to support the assumption that low grade and waste material is unlikely to pose an environmental risk. This work was conducted to support the Yandi JSW approvals.

Reverse circulation (Junction SW) and grab (Junction Central/SE) samples had negligible sulfur content (<0.1%) and were confirmed to be Non Acid Forming (NAF) and had little neutralising capacity. The exception were samples from the alluvium, where there is neutralising capacity that could counter any acid formed. All samples were enriched (when compared to the average crustal abundance) in As, Au, Bi, Sb, Se and Hg though static leach testing has indicated that these elements were not readily leached upon contact with water. For waste fine samples there was negligible sulfur (><0.04%) and all were confirmed to be NAF. Similar to the RC and grab samples, the waste fines samples were enriched in As, Au, Se and Hg, though these elements were not readily leached. The supernatant solution from the waste fines samples were also tested. The pH of the solutions were neutral and were chemically similar to leaches of the waste fines solids. High Fe and Al concentrations in the leach tests were deemed to be in excess of the solubility limits and it is assumed that the elements were present as colloids rather than being dissolved. Follow up testing will be conducted to confirm

RTS058 Yandi Project: Geochemical Testwork on Low Sulfur Samples - Supplemental Samples **2013**

Internal reference: RTIO-PDE-0103854

This work was carried out to test the assumption that low grade and waste from Yandicoogina is unlikely to pose a risk to the environment. This report discusses the results of 19 additional samples supplementing the initial batch of 95. See RTIO-PDE-0099036 for additional information.

The 18 waste rock samples submitted for analysis this time around have been characterised as having low sulfur contents ranging from below the detection limit to 0.26%. The sulfur is either present as sulfides or more likely sulfates and were classified as non-acid forming (NAF) or Uncertain (UC-NAF), having little to no neutralising capacity. Minor and trace elements that were enriched compared to the average crustal abundances include As, B, Bi, Sb, Se and Tl, with element leachability generally limited in pH neutral de-ionised water. One (1) tailings sample was submitted with the results similar to the tailings samples submitted initially. The sample had negligible sulfur and was classified as NAF-Barren due to little to no neutralising capacity. The only enriched minor or trace element was Se and once again the leachability of elements was generally low.

Assessment of Yandicoogina water quality at closure **2013**

Internal reference: RTIO-PDE-0113542

This Technical Memorandum addresses the potential leachability of minor and trace element from backfill materials, and the effects of evaporation on the concentrations of these elements. The report includes an overall water quality assessment for the site based on historical minor and trace elements records, a review of leach tests conducted on Yandi materials, and limited conceptual modelling to illustrate the potential effects of evaporation on water quality and minor and trace element concentration.

The 2011-2013 dataset indicates that in general groundwater at Yandi is of HCO3 type with pH values ranging from 6.7 to 8.3. No clear segregation between alluvium and the deeper CID aquifer was observed in terms of salinity. No changes in salinity or major-ion chemistry were observed. Trace elements such as As, Cr, Ni, Sb and Se have been detected. Poor correlation between reported TDS and EC values was identified in the data. Recent nitrogen exceedances observed at the site appears to originate at surface water discharges, potentially from wash down bays. The water quality data suggests Pilbara creeks have different properties; Marillana Creek is circum-neutral to slightly alkaline, Weeli Wolli Creek is slightly alkaline, while Homestead Creek (not located in catchment area) is neutral. Total dissolved solids indicate that Weeli Wolli is slightly fresher than Marillana Creek. Leach test results suggests that most elements will be mobilized in an initial flush of water from significant rainfall events. Modelling results indicated that groundwater is supersaturated with respect to CO2. Thus, degasing of CO2 may occur as groundwater equilibrates with the atmosphere and mixes withh pore waters from backfill materials; which in turn would increase pH from ~7.4 to ~8.6. A second evapoconcetration phase could drive CO2(g) to exsolve, such that pH could increase to as high as 9.1. These conditions would influence trace element mobility.

RTS058 Yandi Project: Geochemical Test work on low sulfur samples – supplemental leach testing **2013**

Internal reference: RTIO-PDE-0110708

This work forms part of ongoing geochemical characterisation. Leach test, work presented in this report, explored contamination under a wider range of geochemical conditions, following work completed in August 2012 and January 2013.

Mineralogical assessment was completed on 11 waste rock samples and 1 tailings sample. The composition of all leachates was comparable, irrespective of test conditions. The solutions were circum neutral (pH between 7.8 and 8.5 for waste rock and pH 6.5 to 7.6 for tailings) and dilute (average EC approximately 650 uS/Cm for waste rock and 70uS/cm for tailings). Readily detectable elements included major elements: Ca, Mg, Na, K, Cl, Si and SO4 and trace elements AL, B, Ba, F, Fe, Sr and Zn. As expected, the highest concentration of elements were recorded in low L:S leach tests, the majority of which were source term limited (ie very low masses were present and are expected to dissolve completely during the test.) Test work and PHREEQC modelling indicated that AL, Ba, F and Si may be subject to a solubility control in the waste rock samples. In the tailings sample, low but detectable concentrations included: Cd, Cu, Pb, Mn and Ni.

Geochemical Assessment of Tailings from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J **2014**

Internal reference: RTIO-PDE-0123030

This report presents the results from geochemical testing and saline solution extraction of tailings samples from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J deposits.

Overall the tailings from these operations are unlikely to generate acid and are not expected to leach significant levels of metals under oxidising or saline conditions.

Oxidation and solute accumulation in dewatered pit wall rocks **2014**

Internal reference: RTIO-PDE-0109045

Dewatering and removing the water table may result in de-saturation of sulphide-bearing lithologies. This study was undertaken to review how oxygen ingress and consequent sulphide oxidation of Mount McRae Shales could impact water quality when the groundwater table rebounds after mining.

Large Scale Column Construction Procedure and Initial Chemistry **2014**

Internal reference: RTIO-PDE-0123894

Large scale column experiments have been constructed to examine the reactivity of hot and cold black shale material in an operational environment. The memo describes the construction of the columns and the first geochemistry data collected after small rainfall events at Rhodes Ridge.

Initial results suggest that effluent water retains the chemistry of the incident rainfall. Constituents to note in the initial chemistry include nitrate and ammonia detected in the hot black shale effluent. This study provides an important comparison between laboratory characterisation studies and field reactivity of waste rock. Data from the large scale column tests can be applied to reactivity of in pit waste/talus as well as waste rock dumps. It can be used as an intermediate to predict long term reactivity of waste rock.

Physical characterisation

Yandi Geology: Stratigraphy, Lithology, Chemistry, Alterations and modelling parameters — 2004

Internal reference: RTIO-PDE-0012215

This report describes in detail the geology of the Yandi area. Detailed litho-chemical descriptions of each unit are included along with modelling parameters current as of March 2004. Also included are stratigraphic columns, which illustrate the time relationships between the various units. Finally, a table illustrating the main alteration types encountered in the Yandi area, which are routinely logged, are also included for reference.

The Yandicoogina (Yandi) iron ore reserves form part of an extensive series of Channel Iron Deposits (CID) located in the eastern Hamersley Province of the Pilbara region in northwest Western Australia. The ores commonly outcrop as a series of low mesas beside the Marillana, Yandicoogina and Weeli Wooli Creeks and are commonly referred to as “pisolitic limonites” (England 1998). CID is a collective term allocated to material comprising concentric shells of limonite and vitreous goethite (Fe203.H20) around nuclei of hematite (Fe203), goethite, turgite (Fe203.nH20) and iron oxide replaced wood that have accumulated in palaeo-river channels. CID are characterised by the presence of fossilised wood fragments and absence of lithic rock fragments within ore. HI geologists have subdivided the CID into 6 main material types: Eastern Clay Conglomerate / Laterite - Mottled orange-brown and grey-white clays (after dolerite), BIF and ferricrete fragments. Weathered Channel - Partially lateritised upper surface of the CID, which is silicified and penetrated by clay filled solution pipes, but still retains recognisable CID texture. SiO2 & Al2O3 are elevated at the expense of Fe in the weathering process. Goethite Vitreous Upper (GVU) - The Upper Ore Zone is approximately 20m thick and is moderate in silica and low in alumina. The GVU is slightly magnetic with confirmed presence of kenomagnetite. It is thought this zone was above the palaeo-watertable. Goethite Vitreous Lower (GVL) - The Lower Ore Zone is low in silica, moderate in alumina, and approximately 25m thick. It is thought this zone was below the palaeo-watertable. Limonite Goethite Channel - This material forms the footwall of the orebody. It is a clay-rich, leached, yellow, ochreous goethite (limonite) zone. It contains occasional lenses of CID material. Basal Conglomerate – This basal clastic facies of the channel unconformably overlies the Weeli Wolli Formation. The unit varies in thickness from a few centimetres up to 8m and is generally only present in the centre of the channel. The GVU and the GVL are the only units that currently fall within economic mining parameters.

Net solute load response to the installation of infiltration limiting dry cover systems over acid forming waste piles — 2014

Internal reference: RTIO-PDE-0128431

This work was conducted to verify the central design concept of store-and-release covers over sulfidic above water table waste dumps that is, whether limiting net percolation volume through the cover results in a lesser sulfate and acidity load being realised generated and passing through the dump.

The results from this thesis project confirm that the central aim of store-and-release covers to reduce net percolation volume is a valid measure for reducing the net loading of sulfate and acidity. The mechanism through which decreasing net percolation (applied water volume) results in a lesser sulfate and acidity load was identified, however further work in a site context is needed to assess how this relationship between percolation volume and loading persists in the real-world environment.

Groundwater

Hydrogeology review for proposed HI (Yandi) extended mine closure plan — 1998

Internal reference: RTIO-HSE-0070352

This report reviewed the hydrology and hydrogeology of the eastern section of the Channel Iron Deposit (CID) in the palaeo-valley of Marillana Creek, known as the Junction Deposit mine. (Note: The impacts of several closure options are discussed, but may now be invalidated by subsequent expansion activities.)

The principal aquifer in the area of the Junction Deposit is the CID itself with a transmissivity of about 3500 m2/d and estimated throughflow of 2.5 to 3 ML/d. Alluvium beneath Marillana Creek is an aquifer of lesser importance, because of a smaller cross-sectional area and lower hydraulic conductivity. Water levels in the CID are controlled by recharge from Marillana Creek. Marillana Creek normally flows for a period of only 30 to 60 days following heavy rain. During these periods the creek loses water to underlying alluvium. In several places the creek alluvium overlies the CID, which is also recharged by the creek flow. Streamflow loss in the area of the Junction mine during the first flow in the wet season is estimated to be at least 100 ML per kilometre of length along the creek bed. The loss of water by evapotranspiration from pools and riparian vegetation near the Junction mine is estimated to be 0.3 ML/d from each kilometre of the creek bed.

HI Yandi: Phil's Creek and Hairpin Dewatering Borefield Installation Program 2002 — 2002

Internal reference: GDSR 4397

This report examines the hydrogeological characteristics of the intersection of Phil's Creek CID and Marillana CID within the Hairpin area.

The primary targets of new dewatering bores has been cavernous intersects within the Limonite Goethite Unit (situated below the Main Ore Zone) within the Channel Iron Deposit. Transmissivity values derived from the new bores at Hairpin and Phil's Creek indicate that the hydraulic characteristics of the CID aquifer in each of these areas has been influenced by a progressive reduction in the saturated thickness of the aquifer since dewatering commenced. A numerical groundwater model has been constructed based on this field work and is being used to complete a review of the closure impacts at Yandi.

Yandicoogina Water Balance - Pre and Post Mining Hydraulics and Hydrochemistry **2010**

Internal reference:
RTIO-PDE-0073467

The study was undertaken to: update the conceptual hydrogeological model; define the pre mining and current groundwater conditions and hence impacts from mining operations on the flow system; determine the importance of creek seepage into the CID aquifer and mine pits; and provide information on water quality and quantity.

The groundwater level response to changes in the water budget due to natural and human induced processes is immediate, suggesting good connection between various aquifers and creek systems. Long term observations indicate water levels can rise by up to 10m in the CID aquifer after intense rainfall events. This translates to approximately 16GL of water and can be as high as 30GL per event over a 25km length of Marillana Creek. The chloride (Cl) concentrations show 20% of water discharged from the mine is lost by evaporation and evapotranspiration. As a result CID salinity increased by 20% up to the 12km down gradient from Junction Central, beyond which no increase in Cl concentration was observed.

Yandicoogina hydrogeological assessment of the CID & adjacent floodplain **2010**

Internal reference:
RTIO-PDE-0071209

This hydrogeological investigation was undertaken to mining at Oxbow, Junction South West (JSW) and the northern end of Junction South East (JSE). The principal objective of the study was to gain a better understanding of the hydrogeological setting of the Yandicoogina region.

This hydrogeological investigation obtained aquifer parameters for Oxbow and JSW, surface water groundwater interaction, and estimates of dewatering volumes for Oxbow and JSW. Drilling outside the CID aquifer revealed that the material surrounding the CID aquifer in the flood plain is unconsolidated alluvium or in situ weathered Weeli Wolli Formation bedrock. Regardless of the weathering history and origin of the deposits, the material is characterised by hydraulic properties that allow for leakage to the CID, and that this leakage may be greater than previously anticipated. The thickness of the flood plain material at JSW and Oxbow is variable (20 - >50m) depending on elevation and proximity to Marillana Creek.

Yandicoogina hydrogeological assessment of the CID & adjacent floodplain - Bore Installation, test pumping and analyses 2008/09 **2010**

Internal reference:
RTIO-PDE-0071209

The principal objective of the study was to gain a better understanding of the hydrogeological setting of the Yandicoogina region. The hydrogeological investigation focused on obtaining aquifer parameters at principally Oxbow and JSW, surface water groundwater interaction, and estimates of dewatering volumes for the proposed expansion sites.

Drilling outside the Channel Iron Deposit (CID) in the floodplain of Marillana Creek revealed that the material surrounding the CID aquifer in the flood plain is unconsolidated alluvium or in situ weathered Weeli Wolli Formation bedrock. Regardless of the weathering history and origin of the deposits, the material is characterised by hydraulic properties that allow for leakage to the CID, and that this leakage may be greater than previously anticipated. The minimum thickness for the floodplain material that occurs adjacent to the CID deposit is estimated from drilling at JSE to be 37m. The thickness of the flood plain material at JSW and Oxbow is variable (20 - >50m) depending on elevation and proximity to Marillana Creek. Hydraulic connection between the flood plain, the weathered basement and the CID aquifer was confirmed during the test pumping program, where constant rate test pumping showed that the bores installed in the flood plain sediments or weathered basement of the Weeli Wolli Formation adjacent to the CID respond to pumping in the CID aquifer. The CID hydraulic conductivity for was calculated between 3m/d and 25m/d, with an average of roughly 9m/d. Specific yield was more difficult to determine from testing but ranged over two orders of magnitude from 0.01 to as high as 0.3. Yield from the constant rate pumping tests ranged from 60L/s up to 100L/s (the upper limit of the pumping equipment).

Yandicoogina Operations Groundwater Operating Strategy **2012**

Internal reference:
RTIO-HSE-0057642

All water licences contain a set of terms and conditions detailing the licensee's responsibilities and specifying the volume of water that may be taken in any given year (the water entitlement or allocation). This groundwater operating strategy describes how groundwater is managed at the Yandicoogina operation to comply with licence conditions and is a condition of the water licence. As such the report is updated regularly to reflect current operating practice.

Yandicoogina operate several borefields in order to supply drinking water and dewater aquifers ahead of mining. The volume of water abstracted is in excess of site requirements and several discharge outlets are used to dispose of excess water to adjacent creek systems. The plan specifies monitoring activities to include groundwater water levels, electrical conductivity (EC), pH and temperature sampled from selected bores, and total volumes, nutrients (Total-P, Total-N, NO3 and NH3) and metals (Se and Hg) at discharge outlets. Other parameters sampled include Na, K, Ca, Mg, Cl, CO3, HCO3, SO4 and NO3 from some bores and at some discharge outlets and within the local creek system pH, EC, TDS, TSS, Al, Ca, Mg, Na, K, SO4,Pb, Cu, Fe, Mn, Mo, Zn, As, Cd, Cr, TRH.

Surface water

Marillana Creek catchment hydrology and local catchment impacts Yandicoogina +52 Mtpa Expansion Prefeasibility Junction South West (Stage 1) and Oxbow deposits **2008**

Internal reference: RTIO-PDE-0047262

This report describes the hydrology of Marillana Creek past the Oxbow and JSW deposits and provides a conceptual surface water management plan for local, natural surface water runoff.

Flow volumes along Marillana Creek at Oxbow and JSW deposits range from 60 m3/s for a 1 in 2 year average recurrence interval (ARI) to 4700 m3/s for a 1 in 500 year ARI event. Flood protection for the Oxbow and Junction South West deposits is required to minimise the environmental impacts, continue natural flows where possible and protect the pit and pit walls from surface water runoff. A protection level of between 1 in 20 and 1 in 100 year ARI is recommended. Diversion of natural surface water runoff away from the active mine areas from local catchments will be required as part of the mine plan.

Yandicoogina Surface Water Management Report **2010**

Internal reference: RTIO-PDE-0072516

This report describes the interaction between natural surface water runoff, the local environment and the Yandicoogina mine during operations. Closure management is not addressed in this report.

Environmental issues relating to surface water at the Yandicoogina Operation include the potential for surface water runoff from the operation to become contaminated and discharge into the environment, and alteration of natural surface water flow by structures/operations, thereby affecting downstream vegetation or causing flooding/ponding upstream. Management actions implemented at the mine include treatment of surface water prior to discharge into the natural environment and maintaining natural drainage patterns where possible. Yandicoogina mine activities encroach on regional and local floodplains of Marillana Creek and its tributaries. To manage flood risks during the wet season, Yandicoogina JC and JSE currently employ a combination of “sump and pump” and “diversion” surface water management strategies. Sumps are dewatered with portable and permanent pipe and pumping systems. Diversion levees and channels are employed around the JC and JSE operations to prevent flooding from surface water runoff and to minimise pit wall instability associated with runoff flowing uncontrolled over the pit crest. Expansion of the current mine operation will further encroach into regional and local floodplains of the Marillana Creek, Weeli Wolli Creek catchments and their tributaries, necessitating additional surface water management requirements.

Marillana Creek regional flow balance and catchment hydrology **2010**

Internal reference: RTIO-PDE-0081939

At the cessation of mining pit voids adjacent to and intercepting local tributaries to Marillana Creek, Marillana Creek floodplain and possibly Marillana Creek proper may collect or divert tributary flows, while others may only collect local surface water runoff and incident rainfall. This report assess how the hydrological regime of the Marillana Creek catchment will be altered when mine closure and rehabilitation activities are completed at Yandicoogina and BHPIO Yandi mines.

Modelling suggests that the truncation of local creeks associated with leaving pit voids will change the flood frequency and thus lower flood potential within Marillana Creek. For example, at the terminus of Marillana Creek bank full conditions, the maximum capacity of the creek within the banks, will reduce from a 10 year average recurrence interval (ARI) to a 20 year average recurrence interval; such that overbank flooding will only occur after an event greater than a 1 in 20 year ARI. This flood regime change will affect sections of the creek that support riparian vegetation such as Eucalyptus camaldulensis (River Red Gum), whose existence is associated with surface flooding characteristics.

Marillana Creek Regional Flow Balance – Pre and Post-mining comparison **2010**

Internal reference: RTIO-PDE-0072519

A study of the regional flow balance of the Marillana Creek catchment was carried out to identify and compare the response of the catchment to different storm events under pre and potential post-mining conditions. The study presumes BHPIO and RTIO will divert Marillana Creek flows around their deposits while truncating some tributaries.

It was determined that under pre-mining conditions Marillana Creek would flow on average 200 days per year. Continuous flow was recorded at Flat Rocks between 2000 and 2004, with over 350 flow days recorded per year during that period. This may attribute to creek bed interflow which enables water to return to the surface during dry periods and the potential storage capabilities of the retention basins located in the Upper Marillana Creek catchment. The study demonstrated that the creek system would experience approximately 27% reduction in flow contribution at closure, with the RTIO and BHPIO Yandicoogina mine operations individually accountable for 17% and 10% of the total flow reduction. The flood peaks for all ARI rainfall events would also decrease by approximately 50% at the catchment outlet. The cumulative impacts associated with flow reduction and change in catchment water balance post-mining would modify the flood regime and reduce the flooding potential of the creek system. This may result in decreased water availability for riparian ecosystems on floodplains and ultimately lead to biodiversity change within the creek

Baseline hydrology assessment for Yandicoogina discharge **2012**

Internal reference: RTIO-PDE-0074001

This baseline hydrological/hydraulic assessment was carried out to access the existing situation and movement of discharged water along the creek systems and to predict the likely behaviour of the released water for various discharge scenarios. Closure implications are not addressed in this report.

The assessment demonstrated that historically discharged water would not have extended past the Marillana Creek catchment outlet at the confluence with Weeli Wolli Creek; hence anecdotally no flow contribution to Weeli Wolli would have been expected. This suggests the wetting front in Weeli Wolli Creek is likely to have resulted from surplus water discharged from the Hope Downs 1 mine operation. A discharge footprint of 16.3km down gradient from the Weeli Wolli – Marillana Creek confluence was estimated for the maximum modelled 110GL/year regional surplus discharge (based on existing infrastructure). An option to relocate the discharge location in Marillana Creek down gradient from the mine operations would extend footprint to approximately 6.7km to 17.3km down gradient from the Weeli Wolli – Marillana Creek confluence for modelled volumes of 55GL/year to 110GL/year.

Weeli Wolli Creek hydrology and floodplain assessment **2013**

Internal reference: RTIO-PDE-0117748

This flood study defines the hydrological regime and natural flow conditions for Weeli Wolli Creek and investigates several conceptual flood protection levee options for safe mining of the Billiard South deposits within the Weeli Wolli Creek floodplain.

A RORB rainfall runoff model was developed and calibrated to observed data at gauging stations within the regional Weeli Wolli Creek catchment. The calibrated RORB model was used to simulate design flood peaks and hydrographs for the study area. The expected 2, 1 and 0.5 % AEP flows estimated for Billiard South are 2200 m3/s, 4070 m3/s and 4900 m3/s, respectively. The 0.5 % AEP event was selected as the design standard for the levees based on the expected 20 to 30 years of operational life of the infrastructure. The modelling suggests that flood protection may require levee heights, depending on the alignment, ranging from 4.8 m to 6.5 m.

Water interactions and pit lakes

Impacts of mining and mine closure on water quality and the nature of the shallow aquifer, Yandi Iron Ore Mine. Masters Thesis **2002**

Internal reference: GDSR 4746

This study was completed as part of a Masters of Science qualification at Curtin University of Technology. The study aimed to: determine the current water quality in the aquifers; predict future water quality after waste rock from the mining has been returned to the channel; and predict the physical properties of the groundwater system after the waste has been returned to the channel, with a focus on assessing changes in permeability occurring as a result of siltation or secondary mineral formation.

Overburden material that will constitute the backfill was found to have high concentrations of (by material type) Alluvium - As, Fe, Se, Sb, Ba, Te; Eastern clay conglomerate - Pb, Mo, Fe, As, Se, Te, Sb, Ba; and Weathered channel horizon - Mo, Fe, Sb, As, Se, Ba. The Weathered channel horizon was found to contain bands of smectite clay. This clay is known to swell when wet up to 20 times its dry volume. This may impair the permeability of an aquifer with significant amounts of this clay. A solution with a high sodium chloride concentration may inhibit this swelling. The current groundwater quality is slightly acidic or slightly alkaline, and is typically of calcium/magnesium bicarbonate to sodium carbonate. The majority of the bores sampled met the Australian guidelines for potable water with sample three exceedances noted for pH and Pb. The leachate tests indicated: pH may rise towards 8.4 due to the buffering of carbonate minerals; TDS may increase as soluble minerals dissolve into the groundwater; conditions for anoinic elements such as antimony, arsenic, cobalt, chromium, gallium and molybdenum will become more favourable due to the rise in pH; minerals such as diaspore, leonhardite, quartz, ZnSiO3 and hematite will start to precipitate as they become saturated in solution; some elements will reduce in concentration as minerals are precipitated. (Four backfill and landform shaping options were also reviewed as part of this work, however, these options are invalidated by the expansion of the site.)

Yandicoogina closure options: preliminary water modelling results **2012**

Internal reference: RTIO-PDE-0103618

This document intends to provide the basis of a technically defensible, integrated closure plan with respect to managing water quantity and quality post mining at Yandicoogina through the use of water balance modelling. The main objectives for water management at closure will be: to create stable landforms, maintain surface water and groundwater throughflow (albeit with no pre-determined water table elevation), and maintain surface water and groundwater quality to within acceptable limits for the agreed post closure land uses. Salinity levels post-closure were modelled for various scenarios: All pits left open (No Backfill Option) The mining of a complete channel as an open void (Continuous Channel Option) The combination of mining Oxbow, Junction Southwest A and Junction Southwest C pits as open voids and the partial backfilling of Junction Central, Junction Southeast Extension and Billiard South to specified levels (Selected Backfill Option) The mining of individual pits, achieving in-pit backfill to 2m above pre-mining ground water level (Complete Backfill Option)

Water balance modelling results showed the No Backfill Option with open pits act as sinks for groundwater. As such, water cannot leave these pits and salt levels increase, creating a hypersaline environment. The Continuous Channel Option assumes that a creek and lake system is established at the base of the mined out pit from which water would flow into the undisturbed Weeli Wolli Creek channel. Evapo-concentration of salinity is low and the water quality remains fresh—pit salinities of 130mg/L assuming natural creek salinities of 50mg/L. This is because discharge through the system exceeds evaporation. The Selected Backfill Option seeks to optimize the limited backfill material available. Water levels in the backfilled pits reflect the backfill level. After rainfall events, evaporation occurs which quickly reduces water levels back to the backfill level from which no further evaporation occurs. Groundwater throughflow is maintained and the area in which evaporation can occur is reduced, thereby reducing salinity to around 4,800mg/L. However with additional strategic use of remaining backfill, water quality may be improved. Water modelling of the in-pit backfill to 2m above pre-mining water table indicated salinity could increase to 3,800 mg/L at the Billiard pit. This was because the modelling showed the water table would fluctuate and rise more than 2m above the pre-mining water table, exposing the water table to evaporation processes. Diverting surface water into the pits to decrease salinity induced dilution temporarily, but only by 1000mg/L at the Billiard pit. Surface water management studies showed that a combination of diversion drains, bunding and backfilled pit sections (landbridges) will be required to manage surface water drainage during mining. However no recommendations for post-closure management were developed. An internal review of other closure requirements will be necessary to identify the preferred post mining landform option.

"Impacts of mining and mine closure on water quality and the nature of the shallow aquifer, Yandi Iron Ore mine" by Sean Gardiner: Background to study and summary of findings **2012**

Internal reference: RTIO-PDE-0103858

This document summaries the background to, findings and / or relevance of a geochemical investigation of waste rock at Yandi that was undertaken as a part of a study conducted by Masters Student Sean Gardiner from Curtin University of Technology.

The MSc thesis presents considerable information on groundwater quality in the vicinity of Yandi Mine at the time of the study (1998). Whilst, it gives some useful information on the local geochemical background in one area of the Pilbara region it is of insufficient scope to provide meaningful scale to any potential geochemical contamination.

Closure and water strategy synergies at Yandicoogina **2013**

Internal reference: RTIO-HSE-0201688

This memo records a facilitated discussion which looked at opportunities for additional or alternative water disposal options that facilitate closure.

An opportunity to dispose of surplus water by creating pit lakes in the Yandicoogina mined out voids before the planned closure was identified. This concept would require in pit waste dump landscaping / shaping activities to commence as soon as practicable. Water would then be disposed into the void, to create the lake. Appropriate wetland revegetation activities could then commence around the lake fringe. Groundwater re-circulation volume would increase as a result of this activity; however the environmental benefit are anticipated to outweigh the re-circulation impact.

Oxbow Pit Lake – Stochastic salinity and water level conditions post closure **2013**

Internal reference: RTIO-PDE-0116562

The report presents the outcomes of a simple water balance developed to simulate the behaviour of water in Oxbow Pit, based on a 2013 Yandicoogina Closure Groundwater Model.

The predictive model estimates that the steady state water level in Oxbow pit will fluctuate around 514m RL with no likelihood of the pit overtopping. Total Salt Load and salinity continue to slowly rise, reaching approximately 8.7 ×108 kg and 26,000mg/L respectively after 2000 years. If a 30% smaller pit shell is used (within the error range of the groundwater model) values are more likely to fluctuate around 528mRL. It is unlikely the smaller Oxbow pit will overtop; only 14 of the 100 realisations run over a 2000 year period overtopped the pit on at least one occasion. Total salt load and salinity stabilise after 400 years at approximately 1.2 ×108 kg and 2,700 mg/L respectively.

Technical Memorandum: Laboratory modelling for Yandi Selenium concentration **2014**

Internal reference: RTIO-PDE-0118277

This study reviews the potential effect of evaporation on selenium concentration increases in surface water environments and/or during development of mine pit lakes based on water samples from the Yandicoogina Oxbow area. The study includes laboratory scale experiments to measure changes in selenium concentrations, with different acidity levels, by simulating the process of evapoconcentration.

Findings to date show background selenium concentrations on average at<0.002mg/L from Yandicoogina bores. The modelling results showed that Se > 0.01mg/L (the ANZECC 95% limit for the aquatic ecosystems) was measured when evapoconcentration levels exceeded 93.75%. At 98% evaporation Se >0.055mg/L (the ANZECC 80% limit for the aquatic ecosystems) was measured. Changes to pH did not appear to influence the Se results, although a slight increase in general cations was observed under acidic conditions.

Flora

Flora and Vegetation Yandicoogina Junction Area **1995**

Internal reference: RTIO-HSE-0057043

This report summaries the results of a vegetation survey completed of the Yandicoogina Junction area.

A total of 57 plant families and 336 vascular plant species were recorded. No declared or priority flora species were located. Acacia (Mimosaceae), Cassia (Caesalpiniaceae) and Triodia (Poaceae) dominate the vegetation of the Yandicoogina Junction area. A total of 18 plant communities were defined, of these the plant communities of significance are: the Woodlands of Eucalyptus camaldulensis, selected flats and the restricted and localized low shrubland of Eremophila spp, Senna spp and Acacia spp.

Flora and Vegetation Northern Transport Corridor Yandicoogina Junction Project Area **1995**

Internal reference: RTIO-HSE-0014649

This report summaries the results of a vegetation survey completed for the Northern Transport Corridor option for the Yandi Junction Project area.

A total of 57 plant families and 334 vascular plant species were recorded. No declared Rare Flora were located. 2 priority flora speices were recorded; Triumfetta sp. Rudall subsp. Woodstock and Goodenia stellata. Acacia (Mimosaceae), Cassia (Caesalpiniaceae) and Triodia (Poaceae) dominate the vegetation of the transport corridor. A total of 22 plant communities were defined, of these the plant communities of significance are: selected flats supporting Hummock Grasslands due to their species richness.

Yandicoogina Railway Drainage Shadow Monitoring 2001 **2001**

Internal reference:

Drainage shadow monitoring on Hamersley Iron's Yandi railway commenced in 1998. The monitoring program was designed to assess whether construction and operation of the railway had any indirect impact on the survival and health of Mulga, Acacia aneura. It was postulated that downslope impacts in the drainage shadow area might occur, with limited upslope impacts due to flooding also considered.

The results show that although numbers of all mulga age classes and dead mature mulga appeared to be higher in the upslope transects in 2001, none of the results could be interpreted as indicating a difference between them and the downslope transects. However, it was not possible to draw any clear links between vegetation dynamics and the presence of the railway line, and it was recommended monitoring continue.

Yandicoogina Railway Drainage Shadow Monitoring 2002 **2002**

Internal reference:

Drainage shadow monitoring on Hamersley Iron's Yandi railway commenced in 1998. The monitoring program was designed to assess whether construction and operation of the railway had any indirect impact on the survival and health of Mulga, Acacia aneura. It was postulated that downslope impacts in the drainage shadow area might occur, with limited upslope impacts due to flooding also considered.

Similar trends were observed to previous years, with few statistical difference upslope and downslope of the railway. The Highway transects appears to have reached a successional stage where the number of mature mulga have increased, dead mature mulga have decreased and there is some recruitment occurring.

Yandi Expansion Areas Rare Flora Survey - Feb 2003 **2003**

Internal reference: RTIO-HSE-0014711

This document provides a description of the survey methodology and findings of the rare flora survey of the Yandicoogina expansion area.

Large portions of the study area had been either burnt or disturbed in the last few years. Vegetation types varied considerably with landform and included Artistida grassland in disturbed borrow pits, mulga shrublands on clayey plains, hummock grasslands with shrub over storeys of varying density on stony hills and eucalypt woodlands within the Marillana Creek. No declared rare fauna were recorded from the 6 areas surveyed. Six priority flora were recorded from the expansion area. Several mounds of the priority 4 Western Pebble-mound Mouse, Pseudomys chapmani, were recorded, some of which may be active. Two uncapped drill holes and a small fenced area containing numerous bags of aboriginal stone artefacts were located during the survey.

Yandi Mine Expansion Rare Flora Survey **2003**

Internal reference: RTIO-HSE-0014739

This report summaries the results of a survey for flora of conservation significance at the Yandi Mine Expansion Project. Survey comprised three separate areas which surround the mine operation.

A total of 130 species of vascular flora belonging to 73 genera and 34 families was recorded. No DRF were located. 4 Priority flora were recorded: 3 Priority three species: Themeda sp. Mt Barricade, Eriachne tenuiculmis and Rhyncosia sp. Bungaroo Creek and 1 Priority 4 species: Goodenia stellata.

Yandi 2003 Infill Drillling Rare Flora Survey **2003**

Internal reference: RTIO-HSE-0014747

This report summaries the results of a survey for flora of conservation significance completed for an infill drilling program at Yandi, 2003.

A total of 158 vascular species from 38 families were recorded. No DRF were located. Three Priority flora were recorded: Two Priority 3 (Themeda sp. Mt Barricade, Eriachne tenuichulmis) and one Priority 1 (Eriachne sp. Hamersley Range Hilltops).

Yandi 2004 Infill Drillling Rare Flora Survey **2003**

Internal reference: RTIO-HSE-0014744

This report summaries the results of a survey for flora of conservation significance completed for an infill drilling program at Yandi, 2004.

A total of 158 vascular species from 38 families were recorded. No DRF were located. Two Priority flora were recorded: Priority 1 (Eriachne sp. Hamersley Range Hilltops) and Priority 4 (Goodenia stellata).

Yandicoogina Railway Drainage Shadow Monitoring 2003 **2004**

Internal reference:

Drainage shadow monitoring on Hamersley Iron's Yandi railway commenced in 1998. The monitoring program was designed to assess whether construction and operation of the railway had any indirect impact on the survival and health of Mulga, Acacia aneura. It was postulated that downslope impacts in the drainage shadow area might occur, with limited upslope impacts due to flooding also considered. Monitoring of dead Mulga was discontinued as there were problems with species identification, fire, etc. that affected the accuracy of the data.

Similar trends were observed to previous years. None of the changes, ie recruitment, appear to be linked to any difference between Mulga communities located upslope and downslope of the railway line.

Yandicoogina Railway Drainage Shadow Monitoring 2004 **2004**

Internal reference:

Drainage shadow monitoring on Hamersley Iron's Yandi railway commenced in 1998. The monitoring program was designed to assess whether construction and operation of the railway had any indirect impact on the survival and health of Mulga, Acacia aneura. It was postulated that downslope impacts in the drainage shadow area might occur, with limited upslope impacts due to flooding also considered. Monitoring of dead Mulga was discontinued as there were problems with species identification, fire, etc. that affected the accuracy of the data.

In general the proportion of Mulga in each age class remained unchanged. It was concluded that vegetation dynamic differences between upslope and downs slope populations could be identified. Such that the rail has not influenced the survival or health of the Mulga. Monitoring was discontinued.

Yandi Expansion Vegetation and Flora Survey **2004**

Internal reference: RTIO-HSE-0013321

This report summaries the results of a vegetation survey completed of the Yandi Expansion area.

20 vegetation types were identified with vegetation considered to be in very good to excellent condition. A total of 319 taxa of native vascular flora from 150 genera belonging to 53 families was recorded. 13 introduced species were also recorded. No DRF were located. Five Prority flora were recorded: two priority 2 (Olearia fluvialis, Sida sp. Barlee Range), two priority 3 (Abutilon trudgenii ms, Themeda sp. Hamersley Station) and one priority 4 (Goodenia stellata). No TEC's or DRF were recorded and none of the vegetation types are considered to be of regional conservation significance.

Vegetation mapping and rare Flora Searches of Yandi Backfill Hill **2005**

Internal reference: RTIO-HSE-0014923

This document provides an account of the methodology, findings and recommendations of the botanical survey of the Backfill Hill, an area of proposed additional source material that would be mined solely to backfill pit voids in the Yandicoogina mine.

The vegetation types identified at Backfill Hill are comparable with those mapped for the surrounding area and were in very good condition and generally typical of the Newman area. 122 species of flora were recorded. No declared rare flora or priority flora were recorded from the Backfill Hill area, and a single record of Buffel Grass Cenchrus ciliaris in the survey area.

Yandi JSE - Conservation Significant Vegetation, Flora, Fauna and Fauna Habitat Assessment **2005**

Internal reference: RTIO-HSE-0059518

This assessment establishes the conservation significance of and impacts to flora and fauna in the Yandicoogina JSE project area.

None of the 21 vegetation types identified from the area are Threated Ecological Communities, neither are they significant at the level of the Pilbara bioregion. Vegetation of conservation value at the Hamersley subregion comprises vegetation types 1c of breakaways and vegetation types 3c, 3d, 3e, 3f and 3h of major creeklines.

Yandi Riverine Monitoring Data 2005 E. camaldulensis results **2005**

Internal reference:

Surplus water obtained from dewatering of Hamersley Iron's Yandi mine is discharged into Marillana Creek. Monitoring commenced in 1997 to determine whether the water discharge is having an impact on sensitive plant species including large Acacias, Atalaya hemicaulca, Eucalypts (E. camaldulensis, E. victrix) and Melaleuca spp.

Results for 2005 show that the majority of trees at the site are stressed. For example, only 3 of the original 18 trees at the Upstream control site remain alive. However trees in Weeli Wolli and Phils Creek remain in good health.

Yandicoogina Revegetation Reference Sites **2009**

Internal reference: RTIO-HSE-0098922

This report documents the establishment and monitoring of baseline (control) vegetation transects in unmined areas adjacent to Yandicoogina operations.

A total of 82 vascular plant taxa from 45 plant genera and 23 plant families were recorded in the Yandicoogina control transects and one priority flora species. Average plant density and species richness varied between transpects. Although it was noted that recent fire events near transpects C1, C2 and C4 may have contributed to higher species richness. The average foliage cover for each transect varied with no definite pattern in relation to landscape. Pperennial grasses dominated all components of the landscape. Midslope transects recorded the lowest bare ground score while the lower slope/flat transects recorded the highest bare ground score.

Yandicoogina Revegetation Control Transects 2009 **2009**

Internal reference: RTIO-HSE-0108130

This report summarizes the data collected to date on the transects located on uncleared and less disturbed areas adjacent to the Yandicoogina Mine Site . Data was collected on the range, frequency, density, richness and foliage cover of the species, lifeform, and other components of the physical environment (bare ground and soil analyses).

A total of 82 vascular plant taxa from 45 plant genera and 23 plant families were recorded, one Priority Flora species and no introduced taxa. Relatively recent fire events were observed in the areas of transects. The perennial grasses dominated all components of the landscape with shrubs and trees dominating the remaining lifeforms. Most aspects varied between transects or showed no clear pattern. The midslope transects recorded the lowest bare ground score while the lower slope/flat transects recorded the highest bare ground score.

A Flora and Vegetation Survey of the Billiards Deposit, near Yandi **2009**

Internal reference: RTIO-HSE-0087206

This report details the results of field vegetation and flora surveys of the Billards Deposit.

No DRF or Priority flora were located from the study area, however four prioity species could occur on the basis of the habitats present. Overall the vegetation of the Billiards study area was in very good to excellent condition. No TECs or PECs were recorded from the area, however the vegetation of the major seasonally flowing creekline (Weeli Wolli creek) is considered to be of High conservation significance, whilst the vegetation of Marillana Creek and the Mulga stands are of moderate conservation significance. Seven introduced flora species were recorded, none being declared plants.

Vegetation and Flora Surveys of the Oxbow and Junction South West Deposits, near Yandicoogina **2010**

Internal reference: RTIO-HSE-0083283

This report details the results of field vegetation and flora surveys of the Oxbow and Junction South West Deposits.

The DRF species Lepidium catapycnon was recorded at Oxbow and a Priority 3 species Tephrosia sp. Catherdral Gorge. No DRF species were recorded from the JSW area, however Lepidium catapycnon has the potential to occur. Two priority species, Tephrosia sp. Cathedral Gorge and Goodenia nuda (Priority 4) were recorded at JSW. 12 introduced species were recorded in the Oxbow area and 11 were recorded at JSW, none being declared plants.The vegetation types of the Oxbow and JSW areas were generally in very good to excellent condition. The Oxbow and JSW study areas also contained approximately 16% and 13% of disturbed areas respectively, these areas are considered to be completed degraded. The areas of the creekline vegetation unit, and hillcrest unit, supporting the DRF were identified as having high conservation significance. One moderate conservation significance was also identifid, the area of plains vegetaion supporting a popoulation of the Priroity 3 Tephrosia sp. Catherdral Gorge. No vegetation communities listed as TECs or PECs ocurred in the area.

Flora and Vegetation Survey Yandi Village **2012**

Internal reference: RTIO-HSE-0133995

This report documents the results of a vegetation and flora survey completed in 2011 for a car park at Yandi Village

A total of 7 vegetation types were recorded, non were considered to be of significance and are well represented within the Pilbara bioregion. Vegetation type condition ranged from completely degraded to very good. No DRF or priority species were recorded, nore were any TECs or PECs identified.

Yandi JSW/Oxbow Vegetation and Flora Integration Report **2012**

Internal reference: RTIO-HSE-0175486

This report describes a further botanical survey completed in 2012 to provide additional information on the vegetation and flora values associated with the Yandi JSW and Oxbow study areas. Data from previous surveys were reviewed and included were relevant.

None of the vegetation associations comprised a TEC or PEC. The major creekline (Marillana Ck) represents an ecosystem at risk. 17 weed species were recorded, none which are Declared species. One threatened species (Lepidium catapycnon), One priority 3 (Rostellularia adscendens var. latifolia) and one Priority 4 (Goodenia nuda) species was recorded.

Condition of Flora and Vegetation along Marillana (Yandicoogina) Creeklines **2012**

Internal reference: RTIO-HSE-0191027

This report provides a summary of observations and recordings on the flora and vegetation along the Marillana and Weeli Wolli creek systems. Survey completed in 2012.

No plant taxon listed as DRF or threatened were recorded. In general, all tree species were healthy to slightly stressed. Condition of saplings and mature trees reflect past fire events and a range of local site conditions including heavy grazing, hydrological shifts in Marillana and selected WW transects and seasonal fluctuations across the entire river system. 11 weeds were recorded within the creek survey areas.

Yandi Additional Areas Vegetation and Flora Level 2 Assessment **2013**

Internal reference: RTIO-HSE-0175488

This report describes further botanical survey work completed in 2012 in order to provide additional information on the values associated with the JSW, Oxbow and Billiards project areas.

Sixteen vegetation associations were described for the study area. An additional mapping unit comprised cleared ground. None of the vegetation associations comprise Threatened Ecological Communities (TECs) or Priority Ecological Communities (PECs). A total of 313 native vascular flora species from 125 genera and 45 families were recorded from the study area. This species richness is within the range expected for an area of this size in this locality. No Threatened flora species were recorded within the study area. Fourteen introduced flora species (weeds) were recorded from the study area, none of which are Declared Plants for the Pilbara bioregion. *Cenchrus ciliaris (Buffel Grass) was the most prolific introduced flora species observed in the study area. This species often formed dense populations along creek banks and in floodplains.

Autumn Assessment of Flora and Vegetation Condition along Marillana (Yandicoogina) Creeklines **2014**

Internal reference: RTIO-HSE-0252380

This report provides a summary of observations and recordings on the flora and vegetation along the Marillana and Weeli Wolli creek systems. Survey completed in May 2014.

No plant taxon are listed as threatened or priority species. 12 introduced weed species were recorded during this survey. Changes in foilage cover of understorey species along the creeklines have largely reflected seasonal variation between surveys. All tree species were healthy to slightly stressed among all zones across all transects.

Yandi Billiards Vegetation and Flora Survey - Phase 1 and Phase 2 **2014**

Internal reference: RTIO-HSE-0242328

This report summaries the results of a vegetation and flora survey at Yandi Billiards completed in 2014.

23 vegetation types were described, with most vegetation being in good to very good condition, except creekline and floodplain vegetation which ranged from good to very poor condition due to weed invasion and cattle disturbance. One ecosystem at risk was present, vegetation type C1 occurs along Marillana and Weeli Wolli Creeks. None of the vegetation types represented TECs or PECs. One threatened flora species (Lepidium catapycnon) was located, and two priority species (Priority 3 - Sida sp. Barlee Range and Priority 4 - Goodenia nuda). 18 weed species were recorded, with one (Mexican poppy) being a declared plant for WA.

Spring Assessment of Flora and Vegetation Condition along Marillana (Yandicoogina) Creeklines **2014**

Internal reference: RTIO-HSE-0251693

This report provides a summary of observations and recordings on the flora and vegetation along the Marillana and Weeli Wolli creek systems. Survey completed in October 2014.

No plant taxon are listed as threatened or priority species. 14 introduced weed species were recorded during this survey. To date, understorey vegetation is largely associated with seasonal variation with rainfall influencing species richness and foliage cover. Trees above 10.9 cm DBH are stable across all zones regardless of conditions. Control sites show similar responses to conditions as impact sites.

Fauna

Stygofauna Sampling at Brockman and Yandicoogina: 2003 **2003**

Internal reference: RTIO-HSE-0187099

This report describes the November 2003 stygofauna sampling at Yandicoogina.

17 boreholes were sampled. Specimens recorded include: Amphipoda, Isopoda, Ostracoda, Platyhelminthes, Copepoda, Oligochaeta and Hydracarina. The number of individual stygofauna at Yandicoogina was very high, and exceeded Paraburdoo's previously highest count. The species richness is comparable to other sites, with seven high level taxa collected. The most stygofauna were collected from shallow boreholes that intersected river alluvials. Stygofauna such as Tainisopid isopods and copepods were collected away from Marillana Creek.

Yandi Expansion Desktop Fauna Assessment and Targeted Invertebrate Survey **2004**

Internal reference: RTIO-HSE-0057590

The primary aims of the study were to 1) Collect information on the presence of vertebrate fauna and selected invertebrate taxa (short range endemics); 2) Document the components of the physical environment (ie. the fauna habitats); and 3) Document existing levels of disturbance.

Six major habitat types were identified for the Yandi Expansion area. The habitat types within the Yandi Expansion area do not appear to be unique or significant at the bioregion scale. The riverine habitat is significant on a sub-bioregion scale as it would support a range of species not typically recorded from other habitats in the study area. Short range endemics species identified include: several Araneae (Spiders), six Pseudoscorpionida (Pseudoscorpions), one species of scorpionid, one species of Polyxenid millipede (pin-cushion millipede), one species of land snail (family Pupillidae). Two species of Schedule fauna and one Priority listed species have either been recorded from or are likely to occur in the Yandi Expansion area. One species, the Pilbara Olive Python, is also listed as Vulnerable under the EPBC Act 1999.

Yandi Junction South East (JSE) Expansion. Baseline Stygofauna Assessment **2005**

Internal reference: RTIO-HSE-0013441

This report summaries the results of a baseline Stygofauna assessment completed for the Yandi JSE Expansion. This report was based on analysis of existing specimens collected in Nov 2003 and no additional field collection was undertaken.

17 of the 23 bores sampled contained stygofauna. The abundance and diversity of stygofauna collected was considerable. Seven higher-level taxa were collected: Amphipoda, Copepoda, Hydracarina, Isopoda, Ostracoda, Oligochaeta and Platyhelminthes.

Yandi JSE - Conservation Significant Vegetation, Flora, Fauna and Fauna Habitat Assessment **2005**

Internal reference: RTIO-HSE-0059518

This assessment establishes the conservation significance of and impacts to flora and fauna in the Yandicoogina JSE project area.

Habitat types within the area do not appear to be unique or significant at the bioregional scale. The Major Creek (Riverine) habitat is important at a sub-bioregion scale as it supports a range of species not typically recorded from other habitats, and because all major ephemeral water courses are considered to be ecosystems at risk within the Hamersley subregion (threats from cattle, donkeys and weeds). No gazetted vertebrate fauna species of special conservation significance were recorded. No invertebrate species known to be of elevaated conservation significance were recorded, nor did the targeted Short-range Endemic survey detect any species likely to have an elevated conservation significance. Given these conditions no particular management is required over and above the standard management measures already in place for the project.

Yandicoogina Targeted Northern Quoll Survey **2009**

Internal reference: RTIO-HSE-0083042

This report summaries the results of a single-phase targeted Northern Quoll survey in the Yandi Expansion areas.

The targeted survey recorded no evidence of the Northern Quoll from any of the 277 traps. Additionally, pervious faun surveys completed in the area have yielded no records of this species. This may be attributed to lack of good quality habitat.

Yandi Stygofauna Compliance Summary 2009 **2009**

Internal reference: RTIO-HSE-0081567

This report summaries the results of bi-annual sampling of stygofauna completed in April and Oct 2009. This sampling is to ensure compliance with the Yandi EMP and Stygofauna management plan.

Eight higher-order taxa were represented. A total of 2,333 stygobitic invertebrates were collected from 28 of the 40 drill holes sampled. Most of the specimens came from the phylum Crustacea, with the Amphipoda, Copepoda and Ostracoda being the most abundant.

Yandicoogina Junction South West and Oxbow Fauna Survey **2010**

Internal reference: RTIO-HSE-0087749

This report summaries the results of a single-phase fauna survey conducted in July 2008.

The survey yielded a total of 72 vertebrate species, comprising 46 avifauna, 12 mammals and 14 herpetofauna species. Two priority 4 species were recorded, the Star Finch and the Western Pebble-mound Mouse, both are well represented in similar habitats across the Pilbara. The migratory listed Rainbow Bee-eater was also recorded. Fauna habitats described are considered to be widespread and common throughout the local area and within the wider region.

Yandicoogina Expansion Billiard Deposit Fauna Survey **2010**

Internal reference: RTIO-HSE-0087750

This report summaries the results of a single-phase fauna survey conducted in July 2008 of the proposed Billiard project area.

The survey yielded a total of 62 vertebrate species, comprising 44 avifauna, 18 mammals and 10 herpetofauna species. One priority 4 species was recorded, the Western Pebble Mouse, this species is well represented in simiilar habitats across the Pilbara. The migratory listed Rainbow Bee-eater was also recorded. Fauna habitats described are considered to be widespread and common throughout the local area and within the wider region.

Yandicoogina Subterranean Fauna Assessment Phases I-V **2010**

Internal reference: RTIO-HSE-0101408

The report collates all of the subterranean fauna data collected, including all five phases of stygofauna sampling, and a single troglofauna sampling phase in the Yandicoogina area to date. The report also provides recommendations and direction for how to manage them during operations and describes the mine closure and the rehabilitation option.

A total of 3695 specimens of stygobitic fauna were collected. Specimens represented 6 classes and 9 orders. 35.93% of the total collection are Podocopida. 4 specimens of troglofauna have been collected. The report suggests that on mine closure refuge areas will aid in recolonisation of impacted (dewatered) areas surrounding the mine area. The report comments that salinisation of the groundwater may alter stygal community compositions in favor of those species more tolerant to brackish water and could render groundwater inhabitable for stygobitic fauna; however no limiting water chemistry or salinity values are provided.

Yandicoogina Stygobitic Fauna Compliance Monitoring 2012 **2013**

Internal reference: RTIO-HSE-0180459

This report summaries the results collected during the two phases of stygofauna sampling completed in 2012. This sampling is to ensure compliance with the Yandi EMP and Stygofauna management plan.

Nine orders of fauna in five classes (phylum) were represented, dominated by the phylum Crustacea, comprising 85% of specimens collected. A total of 57 specimens of compliance and conservation significant species were collected.

Pocket and Billiard South Level 2 Seasonal Fauna Survey **2014**

Internal reference: RTIO-HSE-0253611

This report documents the results of the first phase (wet season) and second stage (Dry season) fauna surveys in the study area in March and September 2014 respectively.

Eight species of conservation significance were recorded in the study area: Mulgara Dasycercus (species unconfirmed), Pilbara Olive Python (Schedule 1, Vulnerable), Western Pebble-mound Mouse (Priority 4), Star Finch (Priority 4), Australian Bustard (Priority 4), Fork-tailed Swift (Schedule 3, migratory), Eastern Great Egret (Schedule 3, migratory); and Rainbow Bee-eater (Schedule 3, migratory). The study area was considered to be largely unsuitable for the Northern Quoll, with minimal potential core habitat. Targeted searches for SRE taxa yeilded records of several invertebrate species, which are potential SRE's, however all taxa recorded have documented distributions extending outside of study area.

Biodiversity improvement studies

Evaluation of mine waste materials as alternative rehabilitation growth medium **2010**

Internal reference: RTIO-HSE-0109961

This study reviewed the physical and chemical properties of soil, tailing and mineral waste from select Pilbara mining operations, to identify waste material and material combinations for use as a topsoil substitute or supplement.

The study showed plant-available nutrients held within the waste materials, although variable, was characteristically low and comparable to natural soils in the region. The majority of the waste materials had macro and micro nutrient concentrations within the range or above the levels measured in benchmark Pilbara topsoil and rehabilitated soils. The pH and phosphorus buffering index of most waste materials were also comparable to that of the benchmark topsoil materials. However, some of the waste types and tailings may need to be mixed with rocky material due to poor physical / erodibility characteristics.

Irrigated seed orchard trial **2011**

Internal reference:

Commencing in 2011 (and still ongoing), a trial irrigated seed orchard was established at the Hamersley Agriculture Project (Marandoo). The purpose of the trial was to identify an alternate method of addressing seed deficits. If successful, the project may be implemented at other Rio Tinto operations, such as the Nammuldi agriculture project.

Genetic diversity in Eucalyptus leucophloia across the Pilbara: Provenance zone implications **2011**

Internal reference: RTIO-HSE-0108843

This study was undertaken to define the provenance seed collection zones for a common species of the Pilbara, Eucalyptus leucophloia (Snappy Gum). This report details information on genetic analysis conducted on E. leucophloia. Collections of E. leucophloia were made from 20 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in E. leucophloia was high and was typical of that found in other eucalypt species with wide spread distributions. Across the species the level of population differentiation was low and the majority of the diversity was maintained within populations with only 6% of variation partitioned between populations. Genetic variation in E. leucophloia showed little structure across the Pilbara with no clustering of populations based on any geographical proximity or in association with obvious topographical, physiogeographical or geological features such as the Hamersley or Chichester Ranges. Populations towards the edges of the species distribution within the Pilbara showed greater levels of differentiation from populations within the species main range. The high levels of genetic diversity and low levels of differentiation within E. leucophloia implies that seed resources for rehabilitation can be selected from a wide range within the Pilbara.

Genetic diversity in Acacia ancistrocarpa across the Pilbara: Provenance zone implications **2011**

Internal reference: RTIO-HSE-0119260

This study was undertaken to define the provenance seed collection zones for Acacia ancistrocarpa (Fitzroy Wattle). This report details information on genetic analysis conducted on Acacia ancistrocarpa. Collections were made from 24 populations across the Pilbara bioregion and genetic analysis was conducted on 16 populations using microsatellite markers.

Genetic diversity in A. ancistrocarpa was high but lower than that in E. leucophloia, another widespread species in the Pilbara. Across the species Pilbara range the level of population differentiation was low and the majority of the diversity was maintained within populations with only 3% of variation partitioned between populations. Genetic variation in A. ancistrocarpa showed little structure across the Pilbara with no clustering of populations based on geographical proximity or in association with obvious topographical, physiogeographical or geological features. Populations towards the edges of the species distribution within the Pilbara showed greater levels of differentiation from populations within the species main range. The high levels of genetic diversity and low levels of differentiation within A. ancistrocarpa implies that seed resources for land rehabilitation and mine-site revegetation programs can be selected from a wide range within the Pilbara

Root hydraulic conductance and aquaporin abundance respond rapidly to partial root-zone drying events in a riparian Melaleuca species **2011**

Internal reference: RTIO-HSE-0252171

This study examined partial root zone drying (PRD) responses of Melaleuca argentea.

The results demonstrate that PRD can induce rapid changes in root hydraulic conductance and aquaporin expression in roots, which may play a role in short-term water uptake adjustments, particularly in species adapted to heterogeneous water availability.

Baseline Terrestrial Fauna Assessment of Pilbara Rehabilitation Areas **2012**

Internal reference: RTIO-HSE-0134168

In 2011 a fauna survey was conducted within established rehabilitation areas at Brockman 2 and Tom Price mine sites, with the aim of identifying whether fauna is recolonising rehabilitation sites in assemblages comparable to reference sites.

The study found that at least 85 species of native vertebrate fauna, as well as representatives from each of six major groups of invertebrate fauna, are using rehabilitation areas at Brockman 2 and Tom Price, with species compositions that were broadly similar to reference sites. Ant collections were typical of the Pilbara bioregion, with an absence of invasive ant species. The study found greater data correlation between monitoring sites at a particular mine site (Tom Price or Brockman 2) than between rehabilitation and reference sites, indicating the importance of selecting local reference sites. The study concluded that the best candidates for bio-indicators are ants and reptiles.

Genetic diversity in Aluta quadrata:Implication for management and provenance zone **2012**

Internal reference:

This study was undertaken to define the provenance seed collection zones for Aluta quadrata. This report details information on genetic analysis conducted on Aluta quadrata. Collections were made from 8 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in A. quadrata was moderate and lower than in the other two more widespread Pilbara species, E. leucophloia and A. ancistrocarpa. The findings suggest that its populations may have fluctuated significantly in size over time with genetic drift and possibly inbreeding resulting in a reduction in genetic variability, particularly in rare alleles. Despite the narrow geographic range, the level of population differentiation in A.quadrata was relatively high with 25% of the genetic variation maintained between populations and 19% due to differences between the three different locations. This significant genetic structure indicates that A. quadrata consists of three conservation or management units, Western Ranges, Pirraburdoo and Howie's Hole.

Genetic diversity in Acacia atkinsiana across the Pilbara: Provenance zone implications **2012**

Internal reference:

This study was undertaken to define the provenance seed collection zones for Acacia atkinsiana (Atkins wattle). This report details information on genetic analysis conducted on Aluta quadrata. Collections were made from 16 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in A. atkinsiana was low and lower than that observed in its congener Acacia ancistrocarpa, a widespread species across northern Australia. The level of population differentiation was high and 30% of the diversity was partitioned between populations across the range of A. atkinsiana. Genetic variation in A. atkinsiana showed some structure across the Pilbara with clustering of populations in the western part of the distribution and from the Hamersley Range, along with other populations that were divergent from these groups. The low levels of genetic diversity and high levels of differentiation within A. atkinsiana implies that seed for land rehabilitation and mine-site revegetation programs should be restricted to specific zones. For rehabilitation of sites within the Hamersley Range we recommend seed collections be restricted to that region. Similarly, for rehabilitation in the part of the distribution west of Pannawonica, seed collections should be restricted to that area.

Rehabilitation Quality Metric (RQM) Project **2012**

Internal reference: RTIO-HSE-0164020

Western Australia has no formal process to measure habitat quality and as such RTIO has needed to design its own customised metrics. Vegetation condition scoring has previously been developed by RTIO through a Biodiversity Net Positive Impact Assessment, but a more precise metric was needed. The Rehabilitation Quality Metric (RQM) project was developed to provide a repeatable method to assess rehabilitation quality against pre-determined reference sites, on a site by site basis, to predict rehabilitation ecosystem quality at the time of relinquishment.

The RQM methodology employs seventeen parameters to characterise the landscape, including vegetation, fauna habitat, fauna presence, erosion, and ecosystem function. Parameters are tailored to be an applicable measure for both rehabilitation and native vegetation (reference sites). Parameters are scored, based on measured or observed characteristics, with a value between 0 and 1, with 1 being functional (terrestrial ecosystem is functioning for the maintenance of biodiversity values at a local or property scale) and 0 being dysfunctional (terrestrial ecosystem is failing; indicators of ecosystem function have scored below acceptable levels). Both rehabilitation areas and reference sites are scored. Scores are subsequently determined for the entire mine lease, based on the condition of the land before mining (extrapolated from the reference sites, area weighted) and the likely post-mining conditions (extrapolated from the rehabilitation areas and expected closure domain distribution, area weighted, ie pits with no rehabilitation score 0). The difference between the pre-mining and post-mining scores represents the residual impact of mining.

Propagation of Pilbara spinifex (Triodia sp.) **2012**

Internal reference: RTIO-HSE-0169744

Triodia has often been observed to have very poor establishment from broadcast seed. This project investigated alternatives to growing Triodia (spinifex) from seed, focussing on ways to propagate seedlings from wild harvested material.

The project found the most successful propagating material was stolons. Greatest propagation success was achieved when Triodia were collected when semi to fully dormant (mid Winter-Spring). The 'Moist Root Induction Method' recommended by previous researchers was less successful than the standard propagation techniques employed in this project. Success varied notably between populations. Consequently, any future collections of propagating material should target multiple populations to maximise potential for success.

Pilbara Seed Science Project, Part 2 Final Report Jan 2012 **2013**

Internal reference: RTIO-HSE-0174944

Undertaken between 2009-2012, this seed research investigated germination, biology, dormancy classification and treatments for dormancy alleviation for a range of species from the Pilbara.

The *Acacia atkinsiana, Indigofera monophylla and Sida echinocarpa* seed lots have physical dormancy. Heat treatments and mechanical scarification improved germination on dormant seeds, however, heat treatments killed non-dormant seeds. The treatments used for *Goodenia stobbsiana* seeds failed to overcome dormancy, suggesting deep physiological dormancy. The *Hakea lorea/ chordophylla* seed lots were found to be non-dormant, with very high germination results in the controls. As such, they will not require any pre-treatments prior to direct seeding. The florets surrounding the *Triodia pungens* and *T. wiseana* seeds were found to restrict germination, however, many of the freshly extracted seeds out of the florets were found to be physiologically dormant. Treatments for dormancy include mechanical scarifier to rupture seed coat, hot water (noting potential damage to immature or non-dormant seeds) and increases to germination through wet / dry cycling and / or temperature cycling.

Morphological variation in the western rainbowfish (Melanotaenia australis) among habitats of the Pilbara region of northwest Australia. **2013**

Internal reference: RTIO-HSE-0252169

The aim of this honours thesis was to determine and quantify the extent of morphological variation present in M. australis and relate this to environmental variables, which will provide the first step to understanding how the species copes with environmental change.

This results of this thesis found that there was limited evidence that fish morphology correlated with environmental variables

Patterns of water use by the riparian tree Melaleuca argentea in semi-arid northwest Australia **2013**

Internal reference: RTIO-HSE-0249538

This thesis examines the water use physiology of the riparian tree Melaleuca argentea, and the ways in which this species may respond to anthropogenic disturbances to hydrologic processes.

M. argentea displays highly plastic root-level responses to heterogeneous water availability and to waterlogging, facilitating high rates of water use and growth in the riparian wetland habitats of the Pilbara. Mature M.argentea trees appear to tolerate groundwater drawdown of at least several metres, most likely by employing the same plastic root strategies to access deeper water. M.argentea can also withstand short periods of severe drought, by adopting a 'waiting' strategy of ceasing growth and shedding leaves to avoid moisture loss, a state from which they can then recover. M. argentea populations are unlikely to thrive under large and prolonged reductions in water availability.

Priority Species Seed Quality and Germination Final Report **2013**

Internal reference: RTIO-HSE-0207487

This study investigated the quality and germination biology of a range of priority and keystone (Triodia) plant species from the Pilbara.

Eremophila magnifica subsp. Magnifica has physical & physiological dormancy. Propagation methods other than seed may be more successful. Geijera salicifolia and Olearia mucronata has physiological dormancy. Temperature cycling may be required to stimulate germination. Indigofera ixiocarpa and Indigofera sp. Bungaroo Creek has physical dormancy or is non-dormant. Mechanical scarification may be required. Ptilotus subspinescens is non-dormant and will germinate easily without removal from the perianth sheath. However, seed is likely to lose viability with a few years. Sida echinocarpa and Sida sp. Barlee Range has physical dormancy. Seeds should be removed from the mericarp and then scarified in order to germinate. Triodia pungens has T. wiseana non-deeep or deep physiological dormancy. Germination of de-husked seeds can be improved by applying gibberellic acid or 1% smoke water and wet/dry cycling.

Early physiological flood-tolerance and extensive morphological changes are followed by slow post-flooding root recovery in the dryland tree Eucalyptus camaldulensis subsp. Refulgens **2014**

Internal reference: RTIO-HSE-0252170

This study investigated physiological and morphological response to flooding and recovery in Eucalyptus camaldulensis subsp. Refulgens, a riparian tree species from a dryland region prone to intense episodic flood events.

E. camaldulensis subsp. Refulgens underwent considerable morphological changes during flooding, including extensive adventitious root production, increased root porosity and stem hypertrophy. Physiologically, net photosynthesis and stomatal conductance were maintained for at least 2 weeks of flooding before declining gradually. Despite moderate flood-tolerance during flooding and presumably high environmental selection pressure, recovery of reduced root mass after flooding was poor.

Priority Species Project Progress Report 2013 **2014**

Internal reference: RTIO-HSE-0207486

The Priority Species Project, initiated in 2012, aims to improve knowledge of priority plant species and develop methods to successfully germinate and establish priority species, to enable priority plant species to be integrated into Rio Tinto rehabilitation programmes. This work is being undertaken in conjunction with the Department of Parks and Wildlife.

13 plant species were selected as being potentially suitable for establishment in rehabilitation: Eremophila magnifica subsp. magnifica, Indigofera sp. Bungaroo Creek, Indigofera sp. gilesii, Acacia bromilowiana, Sida sp. Barlee Range, Ptilotus subspinescens, Ptilotus mollis, Acacia subtiliformis, Isotropis parviflora, Grevillea sp. Turee, Hibiscus sp. Canga, Themeda sp. Hamersley Station, and Aluta quadrata. Indigofera sp. Bungaroo Creek and Ptilotus subspinescens were found to readily germinate in laboratory conditions, and a field trial was established at Brockman 4 late in 2013.

Regional Variation in Metal Concentrations of Pilbara Fish in Relation to Concentrations in Water and Sediments **2014**

Internal reference: RTIO-HSE-0216967

This study aimed to characterise and document natural, background metal concentrations in freshwater fishes from different locations across the Pilbara in order to understand how local geology may affect baseline metal levels in fish tissues and surface waters. Metal concentrations were analysed from water, sediment and muscle and liver tissues from fish collected from up to 13 sites as yet unimpacted by mining across the Pilbara during October (dry season) of 2012.

Levels of dissolved metals from water samples were generally low. However, some elevated concentrations of Boron, Copper and Zinc were recorded. Concentrations of heavy metals in sediments were variable across the Pilbara. Generally, sediment concentrations were well below the Interim Sediment Quality Guidelines (ISQG). However, metal concentrations in excess of ISQG TVs were recorded for Chromium and Copper at some sites. There was no relationship between metal concentrations in sediment and those in water. Metal concentrations in fish tissue (muscle and liver) varied between species with some significantly higher in some particular species. The study concluded that variation in metal concentrations in water, sediment and fish across pools in the Pilbara was likely to be mainly dictated by the local geological setting in which the pool occurs.

Marandoo Native Pivot. Scope 2 Monitoring. Final Monitoring Report **2014**

Internal reference:

The Native Pivot Project involves a series of scientific trials into the effect of fertigation on plant species native to the Pilbara region. This report details the results from the first year of monitoring.

Fertigation is resulting in measurable differences to soil properties. Soil moisture was higher in the '2x' and the '1x treatments than the '0.5x' and the '0x' treatments. Soil moisture was observed to converge in all treatments during the wet season in Jan/Feb 2014. The germination of target species was low in the seeded species trial component, the presense of non-target native species is thought to have affected germination. The fertigation treatments were determined to have had a significant effect on the abundance, cover and health scores of native vegetation in the Pivot trials.

Dampier Port Rehabilitation Trials **2014**

Internal reference: RTIO-HSE-0246218

This report presents the results of a final monitoring survey of two rehabilitation trials established at the Dampier Port. The aim of the trials was to evaluate the effect of a range of mulch and soil treatments on the success of rehabilitation.

The outcome of the trial in terms of informing rehabilitation methods for the dredge spoil areas, is that the soil properties in both locations support native vegetation growth without treatment or amelioration (the soil has no properties that are considered inhibitive or detrimental to the growth of Pilbara native species). In addition the treatments were shown to have no significant effect and therefore won't be incorporated into future rehabilitation. Salinity and sodicity of the dredge spoil decreased over time and it is likely it will continue to decrease with time, which is considered an improvement in soil properties to enable native vegetation growth

Progress Report 2014, Ecological responses of native fishes to dynamic water flows in northwest arid Australia **2014**

Internal reference: RTIO-HSE-0246021

This three year Australian Research Council linkage Project commenced in 2013 and aims to increase understanding of the effects of altered stream flows on the Pilbara freshwater aquatic environment. Project aims: 1. Quantifying fish biodiversity and population structure in relation to hydrological and environmental parameters to identify thresholds of ecological concern for water management; 2. Determine the fundamental physiological, morphological and behavioural adaptations of fishes to variations in water quality using experimental manipulations; and 3. Examine spatial scales of gene flow to determine if increased flows increase genetic connectivity relative to natural-flow sites.

To date work has focuses on characterisation of baseline physicochemical parameters across aquatic habitats within the Fortescue River catchment (Aim 1), analysis of variation in rainbow fish morphometrics and mechanosensory lateral line systems in response to geographic region and water management regime (Aim 2), and extraction of DNA samples from 17 populations across the Fortescue River catchment (Aim 3). The project will culminate in the development of a predictive model for stream restoration relevant to future closure scenarios for above and below-groundwater mines. Results from an honours thesis indicate that rainbow fish body shape varies according to geographic region but fish from a dewatered site (WW Ck) were more streamlined than other populations from the upper Fortescue catchment. This statement of results has been superseded by the results of the actual thesis report RTIO-HSE-0252169.

Yandi rehabilitation review **2015**

Internal reference:

This study reviewed the implementation success of Pilbara rehabilitation strategies for geologies and vegetation types similar to Yandicooogina. The review includes a discussion on the different rehabilitation methodologies and analogous success / failure rates for different types of ground disturbance.

Monitoring data from other Pilbara mining operations suggest that alluvial-style waste materials can be successfully rehabilitated to achieve a stable, self-sustaining native vegetation community using standard rehabilitation practice. Similar success has been achieved with the rehabilitation of short-term and long-term disturbance areas. However, due to the small number of waste fines rehabilitation projects and limited success to date, the ability to successfully rehabilitate waste fines cells (without capping) is yet to be proven. There is also a knowledge gap pertaining to the rehabilitation of created ecosystems, such as the wetlands proposed to be constructed within the mine voids at Yandicoogina. These gaps include factors such as surface water controls, topsoil application rates and seed mix.

Landform design

Results of flume investigations of the stability of rock mulches **1998**

Internal reference:
RTIO-HSE-0109221

This study assessed the potential for rock mulches to be stripped from the soil surface by overland flows.

Although 150-300mm diameter BIF was not removed by simulated overland flows, even for 100mm/hr simulated runoff on 55% gradients, considerable scour of the spoil between the rocks was observed, indicating potential for long-term development of rills or gullies if the level of rock cover was less than 100%. Large reductions in sediment concentrations were observed when finer rocks were mixed with BIF. The data indicate that it is crucial for any rock mulch to cover a wide range of particle diameters, including a component of finer rocks. The resulting mixed rock created a framework of large rocks that resist movement by flows, while the smaller rocks reduce erosion being anchored within the larger (framework) rock. For rock mulches with a mixture of rock diameters, 80% cover produced acceptable erosion rates. Sediment loads were slightly higher for 40% cover by rock of mixed diameters, and it was speculated that this may also achieve acceptable erosion rates with the addition of vegetation.

Yandicoogina Conceptual Study on Backfilling of Mine Voids **2009**

Internal reference:
RTIO-PDE-0068220

This study was undertaken to estimate backfill volumes to 5 m above the average original water level at Junction Central, Junction South East, Junction South West, Oxbow and Billiard South.

A total of 205 million loose cubic metres (LMm3) of material is required to backfill the pits to 5m above the water table: Junction Central requires 72LMm3, Junction South East 86LMm3, Junction South West 34LMm3, Oxbow 38LMm3 and Billiard South 178LMm3. Thus the deficit of 55LMm3 of material would need to be mined from surrounding hills to meet a total target of all pit voids backfilled to 5m above water table.

Final Landform Design Criteria for Use During Mine Planning **2012**

Internal reference:
RTIO-PDE-0159989

Rio Tinto Iron Ore WA have historically designed closure landforms for waste materials with berms ~10 m, lifts ~20 m and ad hoc alterations to batter gradients where erosion rates have been perceived to be unacceptably high. This report integrates recent advances in characterisation and modelling of materials, climate and erosion processes to provide appropriate final landform batter characteristics for key Pilbara mineral wastes and soils.

Material properties of mineral wastes were assessed and classified for the range of mineral wastes found across Rio Tinto Pilbara sites. Climate sequences were used to model and test potential erosion rates for a range of batter configurations (shapes (linear, concave), heights, gradients, berm capacity) and validated against existing slopes for which material and climate data were available. This information was used to develop a searchable waste dump batter database for all major mineral wastes and soils, intended for use during mine planning design.

Yandicoogina JSE pit landform water balance **2013**

Internal reference:
RTIO-HSE-0208317

JSE is predicted to form a saline sink unless the pit is backfilled to at least the pre-mining water table. This report presents the outcomes from a GoldSim model that simulates water conditions post-mining to calculate the minimum volume of backfill required to create stable and environmentally acceptable conditions in the long term.

To minimise the duration of ephemeral ponding, the modelling showed that a capping layer (above the waste fines cells 495m elevation) between 2.4m and 3.5m thick is required. However, these conditions were only achieved when ET rates of 1,200mm/yr were used on the capping layer. Lower ET rates could be used on the waste fines cell walls (500m elevation). In the event that the rehabilitation scheme failed and the vegetation reverted to typical Pilbara grass vegetation (300mm/yr), the reduced ET rates would result in ponding occurring typically 5 times longer than the base case.

Contamination

Impact of Nitrogen from Explosives on Mine Site Water Quality — 2008

Internal reference: RTIO-PDE-0054638

The likely issues associated with the use of nitrogen based explosives on mineral waste and any leachate water are explored in this report. The amounts of explosives used on site are described, along with nitrogen chemistry and toxicity. Nitrogen concentrations for various mine sites and specific lithologies are presented which includes concentration in rock assays and liquid extracts.

It was concluded that the largest risk of nitrogen contamination is likely to arise from the discharge of surface waters that have been in contact with blasted materials and are discharged off site into creeks or waterways. This becomes a more significant issue if the water is also acidic. Algae (ie cyanobacteria) plumes have been identified in acidic water at Tom Price

Control Measures for Potentially Acid Forming Pit Wall Rocks — 2010

Internal reference: RTIO-PDE-0079541

Desktop study of potential strategies to manage exposed sulfidic materials and find viable options for management was conducted with a focus on the Hope Downs 1 and Tom Price sites.

Chemical treatments have the potential to be effective only in the short-term and only for minor water quality issues. Grouting of the pit walls is expected to have limited applicability, although grout curtains behind the wall may have success (untested). Cover technologies have the greatest potential to be effective over the long term, but would need to be resistant to puncture by underlying rocks, resistant to weathering and UV damage ie shotcrete, geomembranes. For long term performance the exposed surface need to be as stable and free of loose material as possible. Treatment effectiveness will also depend on the site conditions, eg chemical less effective at Tom Price.

Yandicoogina Preliminary Site Investigation (PSI) & Sampling and Analysis Plan (SAP) 2010 — 2010

Internal reference: RTIO-HSE-0094696

A preliminary site investigation was carried out to establish potential sources of contamination resulting from the current and historical site activities. Additionally, assess the implications of potential impact to soil, groundwater, environmental and human receptors.

Based on the findings of the preliminary site investigation, the main sources of contamination from the mining operations include; hydrocarbon (mainly diesel) storage / handling facilities and fuel pumps. Other sources of contamination include vehicle wash-down and maintenance facilities, waste oil handling facilities, liquid waste storage facilities, ammonium nitrate and fuel oil, equipment laydown landfilling, wastewater treatment and land farm facilities. Risk ranking analysis identified four facilities as "potentially high risk". On the basis of the preliminary conceptual site model, it is recommended that a ground investigation is undertaken.

Workshop Summary and Desktop Review: Dewatering and Sulfate Accumulation — 2012

Internal reference: RTIO-PDE-0101903

This is a summary of a workshop held to determine the risks of dewatering sulphides within the pit wall. The outcomes from this workshop will be used to develop models to estimate the mass of sulfate produced as a consequence of dewatering activities.

There are many processes that contribute to poor pit water quality. Most of these processes are known and accounted for in existing models. However, the science of fluid flow in fractured rock is not well developed and this lack of knowledge restricts the outcomes of studies on pit water quality. There is a general lack of empirical data for estimating parameters used in models, creating a large degree of uncertainty in predictive models. Sensitivity analysis can be used to overcome some of these challenges.

Development of a conceptual model: Sulfate accumulation as a consequence of pit dewatering activities, memo — 2012

Internal reference: RTIO-PDE-0101903

Mine dewatering and the consequent lowering of the water table may result in desaturation of sulfide bearing lithologies. The objective of this work was to develop a conceptual model of the associated processes: where sulphide bearing rock intersects the pit walls, and where the sulphide bearing rock is located behind the pit walls but not directly exposed on the pit wall face.

The conceptual model developed estimates the mass of sulfate produced as a consequence of dewatering activities, considering processes during operations and after operations cease, and using sensitivity analysis where parameter inputs are uncertain. The model output provides the basis for an assessment of potential impacts on water quality for general risk assessment applications. Further work was identified to improve parameterisation of the model, including the collection of additional empirical data for pit wall fracturing, saturation of pit wall fractures and sulfide oxidation rates in talus and on pit walls.

Ethnographic or archaeological values

Water and Indigenous People in the Pilbara: A Preliminary Study, CSIRO: Water for a Healthy Country — 2011

Internal reference: RTIO-HSE-0218222

Water resources are vital to Indigenous identities, beliefs, environmental philosophies and livelihoods. This report provides a broad-scale scoping study of Indigenous relationships to water in the Pilbara and considers the potential impacts of Indigenous water values.

Indigenous belief systems perceive water as an elemental part of the broader cultural landscape, held and managed under customary systems of law. Water sources were derived during the Dreaming and are the most important features in the Pilbara cultural landscape. Interviews raised issues of long term drying, obstruction of water flow, over-extraction, inappropriate discharge from de-watering and access restrictions.

APPENDIX C

28. Appendix C Yandi Rehabilitation Review

Rio Tinto

Yandicoogina Rehabilitation Review

31 March 2015

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Context and Purpose

This document provides the information to address the following requirement of the Yandicoogina PER.

> *"Undertake a desktop study of successful and unsuccessful rehabilitation strategies and outcomes in similar geologies and vegetation types in the Pilbara, including a discussion of the different methodology and success rates for the various proposed disturbance types including:*
>
> - *created landforms (e.g. waste rock dump, tailings storage facility)*
> - *short-term disturbances (e.g. borrow pits and access tracks)*
> - *long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings); and*
> - *linear and/or fragmentation disturbances (e.g. roads, power lines, bore fields)"*

The Yandicoogina ore body is a specific type of paleochannel[1] known as a Channel Iron Deposit (CID). The CID mined at Yandicoogina consists of three main layers of overburden material (a mixture of lateritic pisolite, poorly sorted angular to sub-rounded BIF, chert and dolomite gravels in a sandy matrix), the iron deposit and the basement rocks and altered basement rocks.

The key waste types that will result from mining at Yandicoogina are referred to as Channel Iron Deposit (CID) waste and Alluvials. The erodibility potential of these waste types at Yandicoogina has been assessed with the majority of waste classified as high erodibility when utilised in final landform design at Yandicoogina.

Rio Tinto Iron Ore aims to create landforms that are safe and stable, considered aesthetically compatible with the surrounding landscape, supportive of native vegetation, and are non-polluting.

[1] Paleochannels are remnants of ancient streams cut into old rocks and filled with sediments from younger rocks; such that they reflect historical drainage lines. The contemporary equivalent is called an alluvial channel.

Assessment of Rehabilitation Strategies

To enable a discussion of the "success" or otherwise of past rehabilitation strategies and outcomes, a review of rehabilitation monitoring results that compares rehabilitation areas to "similar" reference or control sites has been undertaken. Reference sites can be described as an unmined site, usually representative of the 'natural' landscape surrounding the mine site or rehabilitated area. The reference site generally consists of the target vegetation community, soil type and terrain and provides an example of what the rehabilitated area should achieve. For example to determine the success of waste dump slope rehabilitation it has been compared to a reference site that has been established on an undisturbed slope in the surrounding environment. Similarly rehabilitation of flat areas has been compared to reference sites established in an area of flat undisturbed vegetation, with the vegetation being typical of the surrounding area. By comparing rehabilitated areas to undisturbed reference areas (with similar terrain and topography) effectively it is answering the question as to whether the rehabilitated areas have similar biodiversity to surrounding communities. This aligns with the overall closure and rehabilitation strategy outlined in the Yandicoogina Closure Plan, that is to establish ecosystems with similar biodiversity and cultural heritage values as surrounding reference sites.

This high level approach is suitable for gaining a general understanding of the success of a rehabilitation area (regardless of site specific completion criteria which might apply). As rehabilitation (and related closure strategies and outcomes might differ between sites depending on the site based risks and environmental values) comparing rehabilitation to similar reference sites also allows us to understand how the rehabilitation is performing against the general objective of creating a stable, non-polluting landform, that comprises local native vegetation that is self-sustaining and compatible with the surrounding environment.

It is acknowledged that Yandicoogina has specific objectives and completion criteria proposed in its Closure Plan including those listed relating to stability and biodiversity in ***Table 1***.

Table 1: Yandicoogina objectives and completion criteria relating to biodiversity and landform stability.

Function	Objective	Indicative Completion Criteria
Landform Stability	Rehabilitated landforms are stable and designed to manage floodwater appropriately.	Erosion does not threaten the long term stability of the landform.
Biodiversity	Final landforms are rehabilitated to be compatible with post-mining land use.	Vegetation on rehabilitated land is native and self-sustaining. Habitat for native fauna is provided in appropriate rehabilitated areas. The prevalence of invasive species (weeds, feral animals) is similar to that in nearby reference site.

By reviewing previously completed rehabilitation areas on similar geologies in Pilbara ecosystems (against adjacent similar reference/control sites), we can get an understanding of what rehabilitation methods might be transferable and utilised at Yandicoogina to help Yandicoogina achieve its objectives and completion criteria.

As the rehabilitated areas assessed in this discussion are located at numerous locations and terrains across the Pilbara, a range of vegetation types will be assessed (by default). It is acknowledged that some of the vegetation communities proposed to exist following rehabilitation and closure at Yandicoogina are considered new types of rehabilitation for RTIO such as wetland habitat within mine voids. As a result, examples of this disturbance type and proposed rehabilitation are not included in this discussion. Whilst general methodologies are likely to be transferable to implement this type of new rehabilitation (such as waste characterisation and resulting landform design and shaping, topsoil application, ripping and seeding) there is a recognised knowledge gap as to the details for the rehabilitation methods such as topsoil application rates, surface water controls required and vegetation species mix to utilise.

Created Landforms (Waste Rock Dumps, Tailings Storage Facilities)

The proposed final landform at Yandicoogina on closure will include some rehabilitated slopes external to the pit areas, such as where current infrastructure has been decommissioned and removed. In addition the edge of the backfilled waste within the pit areas that will slope down into what will eventually be pit lakes will also be rehabilitated. It is therefore important to review successful and unsuccessful rehabilitation strategies of slopes built of similar materials to what is predicted to be encountered at Yandicoogina. This rehabilitation type (built slopes) may be present in the rehabilitated land and wetland habitats that are likely to be introduced at Yandicoogina at closure.

At present, as there are no rehabilitated slopes at Yandicoogina with sufficient monitoring data to enable a review and discussion of rehabilitation success, rehabilitated slopes at Pannawonica Operations and Brockman Two Operations have been reviewed. The Pannawonica Operations in the Robe Valley are situated in a similar geology to Yandicoogina, with the mining of iron ore from a channel iron style deposit. In addition Brockman 2 Pit 2 deposit was mined in the late 1990's and involved the mining of ore and waste from a detrital iron ore deposit. The resultant single waste dump from the mining of ore from Brockman 2 Pit 2 deposit is comprised primarily of an erodible waste type considered similar (in terms of physical characteristics and erodibility) to the CID and alluvial wastes that are encountered as a result of mining ore at Yandicoogina from the Channel Iron Deposit.

This section will therefore focus on different strategies utilised for rehabilitated slopes at the Pannawonica Operations by reviewing rehabilitation success at Mesa J Waste Dump S and Mesa J Waste Dump T and Brockman 2 pit 2 Waste Dump 1. The strategy utilised to rehabilitate a tailings storage facility located at Pannawonica's Mesa J operation and early monitoring results will also be discussed.

Successful and Unsuccessful Rehabilitation Strategies

Mesa J Operations Waste Dump S

Waste Dump S at Mesa J Operations had rehabilitation of its slopes completed between 2002-2004 and these have a monitoring transect located on them. The same dump had further slopes rehabilitated in 2007 and has a monitoring transect located on it. Both areas were battered to 15 degrees slopes, comprise of a 12-15m lift height and had 150mm of topsoil applied and ripped into the surface and seed was applied. Approximately 90% of the single lift dump was rehabilitated as at 2007 (~40Ha). The monitoring transects on the slope of Waste Dump S are positioned where the lift height is approximately 8-10m.

The most recent monitoring of these areas, completed in 2013 showed both areas had good perennial species diversity with 13 species present (higher than the slope control sites that had seven species present). The 2002-2004 rehabilitation, lower storey vegetation was absent until 2013, and then only represented a very small proportion of the total cover. The lower storey vegetation at this site was primarily made up of a mixture of *Triodia* and small or juvenile shrubs and the upper storey dominated by *Acacia* shrubs. The 2007 rehabilitation dominant stratum was the upper storey of *Acacia* shrubs, including *Acacia bivenosa* and *Acacia ancistrocarpa.*

Landscape function indices for stability were 61% for the slope reference sites while the rehabilitate sites were 59% (in 2013). The nutrient cycling and infiltration values for the rehabilitation sites were also higher than the values measured in the slope reference site in 2013. All three indices compared favourably to the average scores achieved by the sloping reference sites. Due to the mature stage of ecosystem development these scores are not expected to change substantially in the future until *Acacia* senescence, or a disturbance event occurs, such as fire.

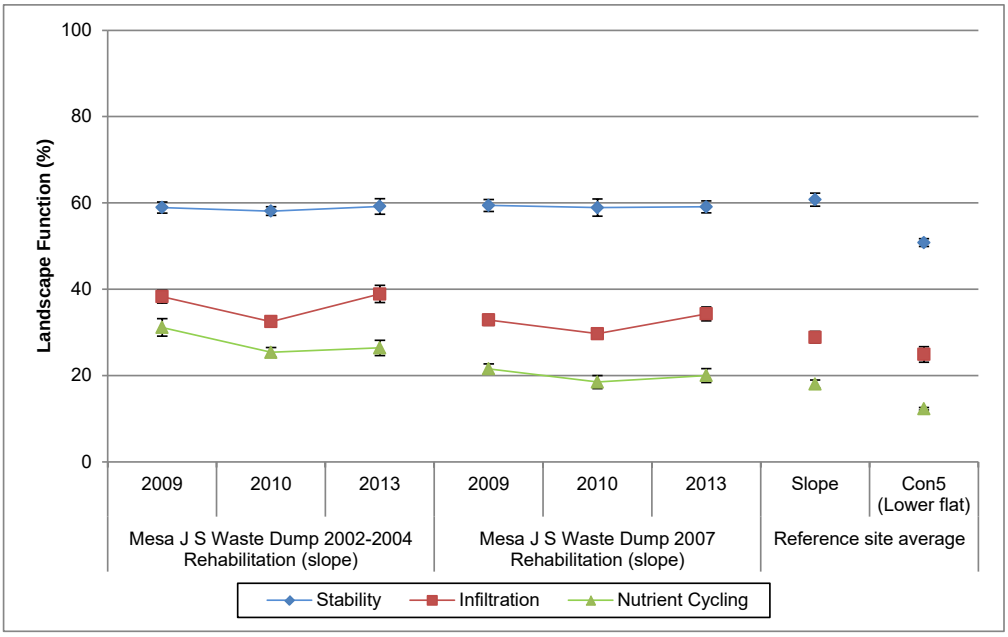


Figure 1: Changes in landscape function of the 2002-2004 and 2007 rehabilitation on the Mesa J S Waste dump (slope), in comparison with the sloping reference sites (Con7 and Con10) average, and Con5.

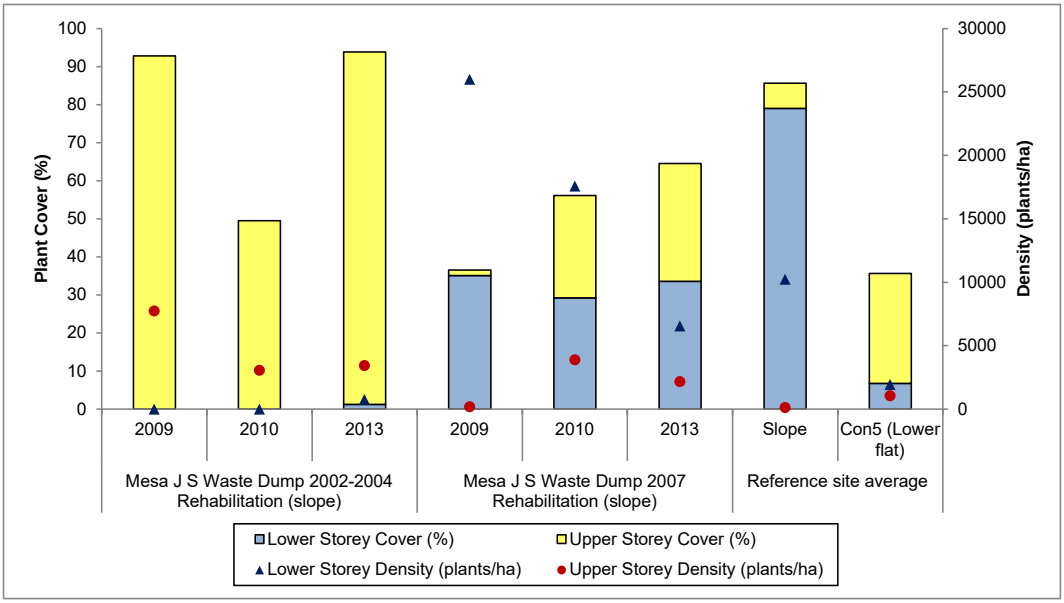


Figure 2: Changes in the plant cover index and density (lower and upper storey) of the 2002-2004 and 2007 rehabilitation on the Mesa J S Waste dump (slope), in comparison with the sloping reference sites (Con7 and Con10) average, and Con5.

The plant cover percentage was 63% and 93% for the two rehabilitation areas which was both higher and lower than the slope reference site which had 85% vegetation cover. The density

of the cover was dominated by upper storey plants in both rehabilitation sites whilst the slope reference site was dominated by a lower story (refer to ***Figure 1*** and ***Figure 2***).

In terms of habitat complexity (which is used as an indicator of suitability of habitat for fauna) of the Waste Dump S rehabilitation areas several faunal niches were available such as litter, logs and rocks. Kangaroo scats were observed at both transects providing evidence that native fauna were utilising the rehabilitation area.

Since this site was first monitored in 2009, the proportion of the slope eroded has decreased on the 2002-2004 rehabilitation area from 14% to less than 9% in 2013. On the 2007 rehabilitation area, erosion increased slightly but the overall proportion of slope eroded was low. The vast majority of the erosion that was present was on the lower slope of the transect; erosion present on the upper slopes of both transects was minor.

Rehabilitation monitoring data to date suggests that the rehabilitation on Waste Dump S at Mesa J Operations is on track to achieving a stable, self-sustaining native vegetation community similar to the control sites. Whilst total plant cover percentages and density values are within or above the range of the combined slope and flat reference sites the composition/breakdown of this cover is different to the reference sites at the older (2002-2004) Mesa J S Waste Dump rehabilitation. A large proportion of the vegetation on the rehabilitation comprises of upper story cover (*Acacia's*) as opposed to lower story cover (*Spinifex sp*.) which is the dominant strata in the reference sites. This aspect will require review over time to determine if any intervention (specific species reseeding) is required. Whilst erosion is present it appears to be either stabilising over time or only on a small proportion of the slope that was assessed.

Overall the indicators of rehabilitation monitoring discussed here suggest that the right species are present (albeit in different proportions to the reference sites), the cover is adequate, and a number of landscape function indices are within the range of (or above) the reference sites indicating that this rehabilitation is heading in the direction of being considered stable, native and self-sustaining with habitat for native fauna present.

Brockman 2 Pit 2 Waste Dump 1

Pit 2 Waste Dump 1 at Brockman 2 Operations is comprised of waste that came from the adjacent Pit 2 deposit (detrital iron ore deposit) and is considered a similar waste type (in terms of physical characteristics and erodibility) to the alluvial and CID wastes that are encountered as a result of mining ore at Yandicoogina from the Channel Iron Deposit. The Pit 2 Waste Dump 1 is built with a single lift with the total dump height ranging from 8-20m and 15-20 degree outer slopes and was rehabilitated in 1999. It is assumed the dump had topsoil applied and was ripped and seeded (no records have been found to confirm this although evidence of cross ripping can be seen on aerial photos). The last monitoring of this rehabilitation was completed in 2012 (via a transect established on the waste dump slope where the lift height is ~8m) and the results are discussed below.

The total species number recorded in the rehabilitation was six which was within the range of values recorded in the three reference sites (six to nine species). *Spinifex, Acacias* and several other native perennial species were identified in the rehabilitation as well as the reference sites. The density of the S*pinifex* and native perennial plants was lower in the rehabilitation at 2.7 plants per quadrant than the range of the reference sites which were 5.8 – 19.4 plants per quadrant. Despite this the percentage perennial cover of the rehabilitation (53%) was within the range of the reference sites (38-70%).

In terms of habitat complexity *Spinifex species*, grass, shrub and litter cover were all comparable to or higher than values recorded in the reference sites, and good numbers of logs and rocks were present. Overall, the fauna habitat could be considered good, with the range of vegetation strata present suggesting that the site is likely to support a diversity of small mammal, reptile, bird and invertebrate species. Erosion monitoring of Pit 2 Waste Dump 1 described the site as very stable, with minimal erosion and no measurements provided for gullies (suggesting they were too small for measurement or that no gullies were located along the monitoring transect). No landscape function measures were completed during this monitoring.

Overall monitoring in 2012 showed that relatively good rehabilitation has developed after 14 years with species diversity and cover similar to reference sites, fauna habitat considered good and the rehabilitated slope in a stable condition. It was noted that the density of the *Spinifex* was lower than in reference sites although this is likely to improve in time (given that the species are present in the rehabilitation area).

Mesa J Operations Waste Dump T

A different rehabilitation strategy was applied at Mesa J operations in 2007 that involved a single lift waste dump having subsoil applied (as opposed to topsoil). The T Waste Landform was reworked in 2007, the slopes were battered to 15 degrees and stockpiled subsoil (less than five years old) was applied, prior to the area being ripped and seeded. The total lift height of the waste dump is 22-25m whilst at the area of monitoring the lift height is 20m. Due to the sloping gradient of the rehabilitation, monitoring results for the rehabilitation slopes were compared to the average achieved by the sloping reference sites.

Rehabilitation monitoring of the T waste landform in 2013 found there were seven species recorded, the same number as both sloping reference sites. Despite the similar number of species present native perennial plants have established poorly and between 2010 and 2013, plant cover and density only slightly improved (***Figure 3***). The rehabilitation had minimal vegetation compared to the average of the sloping reference sites. The lower storey contributed two thirds of the cover with *Triodia pungens* the most frequently sampled species. The upper storey contributed less than 1% cover with only four *Acacia* individuals sampled.

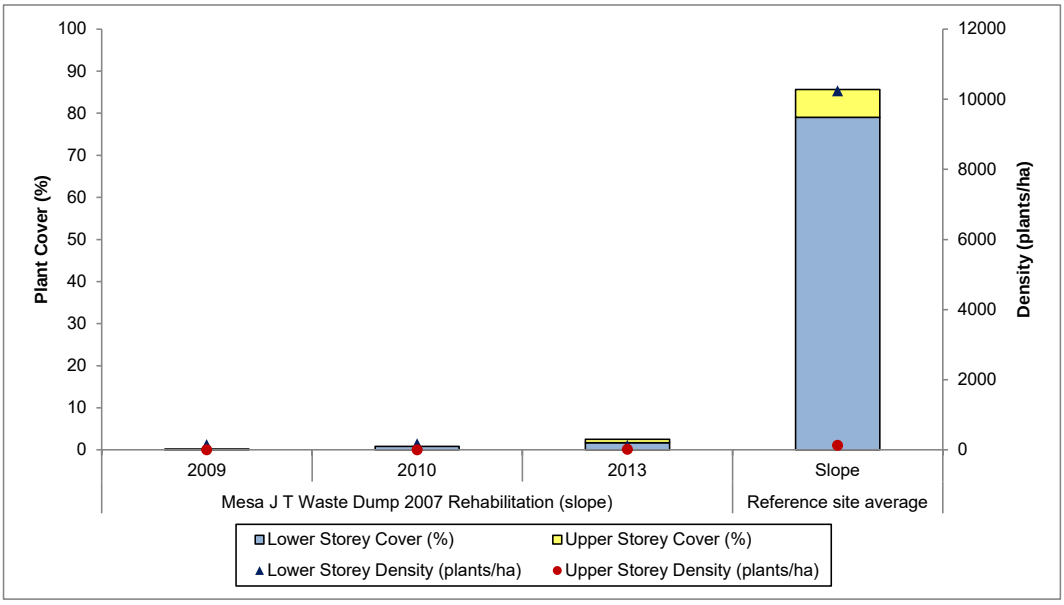


Figure 3: Changes in the plant cover index and density of the 2007 rehabilitation on the Mesa J T Waste Landform (slope), in comparison with sloping reference site (Con7 and Con10) average

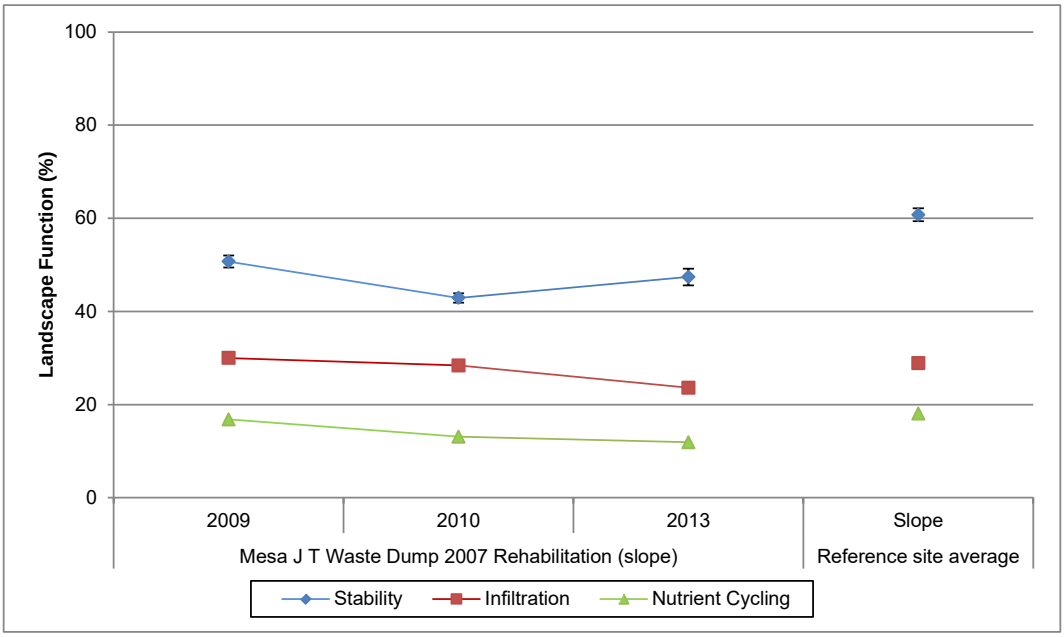


Figure 4: Changes in landscape function of the 2007 rehabilitation on the Mesa J T Waste Landform (slope), in comparison with sloping reference site (Con7 and Con10) average

In terms of landscape function all three indices achieved scores lower than the average scores achieved by the sloping reference sites (refer to ***Figure 4***). The low scores can be attributed to a lack of rocky material on the soil surface and poor vegetation establishment.

A moderate degree of habitat complexity was present with numerous vegetation strata present from grasses to a few shrubs taller than three metres. Faunal habitat was available in the form of grass litter and rocks.

Erosion was a significant issue affecting the performance of the rehabilitation on the T Waste Landform. Since 2009 monitoring, the proportion of the slope eroded doubled to 30%. Both the upper and lower slope display areas of substantial erosion, indicating loss of water resources and therefore reduced potential productivity of the ecosystem.

At the same time as the T waste landform slope rehabilitation was completed, a flat section (on the top of the dump) was also completed. The rehabilitation involved flattening the area, applying subsoil then ripping and seeding. The landscape function scores of this flat area of rehabilitation compare favourably with those achieved by similar flat reference sites. Despite this the vegetation has not established well on the flat rehabilitation with total native perennial cover and density substantially lower than that of the reference sites and the habitat complexity was considered moderate (similar to the slope rehabilitation). There was no erosion (as expected as the area was flat).

The monitoring results to date of the T waste landform slope rehabilitation suggest that while the utilisation of subsoil may assist rehabilitation in achieving some of the rehabilitation indices considered important, in this example it is unlikely to lead to successful rehabilitation. The utilisation of the subsoil on the flat area and slope and resultant low vegetation cover and density suggest the application of subsoil may have contributed to these low values (and not the values being a result of rehabilitation being on a slope versus on a flat area). The use of subsoil should be the subject of ongoing monitoring / trials.

The evidence of extensive erosion also suggests that the subsoil used (and underlying waste type) may not be suitable for use in lift heights of 20m even when battered to 15 degrees.

Mesa J Operations Tailings Storage Facility 1 (Mesa J TSF1)

RTIO has recently rehabilitated a tailings storage facility which was completed in 2014 at Mesa J Operations. The Mesa J TSF1 was originally a pit, however operated as a tailings storage facility between 1999 and 2004. It was decommissioned in 2004 and upon rehabilitation consisted of two low-lying areas that covered ~20% of the surface and an upper, dryer area that covered the remaining 80%. The tailings on the surface of TSF1 had been investigated in 2009 and it was determined suitable for plant growth with few potentially restrictive properties; in addition the TSF already supported areas of regrowth of native vegetation. As a result no topsoil was added during the rehabilitation process to trial whether successful rehabilitation could be achieved on the surface of tailings storage facilities without the utilisation of capping and topsoil.

The TSF rehabilitation commenced in December 2013 and was finished in February 2014 and involved the rehabilitation of the northern two thirds of the facility (~45Ha).

Rehabilitation involved ripping and seeding the surface of the TSF and trees that were present prior to rehabilitation works were retained (and worked around). Contour ripping was conducted to a depth of 600 to 800mm in all areas. Two seed mixes were utilised (with seed collected the year prior to rehabilitation) with one seed mix used for the lower lying potentially wet areas and a second seed mix for the remainder of the TSF. Species were selected specifically to be able to germinate and grow in “wet” inundated clays or water logged soils such as *Cyperus vaginatus.*

Monitoring of Mesa J TSF1 conducted mid 2014 showed that whilst the number of species present in the rehabilitation was within the range of the reference sites, the density of lower storey plants (which represents germination) in the rehabilitation was very low. There was less than 1% cover of lower storey perennial vegetation at the time of the 2014 assessment of the dryer areas, whilst the pre-existing upper story contributed up to 10% cover in some areas. Whilst it is expected the density and cover would be lower than reference sites given the young age of the rehabilitation these are particularly low numbers. The landscape function indices and habitat complexity measures were also lower than references sites, which was to be expected given the young age of the rehabilitation. There was a large amount of the weed species *Acetosa vesicaria* (Ruby Dock) and cattle present at the time of monitoring. Ruby Dock had been noted on the tailings dam prior to the rehabilitation commencing.

In regards to stability and erosion; while no rill or gully formations were present at the three low-lying monitoring transects, some low lying areas at TSF1 were showing signs of subsidence and erosion. A small but deep cavity and other smaller cavities were present adjacent to one of the monitoring transects and contoured rip-lines appeared to be deepening into gully-like flow lines in some areas. It is noted that all of the erosion products would remain internal to the tailings facility due to the shape of the landform.

Initial monitoring results of the rehabilitation suggest that the rehabilitation was showing signs of developing an ecosystem comprising of local native species although the rehabilitated area was threatened by the spread of ruby dock and disturbance by cattle. In addition early signs of erosion suggest that this needs to be monitored to determine if it will result in long term stability concerns.

It is too early to determine if tailings storage facilities similar to the Mesa J TSF1 can be successfully rehabilitated without the use of capping and topsoil. Continued monitoring of this rehabilitation will be undertaken to assess the ongoing development of the vegetation and rehabilitation success.

Early learnings from the rehabilitation methodology used for the TSF1 indicate that for future areas with Ruby Dock infestations it is worth considering completely eradicating Ruby Dock prior to commencing rehabilitation works. This could be achieved through an aggressive and long term spraying program. RTIO has examples of borrow pits along the Tom Price Rail Line located in a national park that are undergoing such a program and have almost eradicated the Ruby Dock.

The other critical learning from the TSF1 rehabilitation that is critical for rehabilitation success related to the post rehabilitation management of cattle (as opposed to rehabilitation methodology). Stray cattle accessed the rehabilitated TSF1 and during monitoring negative impacts on the vegetation and surface of the TSF1 from the cattle were evident. This highlights the need to exclude cattle and potentially other grazing animals as far as possible (such as goats) from rehabilitated areas to assist in the initial establishment of vegetation and long-term success of the areas. Grazing of historically rehabilitated areas can be seen across the Pilbara and anecdotally it appears the vegetation and ecosystems continue to survive. However areas of young rehabilitation (that have not yet become a self-sustaining ecosystem) appear to require protection from grazing animals during the early years of vegetation establishment. This is an important consideration for closure and particularly rehabilitation planning and implementation at Yandicoogina where areas of the operations co-exist with pastoral leases and areas of rehabilitation may be utilised post closure for grazing purposes.

Methodology and Success Rate

Based on the above examples at Mesa J and Brockman 2 of rehabilitation of created landforms comprising of erodible material, the success rates to date indicate the use of topsoil enhances rehabilitation success. Whilst the use of subsoil may assist in improving certain parameters of rehabilitation success (such as habitat complexity and functional indices and does enable some native species germination) it has proven less effective and in some places (such as on slopes) problematic for use in rehabilitation. Whilst this is a limited review of only a few rehabilitated slopes it confirms that topsoil management and the ultimate use of topsoil in rehabilitation greatly enhances rehabilitation success (when compared to subsoil). It also indicates that subsoil may assist in rehabilitation success but should be prioritized for use in flat areas and would require a review of the subsoil properties and seed mixes utilized (to improve germination success and ultimately vegetation establishment).

A review of the three sloped rehabilitation areas comprised of CID or similar waste types Waste Dump S, Pit 2 Waste Dump 1 and T waste landform has indicated that it is possible to achieve a stable, non-polluting landform, that comprises local native vegetation that is self-sustaining and compatible with the surrounding environment containing these waste types if appropriate landform design is utilised and topsoil and seed are applied.

The performance of the rehabilitation area that utilized subsoil suggests that when subsoil is proposed for utilization in rehabilitation it should undergo material testing (physical and chemical properties relevant to plant growth) to determine its applicability as a growth medium and that if subsoil is to be used it may be better placed on flat areas (as opposed to slopes). This testing may also look at potential techniques to improve the performance of the topsoil, such as ameliorants or fertilisers.

The fact that significant erosion was evident on the slopes utilised in a 20m lift, only minor erosion was noted on the lower slopes of the 8-10m lift and no erosion was noted on the 8m lift suggest that CID and alluvial waste if utilising a 15 degree slope should be built with a maximum 8-10m lift height.

The slope stability results seen in the three rehabilitation examples is further supported by testing on CID waste and alluvial materials completed in more recent years that indicate the appropriate maximum lift heights (when using a 15 to 20 degree slope) is from 0m to 10m (depending on the location of the site and associated climate). The "0m lift height" found in testing of some waste types and climate combinations suggest that some wastes will not be stable enough for use in final outer slopes.

The single review of a tailings storage facility highlights that whilst rehabilitation can be completed and germination can be achieved on a tailings storage facility surface without capping and topsoil application, the success of this is yet to be proven. The need for the exclusion of cattle in the immediate years post rehabilitation is also highlighted as a recommendation at Yandicoogina and the control and eradication of Ruby Dock prior to rehabilitation should be considered.

Short-term disturbances and Linear and/or fragmentation disturbances

In addition to created landforms such as built slopes the proposed final landform at Yandicoogina on closure will also have rehabilitation that was completed on short term disturbances and within a short time frame following disturbance. Examples of short term disturbances include; borrow pits, access tracks, clearing for power line and railway construction.

This disturbance can also regularly encompass disturbance described as linear and or fragmentation disturbances such as rehabilitation completed for the construction or removal of pipelines, roads, power lines, rail and bore fields. Whilst a majority of this disturbance is often narrow / long areas of disturbance adjacent to undisturbed vegetation with minor earthworks, it can also include significant earthworks and is likely to range from short term to longer term disturbance timeframes.

The short-term disturbance type often occurs on the surface of the landscape and often involves only minor earthworks that maintain the basic soil profile. Minor earthworks may include clearing topsoil for using an area as a laydown, or following topsoil removal excavating a shallow pit and utilising the material as borrow resulting in a borrow pit that requires rehabilitation. As a result of this disturbance type occurring (often at the surface of the landscape), the material types intersected are usually restricted to the first few metres from surface. This material (first few metres from surface) is generally comprised primarily of topsoil and subsoil (as opposed to alluvial and CID materials). Therefore in discussing rehabilitation methodologies and successful completion of this type of rehabilitation a range of examples from across the Pilbara of different ages have been reviewed and not just examples from Yandicoogina and Pannawonica Operations.

Rio Tinto regularly complete this type of rehabilitation and have refined methodologies over many years of learning and generally achieve good rehabilitation success for this type of rehabilitation. In addition the ability to utilise relatively fresh (young) topsoil, these disturbance areas are usually small or narrow and adjacent to undisturbed vegetation, which greatly enhances the ability to achieve successful rehabilitation.

Successful and Unsuccessful Rehabilitation Strategies

Yandicoogina Borrow Pits

Borrow pits associated with the railway at Yandicoogina were rehabilitated in the second half of 1998 and rehabilitation monitoring commenced in 1999. Monitoring of these borrow pits conducted in 2013 suggest that vegetation communities, in general, are similar to that of reference sites and differences appear to be a result of some reference sites being burnt during the monitoring period.

The rehabilitation methodology for these borrow pits is consistent with methodology used in current borrow pit rehabilitation and includes battering of all slopes, ensuring the borrow pits are free draining and pulling back salvaged vegetation and topsoil across the disturbed area at completion of the rehabilitation, no seed was applied. All borrow pits reviewed appear to have had topsoil replaced and were ripped. There is no evidence of erosion in any of the

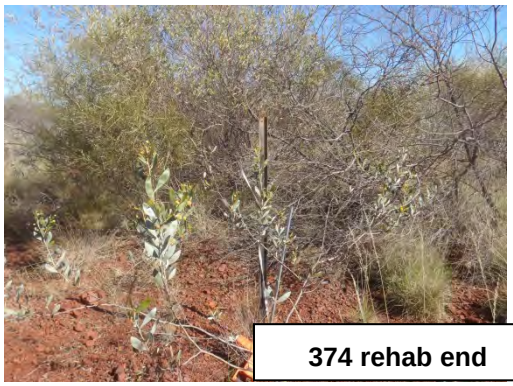
borrow pits. Monitoring results from three of the borrow pits are shown in ***Table 2*** below to give an indication of rehabilitation success as at 2013.

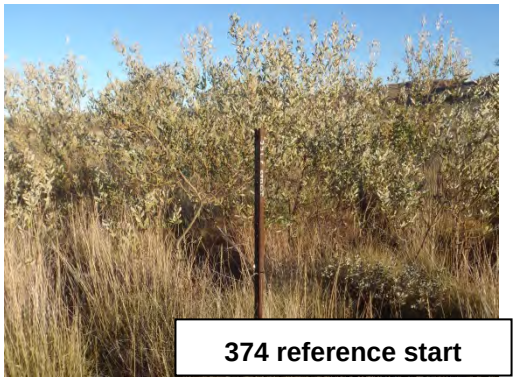
Table 2: Selected monitoring results of the Borrow Pit rehabilitation areas and reference site values (shown in brackets).

Borrow Pit	Age of Rehab (years)	No Species (Rehab)	Plants/ Quadrant	% Perennial Cover	Summary (sourced from the rehabilitation monitoring report)
BP363	14	7 (8)	4.3 (4.2)	45 (64)	The rehabilitated site continues to compare favorably with the reference site
BP374	14	7 (13)	5.6 (20.3)	55 (53)	The 2007 burn in the reference site significantly changed a number of key parameters, making comparison of the two sites difficult, overall, the rehabilitation appears to be developing well
BP417	14	7 (7)	3.3 (13.3)	49 (31)	Results in 2003 indicated that the vegetation communities of the reference and rehabilitated sites had become similar in most regards, a fire in 2010 has since altered this trend.

In addition to the above results all borrow pits were found to have an abundance of *Spinifex* species and *Acacia* species, which were the species dominant in the reference sites they were being compared to.

Figure 5 below shows as an example BP374 monitoring transect at the start and end of the transect and the reference site it is being compared to.





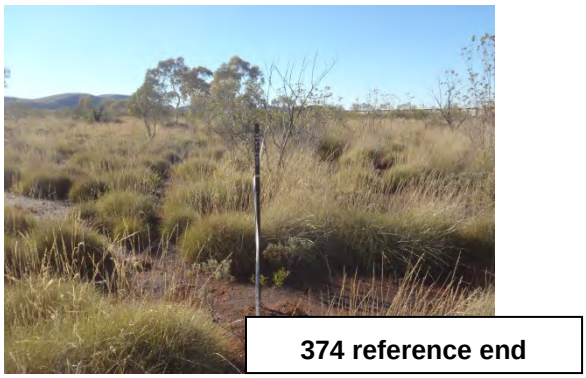


Figure 5: The start and end of the monitoring transect on borrow pit 374 at Yandicoogina and the start and end of the relative reference site transect (in undisturbed vegetation).

Hope Downs 4 Haul Roads, Borrow Pits, Power Line and Railway Rehabilitation

To further review rehabilitation strategies and success relating to short term disturbances the 2014 rehabilitation monitoring conducted across Hope Downs 4 is discussed. The monitoring completed at Hope Downs 4 involved assessing 35 locations across a range of rehabilitated disturbance types and associated reference sites. These included the mine access road (1 location), disturbance for power line construction (4 locations), borrow pits (11 locations), camps (4 locations), railway construction (15 locations) and mine disturbance (5 locations). All of this rehabilitation was completed during 2013 and resulted from disturbance to enable the establishment of the new Hope Downs 4 Mine. The rehabilitation methods utilised included reprofiling areas, replacing topsoil and salvaged vegetation and shallow or deep ripping of areas (dependent on compaction), no seed was applied.

A summary of the rehabilitation shows that vegetation in most of the Railway sites has established well, with good species establishment, species/quadrant and density comparable to that of the reference sites. Spinifex was present in all sites. All Railway and Powerline rehabilitated sites appeared to be stable. Weeds were only present in four of the 19 Railway and Powerline sites, with weed abundance (mostly Buffel Grass) low in all apart from one Powerline site where Spiked Malvastrum was abundant across the whole transect. Vegetation in many of the Mine Access Road, Camp and Mine rehabilitated sites has also established well, with total species numbers, species/quadrant and native plant density comparing favourably with the reference sites. Spinifex was establishing in most rehabilitated sites. Results are shown in ***Table 3*** and ***Table 4***.

Table 3: Rehabilitation monitoring results of the Railway line sites, with green shading indicating values within or above the reference site range which indicate rehabilitation heading in the right direction given its young age.

	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	LHRX	Reference Site Range
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	
Total Spp	10	13	10	6	13	11	7	11	13	19	17	12	9	12	15	14-26
Species/q	2.9	3.4	3	2.2	3.6	1.9	1.2	2.5	2.9	4.9	3.9	2.1	1.5	2.7	3.8	1.8-2.5
Plants/q	8.4	6	7	15.9	11.5	3.1	2	5.9	6.3	30.5	7.4	3.4	1.7	3.2	6.8	5.4-14.2
Spinifex/q	6.9	3.2	4.8	14	8.4	1.5	1	3.1	0.1	18.8	1.2	1	0.3	0.1	4.3	0.5-7.3
% Perenn Cover	30	32	20	11	24	21	1	6	36	19	27	12	7	20	13	44-63

Table 4: Rehabilitation monitoring results of camp, mine access road and mine disturbance sites, with green shading indicating values within or above the reference site range which indicate rehabilitation heading in the right direction given its young age.

	2014_HD4_Mine_Access_Road_T1	2014_HD4_Camp_T1	2014_HD4_Camp_T2	2014_HD4_Camp_T3	2014_HD4_Camp_T4	2014_HD4_Mine_T1	2014_HD4_Mine_T2	2014_HD4_Mine_T3	2014_HD4_Mine_T4	2014_HD4_Mine_T5	Reference Site Range
Total Spp	20	20	14	18	2	6	2	11	6	15	14-26
Species/q	5.5	3.9	2.9	4	0.2	0.9	0.2	2.1	1.4	3.7	1.8-2.5
Plants/q	14.3	7.8	7.3	5.4	0.2	1.7	0.2	3.3	4.8	6.1	5.4-14.2
Spinifex/q	6.5	1	0.4	0.6	0	0.3	0.1	1.5	4.3	3.2	0.5-7.3
% Perenn Cover	25	33	16	15	0.5	6	0.1	8	1.3	4	44-63

A fauna habitat assessment showed that fauna habitat is beginning to develop well in many sites, though more time is needed to assess this.

Methodology and Success Rate

The methodology utilised for rehabilitating short term disturbances in general appears to be working to achieve successful rehabilitation (stable, non-polluting landform, that comprises of local native vegetation that is self-sustaining and compatible with the surrounding environment) and is proposed for use to rehabilitate similar types of disturbance at Yandicoogina. This methodology involves salvaging and stockpiling vegetation and salvaging and stockpiling topsoil prior to disturbance, then reprofiling areas, returning the stockpiled topsoil and vegetation and deep or shallow ripping along the contour as appropriate. With regard to borrow pits the initial placement of them in the landscape and resultant excavation is critical to enabling the borrow pits to be free draining following rehabilitation.

Long-term disturbances (e.g. construction camp, permanent accommodation village and administration buildings)

In addition to created landforms and short term disturbances the proposed landform at Yandicoogina on closure will also have rehabilitation that was completed on long-term disturbances. Examples of long- term disturbances include construction camps, landfill sites and accommodation villages. They are considered in this discussion as any generally flat disturbance that is rehabilitated within a medium to longer time frame following disturbance. The discussion of rehabilitation strategies and success rates for long-term disturbance will involve a review of monitoring results for a rehabilitated landfill at Yandi and fixed plant rehabilitation completed at Mesa A.

Landfill Sites at Yandicoogina

Two landfill sites (adjacent to each other) that were rehabilitated in 2009 after being disturbed (active) at Yandicoogina for three and a half years and last monitored in 2014 are considered examples of longer term disturbance and discussed below.

The decommissioned landfill sites had clean fill imported to cover the pits, then it had topsoil applied, was ripped and seeded and monitored for the first time in 2013, then again in 2014.

Numbers of total species in the two landfill sites were nine and 11 which was similar to those in the two reference sites (11 and 12 species), with a range of *Acacia species* as well as *Spinifex species*, native grasses, and various other native shrub and herb species identified at the rehabilitated sites. Species per quadrant values showed no clear separation between the reference site and the Landfill sites. Native plant density in the two landfill sites had changed very little since 2013, and was comparable to or higher than those in the reference sites. Mean bare areas values (which provides an indication of cover values) in the two landfill sites and the reference sites were similar to each other, with no significant differences.

Results for the two landfill sites show that rehabilitation has established and developed well, with most measured and calculated parameters similar to values recorded in the two reference sites and in some cases higher. No weeds were recorded in either landfill site, and both sites are stable, with no erosion recorded. Field notes for both sites describe the rehabilitation as excellent. Fauna habitat of the two sites is likely to be good for any small reptiles, mammals, birds and invertebrates that utilise spinifex and shrubs, but less suitable for ground dwelling species that utilise litter and logs.

Mesa A Fixed Plant Rehabilitation

A nine hectare area previously utilised as a laydown area for approximately three years by the fixed plant personnel at Mesa A operations was rehabilitated in 2012. The area had topsoil applied, was ripped and seeded. Monitoring of the area in 2013 showed the total numbers of species in the two rehabilitated sites were comparable to or greater than those recorded in the reference sites, species present in the rehabilitation included a number of *Acacia species* and other shrub, herb and grass species as well as *Spinifex species*. The plant density values were lower in the two rehabilitated sites at 2.3 and 2.3 plants per quadrant as compared to the reference sites (5.3 and 6.4 plants per quadrant), which is expected given the young age of

the rehabilitation. The percentage of perennial cover was also very low in the rehabilitated sites (1% and 4%) as compared to the reference sites (43% and 51%).

There were no signs of erosion in the rehabilitated sites and it was too early to do an assessment of habitat diversity (to determine appropriate habitat for fauna). It is too early to determine if the rehabilitation is on track to be successful. The early indicators of the rehabilitation certainly show it is not doing as well as some other shorter term rehabilitated areas such as the areas reviewed at Hope Downs 4. This may be a result of differences in weather and rainfall received at the two sites or as a result of the disturbance being longer term (which may lead to reduced quality of topsoil). The other factor that may be contributing to the rehabilitation success at the Mesa A Fixed plant area is that it is surrounded by disturbed areas (and not immediately adjacent to undisturbed native vegetation).

Methodology and Success Rate

The two examples for longer term disturbance reviewed suggest that it may be more challenging to achieve rehabilitation success in areas of longer term disturbance (than short term disturbance areas). In both cases the rehabilitation methodology has shown that the areas are stable and have native species present, with the landfill indicating density and cover is similar to the reference sites whilst further monitoring of the Mesa A rehabilitation will determine if cover values will be achieved in time. Whilst only a review of two areas the rehabilitation methodology of landform shaping, topsoil application, ripping and seeding appears to support the development of successful rehabilitation in longer term disturbance. An important step of the rehabilitation of the longer term disturbance (as opposed to short term disturbance) is the addition of seed. The addition of seed in the rehabilitation process should be considered regardless of the disturbance type but based on the likely viability of the seed bank with the topsoil utilised in the rehabilitation. In addition the germination of seed in rehabilitation areas may also assist if the proposed rehabilitation habitat being established is different to the habitat from which the topsoil was sourced, which may be the case in Yandicoogina where some wetland habitats will be developed as a part of the closure of the site.

Rehabilitation best practice references

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APPENDIX D

29. Appendix D Conceptual landform design closure options

This section summarises the discussion, considerations and anticipated outcomes of conceptual landform combinations have been developed and reviewed by Rio Tinto over recent years. Any of the scenarios presented below could be adopted at the current stage of mining, but could result in different economic, environmental and social impacts, opportunities and / or outcomes than presented in the Yandicoogina Closure Plan.

29.1 Considered options

The following closure scenarios present different landforms options have been developed by Rio Tinto, taking into consideration the location of CID beneath the existing creek systems and potential expansion activities. Each closure scenario presented below has the potential to influence the surface and ground water systems in different ways, and thereby has the potential to achieve different environmental and social closure outcomes.

As part of Rio Tinto's internal review, it was recognised that landform stability and the management of mineral waste, which can be moved and shaped to control water movement, comprise some of the larger closure cost aspects. While the cost implications of the closure scenarios have been reviewed by Rio Tinto, the cost implications are not discussed in this report.

29.1.1 Closure scenario 1 No backfill

Mining activities to date have maintained a minimum 200m standoff from the existing creeks[45], to preserve the creek ecosystem wherever possible. In the "no backfill" scenario, mineral waste would nominally be used to stabilize pit walls where a high risk of wall collapse is identified, to prevent flood water from entering the voids. Mineral waste not used would remain external to the pit. This would leave large voids exposing the groundwater table (Figure E1).

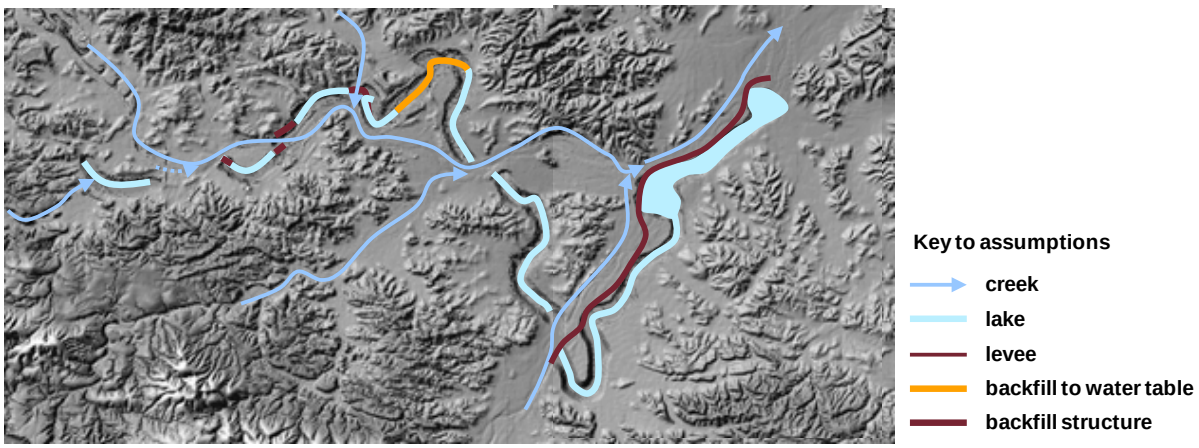

Figure E1: No backfill closure scenario.

Conceptual modelling[46] suggests that due to the strong creek recharge mechanisms, water levels in the voids upstream of JSE would recover in less than 5 years, creating a chain of lakes that are disconnected from the creek system. Water lost through evaporation would result in the water table recovering to a level that is less than 10m below the pre-mining water levels with water quality of less than 1000mg/l (although the cumulative impact of the upstream mining activities has not been accounted for and could result in a doubling of the water salinity[47]).

[45] With the exception of Phils Creek for which mining approval for the removal and realignment of the creek has been approved under Ministerial Statement 914.

[46] RPS Aquaterra (2012) Yandicoogina closure options: Preliminary water modelling results. Prepared for Rio Tinto Iron Ore, 22 December 2011. RTIO-PDE-0103618.

[47] RPS Aquaterra (2012) Yandicoogina closure options: Preliminary water modelling results. Prepared for Rio Tinto Iron Ore, 22 December 2011. RTIO-PDE-0103618.

At JSE, however, the water table would recover to 15m or more below the original water table. The 15m drop results from a combination of the decreasing water level from the upstream voids in Marillana Creek, limited connection to local creek systems and the large surface area subject to evaporation. The evaporation rates would keep the water table suppressed, even though the water table would be higher on both the northern (Marillana Creek) and southern (Weeli Wolli Creek) extents. The change in groundwater gradient draws water from under both the Marillana Creek and Weeli Wolli Creeks, creating a permanent cone of depression under both creeks. Salts[48] would continuously accumulate within the JSE pit, such that the water quality would eventually be classified as hypersaline. Salts trapped within the void would be permanently removed from the water systems.

Regional groundwater flows would be unaffected by the saline sink at JSE. Groundwater flow would be maintained down the alluvial systems associated with Marillana Creek and Weeli Wolli Creek[49]. However, because the groundwater table would not recover to the original levels, the riparian community structure would be permanently changed.

Development of the Billiard deposits, if following this same closure concept of no backfill with the separation of pit void and creek system, would result in similar conditions as JSE – a hypersaline lake with cone of depression permanently extending under Weeli Wolli Creek. However, the Billiard void would have a larger and longer connection to the remaining CID and alluvial aquifers. This would allow more water to be drawn from the regional groundwater system and could terminate groundwater flow from the Weeli Wolli Catchment to the Fortescue Marsh.

29.1.2 Closure scenario 2 Backfill to pre-mining water table

Backfilling mine voids to the pre-mining water table level aims to cover the groundwater table and thereby stop evaporation processes and preserve water quality. As there is insufficient mineral waste generated through the act of mining to cover the groundwater table, it is assumed that the hills adjacent to the voids would be mined to fill the voids (Figure E2). Filling the voids to groundwater level does not, however, reinstate the original topography or create a free draining surface. As such, the pit walls adjacent to the pit are not stabilised and the pit void continues to capture runoff.

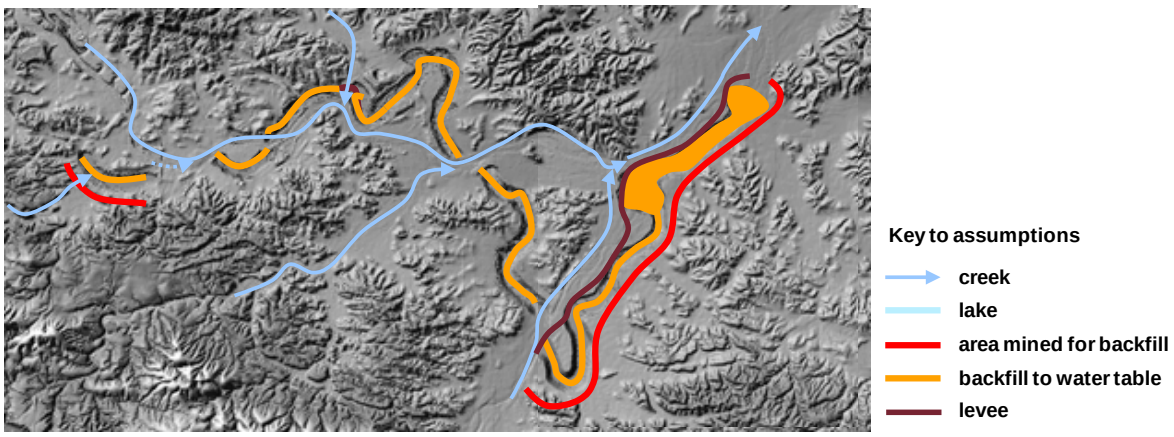

Figure E2: Backfill to pre-mining water table closure scenario. Locations illustrated as "area mined for backfill" (in red) do not represent an intention to mine these areas, and are supplied only to indicate the magnitude of the area required to be mined to achieve this outcome.

Conceptual modelling[50] suggests backfill to the original groundwater table level would facilitate the recovery of the water table to pre-mining levels. However, due to the strong creek recharge mechanisms, the water table would fluctuate significantly (up to 10m). When the water table fluctuates above the backfill level shallow pit lakes would be formed. (Backfill to 10m above the pre-mining was estimated to be required to completely suppress the groundwater table.)

[48] All salts accumulated within the voids in the closure scenarios are derived solely from groundwater constituents. Mineral waste characterisation shows there are no salts that will be leached from mineral wastes under neutral or acidic conditions.

[49] Additional groundwater modelling is required to verify this conclusion as it was not a factor assessed as part of previous modelling activities.

[50] RPS Aquaterra (2012) Yandicoogina closure options: Preliminary water modelling results. Prepared for Rio Tinto Iron Ore, 22 December 2011. RTIO-PDE-0103618.

The lakes would be subject to evapoconcentration processes, causing salts to build up in the void soils. The salts, combined with regular inundation and prolonged water logging, would generate conditions that would not be favourable to vegetation growth.

Groundwater salinity would remain relatively similar from Oxbow through JSW and JC, but would increase by around 60 percent at JSE. If this same scenario was continued through to Billiards, salinity within the Billiard void would increase seven-fold due to the large potential exposure area.

Backfilling above the pre-mining water, to ensure no ephemeral lakes form, would substantially reduce groundwater quality issues and improve the growing conditions within the voids.

Several studies have been undertaken to determine the potential source of material to achieve the necessary backfill. Colloquially referred to as “backfill hill”, the volume of material required to backfill the voids to the water table[51], in addition to the mineral waste generate through mining, is over 55 million m^3. This equates to excavation of an additional +400ha of undisturbed land and hills adjacent to the mine. Backfilling to the water table will still leave shallow (up to 20m deep) pits. Additional excavation would be required if backfill to above the water table was preferred.

Groundwater through flow to Fortescue Marsh would be maintained under this scenario, and no drawdown would be experienced in the alluvial aquifers under the creeks. However, the level of backfill would not stabilise the pit walls. Only a few centimetres of wall failure / erosion on the top of the pit wall could be sufficient to allow flood water to flow into the voids, and start the processes that lead to creek capture. If the voids capture the creek, the frequency of surface water low flow and flood events would change. This could have an impact on the creek flow regimes and ecosystems (as previously discussed).

29.1.3 Closure scenario 3 Maintaining creek flows

The “maintaining creek flows” scenario prioritises the use of available mineral waste to stabilise the pit walls, strengthen flood bunds and thereby preserves the creek systems as far as practicable. No attempt to suppress the groundwater table is made. Instead deep lakes are encouraged to form, and excess mineral waste not required to support the creek system is placed to reduce the surface area of the lakes, rather than reduce the depth of the lake (Figure E3).

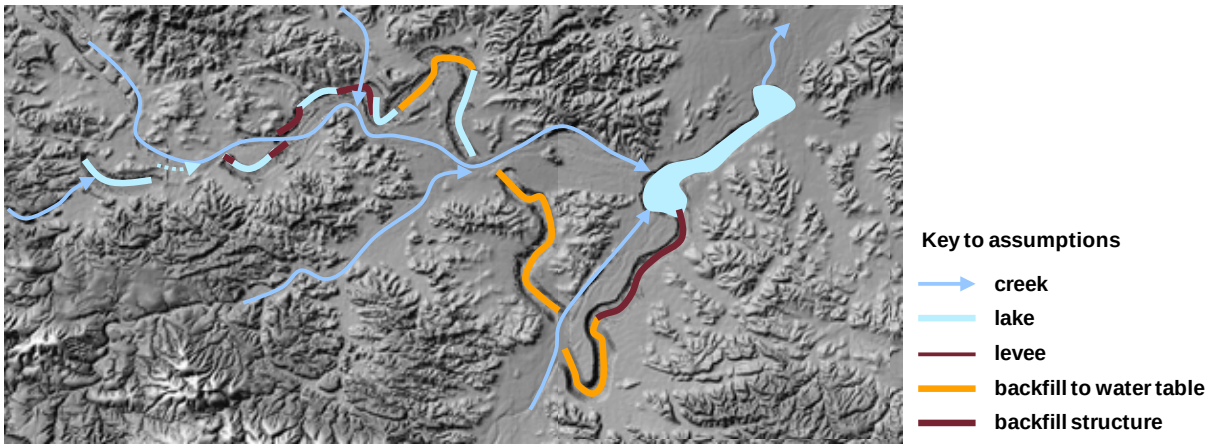

Figure E3: Maintaining creek flows closure scenario.

Mineral waste priority locations were identified (from high to low) to minimise the potential for pit walls to collapse and to increase resilience to large flood events:

- Phils Creek reconstruction. Phils Creek is removed as part of the JSW pit development. Additional mineral waste would be used to strengthen the land bridge (constructed during operations) by increasing the buttressing either side of the land bridge. This configuration would minimise the potential for pit walls to collapse and increase resilience to large flood events.
- Marillana Creek between the JSW A and C areas. The area where Marillana Creek divides the JSW –A (southern) deposit from the JSW-C (northern) deposit restricts surface water flows between two flood bunds. Once the ore is removed, the bridge of CID ore and alluvium that remains under Marillana Creek has the potential to collapse into the void. Mineral waste would be used here to strengthen the pit walls and, leaving the flood bund in place, strengthen the flood bund. This configuration would increase resilience to large flood events.

[51] Rio Tinto (2009) Yandi Conceptual Study on Magnitude of works to Backfill Voids, June 2009, RTIO-PDE-0068220.

- JSW area A adjacent to Marillana Creek. This pit wall is also located in the floodplain. Mineral waste would be used here to strengthen the pit walls and again, leaving the flood bund in place, strengthen the flood bund. This configuration would increase resilience to large flood events.
- JSE waste fines cover. Mineral waste is placed over the JSE waste fines cells to prevent the creation of a lake. This would prevent the permanent drawdown of the groundwater table under Marillana and Weeli Wolli Creek adjacent to the JSE deposit.
- Billiard southern expansion. The Billiard expansion intersects the Weeli Wolli Creek floodplain and could potentially mine through Weeli Wolli Creek. The long pit wall parallel to the creek has a high potential to fail. The mineral waste estimated to be generated from mining the northern portion of the Billiard deposit would allow the entire southern portion of void to be backfilled to surface to reinstate a floodplain.

In this scenario lakes will form in the Oxbow, JSW, JC and Billiard areas.

Modelling suggests the groundwater table would recover to approximately pre-mining levels in spite of the creation of several lakes. This situation evolves due to several different water interactions.

At Oxbow, the lake would behave as sink and water quality would deteriorate over time as a consequence. However, recharge from local runoff (terminating in the lake) would sustain the water levels around the pre-mining level. By behaving as a sink, salts would be prevented from interacting with the downstream alluvial and lake systems.

The JSW lakes would have a strong connection to the alluvial aquifers beneath Marillana Creek and would be rapidly recharged with the fresh alluvial waters. The surface area of the lakes would be relatively small in relation to the through flow rates, enabling the water to stay relatively fresh.

The JC lake would behave as a sink. However, because the lake is fed via water travelling through the CID from the JSW area, the salt content would be relatively low and the lake would take longer to become saline than Oxbow. The water level at JC would not recover to pre-mining level and a cone of depression would extend from JC under Marillana Creek into the JSE area.

The cone of depression at JC would cause the water flow direction to reverse through the JSE area, when compared to the pre-mining flow direction. This would pull the fresh groundwater in the Weeli Wolli aquifers through the JSE area, achieving approximately the pre-mining water levels.

Downstream of the JC cone of depression in Marillana Creek, the alluvial aquifer would be rapidly recharged from the surface water flows. This would sustain the pre-mining water table, in this sensitive riparian area, at the pre-mining water quality.

In the southern backfilled portion of the Billiard expansion area water levels and water quality would be returned to pre-mining conditions. Around the Billiard lake a small cone of depression may form during periods of prolonged dry weather. However, because this lake would receive all flows from Weeli Wolli Creek, the water levels would fluctuate with rainfall and overtop following large flood events (possibly every two to three years or so).

29.1.4 Closure scenario 4 Multiple small, deep lakes

This scenario is the same as scenario 3, with the exception of the Billiard expansion area. In this scenario multiple small, deep lakes are encouraged to develop through the Billiard void by placing the waste back into the void at staggered intervals as well as diverting Weeli Wolli Creek through the void (Figure E4).

This configuration would create a chain of lakes down Weeli Wolli Creek. During dry periods the lake water levels would drop, creating a groundwater cone of depression in the adjacent remnant alluvials aquifer. Because surface water flows are diverted into the voids, filling each void in sequence before overtopping the backfill then filling the next void, the alluvial aquifers would no longer be regularly recharged and the low flow channel and flood plain outside of the mined area could cease to function. As a result the composition of the riparian vegetation adjacent to the Billiard deposit could be significantly altered.

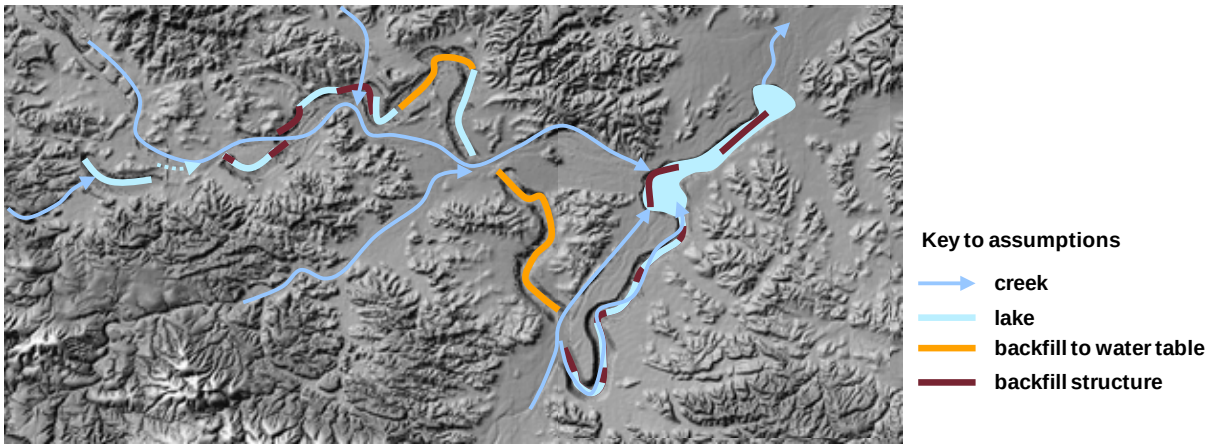

Figure E4: Multiple small, deep lakes closure scenario.

The mineral waste between each lake would be vegetated to create artificial wetlands with waterways to allow the flood water to pass between voids.

As with scenario 3, the water quality would remain relatively fresh as the accumulated surface water area is roughly the same. Similarly, the flood frequency through to Fortescue Marsh would be akin to scenario 3 (overtopping every two to three years).

29.1.5 Closure scenario 5 One permanent lake

This scenario is the same as scenario 3, with the exception that an additional CID deposit located between the existing JSE area and the Billiard expansion area, under Weeli Wolli Creek, is mined. Little to no backfill occurs within the Billiard area, such that waste dumps are left external to the mine area. Weeli Wolli Creek is diverted into the void, creating one long, continuous lake.

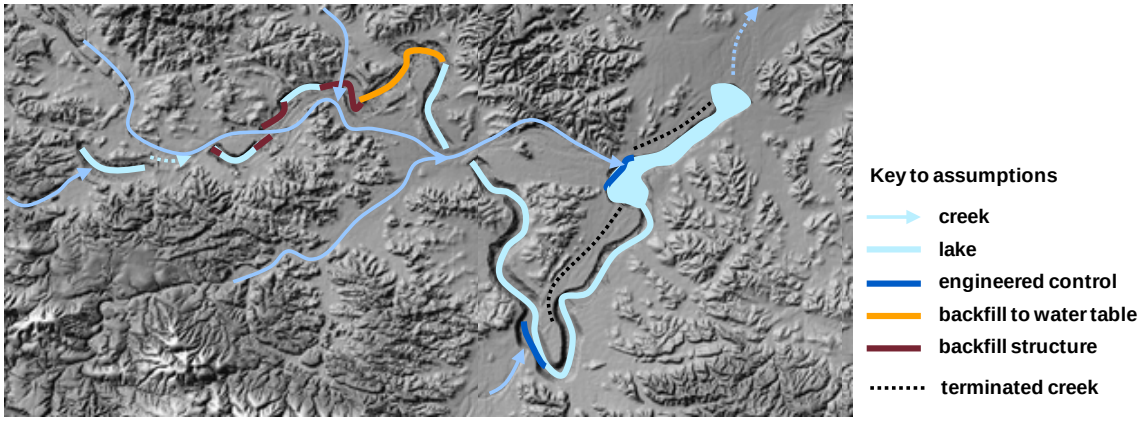

Figure E5: One permanent lake closure scenario.

As with scenario 4, the lake would capture all flows along Weeli Wolli Creek, and the riparian community adjacent to the mined area would experience similar impacts (changes to the vegetation community). The contribution of fresh surface water flows would maintain fresh water quality within the lake for most of the time. During periods of sustained drought, however, the water quality would be expected to diminish.

Due to the magnitude of the surface water volumes during flood events, the flood frequency through to Fortescue Marsh would be akin to scenario 3 (overtopping every two to three years).

29.1.6 Closure scenario 6 Continuous channel

Unlike all of the other scenarios consider, the “continuous channel” scenario does not seek to preserve the existing ecosystem. This scenario was designed to answer the question “can we create a stable alternative ecosystem if we mine the entire CID”. The scenario assumes mining activities remove all of the economic ore within the mapped CID (from Oxbow to Billiards) to create a singular, continuous pit. In this scenario Marillana and Weeli Wolli Creeks and their tributaries are diverted into the mined void and mineral waste is use at strategic locations to control the water movement into the void (Figure E6).

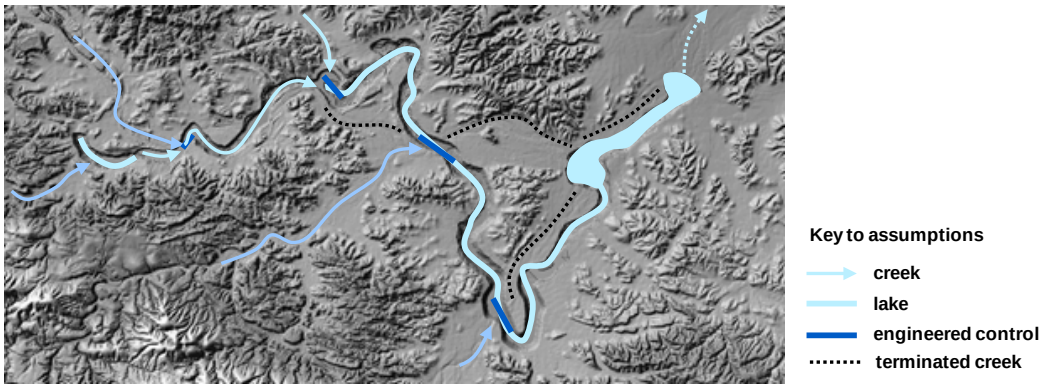

Figure E6: Continuous channel closure scenario.

In Weeli Wolli, surface water would cascade 30m over the edge of the void directly into the lake. In Marillana, surface water would be conveyed over the edge of the pit, and continue to flow along the clay base of the void before merging with the lake. In both creeks, the increase in flow velocities as water enters the voids could cause considerable erosion of the in situ alluvial soils up stream of the void and some degradation or change in the creek bed, banks and riparian community could occur.

Diverting all surface water flows into the void would enable the pit lake water quality to remain permanently fresh (at around 100mg/l to 200mg/l). The lake would extend from the middle of the JC area to Billiards. Groundwater would sustain the freshwater lake throughout the dry season. When the creeks flow, the lake level would rise (up to 6m) and fall, occasionally overtopping to send water through to Fortescue Marsh. A cone of groundwater depression would extend out around the void, such that riparian communities up gradient of the void would also be impacted.

The lake would include a large shallow area of water. The shallow water would encourage a littoral zone to form, which would help regulate the health of the lake by providing habitat for aquatic flora and fauna.

Diversion of the surface water flows into the void would deprive the remnant creek sections, downstream on Oxbow on Marillana Creek and areas adjacent to the Billiard deposit, of flood water. The vegetation community would be substantially altered, which would result in significant habitat loss. However, the creation of permanent freshwater lake could create a new fauna refuge.

Due to the magnitude of the surface water volumes during flood events, the flood frequency through to Fortescue Marsh would be akin to scenario 3 (overtopping every two to three years). However, the total volume of water that would report to Fortescue Marsh is expected to be substantially reduced in comparison to scenario 3.

APPENDIX E

30. Appendix E Yandicoogina closure risk assessment

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Likelihood	Health	Safety	Environment On-site Off-site	Environment Community	Compliance	Risk Management	Detailed Action Descriptions
Planning and knowledge												
Contaminated sites												
Under-estimated general contaminant clean up requirements	• Use of chemicals and hydrocarbons during operations • Housekeeping practice and maintenance of work areas and equipment	• Regular maintenance / inspection / audit of work place procedures • Spill management kits readily available • Contaminated sites register maintained across life of operation	• Some hydrocarbon spills at hydrocarbon (mainly diesel) storage / handling facilities and fuel pumps facilities identified, managed through site processes • Experience with removal of infrastructure suggests some minor additional clean up may be required during decommissioning • Phase 1 inspection to be undertaken on decommissioning	A large, previously unidentified oil spill is found after beneath a concrete slab during the decommissioning activities and requires decontamination.	R			L			I	YA-XX. Complete Phase 1 and Phase 2 (where required) contaminated sites investigations and required actions to remediate contamination.
Under-estimated acid and / or metalliferous drainage management requirements during operations (pre-closure) & decommissioning phase	• Potential for acid / alkaline / metalliferous / neutral / saline drainage generation during operation of mine • Water management, storage and monitoring practices • Water quality prior to return to environment e.g. via infiltration or discharge	• Geochemical characterisation of waste material show material is 'inert', no elevated sulfur, no potential for acid drainage generation • Discharge water quality monitored. Includes sampling and trigger / response requirements • Wet season management plans used to control run off. • Groundwater operating management plan to monitor groundwater quality	• No evidence of alkaline / neutral / saline drainage during operation of mine • Leakage of water through waste fines cell is recognised, however leakage is regularly intercepted by dewatering bores (re-circulation) and monitoring of that water quality has shown no potential issues.	Leakage of water from the waste fines cell(s) compromises the quality of groundwater beneath the waste fines storage facility. Groundwater treatment is required prior to relinquishment.	R			L			I	No further action required at this time.
Acid and / or metalliferous drainage generation (after closure) creates a contaminated site	• Interaction of water and mineral waste could generate acid / alkaline levels that leach metals / salts from the mineral waste or local environment • Presence of temporary or permanent open water bodies, enabling evapoconcentration to occur with creation of alkaline / hypersaline water quality • Ability of metals / salts to move through environment to impact a sensitive receptor, to meet definitions in Contaminated Sites Act 2003	• Geochemical characterisation of waste material show material is 'inert', no elevated sulfur, no potential for acid drainage generation • Geochemical test work completed on mineral waste and natural groundwater shows potential for alkaline water generation and associated metal leaching under specific, extreme evapoconcentration conditions	• Preliminary pit lake water quality modelling completed. Some modelling scenario showed that Oxbow West (and possibly Oxbow East which has yet to be modelled) could generate hypersaline lake water. Model results are highly dependent on climate forecasts and water quality exiting the upstream BHPBIO mine via groundwater. If hypersaline water quality conditions are produced, pit lake will be a groundwater sink, such that saline water and any associated potential metals / metalloids in solution would be confined to the Oxbow West lake. • No modelling undertaken for Oxbow East. Lake is likely to be through flow because Oxbow West as a sink is likely to have a lower head pressure, resulting in water moving from alluvial aquifer through Oxbow East to terminate in Oxbow West. • Preliminary modelling suggested JC would not be hypersaline due to groundwater leakage, i.e. not absolute sink. Further validation of leakage is required. • Geochemical test work suggests hypersaline water quality could create alkaline water conditions, leading to the leaching of metals if pH exceeds ~9. • Geochemical modelling shows that metals are re-sorbed / removed from solution with fresh water addition which reduces pH to <9, e.g. significant rainfall / surface water flows. Further modelling is required to conclude if anticipated regular surface water flow contributions to Oxbow West will prevent / limit pH 9 conditions. • Closure plan for Oxbow West and East pit lakes include minimising potential for biotic activity (i.e. no rehabilitation in pit), to further minimise pathways for metals to move into the environment.	Evapoconcentration processes in Lake Oxbow create highly saline, alkaline water which results in the release of metal contaminates into the lake water at levels that exceed agreed completion criteria. The metals are trapped in the lake water, and are resorbed when the pH is lowered due to fresh water flows from the Oxbow creek into the pit lake.	P				L		II	YA-29. Undertake alkaline leach tests on Yandicoogina waste materials. YA-XX. Update groundwater recovery (level) model to include latest data, Oxbow East and PBS lake scenarios. YA-XX. Develop local scale groundwater model and associated water quality model for JC. Confirm that JC has no hypersaline (as an indicator of potential contamination) water quality risk. YA-XX. Develop local scale (joint) groundwater model and associated water quality model forOxbow East and Oxbow West. Investigate if surface water flow will reduce / eliminate pH 9 conditions or control aqueous metal / metalliod conditions
Human health impacts from in situ fibrous material exposures	• Hazardous fibres exposed in situ by mining, mined and moved to encapsulated areas or naturally present in soils disturbed by mining / rehabilitation activities • Erosion of materials containing hazardous fibres post-closure	• Physical materials characterisation, some fibres present in mineral waste materials, surface alluvials and associated with infrastructure installation (cuts through non-mined geology) • Fibrous materials management plan enacted	• Actinolite in Dolerite intersected during construction of the rail loop, in rail cuttings, F5 canyon and other areas near loop. Exposures around rail loop covered. • Riebeckite/Crocidolite - Weeli Wolli Banded Iron Formation in Central pit. Crocidolite in colluvium Hairpin and Waterstand areas. All intersected potentially fibrous material has been encapsulated. • Fibres (not defined as hazardous, only potential) identified in colluvium / alluvium outside of pit. This material could be disturbed if extensive groundworks undertaken or if erosion management fails. • During pre-closure, progressive rehabilitation and decommissioning, management procedures in accordance with Fibrous Materials Management Plan will need to occur.	Pit wall in junction central area collapses and exposes hazardous fibrous materials after closure.	R	M					II	YA-XX. Before ground disturbance, review potentially hazardous fibrous materials status to resolve areas of hazardous materials. YA-XX. Implement Fibrous Materials Management Plan in designated hazardous fibrous areas

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Likelihood	Health	Safety	Environment On-site	Environment Off-site	Community	Compliance	Risk Management	Detailed Action Descriptions
Void management													
Lake and / or lake fringe habitat has undesirable impacts on general ecosystem function.	• Open water bodies in Pilbara naturally attract fauna (feral and native species) for food/ water/ refuge, safe access to water required • Concentration of natural groundwater or mineral waste derived salts through evapoconcentration in open water bodies • Release of metals from natural geology or mineral waste into water (infiltration or groundwater flow) • Water provides opportunity for plant /weed growth, good and bad (toxic algal blooms, noxious weeds) • Certain plant / animal species bio-accumulate / magnify toxic metals • Instability associated with saturated, unconsolidated ground, can be increased by high trafficability	• Void closure management guidance • Geochemical waste characterisation, good understanding of water chemistry / reaction chemistry • Physical waste characterisation • Rehabilitation handbook • Landform design guidance • Safe access to lake edges established via adjacent waste dumps (except Oxbow) • Wetland rehabilitation trial established to review performance of common riparian species and waste dumps when near water table / pit lake • Aquatic fauna research underway to understand natural levels of toxic metal accumulation / impact on native species	• Water models show salinity to be highly variable between lakes. Water quality including high salinities observed to occur naturally in pools, thus some natural tolerance to salinity and associated water quality conditions expected of flora / fauna; although regular flushing of pools means solutes don't build up over long time periods as expected in some lakes. • Integrated water quality modelling across pit lakes is challenging due to computation limits in current models; will need to continue to update models as technology advances to facilitate integrated modelling of water levels and quality at resolutions suitable for local scale impact resolution. • Only Oxbow has potential for undesirably high salinity. Closure plan aims to discourage plant growth in Oxbow, to minimise potential for environmental interactions. • Only flow from PBS lake expected to have interactions with riparian areas outside pit lake and only during large flood events when dilution will reduce saline water. Further study required to understand surface water flood mixing effects. • Full suite of water quality parameter predictions, including nutrients, still to be developed. May require some physical test areas, early development of pit lake, to better understand behaviours / calibrate models. • Fortescue Marsh wetland bird habitat near by. Expect pit lakes to attract avifauna usually attracted to Fortescue. • Predatory fauna species and weeds noted to increase where discharge is occurring. Plan to manage for similar increase on lake fringe compared to undisturbed riparian areas, e.g. in invasive species management plans. • Novel ecosystem needs to be developed to ensure self-sustaining lake fringe vegetation / healthy littoral zone, no identical lake system exists in Pilbara • Specific vegetation requirements to create sustainable lake fringe ecosystem under investigation. Need to understand performance with respect to water availability, sustainable complex, tolerance for metals, biomagnification potential. • Potential to create habitats for high priority species i.e. Northern Quoll, Pilbara Olive Python due to presence of permanent water supply requires investigation. • Aquatic fauna baseline research underway. Tolerance to heavy /toxic metals under investigation. • Investigation required to understand if / how biotic elements need to be introduced to lakes to achieve acceptable ecosystem health. • Egress to lakes via adjacent, rehabilitated waste dump, but stability of waste dumps could be compromised by heavy traffic i.e. cattle	Heavy cattle incursions to access lake water denudes vegetation, destroys habitat and destabilises pit fringe. Due to high water availability and lack of competition, weedy plants take over and vegetate lake fringe. (Possible - Low - Class II) Toxic blue-green algal bloom occurs in pit lake creating anoxic water conditions. Aquatic species in pit lake suffer including fish mortalities. Impact confined to individual lake. (Unlikely - M)	U				M			II	YA-34. Review the available water balance model technology to enable improved prediction of pit lake water levels. YA-31. Confirm groundwater and pit lake quality, and how the water quality will change over time. YA-19. Assess the impacts of flood water flushing of PBS lake on downstream vegetation and fauna (towards Fortescue Marsh) YA-30. Undertake geochemical modelling with groundwater chemistry to understand additional salt loads and other pit lake water chemistry. YA-XX. Consider early development of pit lake at Yandi to study chemical / geochemical / biogeochem water quality evolution / behaviour and use to calibrate models for other lakes YA-13. Undertake research to improve knowledge of rehabilitation of new landforms / habitats, including the best methods for restoration of Pilbara creek habitats / establishment of novel lake fringe ecosystems. YA-38. Undertake rehabilitation trials for different landform and substrate types to inform restoration / rehabilitation plans YA-XX. Integrate results from aquatic fauna heavy metal studies into closure plan YA-17. Assess the ability of pit lake water to sustain aquatic flora and fauna, and support other species. YA-XX. Investigate means to deter feral / unwanted predator species from lake areas

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Likelihood	Health	Safety	Environment On-site	Environment Off-site	Community	Compliance	Risk Management C	Detailed Action Descriptions
Lake poses public liability and / or health risk	• Lake(s) in a location that is easily accessible by the general public e.g. near or visible from a public road • Lake(s) is near an existing attraction e.g. area of cultural significance or tourist attraction • Access to the lake edge is not via a dedicated, safe path • Contaminants well above recreational guidelines • Strongly acidic or alkaline lake water, or releases noxious gases • Toxic algal blooms and / or noxious weeds • Waterborne pests and disease e.g. mosquitos	• Void closure management guidance • Geochemical waste characterisation, mineral waste does not contain toxic minerals • Water quality modelling ongoing, preliminary results identify areas of potential high salinity e.g. Oxbow and JC only • PBS lake designed to encourage flood flushing, to prevent high salinities/ problematic water quality from developing • Mineral waste buttress designed to merge with natural surface to create safe access areas	• Lakes areas are near tourist attractions (Fortescue Marsh, Weeli Wolli Springs) and cultural sites. Camping adjacent to Weeli Wolli Creek occurs in area. Further work required to establish if water will be acceptable for swimming, fishing etc. to inform post-mining land-use. Discussions with stakeholders on post-mining land-use still in progress. • Geochem tests suggest problematic water, i.e. desorption of metals into water, only likely to occur in very high salinities. Water modelling suggests only Oxbow could experience these conditions. • Access to Oxbow area to be discouraged by: making other areas more inviting, vegetation not encouraged to establish in void, safe egress via haul road ramp only, removing access roads through area. Noting that BHPBIO rail access road adjacent to Oxbow is under BHPBIO control. • Rehabilitated waste dumps adjacent to lakes will provide safe access to lake areas, except in Oxbow where safe egress only via haul road ramp. • Healthy lake littoral zones believed to assist in managing public liability health issues. Rehabilitated waste dumps adjacent to lakes provide opportunity to develop lake littoral zones, to encourage development of ecosystem e.g. fish to eat mosquito larvae. Further investigation required to develop site specific public health risks triggers and cross reference with ecosystem health management plans. Further study is required to identify the timeframe to stabilise the lake ecosystems. • Open faces around pits will be bunded, except where surface water flows are required to enter the pits.	Salinity in JC lake reaches hypersaline / alkaline conditions during an extreme drought period and metal levels increase in the water. The resulting water quality causes some skin irritation to public users.	R	L				L	L	II	YA-XX. Understand which characteristics of lake ecosystem health also address / minimise public health risks YA-XX. Predict how the lake ecosystem will evolve, consider timeframe and biodiversity over time
Degradation of regional groundwater quality or levels	• Concentration of natural groundwater or mineral waste derived salts through evapoconcentration in open water bodies • Groundwater flow through pit lake or mineral waste with connection to regional aquifer • Density driven saline groundwater flow from groundwater sink-style pit lakes • Downstream groundwater users (people, plants or animals)	• Void closure management guidance • Environmental surveys include regional groundwater dependent ecosystem • Geochemical waste characterisation and column leach tests • Preliminary integrated ground-surface water modelling (with recovery) completed • Management of mineral waste to minimise surface water area exposed to evapotranspiration, to minimise salinity • Management of closure landforms to influence groundwater flow direction, to trap potential salts in areas with least potential to influence environment i.e. Oxbow West and JC	• Bores downstream of PBS used for pastoral & mining applications. Further downstream water enters Fortescue Marsh which has naturally saline water. • Preliminary integrated groundwater and surface water modelling complete; however, new information of groundwater systems expected to become available to improve model calibration as more boreholes are drilled in Oxbow and PBS areas and dewatering of mine progresses. • Modelling suggests groundwater interaction from former mine area to regional groundwater system will be limited post-closure because most water moving through mine areas will terminate (groundwater sink) at either Oxbow or JC lakes; only PBS groundwater flow expected to leave area. Climate is a strong influencing factor on water balance. • Basic salinity movement accounted for in models. Oxbow expected to have high salinity but with negligible potential for flow to regional aquifer. JC also may have high salinities but there is higher uncertainty as to potential leakage volume to regional aquifer. Further drilling and local water balance modelling are required to confirm leakage to regional aquifer. • Modelling shows leakage from alluvial aquifer to (former) CID aquifer / pit lakes is a major component of water balance. Water levels in alluvial system will recover to approximately pre-disturbance levels with some depressed (lower level) areas surrounding the JC pit. • Integrated water quality modelling across pit lakes is challenging due to computation limits in current models; will need to continue to update models as technology advances to facilitate integrated modelling of water levels and quality at resolutions suitable for local scale impact resolution. • Water quality changes over time could have an impact on stygofauna habitat. Further investigation is required to quantify the long term implications to stygofauna populations as a consequence of the groundwater changes.	Water quality within the PBS pit deteriorates to significantly more than 4000mg/l salt, such that when the salts are carried via groundwater through flow to the downstream bores the water quality within the aquifer exceeds the completion criteria of 4000mg/l and the water can no longer be used for stock drinking water purposes.	R				M	L	M	II	YA-32. Undertake drilling to develop an improved hydrogeological conceptual model that covers areas relevant to the closure plan YA-33. Undertake program (i.e. drilling) to develop a better understanding of surface water and groundwater interactions. YA-37. Review the behaviour of Phil's Creek during mining to understand the amount of leakage, to inform the water modelling YA-34. REPEAT Review the available water balance model technology to enable improved prediction of pit lake water levels. YA-XX. Investigate the long term implications of groundwater quality changes on stygofauna populations

Yandicoogina 2015 closure risk assessment

Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Risk Evaluation: Likelihood	Health	Safety	Environment On-site	Environment Off-site	Environment Community	Compliance	Risk Management	Detailed Action Descriptions
Geotechnical zone of instability compromises closure outcomes	• Influence of erosion, subsidence, seismicity, wall slip • Influence of groundwater recovery and surface water flow on stability. • Creek system neighbouring or within zone of instability, potential stream capture • Ecosystem downstream of void dependent on surface water flows • Poor communication of zone of instability to facilitate identification of important features	• Geotechnical assessments for wall stability and zone of collapse as part of mine design reviews, as required • Pit walls design factor of safety 1.3, geotechnical assessment show zone of collapse for high risk locations (near creeks, infrastructure etc.) • Pit wall in JSW-A, JSW-C (parts of), JSE and PBS pits to be buttressed to manage risk of pit walls adjacent to creek collapsing. • Commitment to rock armour chute / spillway for floodwater expected to flow into PBS pit lake(s) • Conceptual location for abandonment bunds established	• No material available to buttress JC pit lake next to Marillana Creek, but historically wall has performed well. Buttress gap in JSW-C pit wall could be weak point for wall collapse. Further geotechnical assessment is required. • Oxbow pit walls 30m stand-off from tenure boundary. BHPBIO deposit next to Oxbow pits, could complicate stability management. No material available to buttress Oxbow walls. Stand off from BHPBIO rail expected to be sufficient to prevent rail impacts post-mining. Surface water flow over Oxbow pit walls expected, no management proposed currently. Identification of an appropriate location for water flow to enter Oxbow pits is required. • Flood water expected to flow into PBS pit down dedicated 'chute' ramp protected against erosion using rip-rap. Levee can be robbed for stone, but will still need additional stone on closure. Further design work required to confirm location of 'chute' and design after upper benches of pit are established. Location selection to consider natural flow paths for flood water (geomorphology). • Pit areas are compartmentalised to ensure if pit wall collapses and if flooding of pit occurs, only a known, small volume of flow could be captured such that impact to the creek flood regime would be minimal. • Flood levees along the edge of the JSW-A, JSW-C, JC and part of the PBS area will be left in place and integrated into the closure landform e.g. as abandonment bunds and/or flood protection features.	Geotechnical zone of instability expands beyond predicted areas (e.g. JSW-C) and during a flood the creek flows enter the pit. (Flow to Fortescue would not be impacted as maximum volume captured is very small.) Repair of the collapsed wall is required.	U				M		L	II	YA-39. Review the geotechnical stability of pit walls and design requirements for creek supporting structures YA-41. Assess the stability of pit walls adjacent to the BHPB rail and identify a management strategy to ensure continuity of the rail post-closure. YA-XX Identify and manage location for flow of surface water flow into the Oxbow pits. YA-XX Identify and manage location for flow of surface water flow into the PBS pit.
Closure landforms													
Built landforms (excluding mine void areas) erode and / or collapse	• Physical material properties considered in design • Drainage and erosion management • Construction of landforms / waste dumps to design requirements • Sensitive receptors identified downstream	• Physical materials characterisation completed • Waste dumps proposed to be returned to the pit areas • Multi-disciplinary pit and waste dump design sign-off processes, considers landform design guidelines and provides rehabilitation designs where appropriate • Rehabilitation design developed for Phil's Creek landbridge, to reinstate diverted creek flow • RTIO Rehabilitation handbook used for general rehabilitation activities • Rehabilitation designed to be stable without vegetation • Permanent diversion drains identified, prevents flow over reconstructed landforms • Invasive species management plan will be developed as part of decommissioning activities	• All waste dumps are expected to be returned to pit areas. Mineral waste is dominantly alluvium / colluvium and is erodible. • Areas of pits backfilled with mineral waste to near surface are considered closure landforms rather than mine voids i.e. waste fines / tails storage areas, JC initial mining area, JSE, as all above the water table and away from lake fringe. Pit wall edges will still be present, and bunded to prevent inadvertent access over wall but walls are relatively stable and expected to be subject only to minor erosion. • Large landforms associated with ore crushing / processing infrastructure. Rehabilitation designs for these large landforms, constructed from mineral waste but already integrated into landscape, will be required. • Phils Creek to be reconstructed on original alignment before closure (to complete mining in JSW-C pit), and the structure will be modified on closure to ensure long term stability. Conceptual closure design is complete, based on proposed re-instated structure. Longer term geotechnical stability of landbridge still to be proven, this is the first structure of its kind to be built in the Pilbara. Structure likely to be functioning as a creek for ~20 years before closure, providing time to study and correct any issues or modify closure design to accommodate requirements to ensure structure is stable. • Conceptual drainage requirements included in closure plan, including local drainage controls features, retained diversion structure, retention basin etc. Some run-on from local hills may occur in some backfilled areas. Detailed drainage designs to be produced prior to closure. • Capping of waste fines storage facilities proposed. However, review of local surface conditions will be undertaken to determine if a suitable ecosystem can be established without capping and what the drainage management requirement might be. e.g. high soil moisture storage of fines / clays may encourage development of grassland community habitat rather than plains habitat. • Capping of landfill sites included in closure plan. • Monitoring and remediation activities are undertaken after initial construction of areas. • Feral / cattle management required until vegetation is self-sustaining • A re-work factor to remediate erosion that occurs early after landform constructed is included in the closure cost estimate for the site, to ensure adequate resources are available to address issues.	Phils Creek landbridge seepage causes tunnelling, landform slumps and erodes, results in re-work to stabilise and re-instate landbridge. Downstream flows from Phils Creek to Marillana Creek flow into a neighbouring pit lake. Flow down Marillana Creek is continued, but without contribution (small) from Phils Creek.	U			L	L	VL		II	YA-05. Undertake detailed hydrological and engineering assessment to determine the extent of structures required to control erosion. YA-35. Identify sources of backfill material and capping material to achieve closure landform. YA-XX. Undertake regular reviews of the Phils Creek landbridge performance to understand any potential implications to closure, and modify / complete detailed closure design as appropriate. YA-XX. Complete rehabilitation designs for large process / crusher facilities.

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	**Potential causes (Triggers / Indicators)**	**Existing Controls and Commitments**	**Site specific overview**	**Evaluation Rationale (Maximum reasonable consequence)**	**Likelihood**	**Health**	**Safety**	**Environment On-site**	**Environment Off-site**	**Environment Community**	**Compliance**	**Risk Management**	**Detailed Action Descriptions**
Surface treatment on landforms limits vegetation growth	• Availability of top soil stockpile soil / poor stockpile management e.g. soil washed away • Low moisture retention i.e. hydrophobic soils development, very rocky materials • Chemical properties of materials on waste dump / rehab surface e.g. salt circulation, alkalinity	• Physical and geochemical materials characterisation complete. Material is inert and general expected to be acceptable growth media. • Rehabilitation handbook provides direction on surface treatment options • Annual stockpile reconciliation of top soil and sub soil stockpiles, return of 200mm to create quality surface growth media • Wetland rehabilitation trial established, will provide feedback on general waste erosion performance, will look at value of adding mulch	• Waste material is mainly alluvium or colluvium and is good growth material. • Wetland rehab trial has been established to provide some guidance. Opportunity to undertake further rehabilitation after mining ceases in Junction Central pit. • Sufficient soil stockpiled for application of 200mm across disturbed area is predicted. • A re-work factor to improve the surface conditions is included in the closure cost estimate for the site, to ensure adequate resources are available to address issues. • Site has surplus water, which may be used to improve surface conditions and encourage plant growth. A trial would be required to determine if watering re-vegetation (increasing water availability) improves plant growth.	Soil chemical properties inhibit plant development, such that some plants grow but the completion criteria for revegetation are not achieved. Additional surface treatments, i.e. mulch, fertilisers, gypsum etc. are required to support plant growth.	U				L	VL	M	II	YA-XX. Investigate and implement opportunities for rehabilitation trials YA-09. REPEAT Develop (and maintain) a progressive rehabilitation schedule.
Vegetation is not self-sustaining	• Vegetation established, but does not re-seed in same abundance • Weed competition • Species selection / insufficient species diversity • Animal interference i.e. feral animals eating new growth • Changes to soil water conditions e.g. salinity, water logging etc	• Rehabilitation handbook provides guidance on seed selection for appropriate diversity • Top soil stockpiles provide seed bank • Wetland rehabilitation trial established to assist in appropriate species selection for post-closure soil water conditions • Invasive species management plan will be developed as part of decommissioning activities	• Limited revegetation activities have occurred on site as most of the mine area is being actively mined. Most re-vegetation activities will occur at closure. • Wetland rehabilitation trial established at Phils Creek will provide guidance on some species germination and growth performance. • Top soil seed bank may be degraded by the time rehabilitation occur. Expected that additional seed will be sourced from local area to augment seed bank and ensure key species are present. • Seeds tested for germination prior to revegetation. Seeds sourced from reliable suppliers. Seed mix selected by rehabilitation specialists to provide adequate diversity, based on available species at time of rehabilitation. • Most creek disturbance is immediately rehabilitated i.e. rail disturbance, rehab is successful because of fresh topsoil. Creek areas disturbed for roads, drainage etc., can not be immediately revegetated. • A re-work factor to improve vegetation performance is included in the closure cost estimate for the site, to ensure adequate resources are available to address issues.	Species diversity is not sufficient to demonstrate self-sustaining characteristics and re-work is required post-closure to increase diversity to ensure the system is self-sustaining.	U				VL	VL	M	II	YA-14. Investigate creek rehabilitation requirements, considering landform pre-preparation, top soil application and if tube stock is necessary to achieve required outcomes. YA-09. Develop (and maintain) a progressive rehabilitation schedule.
Access through area post-closure poses public liability risk	• Post-closure access / land-use requirements, e.g. for stock, people, heritage, environmental monitoring, adjacent mining activities etc. • Potential for general public to create their own access if appropriate access not provided.	• Regular review and integration of stakeholder feedback into closure plan updates.	• Access roads will be required for long term monitoring. • Access road from Fortescue Marsh to Weeli Wolli Springs is planned to be kept post-closure. It is recognised this road is used by TO's, pastoral station, tourists. The existing road is planned to be moved to facilitate mining at PBS. • Expect general public interest closed mine area is expected to be high, such that tourist 'exploration' through old mine area is likely to occur. Common for tourist information and internet sites to include old mine areas in brochures. • Other mining companies in area that have historically (recent) travelled through the Yandicoogina mine area to connect their mines to port / distribution areas. • Post-mining land use has yet to be resolved. Key stakeholder access needs are still being investigated. • Cultural sites are located all around mine area. TO's likely to create their own tracks if not provided. • Opportunity to investigate methods to control access, where required e.g. discourage cattle access to lake edges, limit general public access to areas where vegetation still establishing.	An access road provided through the area performs badly without regular maintenance e.g. scours, results in a minor car accident. Minor erosion has minimal environmental impact.	U		M		VL	M		II	YA-XX. Engage with key stakeholders to define post-closure land use YA-XX. Identify what mine features key stakeholders want to be retained, including access roads. YA-XX. Review liability of retention of mine features and agree where ownership of liability for retained features will be transferred. YA-36. Consider the landscape design requirements for the repatriation of cultural artefacts back into the closure landform. YA-XX. Review the design of retained featured, i.e. roads, to ensure they are fit for purpose. YA-XX. Investigate and implement infrastructure options to prevent / discourage access use of retained access routes, i.e. for monitoring, where appropriate.

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Likelihood	Health	Safety	Environment On-site	Environment Off-site	Community	Compliance	Risk Management	Detailed Action Descriptions
Other regional considerations													
Environmental outcomes outside of disturbance areas do not align with approved environmental impacts	• New (previously unidentified) environmental sites, not considered in existing environmental impact assessment • Changes to environmental conditions due to cessation of artificial support / mitigation activities, e.g. water supplementation • Change to drainage patterns on closure e.g. removal of temporary diversions, drains etc.	• Internal ground disturbance approval request system to prevent inadvertent disturbance • Baseline biological / ecosystem health surveys and existing monitoring to define post-mining status • GIS system includes results from all flora, fauna, vegetation surveys • Operational management plan for discharge includes actions relating to water quality and discharge extent targets (proximity to Fortescue Marsh), to ensure environmental issues are managed during operations • Significant species management plan implemented during operation to minimise impact to select species • Vegetation management plan implemented during operations to monitor and manage impacts to vegetation (riparian, understorey and weeds)	• Pools artificially sustained by discharge will dissipate and return to natural conditions post-mining. It is recognised that some species may be displaced (localised environmental 'impact') as these changes occur, i.e. change of current diversity and abundance as the system returns to pre-disturbance environmental conditions. This change will occur early in the pre-closure phase. • Environmental conditions and land use are expected to be very different from the pre-mining conditions, including the introduction of permanent water bodies and altered groundwater levels (lower than pre-mining) closer to pre-disturbance conditions. Pre-disturbance, pre-mining and current environmental conditions provide some guidance as to potential environmental outcomes in the region. However, there are no similar systems present in the Pilbara. As such the measures that define a healthy ecosystem will need to evolve overtime. • Salts from the PBS lakes will be flushed into the Weeli Wolli Creek during very large (100 year) flood events. These salts will be deposited in Fortescue Marsh. Impacts to the ecosystem are expected to be minimal due to flood dilution. Deposition of the salts in the already saline salt Marsh is not expected to have an impact.	The cessation of discharge along Weeli Wolli Creek results in some plant death as vegetation assemblage adapts to reduced water availability. The plant death makes the banks for susceptible to erosion during large flood events and parts of the current creek bank are washed away during a large flood event.	P			VL	L			II	No further action required at this time.
Adverse impact to flora or fauna with conservation status or wider regional impact to high value environment	• Scheduled, listed or declared rare and / or threatened species of flora or fauna present in/adjacent to site - Pilbara Olive Python, Northern Quoll, Lepidium, • Downstream regional area of high value - Fortescue Marsh • Environmental conditions post-closure differ significantly from pre-mining conditions • Post-mining land use differs from pre-mining land use	• Internal ground disturbance approval request system to prevent inadvertent disturbance • Baseline biological / ecosystem health surveys and existing monitoring to define post-mining status • GIS system includes results from all flora, fauna, vegetation surveys • Operational management plan for discharge includes actions relating to water quality and discharge extent targets (proximity to Fortescue Marsh), to ensure environmental issues are managed during operations • Significant species management plan implemented during operation to minimise impact to select species • Vegetation management plan implemented during operations to monitor and manage impacts to vegetation (riparian, understorey and weeds)	• Pools artificially sustained by discharge may currently be utilised by Pilbara Olive Python, although no increases in Python numbers in the area have been observed as a result of increased pool habitat. Pools expected to return to natural size, frequency and duration. No impact to Python is anticipated. • The long term impacts of the changed post-mining ecosystem and post-mining land use on species of significant and conservation significance is yet to be quantified. Basic understanding of impacts to stygofauna understood, but final conclusions based on detailed water outcomes required. Monitoring and management plans will need to be updated during the decommissioning study to address species of conservation significance, to demonstrate closure outcomes are as predicted. • Downstream impacts to Fortescue Marsh have been quantified and negligible impact is expected. Flood water regime will be preserved. Monitoring will be required to demonstrate the closure outcomes are as predicted.	The post-closure ecosystem attracts increased numbers of feral predators which decrease the number of conservation significant fauna species through predation. Direct action / management to reduce predator numbers would be required to assist species recovery.	U				H	M	M	III	YA-18. Assess the impacts of closure implementation on groundwater dependent vegetation. YA-12. Assess impacts of closure implementation on stygofauna populations. YA-XX Assess impacts of closure implementation on species of conservation significance.

Yandicoogina 2015 closure risk assessment					Risk Evaluation								
Threat Title	**Potential causes (Triggers / Indicators)**	**Existing Controls and Commitments**	**Site specific overview**	**Evaluation Rationale (Maximum reasonable consequence)**	**Likelihood**	**Health**	**Safety**	**Environment On-site**	**Off-site**	**Environment Community**	**Compliance**	**Risk Management**	**Detailed Action Descriptions**
Heritage site condition / cultural value is degraded as a result of implementing the closure plan	• New (previously unidentified) heritage sites, not considered in existing assessment, discussions, agreements or with authority to disturb • Changes to landforms on closure have potential to alter conditions at downstream sites, e.g. consider drainage, landform footprint, erosion implications • Cessation of maintenance of / to heritage site	• Internal ground disturbance approval request system • GIS system includes results from heritage surveys • Heritage sites within mine area, S18 application etc. prior to disturbance • Ongoing consultation with Traditional Owners	• Many heritage sites identified throughout area, concentrated along creeks and noted high significance area near confluence of Marillana and Weeli Wolli Creeks. The environmental quality of the creek systems is closely linked to Traditional Owner cultural values. • Creek functions have been preserved as part of closure strategy. This is expected to preserve the cultural value associated with the creeks. • Change in groundwater levels at confluence of Marillana and Weeli Wolli Creek could led to change in vegetation complex during mining or after mining. It is unclear if the change would alter cultural values.	Change in vegetation complex near ethnographic site is viewed unfavourably by Traditional Owners	P					L		II	YA-21. Finalise the Yandicoogina Cultural Heritage Management Plan (to include closure strategies) and implement it as a working document. YA-23. Undertake a gap analysis to identify areas requiring heritage survey and areas of significance which should be avoided and managed. YA-24. Undertake heritage surveys as required (ethnographic and archaeological) with the traditional owners. YA-27. Consult with the traditional owner group regarding specific water values.
Stakeholders Consultation													
Consultation fails to identify stakeholder concerns	• Large number of stakeholders in the project • Clarity of explanation / prediction of closure outcomes, communication styles, long term engagement of agreed outcomes through generational change. • Stakeholder expectations change over time, due to changing global benchmarks for mine rehabilitation success, intergenerational change, regulatory changes etc. • Stakeholders do not endorse site closure as their issues / concerns were not addressed	• RTIO stakeholder engagement practice with key stakeholders i.e. Traditional Owner M&L, etc. • Ad hoc consultation with key stakeholders • Detailed engagement planned during decommissioning study • Stakeholder engagement register	• Key regulators already engaged in discussions. There is a lack of clarity surrounding regulator expectations for pit lakes, and a new guidance note is expected to be released from EPA. Review of the new EPA pit lake guidance with respect to Yandicoogina is required. • DoW have acknowledged the difficulties of water modelling and are willing to work with Rio Tinto to resolve water outcomes in greater detail. Future updates to the groundwater recovery models and water balance salinity models will need to be discussed with DoW. • Gumala TO's already engaged in discussions, have expressed some concerns with regards to water quality. Completion criteria for water quality have been established and discussed with TOs. It is recognised that due to the length of time between opening and closing the mine, TOs will need to be engaged on a regular basis to ensure opinions of current Elders are acknowledged and new opinions of the next generation of TOs are integrated into the closure planning process. • Local Government aware of development, but have not been engaged in closure outcomes or long term public liability / management that could evolve if mining tourism to area becomes fashionable. It is likely that Local Goverment will need to be engaged in discussions regarding post-mining land-use.	Stakeholder perceptions change over time and the predicted outcomes based on the current closure plan are no longer accepted, such that substantial changes to the closure strategy are required.	R					M	L	II	YA-XX Review regulatory advice regarding pit lakes, identify any gaps in plan and update accordingly YA-25 Maintain regular comunication with Gumala and wider TO stakeholders through directed, closure specific enagement sessions. YA-XX Engage Local Government to understand their requirements for mine closure.
Key stakeholder expectations													
Closure outcomes do not meet stakeholder(s) / community expectations	• Absence of rehabilitation trial or data to support predicted outcomes, closure activties fail to achieve completion criteria • Communication of anticipated closure outcomes and post-closure land use needs i.e. wrong plant species established • Unrealistic expectations for economic potential opportunities / post-closure land use capability i.e. aquiculture in pit lakes	• RTIO stakeholder engagement practice with key stakeholders • Monitoring established for water, rehabilitation trials started • Numerical completion criteria established for some aspects	• Limited data available to define numerical targets and / or confirm criteria can be achieved. Opportunity to modify completion criteria over time, following stakeholder consultation • Significant water modelling complexity makes it difficult to provide accurate predictions, technology not yet advanced to provide integrated predictions. • Communication with stakeholders is ongoing and evolving i.e. development of 3D visual aids, maps, cross-sections • Post-closure land use proposes to return to natural ecosystem as land use capability for post-mining land will be limited. It is recognised that underlying tenure is Pastoral land-use, which is not compatible with post-mining landforms. Risks associated with cattle considered as part of landform design, but resolution and agreement of post-closure land-use still pending • Traditional Owners suggest they will use created lakes post-closure.	Completion criteria is still not achieved 15 years after decomissioning activities were finished. Remediation and additional environmental management is required to achieve acceptable standard for relinquishment.	U					M	M	M	II	YA-01. Confirm that the mine plan and schedule can deliver a closure landform that aligns with closure objectives. YA-42. Conduct & communicate visual amenity assessment of final landform options

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Threat Title	Potential causes (Triggers / Indicators)	Existing Controls and Commitments	Site specific overview	Evaluation Rationale (Maximum reasonable consequence)	Risk Evaluation: Likelihood	Health	Safety	Environment On-site	Environment Off-site	Community	Compliance	Risk Management Category	Detailed Action Descriptions
A stakeholder's expectations conflict with that of another stakeholder, causing delays to plan approval and / or closure	• Conflicting stakeholder expectations or areas of authority e.g. different regulators for environment, heritage, health, economic, tourism • Conflicting legal obligations e.g. State Agreement and EPA • Interactions between catchment land uses, including mining developments, at different points in time	• RTIO stakeholder engagement practice with key stakeholders	• Uncertainty associated with BHPBIO Yandi mine upstream of Oxbow. Activities will have direct impact on options / success of closure at Oxbow. Need to seek clarity regarding BHPBIO activities. • Pastoral Station requirements are unknown, but conflict with post-mining land-use capability at Yandicoogina. It is unclear if Yandicoogina is legally obliged to return land to conditions compatible with pastoral land-use. Need to better understand how State regulators, especially Dept State Development, envisage post-mining land development.	A mining tourism campaign centred on Weeli Wolli Creek is undertaken by a third party and increases tourist traffic to the Yandicoogina area. Rubbish left behind by tourists encourages and increases feral animals numbers, placing environmental values (i.e. priority species) at risk.	U				M	L	M	II	YA-07. Consult with BHPBIO to ascertain compatibility of closure strategies with the BHPBIO Yandi mine. YA-07. Consult with BHPBIO to ascertain compatibility of closure strategies with the Marillana Station (owned by BHPB). YA-XX. Consult with DSD with regards to wider development expectations for post-mining land-use.
Closure strategy prevents or limits future exploitation of resources	• Backfill sterilises ore reserves • Lakes or habitat restoration prevent / limit future access to adjacent resources	• RTIO stakeholder engagement practice with key stakeholders • Integration of potential Billiards North expansion deposits into current closure plan options	• Backfill is part of closure strategy and will cover some resources. Future exploitation of the resource will be possible but will require excavation of mineral waste, dewatering and creek diversions (high cost). • An alternate closure strategy to facilitate access to Billiards North and Braid deposits has been considered as part of the closure planning.	Closure strategy prevents access to future mineralisation and expansion, requires closure strategy to be re-negotiated with stakeholders.	U					L		I	YA-XX. Refine closure strategy to include Billiards North and other deposits during Billiards North mining studies
Other expectations													
Mine closure has a significant, long-term detrimental impact on local communities	• Local communities receive direct support from operation for basic community services e.g. doctor • Significant proportion of community are directly or indirectly employed by operation		• Work force is dominantly Fly In- Fly Out and has little interaction with local communities, includes employees and services. No long term detrimental economic impacts to communities from mine closure are anticipated. • TOs receive some financial support associated with mine development.	Local community develops a dependence on revenue / support from Yandicoogina between now and mine closure, some transitional support is required.	R					VL		I	YA-XX. Review impact of closure on local communities (part of decommissioning scope)
Obligations Agreements and commitments													
Closure is not implemented in accordance with the approved closure plan	• Mine development changes prevent closure plan from being implemented as planned • Closure plan proves to be overly challenging to implement or implementation results in a different outcome than anticpated	• Integration of closure plan with LoM report	• Closure plan requires 3 yearly updates, will ensure closure plan remains current with respect to mine developments • The closure requirements have been embedded into the Life of Mine report and are communicated to the Business every 18 months. • Regulator inspection are expected to occur throughout the remaining mine life, potential for regulators to also raise concerns if they identify an aspect that may be in conflict with the intent of the closure plan.	Regulator identifies an inconsistency in closure implementation. Site/stakeholder engagement, updates to the closure plan and potentially re-work is required to ensure an acceptable closure outcome.	R					L	M	II	YA-XX. Review closure aspects with each Life of Mine plan update, to ensure implementation aligns with agreed strategy. YA-XX. Update the closure plan and seek approval for an alternative or modified closure strategy when signficant changes are anticipated to occur on site YA-XX. Send closure plan to regulators for review every three years.

APPENDIX F

31. Appendix F Closure issues identification tracker

The following closure tasks have been completed and the results integrated into the closure plan OR have been retired as the task is no longer relevant to the current strategies or the task is now adequately managed through a standard work practice.

Ref	Issue	Action	Status	Comment
YA-3	Closure landform	Undertake drilling to determine ore quality in currently un-mined areas.	Complete	-
YA-4	Water	Develop a closure water model to predict impacts of the channel configuration.	Complete	2011 Hydrogeology modelling
YA-6	Cultural heritage	Undertake heritage surveys across the length of the Yandicoogina mining operation, including currently undisturbed and un-surveyed areas along creek lines, to identify cultural heritage implications of the channel configuration and closure plan	Retired	Channel configuration no longer strategy Closure plan reviewed through task YA-24
YA-8	Other	Confirm the channel configuration as the preferred closure option, or develop an alternative option if required.	Complete	Alternative developed
YA-20	Cultural heritage	Finalise site salvages audit and register, and implement a method to maintain and update data.	Retired	Action is part of a standard work practice
YA-22	Cultural heritage	Undertake an annual review of Heritage approval consents and ensure statutory obligations and conditions have been met.	Retired	Action is part of a standard work practice
YA-26	Cultural heritage	Regularly update RTIO and DAA heritage site and report registers with new information on sites (recording, salvage etc) in the Yandicoogina mine area.	Retired	Action is part of a standard work practice
YA-30	Contaminants	Undertake geochemical modelling with groundwater chemistry to understand additional salt loads and other pit lake water chemistry	Retired	Action has been split into multiple stages
YA-31	Water	Confirm groundwater and pit lake quality, and how the water quality will change over time.	Retired	Action has been split into individual lakes
YA-15	Biodiversity	Establish faunal reference sites, and commence monitoring faunal assemblages	Retired	Operational control. Part of Monitoring program (not current action)

RIO TINTO
IRON ORE

YANDICOOGINA: Cumulative Impacts of Mining on Marillana & lower Weeli Wolli Creeks

Dry 2013 & Wet 2014 Sampling
FINAL REPORT

WRM
Wetland Research & Management

July 2015

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Frontispiece (left to right): Marillana Creek at MAR1-3; sampling for fish using the electrofisher at MAR2-5; and the creek at MAR1-5 (all photos by WRM ©).

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1 INTRODUCTION

1.1 Background

The Rio Tinto Iron Ore (RTIO) mine at Yandicoogina (Yandi) is located in the East Pilbara region of Western Australia. A number of temporary creeklines traverse the mine area, including Marillana, Yandicoogina, Phil's and Weeli Wolli creeks. The mine has been operating since 1996, and as part of mine operations dewatering of the Yandi Junction South East (JSE) and Central pits has been necessary since 1998, with excess water discharged directly into Marillana Creek (via discharge outlets D02, D03, D05 & D08), and more recently into Weeli Wolli Creek near JSE (via discharge outlet D06). Discharge varies between months and years, but volumes of 12.23, 11.62 and 14.00 GL/year were discharged into Marillana Creek in 2012, 2013 and 2014, respectively (see Table 1).

Rio Tinto is developing three new deposits at Yandi Junction South West (JSW-A & JSW-C) and Yandi Oxbow. Rio Tinto is also proposing to develop the Pocket and Billiard South deposit. Additional dewatering and discharge operations are necessary as part of these developments as around 95% of the ore occurs below the water table. As part of these current developments, discharge at Yandi has been rationalised and, since April 2013, now occurs primarily via a new discharge outlet (D09), located on Marillana Creek approximately 3 km upstream of the Weeli Wolli Creek confluence, and at the existing D06, directly into Weeli Wolli Creek, from JSE. Some discharge still occurs through D02, D03, D05 and D08 adjacent to the operations plant on Marillana Creek, in order to support riparian vegetation and stygofauna communities in this area (see Figure 1 for discharge outlet locations).

Rio Tinto baseline hydrological modelling indicates that under maximum potential discharge, approximately 37 - 43 GL/annum will be discharged. This equates to 99 - 115 ML/day, but will ultimately depend on dewatering discharge rates by BHPBIO's Yandi operations located further upstream on Marillana Creek. Under this maximum discharge scenario, surface flow is modelled to extend from discharge point D09 on Marillana Creek, into Weeli Wolli Creek and up to 17 km downstream of the Weeli Wolli-Marillana Creek confluence (Figure 1).

Additional discharge into Marillana Creek occurs upstream of Rio Tinto's Yandicoogina mine, at BHP Billiton Iron Ore's (BHPBIO) Yandi mine. This mine has been in operation since 1994, and also dewaters their developing pit, with excess dewatering water discharged into the upstream section of Marillana Creek. Downstream of these mining operations, Marillana Creek flows into Weeli Wolli Creek (see Figure 1). Rio Tinto's Hope Downs 1 (HD1) operation is located on Weeli Wolli Creek approximately 20 km upstream of the confluence with Marillana Creek, and HD1 also discharges surplus dewatering water into Weeli Wolli Creek. In 2014, Hope Downs 1 discharged a combined total (via spurs and gabion) of 38 GL into Weeli Wolli Creek. Since late 2007, excess water from Rio Tinto's Yandicoogina operations has also been discharged into Weeli Wolli Creek (from discharge outlet D06; see Figure 1 for discharge location). In 2014, a total of 14.94 GL was discharged from Rio Tinto's Yandicoogina operations directly into Weeli Wolli Creek, upstream of the Marillana confluence and adjacent to the JSE pit (Table 1). Including discharge from all outlets into both creeklines, a combined total of 28.94 GL was discharged to the environment (Marillana and lower Weeli Wolli creeks) by Rio Tinto Yandicoogina operations in 2014 (Table 1). This is up from 25.16 GL in 2013 and 19.61 GL in 2012 (Table 1).

This cumulative dewatering discharge has the potential to affect the health of aquatic ecosystems in the downstream receiving environments of Marillana Creek and lower Weeli Wolli Creek. Potential effects include changes to water quality and to duration and magnitude of flow, as well as changes in macroinvertebrate assemblages with flow-on effects to higher trophic levels, including fish. The JSW development also requires realignment of Phil's Creek (a tributary of Marillana Creek), as well as the construction of flood protection levees within the margins of the creek which will reduce the width

of the creekline. These activities also have the potential for downstream impacts, including increased erosion and turbidity.

Table 1. Volume (GL) discharged from Rio Tinto's Yandicoogina into Marillana Creek and Weeli Wolli Creek between 2010 and 2014.

	Discharge outlet into Marillana Creek						Discharge into Weeli Wolli	Total discharged into Marillana & lower WW creeks
Year	DO2	DO3	DO8	DO5a+b	DO9	Total	DO6	
2010	1.20	0.95	2.93	4.11		9.19	7.41	16.60
2011	2.29	2.61	3.38	4.52		12.80	7.41	20.21
2012	1.10	2.56	2.94	5.63		12.23	7.38	19.61
2013	1.09	1.92	3.10	0.42	5.09	11.62	13.54	25.16
2014	1.05	0.92	2.81	2.12	7.10	14.00	14.94	28.94

The specific and cumulative effects of these operations on Marillana and Weeli Wolli creeks need to be assessed. Therefore, Rio Tinto commissioned *Wetland Research and Management* to undertake a study of the aquatic biota of Marillana Creek and lower Weeli Wolli Creek. The purpose of this was to a.) assess specific effects of Rio Tinto's (and BHPBIO's) Yandi current operations on Marillana Creek, and b.) provide data that supports the HD1 Living Water Survey, to assess Cumulative Impacts on the Weeli Wolli system. To this end, the study area was broken into three reaches of differing discharge regimes to document current ecological condition. The three study reaches were;

1.) Reach One – Marillana Creek downstream of BHPBIO's discharge but upstream of Rio Tinto's Yandi discharge. This covers zones 1, 2 and partially covers zone 5 from Ministerial Statement 914

2.) Reach Two – Marillana Creek downstream of Rio Tinto's Yandi discharge to the extent of surface flows (now approx. 0.25 km upstream of the confluence with Weeli Wolli). This covers zones 2a, 3, 4 and 5 from Ministerial Statement 914.

3.) WW-Five – Weeli Wolli Creek downstream of the previous extent of surface flows (WW-Four) and downstream of the Weeli Wolli-Marillana confluence. Monitoring this reach commenced during the wet season of 2012, to capture the impacts of the extended surface flows along Weeli Wolli Creek as a result of discharge from the JSW orebody. This covers zone 3a from Ministerial Statement 914.

This report presents the findings from two rounds of sampling at both Marillana and Weeli Wolli creeks during October 2013 (late dry) and April 2014 (late wet). Comparisons are made to earlier datasets collected bi-annually since October 2008. Data from the dry-13 and wet-14 sampling rounds reflect the effect of changes in discharge volumes and locations associated with the development of JSW and Oxbow.

1.2 Study objectives

The aim of this study was to:

- document current ecological condition of Marillana Creek and lower Weeli Wolli Creek with respect to water quality and aquatic biota assemblages (microinvertebrates, macroinvertebrates, hyporheic fauna[1] and fish),
- assess the current effects of Rio Tinto's Yandicoogina mine and any change over time, and
- provide data to feed into a Cumulative Impacts study of the Weeli Wolli system.

[1] Aquatic invertebrate fauna which reside in the alluvium below the streambed where water percolates through spaces between the rocks and cobbles.

2 SURVEY METHODS

2.1 Compliance

There are no specific guidance statements for undertaking aquatic fauna surveys. However, field surveys employed sampling design, methods and general approaches consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000);
- Environment Protection Authority (EPA) Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (EPA 2009);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

Aquatic fauna sampling by WRM is consistent with methodology used by government and Universities for similar surveys, including the Pilbara Biological Survey (i.e. Pinder *et al.* 2010) and National Monitoring River Health Initiative (Department of Environment Sport and Territories *et al*. 1994).

This study was conducted under Fisheries Licence EXEM 2314 (Instruments of Exemption to the Fish Resources Management Act 1994 for Scientific Research Purposes) and DPaW Licences SF009111 and SF009720 (Reg. 17; Licence to Take Fauna for Scientific Purposes). As a condition of these licences, taxa lists and reports are required to be submitted to the respective authorities.

Surveys were undertaken in the late dry (29th October - 3rd November) of 2013 and late wet season of 2014 (8th - 13th April). Sampling during the wet and dry seasons allows seasonal changes in fauna composition to be characterised, and provides a more comprehensive record of species present than sampling in a single season.

2.2 Sites and sampling design

Marillana Creek was stratified into two reaches, reflecting differences in mining operations and discharge:

- Reach One - downstream of BHPBIO's Yandi discharge and upstream of Rio Tinto's Yandi discharge,
- Reach Two - downstream of Rio Tinto's Yandi discharge as far as perennial surface flows reach (just upstream of the confluence with Weeli Wolli) (Figure 1).

Weeli Wolli Creek was also stratified into separate reaches of differing historic flow regime. Five reaches along Weeli Wolli Creek have been sampled, including:

- Reach One - in the area of Weeli Wolli Spring where permanent pools historically were located,
- Reach Two - within the reach of historic permanent flow downstream of the spring,
- Reach Three - downstream of this point to the junction with Marillana Creek, where the creek historically was highly ephemeral and dry for much of the year, and
- Reach Four - the now permanent reach below the Marillana Creek confluence towards the Fortescue Marsh (WRM 2013a)

- Reach Five – ephemeral pools located downstream of Reach Four. This reach was added to the sampling program prior to the May 2012 survey in order to collect baseline data for the development of the JSW and Oxbow deposits at Rio Tinto's Yandi (see Figure 1). The additional discharge from these developments is expected to increase the current extent of surface flows along Weeli Wolli Creek by approximately 4 km, depending on volumes discharged and response of the system. The cumulative increase to the surface water footprint will be a further 5 to 9 km from the current extent if BHPBIO's Yandi, Rio Tinto's Yandi and HD1 all discharge at their maximum licensed rates. As such, it was necessary to collect baseline data from pools further downstream than Reach Four.

The sampling design aimed to take six replicate samples within each reach (depending on water availability) to characterise the fauna and conditions along each reach, and to provide adequate statistical power to allow statistical testing of differences between reaches and at a reach over time. Replicates were located to provide a geographical spread within each reach, but positions were also influenced by access (Figure 1). A number of sites on Marillana Creek were dry and unable to be sampled during previous sampling events (i.e. wet-10). This was due to a break in discharge from BHPBIO's Yandi and lack of wet season rainfall at this time. In addition, MAR1-4, MAR1-5 and MAR1-6 were all dry during the dry-13. Sites located in the upper reach of Marillana Creek Reach Two (MAR2-1 through to MAR2-3) were not sampled during the current study due to changes in the dewatering discharge regime at Rio Tinto's Yandi. Sites in this reach have been moved progressively downstream, and now number MAR2-4 through to MAR2-9 (see section 3.1 for a more detailed explanation of changes to sampling sites).

Site photographs are provided in Appendix 1.

2.3 Field sampling

Sampling in the dry-13 and wet-14 was conducted using the same methods as those used in previous years along Marillana and Weeli Wolli creeks. Details and rationale are provided in previous reports (i.e. see WRM 2014a). In summary, methods used were as follows:

- *In situ* measurement of dissolved oxygen (DO), water temperature (^{o}C) and pH was made using hand-held WTW and TPS field meters (Plate 1).

- Water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals and nutrients. Samples for nutrients and dissolved metals were filtered in the field through 0.45 µm Millipore nitrocellulose filters. All sample bottles and filtering gear were acid-washed (0.1% nitric acid) prior to use, double-wrapped in polyethylene bags after collection, with samplers wearing nitrile gloves at all times. All water samples were kept cool in an esky while in the field, and either refrigerated (ions & metals), or frozen (nutrients) as soon as possible for subsequent transport to the laboratory. All laboratory analyses were conducted by the ChemCentre, Bentley, WA (a NATA accredited laboratory). All water quality variables measured are summarised in Table 2.

- Qualitative visual observations of habitat characteristics were made at each site to assist in explaining any patterns in faunal assemblages in relation to possible discharge effects. WRM have standard worksheets for this task so that recordings between sites remain as comparable as possible. Habitat characteristics recorded included proportional (%) cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation. Details of substrate composition were also recorded and included percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay.

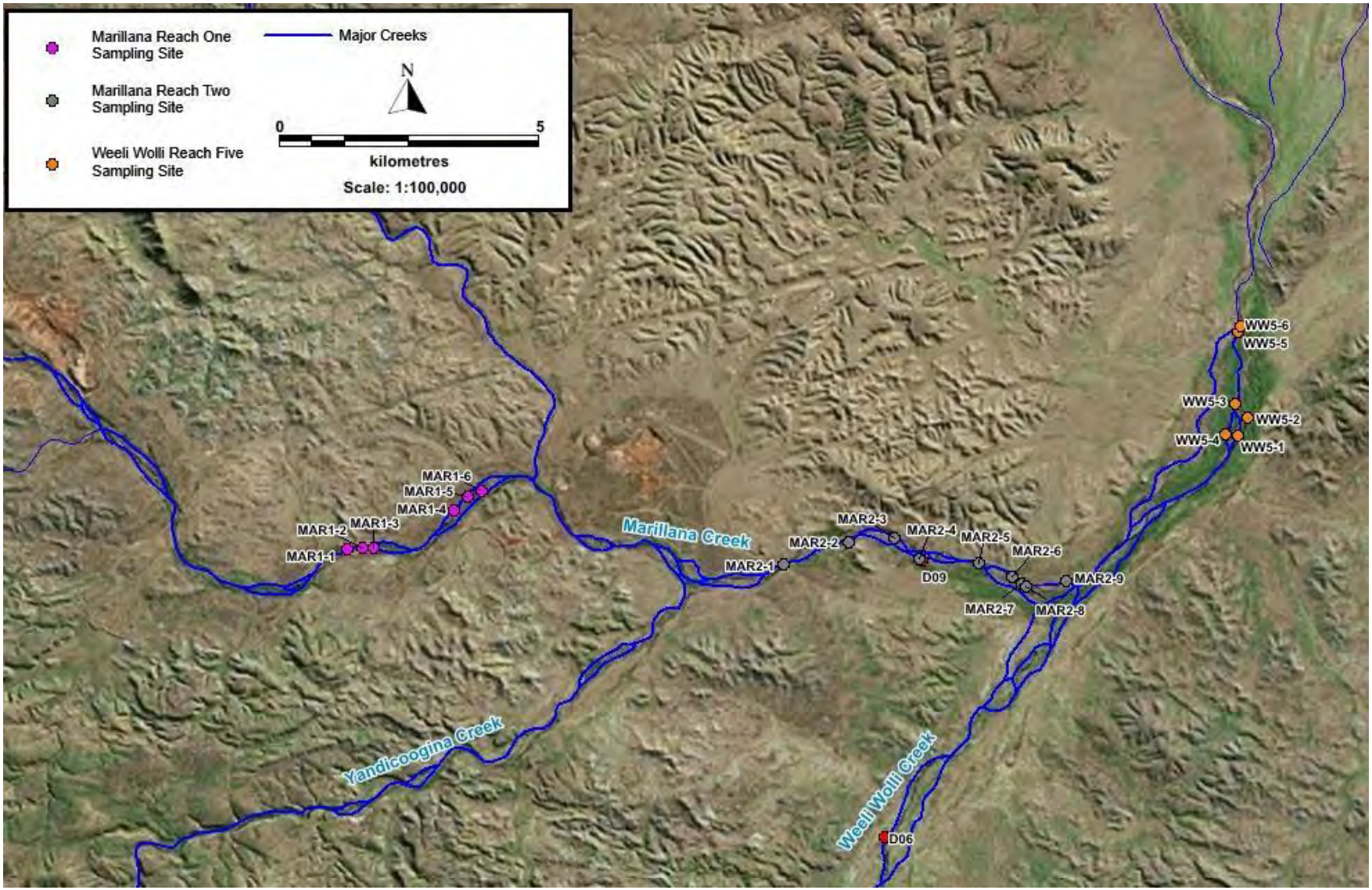


Figure 1. Location of all reaches and sampling sites along Marillana Creek and Weeli Wolli Creek.

Table 2. All water quality parameters measured.

Parameter	*Units*	*Parameter*	*Units*
In situ		***Dissolved metals***	
pH	pH units	Aluminium (Al)	mg/L
Electrical conductivity	µS/cm	Arsenic (As)	mg/L
Redox potential	mV	Boron (B)	mg/L
Dissolved oxygen	% saturation	Barium (Ba)	mg/L
Dissolved oxygen	mg/L	Cadmium (Cd)	mg/L
Water temp	°C	Cobalt (Co)	mg/L
Maximum water depth	m	Chromium (Cr)	mg/L
		Copper (Cu)	mg/L
Ionic composition		Iron (Fe)	mg/L
Sodium (Na)	mg/L	Manganese (Mn)	mg/L
Potassium (K)	mg/L	Mercury (Hg)	mg/L
Calcium (Ca)	mg/L	Molybdenum (Mo)	mg/L
Magnesium (Mg)	mg/L	Nickel (Ni)	mg/L
Chloride (Cl)	mg/L	Lead (Pb)	mg/L
Carbonate (CO_3)	mg/L	Sulfur (S)	mg/L
Hydrogen carbonate (HCO_3)	mg/L	Selenium (Se)	mg/L
Sulfate (SO_4)	mg/L	Uranium (U)	mg/L
Alkalinity	mg/L	Vanadium (V)	mg/L
Hardness	mg/L	Zinc (Zn)	mg/L
Nutrients		***Other***	
Nitrate + nitrite (N_NO_X)	mg/L	Silica (Si)	mg/L
Ammonia (N_NH_3)	mg/L	Silicon dioxide (SiO_2)	mg/L
Total Nitrogen (total N)	mg/L	Total suspended solids (TSS)	mg/L
Total Phosphorus (total P)	mg/L	Turbidity	NTU

- Microinvertebrates (i.e. zooplankton) were collected from the water column using a 53 µm mesh pond net to sweep over a standard 15 m distance at each site. Samples were preserved in 70% ethanol for laboratory enumeration and identification. Samples were processed by identifying the first 200-300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa also taken to species, and recorded as 'present'. Specimens were identified to the lowest taxon possible, *i.e.* species or morphotypes.

- Hyporheic fauna were collected using the Karaman-Chappuis method (Delamare Deboutteville 1960). This involved digging a hole (30 cm deep x 40 cm diameter) in alluvial gravels adjacent to the water's edge (see Plate 1). The hole was allowed to fill with water percolating through the gravel and swept with a small 110 µm mesh hand-net.

Plate 1. Using the portable TPS pH meter at MAR2-5 (left), and hyporheic sampling at WW5-5 using the Karaman-Chappuis method (right). Photos by WRM ©.

- Benthic macroinvertebrates were collected using a 250 µm mesh pond net. In order to allow comparisons to be made between sites, a standardised sampling approach was adopted, whereby 10 m of riffle habitat was selectively sampled at each site. This standardised for habitat and avoided issues with greater fauna diversity due to greater habitat diversity on any reach. Each sample was washed through a 250 µm sieve to remove fine sediment, while leaf litter and other debris were carefully washed into the sieve and then discarded. Samples were preserved in 70% ethanol for laboratory enumeration and identification. Collected specimens were then identified to the lowest possible level (genus or species level) and enumerated to log10 scale abundance scale (*i.e.* 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 – 100 individuals, 4 = 101-1,000 individuals, *etc.*).

- Fish were sampled using a number of methods, including seine netting, gill nets, dip nets and electrofishing. Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher. Light-weight fine mesh gill nets (10 m net, with a 2 m drop, using 10 mm, 13 mm, 19 mm and 25 mm stretched mesh) were used at each site and were set in deeper water for the duration of sampling at that site. Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Generally, two hauls of the seine were conducted at each site to maximise the number of individuals caught. Fish were identified in the field, with standard length[2] (SL) measurements taken, and then released alive.

2.4 Data analysis

All data collected were entered into Excel 2010 spreadsheets.

In order to undertake analyses on faunal data (hyporheic fauna and macroinvertebrate fauna), previous data were amalgamated, and taxonomy was aligned to enable temporal comparisons of taxa richness. This meant that some recent species-level identifications were reverted to genus

[2] Standard length (SL) - measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the midlateral portion of the hypural plate (i.e. this measurement excludes the length of the caudal fin).

level, due to updates in taxonomic knowledge and development of new dichotomous keys for some groups (e.g. species of Oligochaeta, Baetidae mayfly and Lepidoptera moth larvae).

2.4.1 Assessment of conservation significance of fauna

The conservation significance of all aquatic fauna recorded was assessed using established lists of conservation fauna. For invertebrates, reference was made to the IUCN Redlist of Threatened Species (IUCN 2014) and DPaW Threatened and Priority Fauna List (DPaW 2013b). Fish species were compared against the IUCN Redlist of Threatened Species (IUCN 2014), DPaW Threatened and Priority Fauna List (DPaW 2013b), and Australian Society for Fish Biology Conservation List (ASFB 2001). Reference was also made to other Pilbara studies, as well as databases such as The Australian Faunal Directory, The Australian National Insect Collection Database and in-house WRM database for distribution and occurrence information for all aquatic species.

2.4.2 Hyporheic fauna classifications

All taxa recorded from hyporheic samples were classified using Boulton's (2001) categories;

- stygobite – obligate groundwater species, with special adaptations to survive such conditions,
- permanent hyporheos stygophiles - epigean[3] species which can occur in both surface- and groundwaters, but is a permanent inhabitant of the hyporheos,
- occasional hyporheos stygophiles – use the hyporheic zone seasonally or during early life history stages, and
- stygoxene (species that appear rarely and apparently at random in groundwater habitats, there by accident or seeking refuge during spates or drought; not specialised for groundwater habitat).

2.4.3 Univariate analysis

Univariate statistics were performed using SPSS software (Version 19.0 for Windows). Independent samples were used as replicates and two-way analysis of variance (ANOVA) was applied to test for significant differences in species richness of microinvertebrates, macroinvertebrates and hyporheos fauna, and abundance of fish between reaches and years, for each season separately. Two-way ANOVA was also undertaken on environmental data (water quality and habitat characteristics). Any data recorded in percentages were arcsin transformed (proportions) prior to analysis.

A Levene's test was used in the first instance to test for equality of variances (Levene 1960). Data were log transformed where necessary. Tukey's post-hoc tests were utilised in the case of significant differences to locate reach and/or year differences.

To examine change over time in water quality and taxa richness (all faunal groups), regression analysis was undertaken in Excel 2010 for each season separately. Trendlines were fitted for each reach, and r-values and statistical significance determined to assess whether there was a significant linear trend over time. In addition, Spearman Rank Correlation was also undertaken to assess the strength of association between ranked variables (time vs water quality or biotic variables) in the case where relationships over time may not have been exactly linear.

3 Epigean – living or occurring on or near the surface of the ground.

2.4.4 Multivariate analysis

Multivariate analyses were performed using the PRIMER package v 6 (**P**lymouth **R**outines in **M**ultivariate **E**cological **R**esearch; Clarke and Gorley 2006) to investigate differences in water quality and aquatic fauna assemblages (macroinvertebrates, microinvertebrates and fish age-classes) across reaches and years, for each season separately. Relationships between faunal assemblages and physico-chemical characteristics were also examined. The PRIMER package, developed for multivariate analysis of marine fauna samples, has been applied extensively to analysis of freshwater invertebrate data. Multivariate analyses were conducted on all data collected since 2008. Analyses applied to the data included some or all of the following:

1. Describing pattern amongst the fauna assemblage data (macroinvertebrates and microinvertebrates) using ordination techniques based on Bray-Curtis similarity matrices (Bray and Curtis 1957). The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped and the groups themselves form clusters at lower levels of similarity. A group average linkage was used to derive the resultant dendrogram. Similarity matrices for environmental data were based on the Euclidean Distance Measure, and environmental data were log transformed, where necessary, and standardised prior to analyses.
2. To examine whether there were any spatial differences in environmental and/or biotic data between reaches, canonical analysis of principal coordinates (CAP) was undertaken within the PERMANOVA add-on in PRIMER. This test finds axes through the multivariate cloud of points that either (i) are the best at discriminating among *a priori* groups (discriminant analysis) or (ii) have the strongest correlation with some other set of variables (canonical analysis) (Anderson and Robinson 2003, Anderson *et al.* 2008). The CAP analysis produced an ordination and vectors corresponding to Spearman Rank Correlations >0.5 (i.e. of water quality variables or individual species) were superimposed on this ordination.
3. Permutational multivariate analysis of variance (PERMANOVA) was undertaken (two-factor crossed design) to determine whether there was any significant difference in environmental or biotic data (i.e. microinvertebrate, macroinvertebrate fauna assemblages and fish age-class structures) between reach and year (Anderson 2001a, b, McArdle and Anderson 2001, Anderson and ter Braak 2003, Anderson *et al.* 2008).
4. The relationship between the environmental (water quality and habitat) and biotic data was assessed using the BVSTEP routine. This was used to calculate the minimum suite of parameters that explain the greatest percent of variation (i.e. the parameters which most strongly influence the species ordination).
5. Change in water quality and species assemblages over time were further assessed graphically by plotting distance to “baseline” centroid (being the initial sampling event). This created a plot showing change in similarity with “baseline” data over time. Values for water quality were based on Euclidean distances, and values for species assemblages based on Bray-Curtis percent similarity. Plots were prepared for each season separately.

In order to analyse the fish data using these multivariate techniques, each species was first split into ‘pseudo-species’ based on age-classes. Total abundances of each ‘pseudo-species’ were then analysed in PRIMER. Age-classes used in these analyses were estimated from the literature (see section 3.7.4 and Table 14).

3 RESULTS AND DISCUSSION

3.1 Sites affected by current construction and development

A number of Marillana Creek aquatic monitoring sites had undergone considerable change in channel morphology and characteristics between the wet-13 and dry-13 sampling events due to construction associated with developments at Yandicoogina. These changes are detailed below:

New locations for MAR1-2 and MAR1-3

Dewatering associated with the JSW development, along with the construction of a haul road across MAR1-2, meant that the site is now dry and can no longer be used as a sampling point. MAR1-3 was similarly impacted by dewatering, with the site being dry during the dry-13 sampling round and signs of senescence of emergent vegetation apparent. As such, two new sites were established upstream of the old MAR1-2 site to ensure a total of six monitoring sites remain available for sampling now and in the future: MAR1-2, located 0.3 km downstream of MAR1-1, and MAR1-3, located 0.5 km upstream of the haul road at the old MAR1-2 site.

Changes in Marillana Reach Two

Due to changes associated with Yandicoogina's dewatering and discharge operations, pools at MAR2-1, MAR2-2 and MAR2-3 have all dried and no longer contain water associated with discharge (they may still hold water at various times due to intense rainfall associated with cyclonic activity). Since the development of JSW commenced, the majority of discharge now occurs via the D09 outlet located further downstream, with discharge outlets upstream of MAR2-1 being no longer in use. Discharge from the new D09 outlet was clearly affecting the creek in the vicinity of MAR2-4, immediately downstream, creating a broader area of water within the channel (Plate 2). In order to replace impacted sites upstream of the D09 discharge, three new sites downstream of MAR2-6 were established: MAR2-7, MAR2-8 and MAR2-9 (Plate 3).

Plate 2. Images showing the influence of the D09 discharge at MAR2-4 (left) and the new MAR2-7 site established downstream of MAR2-6.

Plate 3. The new MAR2-8 (left) and MAR2-9 (right) sites established downstream of MAR2-6.

3.2 Water quality

Water quality data were compared against ANZECC/ARMCANZ (2000) water quality guidelines, using default trigger values (TVs) for physical and chemical stressors applicable to tropical northern Australia. Water quality data was also compared against site-specific TVs (SSTVs) (WRM 2013b). SSTVs were developed by WRM for Marillana Creek Reaches One and Two, with different SSTVs developed for Weeli Wolli Creek Reach Five. This was necessary because Weeli Wolli Creek in this reach has slightly different water chemistry to Marillana Creek upstream (WRM 2013b).

3.2.1 Dry-13 and Wet-14

Dissolved oxygen (DO)

Daytime dissolved oxygen ranged from 20.6% (at WW5-1) to 129.4% (Mar2-7) during dry-13, and 22.1% (MAR1-1) to 150.6% (MAR2-9) during wet-14 (Figure 2). DO values were outside ANZECC/ARMCANZ (2000) guidelines at a number of sites in both seasons (i.e. below 85% or above 120%; Figure 2). DO values at MAR1-1, MAR2-6 and MAR2-8 during the dry season, and MAR1-1 and MAR1-4 during the wet season were below lower SSTVs for Marillana Creek (62%). DO values at WW5-1, WW5-2 and WW5-4 during the dry season, and WW5-4 during the wet season were below lower SSTVs for Weeli Wolli Creek Reach Five (85%). Low DO concentrations can be caused by high biological oxygen demand (BOD) and the decomposition of algae, which consumes oxygen in the process. Many sites which exhibited low daytime DO were either standing pools, or had sluggish flow passing between pools (e.g. MAR2-8, MAR1-4 and WW-Five sites during the dry season). MAR1-1 also had a large amount of decomposing algae in dry-13, so low oxygen levels would not be unexpected.

Conversely, DO levels recorded from MAR2-7 and MAR2-9 in dry-13, and MAR1-3, MAR2-5, MAR2-9 and WW5-2 in wet-14 were considered super-saturated, i.e. < 120% (Figure 2). Super-saturation occurs when net photosynthesis exceeds total oxygen consumption, and is common in areas of high algal and macrophyte growth, and/or areas of high turbulence (e.g. riffle zones). Sites from which super-saturated DO was recorded are likely to experience oxygen stress overnight, when respiration by plants, algae and fauna depletes oxygen levels. Super-saturation is also known to cause gas bubble disease in fish (Bouck 1980). However, the oxygen needs of aquatic biota differ between species and between life history stages.

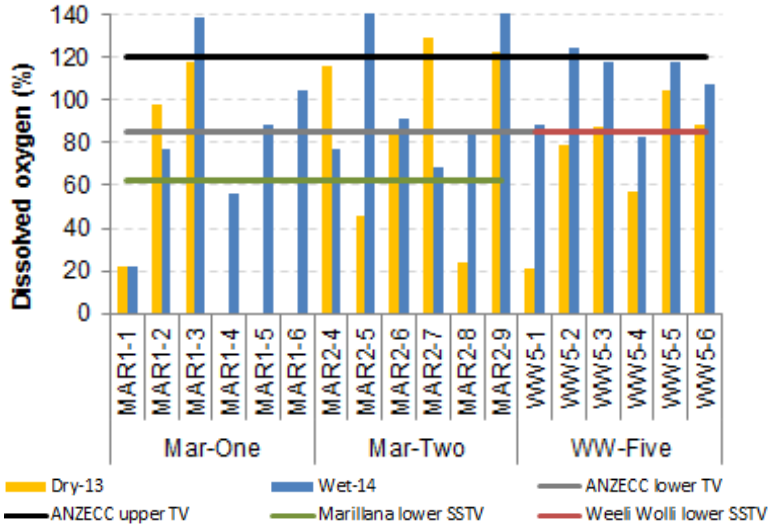


Figure 2. Dissolved oxygen (%) recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14, in comparison to ANZECC/ARMCANZ (2000) TVs and SSTVs. NB: Upper SSTVs were equivalent to the ANZECC upper TVs.

pH

pH was circum-neutral to basic, ranging from 7.2 (MAR2-4) to 7.9 (MAR1-3) in the dry-13, and 7.2 (MAR2-4) to 8.7 (WW5-3) in the wet-14. Although a number of pH values were recorded in excess of ANZECC/ARMCANZ (2000) upper TVs (> 8), Weeli Wolli Creek SSTVs were only exceeded at WW5-3 during the wet-14 (8.74).

Electrical conductivity (EC)

All sites were classified as "fresh" as defined by the DoE (2003)[4]. In the dry-13, EC ranged from 847 µS/cm (MAR2-4) to 1040 µS/cm (MAR1-1 & WW5-2; Figure 3). During the wet-14, EC ranged from 825 µS/cm (MAR2-9) to 941 µS/cm (MAR1-2 & MAR1-5). In both seasons, EC at all Marillana Creek sites was in excess of ANZECC/ARMCANZ (2000) guidelines. However, only at MAR1-1 and MAR1-2 were Marillana Creek SSTVs exceeded, both in the dry-13. EC at all WW-Five sites exceeded ANZECC/ARMCANZ (2000) TVs and SSTVs in both seasons. Naturally, surface waters in arid/semi-arid zones exhibit more concentrated electrical conductivity in the dry season, as a consequence of high evaporation levels and low rainfall. Although some dilution occurs following wet season rains, salinity can often remain high due to the variability of flows and flushing of stored salts (Jolly *et al.* 2008).

Alkalinity

Dry season alkalinity ranged from 202 mg/L (MAR2-4) to 337 mg/L (WW5-2), while in the wet-14 it varied between 217 mg/L (MAR2-9) and 281 mg/L (WW5-1). SSTVs were exceeded at MAR1-1 (306 mg/L), WW5-2 (337 mg/L) and WW5-3 (317 mg/L) in the dry season. No alkalinity value from either Marillana Creek or Weeli Wolli Creek Reach Five exceeded SSTVs in the wet season. Alkalinity of less than 20 mg/L is considered low; under these conditions, water is poorly buffered, and the removal of carbon dioxide during photosynthesis can result in rapidly rising pH (Sawyer and McCarty 1978,

[4] Fresh defined as < 1500 µS/cm, Brackish = 1500 – 4500 µS/cm, Saline = 4500 – 50,000 µS/cm, Hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZECC/ARMCANZ (2000).

Romaire 1985, Lawson 2002). As such, current results indicate the buffering capacities of Marillana Creek and Weeli Wolli Reach Five are good.

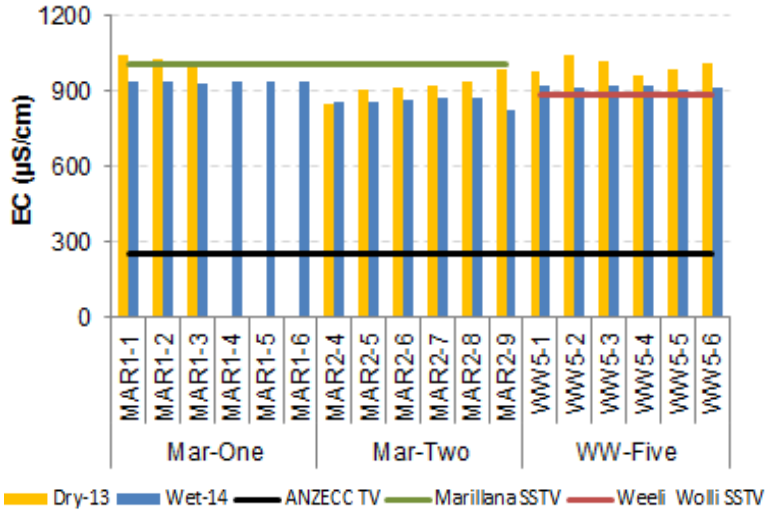


Figure 3. Electrical conductivity (µS/cm) recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14, in comparison to ANZECC/ARMCANZ (2000) TVs and SSTVs.

Ionic composition

The ionic composition of Marillana Creek was dominated by sodium cations and bicarbonate anions (generally in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+ : HCO_3^- > Cl^- > SO_4^{2-} > CO_3^-$). This was consistent between seasons and there was no difference between reaches (Appendix 3). There was some difference in the sub-dominance of cations, with some sites having higher concentrations of calcium and others magnesium. The sub-dominance of cations at a site varied between seasons. In contrast, the composition of major ions at Weeli Wolli Creek was generally dominated by calcium and bicarbonate, with some differences in the sub-dominance of cations along the length of the creek, i.e. $Ca^{2+} > Mg^{2+} > Na^+ > K^+ : HCO_3^- > Cl^- > SO_4^{2-}$ in the upper reaches, and $Ca^{2+} > Na^+ > Mg^{2+} > K^+ : HCO_3^- > Cl^- > SO_4^{2-}$ at the downstream Reach Four. There were some differences in the composition of ions between sites within WW-Five, with some sites being similar to WW-Four and being dominated by $Ca^{2+} > Na^+ > Mg^{2+} > K^+ : HCO_3^- > Cl^- > SO_4^{2-}$ (i.e. WW5-5 and WW5-6), and others being in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+ : HCO_3^- > Cl^- > SO_4^{2-}$ (i.e. WW5-1; Appendix 3).

Nutrients

Nutrient levels varied greatly between reach and season, however concentrations were consistently high at the site located at the D09 discharge outlet (MAR2-4) and generally decreased in concentration in a longitudinal gradient from this point downstream (Figure 4).

During the dry-13, nitrogen oxides (N_NOx) ranged from concentrations less than detection limits (< 0.01 mg/L at WW5-5) to 0.4 mg/L (MAR2-4). Wet season N_NOx ranged from less than detection (WW5-5) to 1.8 mg/L (MAR1-3 & MAR2-4). N_NOx concentrations were above ANZECC/ARMCANZ TVs at the majority of sites in both seasons, and Marillana Creek SSTVs for protection against eutrophication (1.16 mg/L[5]) were exceeded at MAR1-1, MAR1-2, MAR1-3 and MAR2-4 during the

[5] The Marillana Creek SSTV for N_NOx of 1.16 mg/L (WRM 2013b), acknowledges that background levels are already elevated compared to the ANZECC/ARMCANZ (2000) default TV for N_NOx of 0.01 mg/L for lowland rivers, and 0.03 mg/L for upland rivers. As minimal historic data exist, data used to derive SSTVs were collected from Marillana and Weeli Wolli creeks after commencement of dewatering discharge from BHPIO Yandi (in

wet season. Weeli Wolli Creek SSTVs (0.16 mg/L) were exceeded at WW5-2 and WW5-6 in the dry-13, and WW5-1 and WW5-3 in the wet-14 (Figure 4).

Since the development of the SSTVs, it is now understood that the ANZECC/ARMCANZ (2000) default 95% TV for NO_3 (as a toxicant) of 0.7 mg/L (= 0.16 mg/L N_NO_3) is too conservative (R. van Dam, ***eriss***, pers. com.). The new ANZECC/ARMCANZ nitrate TV (95% species protection) will be around 2 - 2.5 mg/L N_NO_3 (R. van Dam, ***eriss***, pers. com.). As such, the nitrate toxicity SSTVs for Marillana Creek and lower Weeli Wolli Creek were revised in the recent Hazard Analysis to 2.5 mg/L N_NO_3 (WRM 2015a). Given that nitrate is generally the largest component of N_NOx, the values recorded during the current study would not exceed the new revised nitrate toxicity SSTV.

Total nitrogen (total N) ranged from 0.1 mg/L (MAR2-9) to 0.4 mg/L (MAR2-4) in the dry-13, and 0.02 mg/L (WW5-5) to 1.8 mg/L (MAR2-4) in the wet-14 (Figure 4). ANZECC/ARMCANZ (2000) TVs (0.3 mg/L) were exceeded at most sites in each season, while Marillana Creek SSTVs (1.2 mg/L) were exceeded at MAR1-1, MAR1-2, MAR1-3 and MAR2-4 in the wet season (Figure 4). Total N concentrations were above Weeli Wolli Creek SSTVs (0.3 mg/L) at a number of WW-Five sites in both seasons (Figure 4).

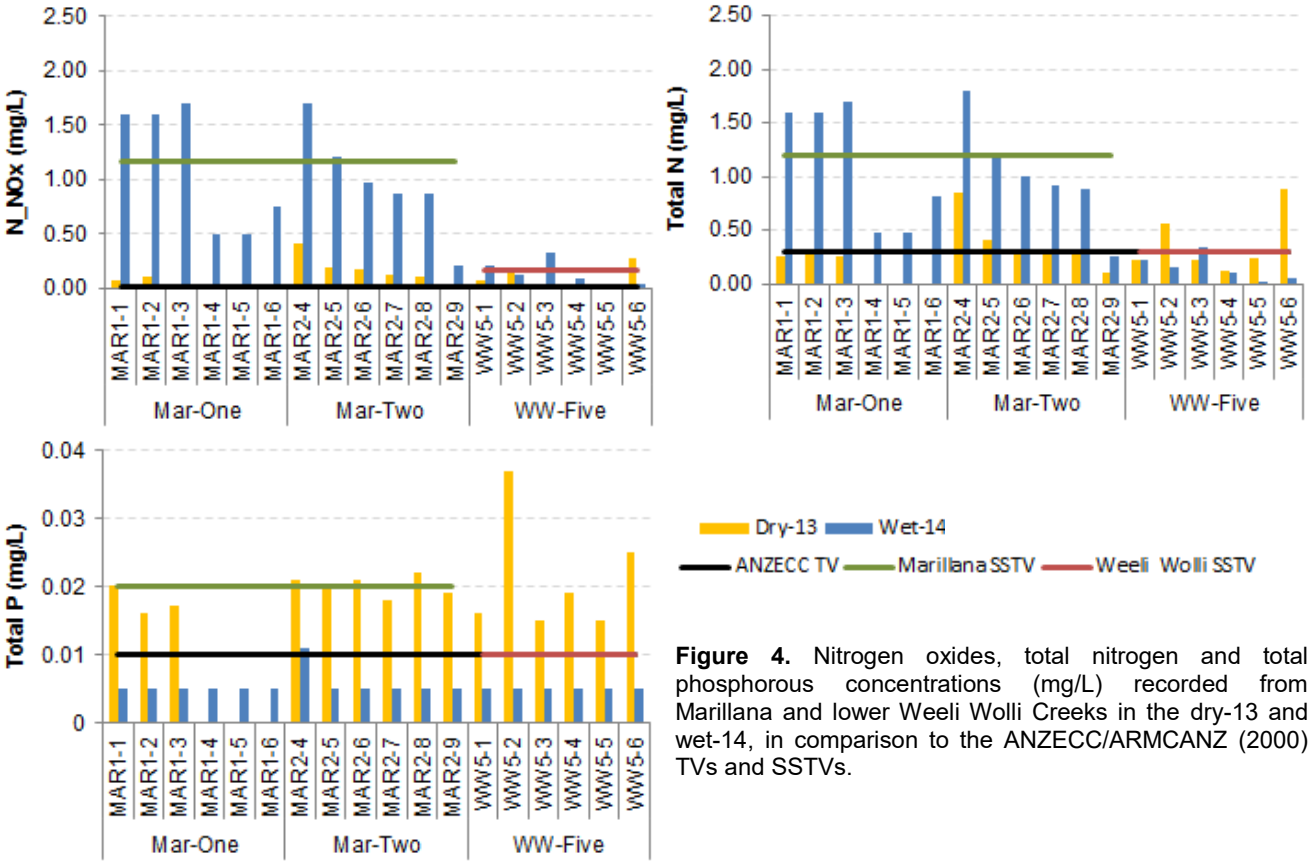


Figure 4. Nitrogen oxides, total nitrogen and total phosphorous concentrations (mg/L) recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14, in comparison to the ANZECC/ARMCANZ (2000) TVs and SSTVs.

Wet season total phosphorous (total P) concentrations were below detection limits at all sites (> 0.01 mg/L), with the exception of MAR2-4 (0.011 mg/L), where they exceeded ANZECC/ARMCANZ (2000) guidelines but not Marillana Creek SSTVs (Figure 4). In the dry-13, total P concentrations were in excess of ANZECC/ARMCANZ (2000) TVs at all sites, and Marillana Creek SSTVs at MAR2-4 (0.021

1994), Junction Central (in 1998), JSE (in 2006) and HD1 (in 2007). While not necessarily indicative of pre-development condition, the SSTVs are indicative of current background levels in the creeks.

mg/L), MAR2-6 (0.021 mg/L) and MAR2-8 (0.022 mg/L). Concentrations of total P were greater than Weeli Wolli Creek SSTVs at all WW-Five sites in the dry season (Figure 4).

Elevated concentrations of N_NOx, total N and total P downstream of MAR2-4 in both seasons was likely due to groundwater discharge from the D09 outlet. Historically, a longitudinal gradient in nutrient levels was observed along Marillana Creek Reach One, with concentrations of N_NOx, total N and total P declining with distance downstream from MAR1-1 (WRM 2012). The cause of this was linked to discharge from the BHPBIO Yandi mine upstream of MAR1-1, with a reduction of nutrient levels downstream due to assimilation by emergent macrophytes and algae. It appears that discharge of groundwater from JC, JSE and JSW via D09 may be having a similar influence on surface waters of Marillana Creek Reach Two, with Figure 4 presenting a longitudinal gradient of nutrient concentrations downstream of MAR2-4. Analysis of data from bores in the JSW and Oxbow deposits did indicate some nutrient enrichment of groundwater of this region (WRM 2013b). Elevated nutrient levels at some lower Weeli Wolli Creek sites were likely due to the large numbers of cattle which often congregate in this reach.

Metals

Concentrations of dissolved metals were generally low, however, dissolved boron (dB) and dissolved zinc (dZn) were elevated above 99% ANZECC/ARMCANZ (2000) guidelines at a number of sites (Figures 5 & 6). dB concentrations greatly exceeded the 99% ANZECC/ARMCANZ (2000) TVs (0.09 mg/L) at all sites both the dry and wet seasons (Figure 5). At MAR1-1, MAR1-2 and MAR1-3, dry season dB concentrations were also above 95% ANZECC/ARMCANZ (2000) TVs and SSTVs (0.37 mg/L[6]). Elevated concentrations of dB have been widely recorded from surface waters across the Pilbara, including the Fortescue River, Kalgan Creek, Marillana Creek, Mindy Mindy Creek, Coondiner Creek, Caves Creek and Duck Creek (WRM, unpub. data).

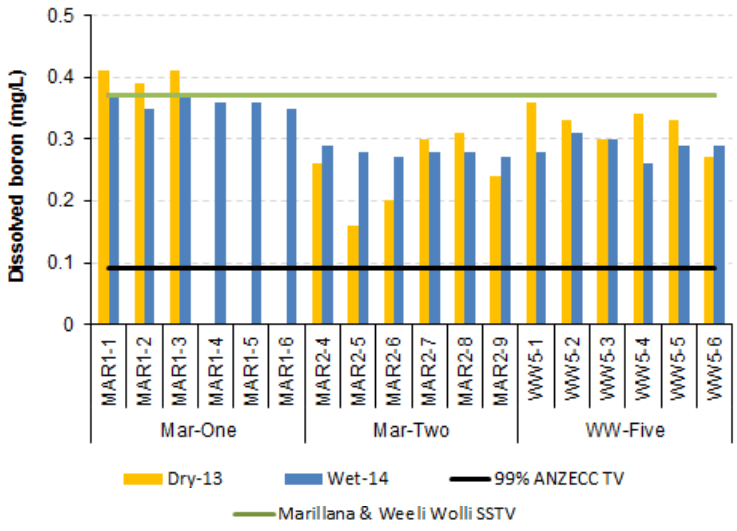


Figure 5. Dissolved boron concentrations (mg/L) recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14, in comparison to the ANZECC/ARMCANZ (2000) TVs and SSTVs.

Concentrations of dZn were in exceedance of 99% ANZECC/ARMCANZ (2000) guidelines at all Marillana Creek sites, and at Weeli Wolli Creek sites WW5-1 and WW5-6 during the dry-13 (Figure 6). In the wet-14, dZn concentrations from five sites along Marillana Creek (MAR1-1, 1-3, 2-4, 2-5 & 2-9)

[6] The SSTVs for dB and dZn were the same for both Marillana Creek and lower Weeli Wolli Creek, and equivalent to the 95% ANZECC/ARMCANZ (2000) TV (WRM 2013).

and four sites along Weeli Wolli Creek Reach Five (WW5-1, 5-2, 5-4 & 5-6) were above the 99% ANZECC/ARMCANZ (2000) TV (Figure 6). Water hardness is known to affect the toxicity of some dissolved metals, including zinc, where greater 'softness' places biota at increased risk, whilst greater water hardness may ameliorate toxicity (Markich *et al.* 2001, Charles *et al*. 2002). ANZECC/ARMCANZ (2000) provide algorithms to calculate trigger values for such metals which take hardness into account. As such, given the high water hardness at Marillana and lower Weeli Wolli Creek, the hardness modified trigger values (HMTVs) were considerably higher than default ANZECC/ARMCANZ guidelines[7] and SSTVs (Figure 6). Taking into account baseline conditions, as well as water hardness, dZn concentrations did not exceed the hardness modified site-specific TVs at any site in either season.

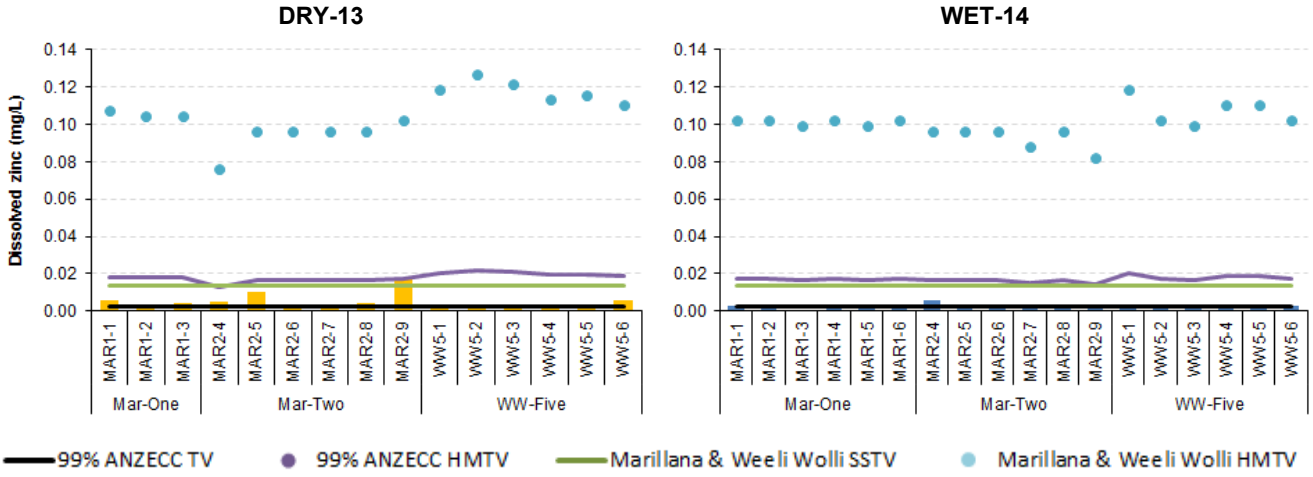


Figure 6. Dissolved zinc concentrations (mg/L) recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 (left) and wet-14 (right), in comparison to the ANZECC/ARMCANZ (2000) trigger values, SSTVs, and HMTVs. NB: the SSTV was the same for both Marillana and lower Weeli Wolli creeks (0.014 mg/L).

3.2.2 Temporal changes in water quality

Temporal changes in water quality can be summarised as follows:

- There was no significant difference in pH between reach in either season. Dry season pH was significantly higher in 2011, compared to all other years, while wet season pH was also highest in 2011. There was a significant decline in Mar-Two pH between the wet seasons of 2009 and 2014 (p = 0.01, r = 0.93, Spearman p = 0.01; Figure 7).
- Dry season water temperature was highest in 2013, though this was statistically similar to that recorded in 2008. Wet season water temperature was highest in 2014, though statistically similar to 2010. Mar-One recorded significantly lower dry season water temperature than either downstream reach (Mar-Two or WW-Five). There was no significant linear relationship between temperature and time at either Marillana reach in either season (Figure 7).
- Significantly higher dry season EC was recorded in 2010, compared to all other years. EC was also significantly higher in the wet season of 2010 (though this was statistically similar to 2009 & 2013). In both seasons, EC was significantly higher from Mar-One compared to Mar-Two and WW-Five. There was no change in dry or wet season EC over time at either Mar-One or Mar-Two (Figure 7).

[7] Hardness modified trigger value considers the effect of hardness ($CaCO_3$) in freshwater on toxicity when deriving a trigger value using the appropriate algorithm. Algorithms for dissolved zinc HMTV = zinc 99% TV*(hardness / 30) $^{0.85}$, or SSTV HMTV = zinc SSTV*(hardness / 30) $^{0.85}$.

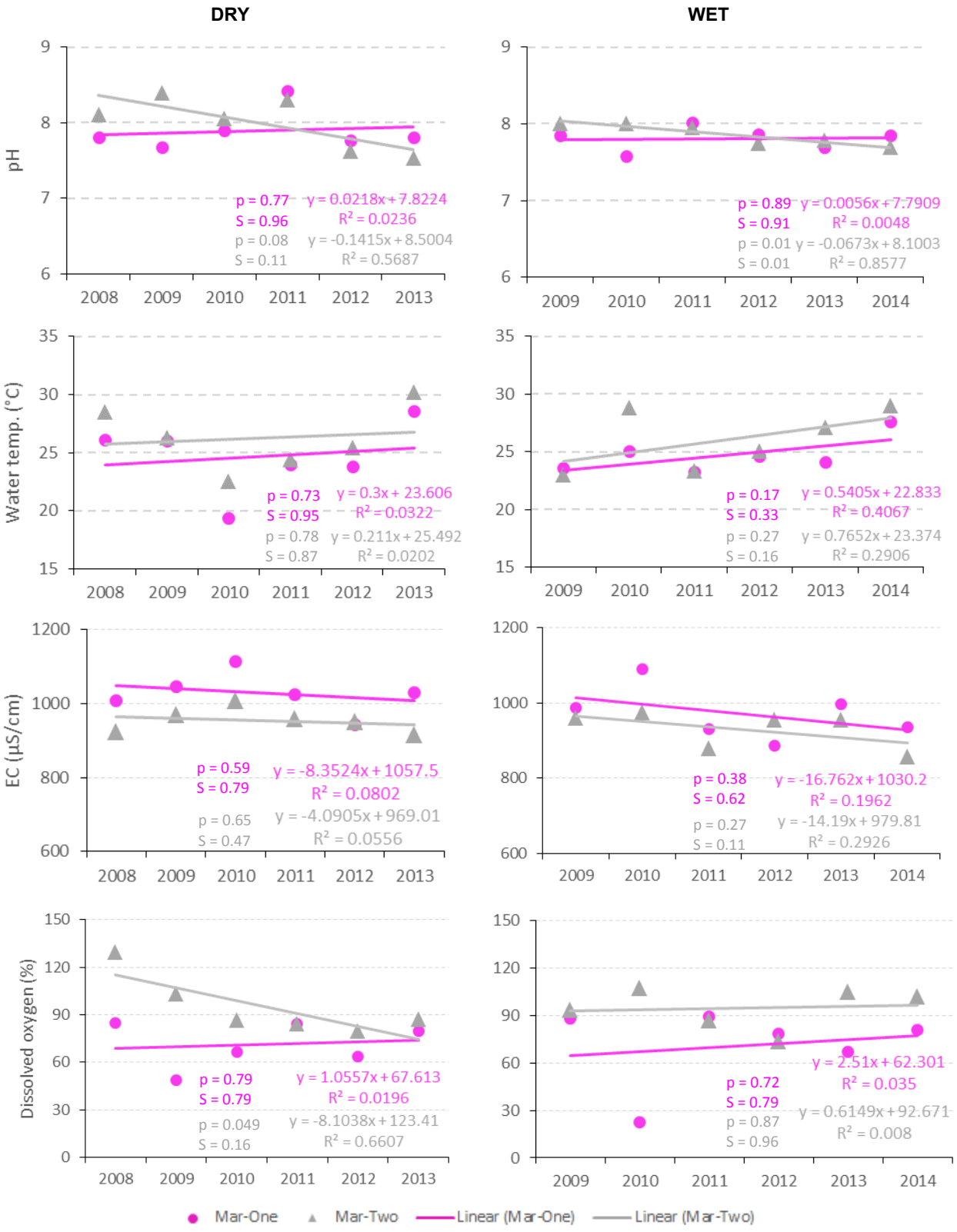


Figure 7. Linear regression plots of mean dry (left) and wet season (right) *in situ* water quality parameters against time for Marillana Reaches One and Two. Equations, *p*, Spearman correlation co-efficient (S) and r^2 values are displayed.

- In the dry season, DO was significantly greater from Mar-Two compared to Mar-One, however it was statistically similar to that of WW-Five. DO did not change significantly over time in either season in either Marillana reach (Figure 7).

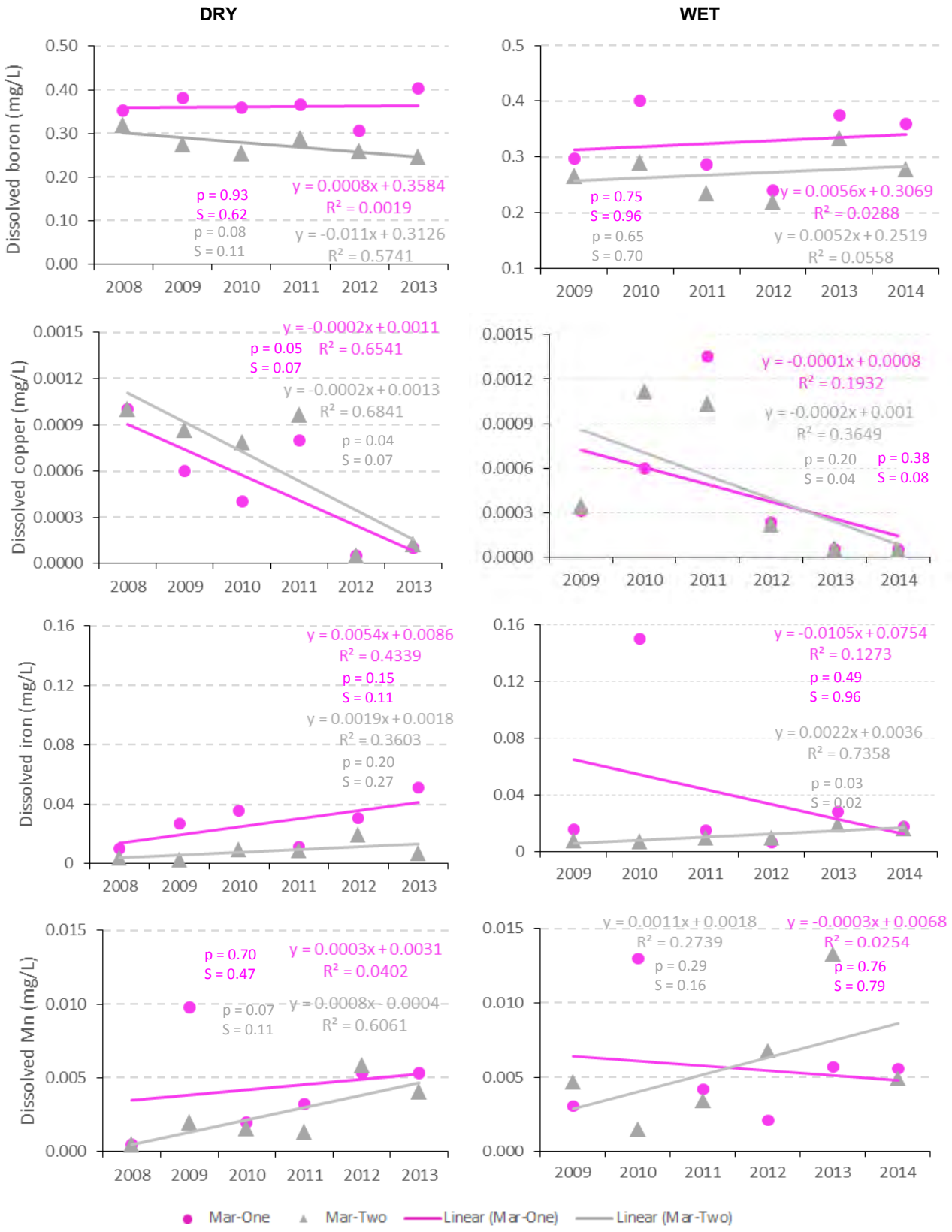


Figure 8. Linear regression plots of mean dry (left) and wet season (right) dissolved metal concentrations against time for Marillana Reaches One and Two. Equations, *p*, Spearman correlation co-efficient (S) and r^2 values are displayed.

- Dry season dB was significantly lower in 2012, compared to all other years, while dB was significantly greater from Mar-One, compared to Mar-Two and WW-Five. During the wet season, dB was significantly higher from Mar-One, while also being significantly greater in

2013 in comparison to other years. There was no significant linear relationship for dry or wet season dB over time at either reach (Figure 8).

- dCu was significantly lower in 2012 and 2013 during the dry season, while dCu was also significantly lower from WW-Five compared to other reaches. In the wet season, highest dCu was recorded in 2011 and 2010. There was no significant difference in wet season dCu between reaches. Regression analysis indicated a significant decline in dry season dCu between 2008 and 2013 at Mar-Two (p = 0.04, r = 0.82), while Spearman correlation co-efficient indicated a significant decline in Mar-Two dCu over time during the wet season (Spearman p = 0.04; Figure 8).
- There was a significant difference in dissolved iron (dFe) between reach (but not year) during the dry season, with highest dFe recorded from Mar-One. Wet season dFe was significantly different between year and reach, where highest dFe was again recorded at Mar-One. There was a significant increase in wet season dFe over time at Marillana Reach Two (p = 0.03, r = 0.86, Spearman p = 0.02; Figure 8).
- Dry season dissolved manganese (dMn) was lowest in 2008, however this was statistically similar that of 2010 and 2011. In the wet season, dMn was significantly lower from Mar-Two compared to Mar-One and WW-Five. There was no significant change in dMn over time from Mar-One or Mar-Two in either season (Figure 8).
- Calcium (Ca) was significantly higher from WW-Five, compared to at Mar-One and Two in the dry season. Similarly, wet season Ca from WW-Five was significantly higher than from other reaches. There was no significant dry or wet season linear relationship between dCa and time for either Marillana Creek reach (Figure 9).
- Dry season chloride (Cl) was significantly greater from Mar-One in comparison to other reaches, and between years, it was highest in 2008 and 2010. During the wet season, Cl was greatest from Mar-One, followed by Mar-Two, and was lowest at WW-Five. Cl did not significantly change over time at either Mar-One or Mar-Two in either season (Figure 9).
- Hydrogen carbonate (HCO_3) during the dry season was greatest in 2011, though this was statistically similar to 2010, 2009 and 2012. Wet season HCO_3 was significantly highest in 2010, and lowest in 2014. Regression analysis indicated a significant decline in dry season HCO_3 from Mar-Two between 2008 and 2013 (p = 0.046, r = 0.82, Spearman p = 0.02; Figure 9).
- Sulfate (SO_4) was highest from WW-Five, and significantly greater in 2010 compared to other years in the dry season. During the wet season, SO_4 was significantly higher from WW-Five compared to other reaches, and was greatest in 2010, though statistically similar to 2013 and 2011. Spearman correlation co-efficient suggested a significant decrease in SO_4 over time at Mar-One during the dry season (Spearman p = 0.04), however ANOVA testing did not concur with this significance (p = 0.16, r = 0.65; Figure 9).
- Total nitrogen (total N) was highest from Mar-One and Mar-Two during the dry season, and was greatest in 2011. In the wet season, total N from WW-Five was significantly greater than all other reaches. Total N concentrations did not change significantly over time at either Marillana reach in either season (Figure 10).
- Dry season total phosphorous (total P) was significantly greatest in 2013, but was statistically similar to 2011 and 2009. During the wet season, total P was significantly different between years, being the greatest in 2009, though statistically similar to 2011 and 2012. There was no significant difference in total P between reaches in either season. ANOVA testing detected a significant decline in wet season total P from Mar-Two between 2009 and 2014 (p = 0.045, r = 0.82; Figure 10).

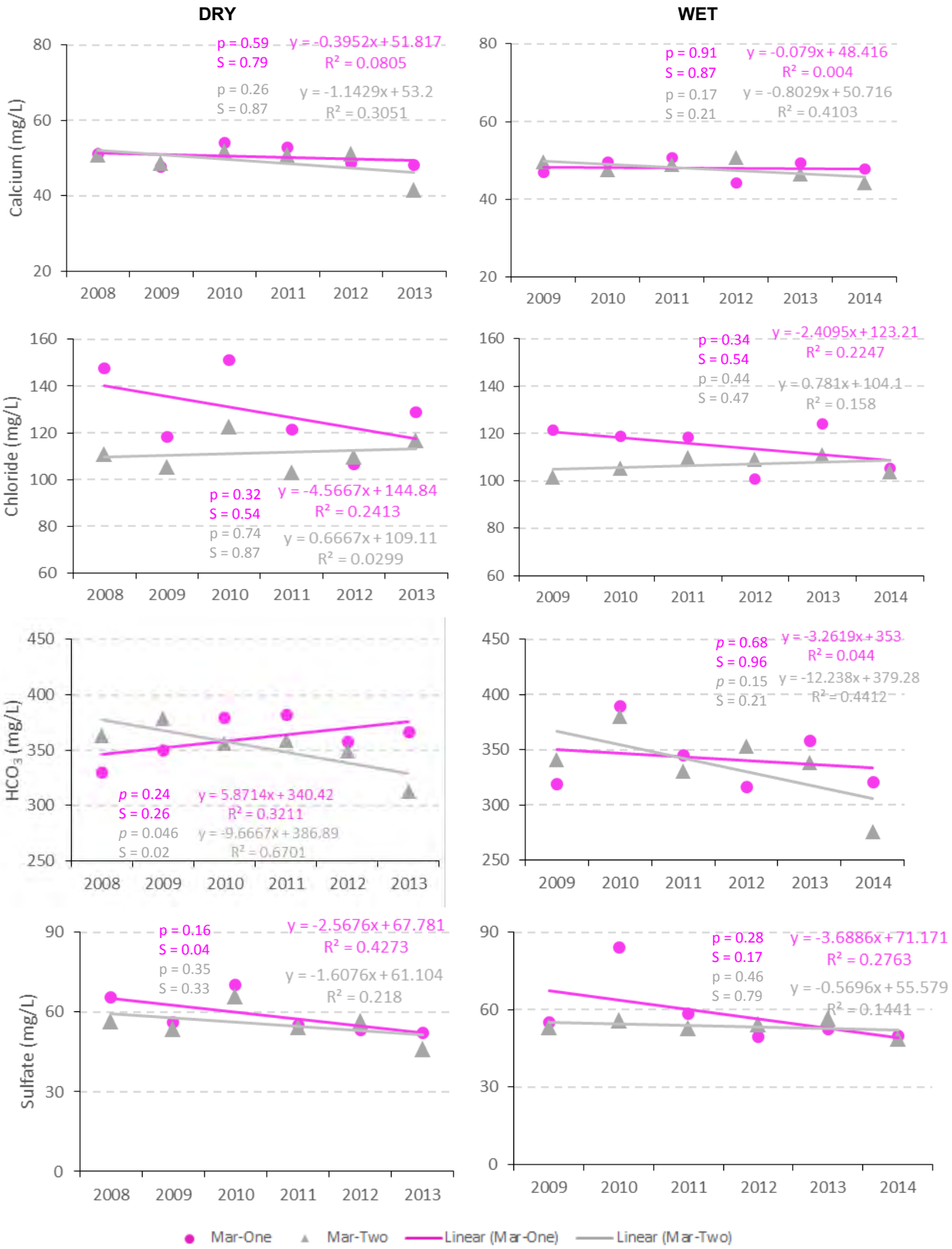


Figure 9. Linear regression plots of mean dry (left) and wet season (right) dissolved ion concentrations against time for Marillana Reaches One and Two. Equations, *p*, Spearman correlation co-efficient (S) and r^2 values are displayed.

Figure 10. Linear regression plots of mean dry (left) and wet season (right) nutrient concentrations against time for Marillana Reaches One and Two. Equations, *p*, Spearman correlation co-efficient (S) and r^2 values are displayed.

3.2.3 Multivariate analysis, including comparisons with Weeli Wolli Creek

All water quality data from Weeli Wolli Creek (four reaches: WW-One, Two, Three and Four, sampled between dry 2008 and wet 2014) were incorporated into the current dataset, and PERMANOVA and constrained CAP analyses performed in order to examine differences among reaches and years in ordination space. During the dry season, significant patterns were evident in the constrained CAP plot examining differences among reach (p = 0.001). The strength of the association between the data cloud and hypothesis of differences in reach was high, with a correlation of 0.98 along CAP axis 1, and 0.91 along CAP axis 2. Water quality samples from Marillana Creek separated from those of Weeli Wolli Creek along CAP1 due to higher concentrations of EC, Total N, chloride, sodium and dissolved vanadium (Figure 11). There was also a longitudinal separation of Weeli Wolli Creek reaches along CAP2 (Figure 11). The separation of upper Weeli Wolli reaches (i.e. WW-One, Two & Three) from downstream reaches (WW-Four & WW-Five) was primarily influenced by higher concentrations of hydrogen carbonate and alkalinity. Greater concentrations of potassium affected the separation of WW-Four and WW-Five sites from upstream sites (Figure 11). Similarly significant patterns were evident in the wet season (p = 0.0001; see Figure 11).

PERMANOVA testing indicated that there was a significant difference between reach (df = 6, *p* = 0.001) and year (df = 5, *p* = 0.001) in the dry season, and a significant difference between reach (df = 6, *p* = 0.001) and year (df = 5, *p* = 0.001) in the wet season (Table 3).

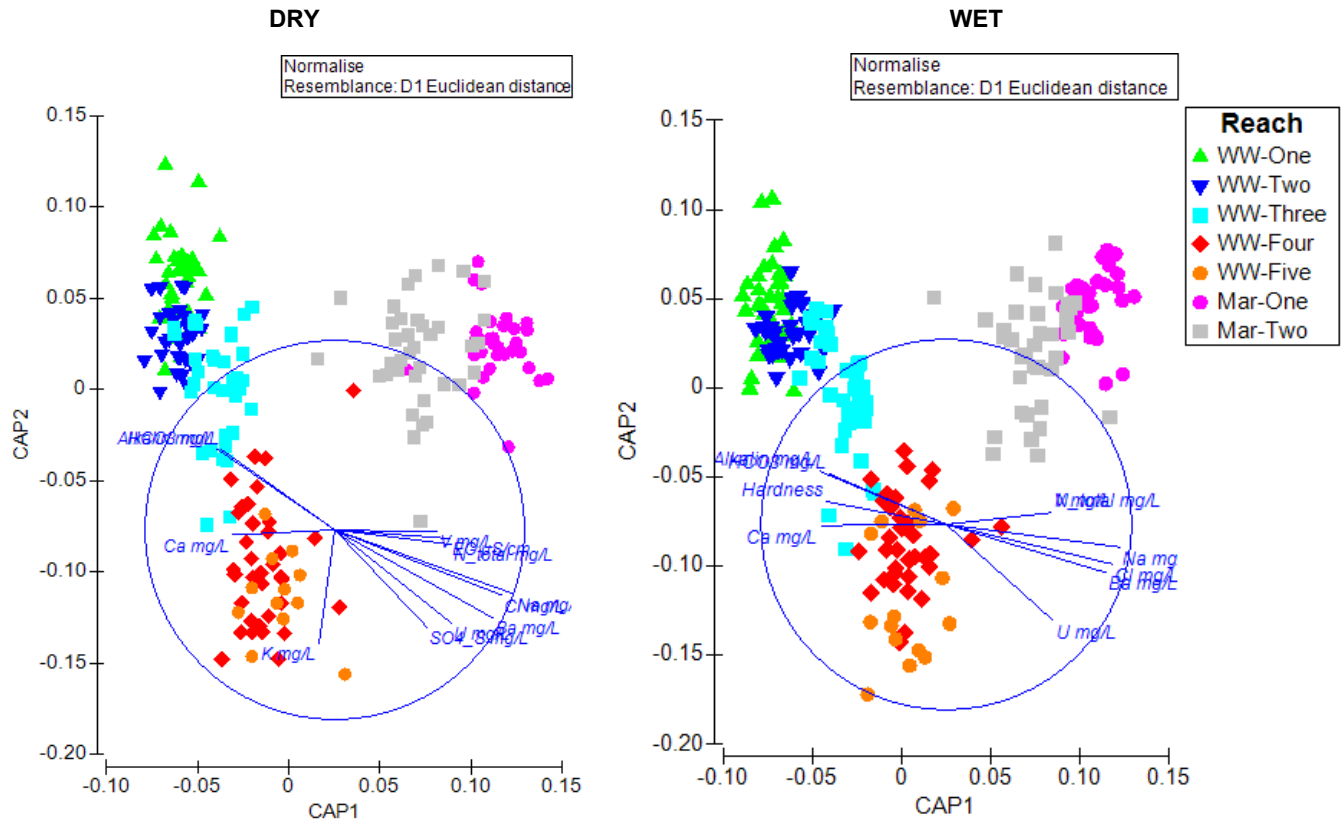


Figure 11. Constrained CAP plots of water quality data between reach in the dry (left) and wet season (right), with vectors of Spearman rank correlations overlain (correlation >0.5).

Table 3. Two-factor PERMANOVA results for dry and wet season data, comparing water quality between reach and year.

Dry Season	df	MS	Pseudo-F	p
Reach	6	301.84	21.862	0.001
Year	5	123.87	8.9716	0.001
Reach*Year	26	38.171	2.7647	0.001
Residual	186	13.807		
Total	223			
Wet Season	**df**	**MS**	**Pseudo-F**	**p**
Reach	6	301.83	26.182	0.001
Year	5	181.94	15.782	0.001
Reach*Year	27	30.67	2.6605	0.001
Residual	185	11.528		
Total	223			

Distance to centroid plots[8] showed varying similarity in water quality data to initial "baseline" monitoring (2008) in Mar-Two during the dry season (Figure 12). Between 2011 and 2013, similarity to "baseline" condition has decreased (increasing Euclidean Distance). In Mar-One dry season water quality has remained fairly consistent over time. In the wet season, there was a considerable change in water quality in Mar-One between the initial "baseline" sampling and the subsequent year (2010;

[8] Distance to centroid = location among groups in multivariate space (PERMANOVA); spatial median in the ordination space of the resemblance measure (in this case, Euclidean distance). An increasing Euclidean Distance indicates a decreasing similarity.

high Euclidean Distance), but after this time there was a decrease in Euclidean Distance, suggesting water quality was becoming more similar to "baseline" (Figure 12). In Mar-Two, wet season water quality remained relatively consistent, but with a decrease in similarity between 2012 and 2014 (Figure 12). This recent difference in water quality of Mar-Two was likely due to the change in dewatering discharge operations, with discharge primarily occurring from D09 and resulting in increased total nitrogen, manganese, dissolved boron and reductions in dissolved copper in this reach.

Figure 12. Temporal consistency in similarity (distance to centroid, PERMANOVA) between water quality data from initial sampling (2008 in the dry season, 2009 in the wet season) and subsequent sampling events. Distance values are based on Euclidean distance.

3.3 Habitat and substrate characteristics

3.3.1 Dry-13 and Wet-14

Substrate characteristics

The substrates of Marillana and lower Weeli Wolli creeks were comprised mainly of coarser rock types, such as cobbles, pebbles and gravel. Pebbles were the dominant substrate character among all three reaches, particularly in the dry-13 (Figure 13). Although still highly represented during the wet season, the cover by pebbles was supplemented by increased sand, silt and clay at some sites (Figure 13). At WW-Five, this may be related to the use of Gray's Crossing as a haul road by another mining company prior to wet season sampling, and also to the flushing of finer substrates into the system following wet season rains. At Marillana Creek, mining and development at Yandicoogina may have influenced substrate composition, with increased sand, silt and clay cover recorded at Mar-One sites located near haul road and mine pit activity (Figure 13).

Habitat characteristics

In both seasons, mineral substrate was the main in-stream habitat type recorded from all three reaches (Figure 14). Submerged macrophyte was more prominent in the dry-13, particularly at MAR1-3, MAR2-5, MAR2-9 and WW5-3, which were all highly receded pools at the time. Pools such as these allow for high light penetration and subsequent macrophyte growth. Algal cover was generally higher during the wet-14 at MAR1-3, MAR2-9, and particularly at WW5-4, where algae accounted for up to 75% of in-stream habitat (Figure 14).

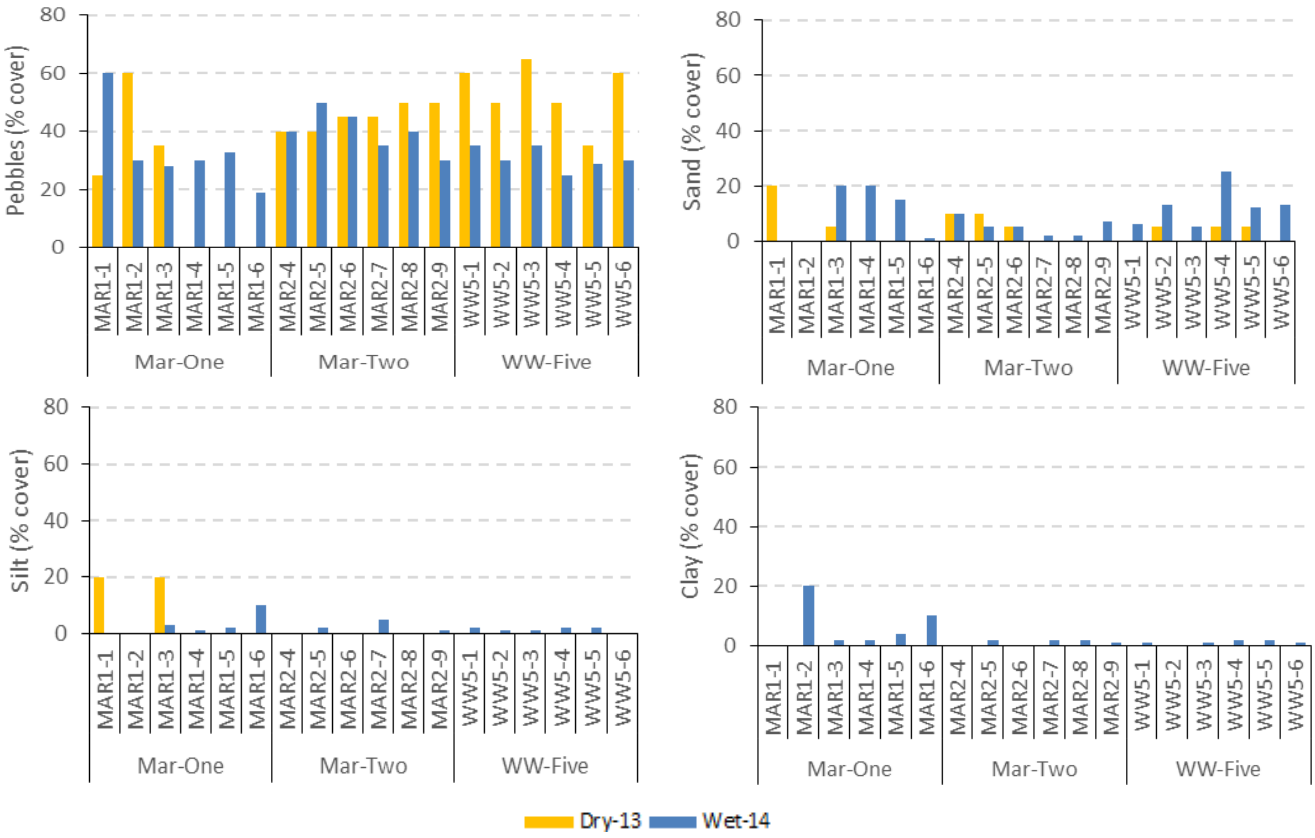


Figure 13. Percent (%) cover of pebbles, sand, silt and clay from Marillana and lower Weeli Wolli Creeks.

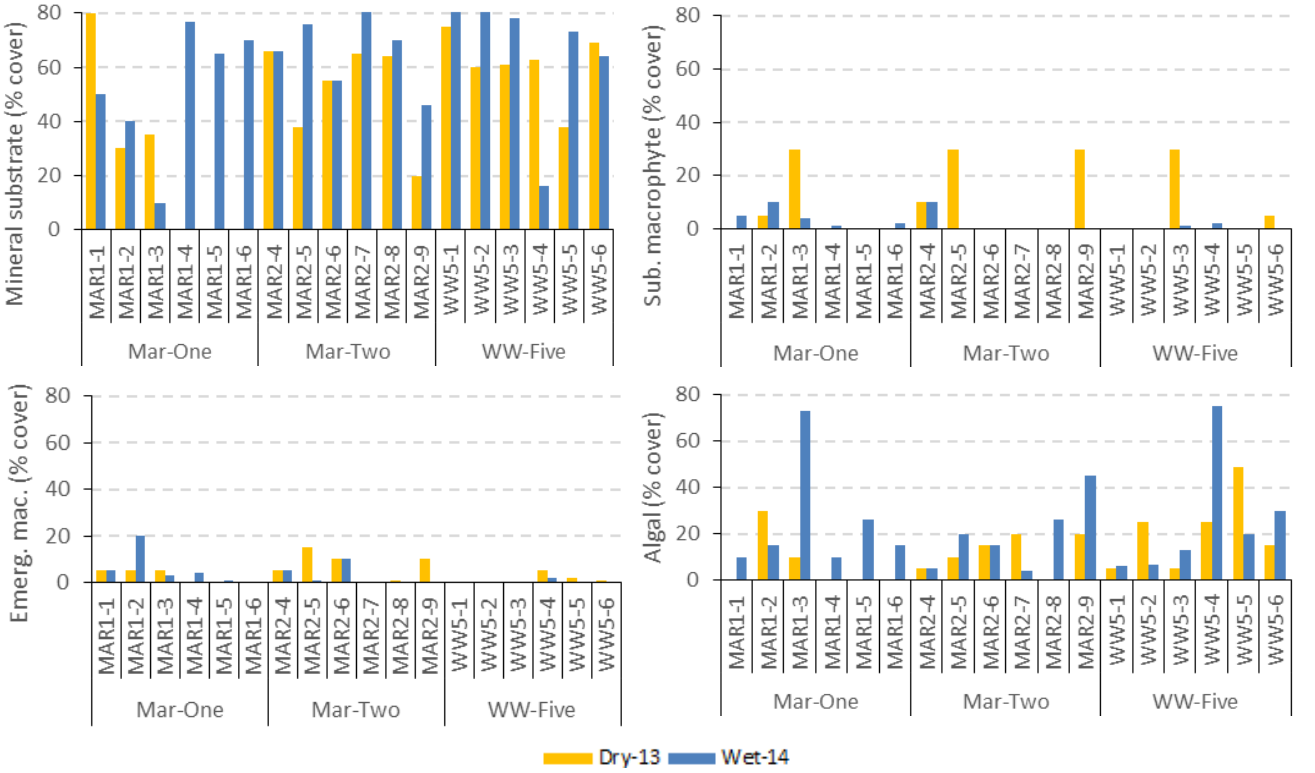


Figure 14. Percent (%) cover of various habitat characteristics of Marillana and lower Weeli Wolli Creeks.

Habitat diversity (number of different habitat types) was generally higher during the wet season, particularly at WW-Five sites, due to a greater area of creek being inundated. Within Mar-Two, there appeared to be a longitudinal gradient of habitat diversity downstream of MAR2-4, with diversity generally decreasing with distance downstream of the D09 discharge outlet (Figure 15). This is likely a reflection of the additional water inundating a greater areal extent of creekline, thus increasing habitat availability and heterogeneity.

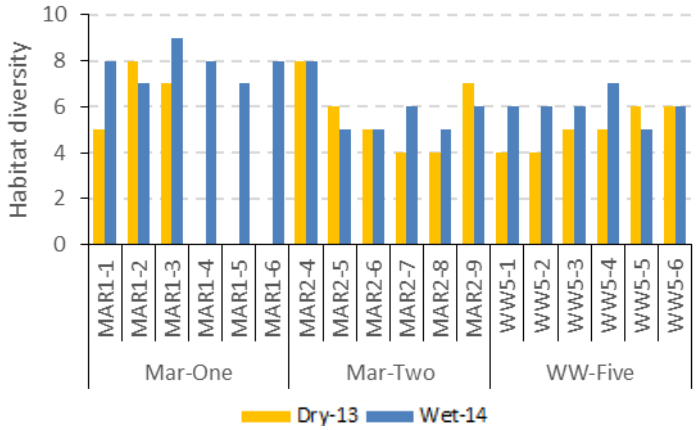


Figure 15. Overall habitat diversity (number of habitat types) of Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14.

3.3.2 Change over time and comparisons with Weeli Wolli Creek

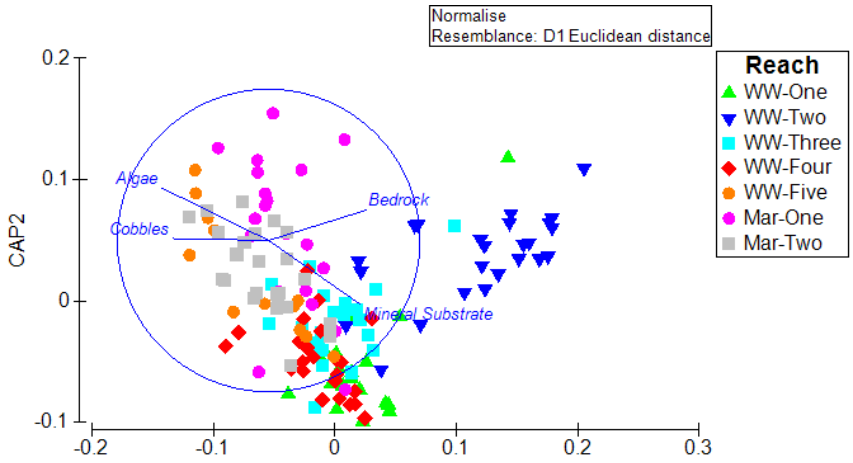
Significant patterns were evident in the CAP ordination examining differences in substrate and habitat composition between reach in the dry season (p = 0.001). The strength of correlations was reasonably high: 0.85 along CAP axis 1, and 0.70 along CAP axis 2. The majority of sites from WW-Two, as well as one site from WW-One (WW1-6) and one site from WW-Three (WW3-1) separated from all others, based on a higher percentage cover of bedrock, as well as greater cover by mineral substrates (Figure 16). The greater bedrock cover at these sites was due to the formation of a calcite precipitate in Weeli Wolli Creek, downstream of the HD1 gabion discharge point[9]. This was first observed during sampling in October 2009, and has since been progressing further downstream, well into WW-Three (WRM 2014b). There was some separation of Mar-One, Mar-Two, and WW-Five sites along CAP2, based on higher percentage cover of algae and cobbles, while mineral substrates influenced the separation of WW-One, Three and Four sites (Figure 16).

Significant patterns were also evident in the CAP ordination between reach in the wet season (p = 0.001), though correlations were not as strong as those of the dry season (0.84 along CAP 1, and 0.60 along CAP 2). The majority of WW-Two sites were again separated from other sites along CAP 1 due to coverage of bedrock (in the form of calcite precipitate), and also by a greater coverage of trailing vegetation (Figure 16). There was a high degree of overlap between Marillana Creek sites and remaining Weeli Wolli Creek sites, indicating increased similarities in habitat and substrate characteristics between these reaches during the wet season (Figure 16).

There was a significant difference in overall habitat and substrate characteristics between reach (df = 6, p = 0.001) and year (df = 3, p = 0.001) in the dry season. There was also a significant difference in habitat and substrate characteristics between reach (df = 6, *p* = 0.001) and year (df = 4, *p* = 0.001) during the wet (Table 4).

[9] For the purposes of making spatial and temporal comparisons the calcite armour was classified as 'bedrock' substrate, given that the armouring of the creek bed creates similar in-stream habitat to bedrock in terms of heterogeneity and diversity.

DRY



WET

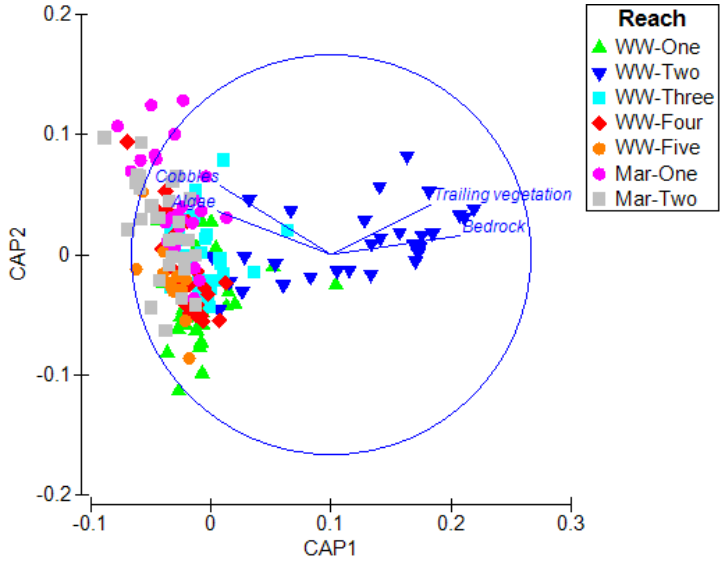


Figure 16. Constrained CAP plots of substrate and habitat data between reach in the dry (top) and wet seasons (bottom), with vectors of Spearman rank correlations overlain (correlation >0.5).

Table 4. Two-factor PERMANOVA comparing habitat and substrate composition between reach and year in the dry and wet seasons.

Dry Season	*df*	*MS*	*Pseudo-F*	*p*
Reach	6	93.53	8.765	0.001
Year	3	66.538	6.238	0.001
Reach*Year	16	15.263	1.430	0.002
Residual	125	10.67		
Total	150			
Wet Season	***df***	***MS***	***Pseudo-F***	***p***
Reach	6	95.126	8.823	0.001
Year	4	70.871	6.565	0.001
Reach*Year	22	20.048	1.857	0.001
Residual	155	10.795		
Total	187			

Figure 17 provides a graphic summary of dry and wet season temporal similarity in habitat and sediment characteristics between 2010 (initial "baseline" year) and subsequent sampling events. The dry season plot indicates a decreasing similarity (increased Euclidean Distance) in sediment and habitat characteristics over time in both reaches (Figure 17). Comparatively, the similarity of habitat characteristics in the wet season (compared to 2010) remained relatively consistent over time in Mar-One, after the initial change between 2010 and 2011 which was quite considerable (Figure 17). In Mar-Two, there was a decrease in similarity in wet season habitat (increasing Euclidean Distance) between 2011 and 2012, and again between 2013 and 2014 (Figure 17). The change in habitat in Mar-Two following the commencement of discharge from the JSW operations (i.e. between 2013 and 2014) was less than the change which occurred previously (between 2011 and 2012), prior to the commissioning of JSW.

Figure 17. Temporal consistency in similarity (distance to centroid, PERMANOVA) between habitat characteristics in 2010 and subsequent sampling events. Distance values are based on Euclidean distance.

3.4 Microinvertebrates

3.4.1 Taxonomic composition and species richness

A total of 110 microinvertebrate taxa were recorded from Marillana Creek and 83 taxa from lower Weeli Wolli Creek (WW-Five) during the current study. The microinvertebrate fauna comprised Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp).

The greatest number of microinvertebrate taxa was recorded from the Mar-Two in the wet-14, and the least recorded from Mar-One in the dry-13 (Table 5). However, the number of sites sampled from each was not the same between seasons, as three sites were dry in Mar-One during the dry-13. As such, the lower microinvertebrate taxa richness recorded from this reach may have been due to the lower number of sites successfully sampled at the time. The high number of microinvertebrate taxa recorded from Mar-Two during the wet-14 was almost entirely due to the high diversity recorded from MAR2-6 (45 taxa) as MAR2-5 recorded only one taxa at this time (Figure 18).

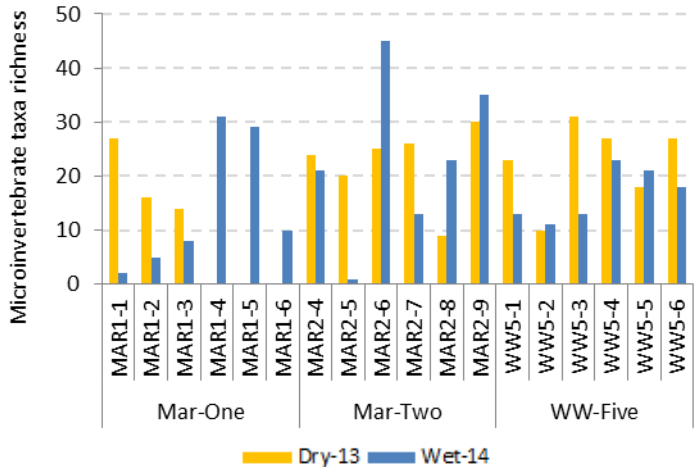


Figure 18. Number of microinvertebrate taxa recorded from each site in the dry-13 and wet-14.

Table 5. Total number of microinvertebrate taxa recorded from each reach during the dry-13 and wet-14.

	Total no. micro taxa	
Reach	**Dry-13**	**Wet-14**
Mar-One	36	46
Mar-Two	54	75
WW-Five	57	48

3.4.2 Conservation significance of microinvertebrates

The majority of microinvertebrate taxa recorded during the current study were common ubiquitous species, with distributions extending throughout Australasia or the world (cosmopolitan species). Of interest within the microinvertebrate fauna was the collection of species endemic to the Pilbara, Western Australia and/or taxa known to be rare or uncommon throughout their range. Such taxa included the rotifers *Lecane noobijupi*, *Lindia torulosa* and *Heterolepadella heterostyla*, and the Copepoda *Australoeucyclops karaytugi.*

The rotifer *Lecane noobijupi* is known only from Western Australia, and appears to have a disjunct distribution. It was described from specimens collected from a wetland in the Muir-Unicup catchment in the south-west of the state (Noobijup Swamp) and it had been thought to be restricted to that catchment (Segers and Shiel 2003). However, the authors have since recorded *Lecane noobijupi* from a number of systems in the Pilbara region, including Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek, Kalgan Creek, Un-named Creek, Hardey River, Beasley River, Caves Creek, Duck Creek and Boolgeeda Creek (WRM, unpub, data), as well as the DeGrey River by DPaW (Pinder *et al.* 2010). It would now appear that the Pilbara may be the normal locality of this species, and the Muir location in the south-west was an isolated occurrence. During the current study, *Lecane noobijupi* was recorded from MAR1-4, MAR1-5, MAR2-8, WW5-4 and WW5-6.

Two rotifers recorded during the current study are species known to be rarely encountered/collected in Australia; *Lindia torulosa* and *Heterolepadella heterostyla*. *Lindia torulosa* has a cosmopolitan distribution but is uncommon in Australia. It has been recorded previously by the authors from Weeli Wolli Creek, Fortescue Falls, Bamboo Spring and the Coondiner Pool claypan (WRM unpub. data). It was not recorded during the PBS (Pinder *et al*. 2010). During the current study *L. torulosa* was recorded from MAR1-3, MAR1-4, MAR2-5, MAR2-6 and WW5-4. *Heterolepadella heterostyla* is thought to have a cosmopolitan distribution, but is uncommon/rarely collected. It is a littoral species and is usually recorded in stagnant waters. During the current study it was recorded from MAR2-9.

As well as Marillana and Weeli Wolli creeks, *H. heterostyla* is also known from Mindy Mindy Creek in the Pilbara (WRM unpub. data).

The Australian endemic cyclopoid copepod *Mesocyclops notius*, was recorded from MAR1-1, MAR1-4 and MAR2-9 during the current study. This species is previously known from the Lake Eyre Basin (Shiel *et al.* 2006), Lake Merrimajeel in the Murray-Darling (Cromel and Carpenter 1988), Mount Isa in Queensland (Hołyńska and Brown 2002), Lake Gregory in the Kimberley, W.A. (Hołyńska and Brown 2002), and the Fortescue Marsh in the Pilbara (Hołyńska and Brown 2002). It has also been previously collected by the authors from a reference site on Weeli Wolli Creek immediately upstream of HD1 (WRM unpub. data).

The copepod *Australoeucyclops karaytugi* is endemic to the Pilbara. Within the region, it is known from Weeli Wolli Spring, as well as other spring systems including Palm Springs (Caves Creek), Bamboo Springs (DeGrey) and Skull Springs (DeGrey), and the permanent pools Coppin Gap (DeGrey), Glen Herring Pool (DeGrey), Wannagunna Pool (Ashburton), Horrigan's Pool (Ashburton), and Pool on Billan Ballan (Yule). It was recorded from MAR1-5 during the current study.

These taxa have been consistently recorded from Marillana Creek since aquatic fauna surveys began in 2008. Other microinvertebrate taxa of significance which have been recorded from Marillana Creek previously, but were not recorded during the current study included *Lecane battilifer*, *Lecane latissima*, *Lecane rhenana*, *Proales micropus* and *Lepadella ptyerygoida*. Of these, the three Lecane rotifers are rare or uncommon throughout their range. The collection of the rotifer *Proales micropus* from MAR1-3 during the dry-10 constituted the first record of this species from Western Australia and perhaps only the second record within Australia. The collection of the rotifer *Lepadella ptyerygoida* from MAR2-1 during the wet-10 constituted the first record of the species in Australia. *Lepadella ptyerygoida* is very rare and previously known from North and South America and the Oriental region (Dr Russ Shiel, University of Adelaide, pers. comm.). The collection of new records and/or species of Rotifer is not unheard of in the Pilbara, as historically, aquatic microfauna have been less sampled across this region than either macroinvertebrates or fish. It is likely all these rotifer species are still present within Marillana Creek, but have simply not been collected in more recent sampling events. Microfauna are cued to natural cycles, with emergence from resting stages dependent on the cues to which they are 'tuned', such as day-length, chemistry, temperature, algal exudates or prey hormones. The speed of these species replacements can be in hours or days (cf. Tan and Shiel 1993, for billabong microfauna in eastern Australia), and as such, may not be timed with our sampling events within the creek. In addition, microfauna tend to be highly spatially patchy.

3.4.3 Spatial and temporal change in microinvertebrates

Taxa richness

During the dry season, there was a significant difference in microinvertebrate richness between year ($df = 5$, $p = 0.013$), but not between reach ($df = 2$, $p = 0.808$; Table 6). Microinvertebrate richness was highest in 2013 (21.80), though this was statistically similar to that recorded in 2010 and 2012. There was no significant difference in microinvertebrate taxa richness between reach ($df = 2$, $p = 0.103$) or year ($df = 5$, $p = 0.093$) during the wet season (Table 6). Regression and Spearman Rank Correlation analyses indicated that there was no significant change in microinvertebrate taxa richness over time for either reach in either season, i.e. no consistent increase or decrease in taxa richness (Figure 19). This suggests that the discharge operations at Yandicoogina have not adversely impacted the microinvertebrate taxa richness of the downstream Marillana Creek environment over time.

Table 6. Two-way ANOVA results comparing microinvertebrate taxa richness between reach and year, for each season. Degrees of freedom, mean squares and p-values are shown. Tukey's *post-hoc* results are presented in ascending order of mean microinvertebrate taxa richness, with groups with no difference in means joined by a black line.

Dry season									
Source	***df***	***MS***	***p***	**Tukey's *post-hoc***					
Reach	2	14.22	0.808	**Mar-Two**	**Mar-One**	**WW-Five**			
Year	5	208.80	0.013	**2011**	**2008**	**2009**	**2010**	**2012**	**2013**
Reach*Year	6	46.79	0.649						
Total	81								
Corrected Total	80								
Wet season									
Source	***df***	***MS***	***p***	**Tukey's *post-hoc***					
Reach	2	256.92	0.103	**Mar-One**	**Mar-Two**	**WW-Five**			
Year	5	216.47	0.093	**2009**	**2013**	**2011**	**2012**	**2014**	**2010**
Reach*Year	7	168.02	0.171						
Total	79								
Corrected Total	78								

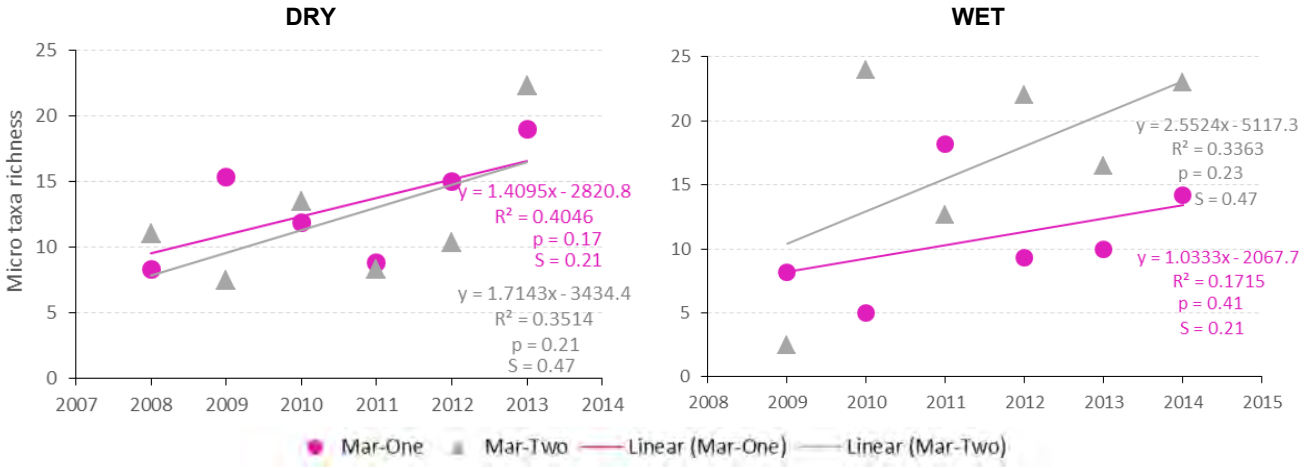


Figure 19. Linear regression plots of mean microinvertebrate taxa richness against time for Marillana Reaches One and Two in the dry season (left) and wet season (right). Equations, p-values, Spearman correlation co-efficient (S) and R^2 values are displayed.

Comparisons with Weeli Wolli Creek

Incorporating all Weeli Wolli Creek and Marillana Creek zooplankton abundance data into the analyses, some patterns were evident in the dry season constrained CAP plot examining differences between reach (Figure 20). The strength of the association between the data cloud and hypothesis of differences in reach was reasonably good, with a correlation of 0.74 along CAP axis 1, and 0.65 along CAP axis 2. Generally, there was some separation of samples amongst reaches, but with considerable overlap (Figure 20). Weeli Wolli Creek microinvertebrate samples from reaches One to Four tended to separate from the Marillana Creek and WW-Five samples along CAP1. This suggests

the microinvertebrate assemblages of WW-Five are more similar to Marillana Creek, than upper Weeli Wolli Creek. Spearman Correlation indicated that the separation of Marillana Creek and Weeli Wolli Creek was influenced by higher abundances of cyclopoid copepodites and nauplii, and small and medium sized indeterminate bdelloid rotifers from Marillana Creek.

Similar patterns were evident in the wet season, however, there was a greater separation of microinvertebrate samples by reach (Figure 20). WW-One separated from other Weeli Wolli Creek reaches along CAP1, and there was a greater separation of Mar-One from Mar-Two and WW-Five along CAP2 during the wet.

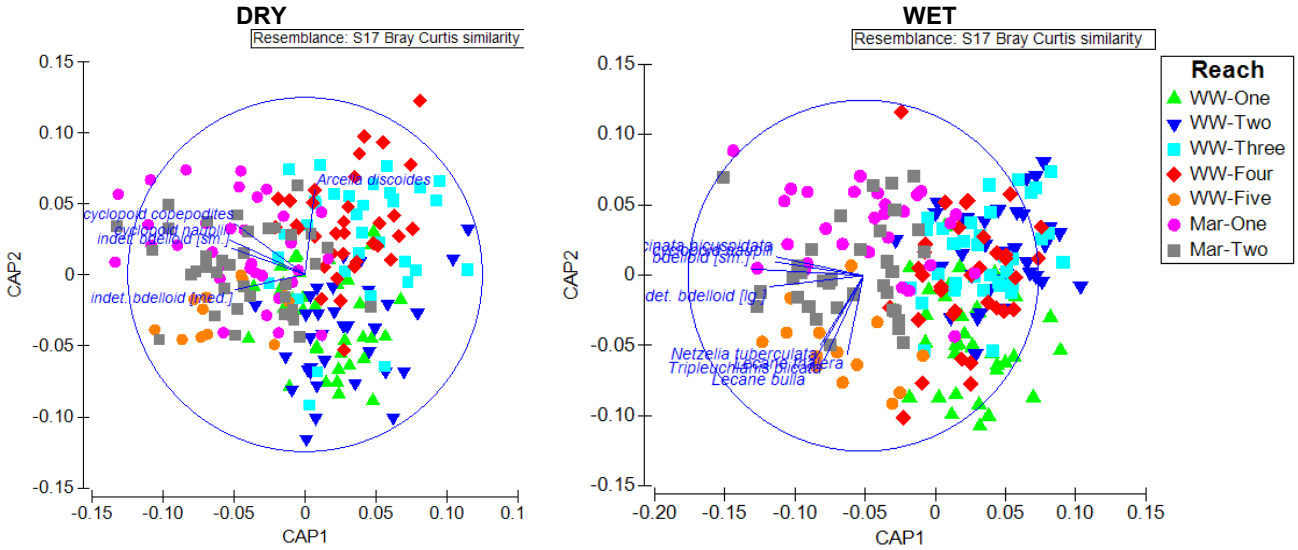


Figure 20. Constrained CAP plot of microinvertebrate abundance data between reaches in the dry season (left) and wet season (right), with vectors of Spearman rank correlations overlain (correlation >0.5).

PERMANOVA testing indicated that there was a significant difference in microinvertebrate assemblages between reach (df = 6, p < 0.001) and year (df = 5, p < 0.001) during the dry season. There was also a significant difference between reach (df = 6, p < 0.001) and year (df = 5, p < 0.001) during the wet season (Table 7). This indicates that the microinvertebrate assemblages of Marillana and lower Weeli Wolli Creek are different between reach irrespective of season, but do change temporally. Post-hoc analyses indicated that during the dry season, there was no significant difference in microinvertebrate assemblages between WW-Five and Mar-Two, nor between Mar-One and Mar-Two. However, during the wet season, the greater separation of samples meant that all Marillana Creek and lower Weeli Wolli Creek reaches were significantly different from one another.

Table 7. Two-factor PERMANOVA results for dry and wet season data, comparing microinvertebrate assemblages (log_{10} abundance data) between reach and year.

Dry Season	df	MS	Pseudo-F	p
Reach	6	9251.1	3.08	<0.001
Year	5	9588.0	3.20	<0.001
Reach*Year	26	4559.9	1.52	<0.001
Residual	181	3000.0		
Total	218			
Wet Season	**df**	**MS**	**Pseudo-F**	**p**
Reach	6	10445	3.52	<0.001
Year	5	12192.0	4.11	<0.001
Reach*Year	27	4547.6	1.53	<0.001
Residual	181	2965.7		
Total	219			

There was generally no correlation between microinvertebrate assemblages and water quality characteristics in either season (dry season BVSTEP; Rho = 0.20; wet season BVSTEP; Rho = 0.28). However, water quality variables which were found to have the greatest influence on the dry season microinvertebrate assemblages were water temperature, alkalinity, and concentrations of potassium, bicarbonate, barium, manganese and zinc. In the wet season, water quality variables showing the greatest influence on the microinvertebrate assemblages included alkalinity, hardness, and concentrations of calcium and sodium.

Change over time was examined using Bray-Curtis similarity between initial "baseline" sampling and each subsequent year. There was a slight increase in similarity of dry season microinvertebrate assemblages over time in both Marillana Creek reaches, suggesting that after a slight initial change, assemblages are becoming more similar to what they were during initial "baseline" sampling in 2008 (Figure 21). Overall, a ~16% increase in similarity occurred between 2009 and 2013 in both reaches. In contrast, there was a reduction in similarity of microinvertebrate assemblages during the dry season up until 2011 in both reaches. This constituted a ~44.4% and 46.6% change in microinvertebrate assemblages in Mar-One and Mar-Two, respectively, between 2009 and 2011 prior to JSW (and Oxbow) commissioning (Figure 21). Since this initial change, wet season microinvertebrate assemblages have remained relatively consistent over time in both reaches (Figure 21).

Figure 21. Temporal consistency in similarity (distance to centroid, PERMANOVA) between microinvertebrate assemblage data from initial sampling (2008 in the dry season, 2009 in the wet season) and subsequent sampling events. Values are based on percent similarity derived from Bray-Cutis similarity matrices.

3.5 Hyporheic fauna

3.5.1 Taxonomic composition and species richness

A total of 106 taxa were recorded from hyporheic samples collected along Marillana Creek and lower Weeli Wolli Creek during the dry-13, and 73 taxa in the wet-14 (Appendix 6). The vast majority of taxa recorded from the hyporheic zone in the dry season were classified as stygoxene (63%) and do not have specialised adaptations for groundwater habitats. However, 15% of the dry season taxa were classified as occasional hyporheos stygophiles, 9% were stygobites[10], and 10% were possible

[10] A stygobite is an aquatic animal that is restricted to groundwater and/or hyporheic environments (i.e. stygofauna). They have adaptations to survive such conditions, including elongated appendages and antennas, no eyes, and a lack of pigmentation.

hyporheic taxa. A taxa considered to be troglobite[11] (Myriapoda spp.) was also recorded from the hyporheic zone in the dry-13. Of the taxa recorded during the wet season, most were stygoxene taxa (56%), with 39% being considered hyporheos fauna[12] (16% occasional hyporheos stygophiles, 11% stygobites, and 12% possible hyporheic taxa). Stygobites were recorded from all sites during the dry-13, with the exception of MAR2-7 and WW5-6 (Figure 22). During the wet-14, stygobites were recorded from all sites except MAR1-5 (Figure 22). Generally, greater numbers of taxa hyporheos fauna were recorded from Mar-Two and lower Weeli Wolli Creek (WW-Five), however, less sites were successfully sampled in Mar-One. MAR1-5 did not support any taxa considered to be restricted to the hyporheic zone (Figure 22).

Classifications followed those of Boulton (2001), however, this type of analysis should be treated with some caution as results are likely affected by available information on life history, taxonomic resolution, and interpretation of classification categories.

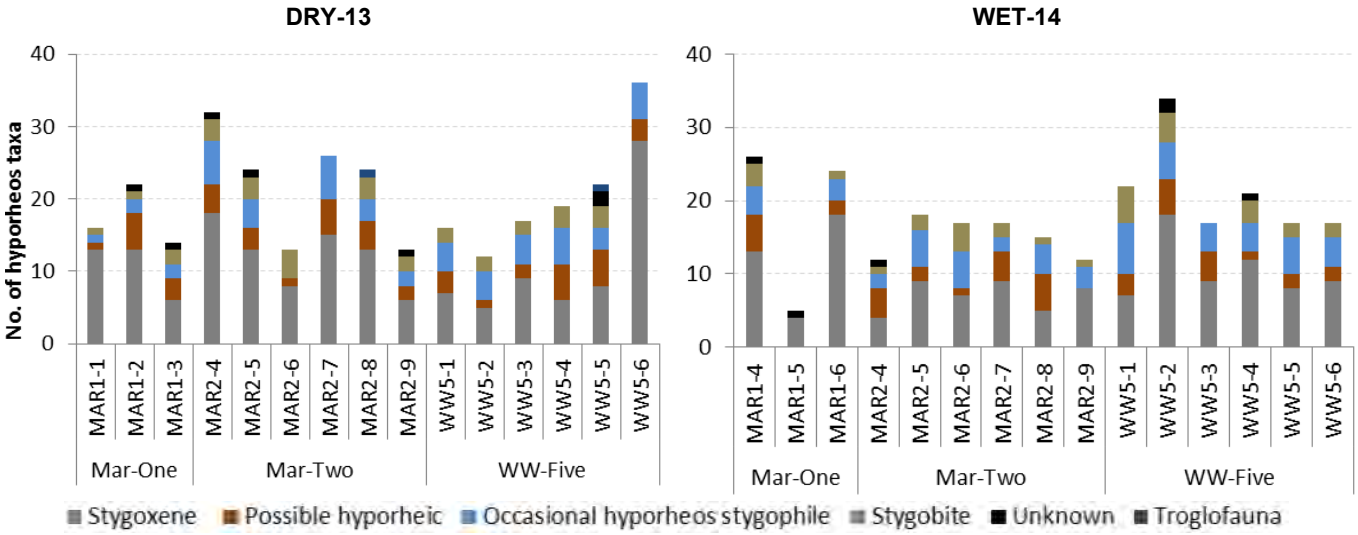


Figure 22. Proportion of taxa from each hyporheic classification category, showing data collected from each site in the dry season (left) and wet season (right).

3.5.2 Hyporheos taxa

Species considered to be restricted to the hyporheos included; the stygobitic amphipods *Chydaekata* sp., Paramelitidae sp. D, Paramelitidae sp. B, *Maarrka weeliwolli* and Paramelitidae spp. (damaged or immature; not possible to positively identify further than family); stygobitic copepod *Parastenocaris* sp.; stygobitic ostracods *Gomphodella* n. sp. (BOS334), juvenile *Vestalenula*, *Candonopsis* cf. *pilbarae* and juvenile *Pilbaracandona*; occasional hyporheos stygophiles including the oligochaetes *Allonais paraguayensis*, *Allonais pectinata*, *Nais communis*, *Pristina aequiseta*, *Pristina longiseta* and *Pristina* nr *sima*, copepods *Australoeucyclops karaytugi*, *Mesocyclops holynskae* and *Microcyclops varicans*, Collembolla Entomobryoidea spp., Poduroidea spp. and Symphypleona spp., Coleoptera *Limbodessus occidentalis*, *Austrolimnius* sp. (L), *Hydraena* sp., *Hydraena* sp. (L), *Limnebius* sp., *Ochthebius* sp., and Scirtidae spp. (L); and possible hyporheics including Nematoda spp., oligochaetes Oligochaeta spp. (imm./dam.), Naidinae spp. (imm.), *Pristina* sp. and Phreodrilidae spp. (imm.), cyclopoid copepodites and *Mesocyclops* sp., indeterminate cypridopsid ostracod, water mites Hydracarina spp. and Trombidioidea spp., immature and/or damaged baetid mayflies, and chironomid *?Pentanuera* sp.

[11] A troglobite is a terrestrial animal which lives entirely in the dark within cave systems or underground within fissures in bedrock. Similar to stygobites (stygofauna) they have adaptations to survive such conditions, including long antennas, no eyes, and a lack of pigmentation. The word 'troglo' means hole.

[12] Hyporheos fauna – animals restricted to hyporheic environments.

All stygobitic amphipods were identified by WRM using a morphological key designed by Helix (2011). However, a number of specimens were unable to be definitively identified to species-level using external morphology due to damage or immaturity. Such specimens have been referred to as Paramelitidae spp. (imm./dam.) here.

Paramelitidae sp. D (also referred to as Paramelitidae Genus 2 sp. B3 by a different environmental consultancy[13]) and Paramelitidae sp. B (also referred to as Paramelitidae Genus 2 sp. B2 by a different environmental consultancy[13]) are both currently undescribed species that appear to be restricted to Weeli Wolli Creek, Marillana Creek (WRM unpub. data; Helix 2010a, b, Helix 2011) and the Coondewanna Flats Catchment (Stuart Halse, Bennelongia, pers comm.). This suggests they are both short range endemics as defined by Harvey (2002)[14], and therefore of high conservation significance. During the current study, Paramelitidae sp. D was recorded from MAR2-6, MAR2-8 and WW5-2. Paramelitidae sp. B was more commonly recorded and widely distributed along lower Marillana Creek and Weeli Wolli Creeks being recorded from all WW-Five sites and all Mar-Two sites except MAR2-4 (Appendix 6). Neither species was recorded from the upper Marillana Creek reach (Mar-One) during the current study.

Chydaekata sp. is also an undescribed SRE. It is known from a small number of systems in close proximity; Weeli Wolli Creek, Marillana Creek, Coondiner Creek and Mindy Mindy Creek (Helix 2010a, Helix 2011, WRM unpub. data). During the current study it was recorded from MAR1-3, MAR2-6, WW5-1 and WW5-2.

The stygobitic amphipod *Maarrka weeliwolli* is also an SRE and has previously been recorded from multiple bores at Weeli Wolli and Marillana creeks (Finston *et al.* 2011). It appears to be restricted to these two creeklines. *Maarrka weeliwolli* appears to be less commonly recorded than the other three species of stygobitic SRE amphipods (WRM unpub. data). During the current study, *M. weeliwolli* was recorded from MAR2-5, WW5-1 and WW5-4.

Specimens of the harpacticoid genera *Parastenocaris* recorded from the hyporheic zone of MAR1-4 during the wet-14 were immature and not able to be accurately identify to species. As there is only one known described species of *Parastenocaris* known from the Pilbara, *Parastenocaris jane*, the specimens collected from Marillana Creek were named *Parastenocaris* cf. *jane* for the purposes of the current study. *Parastenocaris jane* is endemic to the Pilbara and known from bores at Paraburdoo, Turee Creek, Newman Airport, BHPBIO's OB25, BHPBIO's OB23, Homestead Creek and the Cane River (Karanovic 2006). However, morphologically distinct *Parastenocaris* specimens have been previously recorded from the Pilbara by the authors (from Skull Springs on the Davis River and Wanna Munna Up on Weeli Wolli Creek) which did not match the described *Parastenocaris jane* (WRM unpub. data). As such, it is not possible to determine whether the specimens recorded from MAR1-4 belong to the described species or a similar species likely new to science.

Four species of stygobitic ostracod were recorded from hyporheic zones; *Gomphodella* n. sp. (BOS334), *Vestalenula* sp., *Candonopsis* cf. *pilbarae* and *Pilbaracandona* sp. *Gomphodella* n. sp. (BOS334) is an undescribed species new to science. The species appears similar to described species such as *G. glomerosa* and *G. hirsuta*, but differs in that it has no ventral stria, is dorso-ventrally compressed and has a different shaped hemipenis (Dr Russ Shiel, University of Adelaide, pers. comm.). During the current study *Gomphodella* n. sp. (BOS334) was recorded from MAR1-4, MAR1-6, MAR2-6 and WW5-2. This is not the first record of the new species. It has previously been recorded from bores in the Yandi area (Dr Stuart Halse, Bennelongia, pers. comm.), as well as from

[13] Bennelongia morphotype name.
[14] Short range endemic as defined by Harvey (2002): a species occupying an area of less than 10, 000 km^2.

hyporheic zones on Marillana (MAR1-2, MAR1-3, MAR1-6, MAR2-4) and Weeli Wolli creeks (WW2-6, WW5-2 and WW5-5) (WRM unpub. data). *Gomphodella* n. sp. (BOS334) appears to be a short range endemic restricted to Marillana and Weeli Wolli creeks, and as such is a species of high conservation significance. Several *Gomphodella* species are known only from one locality and are commonly found in springs (Karanovic 2006, Reeves *et al.* 2007).

Candonopsis cf. *pilbarae* was recorded from the hyporheic sample of WW5-5 during the dry-13. The specimen was immature, and as such, the species-level identification could not be made with certainty. *Candonopsis pilbarae* is a stygobitic ostracod endemic to the Pilbara region. It is previously known from the DeGrey River and Ashburton River catchments. The collection from WW5-5 constitutes the first record of this species from the Weeli Wolli Creek catchment. Karanovic (2007) did suggest that *C. pilbarae* was likely more widely distributed than current records indicated (DeGrey and Ashburton catchments only) but that it is not a common species.

Juveniles of the stygobitic ostracod genera *Vestalenula* and *Pilbaracandona* were recorded from hyporheic zones during the current study. The *Vestalenula* sp. may be either *V. maltidae* or *V. marmonieri*, but it is not possible to identify juveniles and damaged specimens to species. *V. matildae* is endemic to the Pilbara and currently known only from the Ashburton and Weeli Wolli Creek catchments (Martens and Rossetti 2002, Halse *et al.* 2002). *Vestalenula marmonieri*, however, is also known from New Caledonia (Rossetti and Martens 1999). During the current study, stygobitic juvenile *Vestalenula* were recorded from hyporheic zone of MAR2-4. Six species of *Pilbaracandona* are currently known from the Pilbara, some of which appear to be widely distributed throughout the region and some of which are restricted to one locality, i.e. *Pilbaracandona rhabdote* is known only from the Fortescue Marsh (Karanovic 2007). Juvenile *Pilbaracandona* were recorded from MAR2-4 and WW5-1 hyporheic zones.

The oligochaetes *Allonais paraguayensis*, *Allonais pectinata*, *Nais communis*, *Pristina aequiseta*, *Pristina longiseta* and *Pristina* nr *sima* were all considered to be occasional hyporheos stygophiles. This is because they are known from Pilbara groundwaters, but are not exclusively restricted to the hyporheic zone. All species are widely distributed and have either an Australasian or cosmopolitan distribution, with the exception of *Pristina* nr *sima*. The specimens recorded from the hyporheic zones of MAR2-4 and WW5-4 did not match any currently described species but were closest to *P. sima*. The described species is known only from the south-west of Western Australia from Kalbarri in the north, southeast to Esperance. *Pristina* nr *sima* was also recorded by DPaW during the Pilbara Biological Survey from Chinaman Spring on the DeGrey River (Pinder *et al*. 2010). It is possible that this is a new species to science known only from the Pilbara. Most other oligochaetes collected from hyporheic zones were considered possible hyporheic taxa, except *Pristina leidyi* and *Pristina jenkinae* which are known surface water species (i.e. stygoxene). While most groundwater oligochaetes in Western Australia appear to have fairly widespread distributions, knowledge on the taxonomy and distribution of many groups is limited. Oligochaetes are considered likely to have greater subterranean dispersal capacities than other stygofaunal groups due to their vermiform shape and burrowing capabilities. Occasional hyporheos stygophile and possible hyporheic oligochaetes were recorded from the majority of sites sampled.

Three copepod species considered to be occasional hyporheos stygophiles were recorded from hyporheic samples during the current study. These were *Australoeucyclops karaytugi*, *Microcyclops varicans* and *Mesocyclops holynskae.* These species have all been recorded from Marillana and lower Weeli Wolli Creek hyporheic zones previously (WRM unpub. data). *Australoeucyclops karaytugi* is endemic to the Pilbara region, and is known from springs and surface water pools. During the current study it was recorded from the hyporheic zones of MAR1-2 and MAR1-6. *Microcyclops varicans* has been collected widely from surface waters, as well as groundwater environments including deep bores and hyporheic zone samples (Martens and Rossetti 2002, Halse *et al.* 2002, DEC

2009). It was recorded from all sites sampled during the current study, with the exception of MAR1-5. *Mesocyclops holynskae* is restricted to the Pilbara, but appears to have a disjunct distribution, being known from Weeli Wolli Creek, Mulga Downs Station and Pardoo (Karanovic 2006, Ecowise 2007). During the current study, it was recorded from lower Weeli Wolli Creek only (WW5-1 and WW5-4).

The dytiscid beetle *Limbodessus occidentalis*[15]was classified as an occasional hyporheos stygophile as this species is known from both epigean[16] and stygal habitats. This species is one of several diving beetle species recently found to inhabit groundwater calcrete formations across inland Western Australia (Watts and Humphreys 2006). Most individual calcrete aquifers contain an assemblage of diving beetle species, which also frequent surface waters and hyporheic zones connected to the aquifers (Leys *et al*. 2003, Watts and Humphreys 2006). Elsewhere in the Pilbara, *L. occidentalis* has been recorded from calcrete aquifers at Killara North (approximately 300 km south of Weeli Wolli Creek) and Moorarie (around 125 km west of Killara), and from surface waters and hyporheic habitats of the Fortescue River system (Weeli Wolli Spring, Gregory Gorge, Joffre Creek), the Ashburton River (Creek Pool near Mt Amy, Beasley River, Caves Creek, Duck Creek), the Robe River (Red Hill Creek pools) and the Harding River (Watts and Humphreys 2004, Pinder *et al.* 2010, WRM unpub. data). *Limbodessus occidentalis* specimens are most commonly collected from the edge of pools in sandy and gravelly riverbeds (Watts and Humphreys 2004). *L. occidentalis* was recorded from the hyporheic zone of MAR2-5, WW5-1, WW5-2, WW5-4 and WW5-6.

One of the chironomid species recorded from hyporheic samples was considered to be a possible hyporheic species, the Tanypodinae ?*Pentaneura* sp. This species is currently undescribed and appears to have a highly disjunct distribution in the Pilbara, being known from Weeli Wolli Creek, Marillana Creek, upper Fortescue River, Fortescue River South, Caves Creek (Palm Spring), as well as within the Robe River and DeGrey River catchments (WRM unpub. data). It was considered likely to be a hyporheic species due to its small size (they are at least half the size of other Tanyponids) and characteristic reduced eye (Dr Don Edward, The University of Western Australia, pers. comm.). During the current study, ?*Pentaneura* sp. was collected from the hyporheic sample of MAR2-9.

3.5.3 Temporal changes in hyporheos fauna

Taxa richness

The average number of hyporheos[17] taxa (using standardised, amalgamated taxonomy) collected from Marillana Creek during the dry season generally appeared to have increased over time in both reaches to 2012, with a considerable decrease in 2013, particularly in Mar-One (Figure 23). Two-way ANOVA supported the observation of a change in dry season taxa richness over time and found a significant difference in Marillana Creek hyporheos taxa between years (df = 5, p = 0.000; Table 8). The number of taxa considered to be restricted to the hyporheos was lowest in the 2008 and highest in 2012 (Table 8). This change was not reflected in a significant positive linear relationship between hyporheos taxa richness and time in either Mar-One (r = 0.55, p = 0.25, Spearman Rank Correlation p = 0.21) or Mar-Two (r = 0.71, p = 0.11, Spearman Rank Correlation p = 0.54; Figure 23). This was largely due to the considerable decrease in taxa richness between the dry of 2012 and 2013 in Mar-One, and decrease between the dry of 2010 and 2011 in Mar-Two.

[15] Previously known as *Boongurrus occidentalis* sp. nov. (Watts and Humphreys 2004). The genus *Boongurrus* has since been synomised with *Limbodessus* (Balke and Ribera 2004).
[16] Epigean habitats = on or close to the surface of the ground, i.e. surface water species.
[17] Hyporheos taxa – species adapted to hyporheic environments, including occasional hyporheos stygophiles, permanent hyporheos stygophiles, stygobites and possible hyporheic species.

There did not appear to be any change in hyporheos taxa richness over time during the wet season (Figure 23). In fact, there was no significant difference in hyporheos taxa richness between years (df = 5, p = 0.473), nor was there a significant relationship between taxa richness and time for either Mar-One (r = 0.14, p = 0.80, Spearman Rank Correlation p = 0.80) or Mar-Two (r = 0.29, p = 0.58, Spearman Rank Correlation p = 0.58; Figure 23).

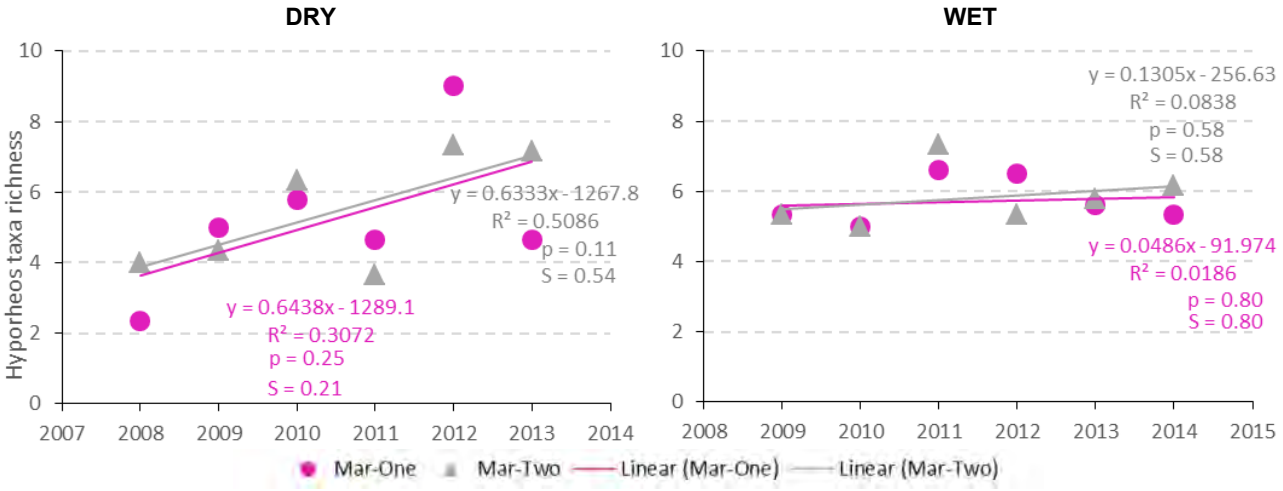


Figure 23. Linear regression plots of mean hyporheos fauna taxa richness against time for Marillana Reaches One and Two in the dry season (left) and wet season (right). Equations, p-value, Spearman correlation co-efficient (S) and R^2 values are displayed.

Table 8. Two-way ANOVA results comparing hyporheos fauna taxa richness between reach and year, for each season. Degrees of freedom, mean squares and p-values are shown. Tukey's *post-hoc* results are presented in ascending order of mean microinvertebrate taxa richness, with groups with no difference in means joined by a black line.

Dry season									
Source	***df***	***MS***	***p***	**Tukey's *post-hoc***					
Reach	2	1.41	0.722	**Mar-One**	**Mar-Two**	**WW-Five**			
Year	5	34.37	0.000	**2008**	**2011**	**2009**	**2010**	**2013**	**2012**
Reach*Year	6	6.58	0.184						
Corrected Total	79								
Wet season									
Source	***df***	***MS***	***p***	**Tukey's *post-hoc***					
Reach	2	7.42	0.308	**Mar-Two**	**Mar-One**	**WW-Five**			
Year	5	5.69	0.473	**2010**	**2009**	**2012**	**2013**	**2014**	**2011**
Reach*Year	7	4.50	0.648						
Corrected Total	75								

Additional hyporheos taxa recorded in more recent sampling events, but not present in the hyporheic zone in the dry-08, include the copepods *Australoeucyclops karaytugi* and *Mesocyclops holynskae*, *Vestalenula* and *Gomphodella* n. sp. (BOS334) ostracods, and the dytiscid *Limbodessus occidentalis*.

Although hyporheos taxa richness was slightly higher from lower Weeli Wolli Creek (WW-Five), this difference was not significant in either the dry (df = 2, p = 0.722) or wet seasons (df = 2, p = 0.308; Table 8).

3.6 Macroinvertebrates

3.6.1 Taxonomic composition and species richness

A total of 151 macroinvertebrate taxa were recorded from Marillana Creek in the dry-13, and 144 in the wet-14. Lower Weeli Wolli Creek (WW-Five) recorded 111 taxa in the dry-13, and 98 in the wet-14. The taxonomy of aquatic macroinvertebrates is constantly advancing, and there is now a greater level of resolution for a number of groups, particularly Oligochaeta, Baetidae and Crambidae. As such, the number of taxa recorded in this study may appear greater than reported for previous sampling events.

The greatest macroinvertebrate taxa richness was recorded at Mar-Two in the dry-13 (132 taxa; Table 9). The high richness at this reach was influenced by high numbers of taxa belonging to groups known to be tolerant to disturbance including Diptera (two-winged fly larvae), Coleoptera (beetles) and Hemiptera (true bugs), in both seasons (Table 9). There was a decline in taxa richness at WW-Five between the dry-13 (111 taxa) and wet-14 (98) sampling events. This was due, in part, to a decline in richness of disturbance-tolerant groups (Coleoptera and Hemiptera). Conversely, groups that favour riffle zones and enhanced water quality, i.e. Trichoptera (particularly Hydropsychids), Lepidoptera and Ephemeroptera increased in richness. This likely reflects the increase in flows across WW-Five sites during the wet season. There was no change in taxa richness at Mar-One between the dry-13 and wet-14 (95 taxa). In both seasons, Mar-One was characterised by high richness of Dipteran taxa (Table 9).

Macroinvertebrate taxa richness also varied between sites. MAR2-4 recorded the highest richness (70 taxa in the wet-14), followed by MAR2-5 (64 taxa in the dry-13; Figure 24). Macroinvertebrate richness was lowest at MAR2-8 (20 taxa), followed by WW5-1 (26 taxa) and WW5-2 (27 taxa), all during the dry season (Figure 24). Within Marillana Creek, taxa richness declined downstream of MAR2-4 and the D09 discharge outlet, in both seasons (Figure 24). Although this followed a similar trend to that of nutrients (see section 3.2.1), the longitudinal pattern in macroinvertebrate richness was more likely due to the greater areal extent of creekline inundated immediately downstream of the discharge point, and concomitant increase in habitat diversity and heterogeneity available for macroinvertebrates at MAR2-4 (see section 3.3.1).

Macroinvertebrate taxa richness is known to be related to hydrological performance; intermittent streams often harbour a lower taxa richness compared to permanent water bodies, with richness increasing with flow duration (Vinson and Hawkins 1998). Taxa richness is also known to increase with stream size, habitat heterogeneity, and macrophyte abundance (Heino *et al.* 2003). As seen in Figure 24, taxa richness is generally more consistent across sites in the wet-14. At this time, the creeklines were flowing consistently, and stream size was similar at each site.

Table 9. Macroinvertebrate taxa richness recorded from each reach during the dry-13 and wet-14.

Invertebrate group	No. of taxa					
	Dry 13			Wet 14		
	Mar-One	Mar-Two	WW-Five	Mar-One	Mar-Two	WW-Five
Nematoda (round worms)	1	1	1	0	0	0
Nematomorpha (horsehair worms)	0	1	0	0	1	0
Cnidaria (freshwater hydra)	1	1	1	0	1	1
Oligochaeta (segmented worms)	6	10	6	11	8	10
Mollusca (snails & bivalves)	3	3	2	4	3	3
Crustacea (amphipods)	0	3	4	0	1	2
Acari (water mites)	2	2	3	1	3	2
Collembola (springtails)	0	0	1	0	0	0
Ephemeroptera (mayflies)	7	6	4	7	7	6
Odonata (damselflies & dragonflies)	11	10	8	7	10	5
Hemiptera (true bugs)	11	18	18	6	10	6
Coleoptera (aquatic beetles)	12	24	36	14	35	21
Diptera (two-winged flies)	31	41	24	32	32	29
Trichoptera (caddisflies)	8	7	3	9	10	8
Lepidoptera (aquatic caterpillar)	2	5	0	4	4	4
Polychaeta (bristle worms)	0	0	0	0	0	1
Total number of taxa	**95**	**132**	**111**	**95**	**125**	**98**

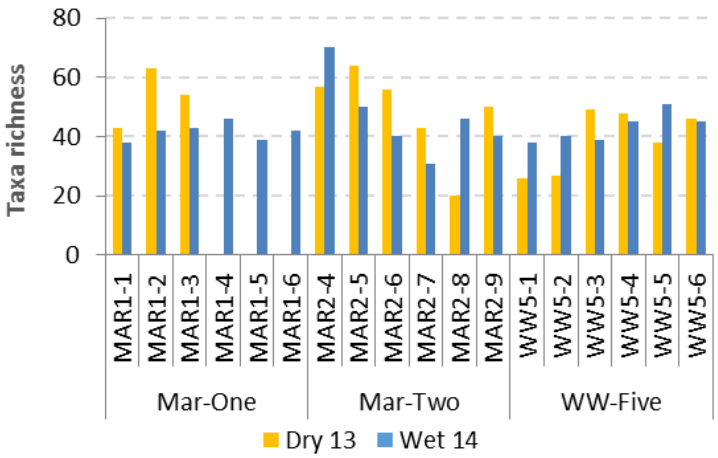


Figure 24. Macroinvertebrate taxa richness recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14.

3.6.2 Conservation significance of macroinvertebrates

Macroinvertebrates recorded during the current study were generally common, ubiquitous species, with distributions extending across Northern Australia, Australia or Australasia. However, a number were endemic to the Pilbara region, including the stygal amphipods *Maarrka weeliwolli, Chydaekata* sp., Paramelitidae sp. B, Paramelitidae sp. D, and immature or damaged Paramelitidae spp. Other endemics included the dragonflies *Nannophlebia injibandi* and *Ictinogomphus dobsoni,* and the aquatic beetles *Tiporus tambreyi and Laccobius billi*. The greatest number of Pilbara endemic taxa was recorded in the dry season; at MAR2-9 and WW5-4 (three taxa each; Figure 25).

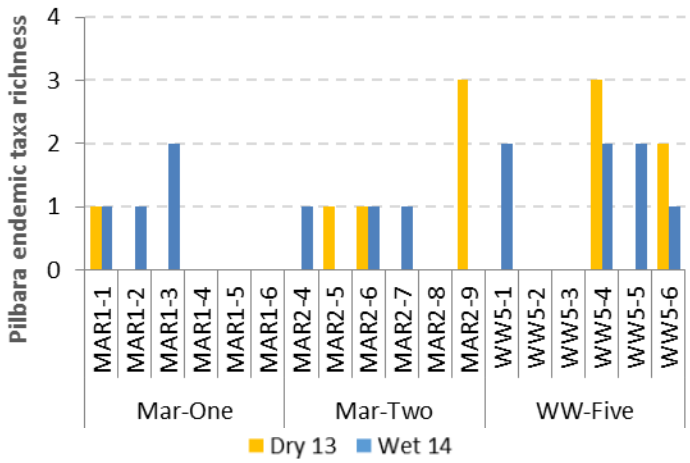


Figure 25. Richness of Pilbara endemic taxa recorded from Marillana and lower Weeli Wolli Creeks in the dry-13 and wet-14.

The Pilbara Archtail dragonfly, *Nannophlebia injibandi*, was recorded from a number of sites, including MAR1-1, MAR2-5, MAR2-6 during dry-13, and MAR1-1, MAR1-2, MAR1-3, MAR2-6, WW5-1 and WW5-5 in the wet-14. *N. injinbandi* was recorded infrequently during the Pilbara Biological Survey (Pinder *et al.* 2010), however it has been recorded from Weeli Wolli Creek, including sites upstream of the HD1 mine, Roy Hill on the Fortescue River, Fortescue Falls in Karijini National Park, and Skull Springs on the DeGrey River by WRM (WRM, unpub. data). There are also records of *N. injibandi* from Koodaideri Spring (Bennelongia 2011, WRM 2014). As such, this species appears to have a relatively broad, albeit disjunct, distribution throughout the Pilbara, but does not appear to be abundant or commonly recorded. It does appear to be distributed along the length of Marillana Creek, and is frequently recorded during WRM monitoring.

The Pilbara Tiger dragonfly, *Ictinogomphus dobsoni* (Plate 4), was recorded at MAR1-3 in the wet-14. *I. dobsoni* is known to frequent permanent still or sluggish waters (Watson 1991), and although endemic, appears to be reasonably common throughout the Pilbara. It has been recorded previously from Gregory Gorge (ANIC Database), Fortescue River on Millstream Station (ANIC Database), Fortescue Falls/Dales Gorge (DEC 2009) and from Hardey River (WRM, unpub. data). It was also recorded from sites across the Pilbara during the Pilbara Biological Survey, including Bobswim Pool (Ashburton), Robe River, Woggina Springs (Yule), Pelican Pool (DeGrey), Red Hill Creek, Horrigan's Pool (Ashburton) and Henry River (Pinder *et al.* 2010).

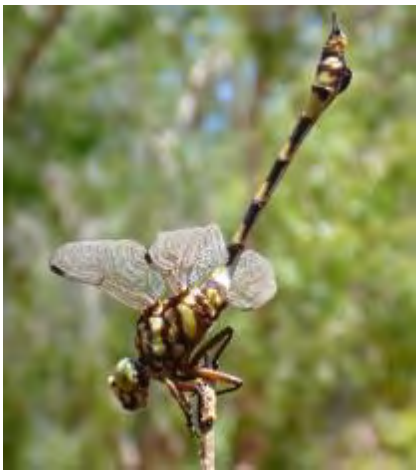


Plate 4. The Pilbara endemic dragonfly *Ictinogomphus dobsoni* (photo by Chris Hofmeester/WRM).

Interestingly, the Pilbara pin damselfly, *Eurysticta coolawanyah*, which has been recorded previously from MAR2-3, MAR2-4, MAR2-5, WW5-5 and WW5-6 downstream of Rio Tinto operations, was not recorded in the present study. This species is listed on the IUCN Redlist as **Near Threatened**, based on its distribution being restricted to an area of less than 500 km^2, and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area). However, the listing of the Pilbara Pin is considered to require revision, as it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al*. 2010). This increases its distribution above the 500 km^2 threshold defined by the IUCN. The absence of *E. coolawanyah* from Marillana Creek and lower Weeli Wolli Creek in the dry-13 and wet-14 is of interest but not of great concern.

As *E. coolawanyah* is known from areas outside the Marillana and Weeli Wolli Creek dewatering-discharge impact zones, populations are considered unlikely to be seriously affected at a regional level. Future monitoring will ascertain whether this species still occurs within the creek and was just not captured during the current study.

The four stygobitic amphipod species recorded in the hyporheic zone were also recorded in macroinvertebrate samples: *Maarrka weeliwolli, Chydaekata* sp., Paramelitidae sp. B and Paramelitidae sp. D, along with immature or damaged Paramelitidae specimens. No stygal amphipods were recorded from MAR-One in either season. Paramelitidae sp. B and Paramelitidae sp. D were both recorded at MAR2-9 during the dry-13, and Paramelitidae sp. B was recorded from MAR2-7 and MAR2-9 during the wet-14. Along lower Weeli Wolli Creek, Paramelitidae sp. D was present at WW5-6 during dry-13, and Paramelitidae sp. B at WW5-1 and WW5-4 during wet-14. *Chydaekata* sp. and *Maarrka weeliwolli* were both recorded at WW5-4 in dry season surface samples. All four stygobitic amphipod species are likely to be short range endemics, given their restricted distributions (see section 3.5.2).

The Pilbara endemic beetles *Tiporus tambreyi* (Dytiscidae) and *Laccobius billi* (Hydrophildae) were recorded at a number of Mar-Two and WW-Five sites, downstream of Rio Tinto. The dytiscid beetle *Tiporus tambreyi* appears to be common and ubiquitous across the Pilbara region (WRM unpub. data). However, the hydrophilid beetle *Laccobius billi* is a Pilbara endemic that appears to be rarely collected. It was only recorded from one site during the Pilbara Biological Survey; Cangan Pool on the Yule River (Pinder *et al.* 2010), approximately 100 km north-west of Marillana Creek. It has been recorded by the authors from Weeli Wolli Creek, Coondiner Creek and Mindy Mindy Creek (WRM, unpub. data).

3.6.3 Spatial and temporal change in macroinvertebrates

Taxa richness

Two-way ANOVAs were performed on amalgamated dry and wet season macroinvertebrate data, in order to test for differences between reaches and years (ANOVA and Tukey's *post-hoc* results are presented in Table 10). During the dry season, there was a significant difference in macroinvertebrate richness between year ($df = 5$, $p = 0.001$), but not between reach ($df = 2$, $p = 0.582$). Mean richness was highest in 2008 (40.75), though this was statistically similar to that recorded in 2013, 2011 and 2012.

Wet season macroinvertebrate richness was significantly different between year ($df = 5$, $p > 0.001$) and reach ($df = 2$, $p = 0.005$). Mean richness was highest in 2013 (41.43), though this was statistically similar to that recorded in 2014 and 2012 (Table 10). Lowest mean richness was recorded in 2010 (25.86), followed by that recorded in 2009 and 2011, respectively. This was due, at least in part, to the low mean taxa richness recorded from Mar-One in 2010 (11 taxa). At this time, only one site in this reach held water. This site appeared to have only recently filled, and therefore the macroinvertebrate re-colonisation and ecological succession of this pool were in their early stages, equating in low species richness. Macroinvertebrate richness was significantly higher at WW-Five, compared to the Marillana Creek reaches (Table 10). The high mean richness recorded at WW-Five in 2012 (48.17), plus the aforementioned low richness at Mar-One in 2010 primarily influenced this result.

Table 10. Two-way ANOVA results for dry and wet season macroinvertebrate taxa richness by reach and year, showing degrees of freedom, mean of squares, f-value and p-value. Tukey's *post-hoc* results are presented in ascending order of mean macroinvertebrate taxa richness, with groups with no difference in means joined by a black line.

Dry Season											
Source	***df***	***MS***	***F***	***p***	**Tukey's *post-hoc***						
Reach	2	38.92	0.545	0.582	**Mar-One**	**Mar-Two**	**WW-Five**				
Year	5	344.44	4.827	0.001	**2009**	**2010**	**2012**	**2011**	**2013**	**2008**	
Reach*Year	6	167.64	2.349	0.04							
Corrected Total	80										
Wet Season											
Source	***df***	***MS***	***F***	***p***	**Tukey's *post-hoc***						
Reach	2	309.36	5.692	>0.001	**Mar-One**	**Mar-Two**	**WW-Five**				
Year	5	387.86	7.137	0.005	**2010**	**2009**	**2011**	**2012**	**2014**	**2013**	
Reach*Year	7	186.66	3.434	0.003							
Total	81										

During the dry season, there was no linear relationship between macroinvertebrate taxa richness and time for Mar-One (r = 0.45, p = 0.37, Spearman p = 0.54) or Mar-Two (r = 0.07, p = 0.90, Spearman p = 0.96; Figure 26). That is, there was no overall increase or decrease in taxa richness over time during the dry. However, during the wet season, there was a significant positive linear relationship between mean taxa richness and time for Mar-One (Spearman p = 0.02; Figure 26). Similarly, there was a significant increase in wet season taxa richness over time at Mar-Two (p = 0.02, r = 0.87; Spearman p = 0.02; Figure 26). Increasing wet season taxa richness at Mar-Two since 2008 is likely due to Rio Tinto's Yandi operations, with discharge providing increased habitat size and heterogeneity, increased flows and an increase in taxa known to be tolerant of environmental change.

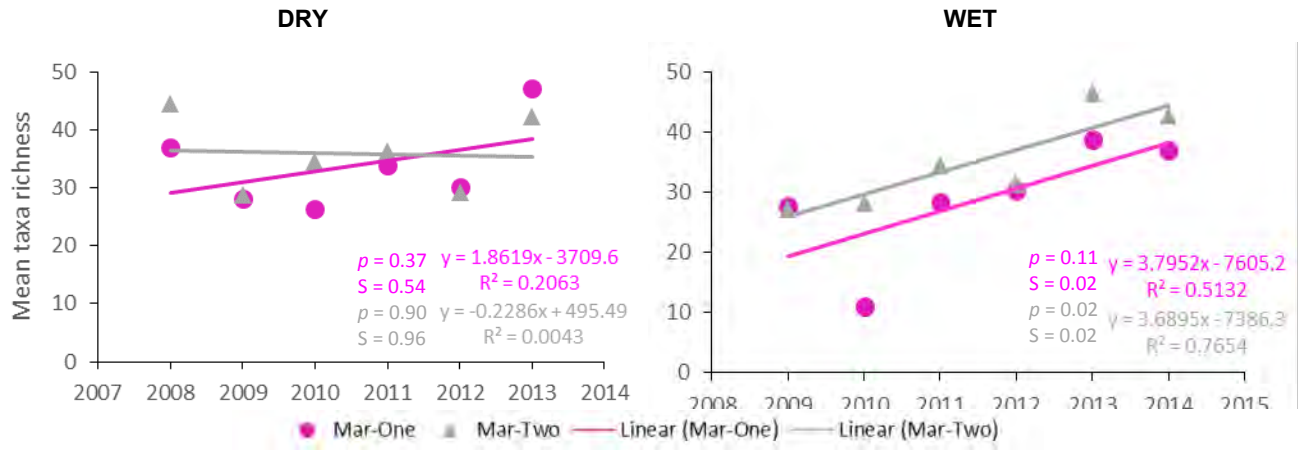


Figure 26. Linear regression plots of mean macroinvertebrate taxa richness against time for Marillana Reaches One and Two in the dry season (left) and wet season (right). Equations, p-value, Spearman correlation co-efficient (S) and R^2 values are displayed.

Comparisons with Weeli Wolli Creek

Incorporating all Weeli Wolli and Marillana Creek macroinvertebrate log_{10} abundance data into the analyses, patterns were evident in the dry season constrained CAP plot examining differences between reach (Figure 27). The correlation along both canonical axes was fairly high: CAP1 was 0.84 and CAP2 was 0.78. Macroinvertebrate assemblages from WW-Five separated from all other reaches along CAP1 based on higher abundances of taxa which prefer slow-flowing waters, such as the freshwater snail *Bullastra vinosa* and non-biting midge larvae *Chironomus* sp. (Figure 27). This reflects the intermittent nature of this reach, where sites are often reduced to small pools during the dry season. There was some overlap of Marillana Creek (Mar-One & Mar-Two) macroinvertebrate samples with those of WW-Four (the Weeli Wolli Creek reach immediately downstream of the confluence with Marillana Creek), suggesting macroinvertebrate assemblages in these areas were similar. There also appeared to be a longitudinal pattern in macroinvertebrate assemblages along Weeli Wolli Creek, with WW-One, WW-Two and WW-Three samples separating along CAP2 (Figure 27). The separation of WW-One from other reaches was influenced by higher abundances of stygal amphipods (Paramelitidae spp.).

Similar patterns were evident during the wet season (Figure 27). The correlation along both canonical axes was again fairly high: 0.84 along CAP1 and 0.72 along CAP2. While there was a longitudinal pattern along Weeli Wolli Creek, it was less pronounced than in dry season, with some overlap of reaches Two and Three (Figure 27). Comparatively, there was considerable overlap of Mar-One and Mar-Two samples with those of WW-Five, with species associated with low flows no longer affecting the separation of these samples (Figure 27). This indicates that the macroinvertebrate assemblages of lower Weeli Wolli Creek are at times more similar to those of Marillana Creek, likely due to increased flow consistency and habitat heterogeneity of these reaches during the wet season.

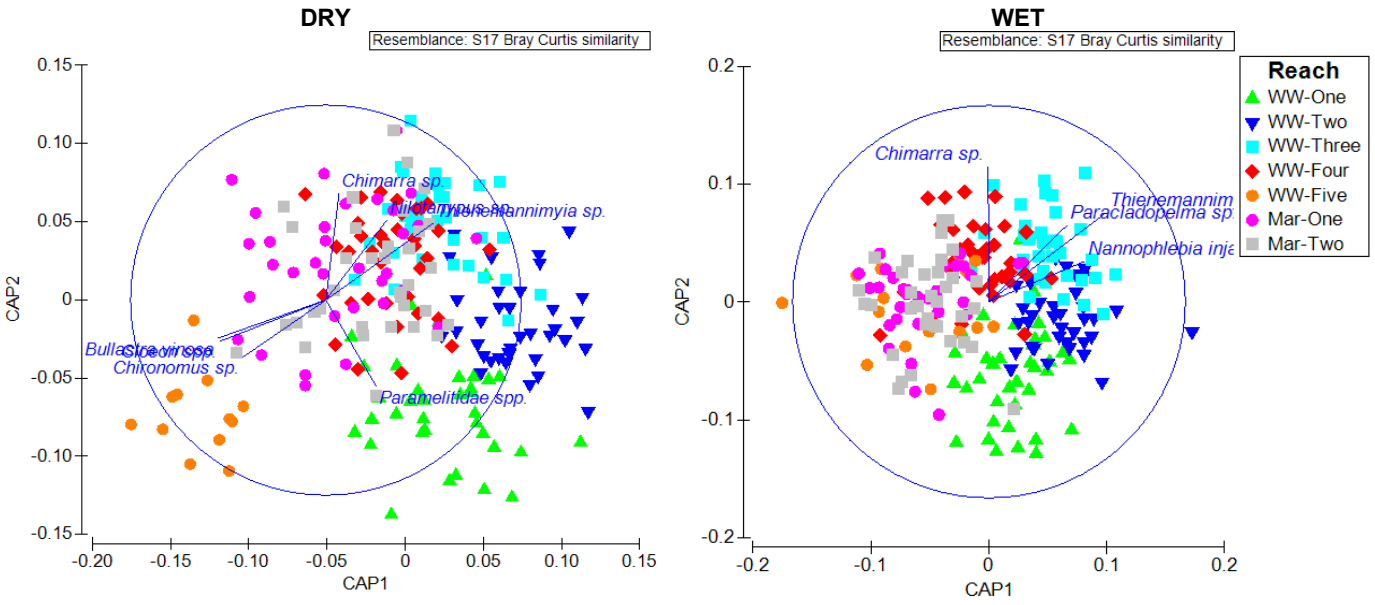


Figure 27. Constrained CAP plot comparing macroinvertebrate abundance data between reaches in the dry (left) and wet season (right), with vectors of Spearman rank correlations overlain (correlation >0.5).

PERMANOVA testing indicated that there was a significant difference between reach (df = 6, p = 0.001) and year (df = 5, p = 0.001) during the dry season. There was also a significant difference between reach (df = 6, p = 0.001) and year (df = 5, p = 0.001) during the wet season (Table 11).

Table 11. Two-factor PERMANOVA results for dry and wet season data, comparing macroinvertebrate assemblages (log_{10} abundance data) between reach and year.

Dry Season	df	MS	Pseudo-F	p
Reach	6	12271	11.125	0.001
Year	5	6968.1	6.3171	0.001
Reach*Year	26	2401	2.1767	0.001
Residual	186	1103.1		
Total	223			
Wet Season	**df**	**MS**	**Pseudo-F**	**p**
Reach	6	8553.6	8.8835	0.001
Year	5	7651.3	7.9464	0.001
Reach*Year	27	1957.8	2.0333	0.001
Residual	186	962.86		
Total	224			

There was generally no correlation between macroinvertebrate assemblages and water quality characteristics in the dry (BVSTEP; Rho = 0.45) or wet (BVSTEP; Rho = 0.36). However, water quality variables which were found to have the greatest influence on the dry season macroinvertebrate assemblages were pH, DO%, and concentrations of chloride, bicarbonate, sulfate, ammonia and total phosphorus. pH, water temperature, DO, and concentrations of magnesium, sulfate, ammonia, and total phosphorus were found to have the greatest influence on the wet season macroinvertebrate assemblages.

Similarity of dry season macroinvertebrate assemblages remained relatively consistent over time in both Marillana Creek reaches, with a slight decrease in similarity occurring between 2009 and 2011, and a slight increase to 2013 (Figure 28). This concurs with regression analysis on macroinvertebrate taxa richness from Marillana Creek reaches, where no significant change over time was detected in the dry season (see Figure 28). During the wet season, however, there was a considerable difference in similarity over time between reaches (Figure 28). In Mar-One, macroinvertebrate assemblages did not show any change in similarity compared to "baseline" until 2011, after which little change was evident (Figure 28). The difference in similarity between the 2010 and the 2011 Mar-One wet season corresponded to a 55% change in assemblage similarity (Figure 28). In contrast, in Mar-Two, assemblages remained relatively consistent between 2010 and 2012, following the initial change. There was some increase in similarity (i.e. some return to "baseline" condition) after 2012 (Figure 28).

Figure 28. Temporal consistency in similarity (distance to centroid, PERMANOVA) between macroinvertebrate assemblage data from initial sampling (2008 in the dry season, 2009 in the wet season) and subsequent sampling events. Values are based on percent similarity derived from Bray-Cutis similarity matrices.

3.7 Fish

3.7.1 Species richness

Three of the twelve freshwater fish species known from the Fortescue River System were recorded from the Marillana and lower Weeli Wolli creeks during this survey: the spangled perch *Leiopotherapon unicolor*, Pilbara tandan (eel-tailed catfish) *Neosilurus* sp.[18], and western rainbowfish *Melanotaenia australis.* All three species were recorded from Mar-One and Mar-Two during the dry-13, however only western rainbowfish were recorded from WW-Five (Table 12). All three fish species were recorded all reaches in the wet-14. The lack of spangled perch and Pilbara tandan from lower Weeli Wolli Creek during the dry season was likely due to receding water levels at the time of sampling, with only small remnant pools remaining along the reach. It appears these species recolonised WW-Five in wet season, as rains increased water levels and reconnected this reach with Marillana Creek and the upper reaches of Weeli Wolli Creek (Table 12).

3.7.2 Abundance

A total of 2715 freshwater fish were collected during the current study; 761 in the dry-13, and 1954 in the wet-14 (Table 12). There was a general increase in fish abundance compared to the previous rounds of sampling, where 693 individuals were collected in the dry season, and 1609 in the wet season (WRM unpub. data). Western rainbowfish was the most abundant species collected in both seasons, making up 76% and 71% of all fish caught in the dry and wet seasons, respectively. During the dry-13, the greatest abundance of fish was recorded from Mar-Two (341), while in the wet-14, greatest fish abundance was recorded from WW-Five (709) (Table 12).

Table 12. Abundance of fish caught from Marillana Creek and lower Weeli Wolli Creek during the dry-13 and wet-14.

Dry-13				
	Western rainbowfish	Spangled perch	Hyrtl's tandan	Total
Mar-One	267	48	16	331
Mar-Two	221	38	82	341
WW-Five	89	0	0	89
Total	577	86	98	761
Wet-14				
	Western rainbowfish	Spangled perch	Hyrtl's tandan	Total
Mar-One	365	139	88	592
Mar-Two	438	187	28	653
WW-Five	586	84	39	709
Total	1389	410	155	1954

3.7.3 Comparisons with historic fish data

Abundance

In both seasons, higher mean abundances of all three fish species were recorded from the downstream reach, Mar-Two (although in most cases, these differences were not significant; see Table 13). The greater abundance of fish in Mar-Two may be due to the more predictable nature of flows in this reach. Discharge from BHPBIO operations upstream of Mar-One appears to be lower in volume and more sporadic than the discharge of Rio Tinto's Yandi operations further downstream, as Mar-One is often dry or appears recently flooded, whilst Mar-Two holds more water consistently.

[18] Previously referred to as *Neosilurus hyrtlii*. Recent genetic evidence indicates the Pilbara species is distinct from elsewhere in Australia.

Similarly, WW-Five is highly seasonal, often reduced to small receding pools for most of the year. The less predictable nature of flows/water availability in Mar-One and WW-Five would make conditions more difficult for fish to persist, particularly in the dry season.

On a temporal scale, the main significant findings of Two-way ANOVA and regression analysis performed on current and historical (dry 2008 – wet 2013) fish data were:

- There was a significant difference in dry season western rainbowfish abundance between years. The lowest abundance was recorded in 2013 and the highest in 2011. Lowest abundances were also recorded in 2013 during the wet season (Table 13). In both seasons, rainbowfish abundances have appeared to decrease in Mar-Two over time, but given the relatively lower numbers present in the initial "baseline" sampling event (2008 in the dry and 2009 in the wet), this reduction over time was not significant (Figure 29). Similarly, there was no significant relationship between rainbowfish abundance and time in Mar-One in either season (Figure 29).

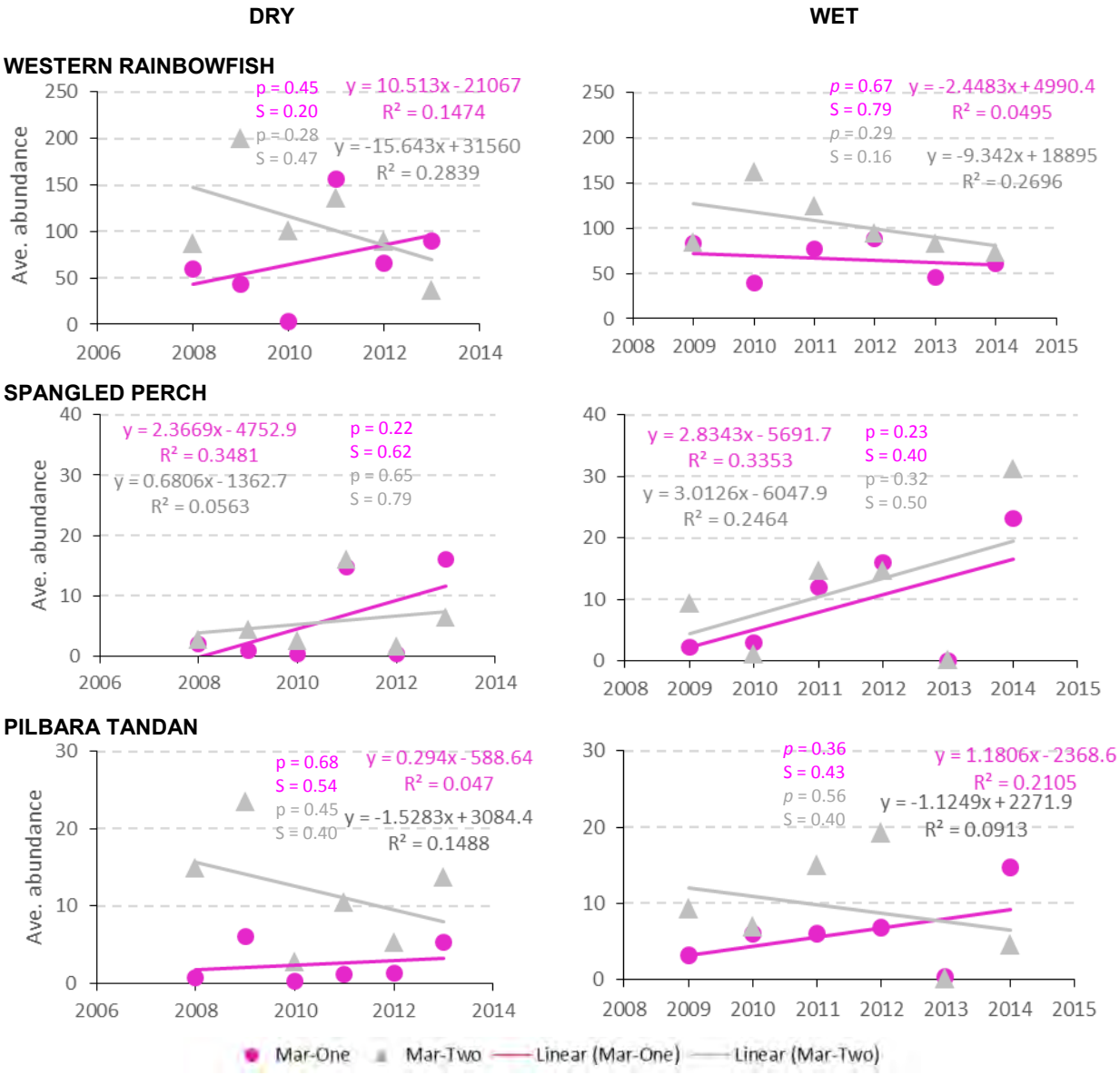


Figure 29. Linear regression plots of mean fish abundance against time for Marillana Reaches One and Two in the dry season (left) and wet season (right). Equations, p, Spearman correlation co-efficient (S) and R^2 values are displayed.

Table 13. Two-way ANOVA results for dry and wet season fish abundance data by reach and year, showing degrees of freedom, F-value and p-value. Tukey's *post-hoc* results are presented in ascending order of mean abundance, with groups with no difference in means joined by a black line.

Dry Season	*Source*	*df*	*F*	*p*	Tukeys *post-hoc*
Western rainbowfish	Reach	2	3.265	0.045	Mar-One, WW-Five, Mar-Two
	Year	5	4.645	0.001	2013, 2010, 2008, 2012, 2009, 2011
	Reach*Year	6	4.026	0.002	
Spangled perch	Reach	2	0.269	0.765	WW-Five, Mar-One, Mar-Two
	Year	5	6.41	0.000	2010, 2012, 2008, 2009, 2013, 2011
	Reach* Year	6	1.946	0.087	
	Corrected total	64			
Pilbara tandan	Reach	2	9.941	0.000	WW-Five, Mar-One, Mar-Two
	Year	5	2.904	0.020	2010, 2012, 2011, 2013, 2008, 2009
	Reach* Year	6	1.449	0.210	
Wet Season	*Source*	*df*	*F*	*p*	Tukeys *post-hoc*
Western rainbowfish	Reach	2	1.84	0.167	Mar-One, WW-Five, Mar-Two
	Year	5	1.532	0.192	2013, 2014, 2009, 2011, 2012, 2010
	Reach*Year	7	0.965	0.464	
	Corrected total	80			
Spangled perch	Reach	2	2.521	0.088	WW-Five, Mar-One, Mar-Two
	Year	5	6.449	0.000	2013, 2010, 2009, 2012, 2011, 2014
	Reach* Year	7	0.475	0.850	
	Corrected total	80			
Pilbara tandan	Reach	2	1.687	0.193	WW-Five, Mar-One, Mar-Two
	Year	5	3.602	0.006	2013, 2009, 2010, 2014, 2011, 2012
	Reach* Year	7	2.59	0.020	

- In the dry season, there was a significant difference in spangled perch abundance between years, although Tukey's *post-hoc* testing could not locate these differences. Wet season spangled perch abundance was highest in 2014, however this was statistically similar to 2011 and 2012 (Table 13). There was no significant change in dry or wet season spangled perch abundance over time at either reach (Figure 29). In the wet season, abundances did appear to increase over time in both reaches, however, due to the apparent absence of spangled perch from Marillana Creek in the wet-13, this increase over time was not significant (Figure 29).

- Catfish abundances were significantly different between years during both seasons (Table 13). The highest dry season abundance of Pilbara tandan was recorded in 2009 and the lowest in 2010. During the wet season, catfish abundance was lowest in 2013 and highest in 2012 (Table 13). The abundance of Pilbara tandan did not significantly increase or decrease over time at the either Marillana Creek reach in either season (Figure 29).

3.7.4 Patterns in age class structures and comparisons with Weeli Wolli Creek

In order to examine patterns in the fish data further, each species was broken into four age classes based on body size (standard length), as measured in the field, with each age class treated as a pseudo-species in multivariate analyses. Age-classes were based on information garnered from published literature, and are provided in Table 14. Abundances within each age-class were totalled across the three reaches in each season. Mar-One from the wet-10, and WW-Five from the wet-13 were ultimately removed from multivariate analyses, due to low site replication (Mar-One) and low fish numbers (WW-Five).

Table 14. Sizes used for each of the age-classes for each fish species.

Species	Age-class	Size mm SL
Western rainbowfish	New recruit	< 30
	Juvenile	31-40
	Sub-adult	41-50
	Adult	>51
Spangled perch	New recruit	< 30
	Juvenile	31-50
	Sub-adult	51-70
	Adult	>71
Pilbara tandan catfish	New recruit	< 30
	Juvenile	31-70
	Sub-adult	71-90
	Adult	>91

Good recruitment of western rainbow fish was observed at Marillana Creek during both seasons. New recruits made up 38% of all rainbowfish recorded from Mar-One, and 32% of rainbowfish recorded at Mar-Two during the dry-13, while also accounting for 28% of all rainbowfish at Mar-One, and 40% of rainbowfish at Mar-Two in the wet-14. In comparison, rainbowfish recruitment was lower at WW-Five (21% of rainbowfish were new recruits in the dry-13, and 19% were new recruits in the wet-14). No spangled perch new recruits were recorded at any reach in either season, and only one Pilbara tandan new recruit was recorded in the current study; at Mar-Two in the dry-13. Similar trends have been recorded in previous surveys of Marillana Creek and Weeli Wolli Creek (WRM unpub. data), however the cause of the seemingly limited recruitment capacities of these species in Marillana Creek are currently unknown. Other age-classes of spangled perch and Pilbara tandan were well represented at both Marillana Creek reaches in each season, and at WW-Five during the wet-14. This suggests that although recruitment does not appear to be occurring within the creek itself, populations are being maintained by migration from downstream environments and/or tributaries during times of connection, i.e. wet season flooding. Spangled perch are known to make general fast migrations to colonise other riverine habitats. They have two types of movement;

1. Migratory behaviour of adults – associated with reproduction
2. Lateral movement (dispersal) of adult and juvenile fish away from dry season refuges and into floodplain habitats (Pusey *et al.* 2004, Marsden and Power 2007).

Migration associated with reproductive behaviour occurs in an upstream direction (generally in the mid-wet season), and in Magela Creek in the Northern Territory, spangled perch have been tracked to move between 8.5 and 9.4 km per day (Bishop *et al.* 1995). Differences in progress rates were noted to occur between size classes of spangled perch because swimming speeds are positively

correlated with body size (Bishop *et al.* 1995). Importantly, spangled perch tend to be found in tributaries and upstream reaches, rather than fast-flowing sections of main channels. In QLD, they were most commonly collected from areas of little or no flow (Pusey *et al.* 2004), and Bishop *et al.* (2001) reported that they do not occur in velocities greater than 0.9 m/s. In a study of stream ecosystem response to coal seam gas water releases in QLD, Takahashi *et al.* (2011) warned that "spangled perch could be affected by increases in flow velocity." However, at this stage, flow velocities in Mar-Two do not appear to be impacting spangled perch sub-adults and adults (see Figure 30). Changes in the abundances of each age-class generally followed the same pattern of change as total abundance of spangled perch in Mar-Two, with the exception of the wet-14, where the increase in total abundance of this time appeared to be influenced by increases in sub-adult and adult spangled perch, rather than all age-classes (Figure 30). This pattern was less apparent in Mar-One, where juvenile spangled perch also increased in abundance in the wet-14 (Figure 30).

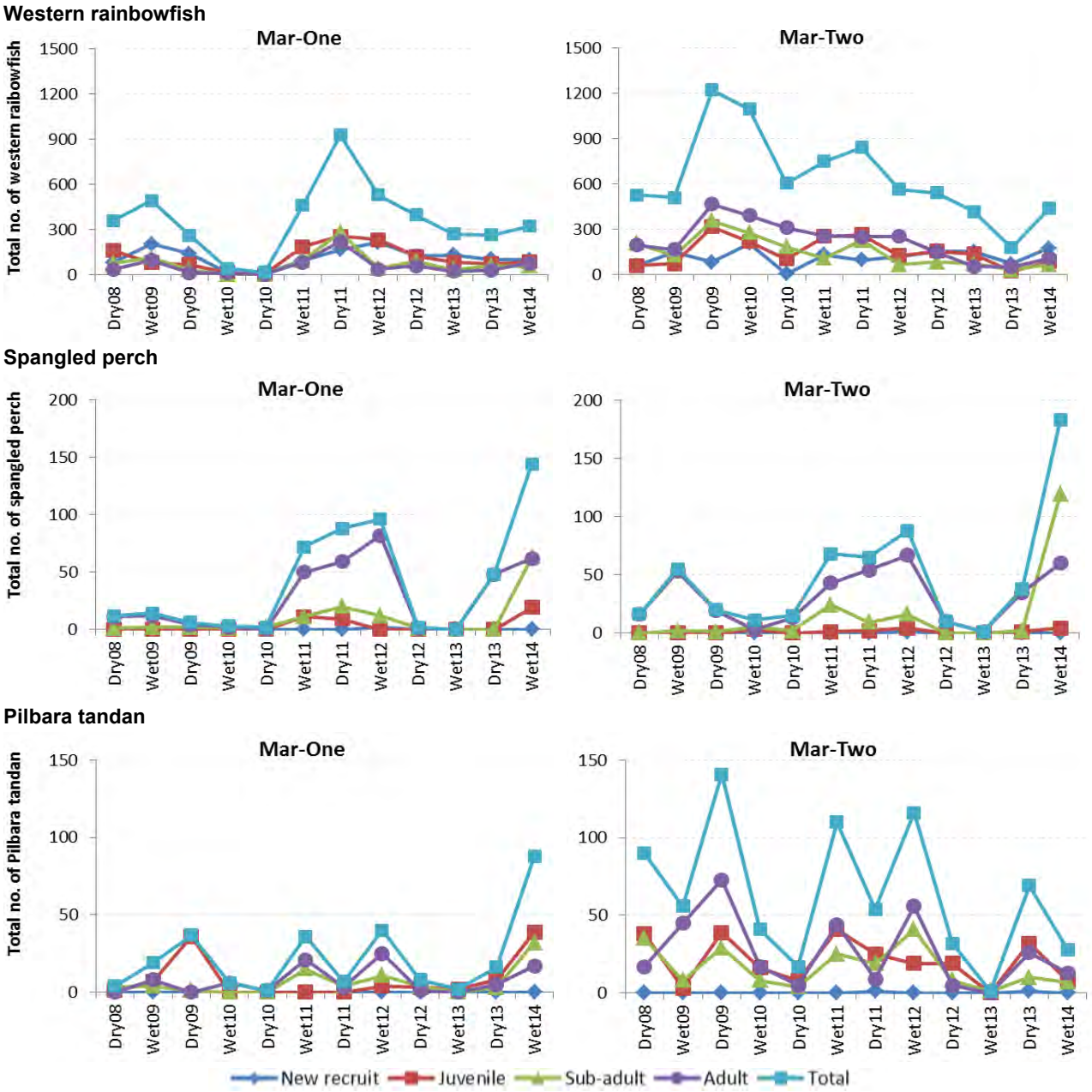


Figure 30. Change in fish abundances of different age-classes of western rainbowfish (top), spangled perch (middle), and Pilbara tandan (bottom) for Mar-One (left) and Mar-Two (right).

Incorporating all Weeli Wolli Creek and Marillana Creek fish age-class abundance data into the analyses, patterns were evident in the dry season constrained CAP plot examining differences between reach (Figure 31). The correlation along both canonical axes was fairly high: CAP1 was 0.83 and CAP2 was 0.68. Upper Weeli Wolli Creek reaches (WW-One, WW-Two and most sites at WW-Three) seemed to cluster separately from the majority of lower Weeli Wolli Creek and Marillana Creek sites, though there was some overlap in ordination space (Figure 31). This was influenced by the differences in abundances of catfish juveniles and sub-adults, and spangled perch adults and juveniles at these reaches (Figure 31). Fish populations of Mar-Two were generally more similar to lower Weeli Wolli Creek populations than the upper Marillana Creek reach (Mar-One). Mar-One fish populations were generally different to all other reaches (Figure 31).

Wet season patterns were also evident in the constrained CAP plot examining differences between reach (Figure 31). The correlation along both canonical axes was again reasonably high: CAP1 was 0.87 and CAP2 was 0.71. There was a longitudinal pattern in Weeli Wolli Creek fish age-class abundance along CAP1 during the wet season, with greater abundances of rainbowfish adults and catfish adults/sub-adults from WW-One & WW-Two influencing the separation with WW-Four (Figure 31). Greater abundances of rainbowfish and catfish juveniles/new recruits from WW-Four also influenced the longitudinal separation of fish samples. Again, Mar-One fish population samples separated from Weeli Wolli Creek reaches, however there was some overlap with Mar-Two sites. There was also some overlap of Mar-Two sites with upper Weeli Wolli Creek sites (Figure 31).

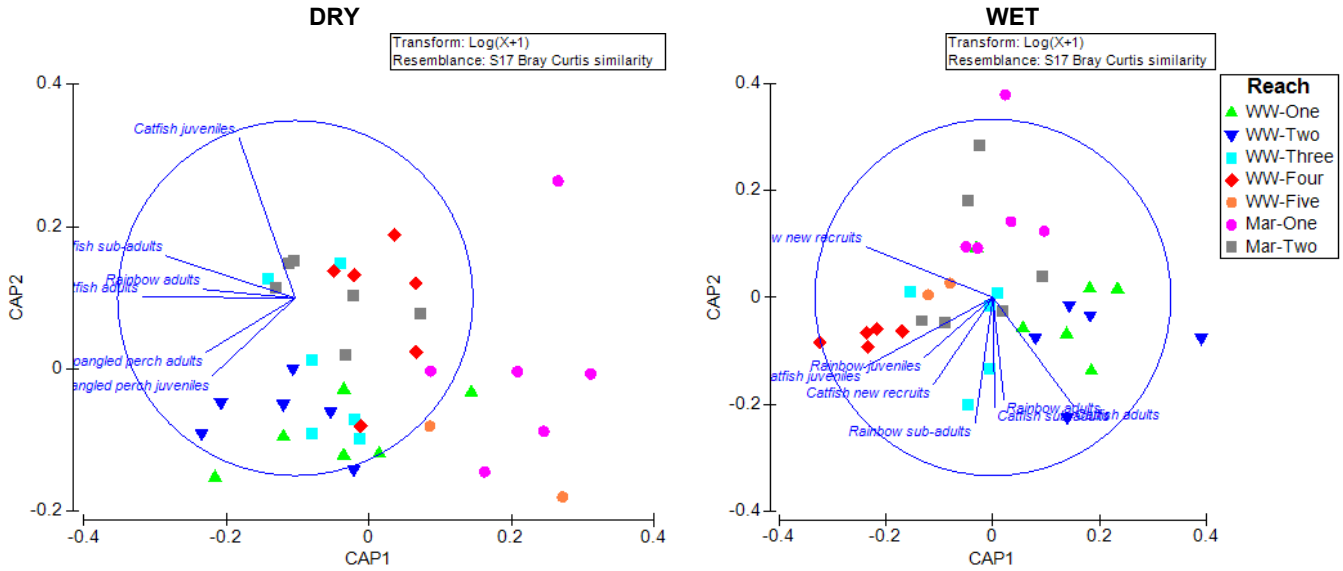


Figure 31. Constrained CAP plots of fish age-class abundance data from Weeli Wolli and Marillana creeks, examining differences between reaches in the dry (left), and wet seasons (right). Vectors of Spearman rank correlations are overlain (correlation > 0.5).

PERMANOVA testing indicated that these patterns were significant. There was a significant difference in fish age-class structures between reach (df = 6, p = 0.002) and year (df = 5, p = 0.005) during the dry season, and there was also a significant difference between reach (df = 6, p = 0.001) and year (df = 5, p = 0.001) during the wet season (Table 15).

Generally, fish age-class structures bore little resemblance to the assemblages present during the initial "baseline" sampling event in either the dry (2008 initial sampling year) or wet season (2009 initial sampling year; i.e. generally less than 20% similarity; Figure 32). However, in Mar-One during the dry season, there was a considerable increase in similarity (~40% increase), i.e. return to more

similar assemblages as those present in 2008. Following the initial change, fish assemblages in Mar-Two remained relatively consistent over time in both seasons (Figure 32).

Table 15. One-factor PERMANOVA results for dry and wet season data, comparing fish age-class abundance between reach and year.

Dry Season	df	MS	Pseudo-F	p
Reach	6	706.3	3.3554	0.002
Year	5	438.72	2.0842	0.005
Residual	26	210.5		
Total	37			
Wet Season	***df***	***MS***	***Pseudo-F***	***p***
Reach	6	296.91	4.2679	0.001
Year	5	548.59	7.8856	0.001
Residual	22	69.569		
Total	33			

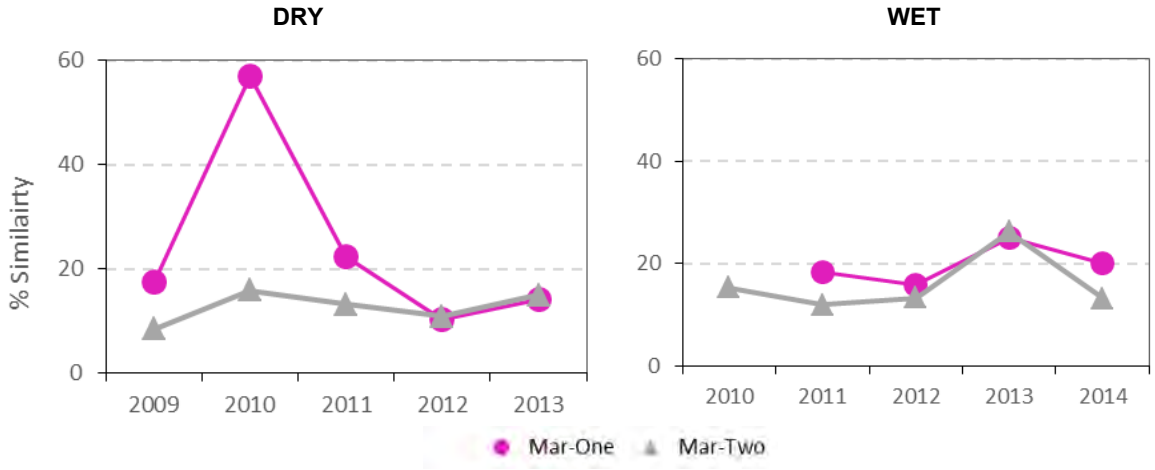


Figure 32. Temporal consistency in similarity (distance to centroid, PERMANOVA) between fish age-class abundance data from initial sampling (2008 in the dry season, 2009 in the wet season) and subsequent sampling events. Distance values are based on percent similarity derived from Bray-Cutis similarity matrices.

4 RISKS IDENTIFIED IN THE HAZARD ANALYSIS

4.1 Eutrophication

Given the elevated nitrate concentrations in the groundwater being discharged, eutrophication was identified as one of the key risks to the aquatic environment in the recent Hazard Analysis for Dewatering Discharge report (WRM 2015a). Nitrate-enriched waters result in eutrophication by fuelling nuisance algal and macrophyte growth (*e.g. Typha*). If growth is excessive/extensive, this may physically smother other life forms, as well as deplete oxygen from the water column due to increased respiration and biological oxygen demand (BOD), leading to anoxia (zero dissolved oxygen) or hypoxia (<20% dissolved oxygen). Increased respiration, particularly at night, is a risk when there is excessive growth of algae and submerged macrophytes, and increased BOD occurs as a result of the breakdown of macrophytes and algae once the plants die-off. The relationship between nitrate-enrichment and enhanced algal growth in freshwaters is well documented, often resulting in very high density/abundance but low species richness (Gorden *et al.* 1982, Townsend *et al.* 2011, Muhid *et al.* 2013). Interestingly, percent algal cover in Mar-Two, downstream of the Rio Tinto's D09 discharge, appeared to follow an inverse relationship with nitrogen concentrations in the most recent sampling rounds of the dry-13 and wet-14, such that algal cover was lower with higher total N (Figure 33). This relationship was not apparent upstream (in Mar-One) during these time periods. While a similar relationship was apparent in the dry-12, prior to the discharge of JSW dewatering water (but not JSE & JC discharge), it was not evident in the wet-13 (Figure 33).

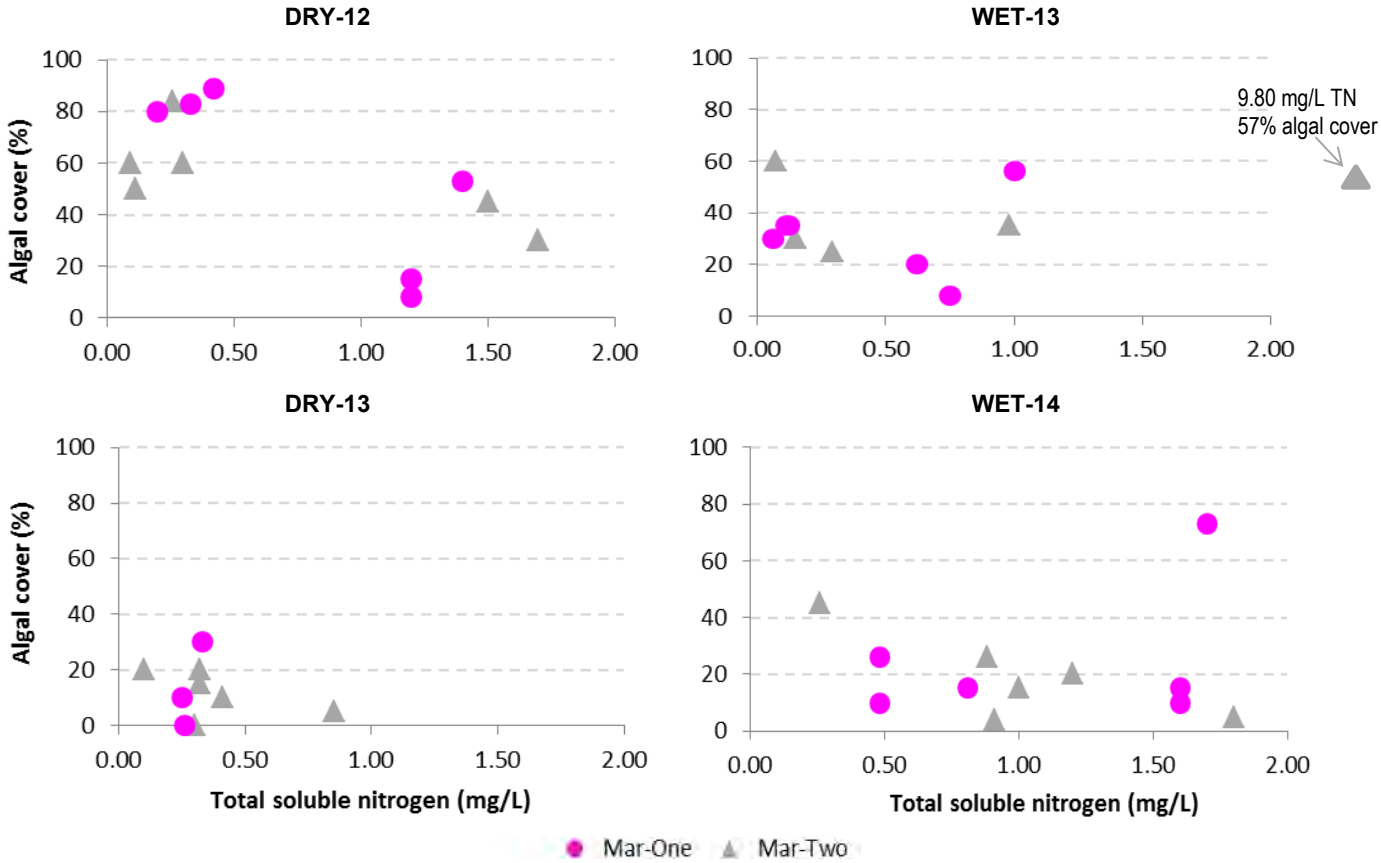


Figure 33. Algal cover (%) versus total soluble nitrogen concentrations (mg/L) along Marillana Creek in the last four sampling events.

The apparent reductions in nitrogen levels recorded in recent sampling events from Mar-Two, coupled with increases in algae and aquatic macrophyte growth may be related to nutrient cycling

within the creek, with nutrients being bound-up in sediments as well as algal and macrophyte growth. Nutrient levels in the water column can often be low, even during algal blooms, as nutrients are tightly cycled and effectively locked-up by the algae itself. There was some evidence for this from studies at Marandoo BWT, where measured concentrations of total dissolved nitrogen and nitrates in the water column rapidly diminished downstream of the discharge point, coupled with increases in algal cover (WRM 2013c). Also, spot measurements of dissolved nutrients in the water column may not pick up any spikes in nutrient levels if and when they are released from algae and sediment. Alternatively, release of nutrients may not occur as a single event, and therefore may not appear as a spike, but instead occur as a slow 'leakage', which is quickly taken up by algae and macrophytes as soon as it becomes available. This is known as tight nutrient spiraling (Solimini *et al*. 2005). The lower algal growth at MAR2-4, where nitrogen levels were highest, may also be a result of the greater flow velocities and high degree of flushing in this area, which is located immediately downstream of the discharge point.

Generally, percent algal cover showed a similar pattern of change over time at all sites within Mar-Two, the lower Marillana Creek reach downstream of Rio Tinto (Figure 34). Within a site, algal growth remained fairly consistent between the wet-10 and dry-11, decreased to the wet-12, increased substantially in the dry-12, and then generally decreased to the dry-13 (Figure 34). There were some increases in algal cover between the dry-13 and wet-14 at sites downstream of the D09 discharge outlet (i.e. MAR2-5, MAR2-8 & MAR2-9), however cover at MAR2-4 and MAR2-6 remained consistent and at MAR2-7 decreased between these time periods (Figure 34). None of the algal cover percentages recorded in the wet-14 were outside values recorded from the creek previously. However, the risk of eutrophication would be highest during periods when natural flow in the creeklines is at its lowest and dewatering discharge constitutes most of the surface water present in channel pools (i.e. the dry season).

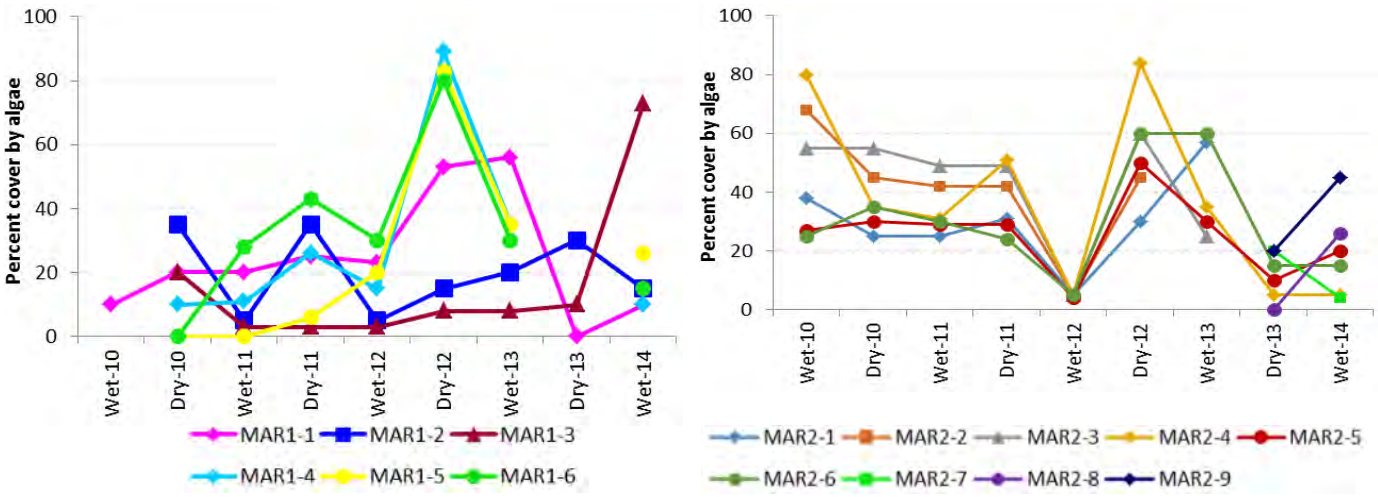


Figure 34. Change in percent algal cover over time at sites within Mar-One (left) and Mar-Two (right).

In contrast, algal growth in the upper Marillana Creek reach (Mar-One) did not show a similar pattern of change over time between sites (Figure 34). For example, algal cover at MAR1-3 saw a substantial increase between the dry-13 and wet-14 which was not seen elsewhere in Mar-One (Figure 34). Aside from the generally high cover of algae recorded at most sites in the dry-12, algal cover was variable amongst sites and over time in Mar-One.

Although algal cover was generally greatest from WW-Five and lowest from Mar-One (Figure 35), overall there was no significant difference in percent algal cover between reach in either season

(Table 16). There was, however, a significant difference in algal cover between year during the dry season (df = 3, p = 0.000), due largely to the high cover recorded during the dry-12 (see Figure 34 & 35, and Table 16). Of importance for the JSW development was the fact that algal cover recorded in the wet-14, following increased discharge from D09, was statistically similar to that recorded during all other wet seasons sampled since 2010 (Table 16).

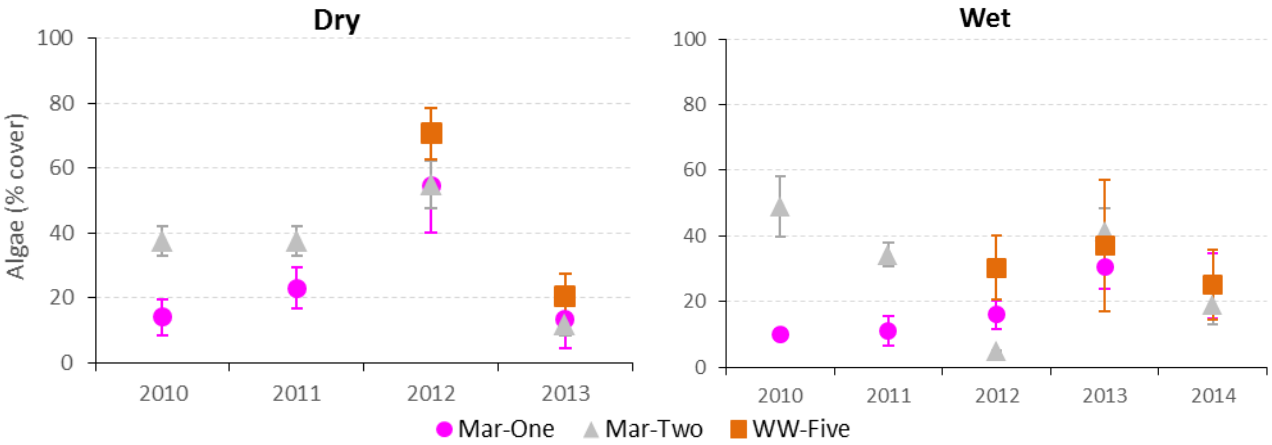


Figure 35. Average percent cover by algae from each reach over time (±se) in the dry season (left) and the wet season (right).

Regression and Spearman Rank Correlation analyses indicated that there was no significant change in percent algal cover over time for either Marillana Creek reach during the dry season (Figure 36). During the wet season, however, there was a significant positive relationship between algal cover and time (Spearman Correlation p = 0.04) in Mar-One (Figure 36). This relationship was not apparent in Mar-Two (Spearman Correlation p = 0.39).

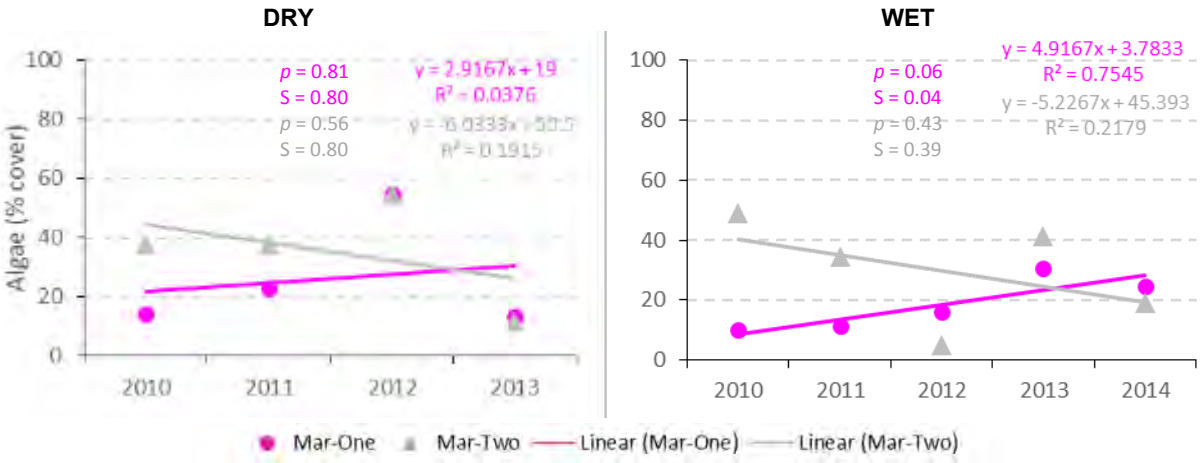


Figure 36. Linear regression plot of algal cover against time during the dry (left) and wet season (right) for Marillana Reaches One and Two. Equations, linear regression p-value, Spearman correlation co-efficient p-value (S) and R^2 values are displayed.

At this stage, the discharge of groundwater with elevated nutrient concentrations from the JSW orebody does not appear to have resulted in eutrophic conditions downstream. However, algal growth patterns and nutrient concentrations downstream of the D09 discharge point will continue to be monitored and assessed in future reports. It should also be noted that the algae currently

recorded from Marillana Creek primarily comprises filamentous algae and/or benthic mats, rather than phytoplankton which is likely to be more responsive to nutrient changes.

Table 16. Two-way ANOVA results comparing percent algal cover (arcsin proportion) between reach and year, for each season. Degrees of freedom, F and p-values are shown. Tukey's *post-hoc* results are presented in ascending order of mean algal cover, with groups with no difference in means joined by a black line

Dry season								
Source	***df***	***F***	***p***	**Tukey's *post-hoc***				
				Mar-One	**Mar-Two**	**WW-Five**		
Reach	2	2.27	0.115					
				2013	**2010**	**2011**	**2012**	
Year	3	16.32	0.000					
Reach*Year	4	0.89	0.475					
Corrected Total	56							
Wet season								
Source	***df***	***F***	***p***	**Tukey's *post-hoc***				
				Mar-One	**Mar-Two**	**WW-Five**		
Reach	2	2.69	0.077					
				2012	**2011**	**2014**	**2013**	**2010**
Year	4	2.05	0.100					
Reach*Year	6	1.68	0.143					
Corrected Total	68							

4.2 Calcite precipitate

The Yandi Hazard Analysis also identified a moderate-high risk of in-stream habitat loss due to carbonate (calcite & dolomite) precipitation in Marillana and lower Weeli Wolli creeks (WRM 2015a). WRM have been monitoring the ecological health of Weeli Wolli Creek as part of the "Living Water Survey" since Sep-07, and, in Oct-09 first observed the formation of a precipitate in the creek bed of WW-Two (Weeli Wolli Creek reach two), several hundred meters downstream of the gabion (WRM 2011). The precipitate was initially observed as an armouring or cementing of the creek bed in riffle zones in WW-Two, but has since extended throughout WW-Three, and more recently it has been observed as far downstream as WW-Four, immediately downstream of the confluence with Marillana Creek (see WRM 2014b). Initially the precipitate was only in the fast flowing riffle sections, but it appears gravel runs in WW-Two and WW-Three have also become armoured. The precipitate appears to form at a rapid rate, with leaves and other organic matter being coated before they can breakdown, and so becoming part of the 'cement' (Plate 5). The formation of the calcite precipitate structurally changes the bed of the creek, impacting habitat availability and heterogeneity for macroinvertebrates by infilling interstices and 'cementing' cobbles and pebbles together.

In 2011, a study undertaken by CSIRO found that the precipitate was caused by super-saturation of calcium carbonate in waters downstream of the gabion and degassing of carbon dioxide (CSIRO 2011). Studies elsewhere have reported that for precipitation to occur, the water generally has to be around five to ten times supersaturated with respect to calcite (Hoffer-French and Herman 1989, Chen *et al.* 2004). However, a number of factors are known to affect the rate and location of calcite precipitation, including outgassing of carbon dioxide (i.e. Hoffer-French and Herman 1989, Merz-Preiß and Riding 1999, Chen *et al.* 2004), abiotic environmental conditions such as humidity and

temperature (Andrews 2006) and microbial/biological activity (i.e. Vasconcelos *et al.* 1995, Arp *et al.* 2001, Shiraishi *et al.* 2008). For carbonate deposition (usually as calcite) to occur, kinetic thresholds of mineral formation must be overcome. This means that precipitation often commences in stream channels well downstream of springs, and can continue for a few kilometres thereafter (Liu *et al*. 2006). Many field based studies have shown that outgassing of CO_2 occurs most rapidly in turbulent areas of the stream, such as riffle zones, cascades and waterfalls (Lorah and Herman 1988, Hoffer-French and Herman 1989, Merz-Preiß and Riding 1999). Chen *et al*. (2004) found that the principal cause of precipitation in waterfall areas was due to enhanced inorganic carbon dioxide outgassing due to the sudden hydrological changes which occur in these areas of the creek, rather than any influence from organisms, evaporation or the solid-water interface. Stream turbulence in waterfall zones enhances CO_2 outgassing through physical dispersion of the water, an increase in surface area relative to volume, and the fact that CO_2 can escape across the water-air phase boundary more readily (Drysdale 2001, Chen *et al.* 2004). While the addition of dewatering discharge from Yandi's D06 into Weeli Wolli Creek, and D09 into Marillana Creek (upstream of the Weeli Wolli confluence), may increase flow and thereby add to the turbulence within the creek/s, and hence outgassing of CO_2, the source geology being dewatered at Yandi is considerably different to that around HD1, and does not appear to support groundwater supersaturated with calcium carbonates. If this is the case, then the net result may be dilution of carbonates in Weeli Wolli Creek rather than addition and super-saturation.

Plate 5. Images of the calcite precipitate in Weeli Wolli Creek, showing total armouring of the bed (left) and coating of twigs and debris (right).

At this time, the dewatering-discharge from JSW, JC and JSE does not appear to have resulted in precipitate forming within Marillana Creek. No calcite precipitate has been observed within Marillana Creek, and in fact there is very little bedrock[19] substrate at all (see Figure 37). In multivariate analysis of habitat and substrate characteristics, Marillana Creek sites separated from WW-Two, and some sites in WW-Three, based largely on the lower cover of bedrock at Marillana Creek sites (see Figure 16 section 3.3.2). In addition, there has been no significant change in percent cover by bedrock between years in either the dry or wet season (Table 17), and no significant linear increase in bedrock cover over time in either Marillana Creek reach (Figure 38). Although Mar-Two recorded greater percent cover by bedrock in both seasons (Figure 37), these differences were not significant (Table 17), and the mean cover by bedrock in Mar-Two was low (i.e. average of 0.56% in the dry and 0.21% in the wet).

[19] For the purposes of this study, calcite precipitate was classified as "bedrock" as the armouring of the creek bed creates similar in-stream habitat to bedrock in terms of heterogeneity and diversity.

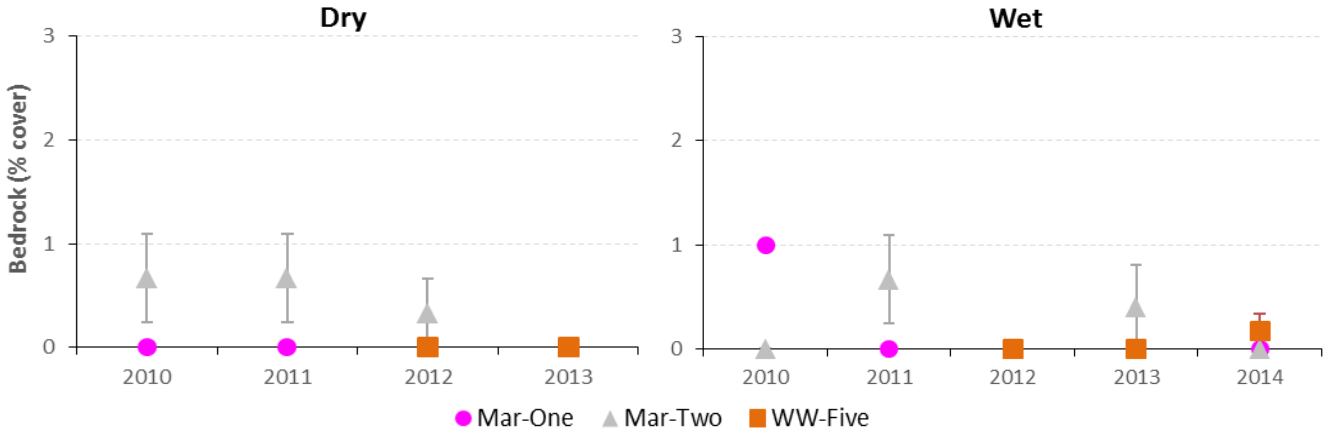


Figure 37. Average percent cover by "bedrock" from each reach over time (±se) in the dry season (left) and the wet season (right).

Table 17. Two-way ANOVA results comparing percent bedrock cover (arcsin proportion) between reach and year, for each season. Degrees of freedom, F and p-values are shown. Tukey's *post-hoc* results are presented in ascending order of mean algal cover, with groups with no difference in means joined by a black line

Dry season								
Source	***df***	***F***	***p***	**Tukey's *post-hoc***				
Reach	2	3.32	0.045	**Mar-One**	**WW-Five**	**Mar-Two**		
Year	3	0.79	0.503	**2013**	**2012**	**2010**	**2011**	
Reach*Year	4	0.70	0.594					
Corrected Total	56							
Wet season								
Source	***df***	***F***	***p***	**Tukey's *post-hoc***				
Reach	2	0.01	0.991	**Mar-One**	**WW-Five**	**Mar-Two**		
Year	4	1.80	1.141	**2012**	**2014**	**2010**	**2013**	**2011**
Reach*Year	6	2.41	0.038					
Corrected Total	68							

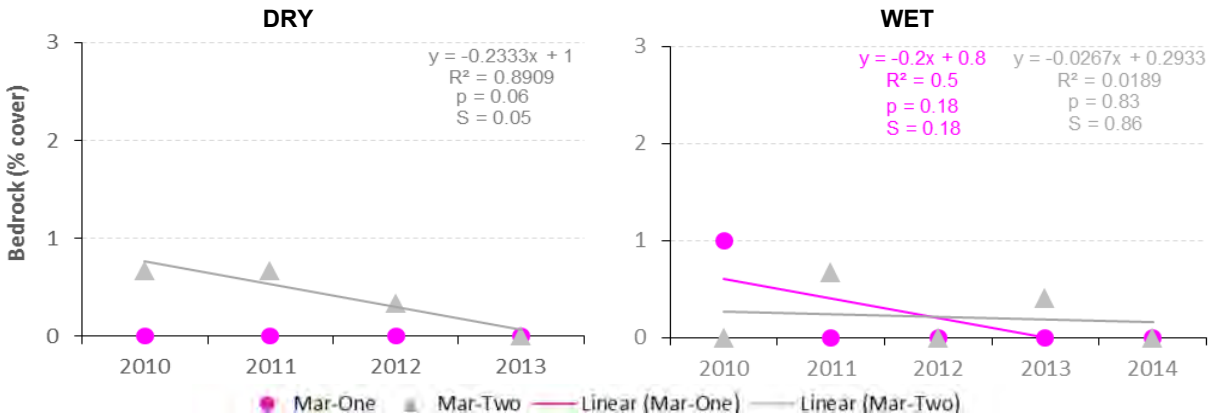


Figure 38. Linear regression plot of bedrock cover against time during the dry (left) and wet season (right) for Marillana Reaches One and Two. Equations, linear regression p-value, Spearman correlation co-efficient p-value (S) and R^2 values are displayed.

5 CONCLUSIONS

5.1 General

This report summarises a valuable dataset for assessing cumulative impacts of Rio Tinto developments in the area. This dataset documents the current aquatic ecological values of Marillana Creek, provides a valuable baseline for assessing the impacts of development of the new JSW and Oxbow deposits, and assists in discriminating effects from BHPBIO operations upstream.

Cumulative impacts on the Weeli Wolli Creek system are already becoming evident. However, the extent and nature of these impacts may increase in the future given the expansions at Rio Tinto Yandi, including increased discharge, as well as increased discharge from BHPBIO Yandi. This report outlines current changes to the aquatic environment, some of which are likely climate-related but some of which may be due to mine operations. The main important changes are summarised below.

5.2 Marillana Creek

- There has been a statistically significant decline in wet season pH in Mar-Two over time. However, this only constitutes a change from 8.00 during the wet of 2008 to 7.70 during the wet of 2014. Such a change is unlikely to adversely affect the resident aquatic fauna.
- Water temperature was significantly higher from Mar-Two than Mar-One in both seasons, indicating there may be some effect of the discharge from Rio Tinto's Yandi on downstream water temperature. However, water temperature has not significantly increased over time in either reach. Increased water temperature resulting from discharge of warm groundwater has been reported for Weeli Wolli Creek close to the HD1 discharge point. Although significantly higher than Mar-One (ave. 24.6°C in the dry & 24.7°C in the wet), water temperature at Mar-Two (ave. 26.2°C in the dry & 26.1°C in the wet) was similar to that recorded from Weeli Wolli Creek downstream, i.e. WW-Five (ave. 26.4°C in the dry & 26.7°C in the dry). Therefore, there has been no increase in temperature in Mar-Two above the natural range.
- The discharge of groundwater from the JSW deposit appears to have resulted in elevated nutrient concentrations, with values for nitrogen oxides and total nitrogen exceeding Marillana Creek SSTVs in Mar-Two during the wet season and total phosphorus during the dry. The SSTVs for nitrogen oxides is for protection against eutrophication. Using the new revised toxicity SSTV for nitrate (2.5 mg/L N_NO_3), all N_NOx concentrations were within limits not anticipated to cause toxic effects to aquatic fauna (N_NOx is generally the largest component of N_NO_3 so values can be compared against the toxicity SSTVs). Despite the recent elevated levels of N_NOx and TN, there has been no significant increase in nutrient levels in Marillana Creek (i.e. no significant positive linear relationship with time).
- While there has been no significant increase in dissolved boron concentrations over time in Mar-Two in either season, there was a considerable increase in concentration between the wet-13 and wet-14 which may be related to the discharge at D09.
- Dissolved copper has declined significantly over time in both Mar-One and Mar-Two in the dry and wet seasons.
- Using all water quality data in the analysis, the overall water quality of Marillana Creek was significantly different to that of Weeli Wolli Creek. This remains unchanged since aquatic monitoring commenced.

- Within Mar-Two, water quality has shown decreasing similarity with the "baseline" initial sampling event in the more recent years (2012 & 2013 in the dry & 2013 & 2014 in the wet). This pattern of change was not recorded from Mar-One, upstream on Marillana Creek. In fact, overall water quality in that reach has tended to become more similar to "baseline" condition, particularly during the wet season.
- Percent cover by algae appeared to follow an inverse relationship with nitrogen concentrations in the most recent sampling rounds of the dry-13 and wet-14, downstream of the D09 discharge outlet, such that algal cover was lower with higher total N. This relationship was not apparent upstream (in Mar-One) during these time periods. As data are limited to twice-yearly sampling events, causal relationships between algal growth and nitrogen concentration could not be confirmed within the scope of the current study. However, a possible explanation for the inverse relationship observed at MAR2-4 is that greater water velocities and high degree of flushing in this area, which is located immediately downstream of the discharge point, are physically disrupting algal colonies. Another explanation is that it is related to rapid nutrient cycling within the creek, with nutrients becoming bound-up in sediments and algal and macrophyte growth.
- Eutrophication was highlighted as one of the key risks in the Hazard Analysis (WRM 2015a). Some increase in algal cover was evident at a number of sites in Mar-Two, downstream of the D09 discharge point during the wet-14 (i.e. MAR2-5, MAR2-8 & MAR2-9); however, overall there was no significant increase in algal cover over time in this reach. As there has been only one round of monitoring post commencement of discharge from D09 (i.e. the wet-14), it is too early at this stage to assess the risk of eutrophication. It is expected that risk of eutrophication will be greatest during the dry season when natural flow and water levels are low, and discharge water constitutes much of the water within the creek. This report does not contain dry season data from after the commencement of discharge from D09, and as such, the pattern of change in algal growth (along with nutrient concentrations) will continue to be monitored and assessed.
- Within Mar-Two, there appeared to be a longitudinal gradient of habitat diversity downstream of MAR2-4, with diversity generally decreasing with distance downstream of the D09 discharge outlet. The additional water essentially inundates a greater areal extent of creekline, thus increasing habitat availability and heterogeneity immediately downstream.
- Calcite precipitation was also highlighted as a key risk within the Hazard Analysis. To-date, there is no evidence of increased precipitation along Marillana (or lower Weeli Wolli) Creek associated with the additional discharge from JSW & JSE. Very little bedrock cover has been recorded from Marillana Creek, and there has been no increase in the percent of this cover over time.
- There has been no significant change in microinvertebrate taxa richness over time for either reach in either season, i.e. no consistent increase or decrease in taxa richness. This suggests that the discharge operations at Yandicoogina have not adversely impacted the microinvertebrate taxa richness of the downstream Marillana Creek environment over time.
- The microinvertebrate assemblages of Marillana Creek are significantly different to Weeli Wolli Creek. However, the assemblages of lower Weeli Wolli reach (WW-Five) are more similar to Marillana Creek than upper Weeli Wolli.
- Since the initial change in microinvertebrate assemblages from "baseline" condition they have remained relatively consistent over time in both Marillana Creek reaches in both seasons.
- Although there appeared to be an increase in hyporheos taxa richness over time in both Marillana Creek reaches, this change was not significant. During the dry season, this was

likely due to a considerable decrease in taxa richness between the dry of 2012 and 2013 in Mar-One, and decrease between the dry of 2010 and 2011 in Mar-Two.

- Within the dry-13/wet-14 data, macroinvertebrate taxa richness declined downstream of MAR2-4 and the D09 discharge outlet in both seasons. This longitudinal pattern was not present in either Mar-One or WW-Five. The higher taxa richness at MAR2-4 may have been due to the greater areal extent of habitat associated with the discharge.
- There was no relationship between macroinvertebrate taxa richness and time during the dry season. However, there was a significant positive relationship between taxa richness and time for both Marillana Creek reaches in the wet season. This increase was generally influenced by high numbers of taxa known to be tolerant to disturbance including Diptera (two-winged fly larvae), Coleoptera (beetles) and Hemiptera (true bugs).
- Overall, the macroinvertebrates assemblages of Mar-One and Mar-Two were similar, with considerable overlap in ordination space when compared with upper Weeli Wolli Creek. Downstream of the confluence, assemblages from WW-Four were more similar to Marillana Creek than upper Weeli Wolli Creek.
- In Mar-Two, wet season macroinvertebrate assemblages have remained relatively consistent between 2010 and 2012, following the initial change, with some increase in similarity (i.e. some return to "baseline" condition) after 2012. This pattern was not as pronounced in Mar-One.
- Higher mean abundances of all three fish species were generally recorded from Mar-Two. This is likely due to the more predictable nature of flows in this reach. Discharge from BHPBIO operations upstream of Mar-One appears to be lower in volume and more sporadic than the discharge of Rio Tinto's Yandi operations further downstream, as Mar-One is often dry or appears recently flooded, whilst Mar-Two holds more water consistently. Similarly, WW-Five is highly seasonal, often reduced to small receding pools for most of the year.
- Although western rainbowfish abundances have appeared to decrease over time in Mar-Two during both seasons, this change was not significant.
- Wet season abundances of spangled perch did appear to increase over time in both reaches, however, due to the apparent absence of spangled perch from Marillana Creek in the wet-13, this increase over time was not significant.
- The abundance of Pilbara tandan did not significantly increase or decrease over time at the either Marillana Creek reach in either season.
- Good recruitment of western rainbowfish was observed at Marillana Creek during both seasons. However, no spangled perch new recruits were recorded at any reach in either season, and only one Pilbara tandan new recruit was recorded from Mar-Two in the dry-13. There has been little recruitment of spangled perch and Pilbara tandan in Marillana Creek since monitoring began, with the last major recruitment event occurring in the wet-12. Despite this, numbers of both species are not declining and juveniles are present in most sampling events. This suggests that migration from downstream environments and/or tributaries during times of connection plays an important role in the population stability of spangled perch and Pilbara tandan within Marillana Creek.
- Generally, Marillana Creek fish age-class structures showed reduced resemblance to the initial "baseline" sampling events in the dry 2008 or wet 2009. For rainbowfish and Pilbara tandan, all age-classes have changed in a similar pattern to total fish abundance over time, but for spangled perch there has been a recent increase in sub-adults and adults, but in no other size classes.

5.3 Weeli Wolli Creek

- Higher water temperatures recorded from WW-Two, which may be due to the discharge of warm groundwater by HD1 operations (see WRM 2014).
- No evidence to date that discharge from D06 has resulted in a significant increase in average water temperature in the downstream receiving environment of Weeli Wolli Creek.
- Higher percentage cover by 'bedrock' in WW-Two than any other reach, primarily due to the 'armouring' of the creek bed as a result of calcite precipitate. 'Armouring' appears to be greatest at sites WW2-3, WW2-4 and WW2-5. This precipitate was first observed during sampling in Oct-09 and has subsequently progressed further downstream, and is now well established in WW-Three (WRM 2014), with the first signs of calcite precipitation in WW-Four. Ongoing monitoring will assess calcite development in WW-Five.
- Reduction in total nitrogen and ammonia concentrations since Sep-07, which was attributable in part to the positive effect of flushing, but also nutrient cycling within the creek, with nutrients being bound-up in algal and macrophyte growth (see WRM 2014).
- Increasing homogeneity of water quality along the length of the creek due to dewatering discharge, as evidenced by the significantly higher multivariate dispersion (spread of samples) in Sep-07 compared to recent surveys (see WRM 2014).
- Significantly lower microinvertebrate taxa richness from WW-Two, downstream of the gabion, which likely reflects the high water velocity, and insufficient distance for planktonic fauna to colonise flow from the gabion in this reach (WRM 2014).
- Significantly lower macroinvertebrate taxa richness recorded from WW-Two was likely a result of 'bed-armouring' (calcite precipitate) effectively reducing habitat heterogeneity and therefore available habitat for macroinvertebrates (WRM 2014).
- Changes in macroinvertebrate assemblage structure due to increased abundance of taxa known to prefer faster-flowing habitats. There has also been a loss in seasonality of macroinvertebrate assemblages associated with the continual discharge (WRM 2014).
- Macroinvertebrate assemblages of WW-Five were significantly different to all other reaches in the dry season due to the higher abundances of taxa which prefer slow-flowing waters. This reflects the intermittent nature of this reach, where sites are often reduced to small pools during the dry. As cumulative surface flows from Rio's HD1 and Yandi operations do not currently extend this far, seasonal hydrological differences still influence the assemblage structure. However, during the wet season, assemblages from WW-Five were similar to Marillana Creek assemblages. This indicates that the macroinvertebrate assemblages of lower Weeli Wolli Creek are at times more similar to those of Marillana Creek, likely due to increased flow consistency and habitat heterogeneity of these reaches during the wet season. Once surface flows associated with the discharge extend this far, and there is a hydrological switch to permanent flows, this seasonal signature will likely be lost as has been the case on upper Weeli Wolli Creek.
- No negative influence from Rio Tinto's Yandi discharge has been noted along lower Weeli Wolli Creek (WW-Five) to-date, given surface flows do not currently extend this far. On-going monitoring will allow any future changes to be assessed.

Of considerable concern in relation to cumulative impacts from mining operations and development is the calcite precipitation and resultant 'armouring' of the creek bed which is occurring in Weeli Wolli Creek downstream of the HD1 discharge outlet. As well as the effects to aquatic fauna

diversity, the increase in rate and extent of calcite precipitation in Weeli Wolli Creek will have implications for flow dynamics and flood response. Changes in bed sediment characteristics, reductions in infiltration to the groundwater, and reduced in-stream roughness due to creek bed 'armouring' may result in a decreased ability for the creek to cope with flooding events. When the precipitate was initially observed in October 2009 it was as an armouring of riffle zones only, however, it now appears to be depositing within gravel runs as well (WRM 2015b). Rio Tinto, in collaboration with the CSIRO, are currently undertaking a project to map the precipitate within the creek. This will assist in quantifying the extent of the armouring. Reduced in-stream roughness and reduced infiltration rates are widely known to increase flood energies and stream flow (Baker 1977, Wolman and Gerson 1978). Increased flows and flood energies can negatively impact benthic communities in streams (Resh *et al.* 1988).

Of importance to the Yandi mine is the fact that discharge operations associated with the JSE and JC development, and more recently JSW developments, do not appear to have adversely affected the taxa richness (viz. diversity) of microinvertebrates, hyporheic invertebrates or macroinvertebrates. Although there have been changes in community structure over time, there was no significant negative correlation between taxa richness (hyporheic fauna or micro- and macro-invertebrates) and time. This indicates that the discharge operations to-date have not adversely impacted the diversity of aquatic fauna present in the downstream Marillana Creek environment. In fact, the wet season macroinvertebrate fauna, as well as the abundances of all three fish species may well have benefited (at least in the short-term) from the greater habitat availability, heterogeneity and security provided by Rio Tinto's discharge.

On-going monitoring will allow any future changes to be assessed in the context of the more recent developments.

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APPENDICES

Appendix 1. Site photographs

MARILLANA CREEK
REACH ONE (Mar-One)

DRY 13 **WET 14**

MAR1-1

MAR1-2

MAR1-3

DRY 13 **WET 14**

MAR1-4 (SITE WAS DRY)

MAR1-5 (SITE WAS DRY)

MAR1-6 (SITE WAS DRY)

REACH TWO (Mar-Two)

DRY 13 **WET 14**

MAR2-4

MAR2-5

MAR2-6

DRY 13 **WET 14**

MAR2-7

MAR2-8

MAR2-9

WEELI WOLLI CREEK - REACH FIVE (WW-Five)

DRY 13 **WET 14**

WW5-1

WW5-2

WW5-3

DRY 12 **WET 13**

WW5-4

WW5-5

WW5-6

Appendix 2. ANZECC/ARMCANZ (2000) trigger values for the protection of aquatic systems in tropical northern Australia

Table A2-1. Default trigger values for some physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH4+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east (ANZECC/ARMCANZ 2000).

	TP ($\mu g\ L^{-1}$)	FRP ($\mu g\ L^{-1}$)	TN ($\mu g\ L^{-1}$)	NOx ($\mu g\ L^{-1}$)	NH_4^+ ($\mu g\ L^{-1}$)	DO % saturation[f]	pH
Aquatic Ecosystem							
Upland River[e]	10	5	150	30	6	90-120	6.0-7.5
Lowland River[e]	10	4	200-300[h]	10[b]	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350[c]	10[b]	10	90-120	6.0-8.0
Wetlands[3]	10-50[g]	5-25[g]	350-1200[g]	10	10	90[b]-120[b]	6.0-8.0

b = Northern Territory values are 5µgL^{-1} for NO_x, and <80 (lower limit) and >110% saturation (upper limit) for DO;
c = this value represents turbid lakes only. Clear lakes have much lower values;
e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
g = higher values are indicative of tropical WA river pools;
h = lower values from rivers draining rainforest catchments.

Table A2-2. Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000).

Aquatic Ecosystem		*Comments*
Salinity	***(µs/cm)***	
Aquatic Ecosystem		
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The fist flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
Turbidity	***(NTU)***	
Aquatic Ecosystem		
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

Table A2-3. Trigger values for toxicants at alternative levels of protection (µg/L).

Compound	Trigger values for freshwater Level of protection (% species) 99%	95%	90%	80%
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 3. Water quality data from the dry-13 and wet-14

Table A3-1. *In situ* water quality data from Marillana and lower Weeli Wolli Creek in the dry-13 and wet-14. Shading indicates values outside ANZECC/ARMCANZ (2000) guidelines.

Sampling event	Reach	Site	pH	EC µS/cm	Temp (°C)	DO %
Dry-13	Mar-One	MAR1-1	7.52	1040	27.8	22.1
		MAR1-2	7.94	1030	28.3	98.4
		MAR1-3	7.95	1020	29.7	118.2
		MAR1-4	Dry	Dry	Dry	Dry
		MAR1-5	Dry	Dry	Dry	Dry
		MAR1-6	Dry	Dry	Dry	Dry
	Mar-Two	MAR2-4	7.20	847	31.7	116.2
		MAR2-5	7.41	908	27.6	46.1
		MAR2-6	7.61	911	31.8	86.1
		MAR2-7	7.87	918	31.6	129.4
		MAR2-8	7.44	937	28.4	23.5
		MAR2-9	7.67	983	30.0	122.2
	WW-Five	WW5-1	7.52	975	25.1	20.6
		WW5-2	7.58	1040	27.6	78.9
		WW5-3	7.33	1020	28.7	87.5
		WW5-4	7.45	963	25	57.4
		WW5-5	7.43	987	30.4	104.4
		WW5-6	7.87	1010	27.3	88.5
Wet-14	Mar-One	MAR1-1	7.52	938	29.4	22.1
		MAR1-2	7.73	941	27.4	76.7
		MAR1-3	8.45	926	28.7	138.6
		MAR1-4	7.60	941	26.2	55.9
		MAR1-5	7.86	934	26.8	88.4
		MAR1-6	7.95	935	27.4	104.3
	Mar-Two	MAR2-4	7.25	856	27.9	77.2
		MAR2-5	7.71	859	30.2	140.8
		MAR2-6	7.70	865	30.2	91.7
		MAR2-7	7.64	868	25.7	68.1
		MAR2-8	7.71	868	25.9	85.1
		MAR2-9	8.20	825	34.2	150.6
	WW-Five	WW5-1	8.01	924	24.8	88.6
		WW5-2	8.28	910	30.7	124.4
		WW5-3	8.74	921	29.2	117.8
		WW5-4	7.66	922	28.6	82.33
		WW5-5	7.96	907	31.4	117.4
		WW5-6	7.86	915	30.3	107.4

Table A3-2. Ionic composition data from Marillana and lower Weeli Wolli Creek in the dry-13 and wet-14.

Sampling event	Reach	Site	Na	Ca	Mg	K	HCO_3	Cl	SO_4_S	CO_3	Alk.	Hardness
Dry-13	Mar-One	MAR1-1	83.8	49.4	49.3	8.1	373	130	52.7	0.5	306	330
		MAR1-2	83.7	48.4	49.5	8	365	129	52.4	0.5	300	320
		MAR1-3	84	46.8	49.2	8.2	361	127	52	0.5	296	320
		MAR1-4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
		MAR1-5	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
		MAR1-6	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Mar-Two	MAR2-4	70.5	21.7	40.4	6.2	246	105	42.9	0.5	202	220
		MAR2-5	71.6	45.7	43.8	7	321	118	45.3	0.5	264	290
		MAR2-6	70	45	43.2	6.9	323	111	44.8	0.5	265	290
		MAR2-7	72.8	44.6	44.1	7	321	115	46	0.5	263	290
		MAR2-8	72.8	45.2	44	7.3	326	121	45.9	0.5	267	290
		MAR2-9	79.2	47.4	45.6	7	341	131	50.6	0.5	280	310
	WW-Five	WW5-1	61.1	56.8	54.4	9.4	372	97	62.1	0.5	305	370
		WW5-2	59.7	60.7	59.2	9.3	411	119	61.2	0.5	337	400
		WW5-3	60.6	64.3	52.4	8.2	386	107	58.6	0.5	317	380
		WW5-4	58.8	54.2	51.2	9	370	112	53.9	0.5	304	350
		WW5-5	61.4	55.5	53.7	8.7	372	129	58.3	0.5	305	360
		WW5-6	71.3	49.4	51.7	9	321	154	69.5	0.5	263	340
Wet-14	Mar-One	MAR1-1	77.6	48.1	46.4	7.9	327	103	51.5	0.5	268	310
		MAR1-2	78	47.8	46.5	7.8	325	103	51.3	0.5	267	310
		MAR1-3	77.8	46.7	45.7	8	281	104	50.7	19	263	300
		MAR1-4	78.2	48.3	45.4	8.1	330	107	49	0.5	271	310
		MAR1-5	76	47.9	44.1	7.9	327	106	47.7	0.5	268	300
		MAR1-6	78.2	48.4	45.5	8.1	335	108	49.6	0.5	275	310
	Mar-Two	MAR2-4	68.9	45.5	42.5	6.2	283	97	48.3	0.5	232	290
		MAR2-5	67.7	45.8	41.5	6.5	287	101	47.6	0.5	235	290
		MAR2-6	67	47.2	41.6	6.7	292	106	47.2	0.5	239	290
		MAR2-7	58.6	41.3	37.1	5.5	286	101	50.5	0.5	235	260
		MAR2-8	67.8	46.9	41.6	6.8	292	112	47.8	0.5	239	290
		MAR2-9	57.6	38.9	34.1	6.1	215	107	50.6	24	217	240
	WW-Five	WW5-1	59.9	59.1	53	8.8	342	98	60.2	0.5	281	370
		WW5-2	51.7	47	46.1	7.4	312	97	62.7	9	271	310
		WW5-3	58.2	47.8	44.3	7.2	321	98	61.3	6	273	300
		WW5-4	56.8	57.6	48.5	9	331	97	56.6	0.5	272	340
		WW5-5	50.3	58.3	46.5	9.1	313	99	58.7	0.5	257	340
		WW5-6	52.7	56	41.7	7.3	313	103	62.2	0.5	257	310

Table A3-3. Nutrient data from Marillana and lower Weeli Wolli Creek in the dry-13 and wet-14. Shading indicates values outside ANZECC/ARMCANZ (2000) guidelines.

Sampling event	Reach	Site	N_NH_3	N_NO_x	N_total	P_total
Dry-13	Mar-One	MAR1-1	0.01	0.07	0.26	0.02
		MAR1-2	0.005	0.11	0.33	0.016
		MAR1-3	0.005	0.02	0.25	0.017
		MAR1-4	Dry	Dry	Dry	Dry
		MAR1-5	Dry	Dry	Dry	Dry
		MAR1-6	Dry	Dry	Dry	Dry
	Mar-Two	MAR2-4	0.005	0.41	0.85	0.021
		MAR2-5	0.005	0.19	0.41	0.02
		MAR2-6	0.02	0.17	0.32	0.021
		MAR2-7	0.05	0.13	0.32	0.018
		MAR2-8	0.01	0.11	0.30	0.022
		MAR2-9	0.005	0.01	0.10	0.019
	WW-Five	WW5-1	0.005	0.07	0.23	0.016
		WW5-2	0.02	0.18	0.57	0.037
		WW5-3	0.005	0.02	0.23	0.015
		WW5-4	0.005	0.03	0.12	0.019
		WW5-5	0.005	0.005	0.24	0.015
		WW5-6	0.005	0.27	0.89	0.025
Wet-14	Mar-One	MAR1-1	0.005	1.6	1.60	0.005
		MAR1-2	0.005	1.6	1.60	0.005
		MAR1-3	0.005	1.7	1.70	0.005
		MAR1-4	0.005	0.5	0.48	0.005
		MAR1-5	0.005	0.49	0.48	0.005
		MAR1-6	0.005	0.75	0.81	0.005
	Mar-Two	MAR2-4	0.005	1.7	1.80	0.011
		MAR2-5	0.005	1.2	1.20	0.005
		MAR2-6	0.005	0.97	1.00	0.005
		MAR2-7	0.005	0.87	0.91	0.005
		MAR2-8	0.005	0.86	0.88	0.005
		MAR2-9	0.005	0.2	0.26	0.005
	WW-Five	WW5-1	0.005	0.21	0.23	0.005
		WW5-2	0.005	0.12	0.15	0.005
		WW5-3	0.005	0.32	0.35	0.005
		WW5-4	0.005	0.08	0.11	0.005
		WW5-5	0.005	0.005	0.02	0.005
		WW5-6	0.005	0.04	0.06	0.005

Table A3-4. Dissolved metals data from Marillana and lower Weeli Wolli Creek. Shading indicates values outside ANZECC/ARMCANZ (2000) TVs. SE = sampling event.

SE	Reach	Site	Al	As	B	Ba	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	S	Se	U	V	Zn
Dry-13	Mar-One	MAR1-1	0.0025	0.0005	0.41	0.049	0.00005	0.00005	0.00025	0.00010	0.0610	0.0090	0.0005	0.0005	0.00005	18	0.0005	0.0010	0.0039	0.0060
		MAR1-2	0.0025	0.0005	0.39	0.049	0.00005	0.00005	0.00025	0.00010	0.0640	0.0030	0.0005	0.0005	0.00005	18	0.0005	0.0010	0.0043	0.0030
		MAR1-3	0.0025	0.0005	0.41	0.052	0.00005	0.00005	0.00025	0.00010	0.0280	0.0040	0.0005	0.0005	0.00005	17	0.0005	0.0010	0.0053	0.0040
		MAR1-4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
		MAR1-5	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
		MAR1-6	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Mar-Two	MAR2-4	0.0025	0.0005	0.26	0.028	0.00005	0.00005	0.00025	0.00005	0.0025	0.0005	0.0005	0.0005	0.00005	14	0.0010	0.0006	0.0010	0.0050
		MAR2-5	0.0025	0.0005	0.16	0.023	0.00005	0.00005	0.00025	0.00030	0.0025	0.0005	0.0005	0.0005	0.00005	15	0.0005	0.0004	0.0021	0.0100
		MAR2-6	0.0025	0.0005	0.20	0.02	0.00005	0.00005	0.00025	0.00005	0.0090	0.0020	0.0005	0.0005	0.00005	15	0.0005	0.0004	0.0018	0.0030
		MAR2-7	0.0025	0.0005	0.30	0.044	0.00005	0.00005	0.00025	0.00010	0.0160	0.0080	0.0005	0.0005	0.00005	15	0.0005	0.0010	0.0042	0.0030
		MAR2-8	0.0025	0.0005	0.31	0.044	0.00005	0.00005	0.00025	0.00020	0.0180	0.0130	0.0005	0.0005	0.00005	15	0.0005	0.0011	0.0048	0.0040
		MAR2-9	0.0025	0.0005	0.24	0.029	0.00005	0.00005	0.00025	0.00005	0.0025	0.0005	0.0005	0.0005	0.00005	17	0.0005	0.0011	0.0020	0.0180
	WW-Five	WW5-1	0.0025	0.0005	0.36	0.037	0.00005	0.00005	0.00025	0.00020	0.0470	0.0090	0.0005	0.0005	0.00005	21	0.0005	0.0017	0.0036	0.0030
		WW5-2	0.0025	0.0005	0.33	0.028	0.00005	0.00005	0.00025	0.00020	0.0100	0.0005	0.0005	0.0005	0.00005	20	0.0005	0.0025	0.0052	0.0020
		WW5-3	0.0025	0.0005	0.30	0.049	0.00005	0.00005	0.00025	0.00010	0.0150	0.0070	0.0005	0.0005	0.00005	20	0.0005	0.0027	0.0019	0.0020
		WW5-4	0.0025	0.0005	0.34	0.039	0.00005	0.00005	0.00025	0.00010	0.0025	0.0005	0.0005	0.0005	0.00005	18	0.0005	0.0018	0.0027	0.0020
		WW5-5	0.0025	0.0005	0.33	0.039	0.00005	0.00005	0.00025	0.00020	0.0025	0.0005	0.0005	0.0005	0.00005	19	0.0005	0.0023	0.0028	0.0020
		WW5-6	0.0025	0.0005	0.27	0.041	0.00005	0.0002	0.00025	0.00160	0.0680	0.0810	0.0005	0.0005	0.00005	23	0.0005	0.0025	0.0017	0.0060
Wet-14	Mar-One	MAR1-1	0.0025	0.0005	0.37	0.041	0.00005	0.00005	0.00025	0.00005	0.0250	0.0070	0.0005	0.0005	0.00005	19	0.0010	0.0008	0.0035	0.0030
		MAR1-2	0.0025	0.0005	0.35	0.043	0.00005	0.00005	0.00025	0.00005	0.0340	0.0090	0.0005	0.0005	0.00005	18	0.0010	0.0008	0.0035	0.0020
		MAR1-3	0.0025	0.0005	0.37	0.025	0.00005	0.00005	0.00025	0.00005	0.0250	0.0060	0.0005	0.0005	0.00005	19	0.0010	0.0008	0.0036	0.0010
		MAR1-4	0.0025	0.0005	0.36	0.041	0.00005	0.00005	0.00025	0.00005	0.0080	0.0020	0.0005	0.0005	0.00005	19	0.0005	0.0010	0.0058	0.0020
		MAR1-5	0.0025	0.0005	0.36	0.041	0.00005	0.00005	0.00025	0.00005	0.0025	0.0005	0.0005	0.0005	0.00005	18	0.0005	0.0010	0.0061	0.0020
		MAR1-6	0.0025	0.0005	0.35	0.042	0.00005	0.00005	0.00025	0.00005	0.0100	0.0090	0.0005	0.0005	0.00005	18	0.0005	0.0010	0.0065	0.0020
	Mar-Two	MAR2-4	0.0025	0.0005	0.29	0.027	0.00005	0.00005	0.00025	0.00005	0.0025	0.0005	0.0005	0.0005	0.00005	17	0.0005	0.0007	0.0013	0.0060
		MAR2-5	0.0025	0.0005	0.28	0.036	0.00005	0.00005	0.00025	0.00005	0.0210	0.0030	0.0005	0.0005	0.00005	17	0.0005	0.0007	0.0039	0.0030
		MAR2-6	0.0025	0.0005	0.27	0.039	0.00005	0.00005	0.00025	0.00005	0.0200	0.0060	0.0005	0.0005	0.00005	17	0.0005	0.0008	0.0040	0.0020
		MAR2-7	0.0025	0.0005	0.28	0.042	0.00005	0.00005	0.00025	0.00005	0.0260	0.0110	0.0005	0.0005	0.00005	17	0.0010	0.0008	0.0038	0.0020
		MAR2-8	0.0025	0.0005	0.28	0.037	0.00005	0.00005	0.00025	0.00005	0.0200	0.0070	0.0005	0.0005	0.00005	18	0.0005	0.0007	0.0037	0.0020
		MAR2-9	0.0025	0.0005	0.27	0.045	0.00005	0.00005	0.00025	0.00005	0.0070	0.0020	0.0005	0.0005	0.00005	17	0.0005	0.0013	0.0047	0.0030
	WW-Five	WW5-1	0.0025	0.0005	0.28	0.03	0.00005	0.00005	0.00025	0.00005	0.0070	0.0005	0.0005	0.0005	0.00005	19	0.0005	0.0014	0.0051	0.0030
		WW5-2	0.0025	0.0005	0.31	0.036	0.00005	0.00005	0.00025	0.00005	0.0025	0.0010	0.0005	0.0005	0.00005	21	0.0005	0.0013	0.0041	0.0030
		WW5-3	0.0025	0.0005	0.30	0.037	0.00005	0.00005	0.00025	0.00005	0.0025	0.0010	0.0005	0.0005	0.00005	20	0.0005	0.0013	0.0040	0.0020
		WW5-4	0.0025	0.0005	0.26	0.013	0.00005	0.00005	0.00025	0.00005	0.0140	0.0020	0.0005	0.0005	0.00005	17	0.0005	0.0011	0.0023	0.0030
		WW5-5	0.0025	0.0005	0.29	0.041	0.00005	0.00005	0.00025	0.00005	0.0025	0.0005	0.0005	0.0005	0.00005	21	0.0005	0.0019	0.0036	0.0020
		WW5-6	0.0025	0.0005	0.29	0.046	0.00005	0.00005	0.00025	0.00005	0.0025	0.0030	0.0005	0.0005	0.00005	21	0.0005	0.0020	0.0033	0.0030

Appendix 4. Water quality ANOVA results

Variable (Dry)	Source	df	F	p	Tukeys post-hoc					
Log pH					**WW-Five**	**Mar-One**	**Mar-Two**			
	Reach	2	1.067	0.350						
					2013	**2012**	**2008**	**2010**	**2009**	**2011**
	Year	5	10.58	0.000						
	Reach*Year	6	4.892	0.000						
	Corrected total	80								
Log Temp.					**Mar-One**	**Mar-Two**	**WW-Five**			
	Reach	2	5.762	0.005						
					2010	**2011**	**2012**	**2009**	**2008**	**2013**
	Year	5	24.2	0.000						
	Reach* Year	6	1.844	0.104						
	Corrected total	80								
Log DO (%)					**Mar-One**	**WW-Five**	**Mar-Two**			
	Reach	2	5.319	0.007						
					2009	**2013**	**2012**	**2010**	**2011**	**2008**
	Year	5	1.553	0.185						
	Reach* Year	6	1.172	0.332						
	Corrected total	80								
Log EC					**Mar-Two**	**WW-Five**	**Mar-One**			
	Reach	2	32.327	0.000						
					2012	**2008**	**2013**	**2011**	**2009**	**2010**
	Year	5	14.74	0.000						
	Reach* Year	6	3.866	0.002						
	Corrected total	80								

Variable (Dry)	Source	df	F	p	Tukeys post-hoc
Log Ca					Mar-Two Mar-One WW-Five
	Reach	2	15.69	0.000	
					2013 2009 2008 2011 2010 2012
	Year	5	3.203	0.012	
	Reach*Year	6	0.786	0.584	
	Corrected total	80			
Log Cl					WW-Five Mar-Two Mar-One
	Reach	2	16.46	0.000	
					2012 2009 2011 2013 2008 2010
	Year	5	11.16	0.000	
	Reach* Year	6	2.894	0.014	
	Corrected total	80			
Log HCO_3					Mar-Two Mar-One WW-Five
	Reach	2	4.189	0.000	
					2008 2013 2012 2009 2010 2011
	Year	5	4.529	0.019	
	Reach* Year	6	8.329	0.000	
	Corrected total	80			
Log SO_4					Mar-Two Mar-One WW-Five
	Reach	2	43.76	0.000	
					2013 2011 2009 2012 2008 2010
	Year	5	37.11	0.000	
	Reach*Year	6	4.37	0.001	
	Corrected total	80			

Variable (Dry)	Source	df	F	p	Tukeys post-hoc
Log Total N					WW-Five Mar-One Mar-Two
	Reach	2	7.299	0.001	
					2010 2008 2012 2009 2013 2011
	Year	5	3.123	0.014	
	Reach*Year	6	4.943	0.000	
	Corrected total	80			
Log Total P					Mar-Two Mar-One WW-Five
	Reach	2	0.437	0.648	
					2008 2012 2010 2009 2011 2013
	Year	5	17.64	0.000	
	Reach* Year	6	1.52	0.185	
	Corrected total	80			

Variable (Dry)	Source	df	F	p	Tukeys post-hoc
Log B					WW-Five Mar-Two Mar-One
	Reach	2	42.28	0.000	
					2012 2013 2010 2009 2011 2008
	Year	5	7.563	0.000	
	Reach*Year	6	6.176	0.000	
	Corrected total	80			
Log Cu					WW-Five Mar-One Mar-Two
	Reach	2	6.462	0.003	
					2012 2013 2010 2009 2011 2008
	Year	5	63.4	0.000	
	Reach*Year	6	0.382	0.888	
	Corrected total	80			

Variable (Dry)	Source	df	F	p	Tukeys post-hoc
Log Mn					**Mar-Two** **WW-Five** **Mar-One**
	Reach	2	3.465	0.037	
					2008 **2010** **2011** **2012** **2013** **2009**
	Year	5	5.192	0.000	
	Reach*Year	6	5.192	0.428	
	Corrected total	80			
Log Fe					**Mar-Two** **WW-Five** **Mar-One**
	Reach	2	8.738	0.000	
					2008 **2009** **2013** **2011** **2012** **2010**
	Year	5	2.303	0.054	
	Reach*Year	6	1.788	0.115	
	Corrected total	80			
Log Zn					**Mar-One** **Mar-Two** **WW-Five**
	Reach	2	0.841	0.436	
					2008 **2013** **2011** **2010** **2009** **2012**
	Year	5	93.96	0.000	
	Reach*Year	6	3.542	0.004	
	Corrected total	80			

Variable (Wet)	Source	df	F	p	Tukeys post-hoc
Log pH					**WW-Five** **Mar-One** **Mar-Two**
	Reach	2	0.165	0.848	
					2013 **2012** **2014** **2010** **2009** **2011**
	Year	5	3.423	0.008	
	Reach*Year	7	2.581	0.020	
	Corrected total	80			

Variable (Wet)	*Source*	*df*	*F*	p	Tukeys post-hoc					
Log Temp.					**Mar-One**	**Mar-Two**	**WW-Five**			
	Reach	2	2.631	0.080						
					2009	**2011**	**2012**	**2013**	**2010**	**2014**
	Year	5	16.88	0.000						
	Reach* Year	7	1.691	0.127						
	Corrected total	80								
Log DO (%)					**Mar-One**	**WW-Five**	**Mar-Two**			
	Reach	2	9.302	0.000						
					2013	**2012**	**2010**	**2011**	**2009**	**2014**
	Year	5	4.389	0.002						
	Reach* Year	7	6.017	0.000						
	Corrected total	80								
Log EC					**Mar-Two**	**WW-Five**	**Mar-One**			
	Reach	2	20.952	0.000						
					2014	**2011**	**2012**	**2013**	**2009**	**2010**
	Year	5	35.19	0.000						
	Reach* Year	7	14.47	0.000						
	Corrected total	80								

Variable (Wet)	*Source*	*df*	*F*	p	Tukeys post-hoc					
Log Ca					**Mar-Two**	**Mar-One**	**WW-Five**			
	Reach	2	28.54	0.000						
					2010	**2009**	**2014**	**2013**	**2011**	**2012**
	Year	5	2.79	0.024						
	Reach*Year	7	3.953	0.001						
	Corrected total	80								
					WW-Five	**Mar-Two**	**Mar-One**			
Log Cl	Reach	2	13.47	0.000						

Variable (Wet)	Source	df	F	p	Tukeys post-hoc
					2014 2012 2010 2009 2013 2011
	Year	5	1.759	0.134	
	Reach* Year	7	0.005	5.149	
	Corrected total	80			
					Mar-One Mar-Two WW-Five
Log HCO_3	Reach	2	3.317	0.042	
					2014 2009 2012 2011 2013 2010
	Year	5	16.31	0.000	
	Reach* Year	7	6.096	0.000	
	Corrected total	80			
					Mar-Two Mar-One WW-Five
Log SO_4	Reach	2	54.8	0.000	
					2014 2009 2012 2011 2013 2010
	Year	5	17.93	0.000	
	Reach*Year	7	7.299	0.000	
	Corrected total	80			

Variable (Wet)	Source	df	F	p	Tukeys post-hoc
Log Total N					WW-Five Mar-Two Mar-One
	Reach	2	18.96	0.000	
					2010 2013 2009 2012 2014 2011
	Year	5	2.824	0.023	
	Reach*Year	7	3.174	0.006	
	Corrected total	80			
Log Total P					WW-Five Mar-Two Mar-One
	Reach	2	1.084	0.344	
					2008 2012 2010 2009 2011 2013
	Year	5	44.05	0.000	
	Reach* Year	7	1.704	0.123	
	Corrected total	80			

Variable (Wet)	Source	df	F	p	Tukeys post-hoc					
Log B					Mar-Two	WW-Five	Mar-One			
	Reach	2	14.89	0.000						
					2012	2011	2009	2010	2014	2013
	Year	5	26.01	0.000						
	Reach*Year	7	0.965	0.464						
	Corrected total	80								
Log Cu					WW-Five	Mar-One	Mar-Two			
	Reach	2	0.222	0.802						
					2014	2013	2012	2009	2010	2011
	Year	5	56.45	0.000						
	Reach*Year	7	1.339	0.246						
	Corrected total	80								
Log Mn					WW-Five	Mar-Two	Mar-One			
	Reach	2	4.74	0.012						
					2012	2010	2009	2014	2013	2011
	Year	5	0.781	0.567						
	Reach*Year	7	0.625	0.734						
	Corrected total	80								
Log Fe					WW-Five	Mar-Two	Mar-One			
	Reach	2	5.897	0.004						
					2008	2009	2014	2010	2011	2013
	Year	5	3.217	0.012						
	Reach*Year	7	1.794	0.103						
	Corrected total	80								
Log Zn					Mar-One	Mar-Two	WW-Five			
	Reach	2	34.84	0.000						
					2012	2014	2013	2010	2009	2011
	Year	5	24.01	0.000						
	Reach*Year	7	22.12	0						
	Corrected total	80								

Appendix 5. Microinvertebrate data from the dry-13 and wet-14.

Dry-13

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
PROTISTA																	
Ciliophora		*Euplotes* sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Rhizopoda	Arcellidae	*Arcella bathystoma*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
		Arcella discoides	2	3	4	2	2	3	3	0	3	0	2	0	0	2	3
		Arcella [sm. discoid]	2	1	0	0	2	0	2	3	3	0	0	4	0	0	0
	Centropyxidae	*Centropyxis aculeata*	2	2	0	3	3	3	2	0	3	1	0	3	3	2	3
		Centropyxis discoides	2	2	0	0	2	2	0	0	3	0	0	2	2	0	0
		Centropyxis ecornis	2	2	4	2	2	2	0	0	3	0	2	3	2	1	3
		Centropyxis [sm, lt br, circular]	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
		Centropyxis [sm, lt br, oblique, spined]	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	Difflugiidae	*Difflugia elegans*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Difflugia cf. *lithoplites*	0	0	0	0	3	2	1	0	3	0	0	3	3	0	4
		Difflugia [med, pyrif.]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Difflugia [sm, ovoid]	1	1	0	2	2	2	2	0	3	2	0	2	0	0	3
	Euglyphidae	*Euglypha* sp. b [gracile]	2	0	0	0	0	0	0	0	0	0	0	3	0	0	0
	Lesquereusiidae	*Lesquereusia spiralis*	1	2	0	2	3	3	4	0	3	2	1	3	2	4	1
	Nebelidae	*Nebela* sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	Phryganelidae	*Phryganella* sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ROTIFERA																	
Bdelloidea	Philodinidae	indet. bdelloid [sm.]	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		indet. bdelloid [med.]	1	3	1	0	2	2	3	2	3	2	2	3	2	3	1
		indet. bdelloid [lg.]	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Monogononta	Brachionidae	*Brachionus angularis*	2	0	0	0	0	0	0	1	2	0	0	2	0	0	0
		Keratella procurva	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Keratella tropica	2	2	1	0	0	2	0	0	2	0	0	0	0	0	0
		Platyias quadricornis	0	0	0	0	0	0	0	0	2	0	0	0	2	0	1
	Dicranophoridae	*Dicranophorus epicharis*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		cf. *Encentrum saundersiae*	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	Epiphanidae	*Microcodides* cf. *chlaena*	2	0	0	1	0	0	0	0	0	0	0	2	0	0	1
	Euchlanidae	*Dipleuchlanis propatula*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Euchlanis dilatata	0	2	0	2	2	0	2	0	2	2	0	2	2	4	1
		Tripleuchlanis plicata	0	0	0	2	0	0	0	0	4	0	0	3	2	0	0
	Lecanidae	*Lecane aculeata*	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0
		Lecane bulla	2	0	0	2	2	2	2	1	3	4	0	3	4	3	5
		Lecane curvicornis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Lecane hamata	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Lecane leontina	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Lecane luna	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Lecane lunaris	1	0	1	1	0	0	0	0	2	2	0	0	2	0	0
		Lecane noobijupi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Lecane obtusa	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Lecane papuana	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
		Lecane thalera	0	0	0	0	0	0	1	0	0	0	0	2	0	2	0
		Lecane (M.) a	1	0	1	0	0	2	2	0	2	2	0	2	2	2	1
		Lecane (M.) b	1	0	0	0	0	2	2	0	2	2	0	0	2	0	1
		Lecane (M.) c [tiny]	0	1	1	0	0	2	2	0	2	2	0	0	4	0	0
		Lecane (s.str.) a	0	0	0	2	0	2	0	2	0	2	0	2	2	0	3
		Lecane (s.str.) b	0	0	0	1	0	2	0	0	0	0	0	1	3	0	3
		Lecane (s.str.) c	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	Lepadellidae	*Colurella uncinata bicuspidata*	2	0	0	0	0	0	0	0	0	0	0	2	2	2	0
		Lepadella patella	2	0	0	0	0	0	0	0	2	3	0	0	2	0	0
		Lepadella a	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Lepadella c [tiny]	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Lindiidae	*Lindia torulosa*	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella gibba*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Cephalodella a	2	0	0	0	2	0	0	0	0	3	0	0	0	0	0
		Cephalodella c [tiny]	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
		Monommata sp. b [sm]	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Notommata sp.	1	0	0	1	0	0	0	0	2	2	0	0	2	4	0
	Synchaetidae	*Polyarthra*	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0
	Testudinellidae	*Testudinella amphora*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
		Testudinella patina	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1
		Testudinella sp.	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Trichocercidae	*Trichocerca* sp. A	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Trochosphaeriidae	*Filinia longiseta*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		indet. glob. rotifer	0	0	1	2	2	0	2	0	0	0	0	1	2	2	3
ARTHROPODA																	
CRUSTACEA																	
MAXILLIPODA																	
Cyclopoida		cyclopoid copepodites	3	3	1	1	3	3	3	4	3	3	0	3	0	3	4
		cyclopoid nauplii	3	2	6	0	2	3	3	3	3	2	0	4	3	0	5
DIPLOSTRACA																	
CLADOCERA	**Chydoridae**	*Alona* sp. [smooth]	0	0	0	0	0	0	3	1	0	0	0	2	2	0	1
		Anthalona sp. [cf. *Alona pseudoverrucosa*]	0	1	1	3	2	3	3	0	0	0	0	0	0	0	0
		Chydorus sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		Dunhevedia crassa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Macrotrichidae	*Macrothrix* cf. *spinosa*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
OSTRACODA																	
PODOCOPIDA	**Cyprididae**	*Cypretta* sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		cf. *Cypridopsis* sp.	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
		cf. *Ilyocypris* sp.	0	0	0	0	0	0	0	0	0	0	2	0	1	2	0
		cf. *Riocypris* sp.	0	0	0	0	0	0	0	0	0	2	0	0	3	2	0
	Darwinulidae	*Vestalenula marmonieri*	0	0	0	1	2	3	2	0	2	0	1	0	0	1	1
	Limnocytheridae	*Limnocythere* sp.	0	0	1	2	0	3	2	0	2	1	2	1	0	0	1
		cf. *Sarscypridopsis*	0	0	0	0	0	0	2	0	3	0	0	4	0	0	0
		juv. ostracods, indet.	0	0	1	3	0	3	2	0	0	3	2	2	0	0	1
		Taxa richness	**27**	**16**	**14**	**24**	**20**	**25**	**26**	**9**	**30**	**23**	**10**	**31**	**27**	**18**	**27**

Wet-14

			Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
PROTISTA																				
Ciliophora		*Euplotes* sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Stentor sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Rhizopoda	Arcellidae	*Arcella discoides*	0	2	2	0	2	0	2	0	3	1	0	2	1	2	2	0	3	0
		Arcella hemisphaerica	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	3	0	0
		Arcella megastoma	0	0	2	0	0	0	2	0	0	0	2	0	1	0	0	0	0	1
		Arcella [sm. discoid]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	Centropyxidae	*Centropyxis aculeata*	0	0	0	0	2	0	2	0	2	0	3	2	0	0	0	1	0	0
		Centropyxis cf. *aculeata* [tiny]	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Centropyxis ecornis	0	1	1	2	2	0	2	0	0	1	3	3	0	0	0	0	2	0
		Centropyxis [lg, irregular]	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Centropyxis [med, dk br]	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	0
		Centropyxis [sm, lt br, circular]	0	0	0	0	2	0	0	0	0	0	3	2	2	0	0	0	0	0
		Centropyxis [sm, lt br, oblique, spined]	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0
		Centropyxis [tiny]	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Difflugiidae	*Difflugia capreolata*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		Difflugia elegans	0	0	0	0	2	0	0	0	2	0	0	2	0	0	0	0	0	0
		Difflugia cf. *globulosa*	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	1
		Difflugia gramen	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Difflugia cf. *lithoplites*	0	0	0	3	3	0	4	0	3	0	2	4	0	2	0	3	4	5
		Difflugia oblonga	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Difflugia [med, pyrif.]	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	3
		Difflugia [sm, ovoid]	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Euglyphidae	*Euglypha* sp. c [tiny, ovoid]	0	0	0	0	0	0	0	0	3	0	2	3	2	0	0	0	3	3
	Lesquereusiidae	*Lesquereusia spiralis*	0	0	0	3	3	0	2	0	3	2	3	3	2	2	3	3	3	3
		Netzelia tuberculata	0	0	0	0	0	0	0	0	2	0	0	0	0	2	2	0	0	0
	Trigonopyxidae	*Cyclopyxis* sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0
ROTIFERA																				
Bdelloidea	Philodinidae	indet. bdelloid [tiny]	0	0	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0	0
		indet. bdelloid [sm.]	0	0	2	3	3	1	2	0	3	2	2	3	2	0	0	3	3	3
		indet. bdelloid [med.]	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
		indet. bdelloid [lg.]	0	0	0	2	2	1	2	0	3	1	0	3	0	0	0	0	3	3
Monogononta	Brachionidae	*Keratella procurva*	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0
		Keratella tropica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Platyias quadricornis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dicranophoridae	*cf. Dicranophoroides sp.*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Epiphanidae	*Microcodides* cf. *chlaena*	0	0	0	2	2	0	0	0	2	0	0	2	0	0	2	3	0	0
	Euchlanidae	*Dipleuchlanis propatula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
		Euchlanis dilatata	0	0	0	2	3	0	0	0	0	0	2	2	0	2	0	0	0	0
		Euchlanis meneta	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	4
		Tripleuchlanis plicata	0	0	0	2	2	0	2	0	2	0	3	4	0	2	2	4	4	3
	Lecanidae	*Lecane bulla*	0	0	0	3	3	2	2	0	3	1	2	4	2	2	2	4	4	4
		Lecane curvicornis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0
		Lecane hamata	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Lecane ludwigii	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Lecane luna	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0
		Lecane lunaris	0	0	0	2	0	0	0	0	2	0	0	2	0	0	0	0	0	0
		Lecane noobijupi	0	0	0	2	2	0	0	0	0	0	2	0	0	0	0	3	0	3
		Lecane obtusa	0	0	0	0	0	0	0	0	2	0	0	3	2	0	0	3	0	3
		Lecane papuana	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Lecane signifera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0

			Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
		Lecane thalera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
		Lecane unguitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Lecane ungulata	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Lecane (M.) a	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Lecane (s.str.) c	0	0	0	2	0	0	0	0	2	0	0	2	0	0	0	0	0	0
	Lepadellidae	*Colurella uncinata bicuspidata*	0	0	0	2	2	0	0	0	2	0	2	0	0	2	0	3	3	3
		Heterolepadella heterostyla	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Lepadella patella	0	0	0	2	0	0	0	0	2	0	2	2	0	0	2	0	2	0
		Lepadella rhomboides	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Lepadella triptera	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Lepadella b	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Lepadella c [tiny]	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
	Lindiidae	*Lindia torulosa*	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0	0
	Mytilinidae	*Mytilina ventralis*	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella forficula*	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	0
		Cephalodella gibba	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
		Cephalodella b	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0
		Cephalodella c [tiny]	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Monommata sp. b [sm]	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Notommata sp.	0	0	0	2	2	0	2	1	2	0	0	2	0	0	0	0	3	3
	Scaridiidae	*Scaridium* sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Testudinellidae	*Testudinella patina*	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	Trichocercidae	*Trichocerca* sp. A	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0
		Trichocerca sp. B	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0
	Trichotriidae	*Macrochaetus* sp.	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0
		indet. glob. rotifer	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0
ARTHROPODA																				
CRUSTACEA																				
MAXILLIPODA																				
Cyclopoida		cyclopoid copepodites	0	2	2	2	3	1	0	0	2	0	2	0	2	0	0	1	0	1
		cyclopoid nauplii	0	1	2	3	3	2	2	0	3	1	2	3	2	0	0	3	0	3
	Cyclopidae	*Australoeucyclops karaytugi*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mesocyclops notius	2	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Mesocyclops sp.	0	0	0	0	2	2	0	0	2	0	2	0	0	0	0	0	1	0
		Tropocyclops sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Harpacticoida		Harpacticoid copepodite	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DIPLOSTRACA																				
CLADOCERA	**Chydoridae**	*Alona* sp. [smooth]	0	0	0	0	3	1	2	0	0	2	0	0	0	0	0	0	0	0
		Anthalona sp. [cf. *Alona pseudoverrucosa*]	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Chydorus sp.	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
		cf. *Coronatella* sp.	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
		Ephemeroporus barroisi	0	0	0	2	0	0	0	0	2	0	0	0	0	2	0	0	2	1
		indet. juvenile	0	0	0	0	0	0	0	0	3	1	0	1	0	2	0	0	0	0
	Macrotrichidae	*Macrothrix* cf. *spinosa*	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
OSTRACODA																				
PODOCOPIDA	**Cyprididae**	*Cypretta* sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Limnocytheridae	cf. *Gomphodella* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Limnocythere sp.	0	0	0	2	1	0	0	0	2	2	0	0	0	0	0	0	0	0
	Notodromadidae	*Newnhamia fenestrata*	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
		juv. ostracods, indet.	0	0	0	2	2	1	0	0	2	2	2	0	2	0	2	3	0	0
		Taxa richness	2	5	8	31	29	10	21	1	45	13	23	35	13	11	13	23	21	18

Appendix 6. Hyporheic fauna data from the dry-13 and wet-14.

Dry-13

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
NEMATODA		Nematoda spp.	0	0	0	2	0	0	0	0	0	0	0	0	3	2	0
NEMATOMORPHA		Nematomorpha sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CNIDARIA																	
HYDROZOA	Hydridae	*Hydra* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
MOLLUSCA																	
GASTROPODA																	
	Lymnaeidae	*Bullastra vinosa*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Planorbidae	*Gyraulus* sp.	0	0	0	0	0	0	0	0	0	2	0	0	3	0	2
ANNELIDA																	
OLIGOCHAETA																	
		Oligochaeta spp. (imm)	2	0	3	2	2	1	2	2	0	2	0	1	1	2	2
		Oligochaeta spp. (earthworm)	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Tubificida	Enchytraeidae	Enchytraeidae sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Naididae	Naidinae spp. (imm./dam.)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
		Allonais pectinata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Nais communis	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Pristina aequiseta	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0
		Pristina jenkinae	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0
		Pristina longiseta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Pristina nr *sima*	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
		Pristina sp.	0	2	4	0	0	0	2	0	0	0	2	0	0	0	2
	Phreodrilidae	Phreodrilidae spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
ARTHROPODA																	
CRUSTACEA																	
MAXILLOPODA																	
COPEPODA																	
Cyclopoida	Cyclopidae	*Australoeucyclops karaytugi*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ectocyclops phaleratus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Microcyclops varicans	0	0	2	3	2	0	3	3	1	2	0	2	3	0	0
		immature cyclopoid copepodites/nauplii	0	2	0	3	0	0	3	3	0	0	0	0	0	1	0
BRANCHIOPODA																	
CLADOCERA	Chydoridae	*Alonella excisa*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
OSTRACODA	Candonidae	*Candonopsis* cf. *pilbarae*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Pilbaracandona sp. (juv.)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Cyprididae	indet. cypridopsid	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Darwinulidae	*Vestalenula* sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Limnocytheridae	*Gomphodella* n. sp. (BOS334)	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
MALACOSTRACA																	
Amphipoda																	
	Paramelitidae	Paramelitidae spp. (imm./dam.)	1	2	1	1	3	3	0	3	3	2	2	1	3	2	0
		Paramelitidae sp. B	0	0	0	0	3	3	0	3	2	2	0	2	2	1	0
		Paramelitidae sp. D	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Chydaekata sp.	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0
		Maarrka weeliwolli	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0
ARACHNIDA																	
Astigmata		Astigmata spp.	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0
Mesostigmata		Mesostigmata spp.	0	0	0	0	2	0	1	1	0	0	2	0	0	2	0
Sarcoptiformes		Oribatida spp.	0	0	2	0	0	0	0	0	0	2	3	0	2	1	3
Trombidiformes		Hydracarina spp.	0	2	3	0	2	0	2	2	2	1	0	0	2	3	0
		Trombidioidea spp.	0	2	0	2	0	0	0	0	0	0	0	2	2	3	0
	Halacaridae	Halacaridae spp.	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
	Pezidae	Pezidae spp.	0	0	0	1	2	0	0	0	1	0	0	0	0	2	0
MYRIAPODA		Myriapoda spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0
COLLEMBOLA																	
Entomobryomorpha		Entomobryoidea spp.	0	0	0	0	2	0	2	0	3	3	3	3	3	3	0
Poduromorpha		Poduroidea spp.	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Symphypleona		Symphypleona spp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
INSECTA																	
Ephemeroptera	Baetidae	Baetidae spp. (imm./dam.)	0	2	0	0	0	0	2	1	0	0	0	0	0	0	0
		Cloeon sp. Red Stripe	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	Caenidae	Caenidae spp. (imm./dam.)	2	2	0	0	0	0	1	0	0	0	0	0	0	0	2
		Tasmanocoenis sp. M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Tasmanocoenis sp. P/*arcuata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Odonata																	
Anisoptera		Anisoptera spp. (imm)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Zygoptera		Zygoptera spp. (imm)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Hemiptera	Belostomatidae	*Diplonychus* sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Carabidae	Carabidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Dytiscidae	Dytiscidae spp. (L)	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0
		Allodessus bistrigatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
		Bidessini spp. (L)	0	0	0	3	0	0	3	3	0	0	0	0	1	0	0
		Copelatus nigrolineatus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		Limbodessus compactus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Limbodessus occidentalis	0	0	0	0	0	0	0	0	0	1	2	0	2	0	1
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	0	0	1	0	0	0	3	0	0	0	3
	Hydraenidae	Hydraenidae sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Hydraena spp.	0	0	0	0	0	0	2	2	0	3	2	0	2	0	2
		Ochthebius sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydrochidae	*Hydrochus* sp. (L)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	*Agraphydrus coomani*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Anacaena horni	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Enochrus deserticola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
		Enochrus elongatulus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Enochrus sp. (L)	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0
		Helochares sp. (L)	0	0	0	2	3	0	0	0	0	0	0	2	0	2	2
		Paracymus sp. (L)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
		Paracymus spenceri	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Regimbartia attenuata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Scirtidae	Scirtidae spp. (L)	1	0	0	3	3	0	2	1	0	0	0	1	0	2	3
	Staphylinidae	Staphylinidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Diptera	**Cecidomyiidae**	Cecidomyiidae spp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Ceratopogonidae	Ceratopogonidae spp. (P)	0	1	0	0	2	0	0	0	0	2	0	0	0	1	1
		Ceratopogoninae spp.	2	4	3	2	3	3	3	3	3	0	2	2	2	2	3
		Dasyheleinae spp.	0	0	0	3	1	1	0	1	0	0	0	0	2	1	2
	Chironomidae	Chironomidae spp. (P)	0	2	0	1	0	2	1	2	0	0	0	2	0	0	0
	Chironominae	*Cladopelma curtivala*	0	3	0	2	0	0	0	0	0	0	0	0	0	0	1
		Polypedilum sp. 1	0	0	1	0	0	0	2	1	0	0	0	0	0	0	0
		Paratendipes sp. K1	2	4	3	2	0	0	0	0	1	0	0	0	0	0	0
		Polypedilum sp. 2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Chironomus sp. (WWC3)	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
		Cryptochironomus griseidorsum	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Polypedilum nubifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Dicrotendipes sp. 2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
		Tanytarsus sp. (WWTS1)	0	2	0	1	0	0	2	2	0	0	0	0	0	0	2
		Cladotanytarsus sp. (WWTS4)	0	3	0	2	0	0	2	2	0	0	0	0	0	0	0
	Orthocladiinae	*Rheocricotopus* sp. (WWO1)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Parametriocnemus sp. (WWO2)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Corynoneura sp. (WWO5)	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Orthocladiinae spp. (WWO7)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Orthocladiinae spp. (WWO8)	0	0	0	0	2	2	0	0	1	0	0	2	0	0	0
	Tanypodinae	*Paramerina* sp. (WWT1)	2	0	0	4	2	2	2	0	0	2	0	0	1	0	3
		Paramerina sp. 2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Thienemannimyia sp. (WWT2)	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Larsia albiceps	2	4	1	0	1	0	2	0	0	0	0	0	0	0	2
		Procladius sp. (WWT5)	0	2	0	0	0	0	0	0	1	0	0	0	0	0	2
		Ablabesmyia hilli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		?Pentanuera sp. (WWT9)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Culicidae	*Anopheles* spp.	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0
	Dolichopodidae	Dolichopodidae spp.	2	0	0	0	2	0	0	0	0	3	0	0	0	1	2
	Stratiomyidae	Stratiomyidae spp.	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera	**Crambidae**	Acentropinae spp. (imm./dam.)	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0
		Taxa Richness	**16**	**22**	**14**	**32**	**24**	**13**	**26**	**24**	**13**	**16**	**12**	**17**	**19**	**22**	**36**

Wet-14

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
PLATYHELMINTHES																	
TURBELLARIA		Turbellaria spp.	2	0	0	0	0	0	0	0	0	0	1	1	0	0	0
NEMATODA		Nematoda spp.	0	0	0	2	0	0	0	1	0	1	1	0	0	0	0
CNIDARIA																	
HYDROZOA	Hydridae	*Hydra* sp.	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ANNELIDA																	
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
Tubificida	Naididae	Naidinae spp. (imm.)	3	0	2	0	3	2	2	1	0	2	3	0	0	2	0
		Allonais paraguayensis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Pristina leidyi	0	0	0	0	2	0	3	1	1	2	2	0	2	0	0
		Pristina longiseta	3	0	0	0	3	2	0	2	2	2	2	2	0	2	2
		Pristina sp.	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
ARTHROPODA																	
CRUSTACEA																	
MAXILLOPODA																	
COPEPODA																	
Cyclopoida	Cyclopidae	*Australoeucyclops karaytugi*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Mesocyclops holynskae	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0
		Mesocyclops sp.	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
		Microcyclops varicans	2	0	2	2	0	3	3	2	2	3	2	2	1	3	2
		cyclopoid copepodites/nauplii	0	0	2	0	0	0	0	2	0	0	0	2	0	0	0
Harpacticoida	Parastenocarididae	*Parastenocaris* cf. *jane* (imm.)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OSTRACODA	Candonidae	*Pilbaracandona* sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Limnocytheridae	*Gomphodella* n. sp. (BOS334)	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MALACOSTRACA																	
Amphipoda	Paramelitidae	Paramelitidae spp. (imm./dam.)	1	0	0	2	1	2	2	0	2	2	2	0	3	1	2
		Chydaekata sp.	0	0	0	0	0	1	0	0	0	2	1	0	0	0	0
		Maarrka weeliwolli	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
		Paramelitidae sp. B	0	0	0	0	3	3	3	1	0	2	3	0	2	2	2
		Paramelitidae sp. D	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
ARACHNIDA																	
Astigmata		Astigmata spp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Mesostigmata		Mesostigmata spp.	0	0	0	0	0	0	1	0	2	0	2	1	0	0	1
Trombidiformes		Hydracarina spp.	3	0	0	3	1	0	2	2	0	3	3	2	0	1	1
		Trombidioidea spp.	1	0	0	0	0	0	3	0	0	0	1	0	2	0	1
	Halacaridae	Halacaridae spp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pezidae	Pezidae sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
COLLEMBOLA																	
Entomobryomorpha		Entomobryoidea spp.	0	0	0	0	0	0	2	1	0	2	2	0	0	1	2
Symphypleona		Symphypleona spp.	0	0	0	0	0	1	0	0	0	1	2	2	0	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
INSECTA																	
Ephemeroptera	Caenidae	Caenidae spp. (dam/imm.)	2	0	2	0	0	0	0	0	0	0	2	1	0	0	0
Odonata		Anisoptera spp. (imm.)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Coleoptera		Coleoptera spp. (L)	0	0	0	0	0	0	0	1	1	0	2	1	0	0	0
	Carabidae	Carabidae spp. (L)	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0
	Dytiscidae	Bidessini spp. (L)	0	0	0	1	0	0	0	0	0	0	0	1	0	2	2
		Limbodessus occidentalis	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	Hydraenidae	Hydraenidae spp. (L)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
		Hydraena sp.	2	0	1	0	2	0	0	0	0	0	0	1	2	1	0
		Limnebius sp.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
	Hydrochidae	Hydrochidae sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Hydrophilidae	Hydrophilidae spp. (hypo/L)	0	2	0	1	0	0	0	0	0	0	1	0	2	0	0
		Chaetarthria nigerrima (L)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Coelostoma fabricii	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
		Enochrus spp. (L)	0	0	0	0	2	0	1	0	1	0	0	0	1	0	1
		Helochares sp. (L)	2	0	0	0	0	0	0	0	0	1	0	0	2	0	0
		Laccobius sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus spenceri	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus sp. (L)	1	0	2	0	0	0	0	0	0	0	0	0	2	0	0
	Ptiliidae	Ptiliidae spp.	2	0	0	0	0	0	2	0	0	0	1	2	0	0	0
	Scirtidae	Scirtidae spp. (L)	2	0	0	2	2	2	0	1	2	1	2	0	0	2	2
Diptera	Ceratopogonidae	Ceratopogonidae spp. (P)	0	1	1	0	0	0	0	0	0	0	0	0	2	1	0
		Ceratopogoninae spp.	3	1	3	2	3	3	2	2	2	2	3	3	3	2	2
		Dasyheleinae spp.	2	3	3	0	2	0	2	0	1	2	3	3	3	2	1
		Forcipomyiinae spp.	0	0	1	0	0	0	0	0	0	0	2	0	0	2	0
	Chironomidae	Chironomidae spp. (P)	0	0	1	0	0	0	0	1	0	0	1	0	2	0	0
	Chironominae	*Dicrotendipes* sp. 2	2	0	2	3	0	0	0	0	0	2	1	0	2	0	0
		Paratendipes sp. K1	1	0	2	0	0	0	1	0	0	0	0	0	0	0	0
		Polypedilum sp. 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Polypedilum watsoni	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Cladotanytarsus sp. (WWTS4)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		Tanytarsus sp. (WWTS1)	1	0	3	0	0	0	0	1	0	0	1	0	0	0	0
	Tanypodinae	*Nilotanypus* sp. (WWT3)	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Paramerina sp. (WWT1)	2	0	1	2	0	2	0	0	0	2	2	0	0	2	2
		Paramerina sp. 2	0	0	0	0	2	2	0	0	1	2	0	1	0	2	2
		Procladius sp. (WWT5)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Orthocladiinae	*Cricotopus albitarsis*	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0
		Orthocladiinae spp. (WWO13)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Culicidae	*Anopheles* sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Culex sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Dolichopodidae	Dolichopodidae spp.	0	1	1	0	2	0	0	0	0	0	0	0	3	0	1
	Tabanidae	Tabanidae sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Thaumaleidae	Thaumaleidae sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Tipulidae	Tipulidae spp.	0	0	2	0	0	0	0	0	2	0	2	2	0	0	0
		Taxa Richness	**26**	**5**	**24**	**12**	**18**	**17**	**17**	**15**	**12**	**22**	**34**	**17**	**21**	**17**	**17**

Appendix 7. Macroinvertebrate data from the dry-13 and wet-14.

Dry-13

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
NEMATODA		Nematoda spp.	0	2	1	0	0	0	1	0	0	2	1	0	0	0	0
GORDIOIDA		Gordioida spp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
CNIDARIA																	
HYDROZOA	Hydridae	*Hydra* spp.	0	0	2	0	2	2	0	0	0	0	0	1	0	0	0
ANNELIDA																	
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	2	0	0	0	0	0	0	2	0	0	0	2	0	0	0
Tubificida	Naididae	Naidinae spp. (imm./dam.)	2	2	2	2	2	3	2	2	2	0	2	3	0	0	0
		Allonais paraguayensis	0	0	1	0	0	2	1	0	0	0	0	0	0	0	0
		Allonais pectinata	0	0	0	2	2	3	0	0	0	0	2	2	3	2	0
		Allonais ranauana	0	0	0	2	2	0	2	0	2	0	0	0	0	0	0
		Dero (Allodero) sp. WA2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Dero furcata	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
		Pristina leidyi	2	0	2	1	0	3	3	2	2	2	0	3	4	3	0
		Pristina longiseta	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Pristina spp.	0	2	2	0	2	0	0	0	0	2	2	0	3	2	0
	Phreodrilidae	Phreodrilidae spp. (imm./dam.)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
MOLLUSCA																	
GASTROPODA	Lymnaeidae	*Bullastra vinosa*	1	3	3	3	1	2	3	0	3	2	2	3	2	3	2
	Planorbidae	*Ferrissia petterdi*	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Gyraulus spp.	3	3	4	3	1	2	2	0	3	3	2	3	3	3	2
ARTHROPODA																	
CRUSTACEA																	
MALACOSTRACA																	
Amphipoda	Paramelitidae	Paramelitidae spp. (imm./dam.)	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0
		Paramelitidae sp. B	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Paramelitidae sp. D	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
		Chydaekata sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Maarrka weeliwolli	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ARACHNIDA																	
Sarcoptiformes		Oribatida spp.	0	2	2	2	0	3	0	0	0	0	0	1	0	0	1
Trombidiformes		Hydracarina spp.	3	3	3	3	2	3	1	3	3	2	0	2	3	2	3
		Trombidioidea spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
COLLEMBOLA																	
Entomobryomorpha		Entomobryoidea spp.	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0
INSECTA																	
Ephemeroptera	Baetidae	Baetidae spp. (imm./dam.)	3	3	2	3	2	2	0	0	3	2	3	0	2	0	3
		Cloeon sp. Red Stripe	2	3	4	3	2	1	3	0	2	3	2	3	2	0	3
		Offadens sp. G1WA2	2	2	0	0	3	3	0	0	0	0	0	0	0	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
	Caenidae	Caenidae spp. (imm./dam.)	3	2	2	3	0	2	0	0	3	0	0	0	0	0	2
		Tasmanocoenis spp. (imm./dam.)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		Tasmanocoenis sp. M	2	2	0	0	2	0	3	0	2	0	0	2	0	0	0
		Tasmanocoenis sp. P/*arcuata*	3	2	0	3	2	3	0	0	2	0	0	0	0	0	0
Odonata																	
Anisoptera		Anisoptera spp. (imm./dam.)	2	3	3	3	2	2	2	0	3	0	0	3	2	2	3
	Aeshnidae	Aeshnidae spp. (imm./dam.)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Hemianax papuensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Corduliidae	*Hemicordulia tau*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0
	Libellulidae	*Diplacodes haematodes*	0	1	2	0	2	2	0	0	2	0	0	3	3	2	3
		Nannophlebia injibandi	2	0	0	0	3	2	0	0	0	0	0	0	0	0	0
		Orthetrum caledonicum	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
		Tramea sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Zygoptera		Zygoptera spp. (imm./dam.)	0	3	2	3	0	0	0	0	3	0	0	0	0	2	0
	Coenagrionidae	*Agriocnemis* spp.	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0
		Argiocnemis rubescens	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0
		Ischnura aurora	0	2	3	2	2	0	0	0	1	0	0	2	0	0	3
		Pseudagrion aureofrons	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
		Pseudagrion microcephalum	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
		Xanthagrion erythroneurum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Hemiptera	**Belostomatidae**	*Diplonychus* spp.	0	0	0	3	0	0	2	0	2	0	0	0	0	2	0
	Corixidae	Corixidae/Micronectidae spp. (imm./dam.)	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0
		Agraptocorixa parvipunctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Agraptocorixa spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Gerridae	Gerridae spp. (imm./dam.)	0	0	0	1	2	1	1	0	0	0	0	2	0	2	0
		Limnogonus fossarum gilguy	0	0	0	0	1	0	0	0	2	0	0	0	0	0	1
		Rhagadotarsus anomalus	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Hebridae	Hebridae spp. (imm./dam.)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Hebrus axillaris	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Hebrus pilosus	0	0	0	0	0	2	2	1	2	0	0	0	0	0	1
	Mesoveliidae	*Mesovelia hungerfordi*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Mesovelia spp. (imm./dam.)	0	1	0	0	2	0	0	0	1	0	0	0	0	0	0
	Micronectidae	*Austronecta bartzarum*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		Micronecta paragoga	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Micronecta spp.	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
	Nepidae	*Ranatra diminuta*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Ranatra occidentalis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Notonectidae	Notonectidae spp. (imm./dam.)	0	0	0	1	0	0	0	0	0	0	0	2	0	2	0
		Anisops hackeri	0	0	2	0	0	0	0	2	0	2	0	0	0	0	0
		Anisops nasutus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Anisops spp. (F)	0	0	3	0	0	0	0	2	1	3	0	1	2	1	3
		Anisops stali	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2
	Pleidae	*Paraplea* spp.	0	0	1	2	0	0	0	0	0	0	0	0	1	0	1
	Veliidae	Veliidae spp. (imm./dam.)	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0
		Microvelia herberti	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Microvelia oceanica	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Microvelia peramoena	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Microvelia spp.	1	1	0	1	1	0	0	0	0	0	0	0	0	2	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
Coleoptera	Dytiscidae	*Allodessus bistrigatus*	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0
		Bidessini spp. (L)	0	0	1	0	1	0	2	0	0	0	0	0	2	0	0
		Hydaticus consanguineus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Hydroglyphus grammopterus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Hydroglyphus leai	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0
		Hyphydrus elegans	0	0	0	0	0	0	0	0	0	1	0	2	0	0	3
		Hyphydrus lyratus	0	0	0	0	0	0	0	0	0	1	0	2	0	0	2
		Hyphydrus sp. (L)	0	0	0	0	0	0	0	0	0	2	0	1	2	0	0
		Laccophilus sharpi	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0
		Limbodessus compactus	0	0	0	0	1	1	0	2	0	2	1	2	1	0	1
		Limbodessus occidentalis	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
		Necterosoma regulare	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
		Necterosoma undecimlineatum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
		Onychohydrus sp. (L)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Platynectes decempunctatus var. *decempunctatus*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Platynectes sp. (L)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Sternopriscus multimaculatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Tiporus tambreyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Elmidae	*Austrolimnius* sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		Austrolimnius sp. (L)	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
	Gyrinidae	*Dineutus australis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
		Macrogyrus gibbosus	0	0	2	0	2	0	0	0	0	0	0	0	0	0	3
		Macrogyrus gouldii	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Macrogyrus sp. (L)	2	1	0	1	2	2	0	0	0	0	0	0	0	0	0
	Hydraenidae	*Hydraena* sp.	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Limnebius sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Ochthebius sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Hydrochidae	*Hydrochus* sp.	2	1	0	1	0	2	0	0	0	0	0	0	0	1	0
	Hydrophilidae	*Agraphydrus coomani*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Anacaena horni	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		Berosus australiae	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
		Berosus dallasae	0	0	0	0	0	0	0	0	0	0	3	1	0	0	3
		Berosus pulchellus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1
		Berosus sp. (L)	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
		Enochrus deserticola	0	0	0	0	0	2	0	0	0	0	0	2	0	2	0
		Enochrus elongatulus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Enochrus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Enochrus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Helochares sp. (L)	0	0	0	2	2	2	1	0	2	0	1	1	2	2	1
		Helochares tatei	0	0	2	0	0	0	1	0	1	0	0	2	1	0	2
		Paracymus sp. (L)	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0
		Paracymus spenceri	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0
		Regimbartia attenuata	0	0	2	2	0	0	0	0	1	2	0	0	2	0	2
		Sternolophus marginicollis	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	Limnichidae	Limnichidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Scirtidae	Scirtidae spp. (L)	3	1	1	0	3	4	0	0	2	0	0	0	0	0	0
Diptera	Cecidomyiidae	Cecidomyiidae spp.	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	Ceratopogonidae	Ceratopogonidae spp. (P)	0	0	1	2	1	1	0	0	2	0	2	2	2	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
		Ceratopogoninae spp.	2	3	3	2	3	2	2	2	2	2	3	3	3	2	3
		Dasyheleinae spp.	0	0	2	2	0	2	2	0	2	0	2	2	2	2	0
		Forcipomyiinae spp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	3	3	3	3	3	3	0	2	0	2	2	2	2	2
	Chironominae	*Cladopelma curtivala*	0	3	3	3	0	0	1	0	0	0	0	0	0	0	0
		Polypedilum sp. 1	0	2	2	0	2	0	1	0	0	0	0	0	0	0	0
		Dicrotendipes sp. (WWC17)	0	0	2	0	0	0	1	0	0	0	0	3	0	0	0
		Paratendipes sp. K1	0	3	2	2	0	0	0	0	0	0	0	0	0	0	0
		Skusella subvittata	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		Polypedilum sp. 2	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0
		Chironomus sp. (WWC3)	0	0	0	0	2	0	2	4	0	4	3	3	2	3	0
		Dicrotendipes sp. 5 (WWC38)	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0
		Cryptochironomus griseidorsum	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0
		Polypedilum nubifer	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
		Polypedilum (Pentapedilum) leei	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Dicrotendipes sp. 1	0	0	0	3	3	0	0	0	2	0	0	2	0	0	0
		Dicrotendipes sp. 2	0	2	2	3	3	2	2	0	2	0	0	3	0	0	3
		Tanytarsus sp. (WWTS1)	2	2	3	2	3	0	3	0	3	4	3	4	3	4	4
		Paratanytarsus sp. (WWTS2)	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0
		Cladotanytarsus sp. (WWTS4)	2	2	2	0	3	3	1	0	2	0	0	0	0	0	0
		Rheotanytarsus sp. 1	3	3	0	0	3	0	1	0	3	0	0	0	0	0	0
	Orthocladiinae	*Rheocricotopus* sp. (WWO1)	2	0	0	0	3	3	1	0	0	0	0	0	0	0	0
		Parametriocnemus sp. (WWO2)	3	3	0	0	0	2	0	0	0	0	0	0	0	0	0
		Cricotopus albitarsis	0	0	0	2	2	3	0	0	0	0	0	0	0	0	0
		Thienemanniella sp. (WWO4)	3	0	0	0	3	2	2	0	0	0	0	0	0	0	0
		Corynoneura sp. (WWO5)	2	2	0	2	0	2	1	0	0	0	0	0	0	0	0
	Tanypodinae	*Paramerina* sp. (WWT1)	2	2	2	0	2	0	3	0	2	0	0	0	1	1	0
		Paramerina sp. 2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0
		Thienemannimyia sp. (WWT2)	4	0	0	0	3	0	0	0	0	0	0	0	0	0	0
		Nilotanypus sp. (WWT3)	2	0	0	0	0	3	1	0	0	0	0	0	0	0	0
		Larsia albiceps	2	3	3	3	3	0	3	0	3	0	0	2	1	0	3
		Procladius sp. (WWT5)	0	2	3	0	2	2	0	0	2	2	0	3	2	0	3
		Ablabesmyia hilli	0	2	4	2	2	0	2	0	2	0	0	3	0	0	3
		Coelopynia pruinosa	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0
	Culicidae	*Anopheles* spp.	0	2	2	0	0	0	0	0	0	1	2	0	2	2	2
		Culex spp.	0	0	0	0	0	0	0	2	0	1	0	0	2	2	0
		Culicidae spp. (P)	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
	Dolichopodidae	Dolichopodidae spp.	3	2	0	0	0	3	1	0	0	0	0	0	0	0	0
	Empididae	Empididae spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Ephydridae	Ephydridae spp.	0	0	0	0	0	2	0	0	0	0	2	0	0	1	0
	Muscidae	Muscidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
	Simuliidae	Simuliidae spp.	3	0	0	0	2	3	1	0	0	0	0	0	0	0	0
		Simuliidae spp. (P)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	0	1	0	2	0	1	2	0	3	0	1	0	3	3	0
	Tabanidae	Tabanidae spp.	0	0	0	2	0	2	2	0	2	0	0	1	0	1	0
	Tanyderidae	Tanyderidae spp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tipulidae	Tipulidae spp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* sp.	0	2	2	2	0	0	1	0	1	0	0	2	0	0	2
	Hydropsychidae	*Cheumatopsyche wellsae*	4	1	0	0	4	4	0	0	0	0	0	0	0	0	0

			Mar-One			Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest taxon	MAR1-1	MAR1-2	MAR1-3	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
	Hydroptilidae	*Hellyethira* sp.	0	2	0	3	0	0	2	0	0	0	0	0	1	0	0
	Leptoceridae	*Leptocerus* sp. AV2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		Oecetis sp.	2	2	2	3	0	2	0	0	0	0	0	0	0	0	0
		Triaenodes sp.	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Triplectides ciuskus seductus	3	4	2	2	3	2	0	0	3	2	0	0	0	0	0
	Philopotamidae	*Chimarra* sp. AV17	3	1	0	0	0	4	0	0	0	0	0	0	0	0	0
Lepidoptera	**Crambidae**	Acentropinae spp. (imm./dam.)	2	2	0	2	2	2	1	0	0	0	0	0	0	0	0
		Eoophyla triplaga	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Margarosticha sp. 3	0	0	0	1	2	3	0	0	0	0	0	0	0	0	0
		Parapoynx sp.	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
		Tetremia sp. 1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Taxa Richness	**43**	**63**	**54**	**57**	**64**	**56**	**43**	**20**	**50**	**26**	**27**	**49**	**48**	**38**	**46**

Wet-14

			Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest Taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
GORDIOIDA		Gordioida spp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
CNIDARIA																				
HYDROZOA	Hydridae	*Hydra* spp.	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	2	1
ANNELIDA																				
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	3	0	2	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1
Tubificida	Naididae	*Allonais paraguayensis*	3	0	1	0	1	0	0	3	4	0	0	0	0	0	0	0	0	0
		Allonais pectinata	0	3	1	3	0	0	2	0	0	0	0	2	0	0	2	2	1	0
		Allonais ranauana	0	0	0	2	0	0	3	0	0	0	0	0	0	0	2	3	0	0
		Naidinae spp. (imm./dam.)	0	0	2	3	2	0	2	3	3	0	3	0	3	0	3	0	2	3
		Nais communis	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	3	0	0
		Nais variabilis	3	2	0	3	2	0	0	0	0	0	0	0	0	3	0	0	0	0
		Pristina leidyi	4	3	0	3	2	1	0	3	2	1	3	3	0	3	3	2	2	3
		Pristina longiseta	0	3	0	3	2	0	0	0	0	0	3	2	3	2	3	0	3	3
		Pristina spp. (imm./dam.)	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3
	Phreodrilidae	Phreodrilidae spp. (imm./dam.)	3	0	0	0	2	1	0	0	0	0	0	0	3	0	0	1	0	0
POLYCHAETA	Aeolosomatidae	Aeolosomatidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MOLLUSCA																				
GASTROPODA	Lymnaeidae	*Bullastra vinosa*	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	1	1
		Lymnaeidae spp. (imm./dam.)	0	0	0	2	1	2	0	0	0	0	0	1	0	0	0	0	0	0
	Planorbidae	*Ferrissia petterdi*	3	1	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
		Gyraulus spp.	2	2	2	2	0	2	3	0	2	0	0	1	0	0	0	3	0	0
ARTHROPODA																				
CRUSTACEA																				
MALACOSTRACA																				
Amphipoda	Paramelitidae	Paramelitidae sp. B	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	0	0
		Paramelitidae spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
ARACHNIDA																				
Sarcoptiformes		Oribatida spp.	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1
Trombidiformes		Hydracarina spp.	4	4	3	4	3	4	3	3	3	3	3	2	3	3	3	0	2	4
		Trombidioidea spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
INSECTA																				
Ephemeroptera	Baetidae	Baetidae spp. (imm./dam.)	3	3	2	3	2	3	3	3	2	3	3	3	3	3	3	0	3	3
		Cloeon sp. Red Stripe	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0	0	0	0
		Cloeon spp.	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0
		Offadens sp. G1WA2	3	2	0	3	3	3	0	2	3	0	0	0	2	4	2	0	3	3
		Pseudocloeon hypodelum	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caenidae	Caenidae spp. (imm./dam.)	3	4	3	2	2	3	3	3	3	3	3	3	3	3	3	2	3	3
		Tasmanocoenis sp. M	0	0	0	2	0	3	0	0	2	2	0	0	2	1	2	1	0	0
		Tasmanocoenis sp. P/arcuata	2	0	2	2	3	3	3	3	3	2	0	0	3	0	2	2	2	2
Odonata																				
Anisoptera		Anisoptera spp. (imm./dam.)	2	1	2	0	0	0	3	0	0	0	2	0	1	0	1	2	2	2
	Gomphidae	*Austrogomphus gordoni*	0	1	2	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0
	Libellulidae	*Diplacodes bipunctata*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Diplacodes haematodes	0	0	0	0	0	2	2	2	0	1	0	0	1	0	0	2	2	0
		Nannophlebia injibandi	2	2	1	0	0	0	0	0	2	0	0	0	1	0	0	0	1	0
		Orthetrum caledonicum	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Tramea spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Lindeniidae	*Ictinogomphus dobsoni*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zygoptera		Zygoptera spp. (imm./dam.)	0	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0

			Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest Taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
	Coenagrionidae	*Agriocnemis* spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Argiocnemis rubescens	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Ischnura aurora	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Belostomatidae	*Diplonychus* spp.	0	0	2	0	0	0	3	1	0	0	0	0	0	0	0	2	0	0
	Corixidae/Micronectidae	Corixidae/Micronectidae spp. (imm./dam.)	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0	0	0	0
	Gerridae	Gerridae spp. (imm./dam.)	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Limnogonus fossarum gilguy	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0
		Limnogonus spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Hebridae	Hebridae spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Mesoveliidae	*Mesovelia* spp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0
	Micronectidae	*Austronecta bartzarum*	0	0	3	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
		Micronecta lansburyi	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Nepidae	*Ranatra diminuta*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Notonectidae	*Anisops hackeri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Pleidae	*Paraplea* spp.	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Veliidae	Veliidae spp. (imm./dam.)	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	2	0	0
Coleoptera	Carabidae	Carabidae spp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Carabidae spp. (L)	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
	Dytiscidae	Dytiscidae spp. (L)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Allodessus bistrigatus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Bidessini spp. (L)	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Cybister sp. (L)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Cybister tripunctatus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
		Hydroglyphus grammopterus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Hydroglyphus leai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Hyphydrus lyratus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Laccophilus clarki	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Laccophilus sharpi	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Limbodessus compactus	0	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
		Limbodessus occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Platynectes decempunctatus var. *decempunctatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Platynectes sp. (L)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2
		Tiporus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Elmidae	*Austrolimnius* sp.	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Austrolimnius sp. (L)	3	4	0	1	2	3	0	1	3	0	2	2	1	1	1	0	2	1
	Gyrinidae	*Macrogyrus darlingtoni*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Macrogyrus spp. (L)	3	3	0	4	0	0	0	2	2	1	0	0	0	1	1	0	0	0
	Haliplidae	*Haliplus halsei*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Hydraenidae	*Hydraena* sp.	0	0	1	2	0	2	3	2	0	0	0	0	0	2	0	2	2	1
		Limnebius sp.	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
	Hydrochidae	*Hydrochus* sp.	0	0	0	0	0	3	3	2	0	2	0	2	0	0	0	0	0	2
		Hydrochus sp. (L)	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	Hydrophilidae spp. (L)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Berosus dallasae	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	2
		Berosus pulchellus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
		Berosus sp. (L)	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	1	0
		Enochrus deserticola	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	2	0	0
		Enochrus sp. (L)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
		Helochares sp. (L)	0	0	0	0	0	0	3	2	0	0	2	3	0	3	0	2	3	3
		Helochares tatei	0	0	0	0	0	1	2	1	0	0	0	1	0	1	1	2	0	0
		Laccobius billi	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1
		Laccobius sp. (L)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Paracymus pygmaeus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus spenceri	0	0	0	0	0	0	2	2	0	0	1	0	0	0	0	0	0	0
		Paracymus spp. (L)	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	1
		Regimbartia attenuata	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

			Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order	Family	Lowest Taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
	Scirtidae	Scirtidae spp. (A)	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Scirtidae spp. (L)	0	0	0	0	0	0	2	1	3	0	3	0	2	0	0	2	2	2
	Staphylinidae	Staphylinidae spp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Diptera	**Cecidomyiidae**	Cecidomyiidae spp.	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0
	Ceratopogonidae	Ceratopogonidae spp. (P)	0	3	1	2	0	0	3	0	0	2	2	2	0	2	0	2	1	2
		Ceratopogoninae spp.	3	4	3	3	2	3	3	4	3	3	3	3	3	3	3	2	3	3
		Dasyheleinae spp.	0	2	0	0	0	2	3	2	0	0	2	3	0	0	0	2	1	0
		Forcipomyiinae spp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	2	2	2	2	3	3	3	3	2	2	3	3	3	3	2	3	3
	Chironominae	Chironomus sp. (WWC3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
		Cladopelma curtivalva	0	0	0	0	2	0	2	0	0	3	2	0	0	2	0	0	0	0
		Cryptochironomus griseidorsum	2	3	1	2	2	0	0	2	3	0	2	0	2	2	2	0	1	0
		Dicrotendipes sp. 1	0	2	0	0	1	2	3	4	2	2	0	3	3	3	3	0	3	3
		Dicrotendipes sp. 2	0	0	1	2	2	3	4	3	3	2	2	3	2	2	3	2	3	3
		Harnischia sp. (WWC22)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Kiefferulus intertinctus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Paracladopelma sp. K2	2	0	0	0	2	3	0	2	2	2	3	2	4	3	3	0	2	3
		Paracladopelma sp. M1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Paratendipes sp. K1	2	2	3	2	0	3	2	0	0	0	0	2	0	0	0	0	0	0
		Polypedilum sp. 1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Polypedilum sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Rheotanytarsus sp. 1	3	2	0	3	2	0	3	0	3	0	2	2	0	2	2	0	0	3
		Stenochironomus watsoni	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Cladotanytarsus sp. (WWTS4)	2	0	0	0	1	0	2	0	2	3	2	0	2	2	3	0	1	2
		Tanytarsus sp. (WWTS1)	3	3	2	2	0	0	3	2	0	0	3	4	0	2	0	4	2	3
	Tanypodinae	*Ablabesmyia hilli*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
		Larsia albiceps	0	0	3	0	3	2	3	2	0	3	3	2	3	2	0	2	3	3
		Nilotanypus sp. (WWT3)	3	2	0	0	2	3	0	2	3	0	0	0	2	2	0	0	3	2
		Paramerina sp. (WWT1)	0	0	2	2	1	2	2	2	0	0	2	2	2	2	2	0	2	3
		Procladius sp. (WWT5)	0	0	2	0	0	0	2	0	0	3	1	0	0	0	0	0	0	2
		Thienemannimyia sp. (WWT2)	0	0	0	0	0	0	0	2	4	0	1	0	3	3	3	0	3	2
	Orthocladiinae	*Corynoneura* sp. (WWO5)	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Cricotopus albitarsis	2	2	0	3	3	4	0	3	4	0	0	3	2	3	3	0	2	3
		Nanocladius sp. (WWO6)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Rheocricotopus sp. (WWO1)	4	4	0	4	3	3	0	2	4	1	2	2	2	3	2	0	3	2
		Thienemanniella sp. (WWO4)	3	3	0	3	3	3	0	0	4	0	2	2	2	2	2	0	2	0
	Culicidae	*Culex* spp.	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Culicidae spp. (P)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dolichopodidae	Dolichopodidae spp.	0	0	0	2	2	3	0	2	1	1	0	2	2	0	2	0	2	0
	Sciomyzidae	Sciomyzidae spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Simuliidae	Simuliidae spp.	3	3	0	2	1	2	0	0	2	0	1	0	2	2	2	0	1	0
		Simuliidae spp. (P)	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	1	1	0
	Tabanidae	Tabanidae spp.	0	0	0	0	0	0	2	0	0	0	1	0	1	1	0	0	0	1
	Tanyderidae	Tanyderidae spp.	1	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	Tipulidae	Tipulidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* spp.	0	0	1	0	1	2	2	3	0	2	0	0	0	0	0	0	0	0
	Hydropsychidae	*Cheumatopsyche wellsae*	4	4	0	4	4	4	0	4	5	0	2	2	4	4	4	1	3	3
	Hydroptilidae	*Hellyethira* sp.	0	0	2	1	2	0	3	2	1	2	1	1	0	0	0	0	1	0
		Orthotrichia sp.	3	3	0	3	0	0	0	0	1	0	0	0	0	1	0	0	2	0
	Leptoceridae	Leptoceridae spp. (imm./dam.)	0	3	3	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
		Oecetis spp.	3	2	0	0	1	1	0	2	2	0	0	1	0	0	0	0	0	0
		Triplectides ciuskus seductus	2	2	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0
	Philopotamidae	Philopotamidae spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Chimarra sp. AV17	3	0	0	3	2	4	0	0	4	0	0	0	3	3	0	0	0	2
		Chimarra spp.	0	4	0	0	0	0	0	2	0	0	1	0	0	0	2	0	0	0

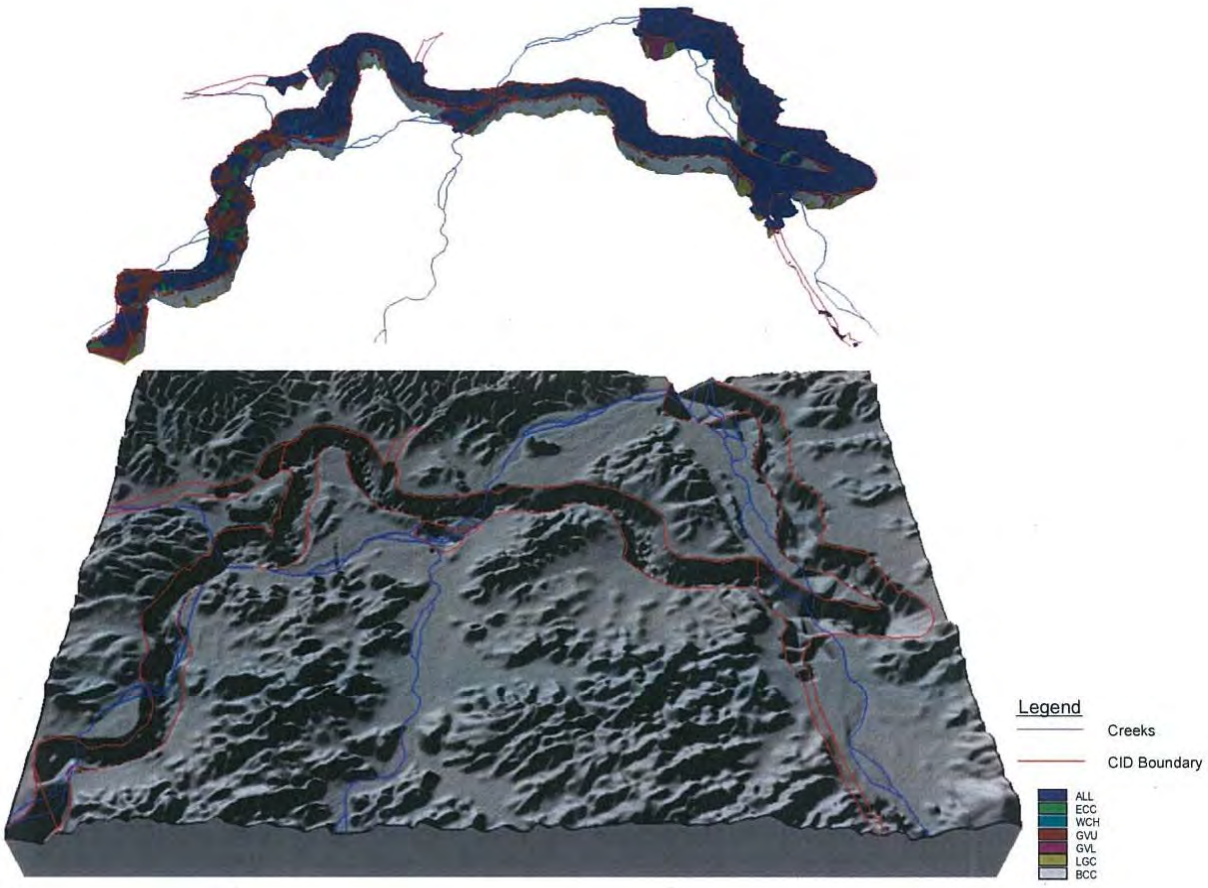
		Mar-One						Mar-Two						WW-Five					
Phylum/Class/Order Family	Lowest Taxon	MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-4	MAR2-5	MAR2-6	MAR2-7	MAR2-8	MAR2-9	WW5-1	WW5-2	WW5-3	WW5-4	WW5-5	WW5-6
Lepidoptera Crambidae	Acentropinae spp. (imm./dam.)	3	3	0	1	3	3	2	0	2	0	3	0	2	3	2	0	2	3
	Margarosticha sp. 3	2	3	0	3	3	4	0	4	3	0	0	2	4	2	3	0	2	0
	Margarosticha sp. WRM01	0	2	0	2	0	3	0	2	2	0	0	0	0	0	2	0	1	0
	Margarosticha spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Parapoynx spp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	Tetremia sp. 1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Taxa richness	**38**	**42**	**43**	**46**	**39**	**42**	**70**	**50**	**40**	**31**	**46**	**40**	**38**	**40**	**39**	**45**	**51**	**45**

Water Resource Evaluation / Projects & Development

Yandicoogina - Pocket and Billiards South Model Setup, Calibration and Estimation of Dewatering Requirements

November 2014

RTIO-PDE-0125389



	Name	Signature	Date
Prepared By:	E. Lim		November 2014
Checked By:	W. Dodson		December 2014
Approved By:	W. Dodson		December 2014

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1. Introduction

Rio Tinto Iron Ore (RTIO) is undertaking a Pre-Feasibility Study (PFS) to expand the Yandicoogina Mine (Yandi) to include mining below water table in Pocket and Billiards South (PBS). As part of the PFS, dewatering requirements and potential environmental impacts of dewatering is needed for the Public Environmental Review (PER). A numerical groundwater was selected as the tool to predict the dewatering requirements to meet the A8 mine schedule released in August 2014 and demonstrate the potential cumulative impacts of increased dewatering.

The numerical groundwater model was developed in 2008 for Yandi Operations medium term plan. The model domain was extended to minimise boundary effects from dewatering in Junction South West (JSW) and PBS. Included in the extension was the inclusion of an alluvium layer defined in the 2010 regional groundwater model (RTIO-PDE-0078850). The number of model layer was increased from 7 to 15 to refine the JSW and PBS geology based on the RTIO Vulcan geology block model. The model was calibrated against observed hydrographs from January 1998 to January 2014, a total of 16 years, at monthly stress intervals. The 2012 Australian groundwater modelling guidelines was used to guide the modelling process.

This report presents the conceptual hydrogeological model, model setup, calibration, dewatering requirement prediction and water table drawdown of the new model for the PFS for PBS.

2. Model Domain

The model domain of the conceptual hydrogeological model covers a window from 707338mE, 7480783mN to 725370mE, 7498814mN to 746583E, 7477601mN to 728551mE, 7459570mN in MGA94 Zone50 coordinate system as shown on Figure 1.

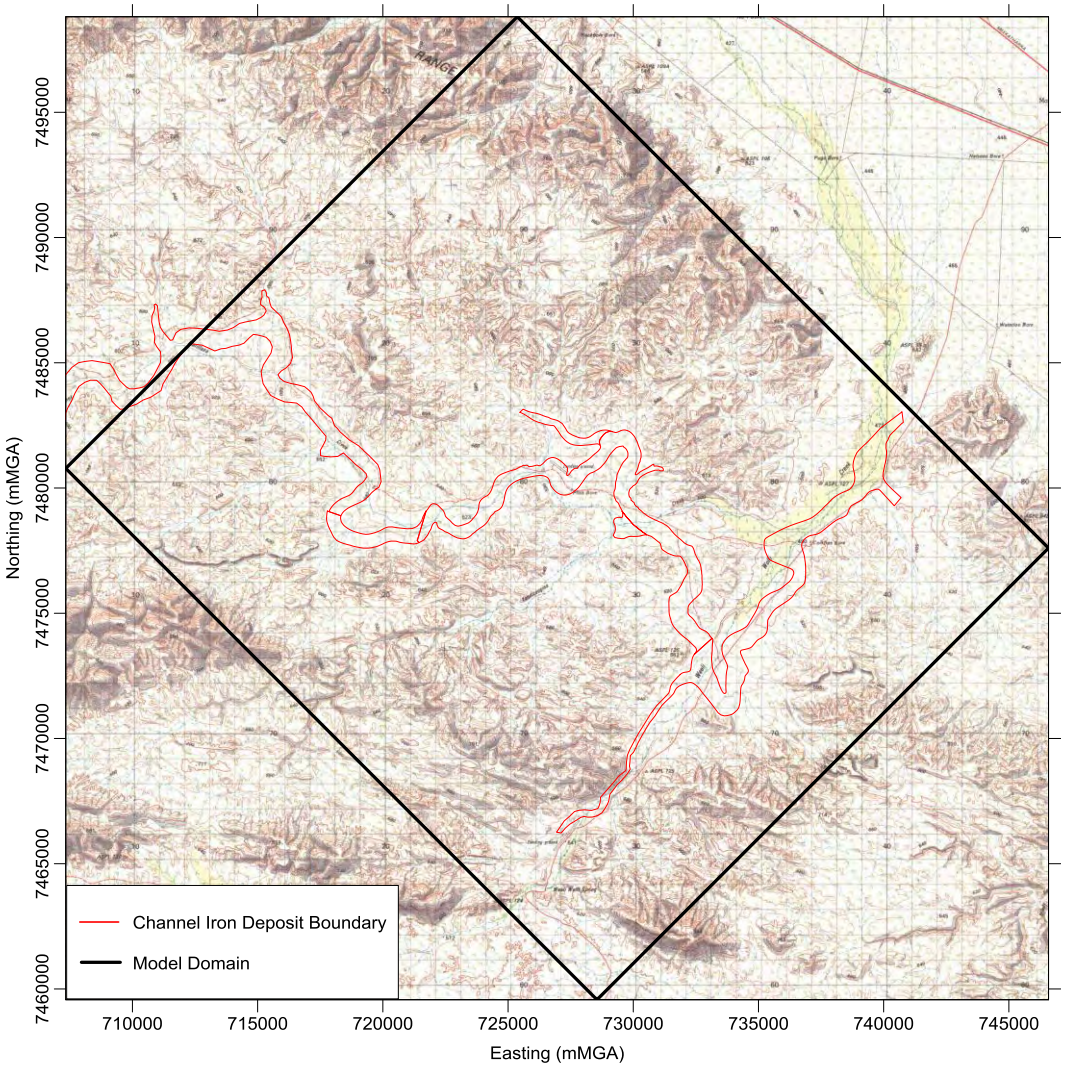

Figure 1. Conceptual Model Domain.

3. Climate

In general, the region is classified as arid-tropical with two distinct seasons; a hot summer extending from October to April and a mild winter from May to September. Average annual rainfall for 1998 to 2013 was 438 mm. Rainfall is episodic and highly variable between years. The majority of rainfall occurs during the hottest months from cyclonic lows with light winter rain in June/July. Due to the low rainfall and brief wet season, watercourses flow, if at all, for only brief periods under natural conditions. Temperature varies from 25°C to 40°C in summer and 10°C to 23°C in winter. Figure 2 shows the seasonal rainfall pattern and averaged monthly maximum and minimum temperatures.

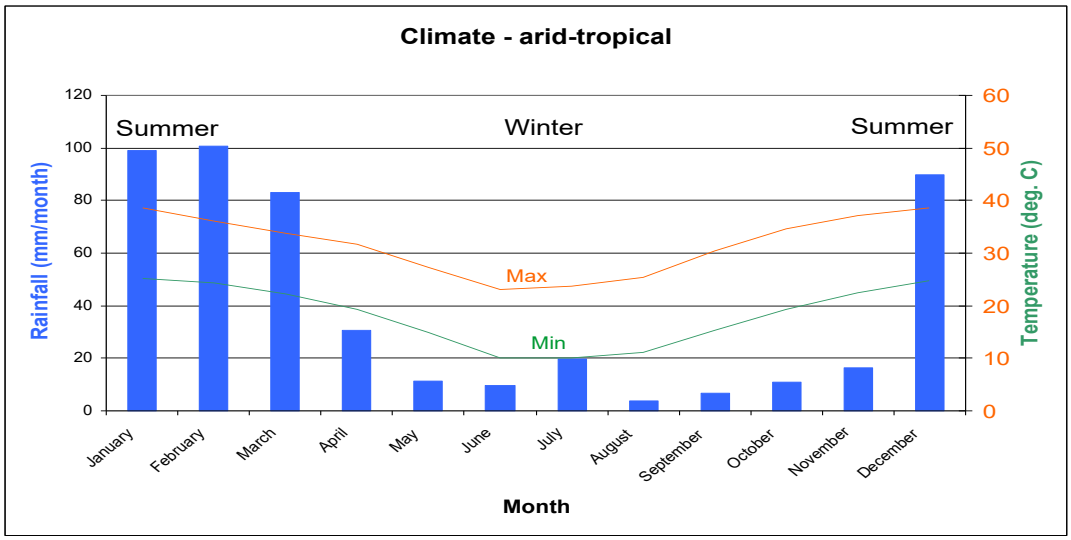

Figure 2. Seasonal Rainfall and Temperature.

The rainfall is episodic and large variations have been observed. Figure 3 shows the average monthly rainfall. It is this high intensity rainfall that poses a risk to mining the PBS.

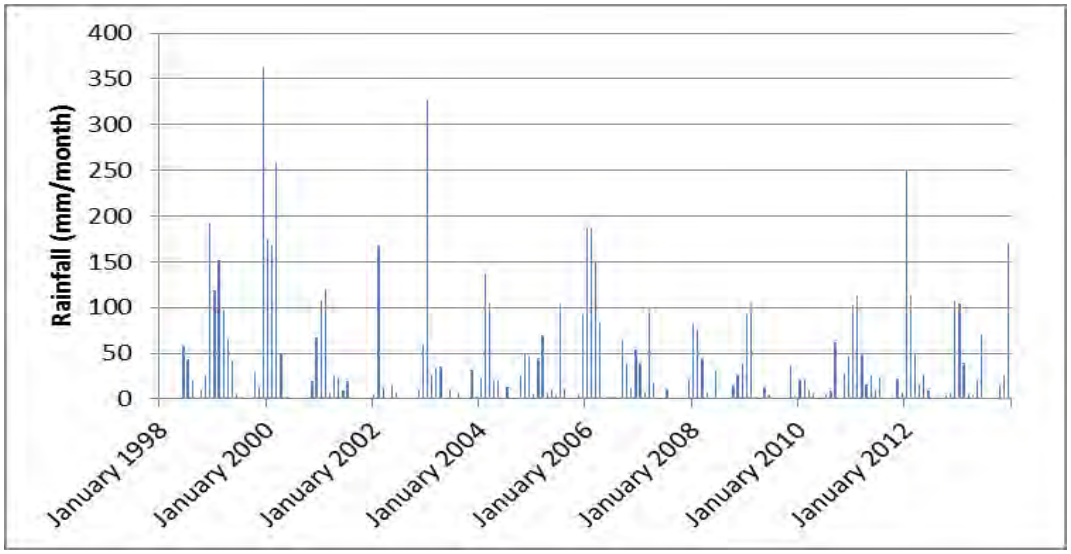

Figure 3. Monthly Rainfall.

Figure 4 shows the seasonal variability of pan evaporation recorded at Yandi weather station. Evaporation is high at about 3,000mm/year in the summer months where availability of water is highest.

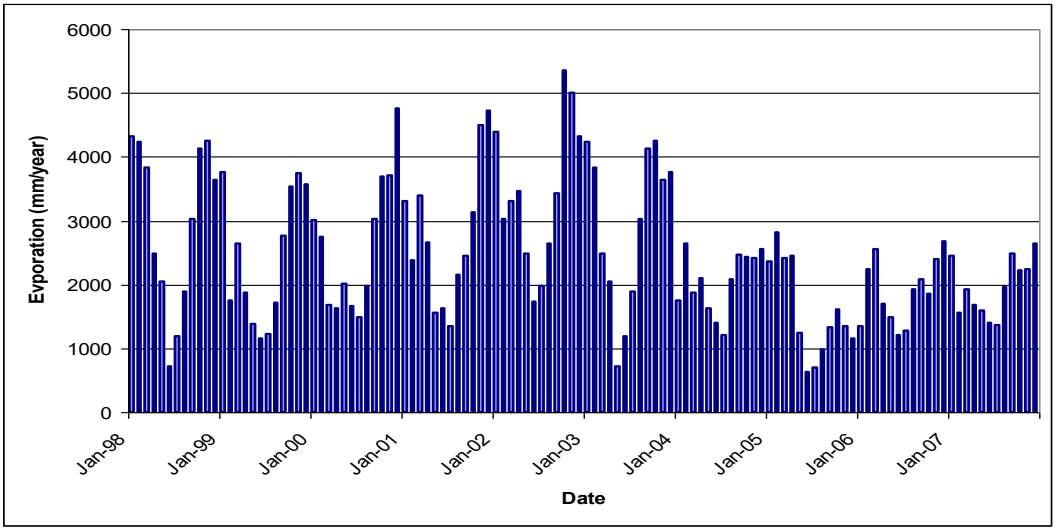

Figure 4. Monthly Pan Evaporation.

4. Geology

The CID is a Tertiary palaeochannel fill deposit, up to 80 m thick and about 500 m wide deposited on the incised Proterozoic basement of the Weeli Wolli and Brockman Iron Formations (Figure 6). The basement consists of inter-bedded banded iron formation, banded chert, shale and dolerite which are relatively less permeable than the CID (Figure 5). However, extensive regional and local fractures within the basement with open fractures and partings parallel to bedding in surface exposures indicates that the basement can transmit and store groundwater where these occur, in addition to the weathered profile. Several large-scale linear structures in the Weeli Wolli Formation are evident from aerial photographs, Landsat images and aeromagnetic maps. These structures trend between north-northeast and east-northeast, and some have surface trace of more than 20 km.

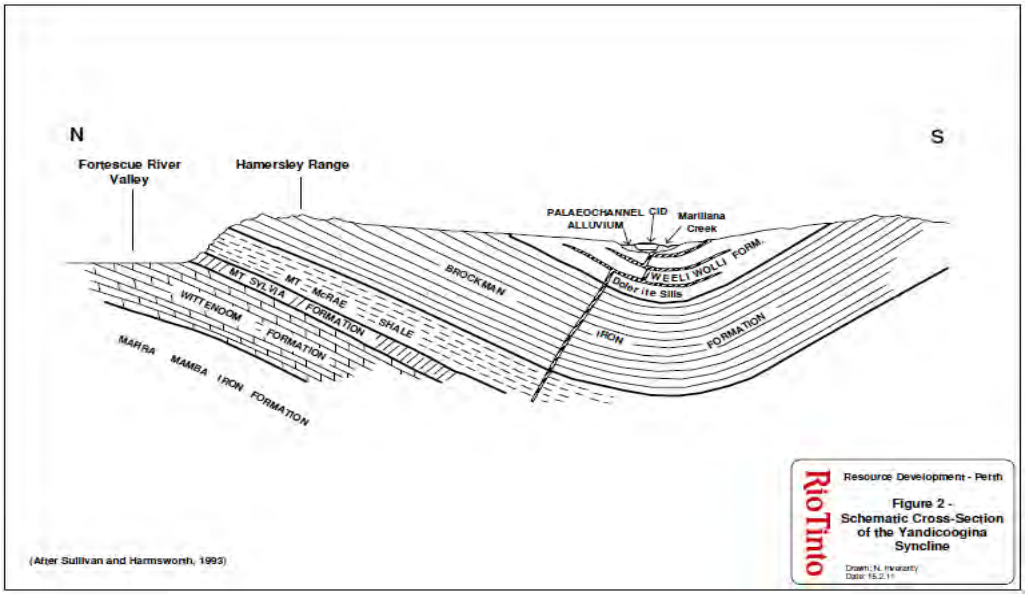

Figure 5. Schematic Cross-Section of the Yandicoogina Syncline.

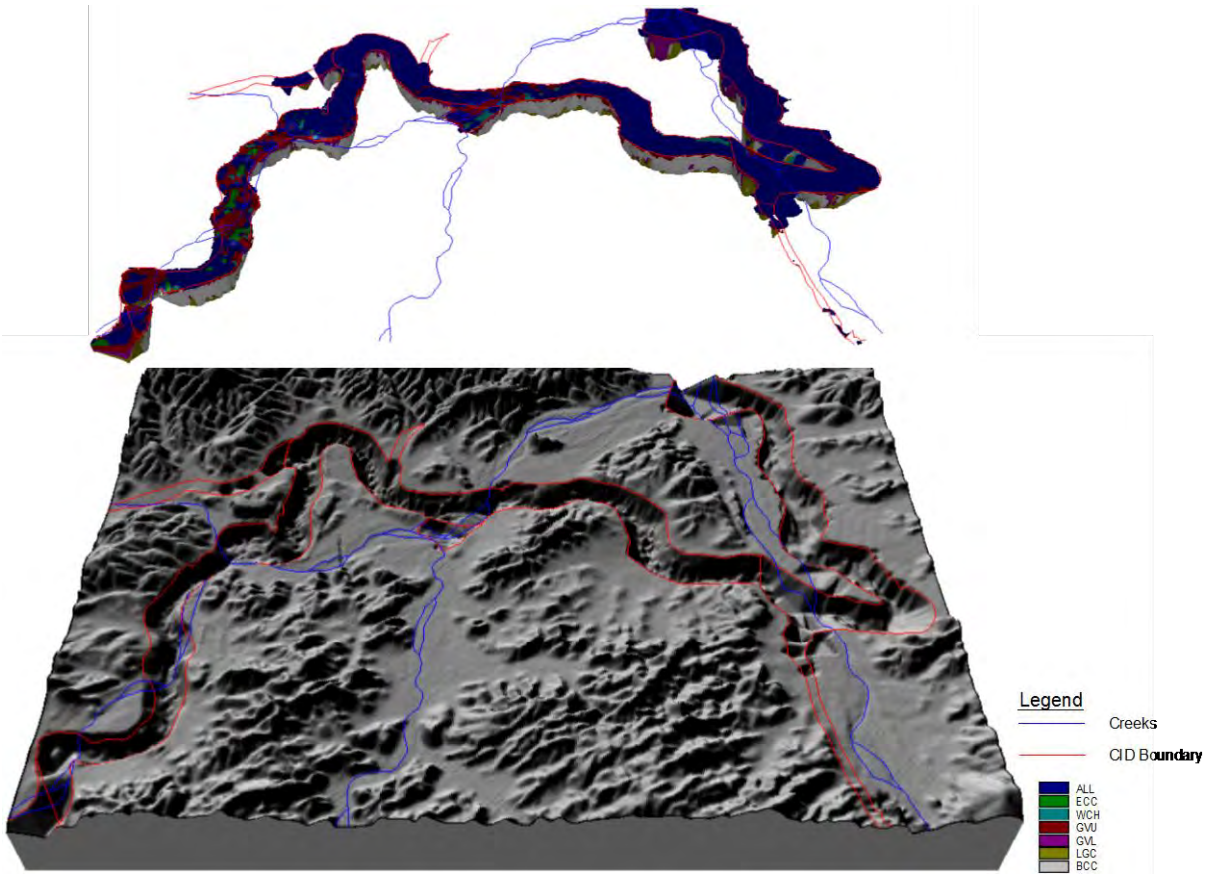

Figure 6. Channel Iron Deposit in Incised Proterozoic Bedrock.

A large east-northeast trending structure crosses Phil's Creek a few kilometres northwest of the Junction Central. Several smaller structures occur between this structure and Marillana Creek in the Junction Central area, and many of them clearly trend into the CID. The northeast trending section of CID at the Junction Central appears to be aligned with one of these structures. Some of the structures are also coincident with current creeks, e.g. Yandicoogina Creek, sections of Marillana Creek, and possibly Weeli Wolli Creek. Sections of the CID that trend in a north-easterly direction may also be aligned with basement structures.

The CID is generally comprised of coarse sand to granule sized placer deposits of predominantly pisoidal granules that have subsequently been cemented in a Geothite matrix. The primary porosity of the original placer deposit has been largely infilled by the goethite cementation of the pisoloid granules. The development of solution features such as vugs and cavities have superseded the interstitial pore space as the primary porosity, with secondary porosity coming from extensive fracturing.

The CID consists of 5 main geo-stratigraphical units within the channel deposit. The uppermost unit consists of recent alluvial (ALL) and the Eastern Clay Conglomerate (ECC). Underlying these, the orebody is comprised of an Upper Vitreous Geothite (GVU) and a Lower Vitreous Geothite (GVL). An upper weathered channel deposit (WCH) overlies the orebody. The orebody is variably broken and vuggy to massive. The GVU and GVL are very similar with GVL generally being less competent and more fractured hence more permeable. The vugs are usually filled with clays which can easily be mobilised. Underlying the main orebody, the Limonite Geothite Clay (LGC) is less

competent than the orebody, being more broken and often has large clay filled or opened cavities that have yielded large volumes of water. It is, however, not continuous throughout the channel. Underlying the CID is a polymictic basal clayey conglomerate (BCC) which can locally provide moderate permeability, but often is clay bound. Figure 7 shows a typical cross-section through the CID.

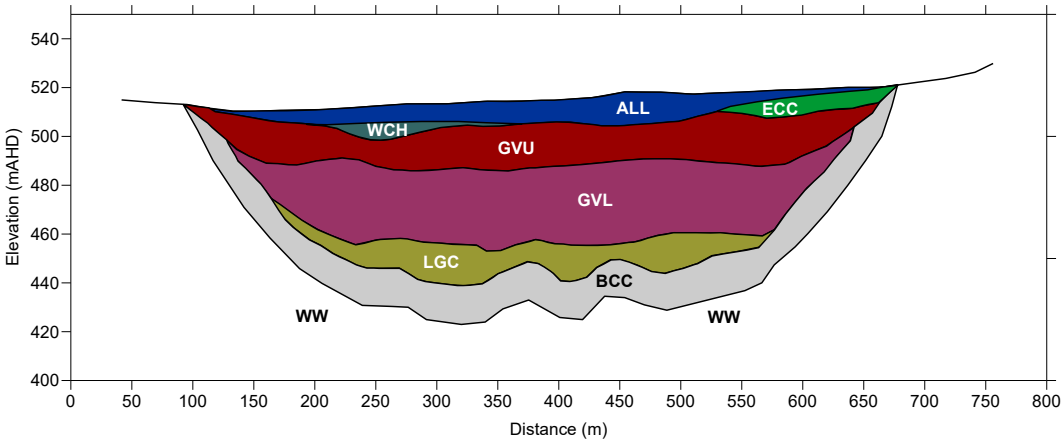

Figure 7. A Typical Cross-Section through the CID.

The creeks lie in narrow strips of unconsolidated Quaternary alluvium consisting of variably sorted material with particle sizes ranging from silt and sand to gravel and boulders. In the Junction Central area the alluvial bed of Marillana Creek is 150 m to 400 m wide, generally broadening in the downstream direction. The thickness of the Marillana Creek alluvium is variable with basement rocks encountered at depths of 5 to 20 m. Very coarse sediments (sand and gravel to boulders) are exposed at the surface and extend to a depth of at least 2 m in alluvium close to the Junction Central area, but finer textured strata (silts and clays) is found at greater depths.

5. Hydrogeology

The groundwater model consists of recharge into the water table from rainfall, leakage from the creeks, aquifer re-injection and throughflow. Discharge occurs through dewatering bores and in-pit sumps, seepage to creeks, evaporation from pools and streams, evapotranspiration from plants and via throughflow.

Rainfall infiltration into the regional water table occurs directly and indirectly. Direct rainfall recharge occurs where rain water infiltrates to the water table close to where the rain drop hits the ground surface. The amount of water reaching the water table depends on the thickness and the conditions of the unsaturated zone. Indirect rainfall recharge occurs where surface flow recharges the aquifers. Leakage from surface run-off into aquifers varies along the creeks. This depends on the vertical permeability of the creek beds, permeability of the receiving aquifers and difference in elevation of the water in the creeks and in the receiving aquifers. Where the creek crosses the CID, leakage may increase due to the relatively more permeable CID aquifer. Surface water recharge occurs along Yandicoogina Creek, Marillana Creek and Weeli Wolli Creek.

Water management at Yandi operations comprises the discharge of surplus dewatering water to previously ephemeral creeks. Both Marillana and Weeli Wolli Creeks are subjected to upstream surplus water discharge activities. Figure 8 and 9 shows hydrograph responses to dewatering and perennial flow in the creeks from the upstream operations. A correlation with rainfall pattern (Figure 10) shows that flow in the creeks is subdued and extends for a longer period; rainwater gets stored in depleted aquifers and seeps from bank storage along the creeks after a rainfall event. Figure 11 shows progressive time lag downstream along the CID from the discharge from Hope Downs 1.

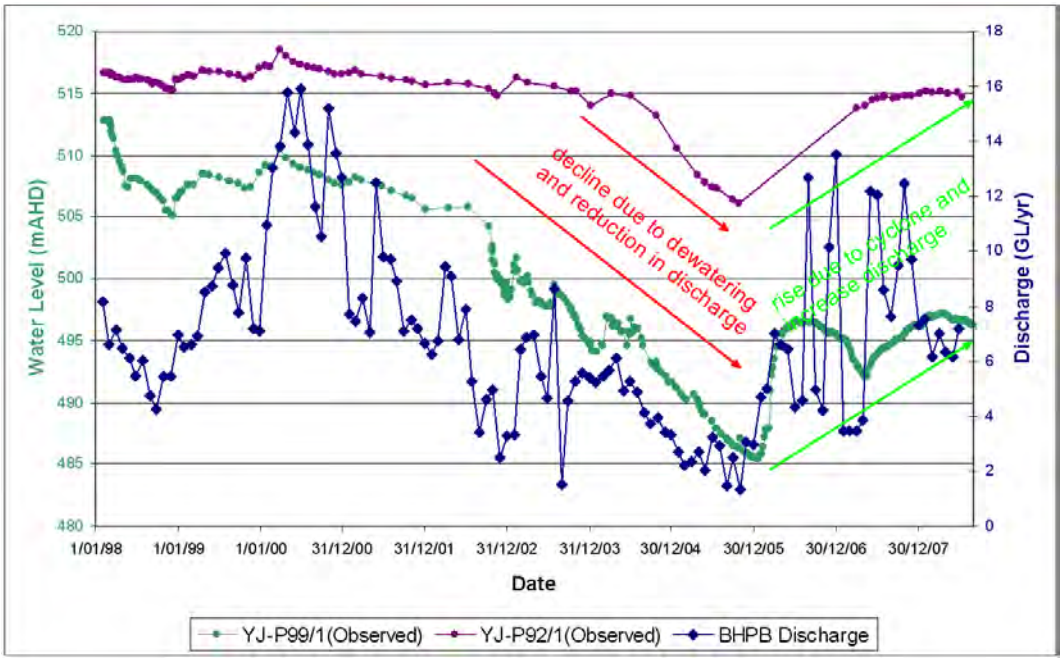

Figure 8. Hydrograph of monitoring bores YJ-P99 and YJ-P92 showing decline due to dewatering and rise due to increase creek flows.

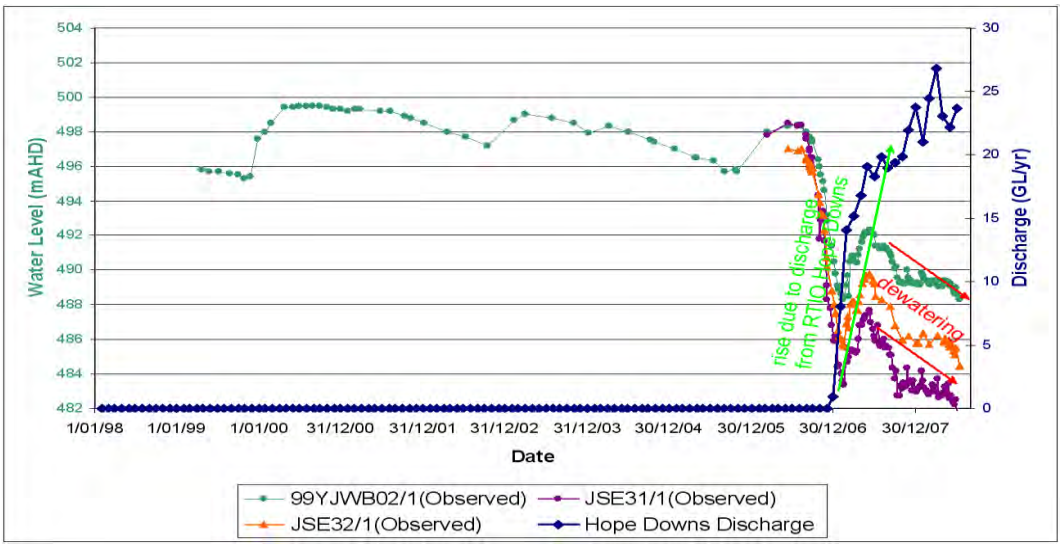

Figure 9. Hydrograph of monitoring bores 99YJWB02, JSE31 and JSE32 showing water level rise due to Hope Downs 1 discharge and decline due to JSE dewatering.

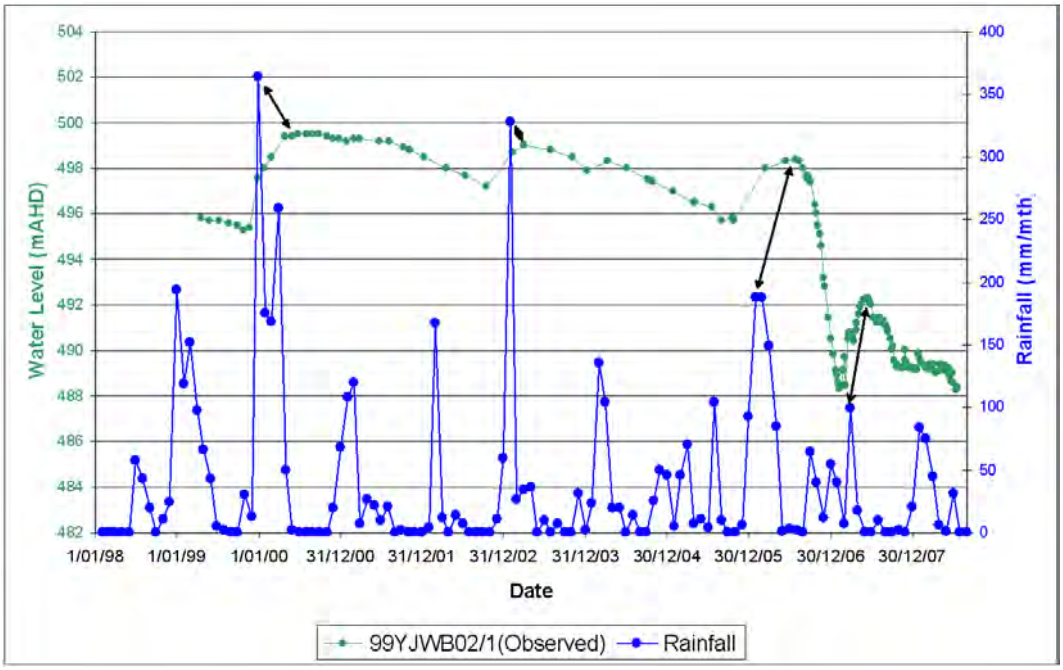

Figure 10. Hydrograph of monitoring bore 99JWB02 showing time lag in water level rise after rainfall events.

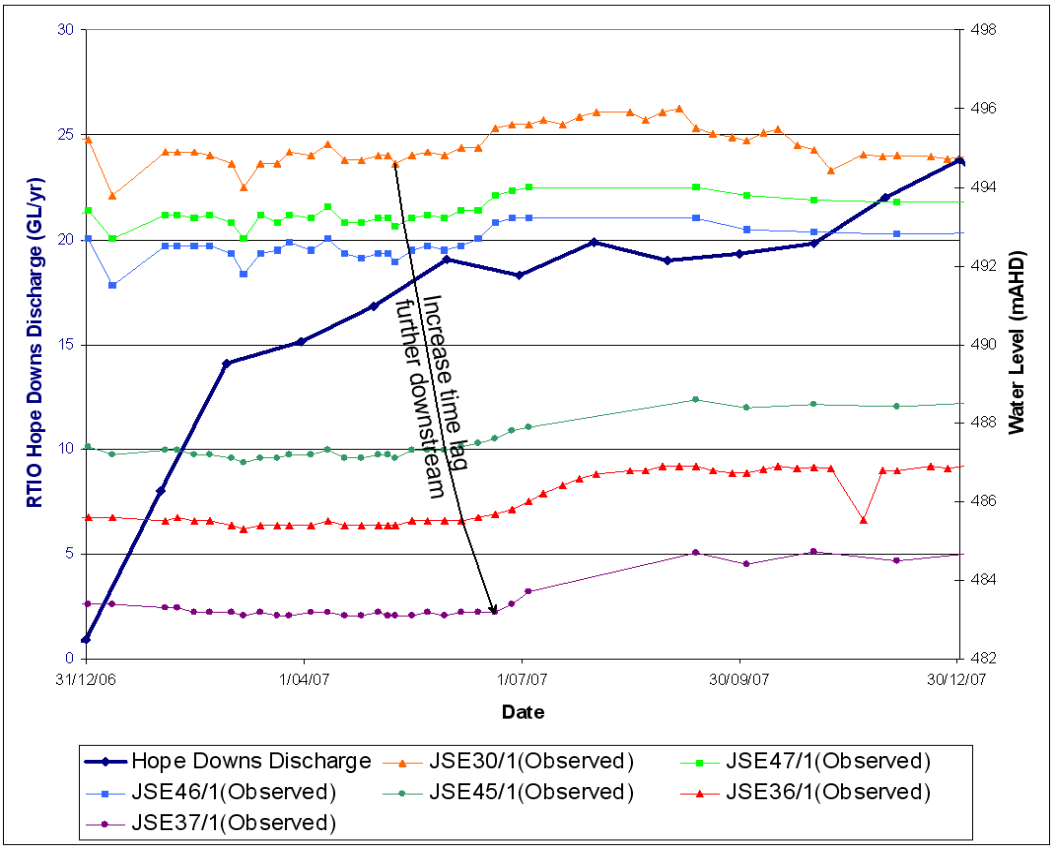

Figure 11. Progressive time lag downstream along the CID from the discharge from Hope Downs 1.

In July 2006 aquifer re-injection commence in Billiards South with dewatering water from JSE. Figure 12 shows monitoring bores in the vicinity of the injection bores mimic the increase in injection with water level rise.

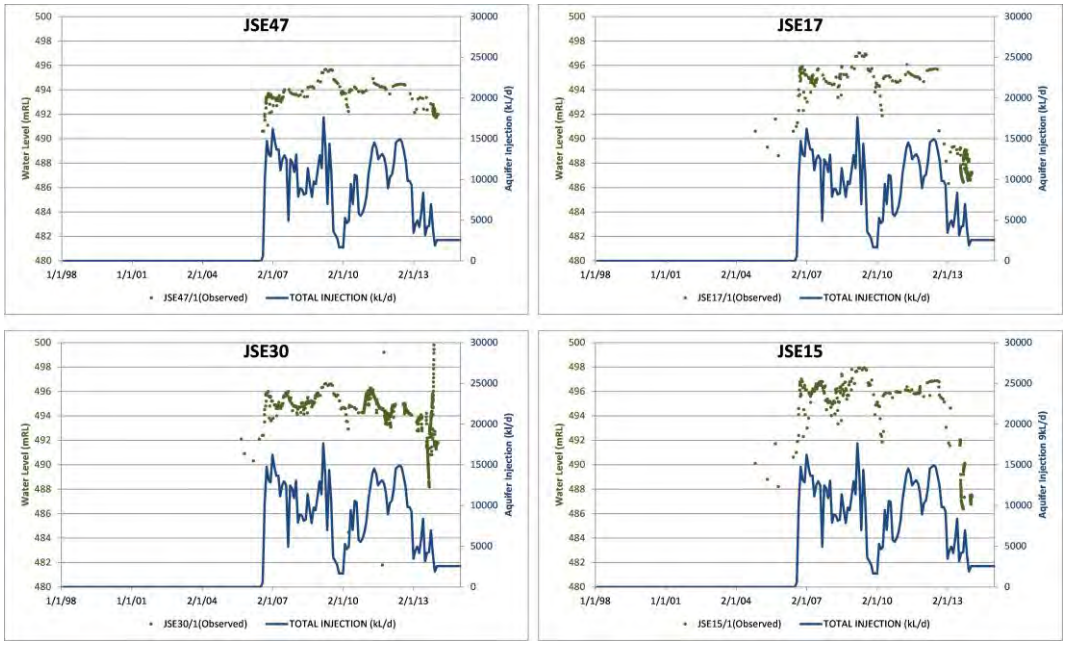

Figure 12 Water level rise in response to aquifer re-injection.

There is a dense network of primary streamlines in the Marillana Creek and Weeli Wolli Creek catchments which developed from the high intensity rainfall, sparse vegetation cover and shallow soils as shown on Figure 13. Marillana Creek and Weeli Wolli Creek drain the main surface water catchment and cross the CID at several places. Marillana Creek drains a catchment of about 2,250 km^2 above its confluence with Weeli Wolli Creek. Weeli Wolli Creek has a catchment of about 1,750 km^2 above the confluence with Marillana Creek. Yandicoogina Creek with catchment area of 200km^2 and Phil's Creek with catchment area of 100 km^2 are major tributaries of Marillana Creek within the model domain.

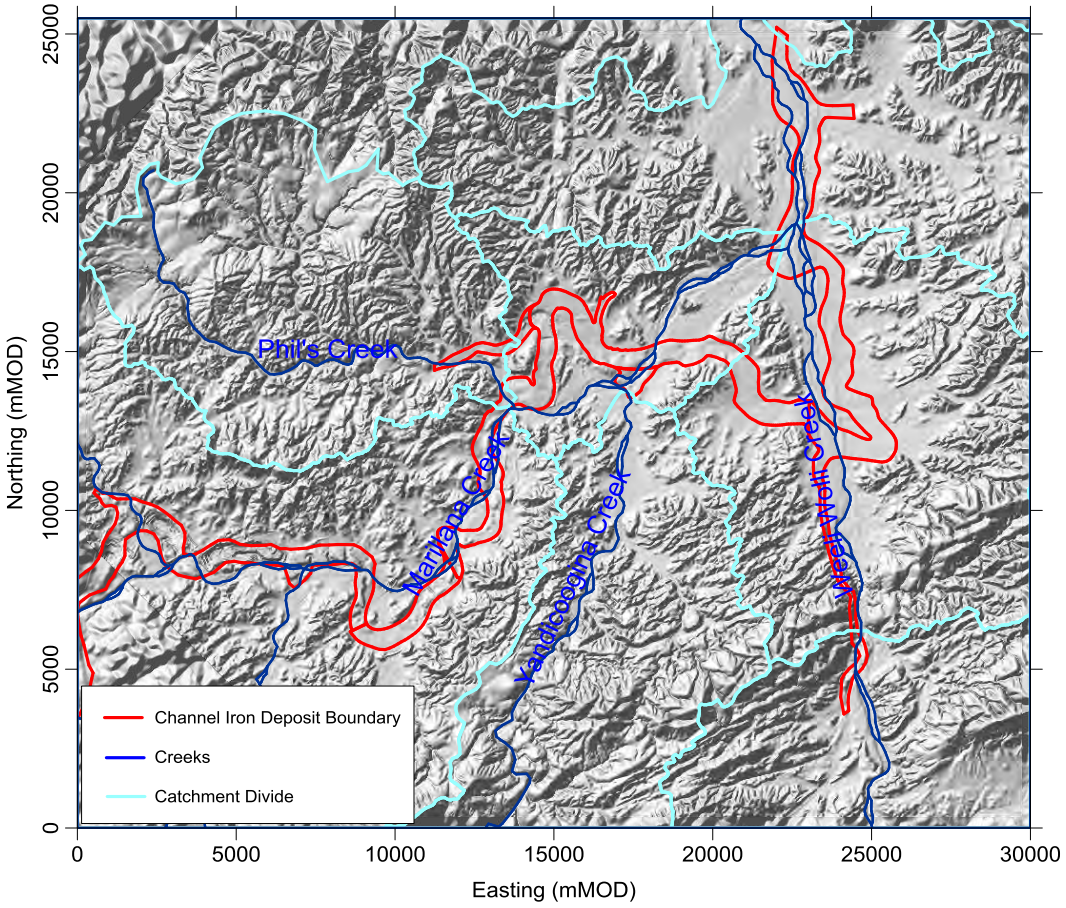

Figure 13. Topography showing dense network of drainage lines developed from intense rainfall on sparse vegetation cover.

Flow rates in the creeks are constantly being modified by BHPB Yandi, Hope Downs 1 and Yandi operations. Groundwater discharge from these operations are adding flow into Marillana and Weeli Wolli creeks making the once ephemeral creek now perennial along the reaches adjacent to mining areas. Yandi Operations discharges groundwater to Marillana Creek from eight (8) discharge outlets. Both Marillana Creek and Weeli Wolli Creek flow to the Fortescue Valley.

Leakage from the creek occurs when water in the creek is higher than the surrounding aquifers. The interconnectivity of the creeks with the CID aquifers mean that increase leakage upstream has the potential to decrease leakage downstream. Dewatering has the potential to increase leakage from the creek within the cone of depression.

Measurements of flow along the creeks have shown reduction in flow rates after the creek crosses the CID. Hydrographs close to the creeks have shown groundwater level rises corresponding to increase creek flows. The formation of braided stream along sections of the creeks meant that the total leakage area could be larger than the observed flowing part of the stream. Seasonally, part of the creek can alternate between a losing stream and a gaining stream depending on the elevation of the groundwater and elevation of the water in the stream. Leakage to and from the creeks depends on the conductance of the material between the creek and the underlying aquifers and the elevation of the creek.

The Yandi Operations in 2013 consist of seven dewatering borefields (JSW, Phils, Marillana, JSE Ridge North, JSE Northern, JSE Central, JSE Southern), a number of in-pit sumps and a re-injection borefield in Billiards. Location of the borefields is shown on Figure 14.

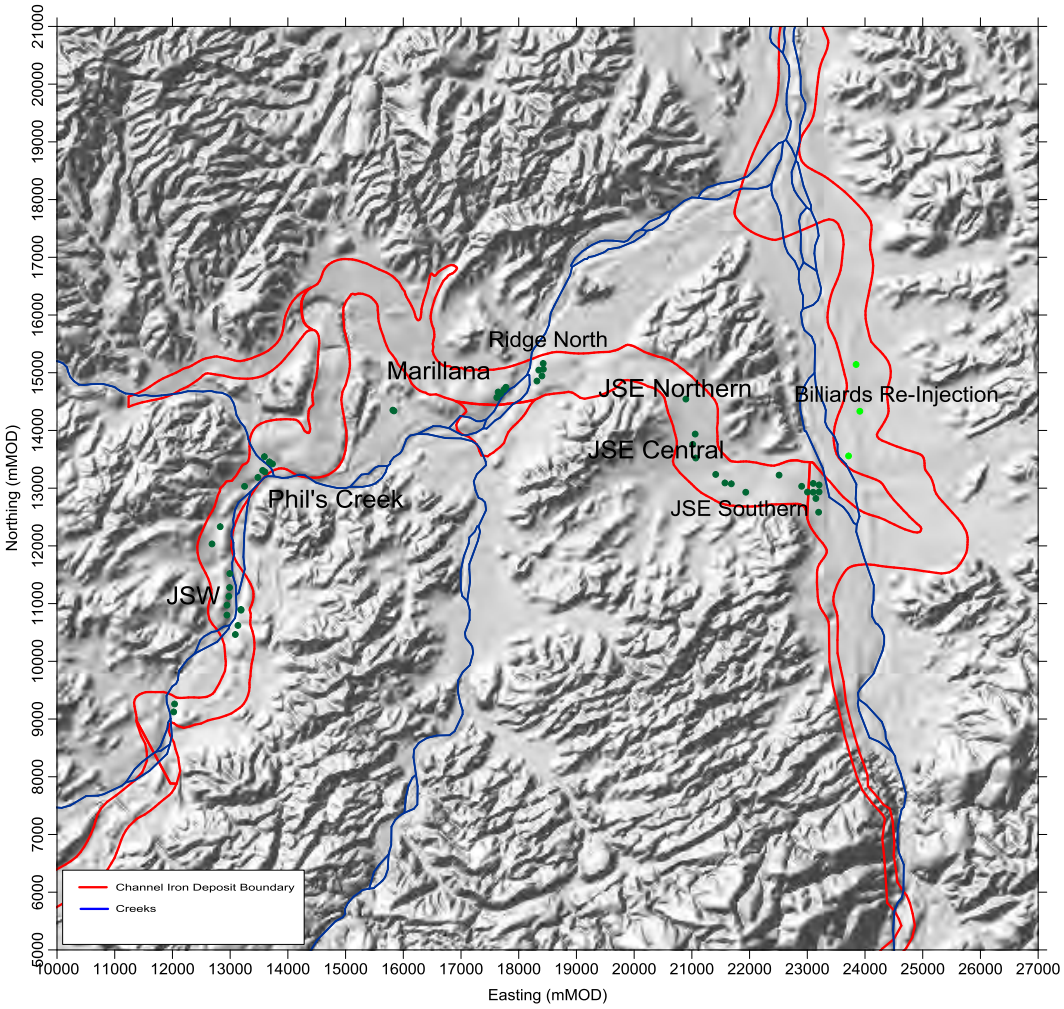

Figure 14. 2013 Borefields.

As part of Yandi Operations, groundwater abstracted from the JSE Southern borefield is being re-injected into the CID aquifer in the Billiards re-injection borefield. Since aquifer re-injection started, groundwater levels in Billiards have risen creating a groundwater mound which may seep back to Weeli Wolli Creek.

Groundwater discharge occurs actively through dewatering bores and in-pit sumps and passively through seepage into creeks, evaporation from pools along the creeks and evapotranspiration from vegetation that rely on groundwater. Areas of major active discharge occurs from the dewatering bores at JSW, Phil's Creek, Marillana, JSE Ridge North, JSE Northern, JSE Central and JSE Southern borefields. Minor discharge occurs from in-pit sumps in Phil's Creek, Hairpin and Waterstand pits, Railway loop borefield and the potable water bores.

The CID, being more permeable than the basement rocks, acts as a conduit for groundwater to flow to Weeli Wolli Creek before ending in the Fortescue Valley.

As part of Yandi's Operations, a wet processing plant was built to wash clays from the ore. Water used in the washing is recycled back to the plant through the waste fines cell (WFC) which is located on the eastern side of the mined out CID east of Phil's Creek borefield and in the Tributary area. Decant sumps located within the WFC pump water back to the plant.

The limited hydrogeological information from the Weeli Wolli and Brockman Iron Formations shows that the general direction of groundwater flow in these units is from the flanks of the catchment towards the valley occupied by Marillana Creek, Weeli Wolli Creek, Phil's Creek, Yandicoogina Creek and the CID before flowing to the Fortescue Valley as shown on Figure 15. Groundwater gradient generally decreases in the CID due to its higher permeability.

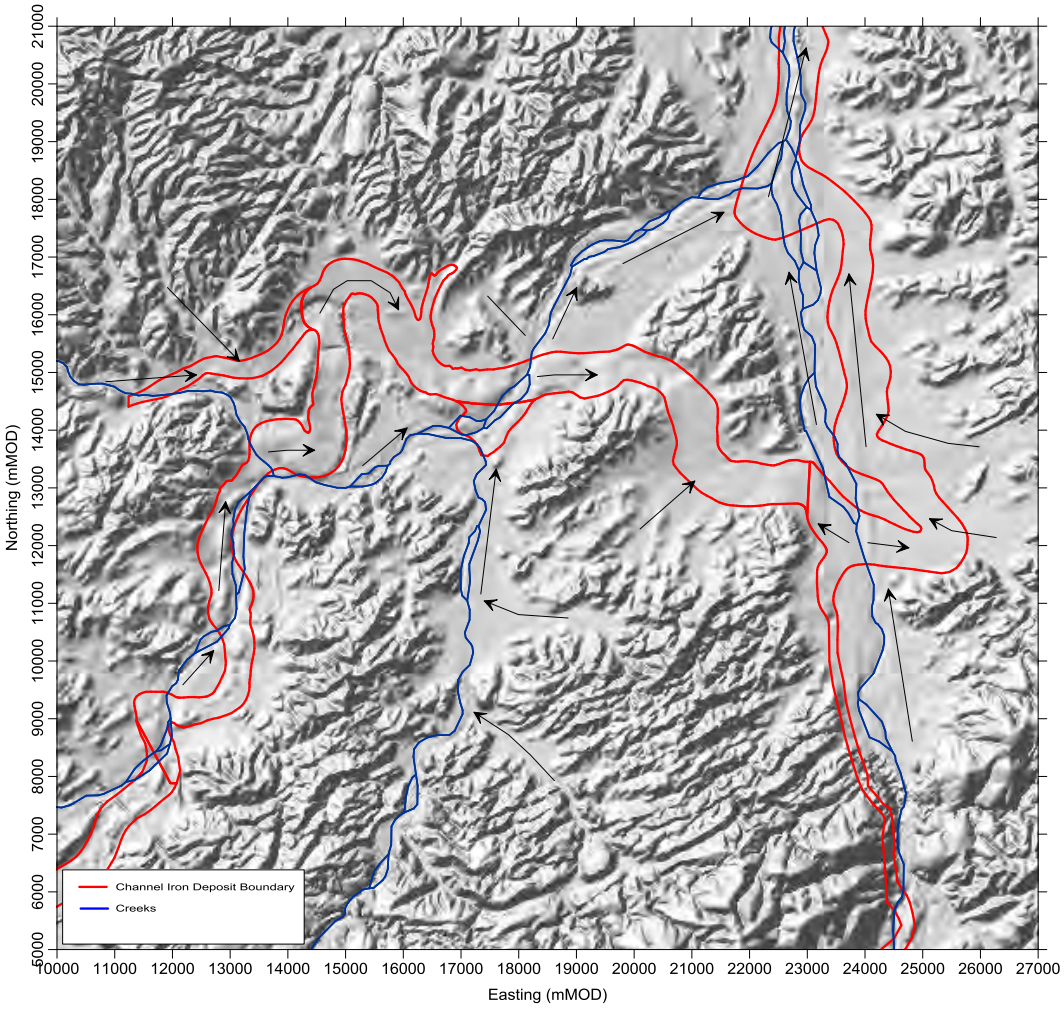

Figure 15. General direction of groundwater flow.

6. Numerical Model Code

The modelling code selected to simulate the groundwater flow condition at Yandi mine was MODSURFACT version 3.0. MODSURFACT is an enhanced version of the widely used United States Geological Survey MODFLOW. MODSURFACT was used mainly to overcome the numerical instability associated with MODFLOW rewetting of dry cells, and better representation of dewatering wells with the Fractured Well Package. The solver selected was PCG5 with adaptive time stepping. MODSURFACT was developed by HydroGeoLogic, Inc. The pre- and post-processor used was Visual MODFLOW version 2011.1 developed by Schlumberger Water Services.

7. Model Setup

The numerical model domain extends 25.5 km north-south and 30km east-west to cover the Channel Iron Deposit (CID) areas and minimise model boundary effects (Figure 16).

MODSURFACT is a finite-difference numerical code that requires the model domain to be discretised into three-dimensional blocks that broadly represent the conceptual hydrogeological model. The model setup consists of 425 rows, 491 columns and 15 layers. Irregular grids were used to capture the required hydrogeological details, maintain numerical stability, and minimise model runtime. The smallest grid measures 31m x 32m and the largest blocks measures 509m x 750m (Figure 16). The top of layer 1 was assigned the elevations of the surface topography and the bottom layer was flat at 250mRL. Variable layer thicknesses were used to capture the geology in the CID as shown on Figures 17 and 18.

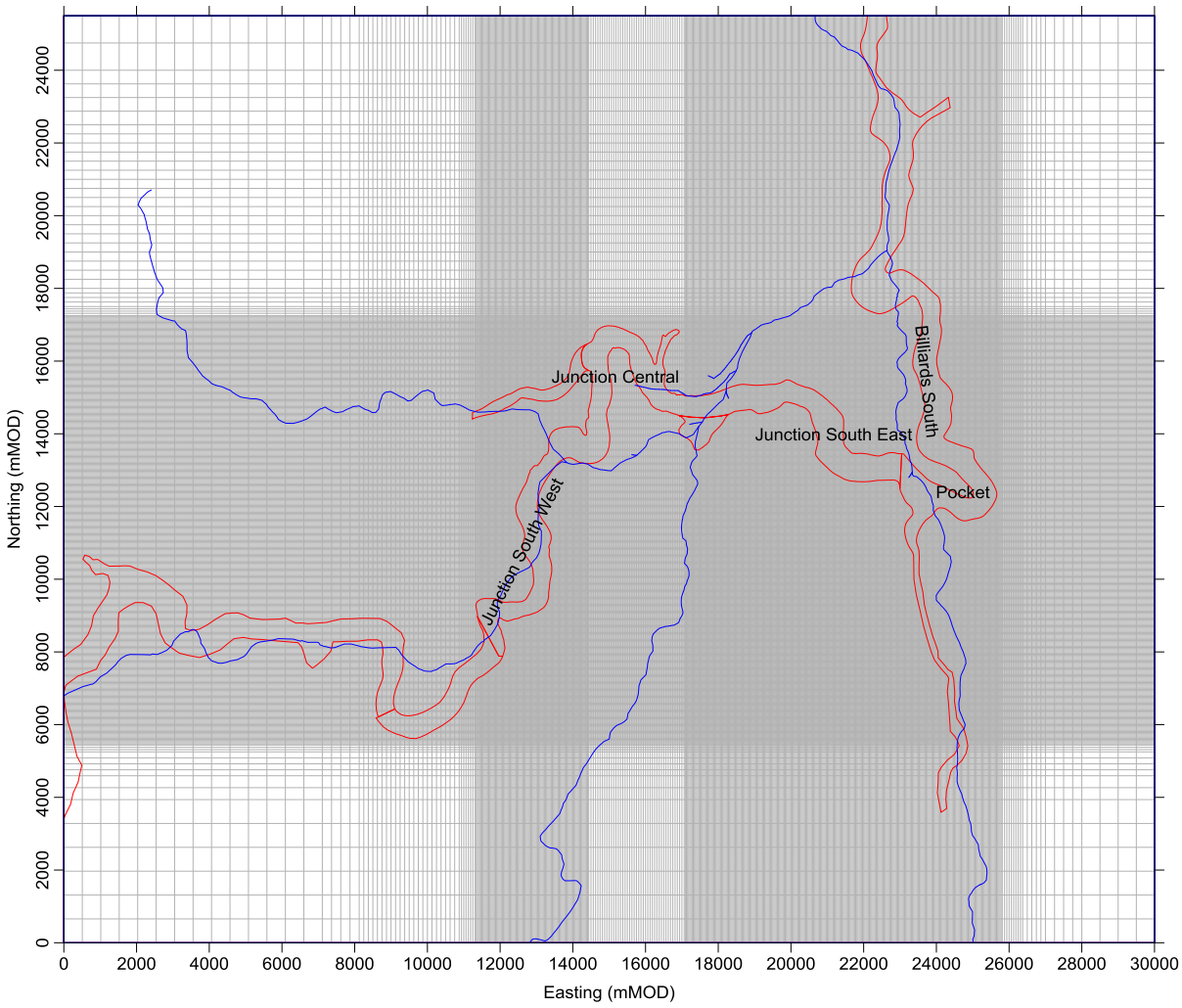

Figure 16. Model Domain and Discretisation.

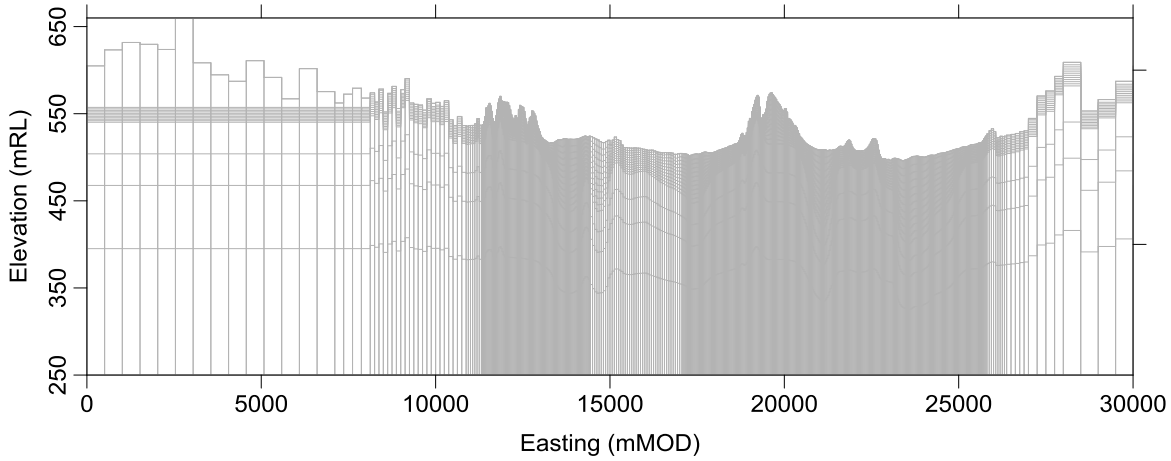

Figure 17. Vertical Discretisation – East West Cross-Section along 13984mN.

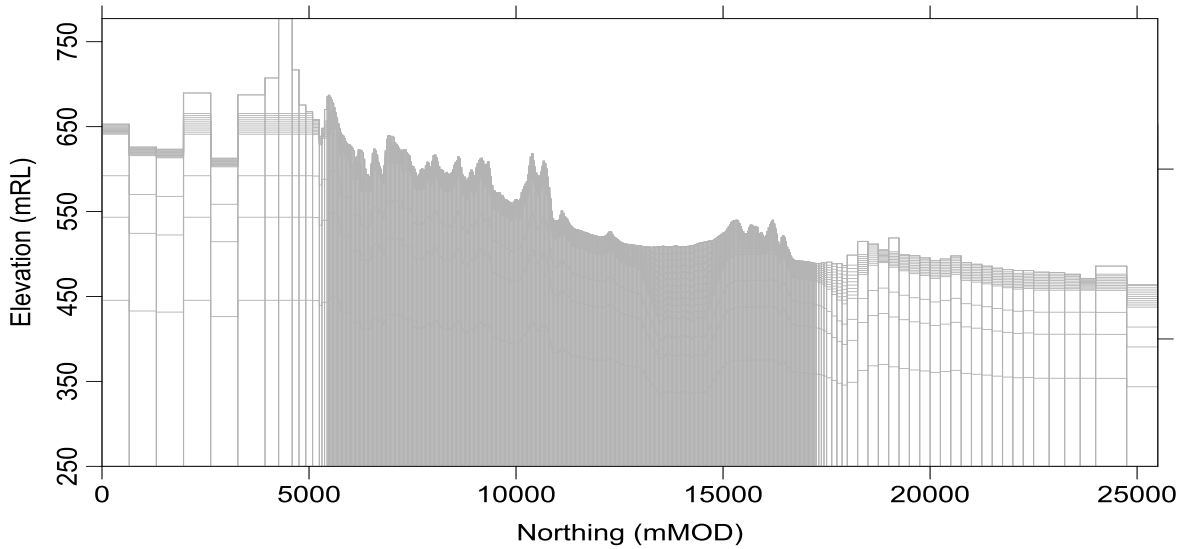

Figure 18. Vertical Discretisation – North South Cross-Section along 21015mE.

Aquifer pumping tests conducted along the CID show there is quite a variation in hydraulic conductivity along the CID as shown in Figures 19 to 22. Figures 23 and 24 show the distribution of the modelled hydrostratigraphic units in layers 1, 3, 6 and 9 and Figures 25 and 26 show cross-sectional views. Based on the interpretations of the aquifer pumping tests analyses and general borelogs interpretations of the competencies of the units encountered, estimates of the conductivity for the different hydrostratigraphic units were assigned to the model by assuming that the GVU is less permeable than the GVL and the GVL is less permeable than the LGC. The hydraulic parameters derived from the aquifer pumping tests were assigned to the numerical model and adjusted, within bounds, in the calibration process to long term pumping.

An aquifer pumping test was conducted in the alluvial in 2009 in bore WB08YJSE002 (Dogramaci and Kirkpatrick, 2010). Analysis of the test shows the hydraulic conductivity of the alluvial to be about 10m/d. Structures outside the CID as evident from aerial photographs, Landsat images and aeromagnetic maps suggest that regionally the basement may be quite transmissive and/or can yield more water than what was observed on a local scale. An equivalent porous media hydraulic conductivity value of 0.5m/d was assumed in the calibration and assumed isotropic.

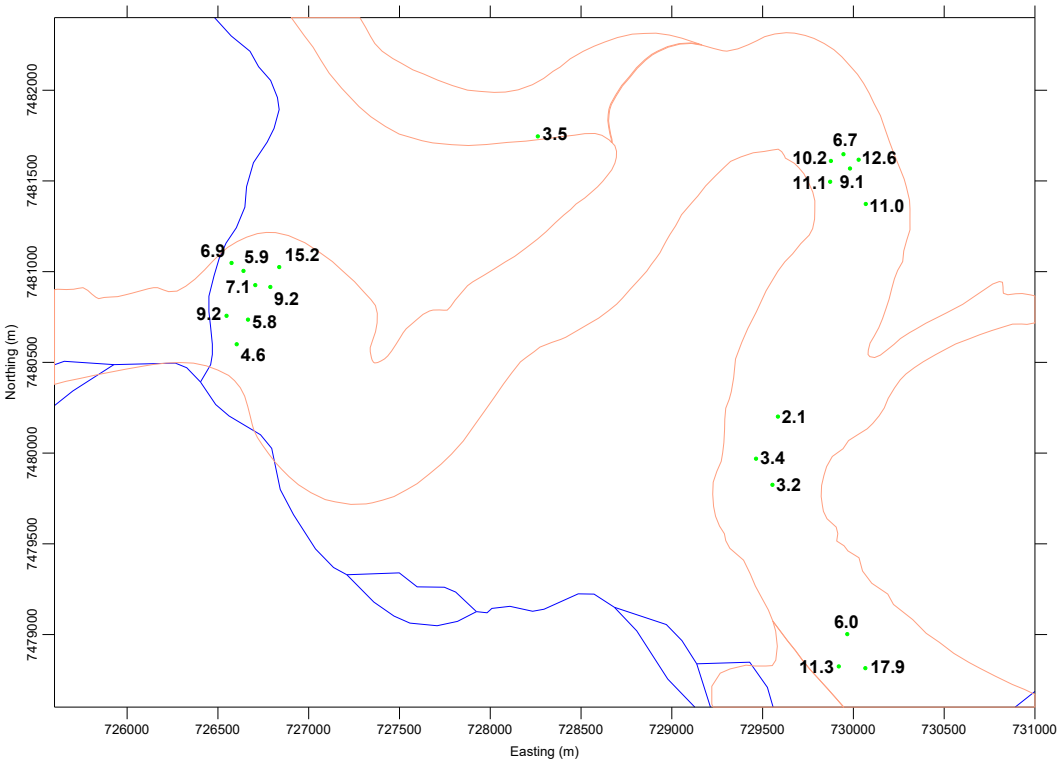

Figure 19. Junction Central - Hydraulic conductivity (m/d) derived from aquifer pumping tests.

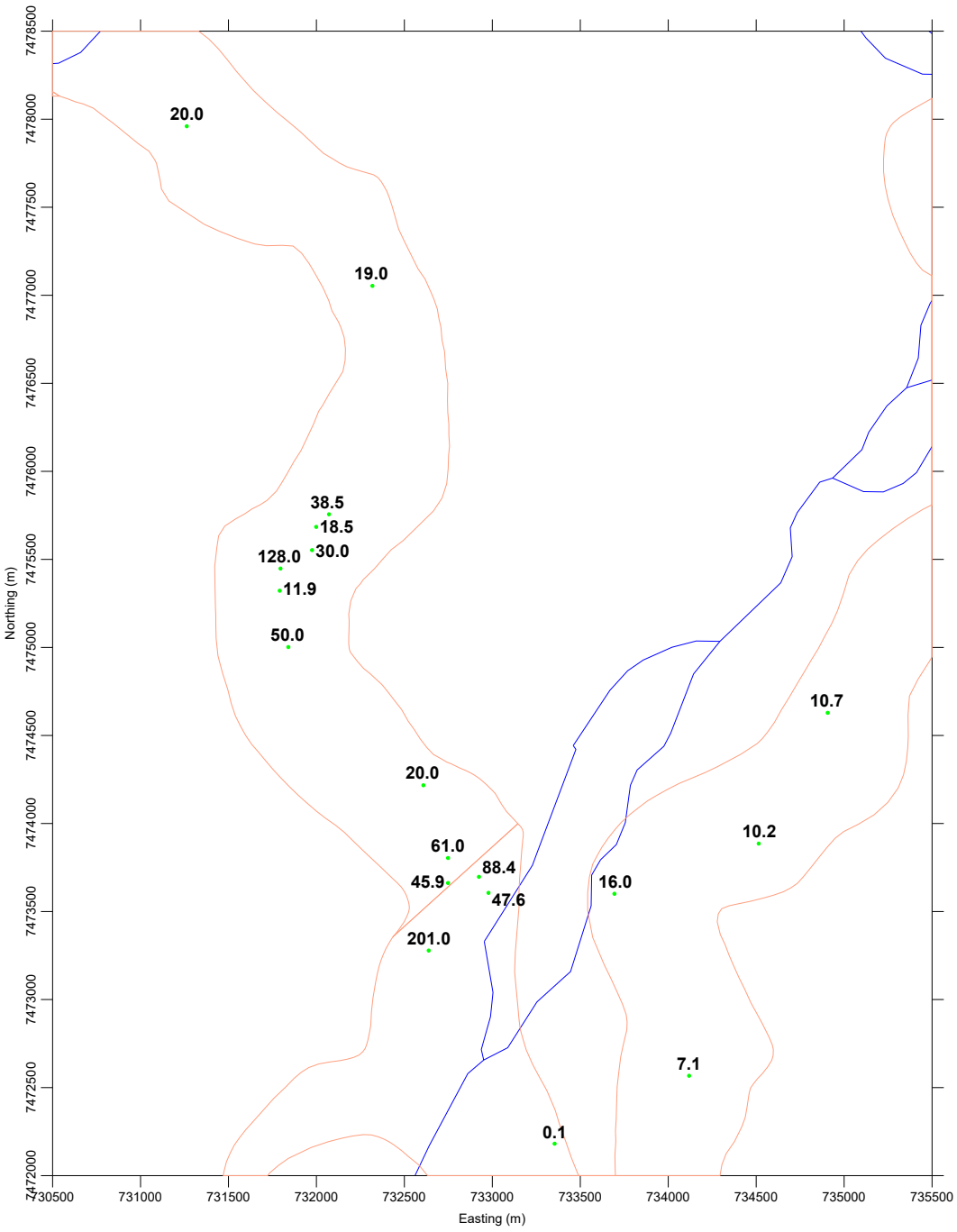

Figure 20. Junction South East - Hydraulic conductivity (m/d) derived from aquifer pumping tests.

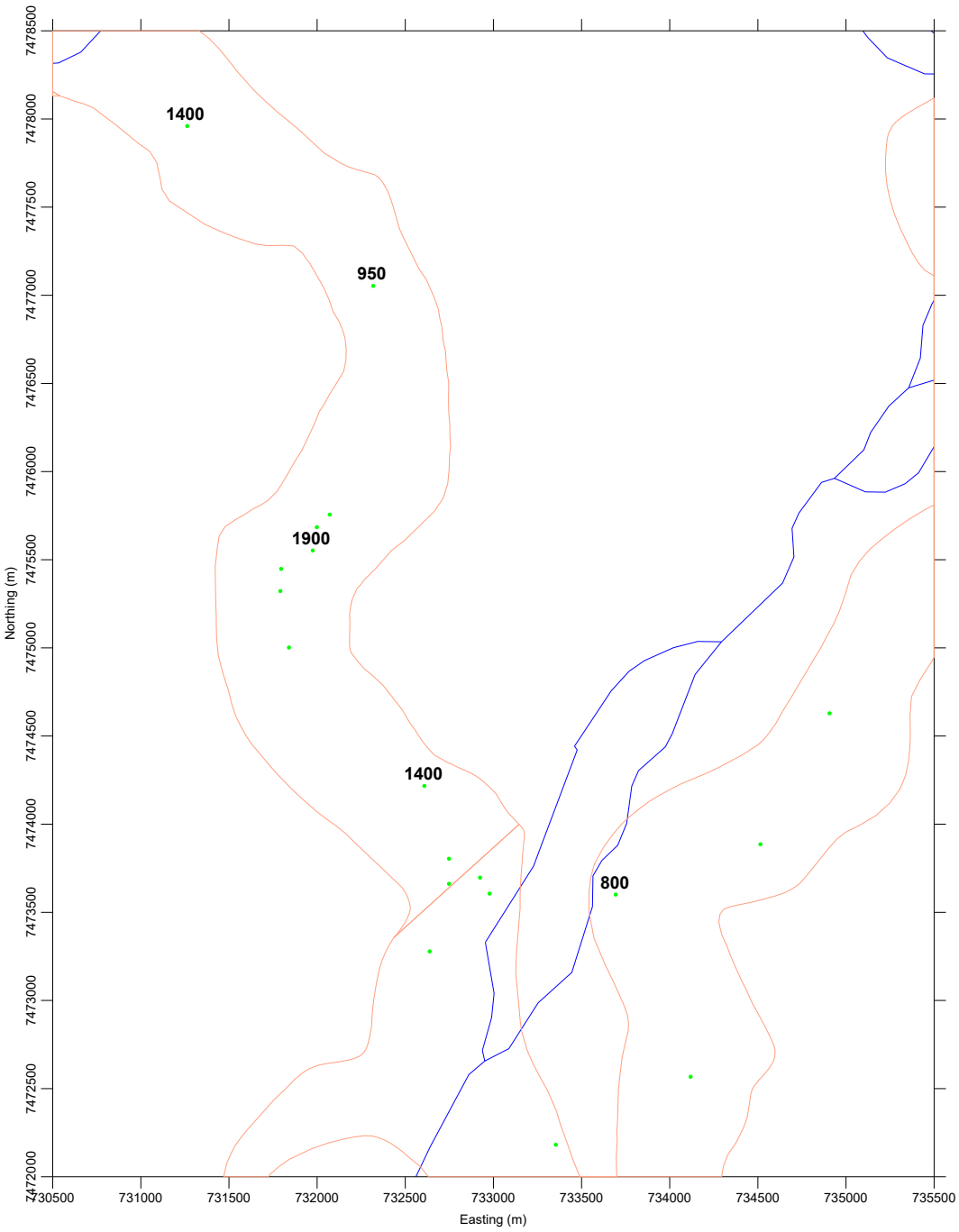

Figure 21. Junction South East and Billiards - Transmissivity (m2/d) derived from aquifer pumping tests.

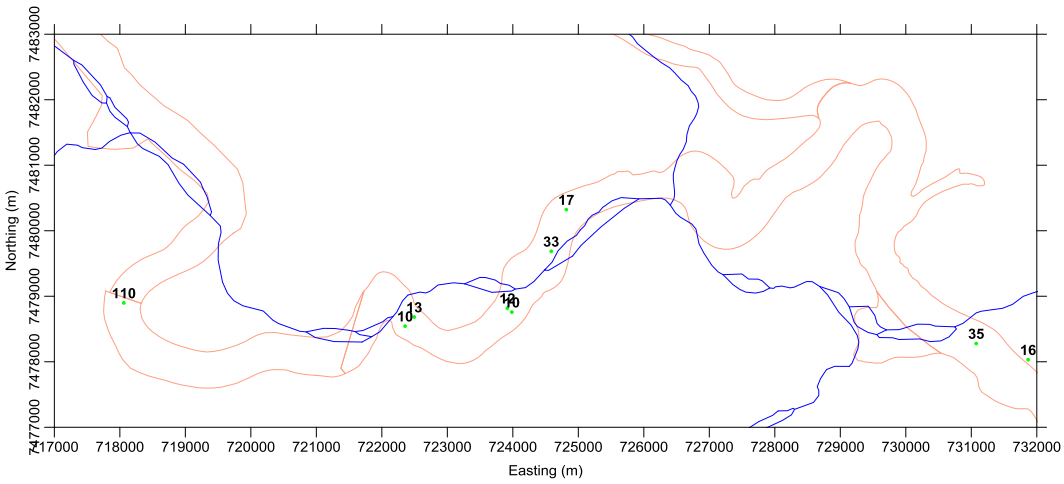

Figure 22. Junction South West - Hydraulic conductivity (m/d) derived from aquifer pumping tests.

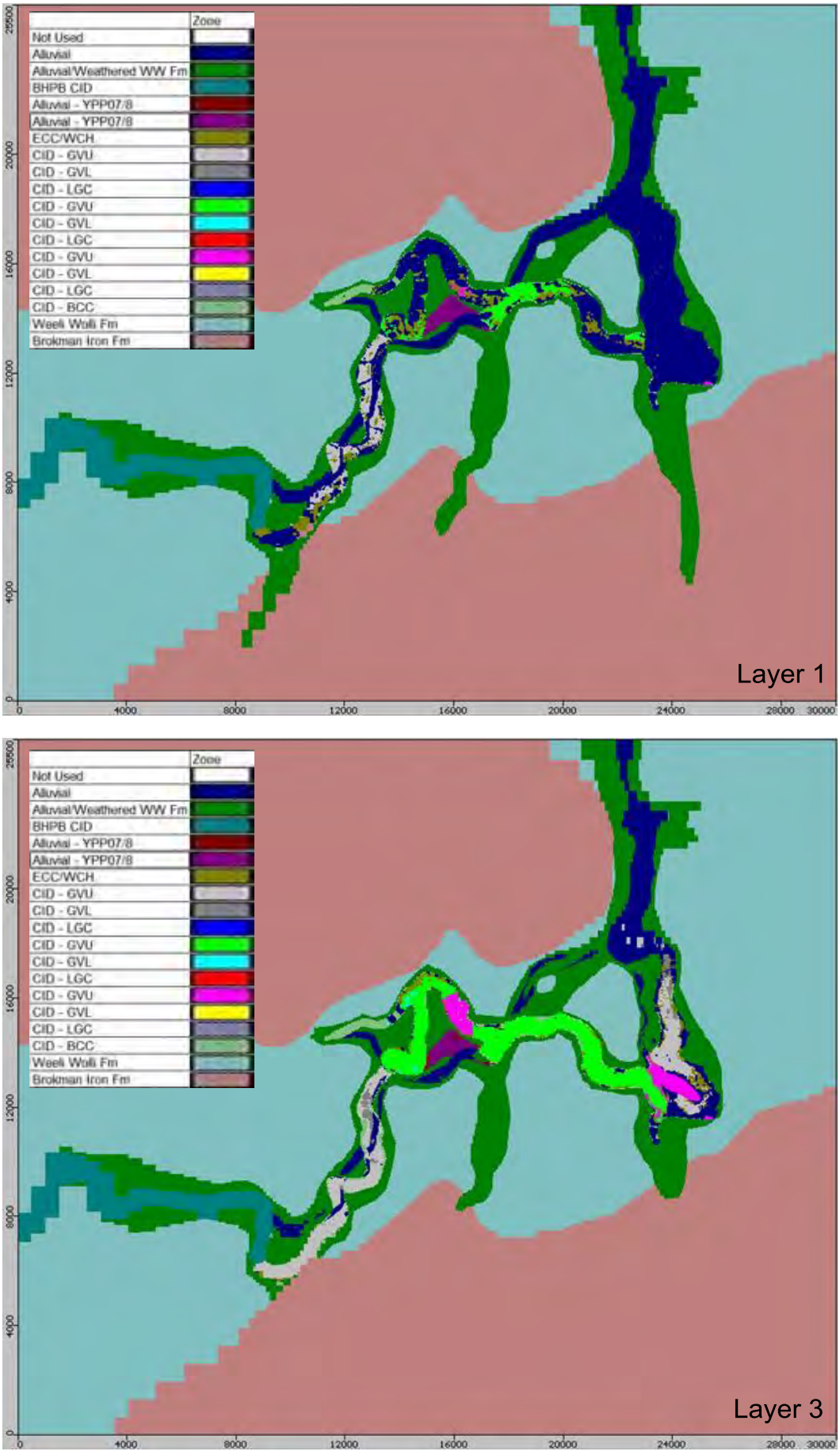

Figure 23. Hydraulic Parameter Zones – Plan View (Layer 1 and 3).

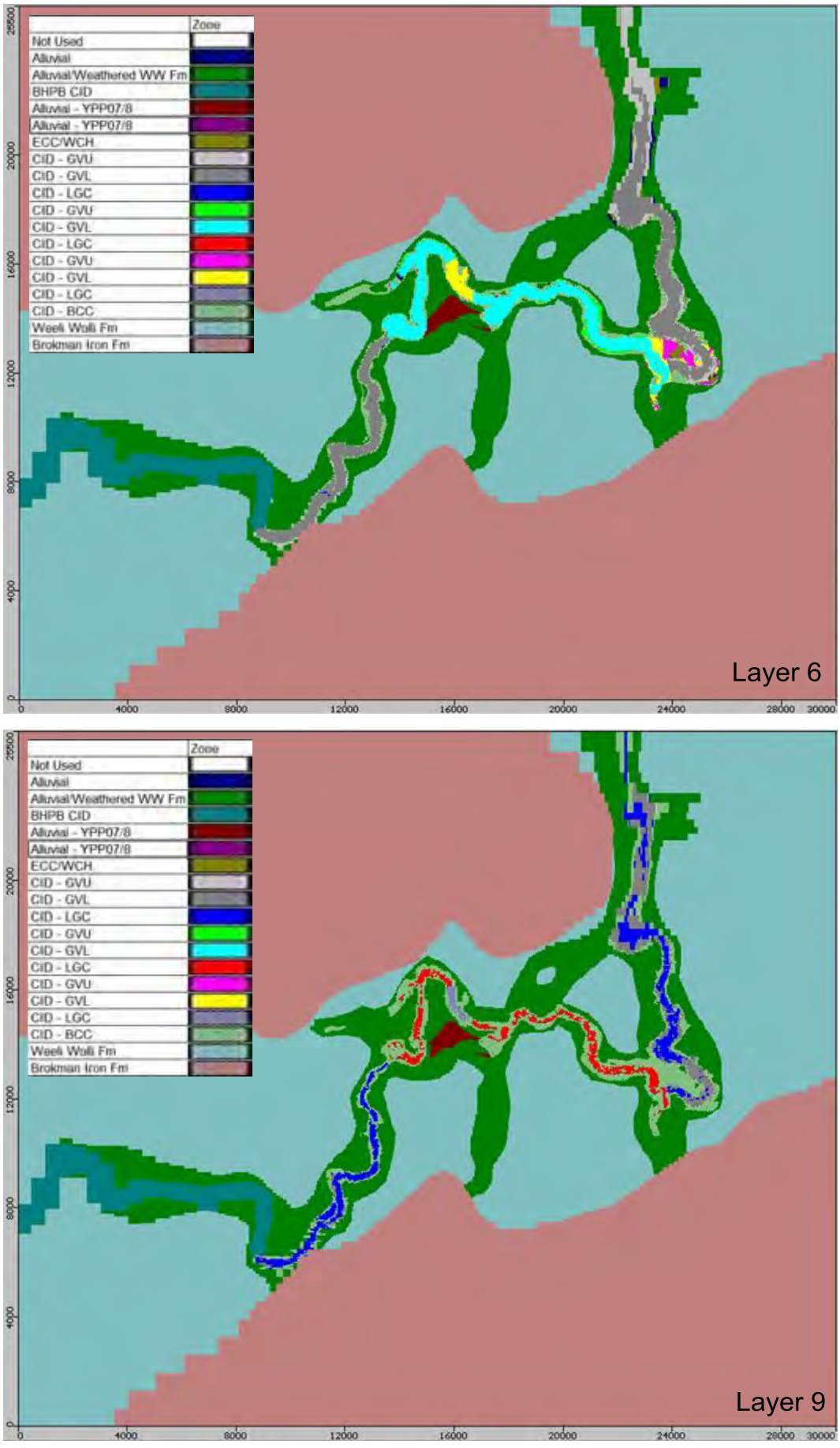

Figure 24. Hydraulic Parameter Zones – Plan View (Layer 6 and 9).

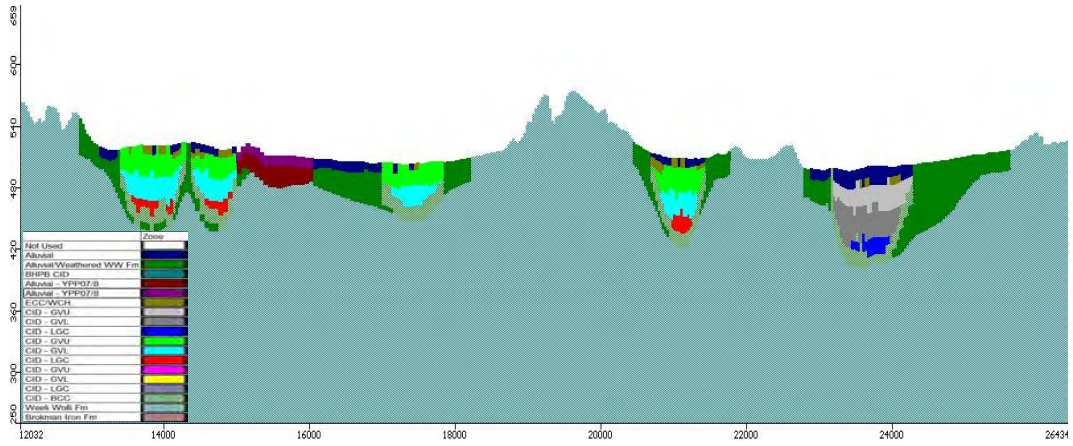

Figure 25. Hydraulic Parameter Zones – East West Cross-Section along Northing 13984mMOD (looking north).

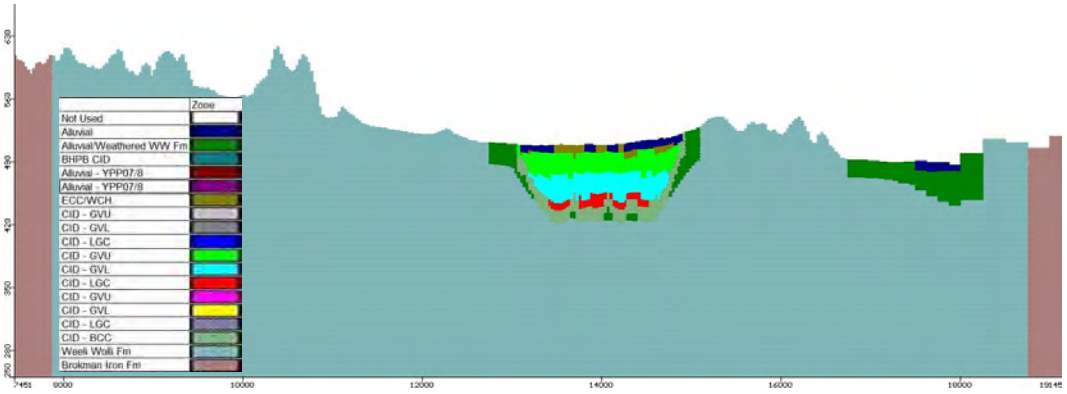

Figure 26. Hydraulic Parameter Zones – North South Cross-Section along Easting 21015mMOD (looking west).

No-flow boundary conditions were assigned to the model boundaries to represent the relatively impermeable Weeli Wolli Formation and Brockman Iron Formation outside the model domain except in the CID. Constant head boundary condition was assigned to the CID upgradient of the mine and MODFLOW drain cells were assigned to the CID down gradient of the mine as shown on Figure 27. This approach facilitates regional groundwater flow from the west and south to the north-north-east matching observations. MODFLOW drain cells were also used in the mined out area at Junction Central to represent in-pit sump pumping.

The upstream assignment of constant heads is recognised as a conservative approach given BHPB dewatering is occurring upstream and will impact the model boundary head over time. However in the absence of BHPB dewatering planning information, a conservative fixed head approach results in RTIO dewatering predictions not being contingent on BHPB meeting their plans.

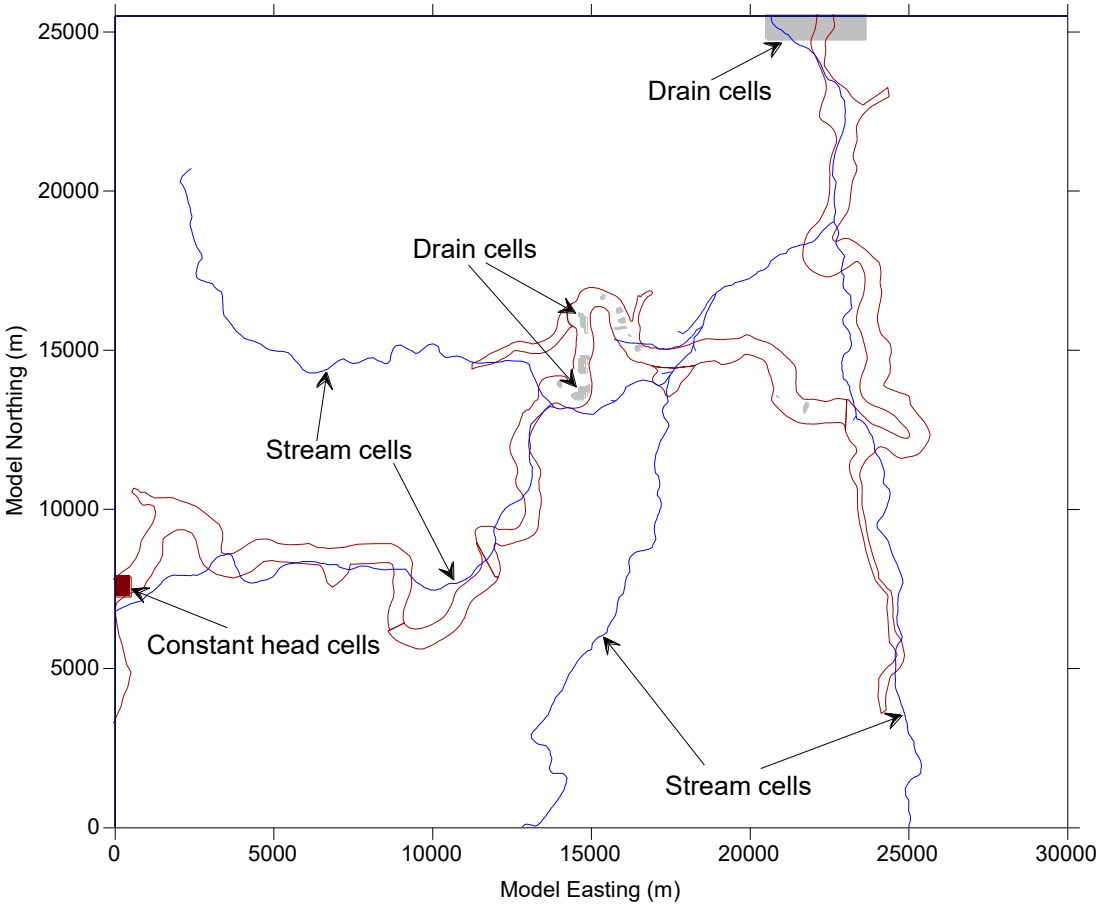

Figure 27. Model Boundary Conditions.

Direct rainfall recharge is represented in the model by MODFLOW recharge cells with selection that recharge enters the highest saturated layer i.e. cells that contain the water table. As direct rainfall recharge to the water table potentially occurs when it rains, measured rainfall were used to temporally vary monthly recharge rates assigned to the MODFLOW recharge cells. This simplified approach scaled the monthly measured rainfall and assumes all infiltration assigned enters the water table. Figure 28 shows the recharge zones assigned to the model based on surface geology and geomorphology. Although this approach is not very accurate in an arid environment, it serves as an approximation of seasonal rainfall recharge. The use of monthly stress period means high intensity rainfall lasting less than a month will be underestimated.

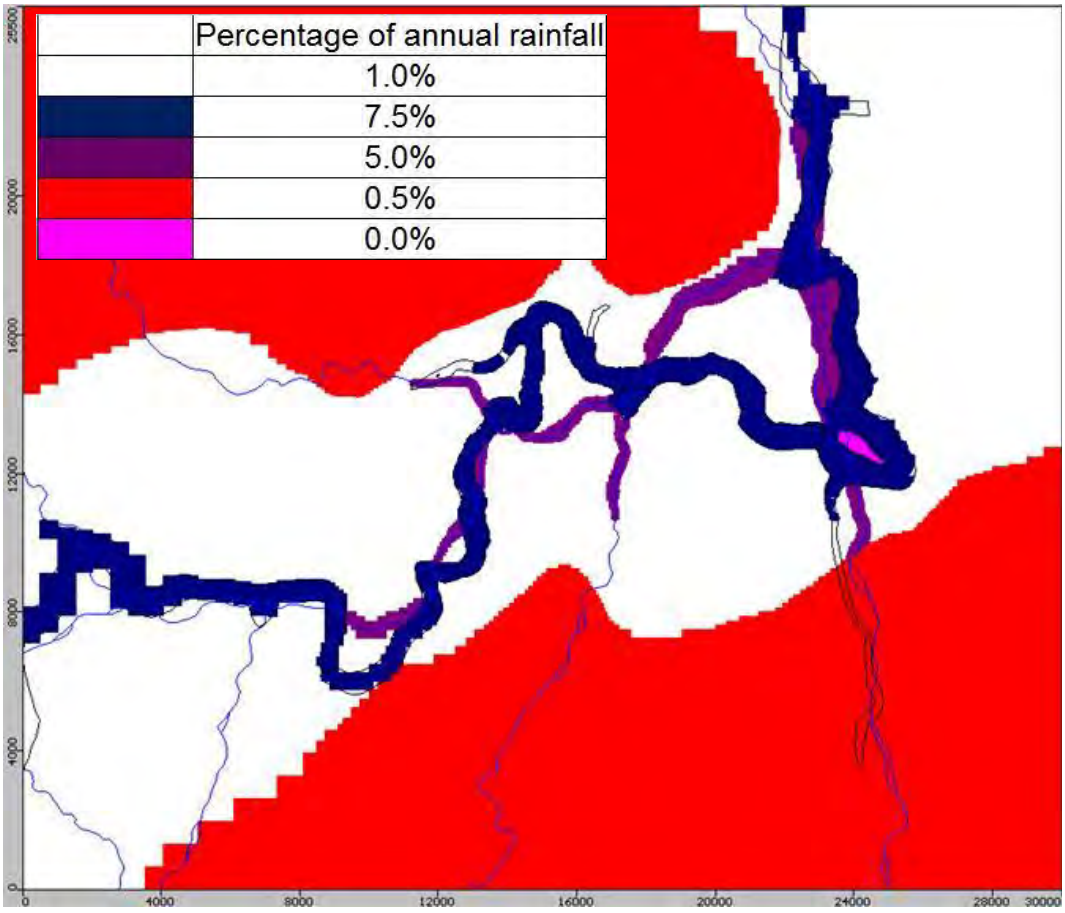

Figure 28. Recharge Zones.

Indirect rainfall recharge from creek leakage was modelled with MODFLOW stream cells. The use of stream cells accounts for losses and gains along the creek i.e. leakage upstream results in reduction in stream flow downstream. This is important in the model because Marillana Creek intersects the CID at a number of places where leakage potentially occurs. Dewatering in the CID has the potential to induce more leakage and hence lessen the amount of water that moves downstream and be available downstream. The rate of leakage is controlled by the streambed conductance of the stream cells. The variability and lack of measured values of the conductance between the creeks and the underlying aquifers has resulted in trial and error adjustment of the streambed conductance in the model calibration. A uniform rectangular stream width of 5m was

assumed and a Manning roughness coefficient of 0.093 was used to calculate the stage height for all the creeks. These values are not meaningful on their own. Current version of MODFLOW has 2 options in treating surface water in the creek. Option 1 is to assign a constant stage height and option 2 uses Mannings coefficients to calculate the stage height based on the equation below.

The depth of water (stage) is calculated based on:

$d = [Qn/ws^{1/2}]^{3/5}$

where

d = depth of water in channel, in metre;

Q = flow in channel in cubic metres per second;

n = Manning's roughness coefficient, dimensionless;

w = width of rectangular channel in metre; and

s = slope of the channel in length per length.

As both options are an imperfect representation of the creek when it floods, option 2 was selected as in part, it allows more water to infiltrate into the aquifers.

Stream cells were assigned to Marillana, Weeli Wolli, Yandicoogina, Phil's Creeks and the eight (8) discharge outlets as shown on Figure 29. Measured discharge rates from the discharge outlets were assigned to the location of the discharge outlets into the highest upstream stream cells. Stream flow in Yandicoogina and Phil's creeks were assumed a function of rainfall, catchment area and runoff assigned to the location shown on Figure 29. Discharge from BHP Billiton Yandi was added to the scaled catchment runoff upstream of the discharge location. Stream flow in Weeli Wolli Creek was modelled with measured flows at Tarina Gauging Station. Bank storage was not modelled.

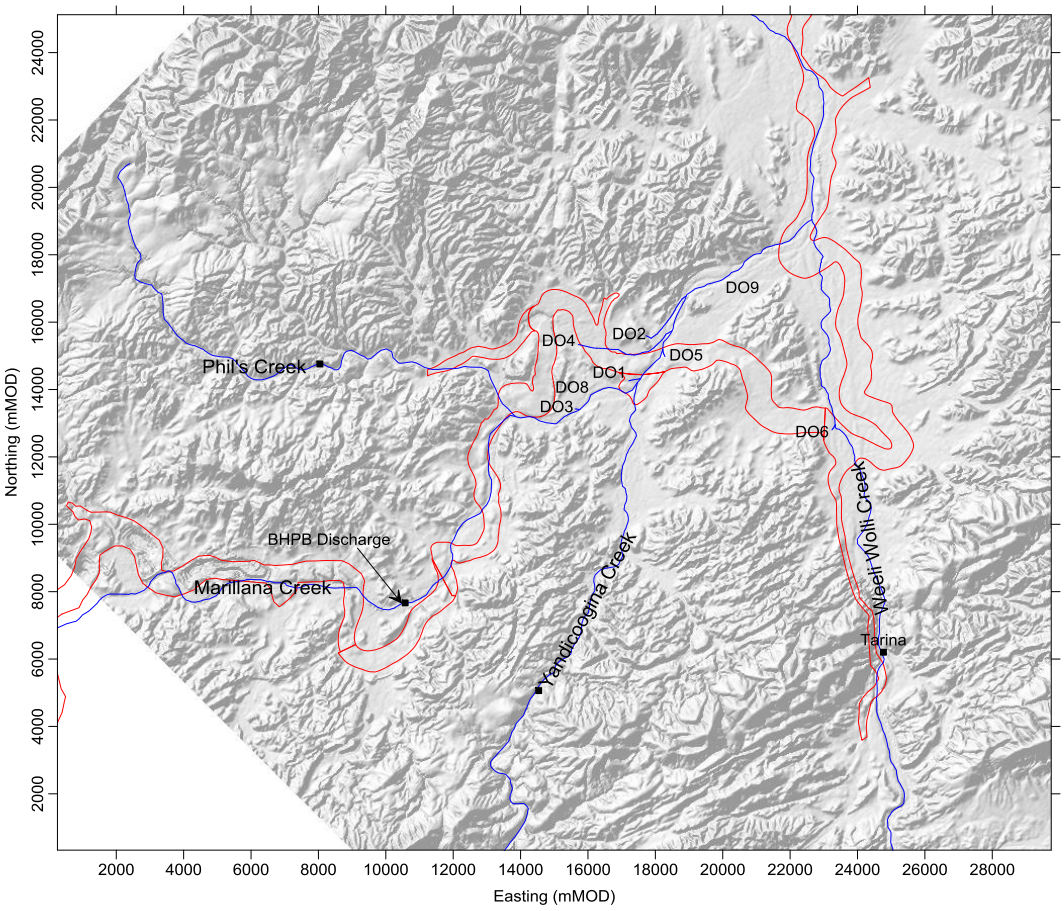

Figure 29. MODFLOW Stream Cells.

Groundwater discharge occurs through evapotranspiration. Evapotranspiration represents the loss of water through uptake by plants. The zoning of the evapotranspiration cells in the model is identical to the recharge cell zoning where groundwater is shallow. This assumes the area with higher recharge has denser vegetation and hence higher evapotranspiration. Extinction depths between 2m to 5m for the evapotranspiration cells were used to broadly represent the effective root depths of the native vegetation. MODFLOW assumes a simplistic approach of linearly reducing the assigned evapotranspiration rate to zero at the extinction depth. Figure 30 shows the evapotranspiration zones.

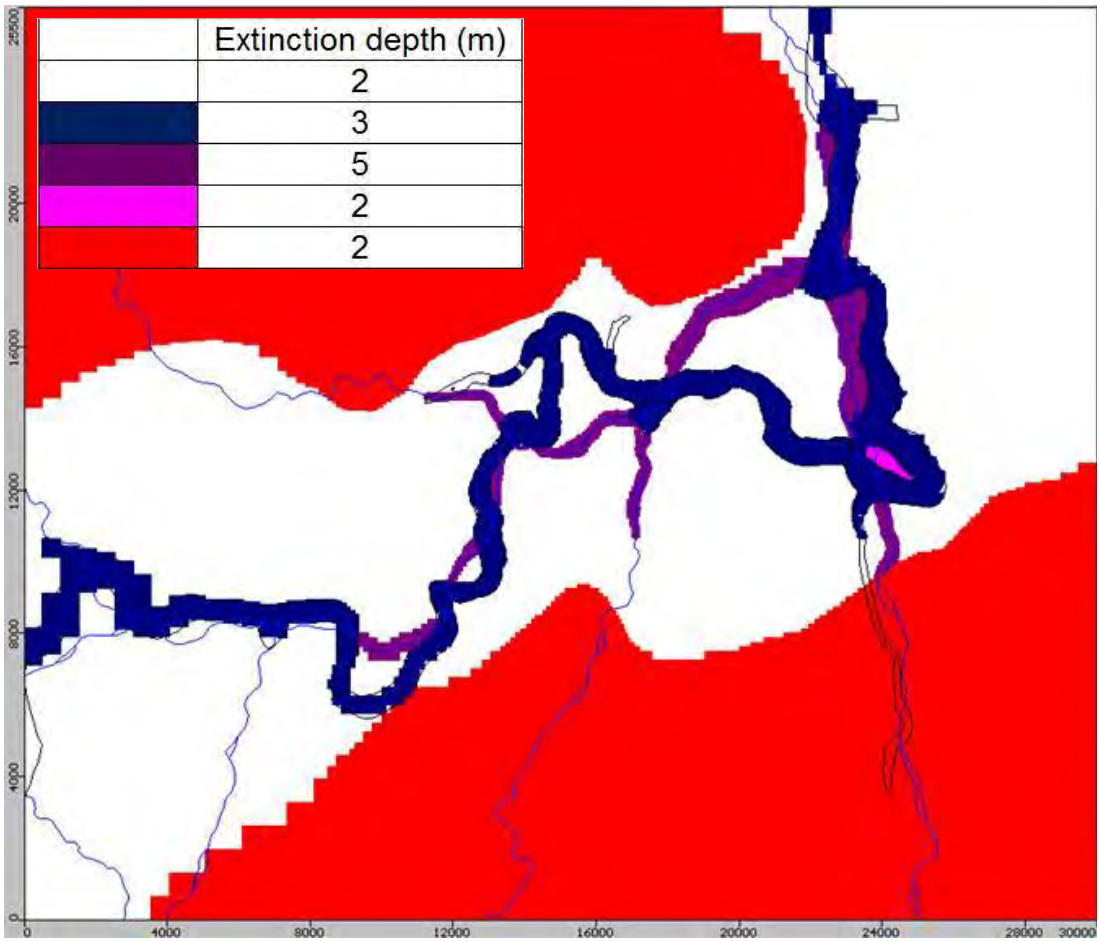

Figure 30. Evapotranspiration Zones.

Indirect discharge occurs through outflow from Weeli Wolli Creek at the model boundary and dewatering bores. MODFLOW drain cells were used in the former. Dewatering and injection bores were modelled with MODSURFACT Fractured Well Package. The package treats the screened section as a highly conductive zone, similar to the behaviour of an actual screen section, in computing inflows into the well from each aquifer intersected. Measured abstraction and injection rates since 1998 were reduced to monthly rates and assigned to the model. The screened intervals were simplified to include the GVL and the LGC layers, however, if these layers are thin then the screened intervals were extended to include the GVU and/or the BCC layers. This assumes that the LGC, being most permeable, can effectively drain the upper layers. Figure 31 shows the location of the dewatering and injection bores assigned to the model since 1998.

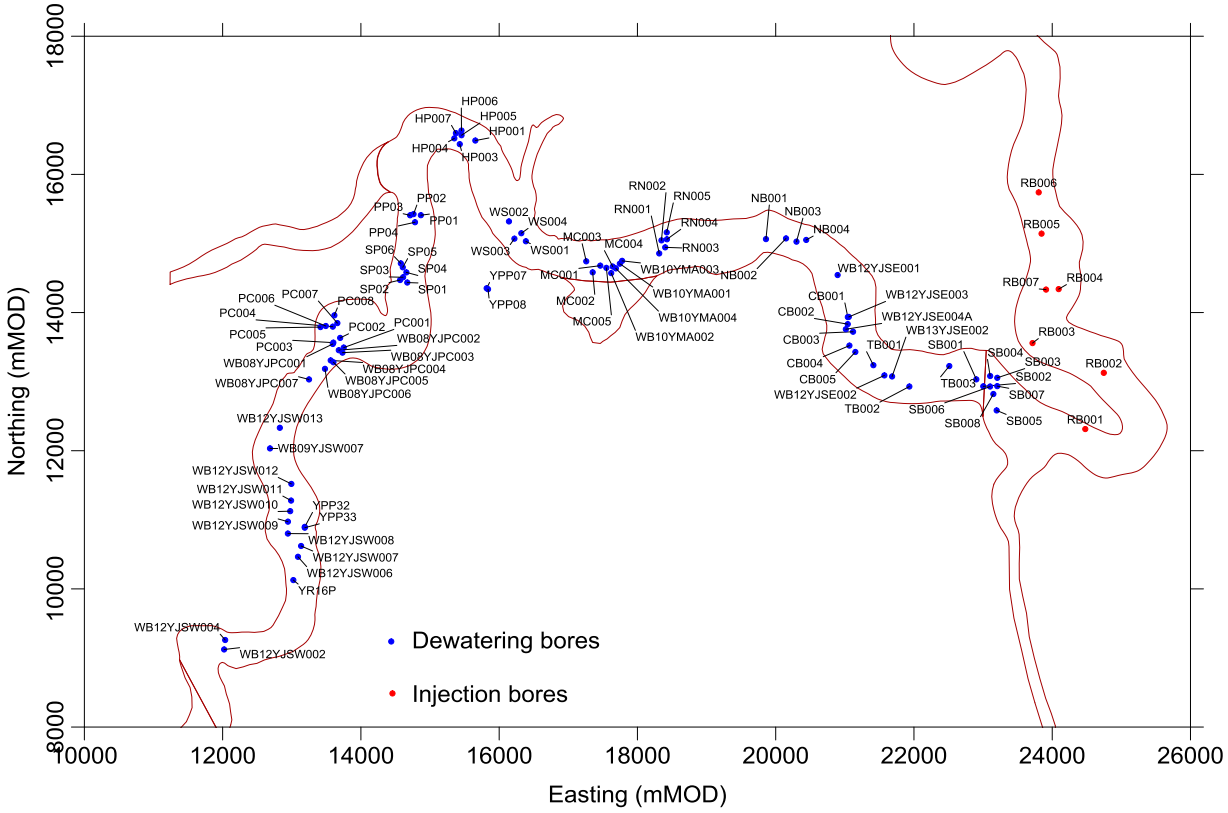

Figure 31. Dewatering and Injection Bores (1998 to 2013).

8. Steady-State Calibration

The model steady-state calibration process adopted involved the establishment of a water level condition consistent with pre-abstraction water level at Yandi. The purpose is to establish an initial/starting water level for the transient calibration consistent with the hydrogeology. Water levels measured pre-1998 was used as target for the steady-state calibration. At RTIO Yandi, this is somewhat compromised by discharge from BHP Billiton Yandi Operations. The dynamic nature of the system to recharge meant that only quasi steady-state conditions exist. Hydraulic conductivity and boundary conditions were adjusted in the calibration process.

Table 1 lists the scaling factors applied to the measured monthly rainfall and Table 2 lists the extinction depths required to calibrate the model.

Table 1. Recharge Zones and Scaling Factors.

Zone	Description	Percentage of annual rainfall
1	Weeli Wolli Formation	1%
2	Channel Iron Deposit	7.5%
3	Alluvial	5%
4	Brockman Iron Formation	0.5%
5	Low permeability WW Fm	0%

Table 2. Evapotranspiration Zones Rates and Extinction Depths.

Zone	Descriptions	Extinction Depth (m)
1	Weeli Wolli Formation	2
2	Channel Iron Deposit	3
3	Alluvial	5
4	Brockman Iron Formation	2
5	Low permeability WW Fm	2

Figure 32 shows the simulated steady-state water table consistent with 1997 water table. Table 3 lists the mass balance from the steady-state model. An inflow/throughflow rate of 3.2 ML/day is in agreement of with an estimated throughflow of 2.5 to 3 ML/day by Peck in 1998.

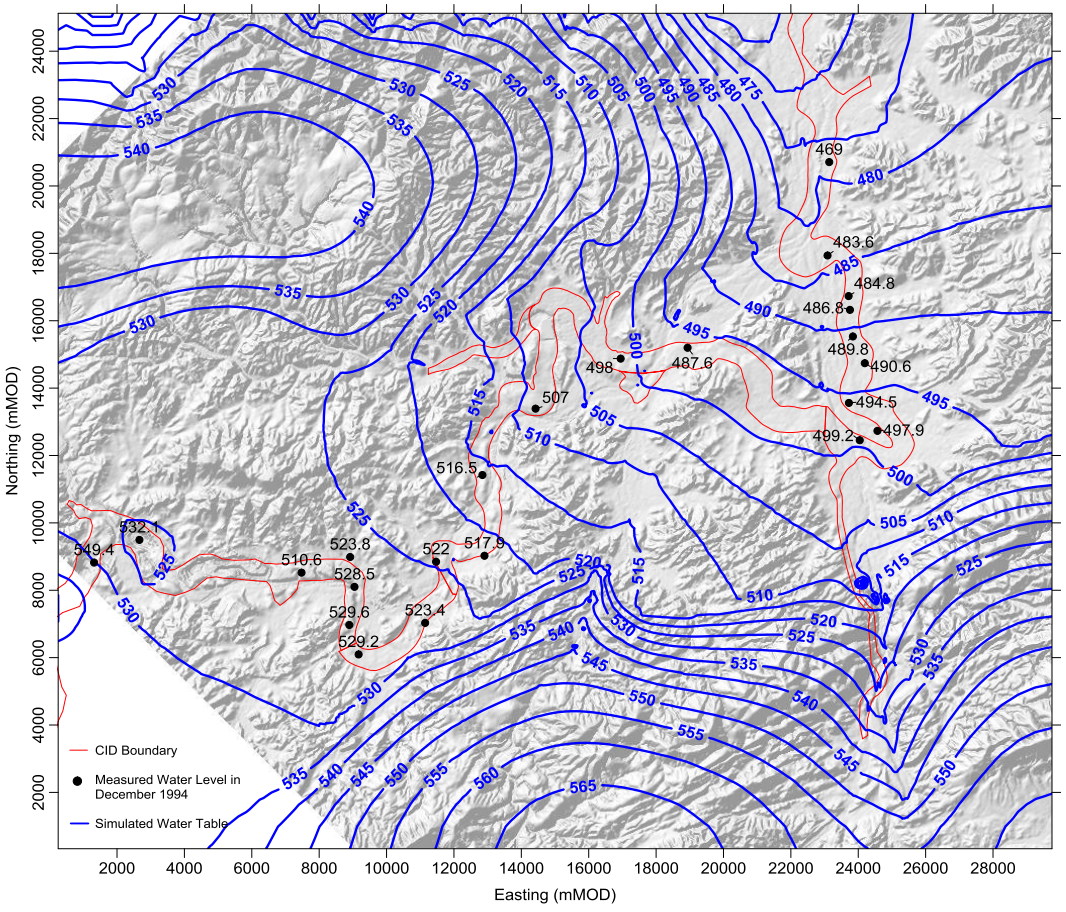

Figure 32. Simulated Steady-State Water Table (mRL).

Table 3. Steady-State Water Balance Summary.

	Volume In		Volume Out	
	Total (kL/day)	**% of Total**	**Total (kL/day)**	**% of Total**
Stream Leakage	138,295	96.5	97,700	68
Recharge	1,768	1.2	0	0
ET	0	0	39,921	27.8
Constant Head	3,239	2.3	30	0
Drain Cells	0	0	6,047	4.2
Total	**143,302**	**100**	**143,668**	**100**

9. Transient Calibration

Following an acceptable match of the simulated steady-state water table with pre-abstraction water levels, the steady-state model was configured with transient conditions by activating all transient parameters and boundary conditions. Historical abstraction, injection and discharge rates, and water levels from observation bores from January 1998 to January 2014 were used in the calibration – a period of 16 years.

Monthly stress periods were used to capture the changes in abstraction, injection, recharge and evapotranspiration rates. Scaling factors for rainfall recharge and stream flows from the steady-state calibration were adopted in the transient calibration. Specific yield and specific storage of each of the hydrostratigraphic units were adjusted, within bounds, in the transient calibration. Calibration was done by comparing simulated hydrographs with measured hydrographs. Figure 33 shows the locations of the calibration bores. Both quantitative (water level matching) and qualitative (trend matching) methods were used to guide the model calibration. Any changes to hydraulic conductivity and boundary conditions require recalibration of the steady-state model. Figures 34 to 40 show simulated versus observed hydrographs in the calibration bores. Observed values are represented by green dots and simulated hydrographs by blue lines.

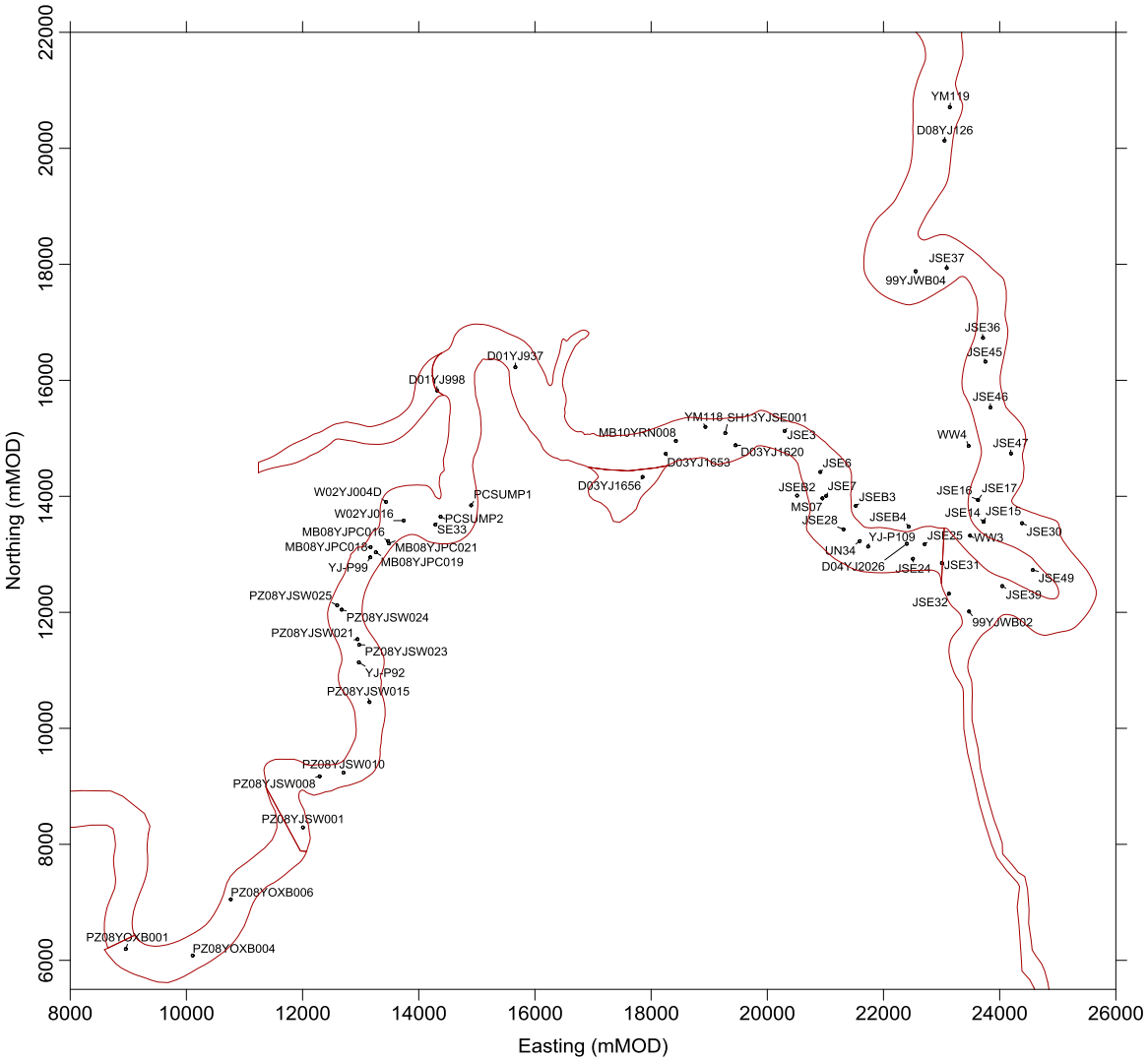

Figure 33. Location of Calibration bores.

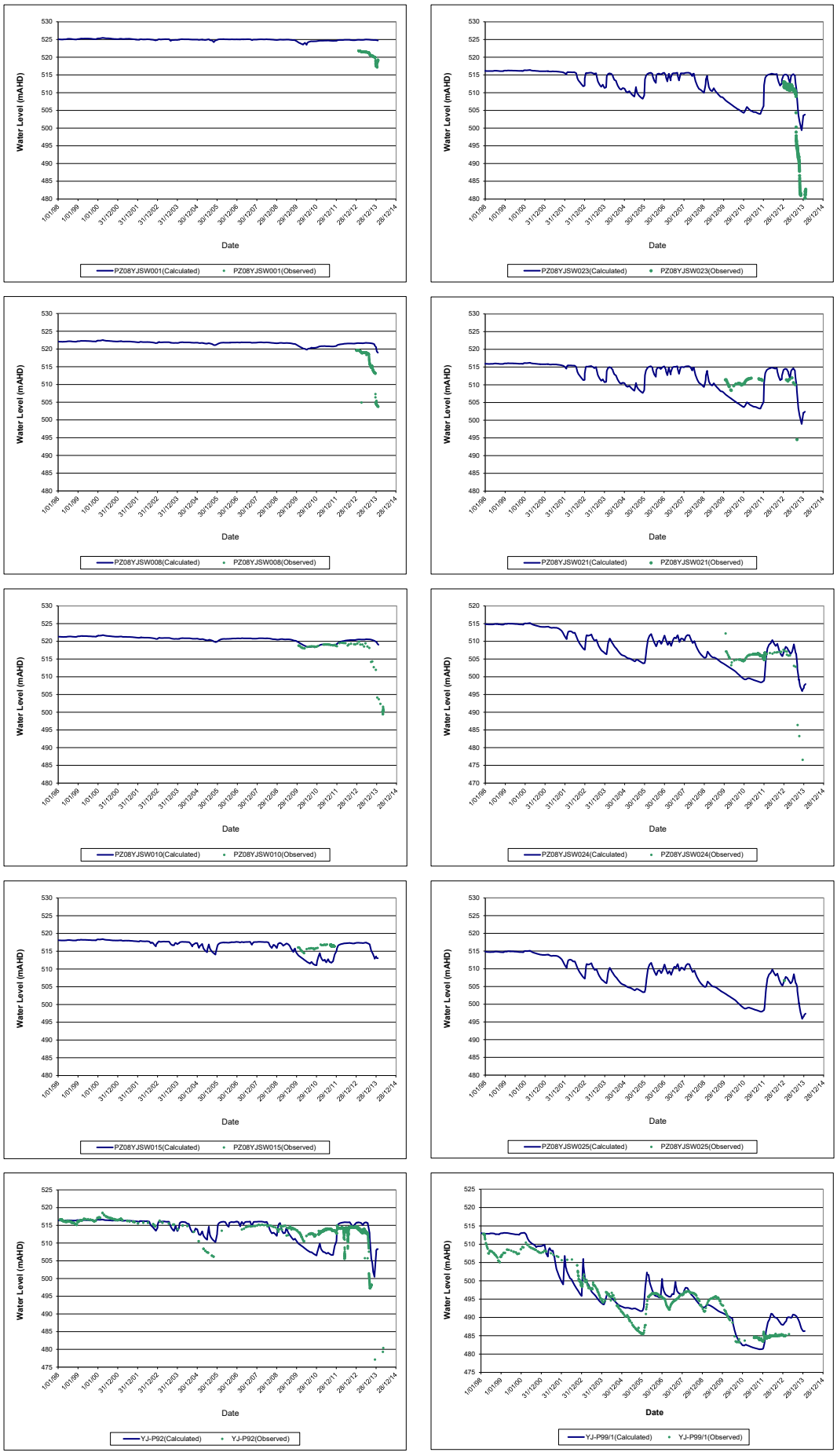

Figure 34. Transient Calibration - Observed versus Calculated Heads.

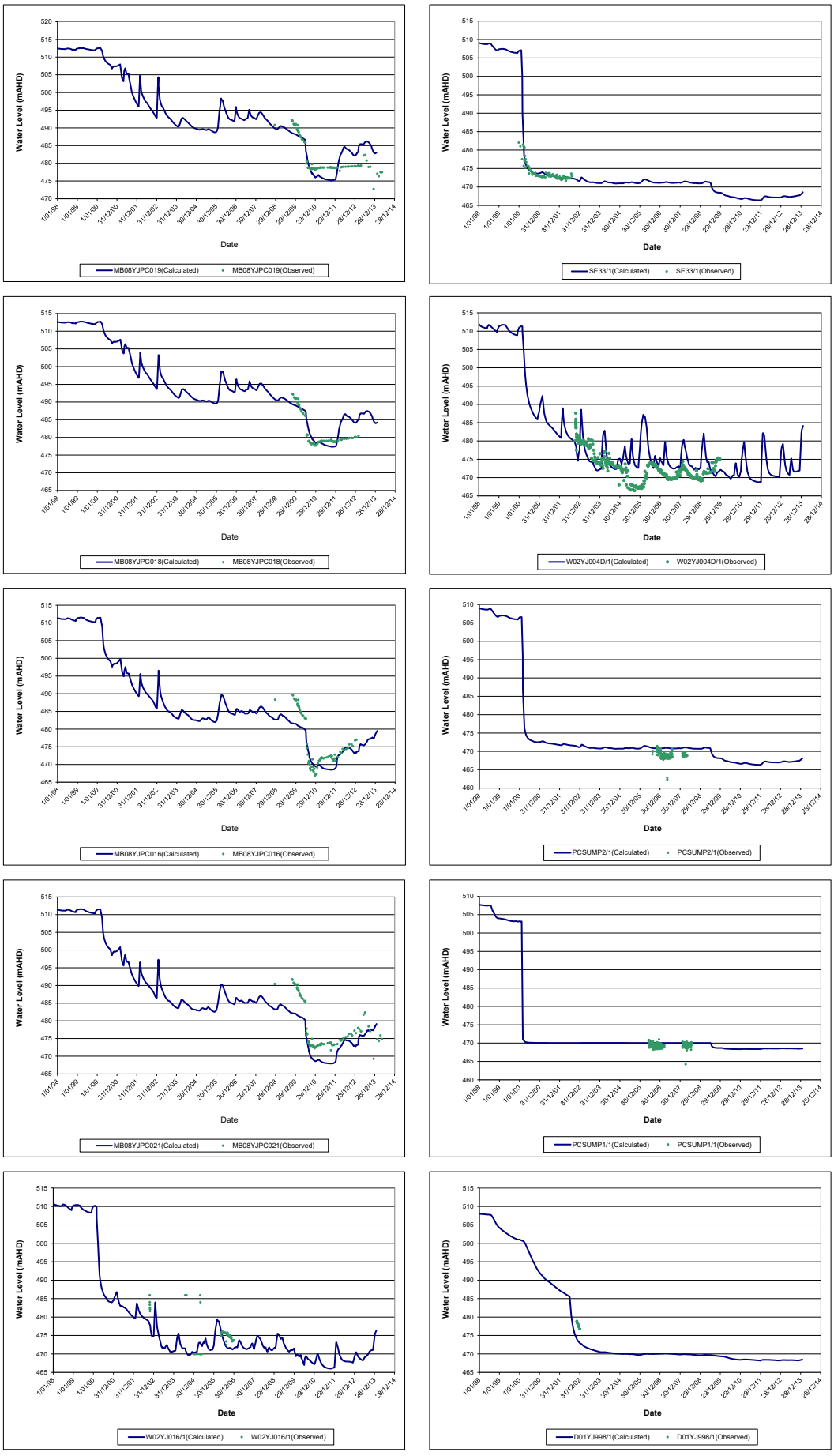

Figure 35. Transient Calibration - Observed versus Calculated Heads.

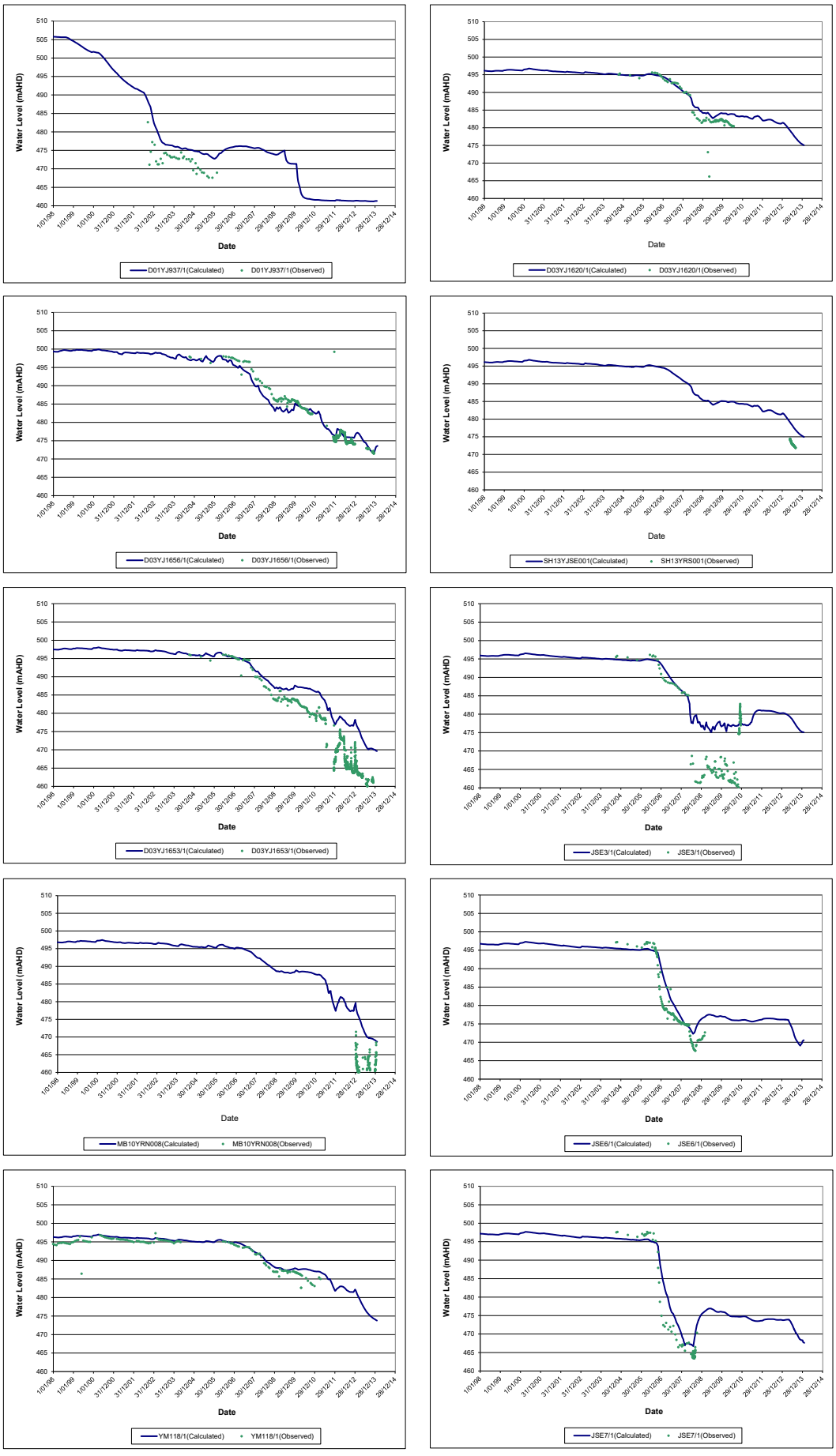

Figure 36. Transient Calibration - Observed versus Calculated Heads.

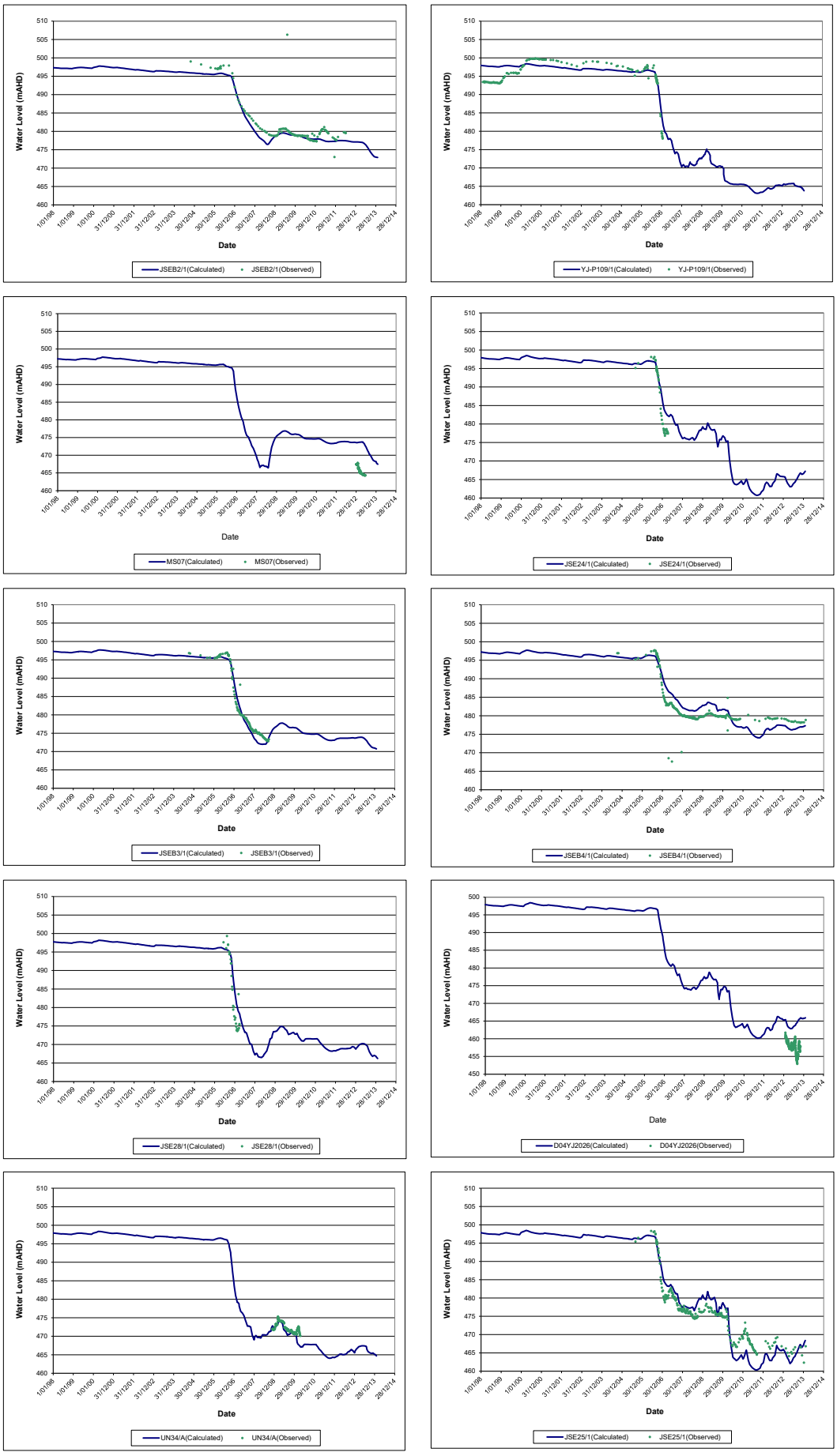

Figure 37. Transient Calibration - Observed versus Calculated Heads.

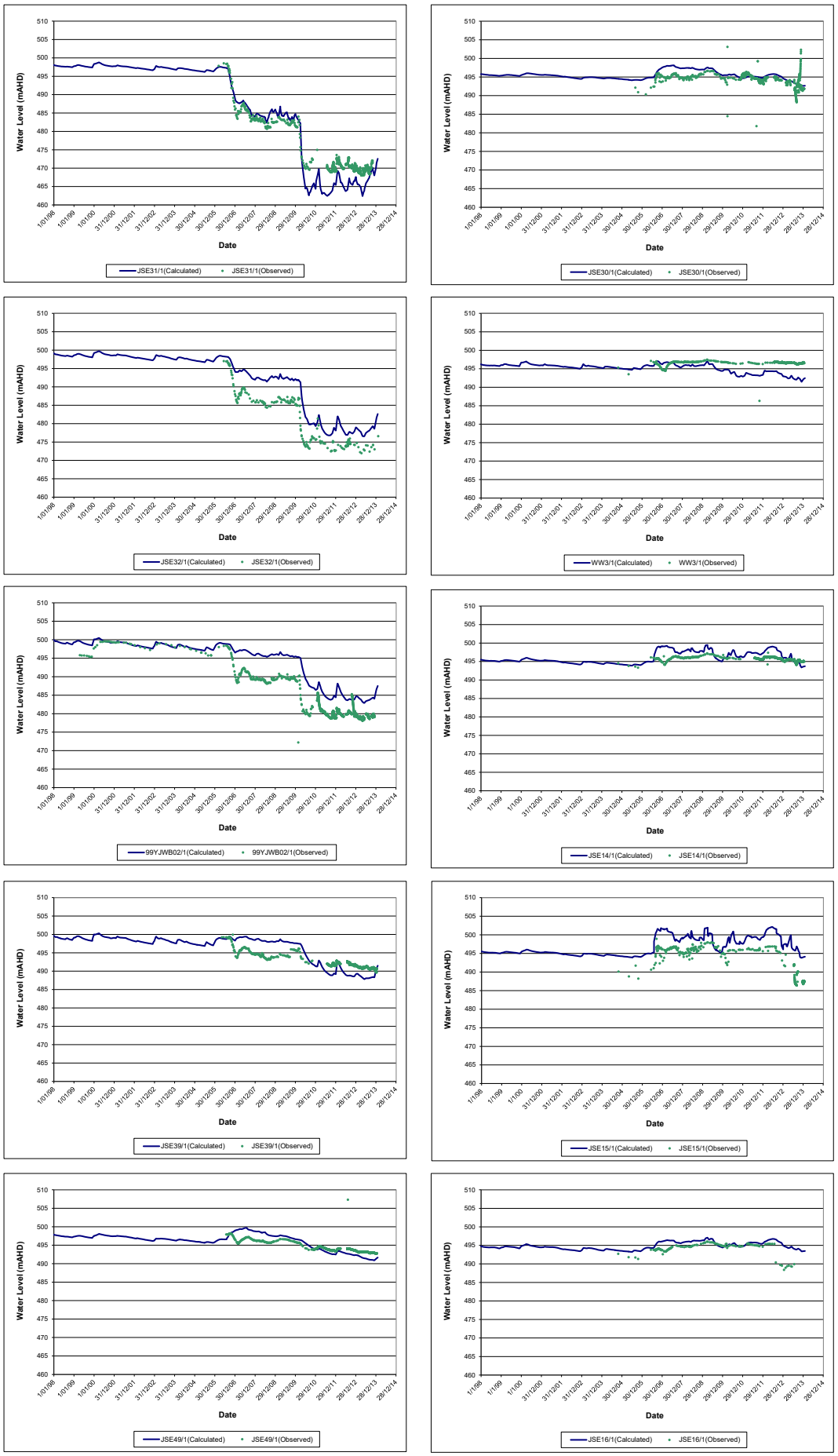

Figure 38. Transient Calibration - Observed versus Calculated Heads.

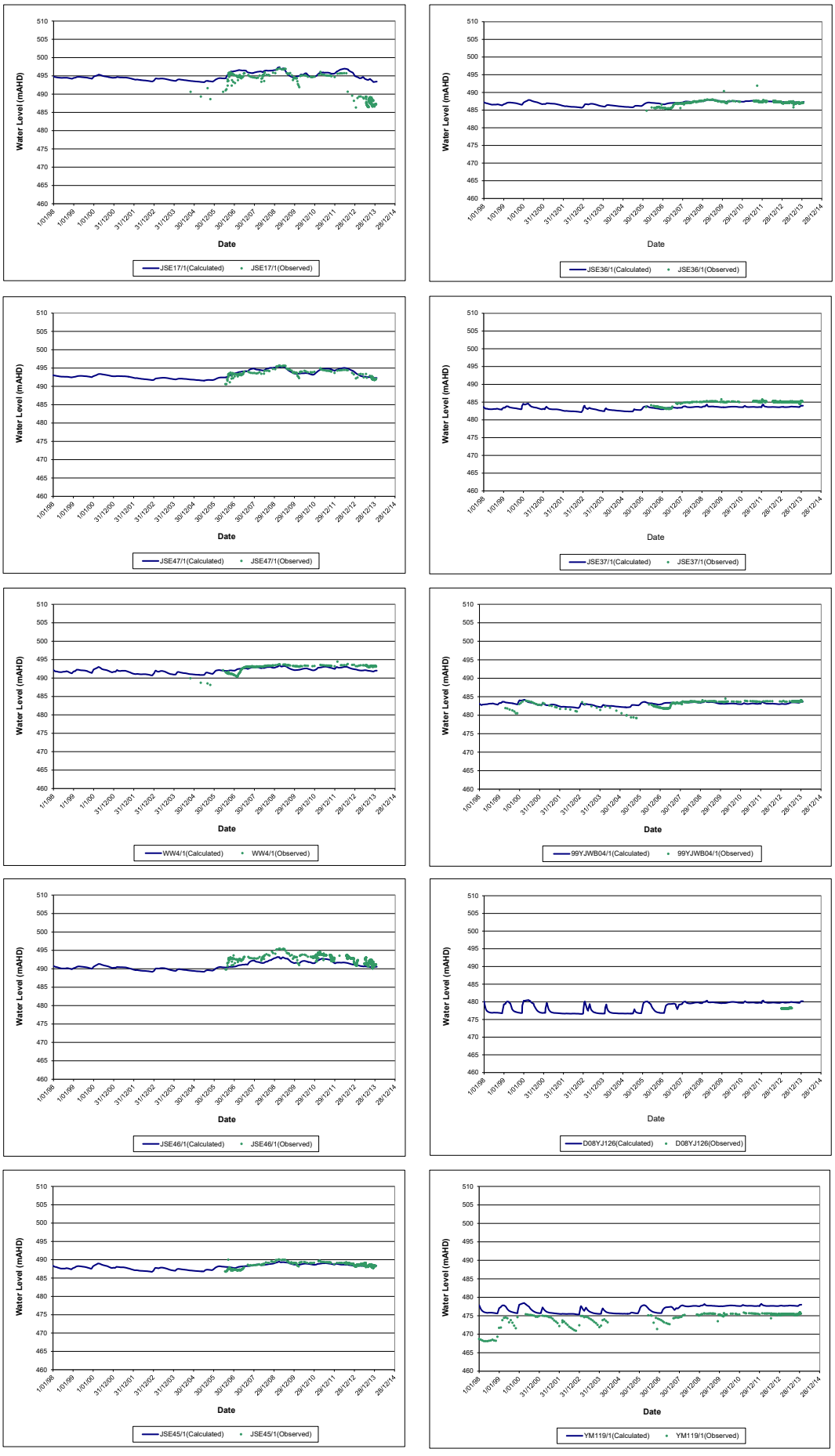

Figure 39. Transient Calibration - Observed versus Calculated Heads.

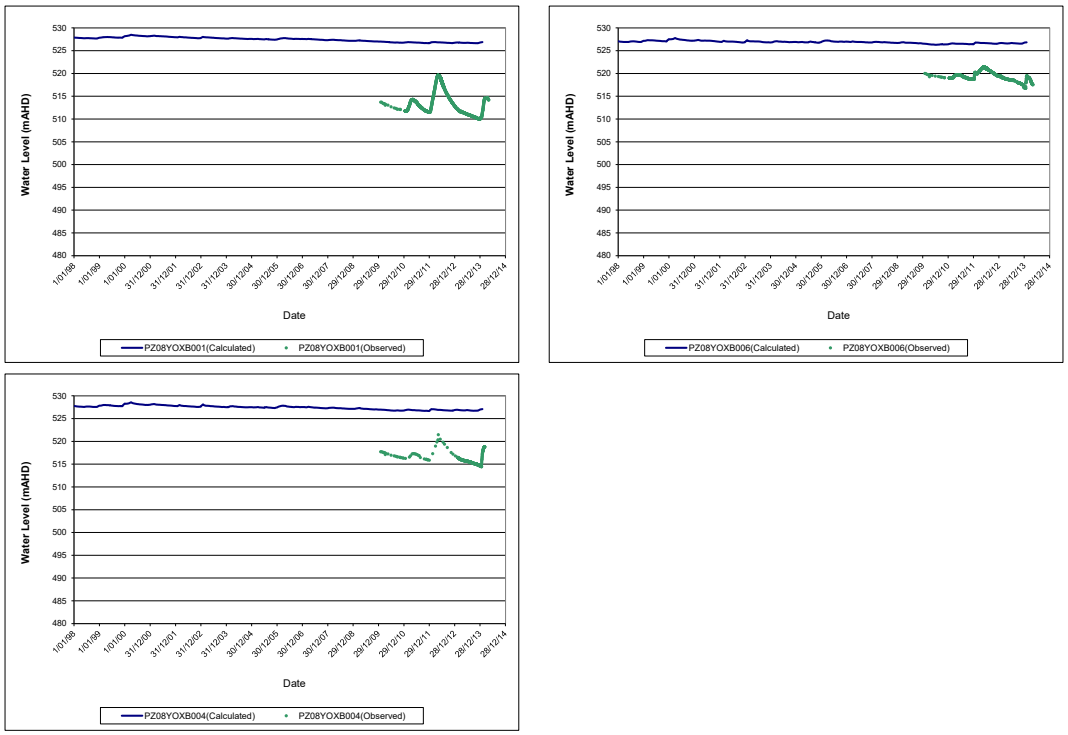

Figure 40. Transient Calibration - Observed versus Calculated Heads.

The simulated hydrographs show the model generally is able to replicate the measured water table over a period of 16 years of dewatering. Where simulated divert from measurements, errors can be attributed to lack of details in the model or measurement error in monitoring water level in the calibration bores and accuracy of the flowmeters. Site has acknowledged that there is insufficient flowmeters in the water circuit to account for all water use on site. Flowmeters once installed were never recalibrated due to operational issues, hence accuracy is compromised. Estimates were made where there is no flowmeter at discharge outlets, sumps and dewatering bores. Overall the transient calibration (TrCal11a_2014.vmf) represents the site hydrogeology very well. The model will need to be recalibrated in the JSW area when more pumping data becomes available. In the Oxbow area, simulated water level is higher than measured. This may be due to dewatering at BHP Billiton Yandi not captured in the model. Table 4 lists the hydraulic parameters derived from the model calibration. The hydraulic parameters were generally similar to the previous model.

Table 4. Hydraulic Parameters of Zones.

	Zone	Kx	Ky	Kz	Sy	Ss
Not Used		0.5	0.5	0.05	0.01	0.000001
Alluvial		20	20	4	0.1	0.0001
Alluvial/Weathered WW Fm		10	10	1	0.1	0.00001
BHPB CID		20	20	4	0.1	0.00001
Alluvial - YPP07/8		50	50	10	0.3	0.0001
Alluvial - YPP07/8		20	20	4	0.3	0.0001
ECC/WCH		1	1	0.1	0.1	0.0001
CID - GVU		2	2	0.5	0.01	0.000001
CID - GVL		10	10	5	0.05	0.000001
CID - LGC		20	20	10	0.1	0.000001
CID - GVU		5	5	2	0.05	0.000001
CID - GVL		20	20	4	0.1	0.000001
CID - LGC		70	70	30	0.2	0.000001
CID - GVU		1	1	0.2	0.005	0.000001
CID - GVL		5	5	1	0.01	0.000001
CID - LGC		10	10	2	0.02	0.000001
CID - BCC		1	1	0.2	0.01	0.000001
Weeli Wolli Fm		0.5	0.5	0.05	0.01	0.000001
Brokman Iron Fm		0.01	0.01	0.01	0.001	0.000001

The water balance from the transient calibration indicates that increased dewatering at Yandi is coupled with increased leakage from the creeks as shown in Figure 41. This is a function of site water management where the discharge of dewatering surplus to creeks results in recirculation to the aquifer. Figure 42 shows most of the leakage comes from Weeli Wolli Creek with the discharge from Hope Downs 1 from July 2006.

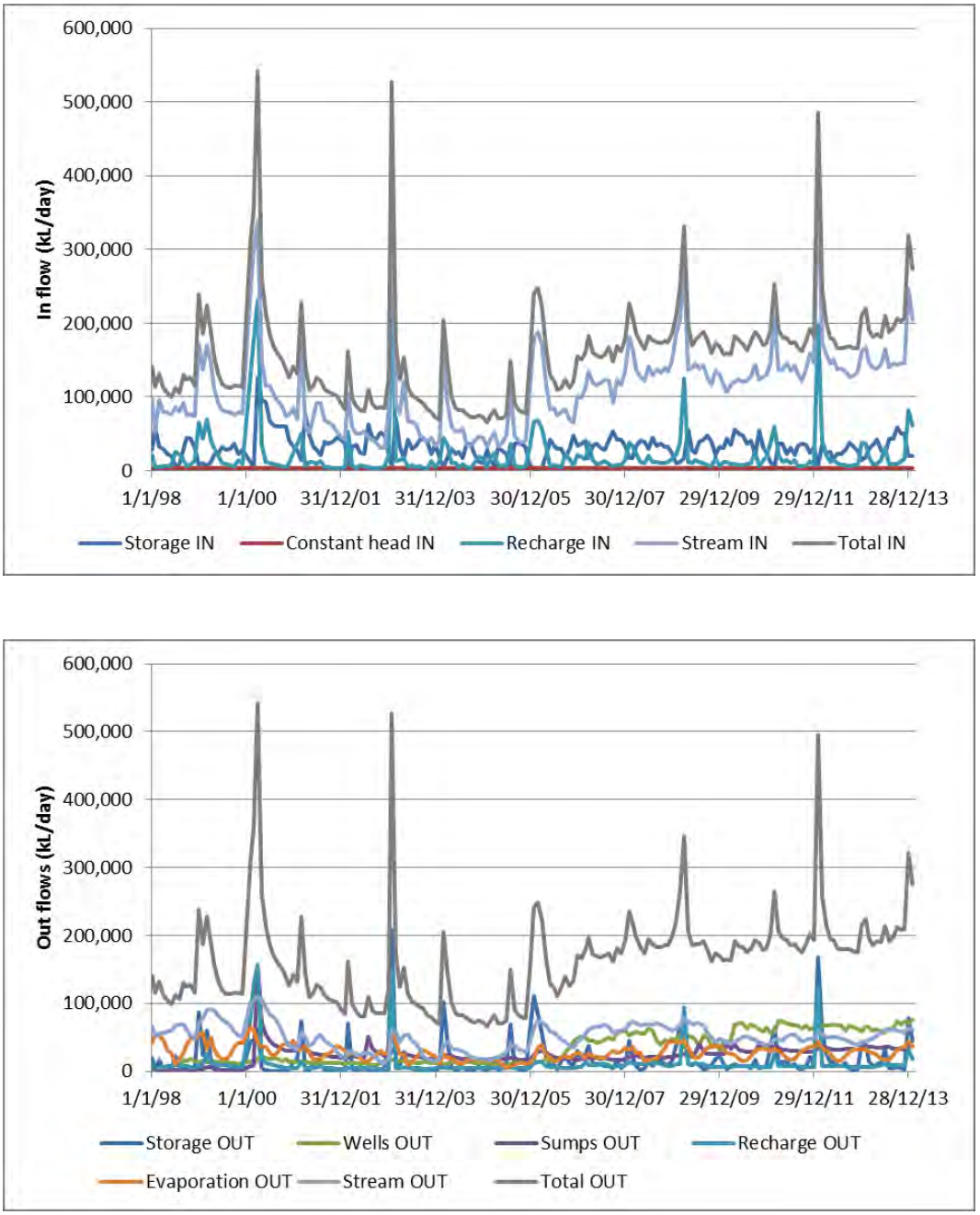

Figure 41. Transient Calibration Mass Balance.

Figure 43 shows the percentage discrepancy errors from the transient model calibration simulation. Percentage discrepancy error below 5% is considered good for complex flow systems.

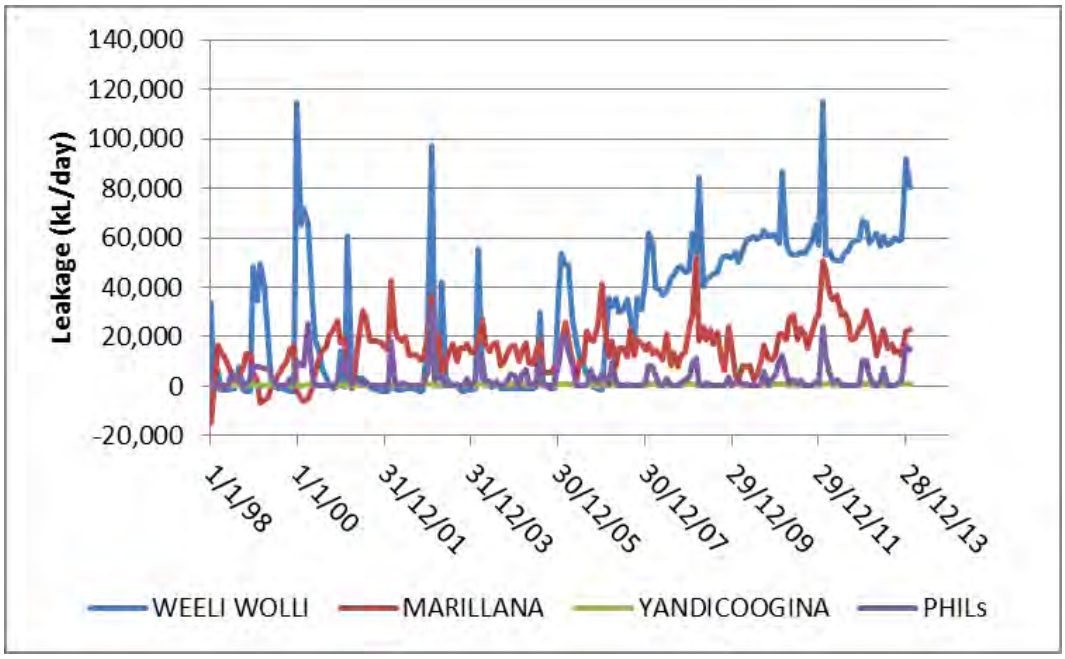

Figure 42. Leakage from creeks.

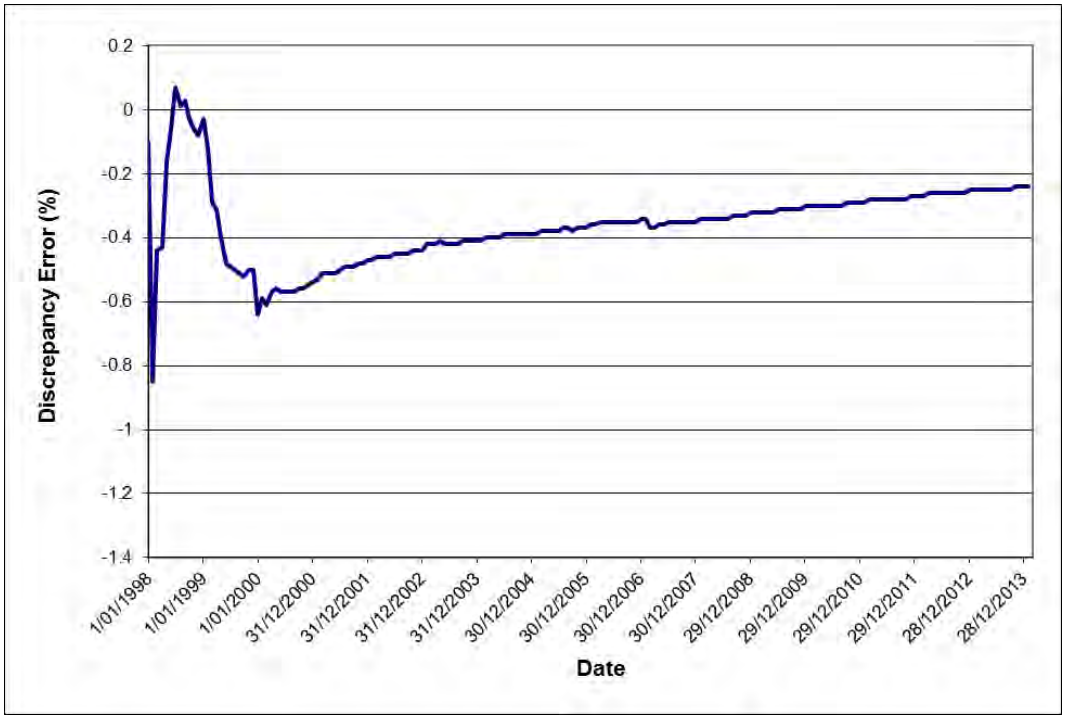

Figure 43. Transient calibration - discrepancy errors.

10. Sensitivity Analysis

Sensitivity analysis was conducted by perturbing the parameters by 20% on either side of the calibrated hydraulic conductivity and 50% on either side of the calibrated specific yield. The results show is the model is not sensitive to hydraulic conductivity of the alluvial at the water supply bores, eastern clay conglomerate/weathered channel deposit and Upper Vitreous Geothite (Figure 44) and specific yield of Limonite Geothite Clay in the Billiards and JSW areas (Figure 45). This implies that these hydrostratigrahic unit parameters can vary without significantly distorting the calibration. These units are identified as potential significant contributing elements to uncertainty in the model predictions and will be tested in the predictive simulations to provide an upper bound of the dewatering requirements as a full suite would take too long and does not add significant value.

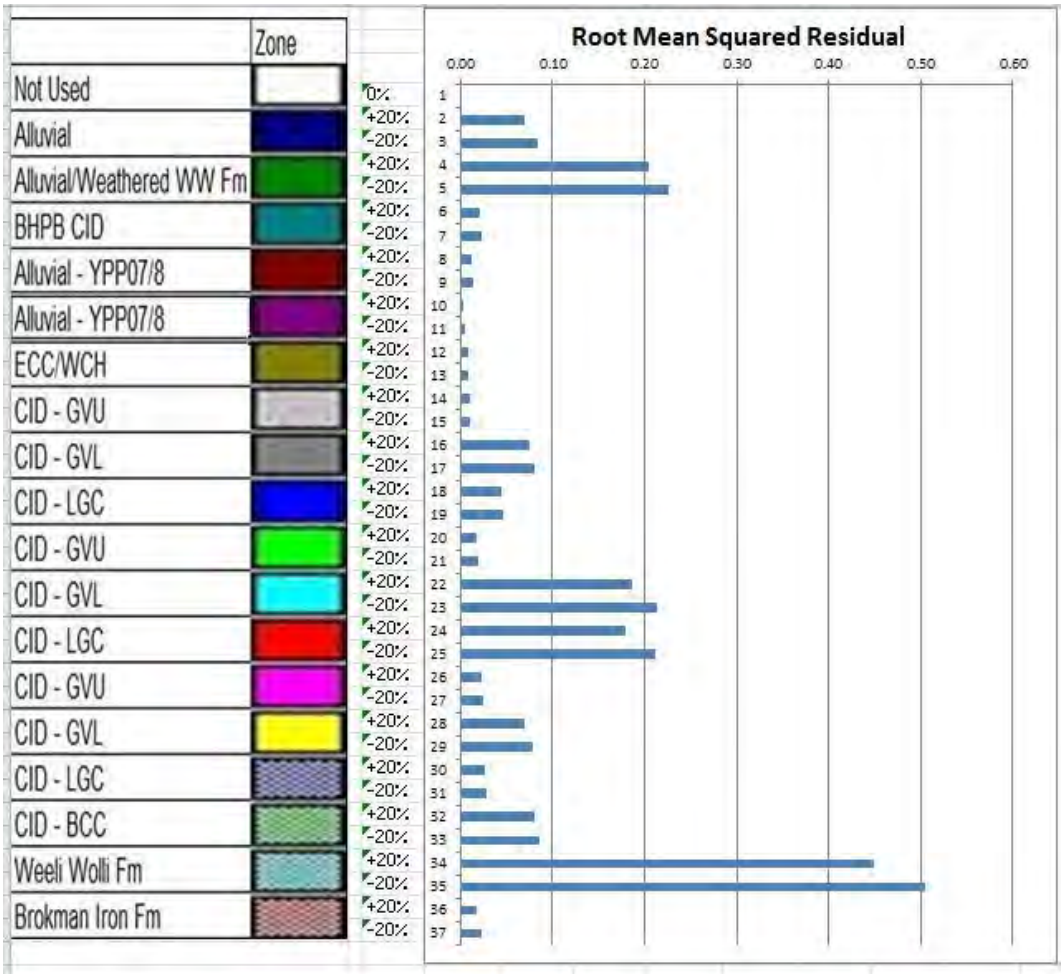

Figure 44. Sensitivity Analysis of Hydraulic Conductivity.

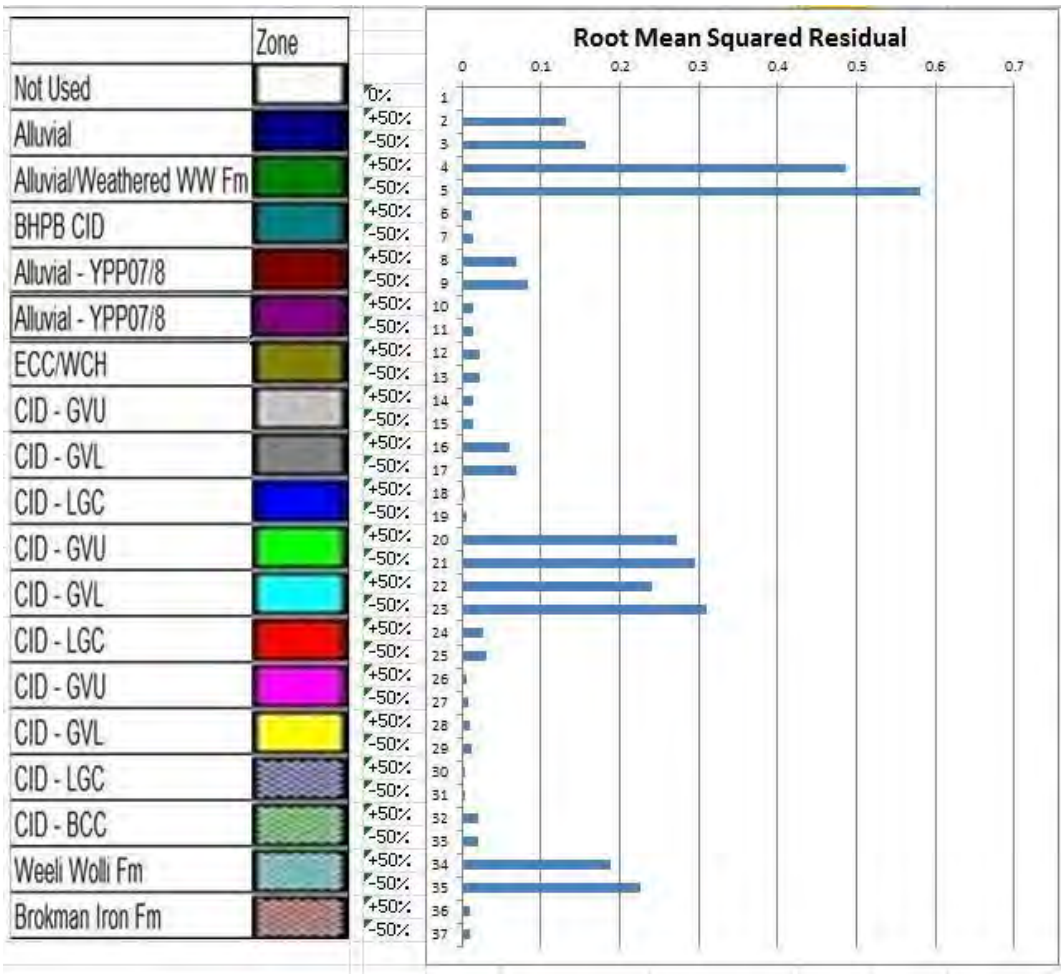

Figure 45. Sensitivity Analysis of Specific Yield.

11. Model Prediction

As part of the PFS for PBS, an estimate of the dewatering requirement is required. Based on the Billiards South A8 mine schedule released in August 2014, the numerical model was configured with predictive conditions to determine the dewatering requirements of the mine as a whole i.e. including Junction Central (JC), Junction South East (JSE), JSW and Oxbow. According to the A8 mine schedule, mining is to commence close to the centre of Billiards South and expand north and south concurrently. Figure 46 shows the start year of mining, Figure 47 shows the end year of mining for each mine block. Figure 48 show the final pit floor elevation. A number of predictive simulations were conducted to optimise the placement of dewatering points. Modelled dewatering points are potential locations for bores not drilled. The number of bores required for each proposed dewatering point depends on the local aquifer yield and bore utilisations.

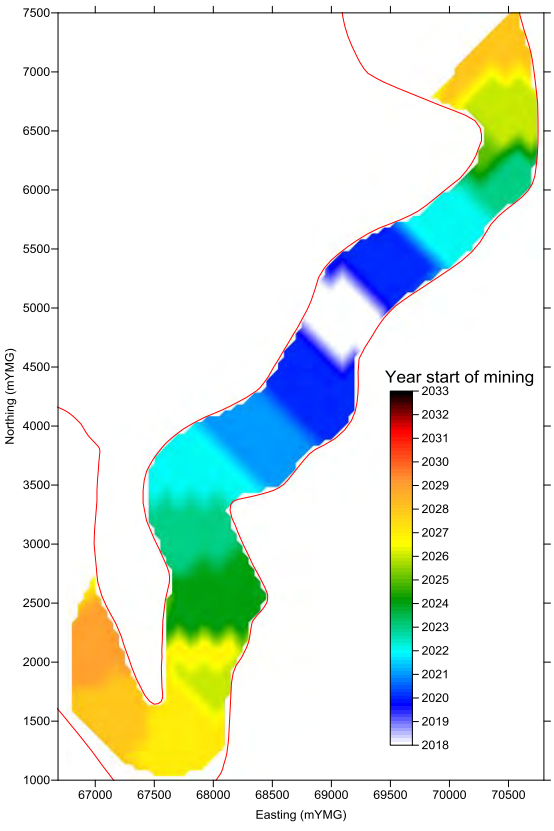

Figure 46. Start year of mining.

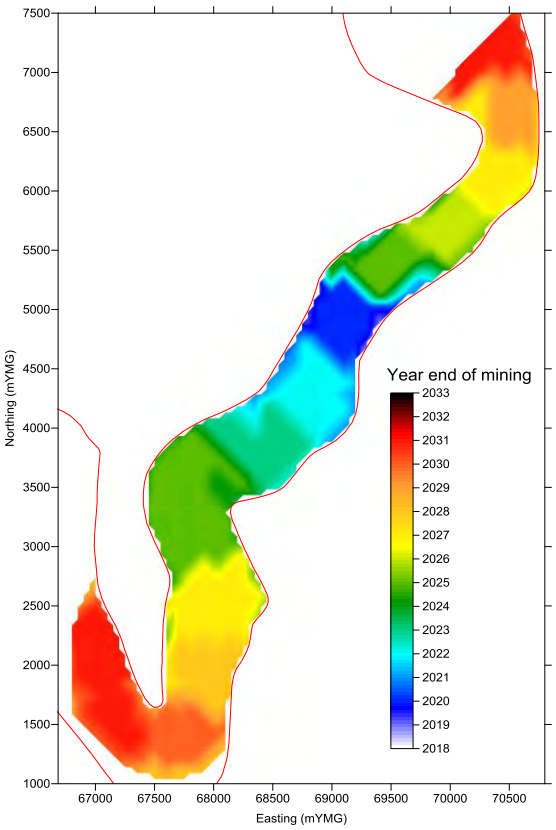

Figure 47. End year of mining.

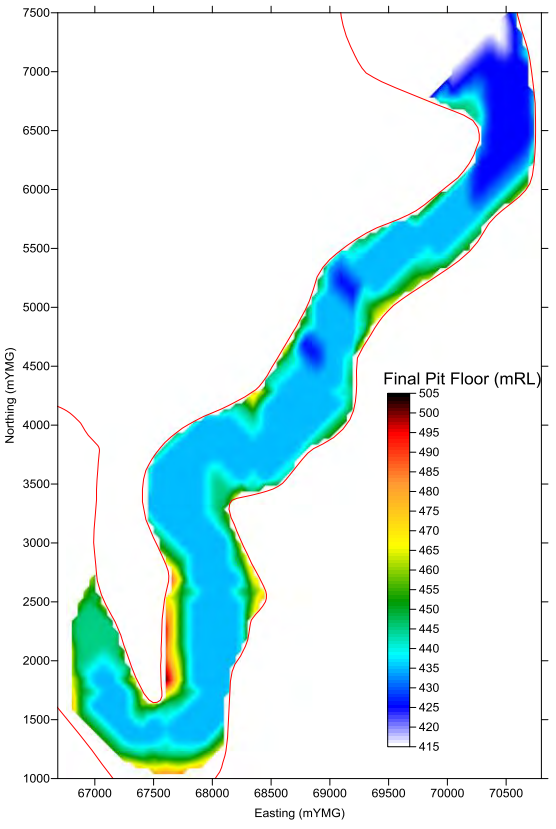

Figure 48. Elevation of pit floor.

For the predictive simulations, flow in the creeks were based on discharge rates from 2009 to 2013, averaged for each calendar month for a year and repeated yearly for the duration of the predictive simulation. Figure 49 shows flows in Marillana Creek at BHPB discharge point and Figure 50 shows flow from Tarina Station into Weeli Wolli Creek.

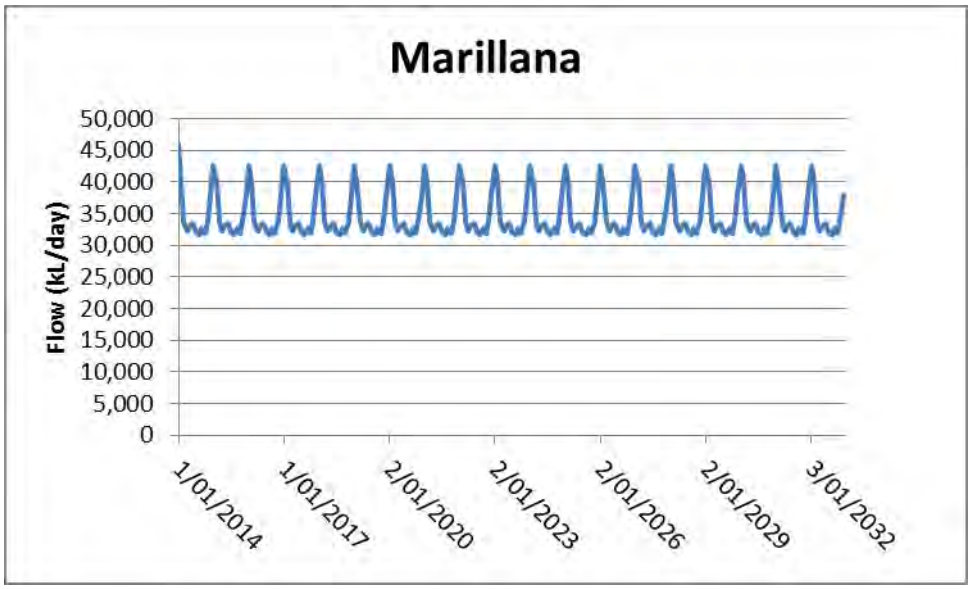

Figure 49. Predictive flow in Marillana Creek.

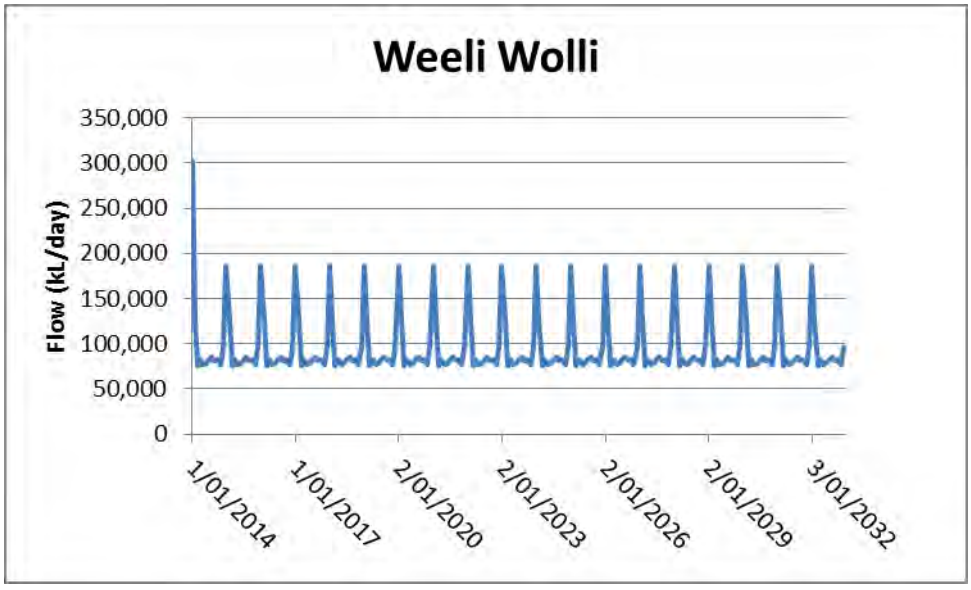

Figure 50. Predictive flow in Weeli Wolli Creek.

To assess the dewatering requirements to meet the mine schedule, thirteen (13) tracking points were assigned to the numerical model, within the CID, to track the decline in water table in response to pumping in the model. Figure 51 shows the location of these points - mainly located close to the deepest part of the pits.

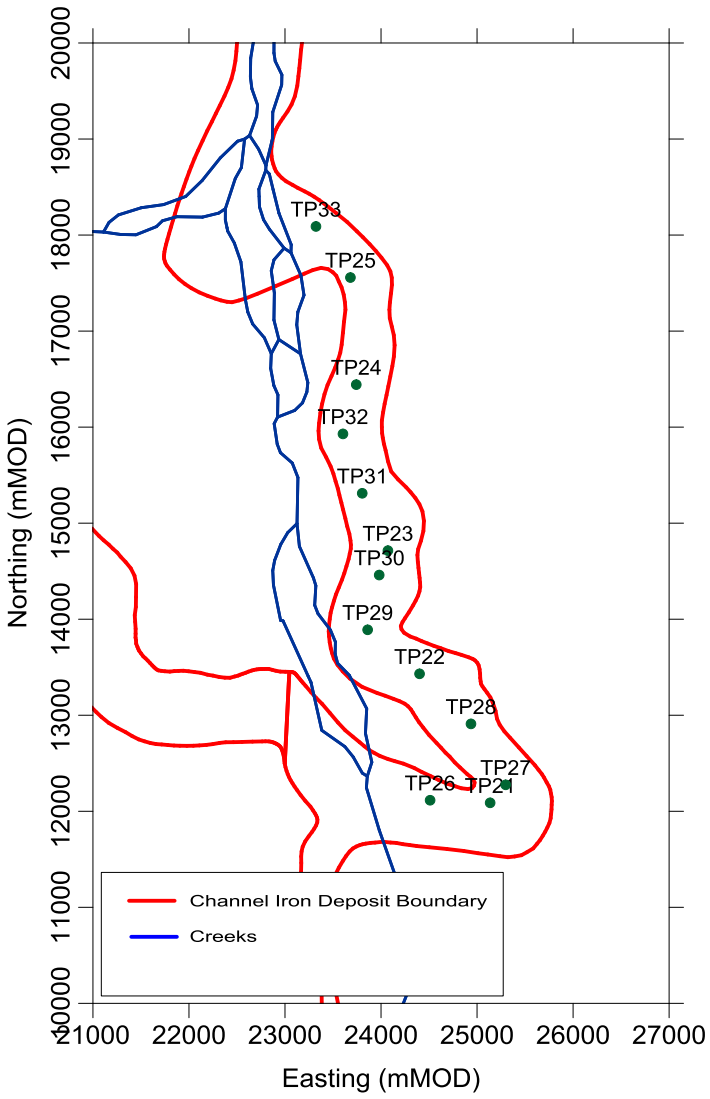

Figure 51. Tracking Points.

Figures 52 to 53 show the simulated water table meeting the mine schedule. Black line shows the bench progression and blue line shows the simulated water table. The yearly bench progression provided is assumed from 1 January to 31 December. This may overestimate advancement of the pit and hence provide a conservative approach in dewatering estimation.

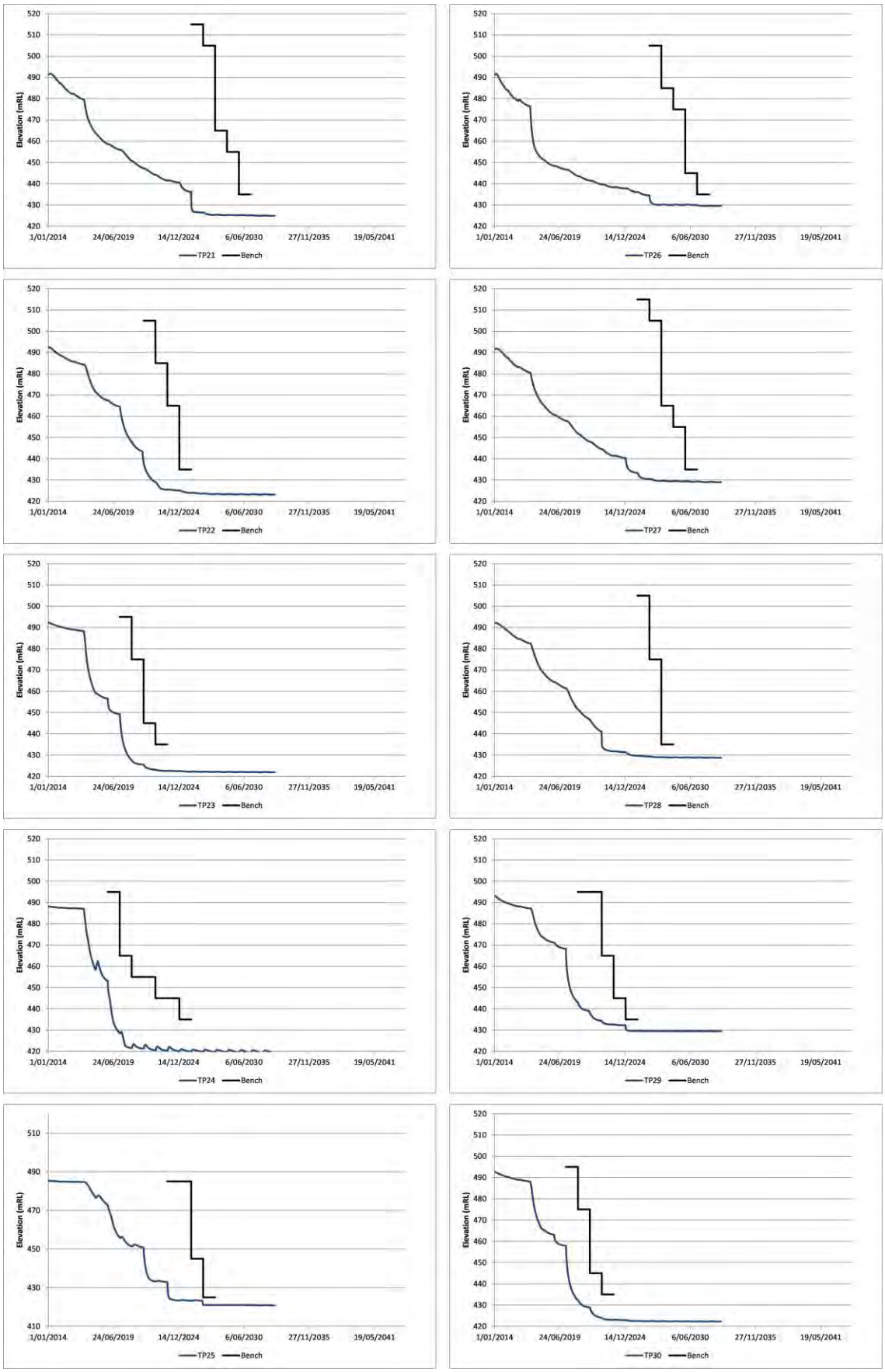

Figure 52. Simulated Hydrographs.

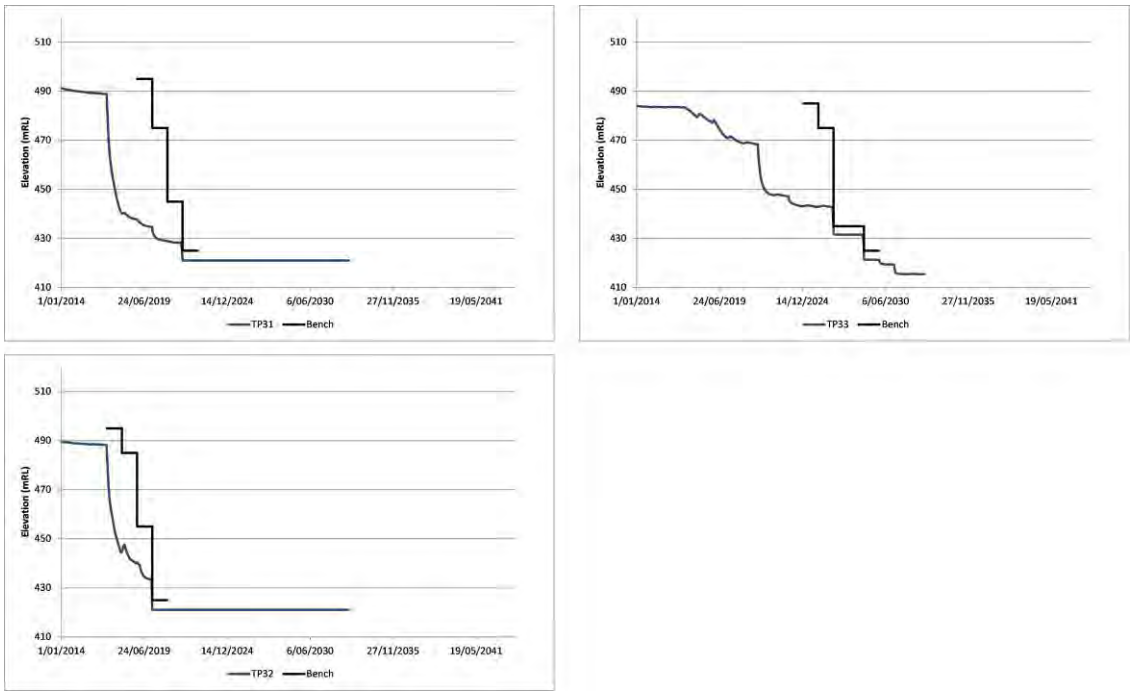

Figure 53. Simulated Hydrographs.

Sumping was required to dewater below the pit floor at tracking point 31, 32 and 33.

The total number of dewatering points is shown on Figure 54. For bores not in the ground already, the dewatering points are the approximate location for the placement of dewatering bores. The number of bores at each of the dewatering point will vary according to the actual bore yield once drilled. Table 5 lists the number of dewatering points in each mining area. Table 6 lists the approximate coordinates of the dewatering points in MGA.

Table 5. Number of Dewatering Points.

Pits	Oxbow	JSW_A	JSW_C	JSE	PBS	Total
Number of dewatering points	9	8	10	24	46	97

The current model assumes the mined out area is being back filled with material similar to the orebody hydraulic parameters and no pit void is being considered due to time constraint for this modelling exercise and the multiple closure scenario options to be investigated.

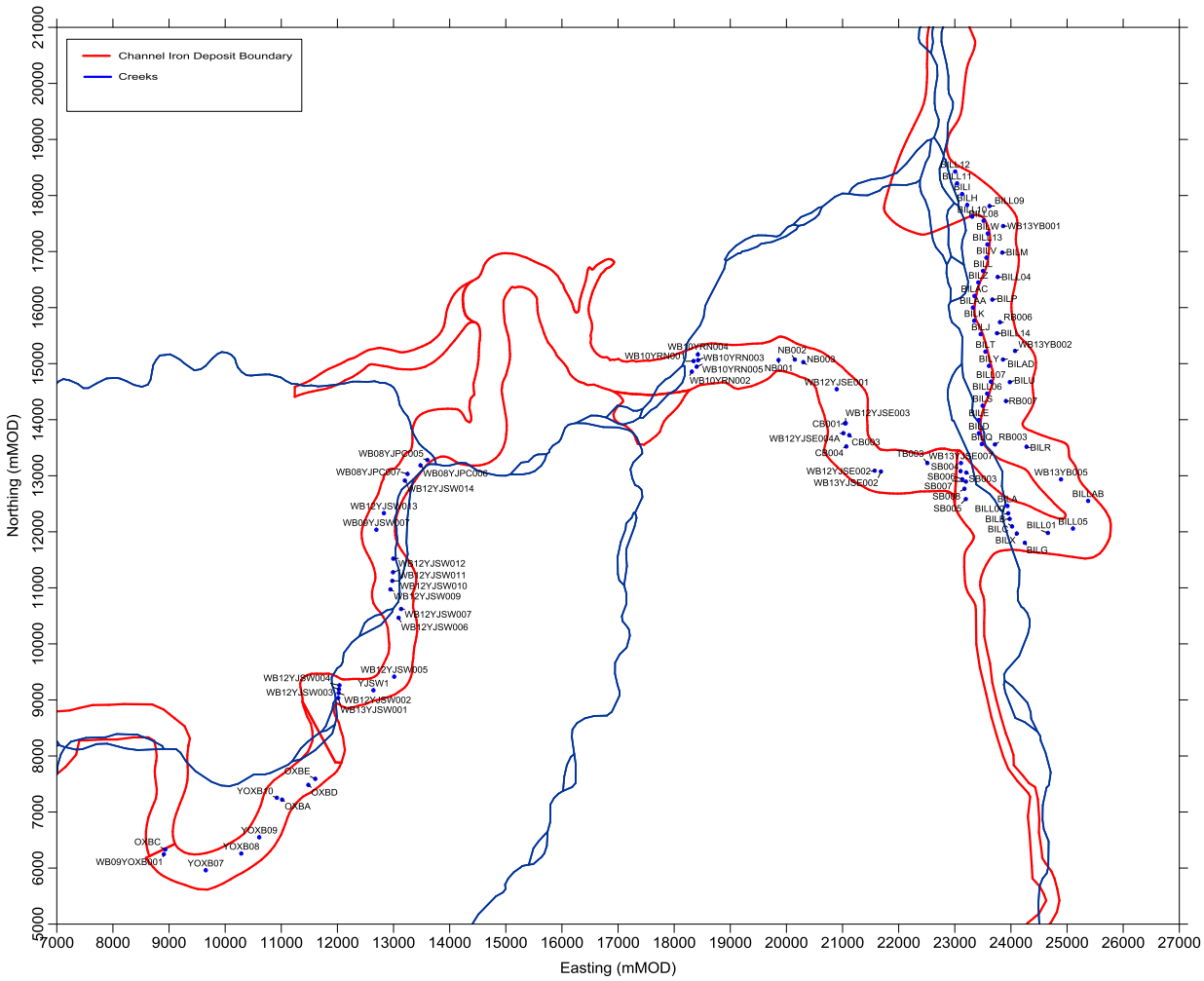

Figure 54. Model Dewatering Points.

Table 6. Approximate Coordinates and Operational Dates of Dewatering Points.

		Easting (mMGA)	Northing (mMGA)	Dewatering Points	Pump on date	Pump off date
Oxbow	1	718054.03	7478902.1	WB09YOXB001	1/1/2017	31/12/2024
	2	718131.73	7478943.2	OXBC	1/1/2017	31/12/2024
	3	718379.63	7478170.8	YOXB07	1/1/2017	31/12/2024
	4	719038.1	7477935.3	YOXB08	1/1/2017	31/12/2024
	5	719469.24	7477913.4	YOXB09	1/1/2017	31/12/2024
	6	720189.86	7478189.8	YOXB10	1/1/2020	31/12/2024
	7	720232.03	7478100.4	OXBA	1/1/2020	31/12/2024
	8	720748.67	7477955.6	OXBD	1/1/2020	31/12/2024
	9	720912.7	7477944.1	OXBE	1/1/2020	31/12/2024
JSW_A	1	722221.79	7478675.6	WB13YJSW001	1/1/2015	31/12/2024
	2	722289.57	7478733.3	WB12YJSW002	1/1/2015*	31/12/2024
	3	722341.3	7478776.2	WB12YJSW003	1/1/2015*	31/12/2024
	4	722397.33	7478819.7	WB12YJSW004	1/1/2015*	31/12/2024
	5	722762.38	7478329.6	YJSW1	1/1/2015	31/12/2024
	6	723195.77	7478239.2	WB12YJSW005	1/1/2015	31/12/2024
	7	723994.27	7478926.8	WB12YJSW006	1/1/2015*	31/12/2024
	8	724135.98	7479006.6	WB12YJSW007	1/1/2015*	31/12/2024
JSW_C	1	724249.66	7479388.3	WB12YJSW009	1/1/2014*	31/12/2023
	2	724380.69	7479472.4	WB12YJSW010	1/1/2014*	31/12/2023
	3	724498.31	7479571.5	WB12YJSW011	1/1/2014*	31/12/2023
	4	724672.6	7479740.7	WB12YJSW012	1/1/2014*	31/12/2023

	5	724825.03	7480318	WB09YJSW007	1/1/2014*	31/12/2023
	6	725129.05	7480432.3	WB12YJSW013	1/1/2014*	31/12/2023
	7	725803.74	7480579.4	WB12YJSW014	1/1/2014*	31/12/2023
	8	725922	7480628.7	WB08YJPC007	1/1/2014*	31/12/2020
	9	726193.56	7480574.2	WB08YJPC006	1/1/2014*	31/12/2020
	10	726347.56	7480554.9	WB08YJPC005	1/1/2014*	31/12/2020
JSE	1	730949.85	7478448.8	WB10YRN001	1/1/2014*	31/12/2019
	2	730793.71	7478337.4	WB10YRN002	1/1/2014*	31/12/2019
	3	731017.23	7478404.1	WB10YRN003	1/1/2014*	31/12/2019
	4	731085.7	7478478	WB10YRN004	1/1/2014*	31/12/2019
	5	730917.01	7478339.6	WB10YRN005	1/1/2014*	31/12/2019
	6	732032.3	7477391.6	NB001	1/1/2014*	31/12/2019
	7	732244.17	7477193.2	NB002	1/1/2014*	31/12/2019
	8	732318.09	7477053.2	NB003	1/1/2014*	31/12/2019
	9	732397.24	7476290.9	WB12YJSE001	1/1/2014*	31/12/2019
	10	732083.01	7475748	WB12YJSE003	1/1/2014*	31/12/2018
	11	732071.31	7475756.1	CB001	1/1/2014*	31/12/2018
	12	731926.71	7475652	WB12YJSE004A	1/1/2014*	31/12/2018
	13	731975.02	7475552.6	CB003	1/1/2014*	31/12/2018
	14	731795.73	7475447.9	CB004	1/1/2014*	31/12/2019
	15	731848.33	7474785	WB12YJSE002	1/1/2014*	31/12/2019
	16	731916.21	7474695.5	WB13YJSE002	1/1/2014*	31/12/2019
	17	732608	7474217	TB003	1/1/2014*	31/12/2019
	18	733031.29	7473794	WB13YJSE007	1/1/2014*	31/12/2019
	19	732978	7473606	SB003	1/1/2014*	31/12/2032
	20	732924	7473697	SB004	1/1/2014*	31/12/2032
	21	732638.1	7473278.4	SB005	1/1/2014*	31/12/2032
	22	732843.4	7473572.2	SB006	1/1/2014*	31/12/2032
	23	732859.99	7473497.2	SB007	1/1/2014*	31/12/2032
	24	732750.89	7473425.5	SB008	1/1/2014*	31/12/2032
PBS	1	732830	7471984	BILG	1/1/2017	31/12/2029
	2	732845	7472201	BILX	1/1/2017	31/12/2032
	3	732875	7472350	BILC	1/1/2017	31/12/2032
	4	732940	7472476	BILB	1/1/2017	31/12/2032
	5	732993	7472564	BILL00	1/1/2017	31/12/2032
	6	733076	7472667	BILA	1/1/2017	31/12/2032
	7	733533	7473771	BILQ	1/1/2020	31/12/2032
	8	733632	7473944	BILD	1/1/2020	31/12/2032
	9	733800	7474112	BILE	1/1/2020	31/12/2032
	10	734027	7474244	BILS	1/1/2020	31/12/2022
	11	734237	7474340	BILL06	1/1/2020	31/12/2032
	12	734435	7474443	BILL07	1/1/2020	31/12/2032
	13	734610	7474667	BILY	1/1/2017	31/12/2032
	14	734745	7474891	BILT	1/1/2017	31/12/2032
	15	734906	7475171	BILJ	1/1/2017	31/12/2032
	16	734994	7475422	BILK	1/1/2017	31/12/2032
	17	735143	7475604	BILAA	1/1/2017	31/12/2032
	18	735309	7475732	BILAC	1/1/2017	31/12/2032
	19	735528	7475854	BILZ	1/1/2019	31/12/2032
	20	735733	7475940	BILL	1/1/2019	31/12/2032
	21	735943	7476064	BILV	1/1/2019	31/12/2032
	22	736122	7476218	BILL13	1/1/2019	31/12/2032
	23	736265	7476352	BILW	1/1/2019	31/12/2032
	24	736374	7476566	BILL08	1/1/2022	31/12/2032
	25	736281	7476762	BILL10	1/1/2022	31/12/2030
	26	736366	7476972	BILH	1/1/2022	31/12/2032
	27	736439	7477174	BILI	1/1/2022	31/12/2032
	28	736511	7477372	BILL11	1/1/2022	31/12/2032
	29	736635	7477544	BILL12	1/1/2022	31/12/2030
	30	733245	7471817	BILL01	1/1/2027	31/12/2032
	31	733616	7471556	BILL05	1/1/2026	31/12/2032

	32	734156	7471714	BILLAB	1/1/2025	31/12/2032
	33	734086	7472328	WB13YB005	1/1/2023	31/12/2032
	34	734063	7473173	BILR	1/1/2022	31/12/2032
	35	733694	7473601	RB003	1/1/2021*	31/12/2023
	36	734380	7474010	RB007	1/1/2020*	31/12/2032
	37	734668	7474200	BILU	1/1/2019	31/12/2032
	38	734867	7474571	BILAD	1/1/2017	31/12/2032
	39	735127	7474527	WB13YB002	1/1/2017	31/12/2032
	40	735300	7475080	RB006	1/1/2017*	31/12/2032
	41	735488	7475461	BILP	1/1/2017	31/12/2032
	42	735842	7475678	BILL04	1/1/2019	31/12/2032
	43	736206	7475929	BILM	1/1/2020	31/12/2032
	44	736553	7476253	WB13YB001	1/1/2024	31/12/2032
	45	736633	7476677	BILL09	1/1/2024	31/12/2032
	46	735123	7474978	BILL14	1/1/2017	31/12/2032

*Note: * bores already in operation*

Abstraction rates assigned to the model were generally 5,000 kL/day at each dewatering point, however, rate as high as 10,000 kL/day and as low as 2,000 kL/day were used in the model. The model shows the assigned abstraction will decline over time as saturated thickness decreases as a result of dewatering. Figure 55 shows dewatering from Pocket and Billiards South. Spikes in dewatering rate are due to both the initial abstraction rates and activation of the sumps in the model. Figure 56 shows the annualised abstraction. Tracking leakage along Weeli Wolli Creek (Figure 57) shows essentially all flows along the creek gets captured by dewatering at PBS.

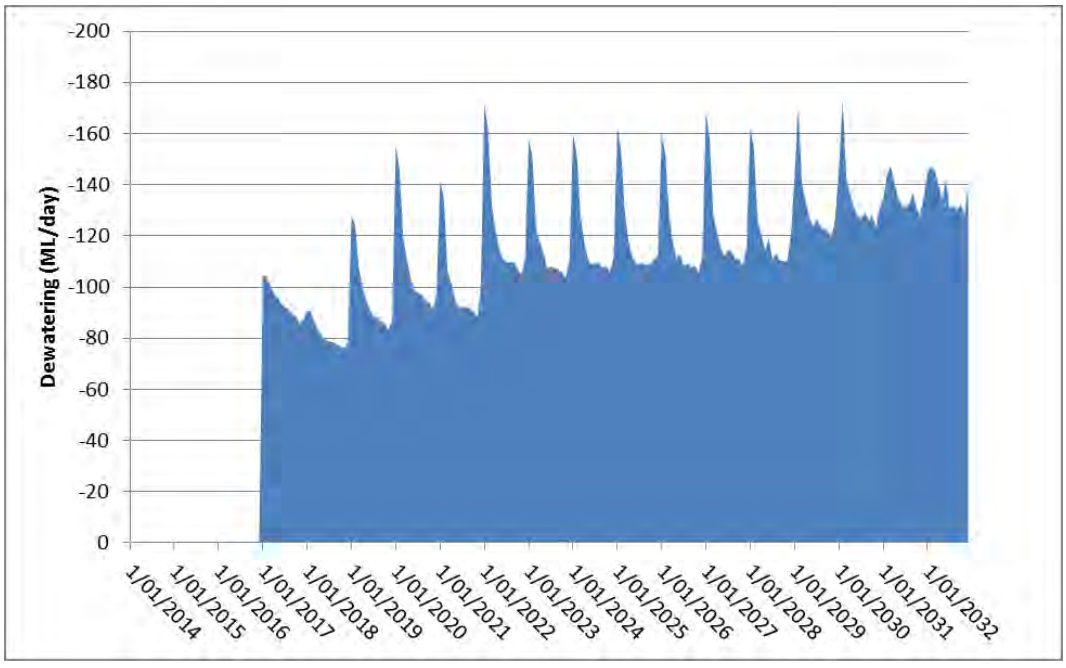

Figure 55. Pocket and Billiards South dewatering.

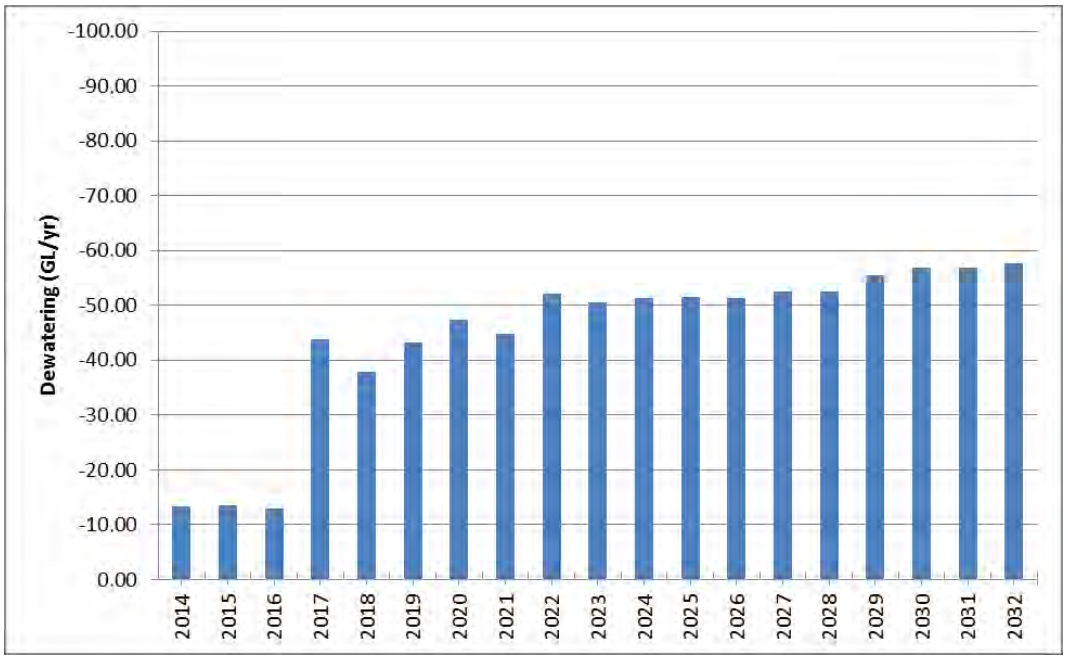

Figure 56. Pocket and Billiards South annualised dewatering.

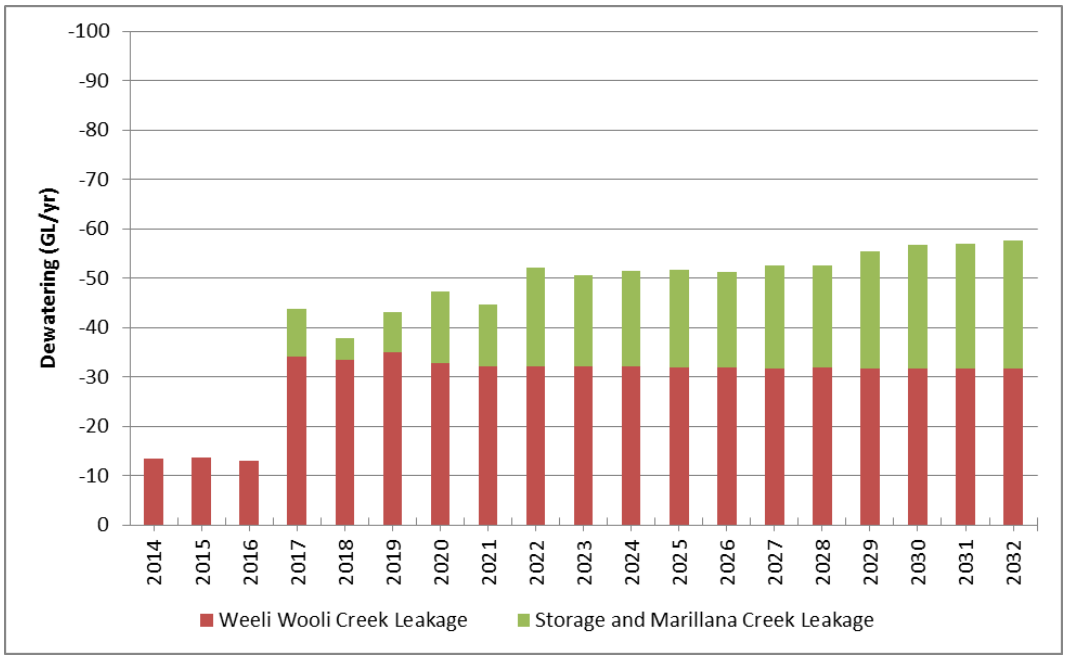

Figure 57. Leakage from Weeli Wolli Creek.

Figure 58 shows the contributions from each mining area at Yandi and annualised dewatering is shown in Figure 59.

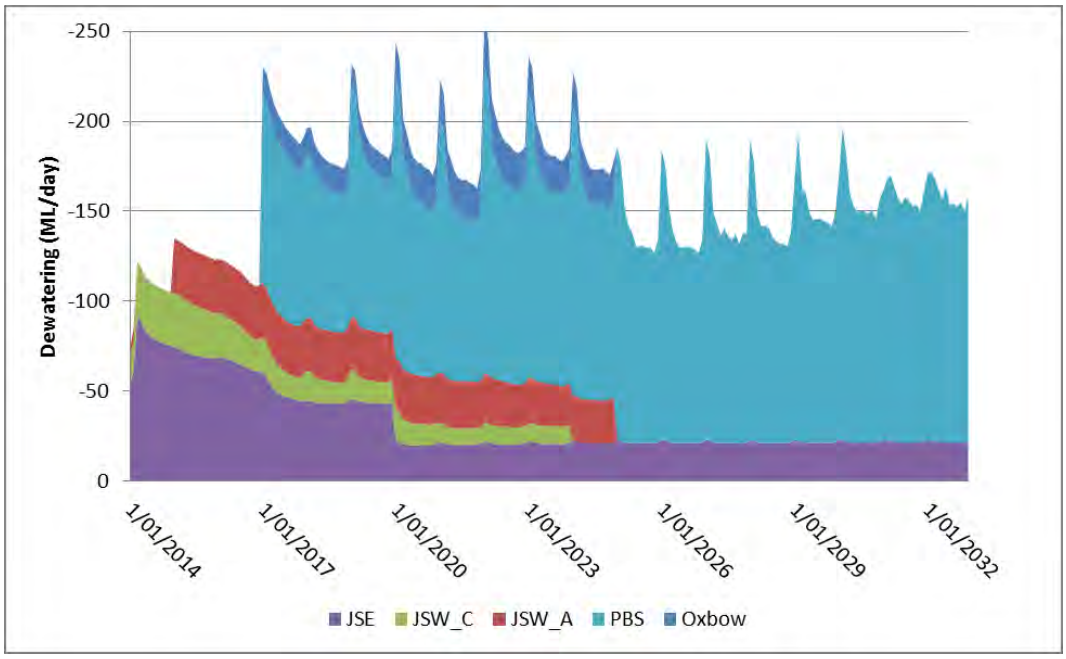

Figure 58. Yandi dewatering.

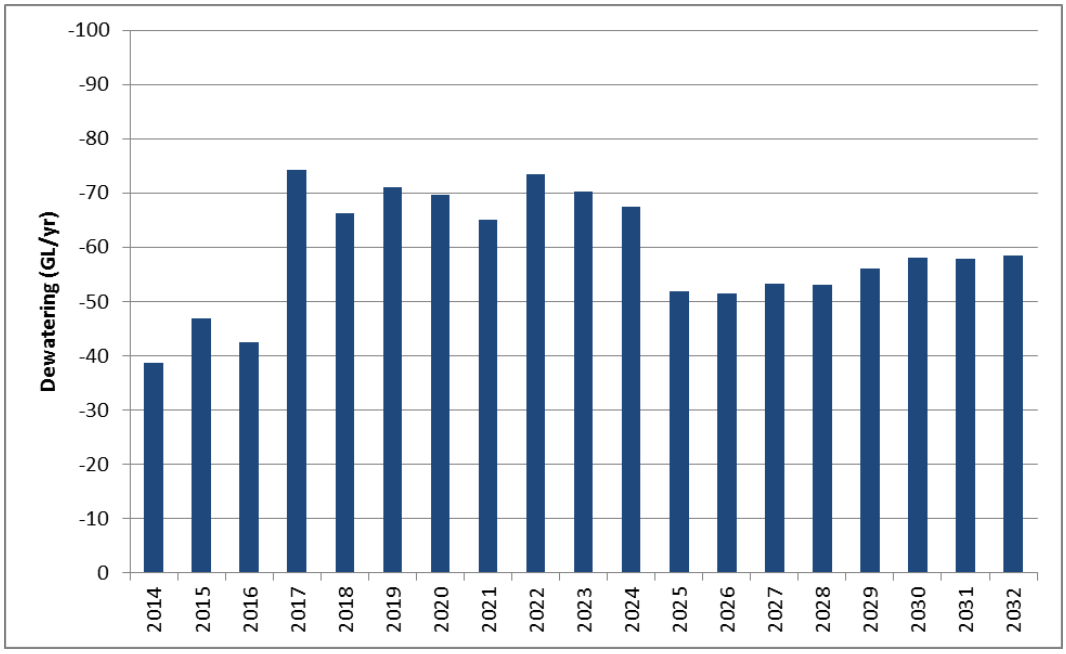

Figure 59. Yandi annualised dewatering.

Figure 60 shows the percentage discrepancy errors from the predictive simulation. A discrepancy error of less than 5% is considered good for such a complex flow systems.

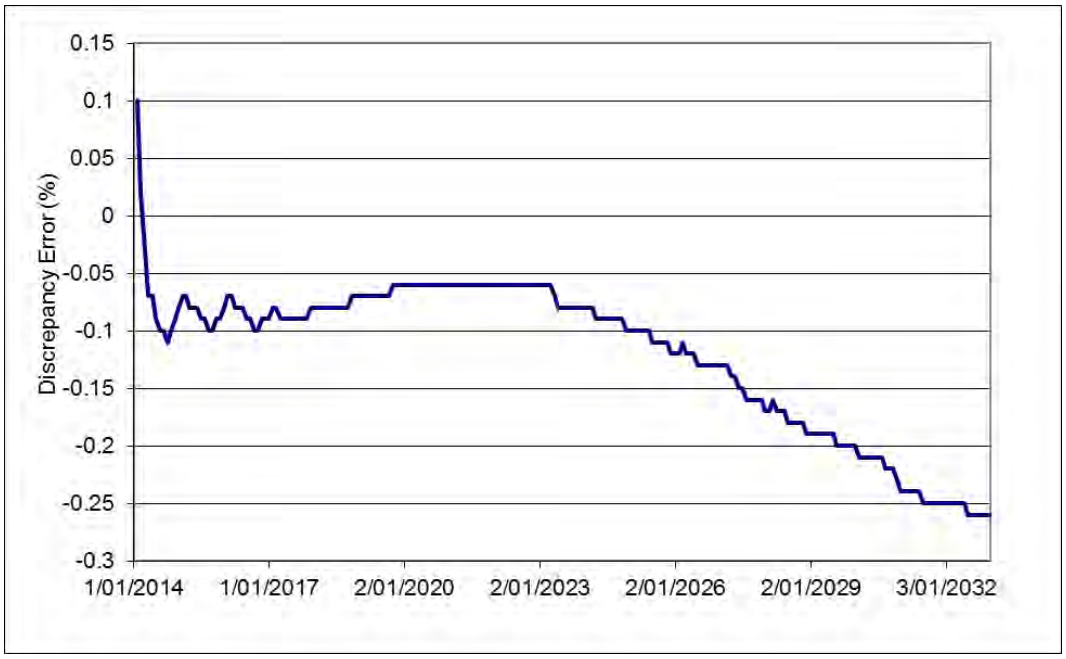

Figure 60. Model discrepancy error.

Potential environmental impacts of dewatering were assessed by assessing the simulated groundwater drawdown from 1997. The model shows the cone of depression from such a large abstraction over such a long time is quite substantial; however, in areas where water table is already deep should have no consequences on the groundwater dependent ecosystems (GDEs). Figure 61 shows the approximate depth to pre-mine water table. Areas with greater than 30m to water table are most unlikely to have any associated GDEs. Figures 62 to 66 show drawdown in December 2017, 2019, 2023, 2027 and 2032 in areas that is less than 30m to pre-mine water table.

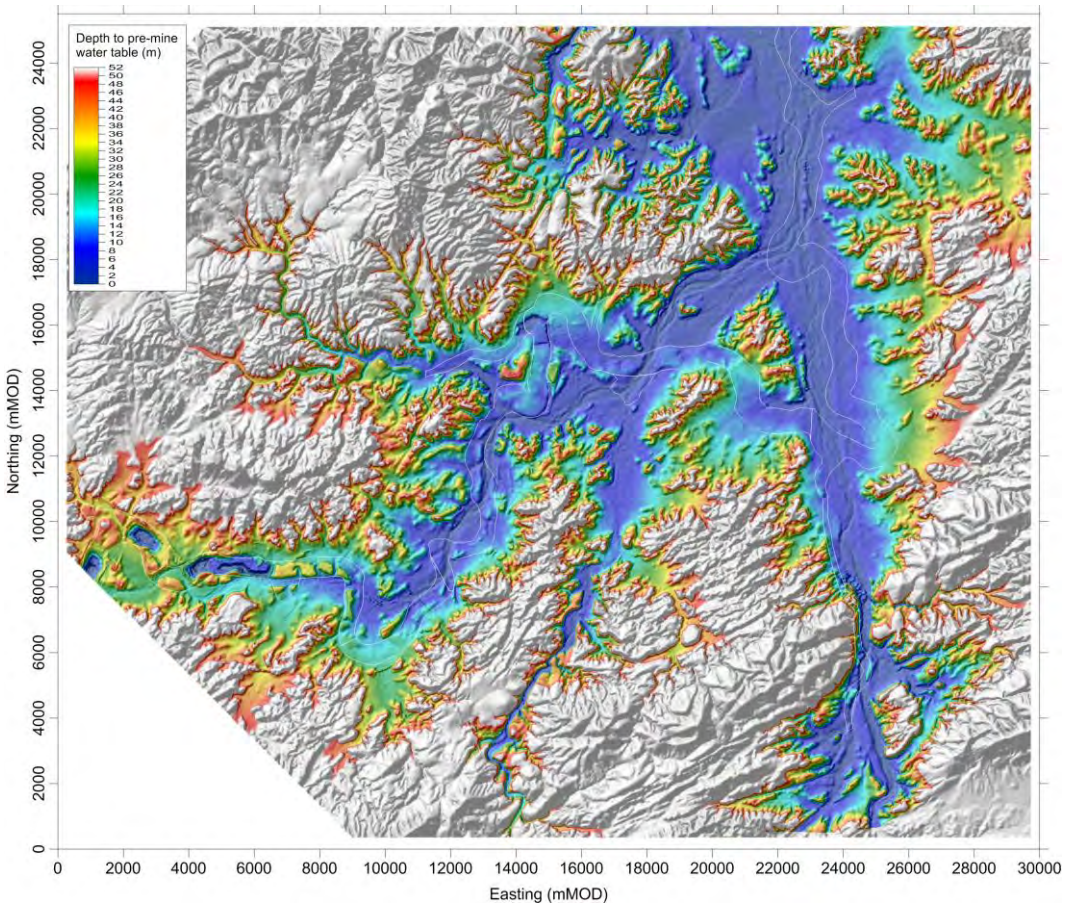

Figure 61. Depth to pre-mine water table.

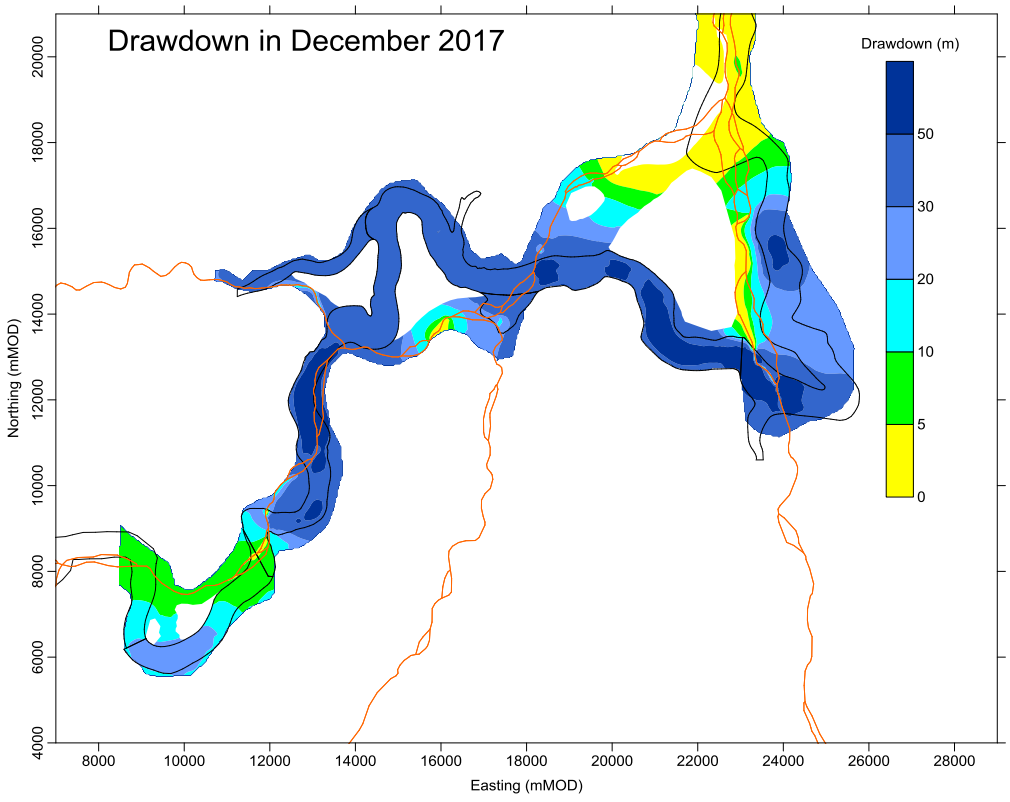

Figure 62. Simulated drawdown in December 2017.

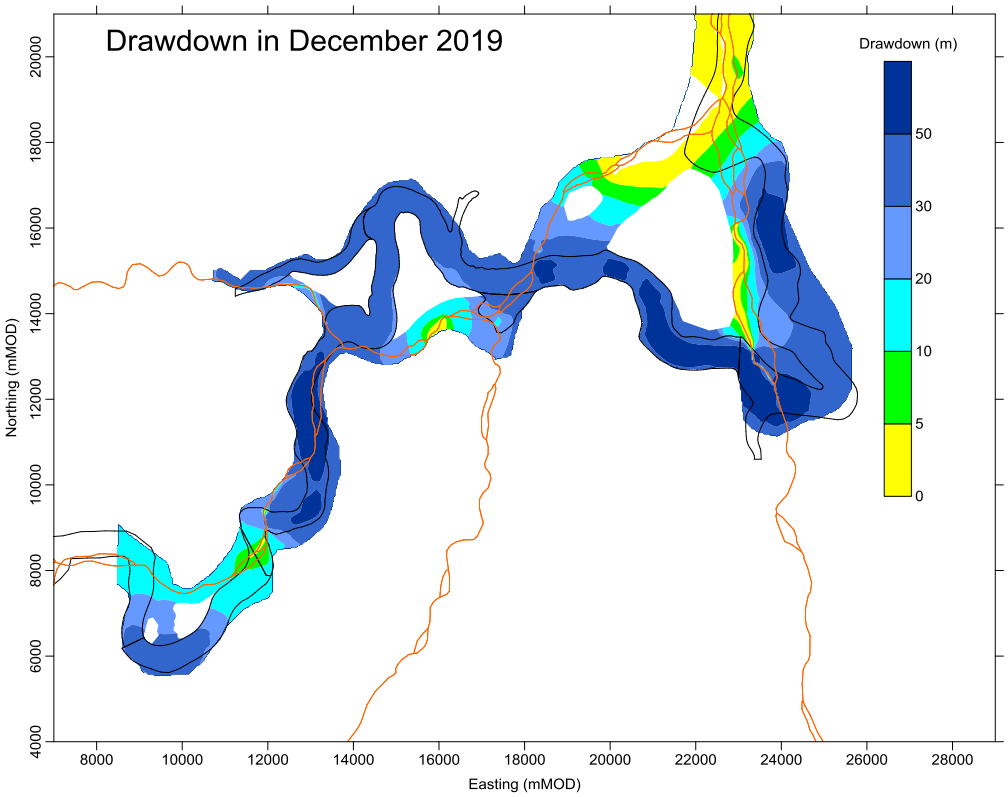

Figure 63. Simulated drawdown in December 2019.

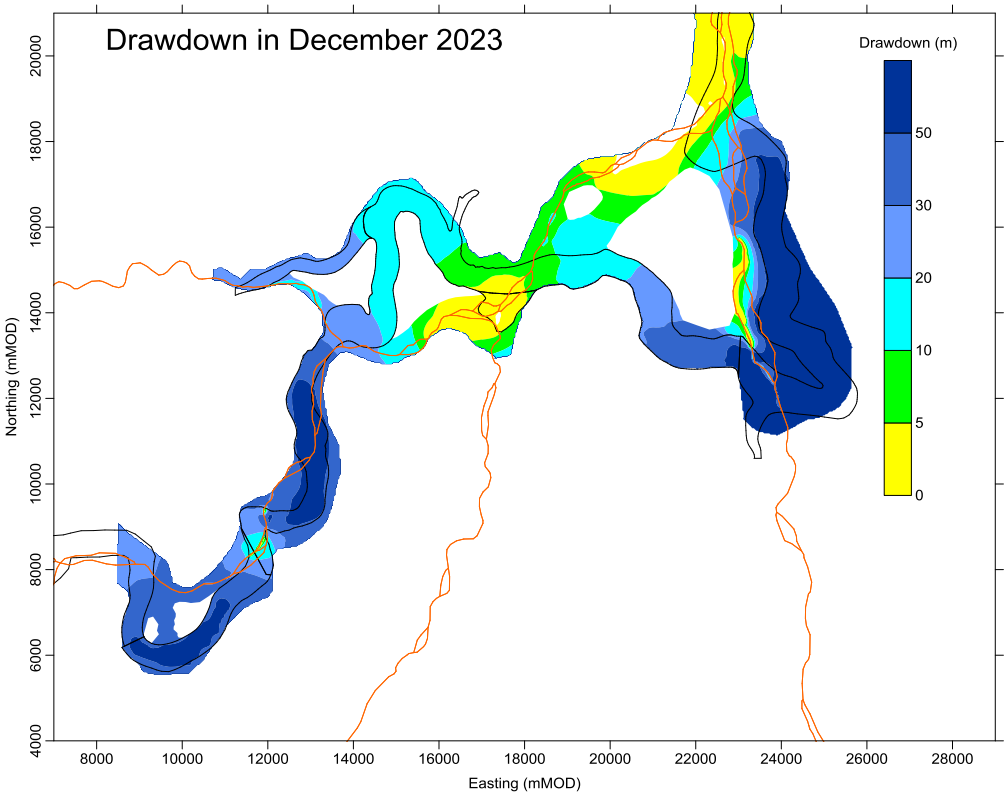

Figure 64. Simulated drawdown in December 2023.

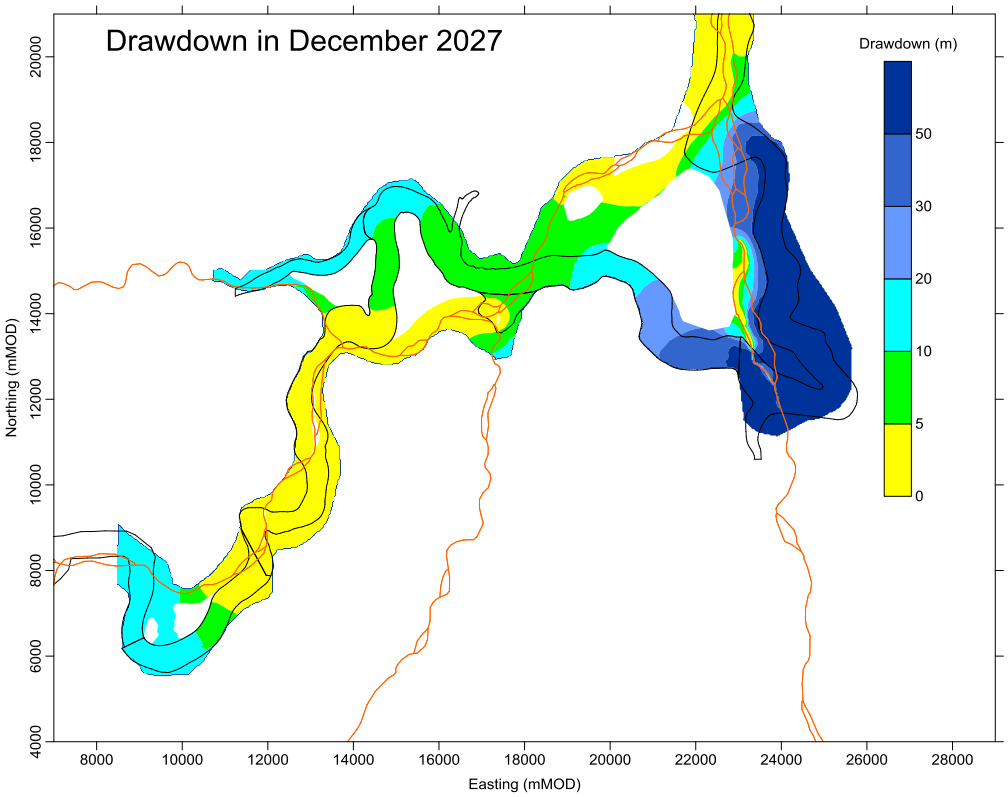

Figure 65. Simulated drawdown in December 2027.

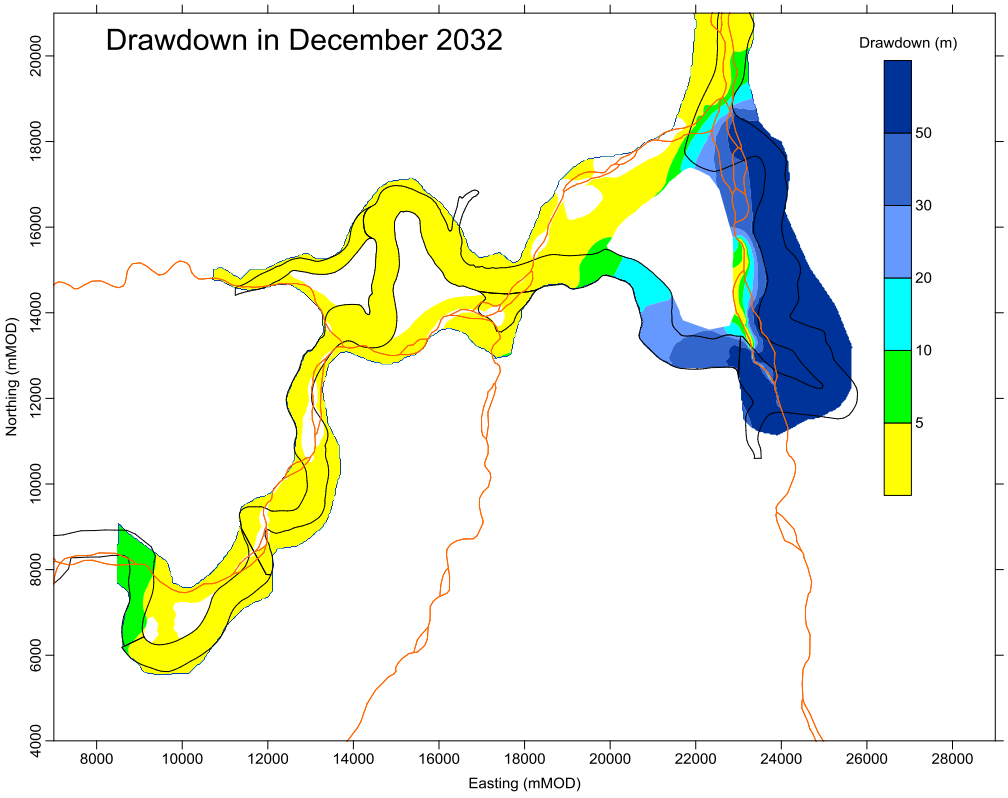

Figure 66. Simulated drawdown in December 2032.

12. Predictive Uncertainty Analysis

Based on the sensitivity analysis of the calibrated model, hydraulic conductivity of the GVU was increased to the upper bound value of 5 m/d and specific yield of the LGC was increased to an upper bound value of 0.2. Table 7 shows there is virtually no difference in the dewatering rates and volumes. This indicates that the dewatering predictions are not sensitive to these parameters.

Table 7. Predictive Uncertainty Analysis – Annualised dewatering volume.

	Hy (2 m/d), Sy(0.1)		Hy (5m/d)		Sy (0.2)	
Year	Annual (GL)	Cumulative (GL)	Annual (GL)	Cumulative (GL)	Annual (GL)	Cumulative (GL)
2014	-39.6	-39.6	-39.3	-39.3	-39.3	-39.3
2015	-51.1	-90.7	-49.8	-89.0	-50.2	-89.5
2016	-44.7	-135.4	-42.1	-131.1	-43.1	-132.5
2017	-77.0	-212.5	-74.2	-205.3	-74.7	-207.2
2018	-68.5	-281.0	-66.7	-272.0	-66.8	-274.0
2019	-72.2	-353.2	-71.3	-343.2	-71.4	-345.4
2020	-69.3	-422.5	-69.2	-412.4	-70.1	-415.4
2021	-64.3	-486.8	-64.6	-477.1	-64.9	-480.3
2022	-71.9	-558.6	-73.0	-550.0	-73.0	-553.4
2023	-68.9	-627.5	-70.2	-620.2	-69.9	-623.3
2024	-67.0	-694.6	-67.4	-687.6	-67.2	-690.5
2025	-51.6	-746.2	-51.9	-739.5	-51.7	-742.2
2026	-51.3	-797.5	-51.7	-791.1	-51.3	-793.4
2027	-52.6	-850.0	-53.7	-844.8	-53.0	-846.4
2028	-52.5	-902.5	-53.6	-898.4	-52.8	-899.2
2029	-55.5	-958.0	-56.6	-955.0	-56.0	-955.2
2030	-56.8	-1014.8	-58.1	-1013.2	-57.6	-1012.8
2031	-57.0	-1071.8	-58.1	-1071.3	-57.6	-1070.4
2032	-57.6	-1129.4	-59.2	-1130.5	-58.1	-1128.5

13. Assumptions

A numerical model is a simplified representation of the real world. Assumptions are required in a numerical model due both to the inability to represent the subsurface accurately and as a consequence of the simplified numerical representations of the varied and complex hydrogeological processes i.e. spatial discretisation and temporal discretisation of inputs. The assumptions made for this model include:

- The hydrostratigraphic units are coincident with the geo-stratigraphic units;
- The relative permeability of the GVU, GVL and LGC hydrostratigraphic units;
- The elevation of the base of the CID coincides with the end-of-hole elevation of the resource drilling logs;
- The materials below the resource drilling end of hole logs have similar hydraulic parameters as the basal clayey conglomerate;
- There is CID beneath the buffer zones of the creeks as interpreted from the resource drilling logs;
- Interpolating and/or extrapolating the symmetry of the CID beneath the creeks to fill in data gaps beneath the buffer zones;

- The calculated monthly abstraction rates assigned to the model are representative of the actual abstraction;
- The discretised screened intervals in the model are representative of the actual inflows into the production bore;
- In-pit sumps were adequately represented by MODFLOW drain cells by setting the elevation of the drain cells to the floor of the pit;
- The amount of water discharged into the WFC was completely recovered by the in-pit sumps or evaporated i.e. no net gain or loss hence ignored in the model;
- The width of the creeks was fixed at 5.0m and a manning roughness coefficient of 0.093 accounts for the increased river stage when flows in the creeks increased;
- The slopes and elevations of the creeks can be computed from the topographical data;
- Conductances for the creek beds derived from model calibration are an accurate representation of the conductance between the creeks and the underlying water table aquifers;
- Scaling of monthly rainfall to represent infiltration to the water table is representative of the total rainfall recharge to the aquifers;
- The recharge zones used in the model can adequately account for the total recharge to the aquifers;
- Scaling of monthly rainfall in catchment upstream of BHPB discharge point is a good approximation of the flow in Marillana Creek upstream of the discharge point;
- Scaling of monthly rainfall in catchment upstream of Phil's and Yandicoogina creeks are good approximation of the flow in these creeks;
- Bank storage can be ignored;
- The evapotranspiration zones and extinction depths used in the model adequately account for the total loss of groundwater to the atmosphere;
- Recent interpretation of the pinching out of the Weeli Wolli Formation north, the CID and alluvium directly overlies the BIF and a large mineralised BIF occurs underneath the outwash has insignificant impacts on the model prediction; and
- Predictive boundary conditions were acceptable.

14. Model Limitations

The model is reasonably calibrated in the JC and JSE areas. Limited calibration to stress condition at JSW, Pocket and Billiard South meant that model prediction in these areas will be subject to larger errors. This model represents a possible solution due to the number of unknowns incorporated into the model; but is not the unique solution.

The hydraulic parameters adopted for the Weeli Wolli and Brockman Iron Formations can be subjected to challenge due to the lack of investigation drilling and observation data in

these areas. The values adopted should represent a conservative estimate for dewatering.

The result from this modelling exercise is limited to Pocket and Billiards South PFS and should be review with extended pumping from JSW and Billiards South.

15. Summary

The Yandi 2008 numerical groundwater model domain was limited to mining and dewatering at Junction Central and Junction South East. As part of Yandi's expansion work to include Junction South West and Billiards South, the model domain was extended to minimise boundary effects from dewatering in these areas in the Channel Iron Deposit. The rebuild/update of the model included the alluvium layer defined in the 2010 regional groundwater model (RTIO-PDE-0078850). The number of model layer was increased from 7 to 15 to refine the geology from RTIO Vulcan geology block model.

The model was calibrated in steady-state and transient with abstraction, injection and discharge rates, and water levels from observation bores from January 1998 to January 2014. Both calibrations show the model is broadly representative of the site.

To meet the A8 mine schedule released in August 2014, the predictive model shows annual abstraction peaked in 2017 at about 80 GL per year. Abstraction will be above the current EP Act Part IV approved abstraction rate of 53 GL a year for more than 50% of the time.

Drawdown impact from the dewatering is quite substantial; however, a large portion of it is in areas where the groundwater is very deep.

16. Recommendations

It is recommended that the model be:

- recalibrated at least once a year to maintain currency of the model;
- Refinement in the Billiards North areas for future model calibration;
- Include aquifer pumping tests data from Billiards South;
- Conduct long term aquifer pumping tests in Billiards South and North;
- Stress the aquifers in JSW;
- Continue to monitor water levels;
- Understand leakage from the creeks especially Weeli Wolli and Marillana creeks; and
- Model the creeks with MODHMS 1D channel and 2D overland flow to better represents flood events.

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Groundwater Modelling Scenarios 2014 - 2015

During the Pre-feasibility study for Pocket and Billiard South (PBS), a number of groundwater modelling scenarios were developed based on optimisation of the proposed mine plans and schedules throughout 2014 and 2015. Up to 30 mine schedules were modelled.

Examples of the modelling estimates for the whole of Yandi Operations are presented in Figures 1 and 2. Whilst the simulations show annualised dewatering requirements vary in volume and timing of the peak abstraction, the overall peak abstraction for the whole of Yandi Operations for all scenarios modelled remains below 83 GL/a. Figure 3 shows annualised dewatering from PBS.

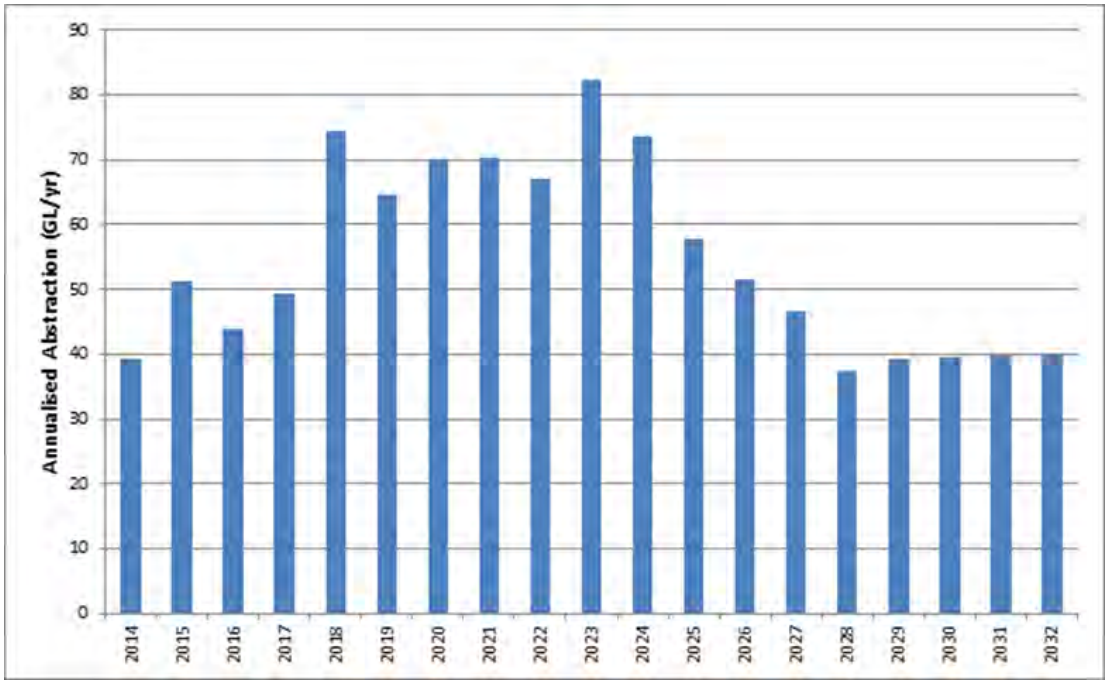

Figure1. Yandi Operations Annualised Dewatering requirements – 2014 Model (PBS A4 mine schedule)

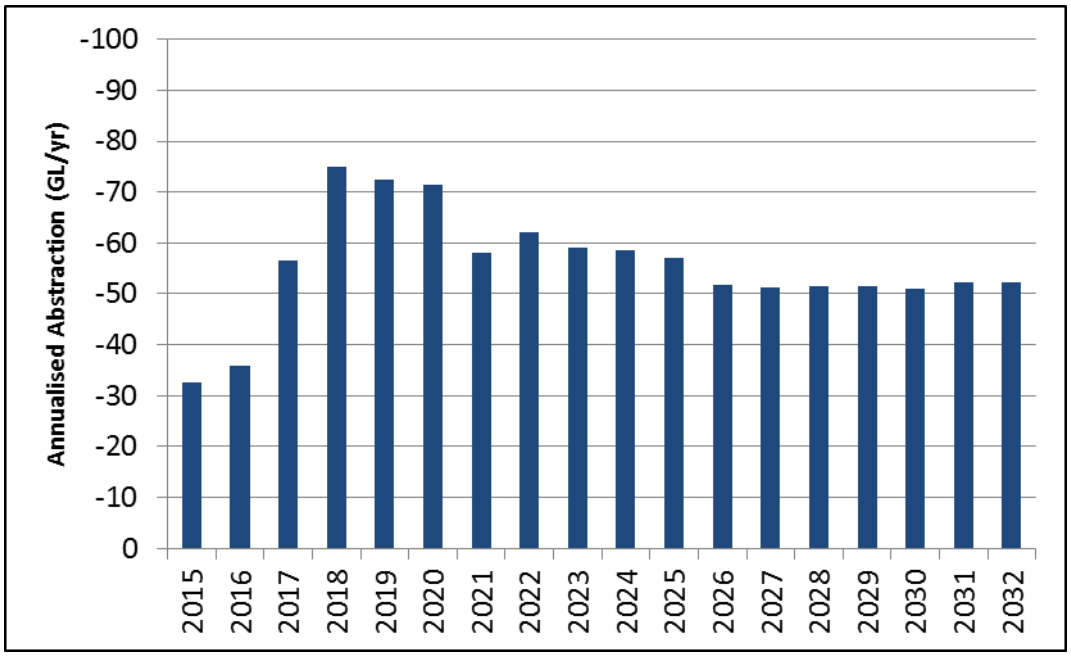

Figure 2. Yandi Operations Annualised Dewatering Volumes – 2015 Model (Yandi A30 Base Case)

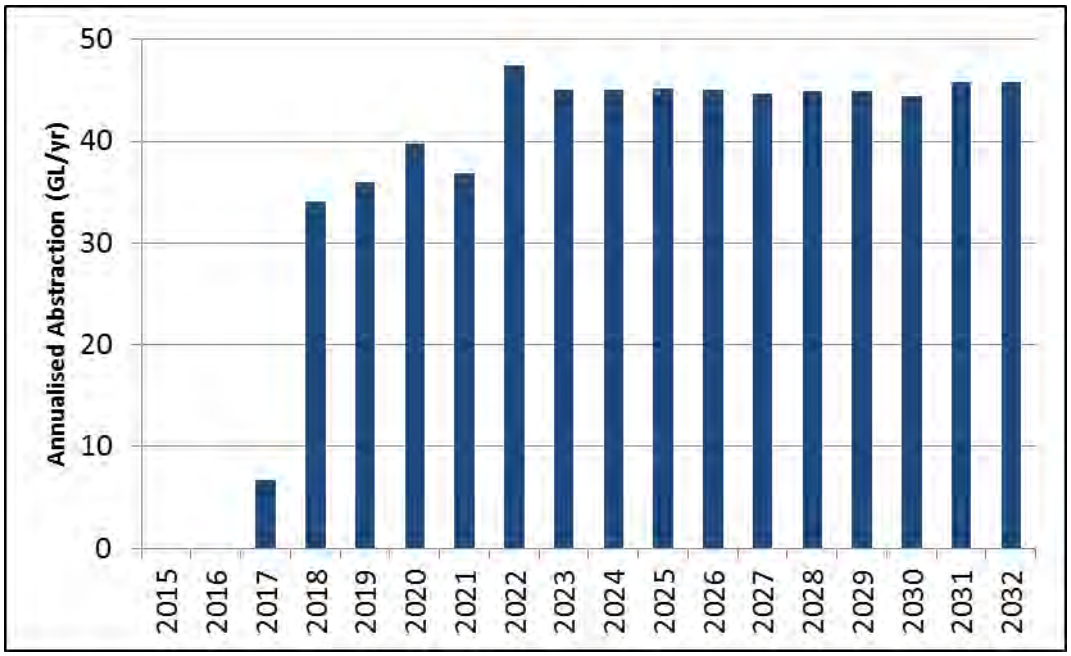

Figure 3. Yandi PBS Annualised Dewatering Volumes – 2015 Model (Yandi A30 Base Case)

Biota Environmental Sciences

Pocket and Billiard South Level 2 Seasonal Fauna Survey

Prepared for Rio Tinto Pty Ltd

November 2014

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1.0 Summary

1.1 Background

Rio Tinto proposes to develop two channel-iron deposits at Pocket and Billiard South (the 'study area'), located approximately 7 km east of the existing Yandi mine. Given the proximity of these deposits to Weeli Wolli Creek and the Fortescue Marsh catchment, Biota Environmental Sciences (Biota) was commissioned to conduct a Level 2 seasonal fauna survey. This was focused on addressing knowledge gaps identified by a review of fauna sampling conducted during previous surveys of the study area, to assist with environmental impact assessment (EIA).

The scope of this study was to:

- undertake a Level 2 fauna survey of the study area consistent with relevant Environmental Protection Authority (EPA) Guidance Statements;
- undertake targeted sampling and searches for species of National Environmental Significance (NES) and terrestrial short-range endemic (SRE) invertebrate species;
- document the vertebrate and SRE fauna assemblage within the study area using established sampling techniques;
- identify and assess the local and regional conservation significance of the fauna assemblage and habitats present in the study area;
- identify vertebrate fauna of particular conservation significance, particularly threatened fauna listed under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999,* Schedule fauna listed under the State *Wildlife Conservation Act 1950*, and species classified as Priority fauna by the Department of Parks and Wildlife; and,
- identify habitats for potential SRE fauna and identify SRE fauna of particular conservation significance.

1.2 Methods

A literature review incorporating searches of databases and previous surveys in the study area locality was conducted to construct a list of species that may potentially occur within the study area. This utilised the following databases and literature:

- NatureMap database;
- the Federal *EPBC Act 1999* Protected Matters database;
- the Atlas of Living Australia; and,
- reports from surveys conducted within 10 km of the study area were used for context in regard to the conservation significance of particular taxa or features.

The fauna survey comprised two phases: the 'wet season' Phase 1 survey was conducted over a 11 day study period, from the 8th until the 18th of March 2014, and the 'dry season' Phase 2 survey was conducted over a 10 day study period from the 10th until the 19th of September 2014.

Phases 1 and 2 employed systematic sampling at 11 trapping sites, consisting of five pitfall trapping grids, four funnel trapping grids and two Elliott trap transects. All pit-trapping sites were open for six to seven nights, resulting in a total trapping effort of 2,070 trap-nights (630 pitfall trapping, 1,014 Elliott trapping and 426 funnel trapping nights).

Systematic avifauna surveys were conducted at trapping sites during both phases; each trapping site was surveyed at least twice during each survey phase, providing a total of 24.5 hours of bird survey time.

Bats were sampled during the survey using echolocation call recordings at 14 locations considered likely to provide foraging, drinking or commuting opportunities for a range of species. Calls were sampled using SongMeter SM2BAT bat detector units, which detect and record ultrasonic echolocation calls emitted by bats during flight. Echolocation recordings were sampled over a total of 36 nights.

In addition to systematic surveying, non-systematic surveying was conducted at 28 locations. The aim was to locate, search and describe habitats that may support fauna of conservation significance, habitat-specific species and species not likely to be trapped. A range of non-systematic techniques were used when conducting these additional searches, including; searching of microhabitats for reptile, frog, avifauna and mammals not commonly recorded through trapping; identification of road kills and other animal remains; opportunistic sightings and records; recording and identification of secondary signs including tracks, scats and diggings; motion camera trapping; nocturnal searches; searches for evidence and secondary signs in suitable NES species habitat; and, audio recording for night birds and amphibian calls using the SongMeter bat detector units configured to record audible noise. The effort from these surveys totalled 17 motion camera trapping days, 15 SM2 recording days, 14 hours (834 minutes) of nocturnal searching, just under five hours (280 minutes) of targeted search time for conservation significant species and just under two hours (110 minutes) search time for avifauna.

SRE fauna sampling was conducted using both systematic (pit-trap transects) and non-systematic (targeted searching) sampling methods. The invertebrate groups targeted during the survey were primarily those considered to potentially support SRE taxa, including:

- Mygalomorphae (trapdoor spiders);
- Diplopoda (millipedes);
- Scorpionides (scorpions);
- Pulmonata (land snails); and
- Pseudoscorpiones (pseudoscorpions).

Thirty sites were searched for SRE fauna, for a total of just over 61 person-hours (3,685 minutes).

Fauna habitats were mapped based on an assessment of the landforms and vegetation in the study area. The fauna habitats present in the study area were Alluvial Plain (Flood Plain), Floodout Plain, Mulga Woodland, Minor Alluvial Fan, Hilltops and Slopes, Pediment and Major Drainage Line. A small area was Disturbed through mining. It was noted that much of the area has been degraded by cattle, particularly riparian vegetation associated with Weeli Wolli Creek, Mulga Woodlands and open grasslands on softer sandy soils such as those of the Urandy land system.

1.3 Vertebrate Fauna Results

A total of 182 vertebrate fauna species from 65 families were recorded during the survey, comprising 14 native non-volant mammals, three introduced non-volant mammals, ten volant mammals, 93 avifauna, 59 reptiles and three amphibians.

1.4 Conservation Significant Vertebrate Fauna

Eight species of conservation significance were recorded in the study area:

- Mulgara, *Dasycercus* sp. (species unconfirmed, most likely *D. blythi*);
- Pilbara Olive Python, *Liasis olivaceus barroni* (Schedule 1, Vulnerable);
- Western Pebble-mound Mouse, *Pseudomys chapmani* (Priority 4);
- Star Finch, *Neochmia ruficauda* (Priority 4);
- Australian Bustard, *Ardeotis australis* (Priority 4);

- Fork-tailed Swift, *Apus pacificus* (Schedule 3, Migratory);
- Eastern Great Egret, *Ardea modesta* (Schedule 3, Migratory); and,
- Rainbow Bee-eater *Merops ornatus* (Schedule 3, Migratory).

In addition, one noteworthy bat species was recorded. Individuals of the isolated Pilbara population of the Chocolate Wattled Bat (*Chalinolobus morio*), were recorded near Weeli Wolli Creek. While this species has a wider distribution in the southwest of WA, its distribution in the Pilbara is separated from other populations, and as a result it is possible that these populations are genetically distinct. Weeli Wolli Creek represents one of only two locations in the Pilbara where this species has been recorded, the other being Marillana Creek.

A further 18 species of conservation significance were identified from database and literature searches as being recorded within close proximity to the study area (within 10 km) or within the locality (within 40 km). Their likelihood of occurrence in the study area was assessed by giving consideration to habitat availability, species distributions and past records. Based on this, seven species were considered likely to occur:

- Orange Leaf-nosed Bat, *Rhinonicteris aurantius* (Schedule 1/Vulnerable);
- Peregrine Falcon, *Falco peregrinus* (Schedule 4);
- Pilbara Barking Gecko, *Underwoodisaurus seorsus* (Priority 1);
- Blind Snake, *Anilios ganei* (Priority 1);
- Ghost Bat, *Macroderma gigas* (Priority 4);
- Bush Stone-curlew, *Burhinus grallarius* (Priority 4); and,
- Common Greenshank, *Tringa nebularia* (Schedule 3, Migratory).

Four species were considered to have the potential for occurrence:

- Northern Quoll, *Dasyurus hallucatus* (Schedule 1/Endangered);
- Australian Painted Snipe, *Rostratula australis* (Schedule 1)
- Grey Falcon, *Falco hypoleucos* (Schedule 1)*;*
- Cattle Egret, *Ardea ibis* (Schedule 3, Migratory);

Six species were considered to be unlikely to occur:

- Night Parrot, *Pezoporus occidentalis* (Schedule 1, Endangered)*;*
- Crest-tailed Mulgara, *Dasycercus cristicauda* (Schedule 1, Vulnerable);
- Bilby, *Macrotis lagotis* (Schedule 1, Vulnerable);
- Short-tailed Mouse, *Leggadina lakedownensis* (Priority 4);
- Long-tailed Dunnart, *Sminthopsis longicaudata* (Priority 4); and,
- Oriental Plover, *Charadrius veredus* (Schedule 3, Migratory).

One species was considered to not occur in the study area:

- Northern Marsupial Mole, *Notoryctes caurinus* (Schedule 1, Endangered);

1.5 SRE Fauna Results

Nineteen mygalomorph spider specimens were collected from the study area. Genetic analysis of the specimens detected five putative species from two families. All species detected have been found previously outside of the study area. Three of the five putative species were considered potential SRE fauna (Idiopidae species ‘I53’, Nemesiidae species ‘N42’ and ‘N44’), while the remaining two species were not considered to represent SREs (Nemesiidae species ‘N16’ and ‘N1’).

One pseudoscorpion specimen was collected from the study area and assigned to *Beirolpium* sp. (family Olpiidae). The SRE status of this taxon is currently undetermined as the group requires further taxonomic investigation, however it has been found previously outside of the study area.

2.0 Introduction

2.1 Project Background and Study Area

Rio Tinto currently operates the Yandicoogina (Yandi) iron ore mine as part of its Pilbara Iron operations. Yandi is located approximately 90 km northwest of Newman in the Pilbara region of Western Australia. The original Yandi mine, Junction Central, started construction in 1997 with the first shipment of ore occurring in 1999.

Rio Tinto is currently undertaking a pre-feasibility study for the potential development of two nearby channel-iron deposits called Pocket and Billiard South (PBS), located approximately 7 km east of the existing Yandi mine (Figure 2.1). Given the proximity of these deposits to Weeli Wolli Creek and the Fortescue Marsh catchment, the proposal was referred under the WA *Environmental Protection (EP) Act 1986* and under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. The proposed development was subsequently deemed to not be a Controlled Action under the *EPBC Act 1999*, but formal environmental assessment will still occur at State level.

A desktop review of the surveys completed in the Pocket and Billiard South area was recently conducted (Biota 2013a) to determine knowledge gaps and whether further work was required to bring the amount of information for the area to a level suitable for environmental impact assessment (EIA) under Part IV of the WA *EP Act 1986*. This review found that fauna sampling in the northern and western portions of the study area, coinciding predominantly with the Newman, McKay and Urandy land systems, was under-represented by existing surveys. As a result, Biota was commissioned to address zoological knowledge gaps outlined in the review, by undertaking a Level 2 fauna survey in the Pocket and Billiard South area. The Pocket and Billiard South study area is approximately 8,640 ha in size and is hereafter referred to as the 'study area'.

2.2 Study Objectives and Scope

This report documents the combined methods, results and key findings of the first phase (Phase 1: 'wet season') and second phase (Phase 2: 'dry season') fauna surveys in the study area in March and September 2014, respectively. The results of the first phase of sampling in the study area were previously presented in an interim report (Biota 2014a). Information presented in the current report has been reviewed and updated as necessary, based on the combined results of the two field surveys.

The scope of the survey was to:

- undertake a Level 2 fauna survey of the study area consistent with relevant EPA Guidance Statements;
- complete targeted searches and non-systematic data collection within habitats suitable for Short Range Endemic (SRE) species or fauna of National Environmental Significance (NES species); and,
- conduct vertebrate and SRE fauna habitat mapping and potential NES species habitat mapping.
- document the vertebrate and SRE fauna assemblage within the study area using established sampling techniques;
- identify and assess the local and regional conservation significance of the fauna assemblage and habitats present in the study area; and,
- identify vertebrate and SRE fauna of particular conservation significance, particularly threatened fauna listed under the Commonwealth *EPBC Act 1999,* Schedule fauna listed under the State *Wildlife Conservation Act 1950*, and species classified as Priority fauna by the Department of Parks and Wildlife.

The survey was planned and implemented in accordance with:

- EPA Position Statement No. 3 – Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance Statement No. 56 – Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004); and
- EPA and the then Department of Environment and Conservation (DEC) Technical Guide – Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment (EPA and DEC 2010).

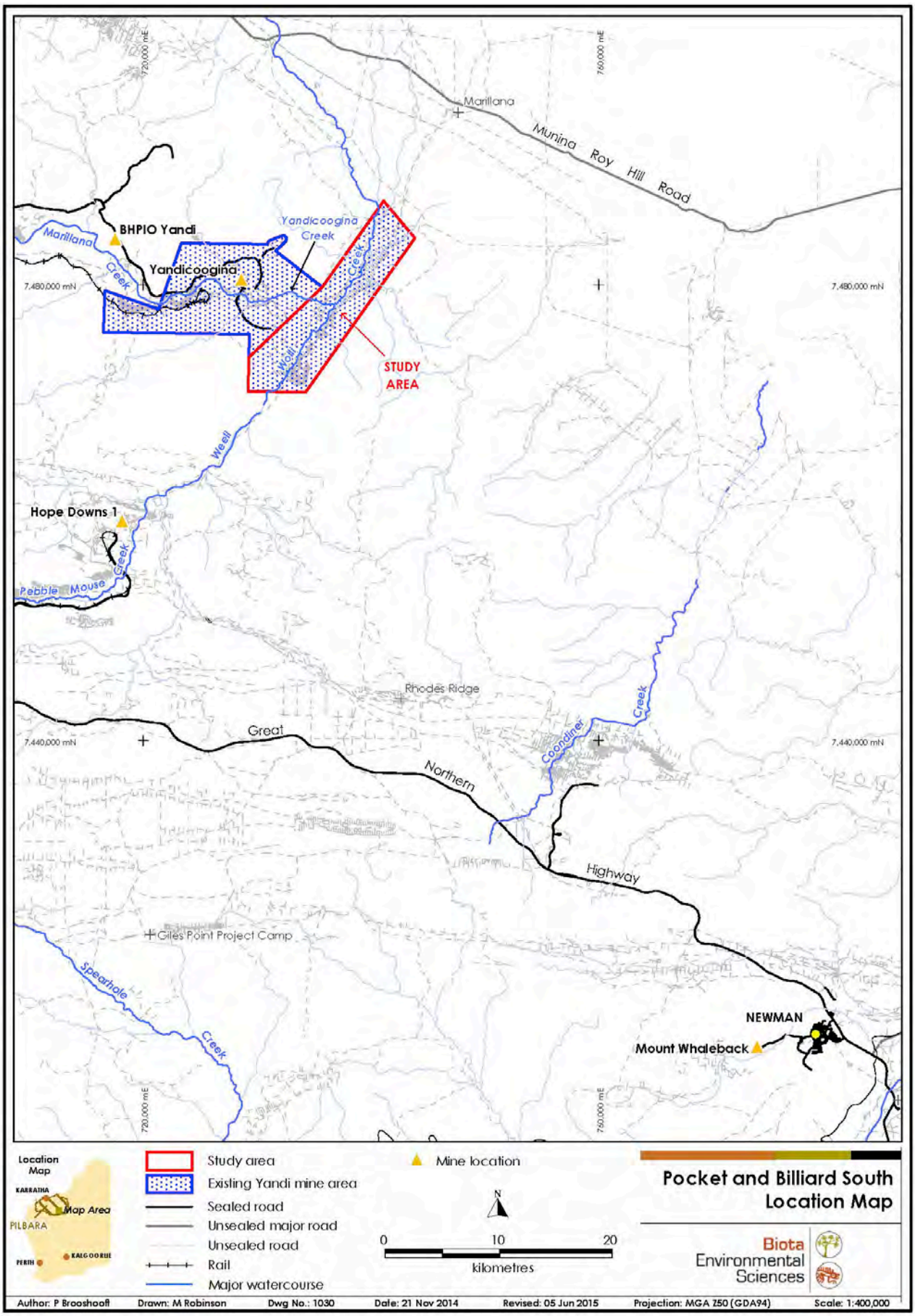

Figure 2.1: Location of the Pocket and Billiard South study area showing the existing Yandi mine.

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3.0 Regional Context of Study Area

3.1 IBRA Bioregion and Subregion

The Interim Biogeographic Regionalisation for Australia (IBRA) recognises 89 distinct bioregions and 419 subregions within Australia (Department of Environment 2013). The study area is located at the boundary between two subregions of the Pilbara:

- Hamersley (PIL3): mountainous area of Proterozoic ranges and plateaus with low Mulga (*Acacia aneura*) woodland over bunch grasses on fine textured soils, and Snappy Gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on the skeletal sandy soils of the ranges (Kendrick 2003a); and
- Fortescue Plains (PIL2): alluvial plains and river frontages with salt marsh, Mulga-bunch grass and short grass communities on alluvial plains and River Gum (*Eucalyptus camaldulensis*) woodlands fringing drainage lines (Kendrick 2003b).

3.2 Priority Ecological Communities in the Locality of the Study Area

Four Priority Ecological Communities (PECS) exist within 40 km of the study area:

- Weeli Wolli Spring Community (Priority 1) overlaps the southern section of the study area;
- Fortescue Valley Sand Dunes (Priority 3) lies within 5 km to the north east and north west of the study area;
- Fortescue Marsh (Priority 1) is approximately 20 km north of the study area; and
- Coolibah-Lignum Flats (Priority 3), approximately 40 km southwest of the study area.

Areas surrounding the Fortescue Marsh are also proposed to be excluded from the Marillana Station pastoral lease in 2015 to assist with management of this important ephemeral wetland (Bell et al. 2014).

3.3 Conservation Reserves in the Locality of the Study Area

Karijini National Park (Karijini) is the closest conservation reserve to the study area. The nearest boundary of Karijini to the study area is approximately 64 km to the west.

3.4 Geology

The geological units of the Pilbara have been documented broadly (Thorne and Trendall 2001). These units form the basis for the description of landforms and substrates that underlie the habitats found within the study area. The study area encompasses eight geological units mapped by the Geological Survey of Western Australia (1984). These units are described in and displayed in Figure 3.1.

Table 3.1: Geological units occurring within the study area.

Unit Code	Geological Description	Area (ha)	Percentage of Study Area
Qa	Alluvium: unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains.	2,413	27.9%
PLHj	Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), pelite and numerous metadolerite sills.	2,350	27.2%
Czc	Colluvium: partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits.	2,337	27.0%
PLHb	Brockman Iron Formation: banded iron-formation, chert, and pelite.	637	7.4%
Qw	Alluvium and colluvium: red-brown sandy and clayey soil; on low slopes and sheetwash areas.	557	6.4%
Czk	Calcrete-sheet carbonate; found along major drainage lines.	341	3.9%
Czp	Robe Pisolite: pisolitic limonite deposits developed along river channels.	4	0.05%
Qs	Eolian deposit-sand; in sheets and longitudinal dunes.	1	0.01%

3.5 Land Systems

Land systems are repeating patterns in the landscape, grouped by topography, soils, and vegetation. These units are mapped by the Western Australian Department of Agriculture (Payne et al. 1988), and provide a broad description of the habitats potentially occurring within the study area. The Pilbara bioregion contains a total of 107 land systems[1], with 63 land systems occurring in the Hamersley subregion and 54 occurring in the Fortescue Plains subregion.

Land system mapping covering the study area has been prepared by van Vreeswyk et al. (2004). The study area intersects five land systems, which are summarised in Table 3.2. These land systems are widespread and extensive in terms of their area within the Pilbara bioregion. Their location in relation to the study area is shown in Figure 3.2.

3.6 Landforms and Surface Hydrology

The study area encompasses the northern portion of the Weeli Wolli Creek valley, where this widens from a shallow gorge to form a true valley, and its associated floodplains and hillslopes.

Drainage within the study area is dominated by Weeli Wolli Creek, which flows in a northeast direction through the Hamersley Range and ends in an alluvial fan. The alluvial fan stretches from the footslopes of the Hamersley Range scarp, across the pediment slope to the edge of the Fortescue Marsh. The confluence of Weeli Wolli Creek and Marillana Creek occurs in the centre of the study area, just behind the scarp of the Hamersley Range. There are numerous floodout areas adjacent to the creeks, and islands in the anabranching creek beds of both creek systems. Following seasonal rainfall, both creek systems often support ephemeral pools of water.

Low crests and hillslopes define the edge of the creek valley. Numerous short minor drainage lines dissect the hills, forming shallow gorges and narrow floodplains before they flow into Weeli Wolli Creek. In an area near the southern end of the eastern boundary of the study area, the creek valley widens considerably and several minor drainage lines flow through a narrow pediment zone before entering the Weeli Wolli Creek floodplain.

[1] This information was obtained by merging the Ashburton land system mapping (Payne et al. 1988) and Pilbara land system mapping (van Vreeswyk et al. 2004), and intersecting this with the Pilbara bioregion (Environment Australia 2000) in ArcView (v. 3.2).

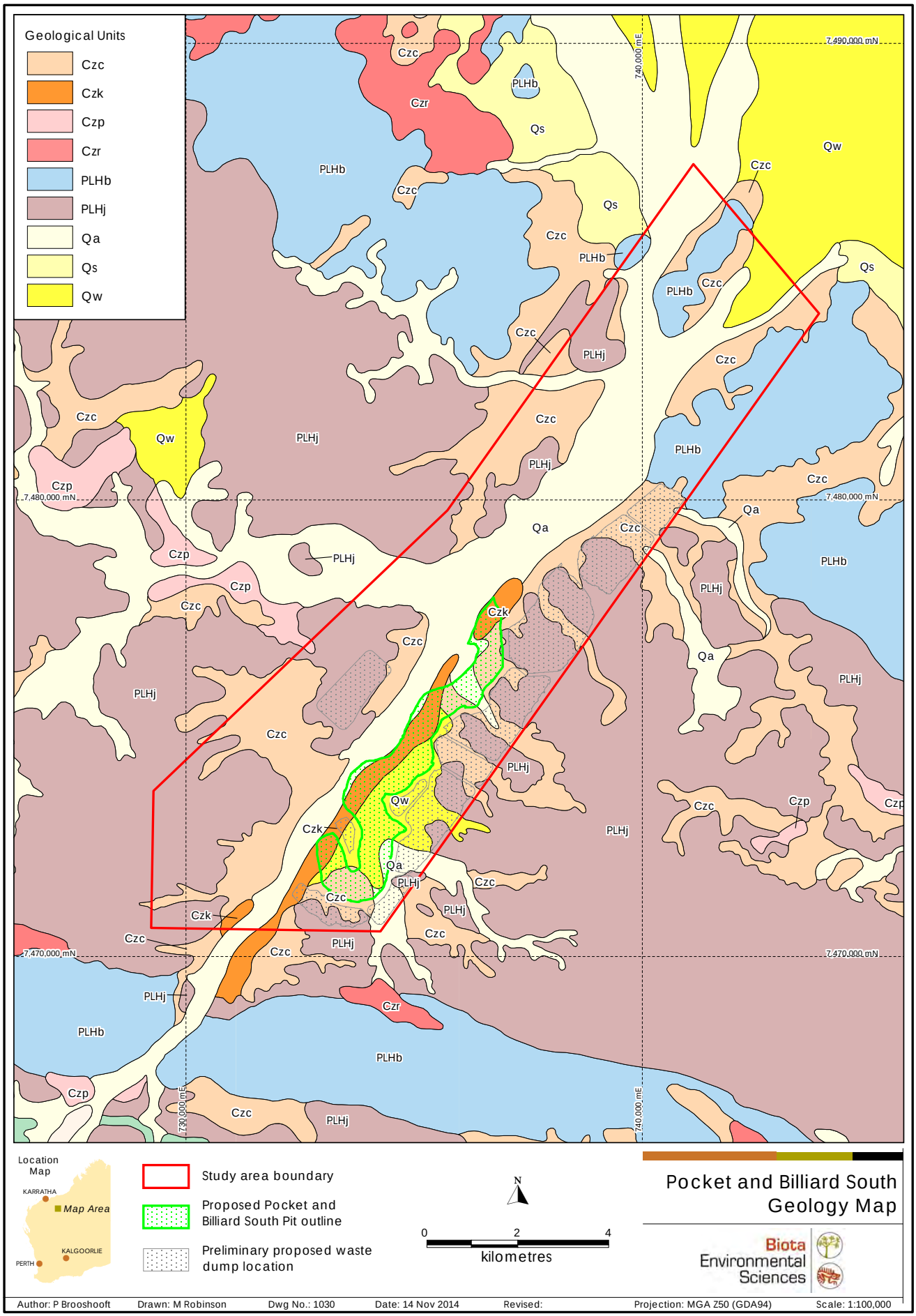

Figure 3.1: Geological units mapped in the vicinity of the study area.

Table 3.2: Extent of land systems in the study area and the percentage this represents of their total extent in the Pilbara bioregion.

Land System	Description (van Vreeswyk et al. 2004)	Total Area of Land System within the Study Area	Percentage of Study Area	Total Area of Land System in the Pilbara	Percentage of Total Land System in Study Area
Boolgeeda	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands. Component landforms include low hills and rises (4%), stony slopes and upper plains (20%), stony lower plains (65%), groves (1%), and narrow drainage and channels (10%). Not susceptible to degradation or soil erosion.	2,221 ha	25.8%	961,637 ha	0.2%
McKay	Hills, ridges, plateaus and breakaways of meta-sedimentary rocks supporting hard spinifex grasslands. Component landforms include hills, ridges ad plateaus remnants (60%), breakaways (2%), lower foot slopes (10%), stony plains (20%), and drainage floors (8%). Not susceptible to degradation or soil erosion.	1,455 ha	16.8%	426,145 ha	0.3%
Newman	Rugged jaspilite plateaus, ridges and mountains supporting hard spinifex grasslands. Component landforms include plateaus, ridges, mountains and hills (70%), lower slopes (20%), stony plains (5%), and narrow drainage floors with channels (5%). Not susceptible to degradation or soil erosion.	2,326 ha	26.9%	1,993,745 ha	0.1%
River	Active floodplains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands. Component landforms include sandy levees and sand sheets (15%), upper terraces (5%), floodplains and lower terraces (50%), stony plains (10%), and minor and major channels (20%). Susceptibility to erosion is high or very high if vegetation is removed.	2,142 ha	24.8%	497,421 ha	0.4%
Urandy	Stony plains, alluvial plains an drainage lines supporting shrubby soft spinifex grasslands. Component landforms include stony plains (58%), alluvial plains (35%), and drainage zones and channels (7%). Most of the system is not susceptible to degradation or soil erosion.	496 ha	5.7%	131,975 ha	0.4%

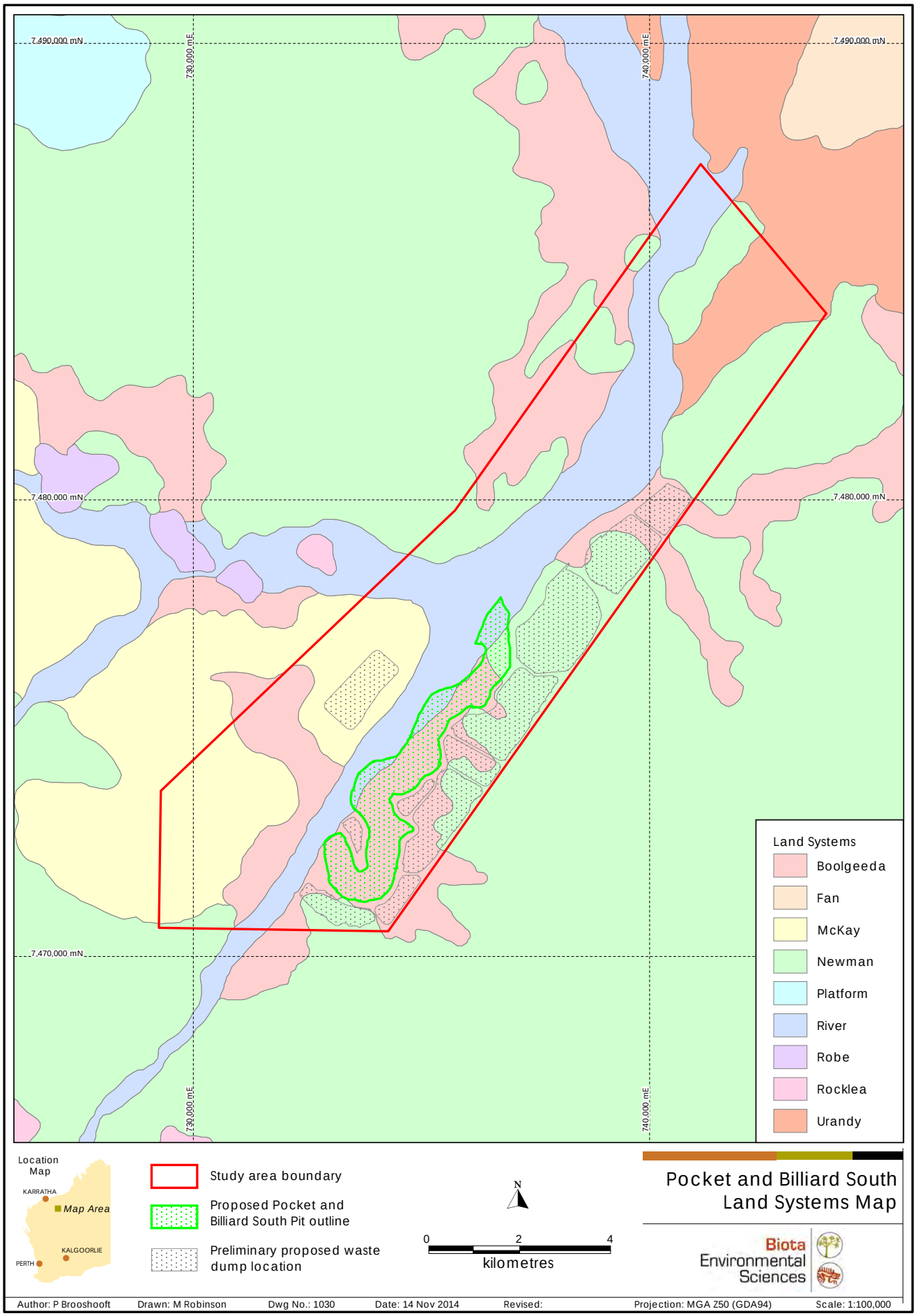

Figure 3.2: Land systems of the locality including the study area.

3.7 Beard's Vegetation Mapping

Beard (1975a, 1975b) described and mapped the vegetation of the Pilbara at a scale of 1:1,000,000. The study area is located on the Hamersley Plateau, which is within the Fortescue Botanical District of the Eremaean Botanical Province as defined by Beard. The vegetation of this province is typically open, and frequently dominated by spinifex, wattles and occasional eucalypts.

Three vegetation units mapped by Beard (1975b) occur within the study area (see Figure 3.3), two of which are essentially the same vegetation type:

- Fortescue Valley 29: Sparse low woodland; Mulga (*Acacia aneura* sens. lat.), discontinuous in scattered groups; and
- Fortescue Valley 82 and Hamersley 82: Hummock grasslands, low tree steppe; Snappy Gum (*Eucalyptus leucophloia*) over Limestone Spinifex (*Triodia wiseana*).

These vegetation units are widespread in the Pilbara bioregion and largely uncleared (see Table 3.3). Given the scale of Beard's mapping, these units only broadly characterise the vegetation of the study area.

Table 3.3: Beard's (1975b) mapping units that occur in the study area and their extent in the Pilbara bioregion (data from Government of Western Australia 2013).

Beard's Vegetation Mapping Unit	Pre-European Extent in the Hamersley or Fortescue Subregion (as relevant)	Current Extent in the Hamersley or Fortescue Subregion (% Remaining)	Extent within the Study Area (% of Total Current Extent in the Hamersley or Fortescue Subregion)
Fortescue Valley 29	893,395 ha	893,222 ha (>99.9%)	4,512.1 ha (0.5%)
Fortescue Valley 82	24,192 ha	24,192 ha (>99.9%)	1,021.8 ha (4.2%)
Hamersley 82	2,177,574 ha	2,165,235 ha (99.4%)	3,105.2 ha (0.1%)

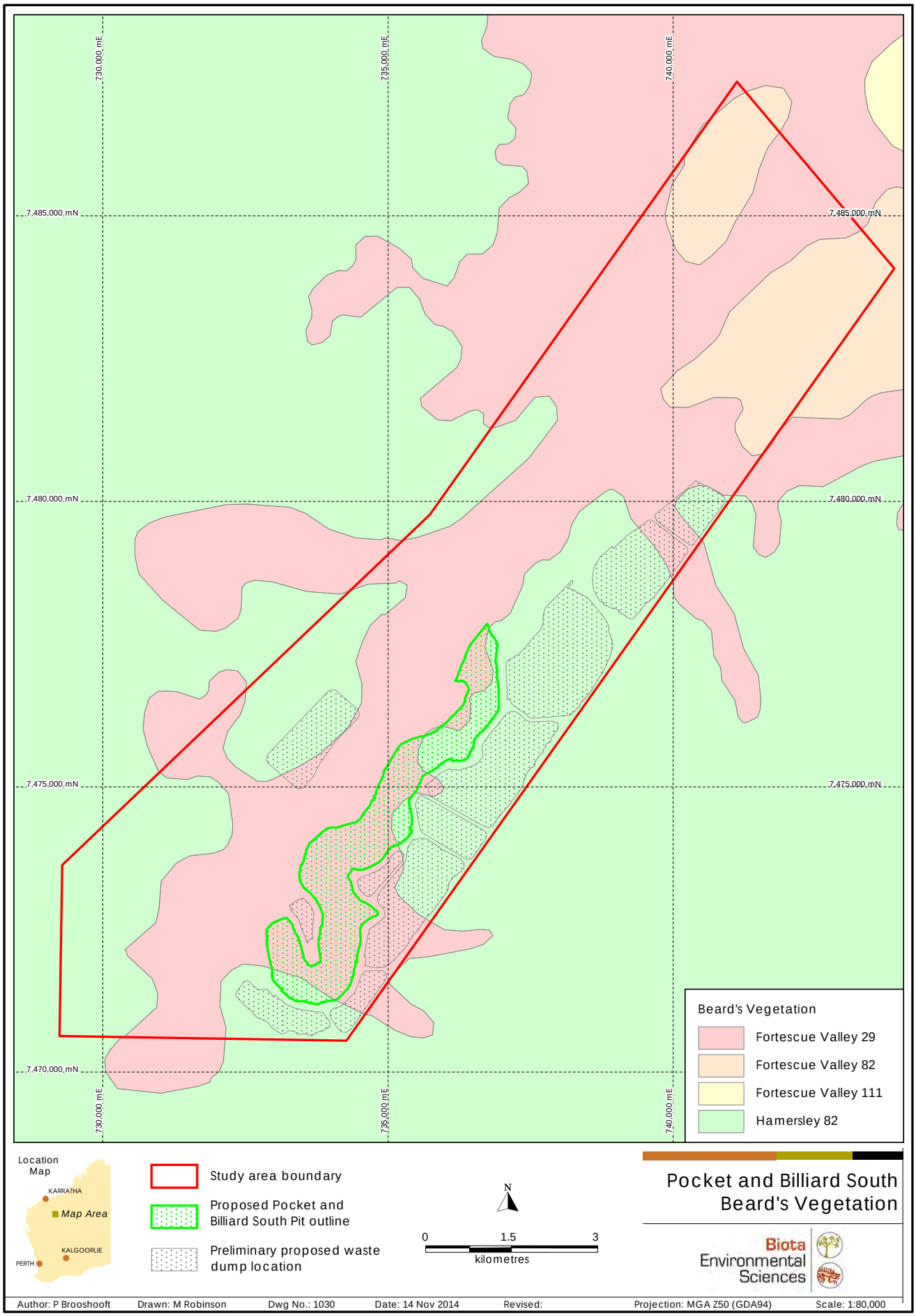

Figure 3.3: Beard's vegetation mapping for the locality including the study area.

3.8 Vegetation of the Study Area

The vegetation of the study area has been mapped previously by Biota (Biota 2014b). Twenty-three vegetation types were described for the study area (Table 3.4).

These vegetation types were broadly associated with the following landforms:

- major creeklines and tributaries;
- minor creeklines, floodplains and valleys;
- hills, ridges and breakaways; and
- plains.

Soils in the study area were generally described as red-brown loams, clay loams or sandy clay loams and were covered with a loose surface layer of stones and pebbles (Biota 2014b). Soils were stonier at the margins of the valley and on the associated footslopes. Heavier soils were found in the lower parts of the valley and in the flood-out areas. Some small areas of light clay supported Mulga woodland on the plains. Soils of the creek beds were a coarse sand-pebble mix.

Table 3.4: Vegetation types described for the study area by Biota (2014b). .

Vegetation Code	Description
Vegetation of Major Creeklines and Tributaries	
C1: EcEvMaMgAc	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
C2: EvChAtuGwTErCYpERItTHt	*Eucalyptus victrix, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland
C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
C4: EvAciAprAThCEc	*Eucalyptus victrix* open *woodland* over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
Vegetation of Minor Creeklines, Floodplains and Valleys	
F1: ChAtuGwTp	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland
F2: AprAciCEc	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland
F3: ElChAtuAaAbGwTspp	*Eucalyptus leucophloia, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland
F4: ChAtuAaPcAtenBONeARhPAmTp	*Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland.
F5: ChAciAaAiSENsppTp	*Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland.

Vegetation Code	Description
Vegetation of Hills, Ridges and Breakaways	
H1: ElHcAiGwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
H2: ElAiTwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
H3: ElGwAarTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland
H4: ChAarTspsTw	*Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland
H5: ElCfERImTHspp	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis, Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade (M.E. Trudgen 2471), *T. triandra* open tussock grassland
Vegetation of Plains	
P1: ElEgAprAbAaAdTwTpTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
P2: ChAprAiAsclApaTp	*Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland
P3: AprAciAiAsclTlo	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland
P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
P5: ElEgAbAaTb	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
P6: AapERfoERl/g	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
P7: ERf/g	*Eremophila fraseri* subsp. *fraseri* open shrubland over mixed very open grassland
P8: EgAiTs	*Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland
P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland

3.9 Fauna Habitats of the Study Area

Fauna habitats of the study area were mapped during the first phase of the survey (Biota 2014a). Habitat mapping was based on Biota's fauna landscape approach (Biota 2013b), which identifies landforms within a broader landscape. Landforms are composed of a mosaic of larger landform patterns (such as flood plains, hills and dune fields) and smaller landform elements (such as a breakaway, cliff or hill slope). The distributions of fauna are typically not limited to specific landform elements, rather fauna may utilise many components of a landform. Therefore, fauna habitats are mapped based on an amalgamation of landform patterns and elements that are considered to represent suitable habitats for species, and in particular, species of conservation significance. This approach formed the basis of NES species habitat mapping, further described in Section 6.6.

Eight fauna habitats were mapped during Phase 1. These habitats are depicted in Figure 3.4 and further described in Table 3.5.

Table 3.5: Landforms and descriptions of fauna habitats within the study area.

Landform Pattern (Data Standard Analogue)	Fauna habitat	Description
Flats	Alluvial Plain (Flood Plain)	An area of land adjacent to a drainage line that stretches from the banks of its channel to the base of the enclosing valley walls. It experiences flooding during periods of high discharge but does not experience a strong current.
Flats	Floodout Plain	A type of alluvial plain that receives water during periods of overbank flow associated with normal or extreme flood events.
Flats	Mulga Woodland	Mulga woodlands at PBS occur on areas of alluvial plain. They are delineated as a discrete fauna habitat because they support a distinct fauna assemblage not present in other habitats within the PBS.
Flats	Minor Alluvial Fan	A large sloping landform element, formed by the deposition of sediment and debris eroded from adjacent upland areas. Alluvial fans usually contain a number of dominant drainage pathways. There is a gradation from coarse material to fine grained material from the outlet point to the end point of the fan.
Hilltops and Slopes	Hilltops and Slopes	Hilltops and slopes make up much of the study area and consist of a number of landform elements, notably (from highest to lowest elevation): Crests, Free Faces, Breakaways (not always present), Transitional Slopes and Foot Slopes.
Hilltops and Slopes	Pediment Slope	The large, gently inclined lower slopes below hills underlain by bedrock at varying depths. Pediments in the PBS vary in width and exhibit sharp breaks of slope between the pediment and the steeper hillside above them. Water passes across the pediment by laminar sheet flow, but if this is disturbed, the flow becomes turbulent and gullies develop.
Drainage	Major Drainage Line	A linear, sinuous open depression forming the floor of the major drainage channel (Weeli Wolli Creek) that is eroded or aggraded (built up) by stream flow. In the PBS this supports taller eucalypts, dense shrublands and reedbeds around water pools that are semi-permanent due to upstream mine dewatering.
Disturbed		Areas of disturbed land originating from clearing.

It was noted that much of the area showed signs of degradation by cattle, particularly riparian vegetation associated with Weeli Wolli Creek, Mulga Woodlands and open grasslands on softer sandy soils such as those of the Urandy land system. Parts of these areas were also heavily affected by introduced weeds such as Buffel Grass (**Cenchrus ciliaris*).

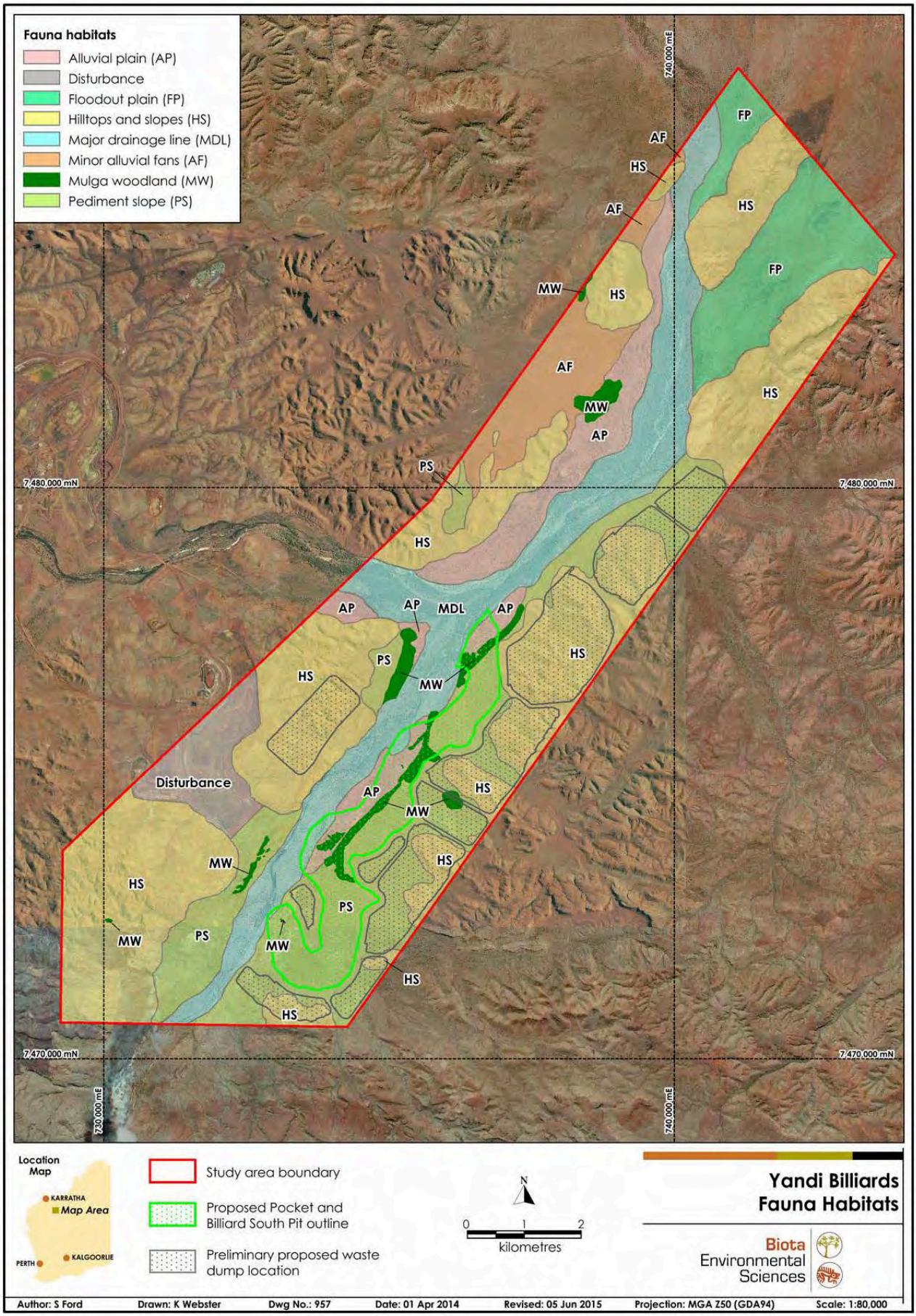

Figure 3.4: Fauna habitats within the study area.

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4.0 Methodology

4.1 Desktop Review

4.1.1 Literature Review

A number of vertebrate and SRE fauna surveys have been conducted in proximity to the study area. Table 4.1 provides a summary of surveys reviewed that provide context to the current survey. Reports reviewed were chosen on the basis of data availability and proximity to the study area (all surveys were conducted within 10 km of the study area boundary). The species recorded during the vertebrate fauna surveys, in conjunction with records returned from the database searches detailed in Section 4.1.2, have been compiled to construct a potential species list for the study area, and are presented in Appendix 1.

4.1.2 Database Searches

The following databases were searched to assist in the determination of the potential fauna assemblage of the study area:

1. NatureMap Database (http://naturemap.dpaw.wa.gov.au) (Appendix 2). This database is a joint project of the Department of Parks and Wildlife and the Western Australian Museum (WAM), and represents the most comprehensive source of information on the distribution of Western Australia's fauna and flora. It comprises records from the Fauna Survey Returns database and WA Threatened Fauna database, the WAM Specimen database, and BirdLife Australia's Birdata database. The search was performed on the 31st October 2014 and requested the return of records from a radius of 40 km around a central point within the study area (22°47'08" S 119°18'36" E).
2. The Commonwealth *EPBC* Protected Matters Database (Appendix 3). This database comprises matters of National Environmental Significance protected under the *EPBC Act 1999*, including Threatened Species and Migratory Species. The search was conducted on the 31st October 2014 and requested the return of records from a radius of 40 km around the central point 22°47'08" S 119°18'36" E.
3. The Atlas of Living Australia (ALA) (http://www.ala.org.au/) (Appendix 4). The ALA is a joint project between academic collecting institutions, private individual collectors and community groups. It contains occurrence records, environmental data and images and lists the conservation status of species throughout Australia. This search was conducted on the 31st October 2014 and requested the return of records from a radius of 40 km around the central point 22°47'08" S 119°18'36" E.

Table 4.1: Previous studies conducted within 10 km of the Pocket and Billiard South study area.

Report/Survey	Dates of Survey	Description of Survey	Approximate Distance From Study Area
Vertebrate Fauna Reports			
Ninox Wildlife Consulting (1994) Vertebrate Fauna of the Proposed Junction Deposit Mine and the Central Pilbara Transport Corridor. Report prepared for Hamersley Iron.	March 1994	Level 2 vertebrate fauna survey of the Junction Deposit in the proposed Yandi mine area	Overlaps study area
Biota (2002a) Vertebrate Fauna Survey of the Proposed Hope Downs Rail Corridor from Weeli Wolli Siding to Port Hedland. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 29/04/01 – 14/05/01 01/05/01 – 08/05/01 23/06/01 – 01/07/01 Phase 2: November 2001	Level 2 terrestrial vertebrate fauna survey of a proposed rail corridor.	Overlaps study area
Biota (2002b) An Assessment of the Distribution of the Mulgara *Dasycercus cristicauda* and Bilby *Macrotis lagotis* Along and Adjacent to the Proposed Hope Downs to Port Hedland Rail Corridor. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 10/10/01 – 18/10/01	Targeted survey for Mulgara and Bilby along the Hope Downs Rail Alignment	Overlaps study area
Biota (2004a) Hope Downs Additional Rail Corridor - Chichester Range Vertebrate Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 30/04/03 – 07/05/03	Level 2 terrestrial vertebrate fauna survey of the Hope Downs rail corridor through the Chichester Range.	Overlaps study area
Biota (2004b) Hope Downs Rail Corridor Extension - Hamersley Range Vertebrate Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 22/04/03 – 29/04-03	Level 2 terrestrial vertebrate fauna survey of the Hope Downs rail corridor through the Hamersley Range.	Overlaps study area
Biota (2005a) Fauna Habitats and Fauna Assemblage of the Proposed FMG Stage B Rail Corridor and Mindy Mindy, Christmas Creek, Mt Lewin and Mt Nicholas Mine Areas Fauna Habitat and Fauna Assemblage Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 21/06/04 – 16/07/04	Level 2 terrestrial vertebrate fauna survey of the proposed Stage B rail corridor, Mindy Mindy, Christmas Creek, Mt Lewin and Mt Nicholas mine areas.	5 km east-southeast
Biota (2004c) Fauna Habitats and Fauna Assemblage of the Proposed FMG Stage A Rail Corridor. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 20/03/04 – 07/04/04	Level 2 terrestrial vertebrate fauna survey of the proposed north-south rail corridor.	Overlaps study area
Biota (2005b) Yandi JSE Project – Conservation Significant Fauna and Fauna Habitat Assessment. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 30/08/04 – 03/09/04	Level 1 fauna habitat assessment, targeted sampling of invertebrate fauna and desktop assessment of terrestrial vertebrate fauna.	Overlaps study area

Report/Survey	Dates of Survey	Description of Survey	Approximate Distance From Study Area
Vertebrate Fauna Reports			
Biota (2010a) Yandicoogina Expansion Billiard Deposit Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 05/07/08 – 12/07/08	Level 2 terrestrial vertebrate and SRE fauna survey of the Yandi Billiards project area.	Overlaps study area
Biota (2010b) Yandicoogina Junction South West and Oxbow Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 05/07/08 – 12/07/08	Level 2 terrestrial vertebrate and SRE fauna survey of the Yandi Junction South West and Oxbow areas.	Overlaps study area
Biota (2009a) Yandicoogina Targeted Northern Quoll Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 06/10/09 – 12/10/09	Targeted Northern Quoll survey of the Oxbow, Billiard and Junction South West areas.	Overlaps study area
Biota (2011a) Hope Downs Project Life of Mine Targeted Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 21/06/10 – 27/06/10	Targeted SRE invertebrate fauna and Northern Quoll survey of the Hope Downs project.	7 km south-southwest
Biota (2012a) South Flank to Jinidi Level 2 Vertebrate Fauna Survey. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 11/04/11 – 20/04/11 Phase 2: 02/11/11 – 11/11/11 Phase 3: 31/01/12 – 03/02/12	Level 2 vertebrate fauna survey of the South Flank to Jinidi project area.	9 km south
Biota (2013c) Area C West to Yandi Level 2 Vertebrate Fauna Survey. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 25/05/11 – 02/06/11 Phase 2: 07/09/11 -15/09/11 Phase 3: 05/02/12 – 08/02/12	Level 2 vertebrate fauna survey of the Area C West to Yandi project area.	7 km west-northwest
Biota (2012b) Koodaideri Project Targeted Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 19/07/11 – 27/07/11	Targeted Northern Quoll and Orange Leaf-nosed Bat fauna survey.	9 km north-northwest
Biota (2014a) Yandi Billiards Phase 1 Seasonal Fauna Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 08/03/14 – 18/03/14	Phase 1 of a Level 2 vertebrate and SRE invertebrate fauna survey of Pocket and Billiard South.	Overlaps study area
Biota (2014c) Yandi Billiards Targeted Northern Quoll Survey. Unpublished report for Rio Tinto Iron Ore.	Phase 1: 05/08/14 – 13/08/14	Targeted Northern Quoll survey at Pocket and Billiard South.	In study area
Short Range Endemic Reports			
(Biota 2011b) Area C and Surrounds Short Range Endemic Fauna Survey. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 15/02/10 – 26/02/10 Phase 2: 23/06/10 – 30/06/10	Targeted SRE invertebrate fauna survey of the Area C and Surrounds area.	5 km south-southwest
(Biota 2011c) Jinidi Lease and Jinidi to Mainline Rail SRE Review. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 25/07/11 – 02/08/11	Targeted SRE survey of the Jinidi to Mainline corridor	Overlaps study area

Report/Survey	Dates of Survey	Description of Survey	Approximate Distance From Study Area
(Biota 2013d) Short Range Endemic Fauna Survey of the Southern Flank to Jinidi Project Area. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 11/04/11 – 20/04/11 Phase 2: 02/11/11 – 11/11/11 Phase 3: 30/01/12 – 08/02/12	Targeted SRE invertebrate fauna survey of the Southern Flank to Jinidi area.	9 km south
(Biota 2013e) Short Range Endemic Fauna Survey of the Area C West to Yandi Project Area. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 25/05/11 – 02/06/11 Phase 2: 07/09/11 – 15/09/11 Phase 3: 05/02/12 – 08/02/12	Targeted SRE invertebrate fauna survey of the Area C and Surrounds area.	7 km west-northwest
(Biota 2013f) A Survey of the Short Range Endemic Fauna of Marillana. Unpublished report for BHP Billiton Iron Ore.	Phase 1: 13/06/11 – 22/06/11 Phase 2: 07/02/12 – 08/02/12	Targeted SRE invertebrate fauna survey of the Area C and Surrounds area.	2 km northwest
(Biota 2012c) Jinidi Iron Ore Mine - Terrestrial Invertebrate SRE Impact Assessment. Unpublished report for BHP Billiton Iron Ore.	2012	Impact assessment and desktop review of SRE fauna	8 km south

4.2 Survey Timing and Weather

4.2.1 Timing

The Pocket and Billiard South field survey was completed over two phases. Phase 1 was conducted over an 11 day study period, from the 8th until the 18th of March 2014, and Phase 2 was conducted over a ten day study period from the 10th until the 19th of September 2014.

4.2.2 Daily Weather Observations

The observations below use daily and long-term rainfall data collected at Marillana weather station (number 5009), located 32 km north of the study area. Temperature data were not available from Marillana, so daily and long-term temperature data from Wittenoom weather station (number 5026), located approximately 94 km northwest of the study area, were used.

4.2.2.1 Phase 1

During Phase 1, minimum temperatures ranged from 24.1ºC to 29.1ºC, while maximum temperatures ranged from 38.9ºC to 41.2ºC (Table 4.2). No rainfall was recorded at Pocket and Billiard South during the Phase 1 survey (Table 4.2).

Table 4.2: Daily meteorological observations for Pocket and Billiard South during Phase 1.

Date	08/03	09/03	10/03	11/03	12/03	13/03	14/03	15/03	16/03	17/03	18/03	Total/ Mean
Rainfall (mm)	0	0	0	0	0	0	0	0	0	0	0	0
Max. Temp (ºC)	39.5	39.5	40.2	41.2	39.6	41.1	41.1	40.4	40.2	38.9	40	40.2
Min. Temp (ºC)	26	26.4	26	25.8	27.7	27.4	24.9	29.1	25.9	24.1	25.4	26.2

4.2.2.2 Phase 2

During Phase 2, minimum temperatures ranged from 14.8ºC to 24.8ºC, while maximum temperatures ranged from 33.3ºC to 37ºC (Table 4.2). Again, no rainfall was recorded (Table 4.3).

Table 4.3: Daily meteorological observations for Pocket and Billiard South during Phase 2.

Date	10/09	11/09	12/09	13/09	14/09	15/09	16/09	17/09	18/09	19/09	Total/ Mean
Rainfall (mm)	0	0	0	0	0	0	0	0	0	0	0
Max. Temp (ºC)	33.3	34	35.3	35.6	36.3	37	36.7	36	34.4	34.4	35.3
Min. Temp (ºC)	14.8	17	15.4	23.1	24.8	24.8	18.9	23.5	16.8	21.4	20.05

4.2.3 Climatological Data

The Pilbara experiences an arid-tropical climate, with a hot, wet summer between October and April, and a mild, dry winter between May and September. Rainfall in the Pilbara is sporadic and can occur at any time of the year, but heaviest rainfall occurs over the summer months.

Figure 4.1 illustrates the average monthly minimum and maximum temperatures and rainfall of the year preceding the survey as compared with the long-term averages (Bureau of Meteorology

1951-2014). Maximum and minimum temperatures in the year preceding the survey were higher than average long-term temperatures, with the exception of the December-February period where they fall below average (Figure 4.1). The study area received noticeably higher than average rainfall in January prior to the first phase of survey, but February and March were relatively dry (Figure 4.1).

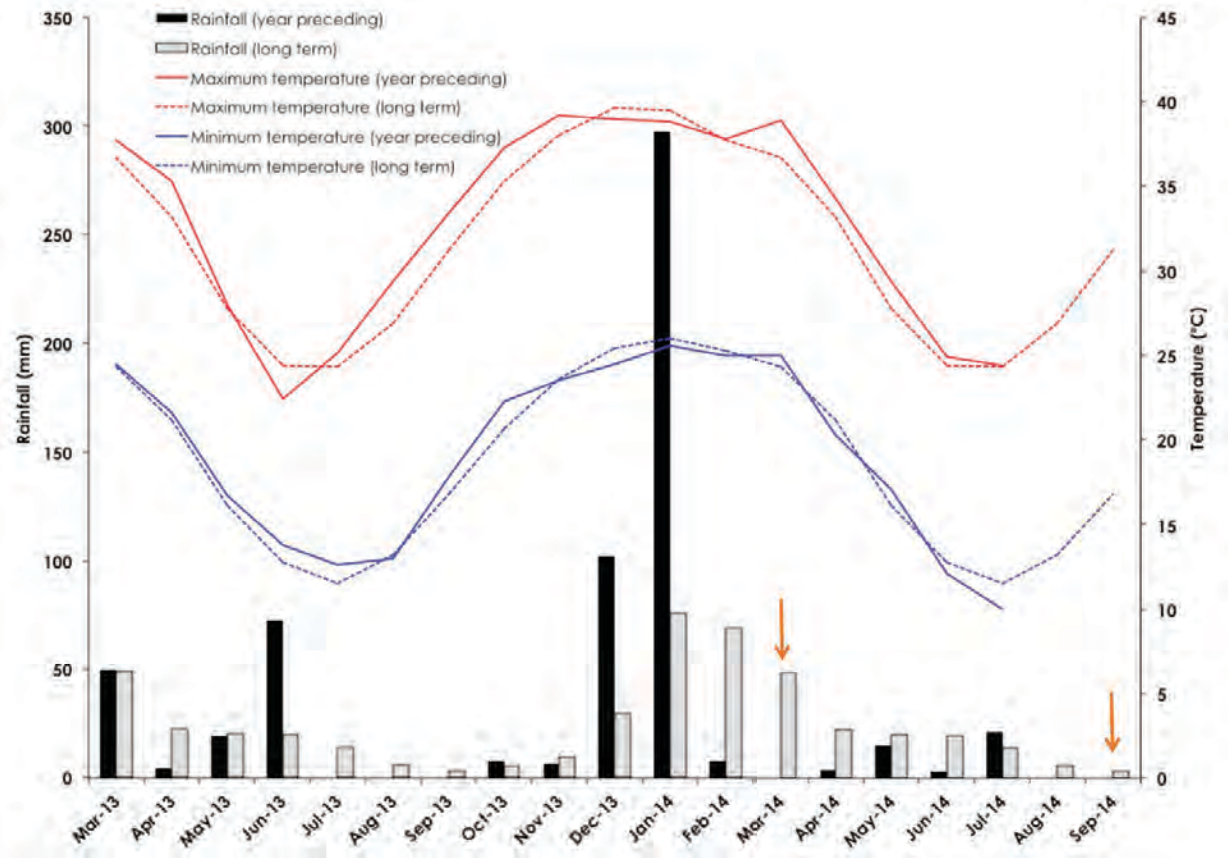


Figure 4.1: Monthly long-term and year preceding the survey climate averages recorded at Marillana (rainfall) and Wittenoom Station (temperature).
Arrows indicate survey timing.

4.3 Vertebrate Fauna Sampling

The vertebrate fauna survey of Pocket and Billiard South consisted of two phases of trapping combined with opportunistic and targeted searching. Figure 4.4 illustrates the distribution of sites sampled across the study area, with each site further detailed in Table 4.4 to Table 4.10.

4.3.1 Systematic Trapping of Vertebrate Fauna

Phases 1 and 2 employed the following trap types as the principal components used to determine species assemblage present in the study area: pitfall traps (bucket and PVC pipes), Elliott box traps, cage traps and funnel traps.

Systematic terrestrial fauna sampling was carried out at 11 sites located in land systems that were not sampled, or were sampled less, during previous surveys in the study area (based on findings of Biota 2013). These trapping sites comprised:

- Five pitfall trapping transects, each consisting of a single row of ten pitfall traps arranged as alternating plastic buckets (20L volume) and PVC pipe (150 mm diameter x 600 mm long), spaced at approximately 10 m intervals and connected with a 100 m long length of 30 cm high flywire fence (see Figure 4.2).

- Four funnel trapping grids, each consisting of 8-10 pairs of funnel traps (i.e. 16-20 traps) placed in pairs at approximately 10 m intervals along a 100 m single length of 30 cm high flywire fence (see Figure 4.3).
- Two Elliott and cage trap transects, each consisting of 25 medium Elliott box traps, ten large Elliott box traps, and four cage traps, spaced at approximately 10 m intervals. Elliott and cage traps were baited with a mixture of peanut butter and oats.

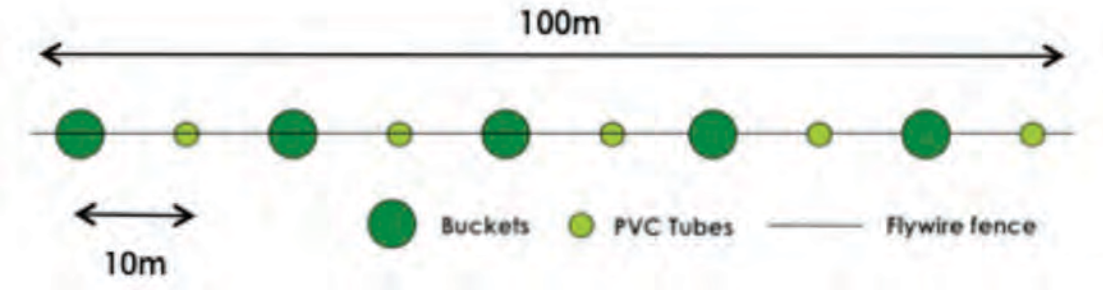


Figure 4.2: Layout of pitfall trapping transects used during the survey.

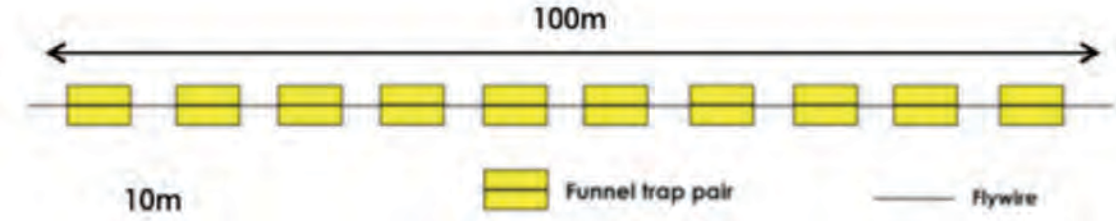


Figure 4.3: Layout of funnel-trapping transects used during the survey.

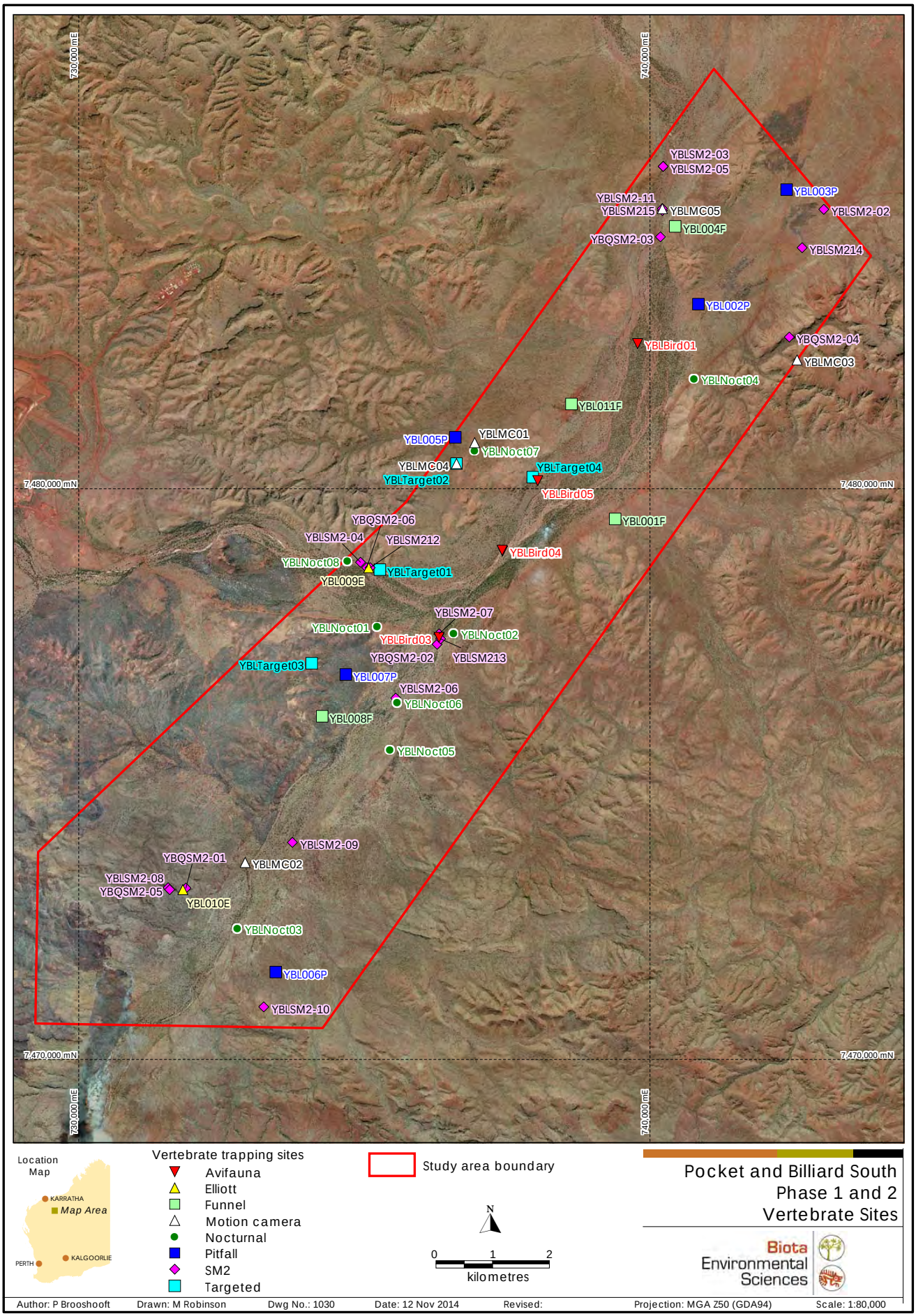


Figure 4.4: Locations of systematic and non-systematic trapping locations within the study area.

Table 4.4: Trapping site locations and effort applied during the Pocket and Billiard South fauna survey.

				Phase 1					Phase 2					
Site	Latitude	Longitude	Trap Type	Date Opened	Date Closed	Nights Open	No. of Traps	Trap Effort	Date Opened	Date Closed	Nights Open	No. of Traps	Trap Effort	Total Effort
YBL001F	22º46'31"S	119º19'54"E	Funnel traps	c	17/03/14	7	10	70	11/09/14	18/09/14	7	10	70	140
YBL002P	22º44'28"S	119º20'43"E	Pitfall traps	11/03/14	18/03/14	7	10	70	11/09/14	18/09/14	7	10	70	140
YBL003P	22º43'22"S	119º21'36"E	Pitfall traps	11/03/14	18/03/14	7	10	70	11/09/14	18/09/14	7	10	70	140
YBL004F	22º43'44"S	119º20'28"E	Funnel traps	10/03/14	12/03/14	2	8	16	Closed due to heat					16
YBL005P	22º45'46"S	119º18'15"E	Pitfall traps	10/03/14	17/03/14	7	10	70	Closed due to access restrictions					70
YBL006P	22º50'52"S	119º16'30"E	Pitfall traps	10/03/14	17/03/14	7	10	70	12/09/14	19/09/14	7	10	70	140
YBL007P	22º48'02"S	119º17'10"E	Pitfall traps	10/03/14	17/03/14	7	10	70	11/09/14	18/09/14	7	10	70	140
YBL008F	22º48'26"S	119º16'56"E	Funnel traps	10/03/14	17/03/14	7	10	70	11/09/14	18/09/14	7	10	70	140
YBL009E	22º47'01"S	119º17'23"E	Elliott and cage traps	11/03/14	18/03/14	7	35 4	273	11/09/14	18/09/14	7	35 4	273	546
YBL010E	22º50'06"S	119º15'32"E	Elliott and cage traps	12/03/14	18/03/14	6	35 4	234	11/09/14	18/09/14	7	35 4	234	468
YBL011F	22º45'26"S	119º19'26"E	Funnel traps	12/03/14	18/03/14	6	10	60	12/09/14	19/09/14	7	10	70	130
												Total Pitfall Trapping Effort		630
												Total Elliott Trapping Effort		1,014
												Total Funnel Trapping Effort		426

Table 4.5: Description of trapping sites sampled during the vertebrate fauna survey of the Pocket and Billiard South study area.

Site Description	Landform Pattern	Landform Element	Site Photograph
YBL001F Scattered low trees of *Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* over scattered tall shrubs of *Hakea lorea* over low mixed *Solanum* and *Senna* shrubland over *Triodia* hummock grassland and *Aristida* sp. tussock grassland. Slight rocky outcropping. Recent fire history (<1yrs)	Hilltops and Slopes	Crest	
YBL002P Low woodland of *Corymbia hamersleyana, Acacia pruinocarpa* and mixed *Acacia* spp. over low shrubland of *Senna* sp. over *Triodia* hummock grassland and *Cenchrus ciliaris* and *Cleome viscosa* open tussock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBL003P Scattered low trees of *Corymbia hamersleyana* over tall shrubland of *Acacia inaequilatera* and *A. bivenosa* over low *Rhynchosia* sp. shrubland over *Triodia* hummock grassland.	Flats	Alluvial Plain (Flood Plain)	

YBL004F Low open woodland of *Corymbia hamersleyana* over tall open mixed *Acacia* spp. scrub over *Triodia* hummock and *Themeda triandra* tussock grassland. Some cattle grazing evident.	Drainage	Minor Drainage Line	
YBL005P Tall shrubland of *Acacia ancistrocarpa* and *Hakea lorea* over low shrubland of *Dampiera* sp. over *Triodia* hummock grassland. Cattle grazing evident.	Flats	Alluvial Plain (Flood Plain)	
YBL006P Low open woodland of *Eucalyptus gamophylla* over open *Acacia ancistrocarpa* heath over low open shrubland of *Ptilotus astrolasius* over *Triodia melvillei* hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBL007P Low open forest of *Eucalyptus gamophylla* over *Acacia pirifolia* shrubland over low shrubland of *Dampiera* sp. over *Triodia* hummock grassland. Rocky outcropping present approximately 20 m from end of trap line.	Hilltops and Slopes	Foot Slope	

YBL008F Low open woodland of *Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* over tall open shrubland of mixed *Acacia* species over *Triodia* hummock grassland. Fire history >5yrs	Hilltops and Slopes	Transitional Slope	
YBL009E Open forest to low open woodland of *Eucalyptus victrix* and *E. camaldulensis*. Stony riverbed.	Drainage	Major Drainage Line	
YBL010E Scattered tall *Eucalyptus leucophloia* subsp. *leucophloia* trees over low open woodland of *E. l. leucophloia* and *Corymbia ferriticola* over scattered *Senna glutinosa* shrubs and scattered *Ptilotus* sp. low shrubs over mixed *Eriachne* tussock grassland.	Hilltops and Slopes	Breakaway	
YBL011F Open forest of *Acacia aneura* over low open shrubland of *Ptilotus* sp. and *Triodia* sp. hummock grassland. Heavy cattle grazing.	Flats	Alluvial Plain (Flood Plain)	

4.3.2 Avifauna Sampling

Sampling of avifauna was conducted using a combination of techniques including:

- unbounded, habitat-specific area searches (30 minute duration) conducted at each of the systematic trapping sites; and,
- opportunistic observations of birds while traversing the study area.

Forty-five avifauna censuses were completed across the systematic trapping sites, with each site being surveyed at least twice (Table 4.6). Avifauna were surveyed for a total of 1,470 minutes across sites, providing just over 24 hours of dedicated systematic avifauna survey.

Table 4.6: Date and time of avifauna surveys undertaken during the Pocket and Billiard South fauna survey.

		YBL001F	YBL002P	YBL003P	YBL005P	YBL006P	YBL007P	YBL008F	YBL009E	YBL010E	YBL011F	Total Minutes
Phase 1	11/03/14						09:40 – 10:10	08:30 – 09:00				60
	12/03/14					09:45 – 10:15			08:50 – 09:20			60
	13/03/14	06:10 – 06:40	07:05 – 07:35									60
	14/03/14	06:50 – 07:20		07:55 – 08:25	09:15 – 09:45						10:10 – 10:40	120
	15/03/14		10:40 – 11:10	09:55 – 10:25	09:00 – 09:30	06:20 – 06:50					07:50 – 08;20	150
	16/03/14						09:40 – 10:10	08:30 – 09:00	10:45 – 11:15	07:30 – 08:00		120
	17/03/14									06:15 – 06:45		120
Phase 2	12/09/14	07:00 – 07:30	07:40 – 08:10	08:40 – 09:10								90
	13/09/14	07:00 – 07:30	07:40 – 08:10	08:15 – 08:45							09:30 – 10:00	120
	14/09/14					10:00 – 10:30	8:25 – 08:55	07:50 – 08:20	09:10 – 09:40	07:00 – 07:30		150
	15/09/14					06:50 – 07:20	09:50 – 10:20	09:10 – 09:40	10:45 – 11:15	07:50 – 08:20		150
	16/09/14	06:50 – 07:20	07:35 – 08:05	08:15 – 08:45							09:20 – 10-00	130
	17/09/14					10:45 – 11:15	08:45 – 09:15	08:10 – 08:40	09:30 – 10:00			140
	Total Minutes	150	150	150	60	150	150	150	150	120	130	1,470

4.3.3 Bat Sampling

Bats were sampled during both phases of survey using echolocation call recordings at eight locations. The effort applied to sampling bats during Phase 1 and 2 is detailed in Table 4.7 and Figure 4.4. Bat sampling was also undertaken during a previous survey of the study area which targeted the Northern Quoll (Biota 2014c). Bats were sampled during this survey at six sites, and the results of the survey have been included here (Table 4.7).

Sampling equipment was placed in habitats considered likely to provide foraging, drinking and commuting opportunities for a range of species. Such habitats included cave or rock shelter entrances overlooking valleys/gorges, drainage lines and ephemeral pools of water. The bat habitat at each of the sites is described in Table 4.8.

Calls were sampled using SongMeter SM2BAT bat detector units, which detect and record ultrasonic echolocation calls emitted by bats during flight. The selectable filters and triggers, jumper and audio settings used for the SM2BAT followed the manufacturer's recommendations for bat detection contained in the user manual (Wildlife Acoustics 2010).

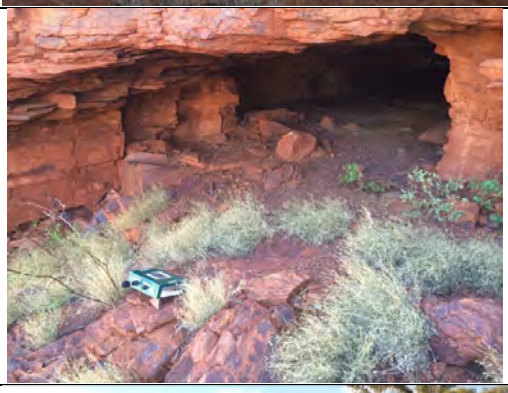
Details of calls were analysed by Mr Bob Bullen (Bat Call WA) using methods recommended by the Australasian Bat Society (Australasian Bat Society 2006) in conjunction with available reference data (Bullen and McKenzie 2002, McKenzie and Bullen 2003, 2009) (Appendix 5). Only sequences containing good quality search phase calls were considered for identification.

Table 4.7: Effort and location of SongMeter bat sampling sites in the Pocket and Billiard South study area.

	Site	Latitude	Longitude	Date Opened	Date Closed	Nights Open
Phase 1	YBLSM2-03	22º43'10"S	119º20'20"E	13/03/14	16/03/14	3
	YBLSM2-04	22º46'58"S	119º17'18"E	15/03/14	17/03/14	2
	YBLSM2-06	22º48'15"S	119º17'41"E	16/03/14	18/03/14	2
	YBLSM2-07	22º47'38"S	119º18'07"E	17/03/14	18/03/14	1
Phase 2	YBLSM2-08	22º50'05"S	119º15'23"E	12/09/14	15/09/14	3
	YBLSM2-09	22º49'38"S	119º16'39"E	16/09/14	19/09/14	3
	YBLSM2-10	22º51'12"S	119º16'23"E	12/09/14	13/09/14	1
	YBLSM2-11	22º43'35"S	119º20'20"E	16/09/14	19/09/14	3
Northern Quoll Survey	YBQSM2-01	22 50' 05"S	119 15' 34"E	6/08/14	9/08/14	3
	YBQSM2-02	22 47' 44"S	119 18' 06"E	6/08/14	9/08/14	3
	YBQSM2-03	22 43' 50"S	119 20' 19"E	6/08/14	9/08/14	3
	YBQSM2-04	22 44' 46"S	119 21' 39"E	9/08/14	12/08/14	3
	YBQSM2-05	22 50' 06"S	119 15' 24"E	9/08/14	12/08/14	3
	YBQSM2-06	22 47' 01"S	119 17' 22"E	10/08/14	13/08/14	3
					Total Effort Phase 1	8
					Total Effort Phase 2	10
					Total Effort during Northern Quoll Survey	18
					Total Overall Effort	36

Table 4.8: Description of bat sampling sites in the Pocket and Billiard South study area.

Site Description	Landform Pattern	Landform Element	Potential Habitat Use	Site Photograph
YBLSM2-03 Riverbed with scattered tall *Eucalyptus victrix*.	Drainage	Major Drainage Line	Foraging	
YBLSM2-04 Riverbed with scattered tall *Eucalyptus victrix* over *Typha* sp.	Drainage	Major Drainage Line	Foraging	
YBLSM2-06 Ephemeral pool adjacent to Weeli Wolli Creek, surrounded by *Eucalyptus victrix*.	Drainage	Major Drainage Line	Foraging	
YBLSM2-07 Flyway adjacent to Weeli Wolli Creek. Low open forest of *Melaleuca* sp.	Drainage	Major Drainage Line	Commuting and foraging	

Site Description	Landform Pattern	Landform Element	Potential Habitat Use	Site Photograph
YBLSM2-08 Cave situated in breakaway overlooking hill slope of low *Triodia* hummock grassland.	Hilltops and Slopes	Breakaway	Roosting	
YBLSM2-09 Mixed tall *Eucalypt* sp. trees over mixed *Triodia* and **Cenchrus ciliaris* tussock grassland. Highly cattle damaged.	Drainage	Major Drainage Line	Foraging and commuting	
YBLSM2-10 Cave overlooking scattered low *Eucalyptus leucophloia* subsp. *leucophloia* over mixed *Senna* and *Acacia* spp. over *Aristida* sp. grassland.	Hilltops and Slopes	Cave	Roosting	
YBLSM2-11 Riverbed with scattered tall *Eucalyptus victrix*.	Drainage	Major Drainage Line	Foraging	

Site Description	Landform Pattern	Landform Element	Potential Habitat Use	Site Photograph
YBQSM2-01 Mouth of a shallow cave.	Hilltops and Slopes	Cave	Roosting	
YBQSM2-02 Large ephemeral pool adjacent to Weeli Wolli Creek.	Drainage	Minor Drainage Line	Foraging	
YBQSM2-03 Adjacent to flowing waterway. Scattered *Eucalyptus* species.	Drainage	Major Drainage Line	Foraging	

Site Description	Landform Pattern	Landform Element	Potential Habitat Use	Site Photograph
YBQSM2-04 Entrance to a deep cave overlooking hill slope with scattered *Eucalyptus* species over *Triodia* hummock grassland.	Hilltops and Slopes	Cave	Roosting	
YBQSM2-05 Entrance of a small cave	Hilltops and Slopes	Cave	Roosting	
YBQSM2-06 Low rocky riverbank breakaway adjacent to a junction of two drainage arms along Weeli Wolli creek. Open forest of *Eucalyptus* sp.	Drainage	Minor Drainage Line	Foraging	

4.3.4 Non-Systematic Sampling of Vertebrate Fauna

Further habitat assessment and targeted searching for fauna was conducted on foot, often in areas inaccessible by vehicle and not practical for trap installation. These sites were selected when observed traversing the study area. The aim was to locate, search and describe habitats that may support fauna of conservation significance, habitat-specific species and species not likely to be trapped.

A range of non-systematic techniques were used when conducting these additional searches, including:

- searching of microhabitats for reptile, frog, avifauna and mammals not commonly recorded through trapping;
- identification of road kills and other animal remains found during the survey;
- opportunistic sightings and records;
- recording and identification of secondary signs including tracks, scats and diggings;
- motion camera trapping;
- nocturnal searches;
- searches for evidence and secondary signs in suitable NES species habitat; and,
- audio recording for night birds and amphibian calls using the SongMeter II bat detector units configured to record audible frequencies.

The locations of each targeted search site and the effort applied across these sites is detailed in Table 4.9 and Figure 4.4, with each site further described in Table 4.10.

Table 4.9: Non-systematic sampling locations and effort applied during the fauna survey.

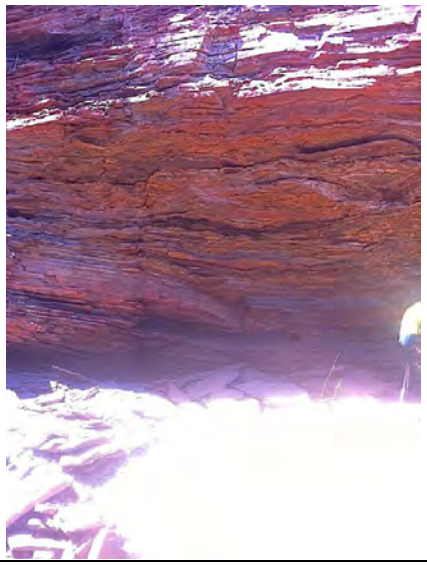
	Site	Site Type	Species Targeted	Latitude	Longitude	Nights Open	Search Time (mins)
Phase 1	YBLMC01	Motion camera	Mulgara (*Dasycercus* sp.)	22º45'49"S	119º18'27"E	6	-
	YBLSM2-02	SM2 site	Night Parrot (*Pezoporus occidentalis*)	22º43'33"S	119º21'59"E	3	-
	YBLSM2-05	SM2 site	Night Parrot (*Pezoporus occidentalis*)	22º43'10"S	119º20'20"E	2	-
	YBLNoct01	Nocturnal	All species	22º47'34"S	119º17'29"E	-	150
	YBLNoct02	Nocturnal	All species	22º47'37"S	119º18'16"E	-	195
	YBLNoct03	Nocturnal	All species	22º50'27"S	119º16'06"E	-	30
	YBLNoct04	Nocturnal	All species	22º45'10"S	119º20'41"E	-	195
	YBLNoct05	Nocturnal	All species	22º48'44"S	119º17'38"E	-	35
	YBLNoct06	Nocturnal	All species	22º48'17"S	119º17'42"E	-	64
	YBLTarget01	Targeted	Star Finch (*Neochmia ruficauda subclarescens*)	22º47'02"S	119º17'30"E	-	60
	YBLBird01	Targeted	Star Finch (*Neochmia ruficauda subclarescens*)	22º47'40"S	119º18'07"E	-	30
	YBLBird02	Avifauna search	All avifauna	22º46'50"S	119º18'45"E	-	20
	YBLBird03	Avifauna search	All avifauna	22º44'51"S	119º20'06"E	-	20
	YBLBird04	Avifauna search	All avifauna	22 º49'02"S	119º17'35"E	-	20

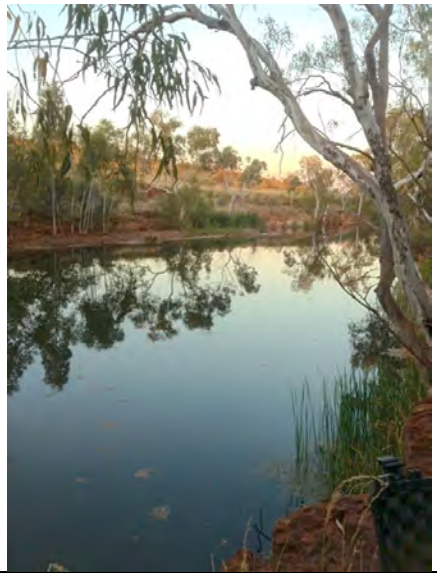
	Site	Site Type	Species Targeted	Latitude	Longitude	Nights Open	Search Time (mins)
Phase 2	YBLMC02	Motion camera	All species	22º49'50"S	119º16'10"E	3	-
	YBLMC03	Motion camera	Northern Quoll (*Dasyurus hallucatus*)	22º44'59"S	119º21'44"E	3	-
	YBLMC04	Motion camera	Mulgara (*Dasycercus* sp.)	22º46'01"S	119º18'16"E	3	-
	YBLMC05	Motion camera	Night Parrot (*Pezoporus occidentalis*)	22º43'34"S	119º20'20"E	2	-
	YBLSM212	SM2 site	Night Parrot (*Pezoporus occidentalis*), night birds and amphibians	22º47'01"S	119º17'24"E	2	-
	YBLSM213	SM2 site	Night Parrot (*Pezoporus occidentalis*), night birds and amphibians	22º47'41"S	119º18'08"E	2	-
	YBLSM214	SM2 site	Night Parrot (*Pezoporus occidentalis*), night birds and amphibians	22º43'55"S	119º21'46"E	3	-
	YBLSM215	SM2 site	Night Parrot (*Pezoporus occidentalis*), night birds and amphibians	22º43'34"S	119º20'20"E	3	-
	YBLNoct07	Nocturnal	All species	22º45'53"S	119º18'27"E	-	45
	YBLNoct08	Nocturnal	All species	22º46'57"S	119º17'10"E	-	120
	YBLTarget02	Targeted	Mulgara (*Dasycercus* sp.)	22º46'01"S	119º18'16"E	-	120
	YBLTarget03	Targeted	Ghost Bat (*Macroderma gigas*) and Northern Quoll (*Dasyurus hallucatus*)	22º47'56"S	119º16'49"E	-	40
	YBLTarget04	Targeted	Northern Quoll (*Dasyurus hallucatus*)	22º46'08"S	119º19'03"E	-	60
	YBLBird05	Avifauna Search	All avifauna	22º46'10"S	119º19'06"E	-	20

Total Effort Motion Camera (Days)	17
Total Effort SM2 Recording (Days)	15
Total Effort Nocturnal Search (Minutes)	834
Total Effort Targeted Searches (Minutes)	280
Total Effort Avifauna Search (Minutes)	110

Table 4.10: Description of non-systematic search sites in the Pocket and Billiard South study area.

Site Description	Landform Pattern	Landform Element	Site Photograph
YBLMC01 Scattered tall *Acacia inaequilatera* shrubs over *Petalostylus labicheoides* shrubland over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSM2-02 Low woodland of *Acacia pruinocarpa* over *Triodia* sp. hummock grassland and *Corchorus* sp. herbs.	Flats	Alluvial Plain (Flood Plain)	
YBLSM2-05 Riverbed with scattered tall *Eucalyptus victrix*.	Drainage	Major Drainage Line	
YBLTarget01 Mixed *Eucalyptus* sp. over *Typha* sp. and sedges.	Drainage	Major Drainage Line	

Site Description	Landform Pattern	Landform Element	Site Photograph
YBLMC02 Temporary waterway at a mine dewatering outflow site. Low open woodland of *Eucalyptus* sp. over *Typha* sp.	Drainage	Major Drainage Line	
YBLMC03 Breakaway in gully. Sparse *Eucalyptus* sp. low trees and mixed shrubs. Recent fire history (<1yr).	Hills and Slopes	Breakaway	
YBLMC05 Open forest in riverbed of *Eucalyptus camaldulensis* and *E. victrix*.	Drainage	Major Drainage Line	

Site Description	Landform Pattern	Landform Element	Site Photograph
YBLSM2-12 Open forest to low open woodland of *Eucalyptus victrix* and *E. camaldulensis* adjacent to ephemeral pool.	Drainage	Major Drainage Line	
YBLSM2-13 Woodland of *Eucalyptus* sp. over low open woodland of *Acacia aneura* over **Cenchrus ciliaris* and *Cypress* sp. grasses.	Drainage	Major Drainage Line	
YBLSM2-14 Low open forest of *Acacia inaequilatera, A. pruinocarpa* and sparse mixed *Eucalyptus* sp. over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSM2-15 Riverbed with scattered tall *Eucalyptus victrix*	Drainage	Major Drainage Line	

Site Description	Landform Pattern	Landform Element	Site Photograph
YBLMC04/ YBLTarget02 Scattered tall *Acacia inaequilatera* shrubs over *Petalostylus labicheoides* shrubland over *Triodia* sp. hummock grassland	Flats	Alluvial Plain (Flood Plain)	
YBLTarget03 Scattered *Acacia aneura* and *Eucalyptus* sp. over *Triodia* sp. hummock grassland.	Drainage	Gully	
YBLTarget04 Scattered *Eucalyptus* sp. over pool fringed *Typha* sp. and **Cenchrus ciliaris* grassland.	Hilltops and Slopes	Foot slope	
YBLBird01 Closed *Melaleuca* sp. and mixed *Eucalyptus* sp. woodland over *Typha* sp. reeds and sedges.	Drainage	Major Drainage Line	
YBLBird02 Mixed *Eucalyptus* sp. over *Typha* sp. and sedges.	Drainage	Major Drainage Line	

Site Description	Landform Pattern	Landform Element	Site Photograph
YBLBird03 Mixed *Eucalyptus* sp. over **Cenchrus ciliaris* grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLBird04 Open shrubland of Mulga (*Acacia aneura*) over mixed grasses and herbs.	Flats	Alluvial Plain (Flood Plain)	
YBLBird05 Scattered *Eucalyptus* sp. over pool fringed *Typha* sp. and **Cenchrus ciliaris* grassland.	Hilltops and Slopes	Foot slope	

* introduced species

4.3.5 Assessment of Likelihood of Occurrence in the Study Area

In order to determine which vertebrate species of conservation significance had the potential to occur in the study area, consideration was given to the results of the database and literature searches, as well as to the known habitat preferences, distributions and last known records for the species. For each vertebrate species of conservation significance considered as having potential to occur, a set of rankings and criteria was subsequently applied to assess the likelihood of its occurrence within the study area (Table 4.11). Through the remainder of this report, the term "close proximity" has been defined as being within 10 km of the study area, while the broader "locality" comprises the area up to 40 km from the study area.

Table 4.11: Ranking system used to assign the likelihood that a species would occur in the study area.

Rank	Criteria
Recorded	1. The species has been previously recorded in the study area.
Likely to occur	1. There are existing records of the species in close proximity to the study area (within 20 km); and • the species is strongly linked to a specific habitat, which is present in the study area; or • the species has more general habitat preferences, and suitable habitat is present.
May potentially occur	1. There are existing records of the species from the locality (within 40 km), however • the species is strongly linked to a specific habitat, of which only a small amount is present in the study area; or • the species has more general habitat preferences, but only some suitable habitat is present. 2. There is suitable habitat in the study area, but the species is recorded infrequently in the locality.
Unlikely to occur	1. The species is linked to a specific habitat, which is absent from the study area; or 2. Suitable habitat is present, however there are no existing records of the species from the locality despite reasonable previous search effort in suitable habitat; or 3. There is some suitable habitat in the study area, however the species is very infrequently recorded in the locality.
Would not occur	1. The species is strongly linked to a specific habitat, which is absent from the study area; and/or 2. The species' range is very restricted and does not include the study area.

4.4 Short Range Endemic Invertebrate Sampling

SRE fauna sampling of the study area involved both systematic (pit-trap transects) and non-systematic (targeted searching) sampling methods.

Invertebrate groups with potential to contain SREs were targeted, which included the following taxa:

- Mygalomorphae (trapdoor spiders);
- Diplopoda (millipedes);
- Scorpionidae (scorpions);
- Pulmonata (land snails); and
- Pseudoscorpiones (pseudoscorpions).

4.4.1 Targeted Searches

Mygalomorph spider burrows were located visually and were photographed prior to excavation. Holes were dug adjacent to each burrow, allowing the burrow to be followed down with forceps until the spider was located. Collected spiders were preserved in 70% ethanol, with one leg removed and placed in 100% ethanol for molecular studies.

Searches for millipedes, scorpions, land snails and pseudoscorpions were conducted by overturning rocks, foraging through leaf litter or, for scorpions, visually locating burrows.

4.4.2 Sampling Effort

Twenty-three sites were sampled across Phases 1 and 2 (Table 4.12). Searches for SREs were also performed on a previous survey of the study area which targeted the Northern Quoll (Biota 2014c). Habitats located just outside of the study area were searched during the Northern Quoll

survey to provide context to those sampled within the study area. Seven sites were sampled during this survey, and the results have been included here (Table 4.12).

Table 4.12: Short Range Endemic sampling locations during the Pocket and Billiard South fauna survey.

	Site	Latitude	Longitude	Date	Search Time (mins)	Number of People	Search Effort (min)
Phase 1	YBLSRE01	22º44'34"S	119º18'34"E	13/03/14	120	4	480
	YBLSRE02	22º49'27"S	119º16'46"E	14/03/14	80	2	160
	YBLSRE03	22º48'32"S	119º17'47"E	14/03/14	30	2	60
	YBLSRE04	22º50'40"S	119º16'18"E	15/03/14	45	2	90
	YBLSRE05	22º50'44"S	119º16'52"E	15/03/14	55	2	110
	YBLSRE06	22º46'24"S	119º20'38"E	16/03/14	60	2	120
	YBLSRE07	22º46'24"S	119º20'05"E	16/03/14	45	2	90
	YBLSRE08	22º50'59"S	119º16'38"E	16/03/14	60	4	240
	YBLSRE09	22º45'43"S	119º18'11"E	17/03/14	60	2	120
	YBLSRE10	22º46'32"S	119º19'56"E	17/03/14	40	2	80
	YBLSRE11	22º50'50"S	119º16'09"E	16/03/14	60	2	120
	YBLSRE12	22º50'04"S	119º15'56"E	17/03/14	60	3	180
	YBLSRE13	22º50'40"S	119º15'28"E	17/03/14	30	3	90
Phase 2	YBLSRE14	22º51'00"S	119º16'30"E	13/09/2014	60	2	120
	YBLSRE15	22º46'12"S	119º18'13"E	14/09/2014	60	2	120
	YBLSRE16	22º45'36"S	119º19'26"E	15/09/2014	60	2	120
	YBLSRE17	22º48'00"S	119º17'11"E	15/09/2014	25	1	25
	YBLSRE18	22º49'48"S	119º16'55"E	17/09/2014	15	2	30
	YBLSRE19	22º49'12"S	119º18'02"E	17/09/2014	80	2	160
	YBLSRE20	22º49'54"S	119º17'29"E	18/09/2014	40	2	80
	YBLSRE21	22º46'07"S	119º19'02"E	17/09/2014	30	1	30
	YBLSRE22	22º46'45"S	119º19'38"E	18/09/2014	15	2	30
	YBLSRE23	22º49'11"S	119º18'32"E	18/09/2014	25	2	50
Northern Quoll Survey	YBQSRE01	22º45'30"S	119º19'28"E	10/08/14	61	2	120
	YBQSRE02*	22º44'49"S	11918'54"E	10/08/14	61	2	120
	YBQSRE03	22º45'19"S	119º19'29"E	11/08/14	30	2	60
	YBQSRE04	22º43'41"S	119º19'59"E	11/08/14	60	2	120
	YBQSRE05*	22º43'53"S	119º18'54"E	11/08/14	100	2	200
	YBQSRE06*	22º44'41"S	119º18'37"E	12/08/14	41	2	80
	YBQSRE07	22º43'44"S	119º19'56"E	12/08/14	139	2	280
						Total Effort Phase 1	1,940
						Total Effort Phase 2	765
						Total Effort Targeted Northern Quoll Survey	980
						Total SRE Search Effort	3,685

* denotes contextual sites sampled outside of the study area

Sampling sites were spread across the range of landform elements present in the study area (Table 4.13) but searches were targeted towards microhabitats that are considered likely to support SRE fauna. Searches for SRE fauna totalled over 61 hours (3,685 minutes) across the total of 30 sites. The SRE sites sampled are detailed in Table 4.14 and the locations are illustrated in Figure 4.5.

Table 4.13: Number of SRE sampling sites in relation to landform elements present in the study area.

Landform Pattern	Landform Element	Number of sites
Flats	Alluvial Plain (Flood Plain)	13
	Clay Pan	1
Hills and Slopes	Foot Slope	4
	Transitional slope	1
	Upper slope	1
	Crest	1
Drainage	Major Drainage Line	1
	Minor Drainage Line	1

Table 4.14: Description of SRE search sites in the Pocket and Billiard South study area.

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE01 Low woodland of mixed *Acacia* and *Eucalyptus* sp. over *Acacia* shrubland over *Triodia* sp. hummock grassland.	Drainage	Minor Drainage Line	
YBLSRE02 Mixed tall *Eucalypt* sp. trees over mixed *Triodia* and *Cenchrus ciliaris* hummock grassland. Highly cattle damaged.	Drainage	Major Drainage Line	
YBLSRE03 Open shrubland of *Acacia aneura* over mixed grasses and herbs.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE04 Scattered tall *Acacia pruinocarpa* and *Hakea* sp. shrubs over low open shrubland over *Triodia* sp. open hummock grassland.	Flats	Alluvial Plain (Flood Plain)	

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE05 Low *Acacia aneura* woodland over mixed low open shrubland over *Triodia* sp. and **Cenchrus ciliaris* very open hummock grassland. Recent fire history (<1yr) and cattle grazing.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE06 Scattered mixed *Acacia* sp. shrubs over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE07 Scattered mixed *Acacia* sp. shrubs over *Triodia* sp. hummock grassland. Cattle grazing evident.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE08 Tall open shrubland of *Hakea* sp. and *Acacia* sp. over open *Senna glutinosa* shrubland over low open *Senna artemisioides* shrubland over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE09 Open shrubland of mixed *Acacia* sp. and *Eucalyptus* sp. over *Triodia* sp. hummock grassland.	Hills and Slopes	Transitional slope	
YBLSRE10 Low open Mulga woodland of *Acacia aneura* over *Triodia* sp. hummock grassland.	Hills and Slopes	Upper slope	
YBLSRE11 Scattered low *Corymbia hamersleyana* over mixed *Acacia* sp. open shrubland over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE12 Mulga (*Acacia aneura*) low woodland over open *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE13 Scattered low *Corymbia hamersleyana* trees over scattered tall *Acacia bivenosa* over open hummock *Triodia* sp.	Hills and Slopes	Foot Slope	
YBLSRE14 Low open mixed *Acacia* sp. shrubland over *Triodia* sp. hummock grassland.	Hills and Slopes	Foot Slope	
YBLSRE15 Mixed *Acacia* sp. shrubland over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE16 Open *Acacia aneura* forest over low *Acacia pruinocarpa* woodland over open *Triodia* and **Cenchrus ciliaris* grassland.	Flats	Clay Pan	
YBLSRE17 Scattered low mixed *Acacia* sp. trees over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE18 Low open forest of *Acacia pruinocarpa, A. aneura* and sparse *Eucalyptus* sp. over open heath of mixed *Senna* sp. over *Triodia* sp. and **Cenchrus ciliaris* grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE19 Low open Mulga (*Acacia aneura*) and *A. pruinocarpa* forest over open heath of *Senna* and *Ptilotus* spp. over *Triodia* sp. and **Cenchrus ciliaris* grassland.	Flats	Alluvial Plain (Flood Plain)	

Site	Landform Pattern	Landform Element	Site Photograph
YBLSRE20 Low open *Acacia aneura* and *A. pruinocarpa* forest over *Senna* sp. and mixed *Acacia* sp. open heath over *Triodia* sp. hummock grassland.	Flats	Alluvial Plain (Flood Plain)	
YBLSRE21 Open *Eucalyptus victrix* woodland over **Cenchrus ciliaris* and *Aristida* grassland.	Hills and Slopes	Foot Slope	
YBLSRE22 Open *Triodia* hummock grassland. Recently burnt (<1yr).	Hills and Slopes	Crest	
YBLSRE23 Scattered low *Corymbia hamerslyana* over mixed open *Acacia sp.* shrubland over scattered low *Ptilotus* sp. shrubland over open *Triodia* sp. hummock grassland.	Hills and Slopes	Foot Slope	

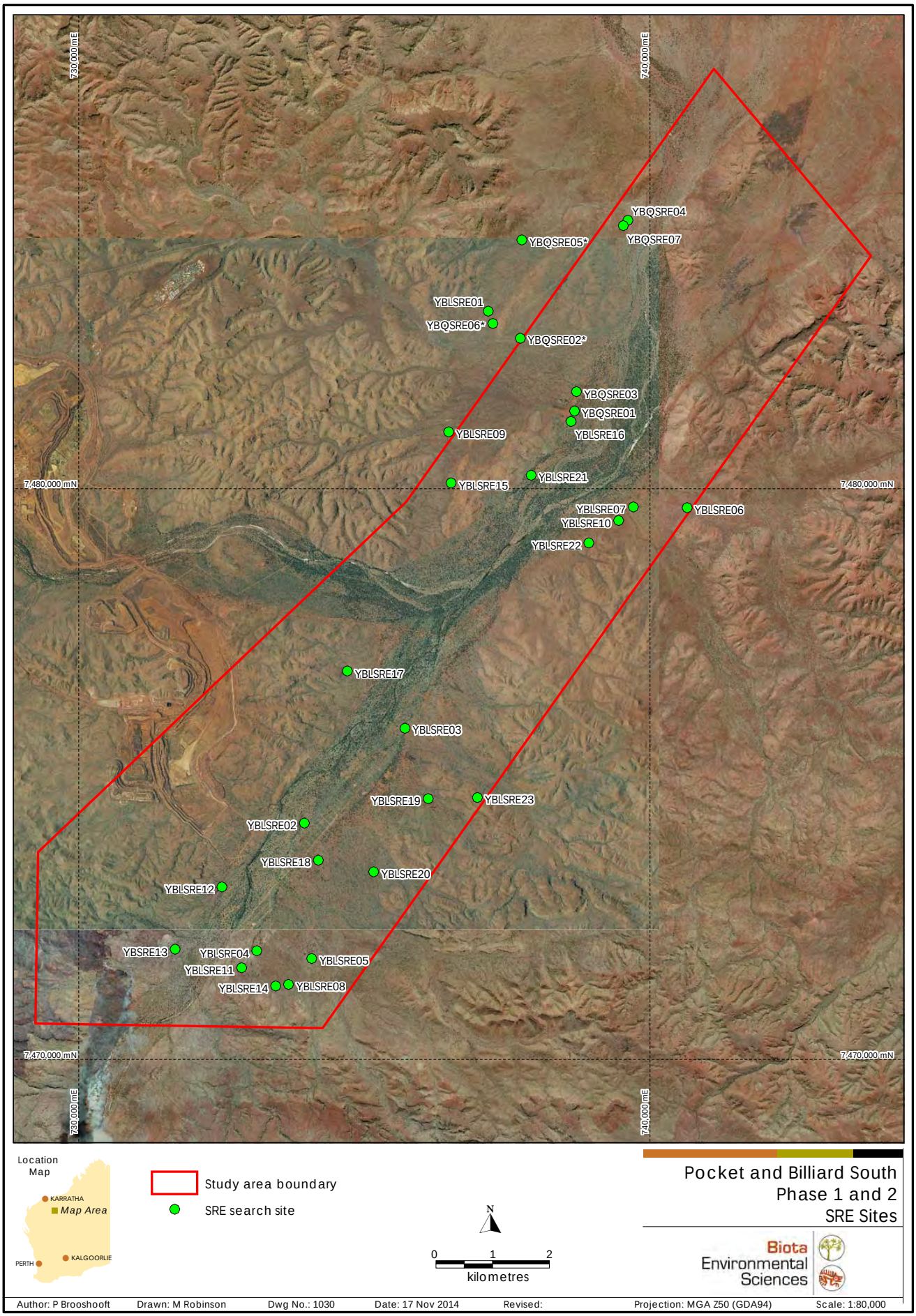


Figure 4.5: SRE survey site locations in the Pocket and Billiard South study area.

4.4.3 Genetic Analysis

For mygalomorph spiders, species identification on the basis of morphology is not possible in the case of many juvenile and female specimens, as male reproductive parts are typically necessary for taxonomic allocation. In addition, in many cases individuals may be morphologically identical, but represent distinct reproductively isolated species (cryptic species).

To overcome these issues, Biota, the WA Museum and Helix Molecular Solutions (Helix) jointly developed a DNA barcoding approach to delimit species and identify collected specimens (Helix 2012). The aim of this is not to describe species as formal taxonomic entities, but rather, to generate a preliminary taxonomy, consisting of a series of genetically distinct operational units, defined here as species. Extensive molecular work has been conducted on mygalomorph fauna in Western Australia, providing a contextual baseline for the region. This dataset has subsequently provided a molecular framework, from which the potential SRE status of specimens may be evaluated.

The SRE status of species is based on their geographic distributions, which are described by two summary statistics. The first is the 'Maximum Spanning Distance' (MSD), which is the maximum linear distance between two records. The second statistic is the 'Minimum Spanning Area' (MSA), which is the area of the smallest polygon that can be drawn around all of the records. The minimum spanning area can be used as a means for objectively establishing SRE status by comparison against the 10,000 km^2 criterion established by Harvey (2002).

During this survey, 19 specimens (11 from Phase 1, eight from Phase 2) were collected from the study area and were submitted to Helix for molecular analysis. The specific methods used in this molecular analysis are presented in Appendix 6.

4.4.4 Determining SRE Status

Potential SRE specimens were collected in accordance with the SRE criteria outlined in the EPA Guidance Statement 20 (EPA 2009). Table 4.15 details the criteria used to determine the SRE status of putative species.

Table 4.15: Categories of SRE status and defining criteria.

SRE Status	Defining Criteria
Known SRE	• Species, morphotype or genetic type has a documented range of <10,000km^2. • Species, morphotype or genetic type is well collected, with numerous specimens typed and habitat preferences understood.
Potential SRE	• Species, morphotype or genetic type has a documented range of <10,000km^2 but is poorly sampled. • Specimen may not be formally described or assigned to a morphotype / genetic type. • Short-range endemism may be common in genus or family. • May have been collected from restricted, refugial or isolated habitats.
Unlikely to be an SRE	• Species, morphotype or genetic type has a documented range of <10,000km^2 but is poorly sampled. • Specimen may not be formally described or assigned to a morphotype / genetic type. • Short-range endemism is not common in the genus or family. • Specimen was not collected from restricted, refugial or isolated habitats. • Few other individuals of the taxon collected, but records separated by long distances (>100 km).
Not an SRE	• Specimen formally described or assigned to a morphotype / genetic type. • Species, morphotype or genetic type has a documented range of >10,000 km^2.
Undetermined	• Taxa where there is insufficient taxonomic framework available to provide any informed comment on the species-level distribution of the fauna or, therefore, the risk of small-scale spatial restrictions.

4.5 Fauna Survey Team

The fauna survey was conducted under "Licence to Take Fauna for Scientific Purposes" Permit No. SF009991 issued to Dr Stewart Ford (Appendix 7). The survey team for both phases comprised Dr Stewart Ford, Mr Jason Alexander, Mr Andrew Sheppard, Mr Chris Cole, Mr Garth Humphreys and Ms Penny Brooshooft (all of Biota).

Analysis of bat call recordings was completed by Mr Bob Bullen (Bat Call WA). Analysis of audio recordings was completed by Dr Stewart Ford (of Biota). Geographical Information System (GIS) analyses and maps presented in this report were prepared by Mrs Melissa Robinson, Mr Paul Sawers and Ms Kylie Webster.

4.6 Survey Limitations

The following limitations should be recognised with regard to this report:

- Not all sections of the study area were ground-truthed or equally sampled for fauna as this survey targeted areas that were under-represented by fauna sampling during previous surveys of the study area. Parts of the study area were inaccessible by vehicle, and installation and regular checking of fauna traps in these areas would not have been possible. However, habitats potentially supporting different faunal assemblages to those that were systematically sampled were sampled opportunistically on foot, where possible.
- there is only a limited taxonomic framework and ecological knowledge for the majority of potential SRE invertebrates (EPA 2009);
- sampling difficulties exist for potential SRE taxa. For example, mygalomorph spiders are difficult to locate, and accurate morphological identification requires adult male specimens or genetic identification. In addition, weather conditions can affect capture ability; male mygalomorphs are more likely to be captured in pitfall traps following rainfall events, and no rainfall was recorded during both phases of survey; and,
- while the most recent phylogenetic data are presented in this report, molecular work is ongoing and will make use of specimens collected during future surveys in the Pilbara. As additional data are incorporated into the DNA barcoding framework, species' distributions and SRE status may be revised.

5.0 Vertebrate Fauna Results

5.1 Overview

A combined total of 182 species of vertebrate fauna from 65 families (42 avifauna, six mammals, three bat, 12 reptiles and two amphibian) were recorded across both phases of the Pocket and Billiard South survey. Table 5.1 provides a summary of the number of species recorded from each major vertebrate group during each phase of survey.

Table 5.1: Overview of vertebrate fauna recorded from the Pocket and Billiard South study area.

Fauna Group	Number of Species			Overall
	Phase 1	Phase 2	Targeted Northern Quoll Survey	
Native Non-Volant Mammals	12	13	-	14
Introduced Non-Volant Mammals	2	2	-	3
Volant Mammals (Bats)	7	8	10	10
Avifauna	78	74	-	93
Reptiles	54	35	-	59
Amphibians	3	2	-	3
Totals	156	134	10	182

The species composition of the reptile assemblage differed between the two surveys; 19 more reptile species were recorded in Phase 1 than Phase 2. This is often the case with wet season and dry season surveys, and may reflect good conditions during the first phase following significant rainfall in January 2014.

The species composition of other fauna groups did not differ markedly between the two survey phases, although there was a marked decrease in the number of individuals recorded during survey Phase 2, particularly in the reptile assemblage.

The Phase 2 survey added 15 avifauna species, four non-volant mammal species and five reptile species to the inventory. The bat sampling conducted during the targeted Northern Quoll survey (Biota 2014c), recorded one additional species to those recorded during Phase 1 and 2.

5.2 Mammals

5.2.1 The Assemblage – Non-Volant Mammals

Eighteen non-volant mammal species, of which three were non-native, were recorded in the Pocket and Billiard South study area (Table 5.2). Of the six families recorded, the Dasyuridae (carnivorous marsupials) and Muridae (rodents) were the most speciose, each represented by six species. The non-native mammal species were the Camel (*Camelus dromedarius*), Horse (*Equus caballus*) and House Mouse (*Mus musculus*). Non-volant mammals accounted for 9.8% of the species records from the survey.

The most frequently recorded non-volant mammal was the House Mouse; 32 individuals were recorded, accounting for 26% of the total non-volant mammals recorded during the survey. The next most frequently recorded species was the Common Rock-rat with 15 records, accounting for 12.2% of the total mammal records.

5.2.2 The Assemblage – Volant Mammals

Ten bat species were recorded during the fauna survey (Table 5.3). These represented species from three families including two species of sheathtail bat (Emballonuridae), three species of freetail bat (Molossidae) and five species of evening bat (Vespertilionidae). The Northern Freetail-bat (*Chaerephon jobensis*), Gould's Wattled Bat (*Chalinolobus gouldii*) and the Little Broad-nosed

Bat (*Scotorepens greyii*) were the most commonly recorded species, with echolocation records documented at every bat sampling site.

The evening bats (Vespertilionidae) were the most speciose bat family, with five species recorded. Bats represented 5.5% of all vertebrate species recorded within the study area.

5.2.3 Mammals of Conservation Significance

Two mammal species of conservation significance were recorded from the Pocket and Billiard South study area. These were the Mulgara (*Dasycercus* sp.) and the Western Pebble-mound Mouse (*Pseudomys chapmani*). The Mulgara was detected from burrows found, however the species (*Dasycercus blythi* or *D. cristicauda*) that the burrows belonged to is uncertain as no individuals were recorded. However, recent taxonomic and phylogeographic revisions of these species would suggest that *D. blythi* (listed as Priority 4 by the Department of Parks and Wildlife) is the most likely species to occur in the study area. The Western Pebble-mound Mouse is listed as Priority 4 by the Department of Parks and Wildlife. Further details of these records are provided in Section 6.1.

One noteworthy bat species, the Chocolate Wattled Bat (*Chalinolobus morio*), was recorded during Phase 1 at site YBLSM2-03 and during the targeted Northern Quoll survey at sites YBQSM2-03 and YBQSM2-05. This species is not listed as conservation significant as it is common in southwest Australia (Churchill 2008), however an isolated population of this species occurs in the Pilbara in a small area surrounding Weeli Wolli Creek and Marillana Creek (Biota Internal database). Given its geographic separation from the main population in the southwest of WA, the Pilbara population may be genetically distinct. If it is genetically distinct, the Pilbara population may warrant protection as a result of its restricted distribution and apparent habitat specificity.

Table 5.2: Non-Volant mammals recorded during the Pocket and Billiard South fauna survey.

			YBL002P		YBL003P		YBL005P	YBL006P		YBL007P		YBL008F		YBL009E		YBL010E		YBLMC01	YBLMC02	YBLMC03	YBLMC04	YBLTarget03	YBLOPP		Total		
Species Name	Common Name	Consv. Status	P1	P2	P1	P2	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P2	P2	P2	P1	P2	P1	P2	N
Dasyuridae																											
Dasycercus sp.*	Mulgara sp.	P4/S1																T			T				T	T	T
Dasykaluta rosamondae	Little Red Kaluta						1			1			1												2	1	3
Ningaui timealeyi	Pilbara Ningaui		2		2	1		1		1	4														6	5	11
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart		1	6		1			1		1														1	9	10
Sminthopsis macroura	Stripe-faced Dunnart				1		2																		3	0	3
Macropodidae																											
Macropus robustus	Euro																						1	2	1	2	3
Macropus rufus	Red Kangaroo																			5			3	1	3	6	9
Petrogale rothschildi	Rothschild's Rock-wallaby																			1					0	1	1
Muridae																											
Mus musculus	House Mouse		1		1		2			1	2				4				21						5	27	32
Notomys alexis	Spinifex Hopping-mouse																				1				0	1	1
Pseudomys chapmani	Western Pebble-mound Mouse	P4																					11	7	11	7	18
Pseudomys desertor	Desert Mouse								1	1															1	1	2
Pseudomys hermannsburgensis	Sandy Inland Mouse			1	3	3	1	1	1	1	1														6	6	12
Zyzomys argurus	Common Rock-rat															2	13								2	13	15
Canidae																											
Canis lupus dingo	Dingo																						3	3	3	3	6
Equidae																											
Equus caballus	Horse																					1			0	1	1
Camelidae																											
Camelus dromedarius	Camel																						1		1	0	1
	Total number of records		4	7	7	5	6	2	3	5	8	0	1	0	4	2	13	T	21	6	1 + T	1	19	13	45 + T	83 + T	128 + T
	Number of species		3	2	4	3	4	2	3	5	4	0	1	0	1	1	1	1	1	2	2	1	5	4	13 + T	14 + T	16 + T
	Total number of species		4		5		4	4		6		1		1		1		1	1	2	2	1	5		17 (14 native)		

P4 = Priority 4, S1 = Schedule 1, T = Fauna trace e.g. burrow, scat, track, * species unknown

Table 5.3: Bats recorded during the Pocket and Billiard South fauna survey.

		YBLSM2-03	YBLSM2-04	YBLSM2-06	YBLSM2-07	YBLbat85-10	YBLbat85-13	YBLbat88-10	YBLSM2AU84-2	YBQSM2-01-93	YBQSM2-02-85	YBQSM2-03-84	YBQSM2-04-85	YBQSM2-05-93	YBQSM2-06-84	Number Sites Recorded
Family/ Species Name	Common Name	P1	P1	P1	P1	P2	P2	P2	P2	Targeted Northern Quoll Survey						
Emballonuridae																
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat					•	•			•	•	•	•	•	•	8
Taphozous georgianus	Common Sheathtail-bat					•	•	•		•	•	•	•	•		8
Vespertilionidae																
Chalinolobus gouldii	Gould's Wattled Bat	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
Chalinolobus morio	Chocolate Wattled Bat	•										•		•		3
Nyctophilus geoffroyi	Lesser Long-eared Bat	•				•	•		•	•	•	•	•			8
Scotorepens greyii	Little Broad-nosed Bat	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
Vespadelus finlaysoni	Finlayson's Cave Bat	•	•	•		•	•	•	•	•	•	•	•	•	•	13
Molossidae																
Chaerephon jobensis	Northern Freetail-bat	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
Mormopterus beccarii	Beccari's Freetail-bat	•		•	•	•	•		•	•	•		•		•	10
Tadarida australis	White-striped Freetail-bat										•	•				2
	Total Number of Species	7	4	5	4	8	8	5	6	8	9	9	8	7	6	10

• = echolocation recording

5.3 Avifauna

5.3.1 The Assemblage

Ninety-three species of avifauna were recorded from the study area, comprising 46 non-passerine and 47 passerine species from 42 families (Table 5.4). Avifauna represented approximately 50.8% of all vertebrate species recorded within the study area.

The Zebra Finch (*Taeniopygia guttata*) was the most abundant species recorded in the study area with 85 records, representing 8.2% of the individuals recorded. The Weebill (*Smicrornis brevirostris*) was the next most commonly recorded species with 78 records, representing 7.5% of total avifauna records. The most speciose family was the Meliphagidae (Honeyeaters and Chats), with 11 records.

5.3.2 Avifauna of Conservation Significance

Five avifauna species of conservation significance were recorded during the survey. These were the Star Finch (*Neochmia ruficauda subclarescens*) and Australian Bustard (*Ardeotis australis*), listed as Priority 4 by the Department of Parks and Wildlife, and the Fork-tailed Swift (*Apus pacificus*), Eastern Great Egret (*Ardea modesta*) and Rainbow Bee-eater (*Merops ornatus*) which are listed as Schedule 3 under the State *Wildlife Conservation Act 1950-1979* and Migratory under the Federal *EPBC Act 1999.*

Further information on these species and other conservation significant avifauna species potentially occurring in the study area can be found in Section 6.1 and 6.2.

Table 5.4: Avifauna species recorded during the Pocket and Billiard South fauna survey.

			YBL001F		YBL002P		YBL003P		YBL004P	YBL005P	YBL006P		YBL007P		YBL008F		YBL009E		YBL010E		YBL011F		YBLMC03	YBLNoct08	YBLBird01	YBLBird02	YBLBird03	YBLBird04	YBLBird05	YBLOpp		Total		
Family/ Species Name	Common Name	Consv. Status	P1	P2	P1	P2	P1	P2	P1	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P2	P2	P1	P1	P1	P1	P2	P1	P2	P1	P2	N
Casuariidae																																		
Dromaius novaehollandiae	Emu																														2	0	2	2
Phasianidae																																		
Coturnix ypsilophora	Brown Quail																													4		4	0	4
Anatidae																																		
Anas superciliosa	Pacific Black Duck																1	1													1	1	2	3
Columbidae																																		
Phaps chalcoptera	Common Bronzewing																													1		1	0	1
Ocyphaps lophotes	Crested Pigeon		2	5	1	1						1				1				1												3	9	12
Geophaps plumifera	Spinifex Pigeon															1	1	1				1										1	3	4
Geopelia cuneata	Diamond Dove		3	3	8	4	1	2			1	1	3		1		3	1		1	3	1	1		3	1		10				37	14	51
Geopelia striata	Peaceful Dove			1	1	1							1				2	1		1		1										4	5	9
Eurostopodidae																																		
Eurostopodus argus	Spotted Nightjar																													4		4	0	4
Aegothelidae																																		
Aegotheles cristatus	Australian Owlet-nightjar																													2	1	2	1	3
Apodidae																																		
Apus pacificus	Fork-tailed Swift	S3/M																												9		9	0	9
Anhingidae																																		
Anhinga novaehollandiae	Australasian Darter																	3								1				5		6	3	9
Ardeidae																																		
Ardea pacifica	White-necked Heron																														2	0	2	2
Ardea modesta	Eastern Great Egret	S3/M																													1	0	1	1
Threskiornithidae																																		
Threskiornis spinicollis	Straw-necked Ibis														2																2	0	2
Accipitridae																																		
Elanus axillaris	Black-shouldered Kite																														1	0	1	1
Hamirostra melanosternon	Black-breasted Buzzard																													1	1	1	1	2
Haliastur sphenurus	Whistling Kite		1			1																								1	2	2	3	5
Milvus migrans	Black Kite			1													1														1	1	2	3
Accipiter fasciatus	Brown Goshawk																													3		3	0	3
Accipiter cirrocephalus	Collared Sparrowhawk																													1	1	1	1	2
Circus assimilis	Spotted Harrier					1								1		1				1										1		1	4	5
Hieraaetus morphnoides	Little Eagle									1																					1	1	1	2
Falconidae																																		
Falco cenchroides	Nankeen Kestrel																													1		1	0	1
Falco berigora	Brown Falcon				1																									1	1	2	1	3
Falco longipennis	Australian Hobby		1																													1	0	1
Rallidae																																		
Porphyrio porphyrio	Purple Swamphen																														1	0	1	1
Porzana tabuensis	Spotless Crake																	1											1		1	0	3	3
Otididae																																		
Ardeotis australis	Australian Bustard	P4						1		1	2	2				1												1		4	4	6	8	14
Charadriidae																																		
Elseyornis melanops	Black-fronted Dotterel																1	1												3	1	4	2	6
Erythrogonys cinctus	Red-kneed Dotterel																							2								0	2	2
Turnicidae																																		
Turnix velox	Little Button-quail									1																				2	1	3	1	4
Cacatuidae																																		
Eolophus roseicapillus	Galah		4		2																1									2		8	1	9

			YBL001F		YBL002P		YBL003P		YBL004P	YBL005P	YBL006P		YBL007P		YBL008F		YBL009E		YBL010E		YBL011F		YBLMC03	YBLNoct08	YBLBird01	YBLBird02	YBLBird03	YBLBird04	YBLBird05	YBLOpp		Total		
Family/ Species Name	Common Name	Consv. Status	P1	P2	P1	P2	P1	P2	P1	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P2	P2	P1	P1	P1	P1	P2	P1	P2	P1	P2	N
Cacatua sanguinea	Little Corella		2			1									10			1		1					6					2		20	3	23
Nymphicus hollandicus	Cockatiel				2	1	5	1			11		2			1	2								1							23	3	26
Psittacidae																																		
Barnardius zonarius	Australian Ringneck															1			1								1			4		6	1	7
Psephotus varius	Mulga Parrot																					1										0	1	1
Melopsittacus undulatus	Budgerigar		4	3	13	2						1	3		1		2				1											24	6	30
Cuculidae																																		
Chalcites basalis	Horsfield's Bronze-Cuckoo						1			1	1			1																	3	1	4
Strigidae																																		
Ninox connivens	Barking Owl																													2		2	0	2
Ninox novaeseelandiae	Southern Boobook																							1						4		4	1	5
Ninox novaeseelandiae	Southern Boobook																													4		4	0	4
Tytonidae																																		
Tyto javanica	Eastern Barn Owl																														1	0	1	1
Halcyonidae																																		
Dacelo leachii	Blue-winged Kookaburra														1											2				2	3	2	5
Todiramphus sanctus	Sacred Kingfisher																	1								1					1	1	2
Meropidae																																		
Merops ornatus	Rainbow Bee-eater	S3/M			2	4					1				1		1	5	3						13	15	1		2	7	4	44	15	59
Ptilonorhychidae																																		
Ptilonorhynchus guttatus	Western Bowerbird																														1	0	1	1
Maluridae																																		
Malurus leucopterus	White-winged Fairy-wren		2	3		1	3	1			3	1	6	1		2				1												14	10	24
Malurus lamberti	Variegated Fairy-wren				6	3	3	2		10	2	2	6			2		1			1	1						4				32	11	43
Acanthizidae																																		
Smicrornis brevirostris	Weebill		8	3		2				4	3	2	8	3	7	3	9	4	13	3	2					2		2				58	20	78
Gerygone fusca	Western Gerygone																1	1			5	3					1	1				8	4	12
Acanthiza uropygialis	Chestnut-rumped Thornbill																											1				1	0	1
Acanthiza apicalis	Inland Thornbill												1																			1	0	1
Pardalotidae																																		
Pardalotus rubricatus	Red-browed Pardalote				1	3		2		1					3		3										2					10	5	15
Pardalotus striatus	Striated Pardalote									1				1	1			2	2	1												4	4	8
Meliphagidae																																		
Lichenostomus virescens	Singing Honeyeater			1		5		1				4		3		1				2		3										0	20	20
Lichenostomus virescens	Singing Honeyeater		2		4		6			6	4		1		1				2		2							1				29	0	29
Lichenostomus keartlandi	Grey-headed Honeyeater											1	2	1	2						1											5	2	7
Lichenostomus penicillatus	White-plumed Honeyeater																9	5							3	5	2		1			19	6	25
Purnella albifrons	White-fronted Honeyeater													1																		0	1	1
Manorina flavigula	Yellow-throated Miner			1						2									2	1	3											7	2	9
Acanthagenys rufogularis	Spiny-cheeked Honeyeater																3			1	2	2							1			6	3	9
Conopophila whitei	Grey Honeyeater																				1								1			2	0	2
Epthianura tricolor	Crimson Chat																													2		2	0	2
Lichmera indistincta	Brown Honeyeater		2		3	1		1		1		1	2	4		3	5	3	1	1	3				2	2	2					23	14	37
Melithreptus gularis	Black-chinned Honeyeater									2							3	1														5	1	6
Pomatostomidae																																		
Pomatostomus temporalis	Grey-crowned Babbler		1		1	1						1	1		1		2	1														6	3	9
Campephagidae																																		
Coracina novaehollandiae	Black-faced Cuckoo-shrike		1	2		1	1	1							1	1	1	2			3											7	7	14
Lalage sueurii	White-winged Triller						1			3																				1		5	0	5
Pachycephalidae																																		
Pachycephala rufiventris	Rufous Whistler				1	4						2			1		2	2			4	5				1	3		1			12	14	26
Colluricincla harmonica	Grey Shrike-thrush		1			1												1	1								1					3	2	5

Family/ Species Name	Common Name	Consv. Status	YBL001F		YBL002P		YBL003P		YBL004P	YBL005P	YBL006P		YBL007P		YBL008F		YBL009E		YBL010E		YBL011F		YBLMC03	YBLNoct08	YBLBird01	YBLBird02	YBLBird03	YBLBird04	YBLBird05	YBLOpp		Total		
			P1	P2	P1	P2	P1	P2	P1	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P2	P2	P1	P1	P1	P1	P2	P1	P2	P1	P2	N
Oreoica gutturalis	Crested Bellbird		1								2											1										3	1	4
Artamidae																																		
Artamus personatus	Masked Woodswallow						19																									19	0	19
Artamus cinereus	Black-faced Woodswallow											1		2							1	1								1		2	4	6
Artamus minor	Little Woodswallow													1		1															1	0	3	3
Cracticus torquatus	Grey Butcherbird																														1	0	1	1
Cracticus nigrogularis	Pied Butcherbird			1	1	2													1	1												2	4	6
Cracticus tibicen	Australian Magpie			1												1			2	1										3		5	3	8
Rhipiduridae																																		
Rhipidura leucophrys	Willie Wagtail		2				1	1				3		1	1		3	2		1	1	2			1				1			9	11	20
Corvidae																																		
Corvus orru	Torresian Crow		1				1				2		1	1				1	2	2					2							9	4	13
Monarchidae																																		
Grallina cyanoleuca	Magpie-lark														1		1	2					7									2	9	11
Petroicidae																																		
Petroica goodenovii	Red-capped Robin																				3	3						1				4	3	7
Melanodryas cucullata	Hooded Robin		2																			1						1				3	1	4
Alaudidae																																		
Mirafra javanica	Horsfield's Bushlark																													2		2	0	2
Acrocephalidae																																		
Acrocephalus australis	Australian Reed-Warbler																	3							1	2			1	1		4	4	8
Megaluridae																																		
Cincloramphus mathewsi	Rufous Songlark		3								4	1			2	1												1				10	2	12
Eremiornis carteri	Spinifexbird											1							5	2	1											6	3	9
Hirundinidae																																		
Cheramoeca leucosterna	White-backed Swallow																												1			0	1	1
Petrochelidon nigricans	Tree Martin																													1		1	0	1
Nectariniidae																																		
Dicaeum hirundinaceum	Mistletoebird			2		3							1				1	3				2							1			2	11	13
Estrildidae																																		
Taeniopygia guttata	Zebra Finch		13	3	2	5	6	1		9	4	5	2	3		2	2	4	1		13	4	1			2	2		1			56	29	85
Neochmia ruficauda	Star Finch	P4																							3					6	11	9	11	20
Emblema pictum	Painted Finch		3		1	4	2				13	3	5	4	3	5	7	3	1	2	1								1			36	22	58
Total number of records			59	30	50	52	50	14	0	43	53	33	45	28	40	28	66	57	37	24	51	33	9	3	35	34	15	25	11	87	34	686	365	1043
Number of species			21	14	17	23	13	11	0	14	14	18	16	15	18	17	24	28	14	18	19	17	3	2	9	11	9	12	10	31	24	78	74	93
Total number of species			27		26		16		0	14	24		24		31		33		23		27		3	2	9	11	9	12	10	45		93		

S3 = Schedule 3, M = Migratory, P4 = Priority 4

5.4 Reptiles

5.4.1 The Assemblage

Fifty-nine reptile species from 12 families were recorded during the survey (Table 5.5). The assemblage included nine species of gecko (Carphodactylidae, Diplodactylidae and Gekkonidae), four species of flap-footed lizards (Pygopodidae), six species of dragon (Agamidae), 19 species of skink (Egerniidae, Eugongylidae and Sphenomorphidae), nine species of monitor lizards (Varanidae), two species of blind snake (Typhlopidae), three species of python (Boidae) and seven species of front-fanged snake (Elapidae). Reptiles represented approximately 32.2% of all recorded vertebrate species in the study area.

The fat-tailed gecko (*Diplodactylus conspicillatus*) was the most commonly recorded species with 90 records, accounting for 14.6% of the total reptile records. The next most commonly recorded species was *Ctenotus duricola* with 75 records, accounting for 12.2% of the total reptile records. The Sphenomorphidae family was the most speciose with 11 species recorded.

5.4.2 Reptiles of Conservation Significance

One reptile species of conservation significance was recorded from the study area. This was the Pilbara Olive Python (*Liasis olivaceus barroni*), which is listed as a Schedule 1 species under the State *Wildlife Conservation Act 1950-1979* and Vulnerable under the Federal *EPBC Act 1999.*

Further details of this species and other reptile species of conservation significance potentially occurring in the study area are provided in Section 6.1 and 6.2.

Table 5.5: Reptile species recorded during the Pocket and Billiard South fauna survey.

			YBL001F		YBL002P		YBL003P		YBL004F	YBL005P		YBL006P		YBL007P		YBF008F		YBL009E		YBL010E	YBL011F		YBLMC03	YBLTarget04	YBLNoct07	YBLOpp		Total		
Family/ Species Name	Common Name	Consv. Status	P1	P2	P1	P2	P1	P2	P1	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P1	P2	P2	P2	P2	P1	P2	P1	P2	N
Carphodactylidae																													
Nephrurus wheeleri			1																								1	0	1
Diplodactylidae																													
Diplodactylus conspicillatus	Fat-tailed Gecko		3	3	30	1	7			4	25	2	2							12	1						83	7	90
Lucasium stenodactylum					3		1			5	3	1	1							1							14	1	15
Rhynchoedura ornata	Western Beaked Gecko				3					1											5						4	5	9
Strophurus wellingtonae					1	2						1		1		1									2		3	5	8
Strophurus jeanae					4		1				1														1		7	0	7
Gekkonidae																													
Gehyra punctata													1												2	2	3	2	5
Gehyra variegata								1		2			2							1				1	3		8	2	10
Heteronotia binoei	Bynoe's Gecko		5		2		3		2	1	1		2		6					6					1		29	0	29
Pygopodidae																													
Delma pax						1					2																2	1	3
Lialis burtonis									1	1					1	4									1		4	4	8
Delma butleri							1																				1	0	1
Delma tincta													1		1												2	0	2
Agamidae																													
Amphibolurus longirostris											1							1							4	1	5	2	7
Ctenophorus caudicinctus	Ring-tailed Dragon								1	2			4		1						1				2	1	10	2	12
Ctenophorus isolepis	Military Dragon				3	1	12			10	11	2	2	1						2	2				2		42	6	48
Ctenophorus nuchalis	Central Netted Dragon		1		1			1																		1	2	2	4
Ctenophorus reticulatus	Western Netted Dragon		1																							1	1	1	2
Pogona minor				1						2																1	2	2	4
Egerniidae																													
Cyclodomorphus melanops	Slender Blue-tongue															3											0	3	3
Egernia formosa																	3								1		4	0	4
Tiliqua multifasciata	Central Blue-tongue																								1		1	0	1
Eugongylidae																													
Carlia munda							1		2				2		1	2				2	2						8	4	12
Carlia triacantha								1																			0	1	1
Cryptoblepharus ustulatus																									4	2	4	2	6
Morethia ruficauda																									1	1	1	1	2
Menetia greyii													1														1	0	1
Sphenomorphidae																													
Ctenotus duricola				3	10		8		2	1	18		30	1						1	1						70	5	75
Ctenotus grandis					2		11	1		4	4		3		1					3					7		35	1	36
Ctenotus pantherinus	Leopard Ctenotus		6		1	1			1	5	1		3		2					7	6						26	7	33
Ctenotus saxatilis	Rock Ctenotus		5		5		1	1	4	1	4		7	2	9	1				18	4						54	8	62
Ctenotus serventyi					3		6	1					1														10	1	11
Lerista labialis					4	3	5	1		1		1	2	2													12	7	19
Lerista muelleri						1																					0	1	1
Ctenotus ariadnae					1		9			5															3		18	0	18
Ctenotus helenae													1														1	0	1
Ctenotus schomburgkii							1																				1	0	1
Lerista bipes											1																1	0	1
Varanidae																													
Varanus acanthurus	Spiny-tailed Monitor													1		3											0	4	4
Varanus brevicauda	Short-tailed Pygmy Monitor		3	2	2		1			2	3				1												12	2	14
Varanus bushi	Pilbara Mulga Monitor				1																				1	1	2	1	3

			YBL001F		YBL002P		YBL003P		YBL004F	YBL005P		YBL006P		YBL007P		YBF008F		YBL009E		YBL010E	YBL011F		YBLMC03	YBLTarget04	YBLNoct07	YBLOpp		Total		
Family/ Species Name	Common Name	Consv. Status	P1	P2	P1	P2	P1	P2	P1	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P1	P2	P2	P2	P2	P1	P2	P1	P2	N
Varanus eremius	Pygmy Desert Monitor			2	1		2			1	2															1		7	2	9
Varanus panoptes	Yellow-spotted Monitor																						1					0	1	1
Varanus tristis	Racehorse Monitor																1	1										1	1	2
Varanus giganteus	Perentie																									1		1	0	1
Varanus gouldii	Bungarra or Sand Monitor																				1					2		3	0	3
Varanus pilbarensis	Pilbara Rock Monitor																									1		1	0	1
Typhlopidae																														
Anilios ammodytes					1																							1	0	1
Anilios grypus														5														5	0	5
Boidae																														
Antaresia perthensis	Pygmy Python													1											1			1	1	2
Antaresia stimsoni	Stimson's Python																									1		1	0	1
Liasis olivaceus barroni	Pilbara Olive Python	S1/VU																								1		1	0	1
Elapidae																														
Demansia psammophis	Yellow-faced Whipsnake					1															1							1	1	2
Pseudechis australis	Mulga Snake																				2				1	1		3	1	4
Acanthophis wellsi	Pilbara Death Adder													1														1	0	1
Brachyurophis approximans					2						1															1		4	0	4
Demansia rufescens	Rufous Whipsnake													1														1	0	1
Parasuta monachus					1									1														2	0	2
Pseudonaja mengdeni	Western Brown Snake																									1		1	0	1
Total number of records			25	11	81	11	70	7	13	48	78	7	74	8	23	15	4	1	0	57	22	1	0	3	46	11	518	97	615
Number of species			8	5	21	8	16	7	7	17	15	5	22	6	9	7	2	1	0	13	8	1	0	3	25	9	54	35	59
Total number of species			11		24		19		7	17		17		24		13		3		0	15		1	0	3	28		59		

S1 = Schedule 1, VU = Vulnerable

5.5 Amphibians

5.5.1 The Assemblage

Three amphibian species from two families were recorded during the survey (Table 5.6). The assemblage included two species of tree frog (Hylidae) and one species of ground-dwelling frog (Myobatrachidae).

Table 5.6: Amphibian species recorded during the Pocket and Billiard South fauna survey.

		YBL006P	YBL009E	YBLTarget04	YBLNoct08	YBLOpp
Family/ Species Name	Common Name	P1	P1	P2	P2	P1
Hylidae						
Litoria rubella	Little Red Tree Frog	1	1		•	•
Cyclorana maini	Sheep Frog					1
Myobatrachidae						
Uperoleia saxatilis	Pilbara Toadlet			•	•	•
Total number of records		1	1	•	•	1 + •
Total number of species		1	1	1	2	3

• denotes calls recorded

The Little Red Tree Frog was the only species recorded at trapping sites, but was not commonly recorded in wet areas along Weeli Wolli Creek. The most abundant frog during both phases of the survey was the Pilbara Toadlet, which was heard chorusing wherever there was water available. The least common species was the Sheep Frog, only one of which was recorded.

5.5.2 Amphibians of Conservation Significance

No amphibian species of conservation significance were recorded during the survey.

6.0 Vertebrate Conservation Significance

Native fauna species that are rare, threatened with extinction, or have high conservation value, are specially protected by law under the WA *Wildlife Conservation Act 1950*. In addition, some of these species are listed for their protection under the Commonwealth *EPBC Act 1999* (see Appendix 8 for statutory framework definitions).

6.1 Conservation Significant Fauna Recorded

The following eight species of conservation significance were recorded in the study area during this survey:

- Mulgara, *Dasycercus* sp. (species unconfirmed, however it is most likely D. *blythi* see Section 6.1.1);
- Pilbara Olive Python, *Liasis olivaceus barroni* (Schedule 1, Vulnerable);
- Western Pebble-mound Mouse, *Pseudomys chapmani* (Priority 4);
- Star Finch, *Neochmia ruficauda subclarescens* (Priority 4);
- Australian Bustard, *Ardeotis australis* (Priority 4);
- Fork-tailed Swift, *Apus pacificus* (Schedule 3, Migratory);
- Eastern Great Egret, *Ardea modesta* (Schedule 3, Migratory); and,
- Rainbow Bee-eater, *Merops ornatus* (Schedule 3, Migratory).

The location of these species is illustrated in Figure 6.1 and detailed descriptions of these species are provided in Sections 6.1.1 to 6.1.4.

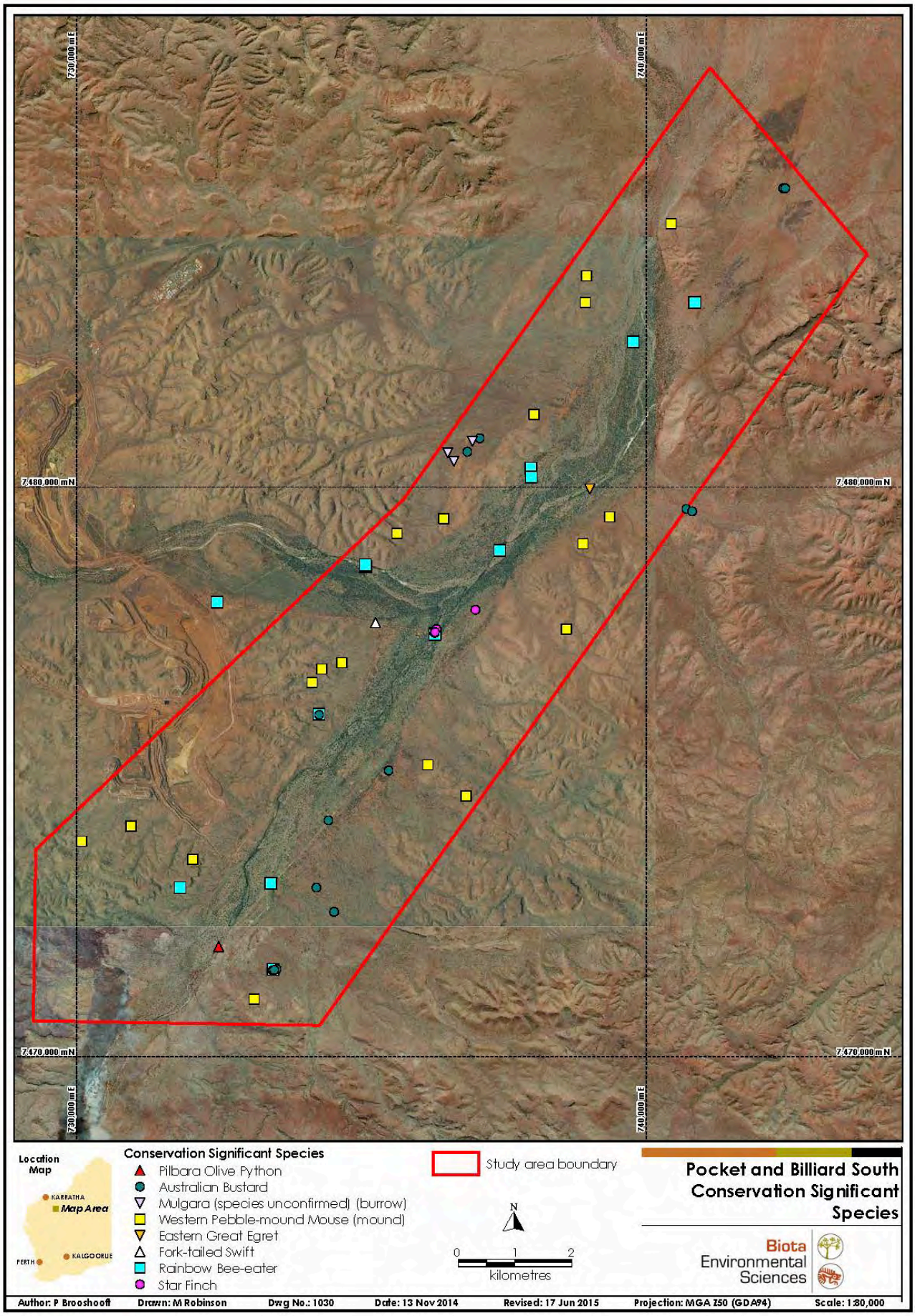


Figure 6.1: Locations of conservation significant fauna recorded during the Pocket and Billiard South fauna survey.

6.1.1 Mulgara, *Dasycercus* sp.

There has been a history of taxonomic confusion within the genus *Dasycercus*. For the last 30 years only a single species, *D. cristicauda*, was recognised; this is listed as Schedule 1 (Vulnerable) under the State *Wildlife Conservation Act 1950-1979* and Vulnerable under the Federal *EPBC Act 1999*. More recent genetic and morphological reviews resulted in the recognition of two species: the Crest-tailed Mulgara, *D. cristicauda,* and the Brush-tailed Mulgara, *D. blythi* (listed as a Priority 4 species by the Department of Parks and Wildlife).

While it is not impossible that *D. cristicauda* could occur in the study area locality, the current reliable data suggest it is much more likely that *D. blythi* is the taxon present. This view is based on the distribution maps of the Australian Museum (van Dyck and Strahan 2008) and Moseby et al. (2012), DSEWPaC's species profiles for the two species (DSEWPaC 2014), and most reliably from recent re-examination and assignment of the WA Museum's collection of *Dasycercus* specimens by taxonomic specialist Pat Woolley. The latter exercise found that all of the Pilbara region vouchers designated as *D. cristicauda* were more properly assigned to *D. blythi* (Biota 2014d).

Mulgara burrows were recorded in both phases of survey (Table 6.2), however no specimens were captured. The burrows were thought to be inactive, as no signs of fresh diggings, scats or tracks were noted. In addition to current views on *Dasycercus* species outlined above, habitat differences may also provide an indication for species identification when used in conjunction with identifications based on morphology (Woolley 2005, 2008, Pavey et al. 2011). Differences in habitat preference have long been recognised (Woolley 2005, 2008) and a study at a point of sympatry of the two species demonstrated discrete habitat preferences (Pavey et al. 2011). In this case, however, it is obviously difficult to ascertain which species (*Dasycercus cristicauda* or *Dasycercus blythi*) the burrows belonged to without captured specimens or tissue, but the habitat present within the study area is more congruous with the preferred habitat of the Brush-tailed Mulgara (*Dasycercus blythi*). This, combined with recent taxonomic revisions of the species, suggest that it is most likely this species that occurs within the study area (see Section 6.1.1.1), however specimens would need to be captured to confirm this.

Table 6.1: Locations of Mulgara burrows found during the Pocket and Billiard South fauna survey.

Site	Latitude	Longitude	Burrow Photograph
YBLMC01	22º45'49"S	119º18'27"E	
YBLMC04/YBLTarget02	22º45'56"S	119º18'13"E	

Site	Latitude	Longitude	Burrow Photograph
YBLMC04/YBLTarget02	22º46'01"S	119º18'16"E	

6.1.1.1 Brush-tailed Mulgara, *Dasycercus blythi*

There has been much taxonomic confusion surrounding the classification of *D. blythi* and *D. cristicauda,* however based on a combination of differences in tail morphology, nipple number (six, not eight), habitat preference and molecular distinction, the species may be identified. This species has a characteristic short tail, which is generally fattened at the base and covered in black hairs for much of its length.

Distribution: This species is known to inhabit spinifex grasslands on sand plains and sandy swale between low dunes from south-western Queensland across the Simpson, Tanami, and Great Sandy Deserts of southern and central Northern Territory and central Western Australia (van Dyck and Strahan 2008, Pavey et al. 2011). It is also known to inhabit areas on gibber (rock and pebble covered flat plains), and is closely associated with gently sloping to flat topographic positions rather than steep-sided sand ridges (Pavey et al. 2011). The presence of *Triodia* hummocks are not a requirement of the Brush-tailed Mulgara habitat (Pavey et al. 2011).

Ecology: The Brush-tailed Mulgara is a medium sized (60 – 110 g) carnivorous marsupial. Little is known about the breeding of this species in the wild, although females in central Australia have been captured in September with up to six young in the pouch. It is thought to be generally solitary, males and females being found in the same burrow only during the mating season.

Likelihood of Occurrence: Mulgara burrows were recorded at sites YBLMC01 and YBLMC04. Previous surveys conducted outside of Rio Tinto scopes of work have recorded active Mulgara diggings, burrows and burrow complexes and individuals in the northwestern section of the study area (S Ford pers. obs.). Despite the inactivity of the burrows, the recordings suggest that Mulgara were recently present (burrows were thought to be at least two months old) within the study area, but may indicate the individuals have moved from the site in search of new resources. Based on habitat preferences and distribution, it was assumed that the burrows recorded during the survey belonged to *D. blythi*; however, without direct captures identification remains uncertain. Previous surveys have recorded the Crest-tailed Mulgara (*D. cristicauda*) within 10 km of the study area (Biota 2002a, 2002b), however current knowledge would suggest that these records were most likely to be *D. blythi* rather than *D. cristicauda.*

6.1.2 Schedule 1 / Vulnerable Species

6.1.2.1 Pilbara Olive Python, *Liasis olivaceus barroni*

Distribution: The Pilbara Olive Python has a known distribution that coincides roughly with the Pilbara bioregion (Environment Australia 2000). It is known from 17 localities in the Pilbara and four areas where reliable populations occur: Pannawonica, Millstream, Tom Price and the Burrup Peninsula. At some of these sites, the species is considered stable and in sizeable numbers (Department of the Environment 2014a).

Ecology: Preferred habitat for the Pilbara Olive Python includes gorges, escarpments, rocky outcrops and water holes where it may find suitable prey that utilise these environments (Department of the Environment 2014a). It seeks shelter in caves, beneath boulders, in pools of water and occasionally in trees overhanging water (Bush and Maryan 2011). It is often associated with ephemeral or permanent water, but may also be recorded in rocky habitats some distance from these features (Biota 2009b). Males were found to travel large distances (Biota 2009b), suggesting that the species can have a large range (estimated between 88 ha and 449 ha) (Department of the Environment 2014a).

Occurrence in study area: This species was observed swimming downstream in Weeli Wolli Creek during the nocturnal search YBLNoct04 (22º50'39"S, 119º15'56"E). It has been recorded in the area previously, with several sightings made at the existing Yandi operations in addition to records from Marillana Creek.

6.1.3 Priority 4 Species

6.1.3.1 Western Pebble-mound Mouse, *Pseudomys chapmani*

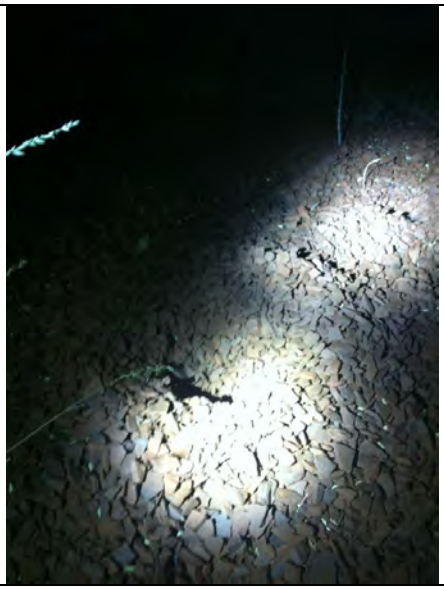
Distribution: This species is endemic to the central and eastern parts of the Pilbara including Karijini National Park (Menkhorst and Knight 2011).

Ecology: This species is typically found on stony hillsides with hummock grasslands (Menkhorst and Knight 2011) and is common to very common in suitable habitat within the Hamersley and Chichester subregions of the Pilbara bioregion. The Western Pebble-mound Mouse is well known for its behaviour of constructing extensive mounds of small stones covering areas from 0.5 to 9.0 square meters (van Dyck and Strahan 2008). This mound formation is most common on spurs and gentle slopes where suitably sized stones are present.

Occurrence in study area: Pebble mounds were recorded from 18 locations within the study area. Four mounds appeared inactive, while the rest appeared active (Table 6.2).

Table 6.2: Mounds of the Western Pebble-mound Mouse recorded in the study area.

	Mound Number	Latitude	Longitude	Activity	Mound Photograph
Phase 1	PC1	22º43'43"S	119º20'28"E	Active	
	PC2	22º49'50"S	119º15'40"E	Active	

	Mound Number	Latitude	Longitude	Activity	Mound Photograph
	PC3	22º49'32"S	119º15'01"E	Active	
	PC4	22º44'29”S	119º19'36”E	Inactive	Mound recorded during flora survey, photo N/A
	PC5	22º45'33”S	119º19'05”E	Active	Mound recorded during flora survey, photo N/A
	PC6	22º46'34”S	119º18'11”E	Inactive	Mound recorded during flora survey, photo N/A
	PC7	22º47'56”S	119º17'10”E	Active	Mound recorded during flora survey, photo N/A
	PC8	22º47'35”S	119º19'27”E	Active	Mound recorded during flora survey, photo N/A
	PC9	22º49'40”S	119º14'31”E	Inactive	Mound recorded during flora survey, photo N/A
	PC10	22º44'14”S	119º19'36”E	Active	Mound recorded during flora survey, photo N/A
	PC11	22º46'42”S	119º17'42”E	Active	Mound recorded during flora survey, photo N/A
Phase 2	PC12	22º51'09"	119º16'19"	Inactive, old mound	
	PC13	22º48'00"	119º16'57"	Inactive	

Mound Number	Latitude	Longitude	Activity	Mound Photograph
PC14	22º48'08"	119º16'51"	Active	
PC15	22º46'31"	119º19'53"	Inactive, old mound	
PC16	22º46'46"	119º19'37"	Inactive	

Mound Number	Latitude	Longitude	Activity	Mound Photograph
PC17	22º48'54"	119º18'03"	Active	
PC18	22º49'11"	119º18'27"	Active	

6.1.3.2 Star Finch (western), *Neochmia ruficauda subclarescens*

Distribution: The western subspecies of Star Finch occurs in the north of Western Australia and into the Northern Territory (Schodde and Mason 1999). It remains most common about major watercourses in the tropics and is typically patchy and highly variable in abundance.

Ecology: This species is considered to be resident in most of its range but is generally uncommon and is patchily distributed in the Pilbara. It is typically confined to rushes, reed beds and adjacent vegetation communities along major waterways and permanent pools in the Pilbara where it feeds on seed of sedges. Insects may become a common part of the diet during the breeding season, while in other parts of its range seeds comprise a major part of its diet. This species usually nests in March and April, as seeds are maturing after summer rainfall, and its domed nest is usually built in reeds up to several metres from the ground. The main threat to the species is considered to be overgrazing by stock along waterways, which destroys the riparian vegetation on which they depend (Garnett and Crowley 2000).

Occurrence in study area: This species was recorded at search site YBLBird01 and opportunistically in Phase 2 from reeds and *Typha* sp. and *Melaleuca* sp. vegetation adjacent to a flowing section of Weeli Wolli Creek near site YBLBird01 (Record locations: 22º47'40"S, 119º18'07"E; 22º47'38"S, 119º18'06"E; 22º47'39"S, 119º18'06"E; 22º47'25"S, 119º18'31"E). This species was recorded on both survey phases from the same locality, suggesting that there is a resident

group. It was recorded regularly in the vicinity of Grey's Crossing, both upstream and downstream where the initial discovery was made. Searches at some other reed beds along the creek system were conducted, and call playback was used but elicited no response. This species is thought to be a breeding resident in suitable reed habitat adjacent to waterways within the study area.

6.1.3.3 Australian Bustard, *Ardeotis australis*

Distribution: The Australian Bustard occurs over much of Western Australia, with the exception of the more heavily wooded southern portions of the state (Johnstone and Storr 1998). It is mostly extinct from the settled districts, but common away from settled parts of Western Australia (Pizzey and Knight 2007).

Ecology: Bustards are typically nomadic and occupies large home ranges (Marchant and Higgins 1993) in open or lightly wooded grassland including *Triodia* sandplains (Johnstone and Storr 1998). It is considered scarce to common depending on season and habitat. It has an omnivorous diet and occurs in a relatively broad range of habitats, but is often recorded from recently burnt areas (Marchant and Higgins 1993). This species breeds from March to September and the eggs are laid on bare, preferably stony ground (Johnstone and Storr 1998).

Occurrence in study area: four observations, 12 tracks and one scat of this species were recorded during the field surveys (Table 6.4). This species has also been recorded multiple times from previous surveys within the study area.

Table 6.3: Locations of the Australian Bustard recorded in the Pocket and Billiard South study area.

	Site	Latitude	Longitude	Type of Observation
Phase 1	YBL005P	22º43'22"S	119º21'37"E	Track
	YBLBird04	22º48'58"S	119º17'39"E	Track
	YBL006P	22º50'52"S	119º16'30"E	Track (x2)
	YBLOPP	22º50'52"S	119º16'31"E	Track
	YBLOPP	22º45'47"S	119º18'32"E	Observation
	YBLOPP	22º46'26"S	119º20'40"E	Observation
	YBLOPP	22º46'27"S	119º20'44"E	Track
Phase 2	YBL003P	22º43'22"S	119º21'36"E	Track
	YBL006P	22º50'52"S	119º16'30"E	Track (x 2)
	YBL008F	22º48'26"S	119º16'56"E	Track
	YBLOPP	22º50'19"S	119º17'07"E	Track
	YBLOPP	22º45'55"S	119º18'25"E	Track
	YBLOPP	22º49'26"S	119º17'03"E	Observation (x2)
	YBLOPP	22º50'05"S	119º16'56"E	Scat

6.1.4 Schedule 3 / Migratory Species

6.1.4.1 Fork-tailed Swift, *Apus pacificus*

Distribution: Almost cosmopolitan distribution throughout Australia.

Ecology: The Fork-tailed Swift is most often observed following thunderstorms and cyclonic weather patterns and the associated emergence of invertebrate fauna, which are a food source for this species (Johnstone et al. 2013). Fork-tailed Swifts are thought to be exclusively aerial in Australia as they breed in the northern hemisphere, migrating south to the Australasian region from October to April. Irregular summer visitor to the Pilbara during November to early April (Johnstone et al. 2013).

Occurrence in study area: An opportunistic observation of nine individuals of this species flying overhead was made during Phase 1 (22º47'33"S, 119º17'30"E). This species is expected to be a transient visitor to the study area and does rely on any terrestrial habitats within the study area.

6.1.4.2 Eastern Great Egret, *Ardea modesta*

Distribution: Cosmopolitan distribution throughout Australia.

Ecology: The Eastern Great Egret is largely dependent on the presence of significant water bodies, which may be temporally available in creeklines throughout the Pilbara, following periods of rainfall. These creeklines may attract Eastern Great Egret, particularly when drying pools result in an accumulation of tadpoles and fish.

Occurrence in study area: An opportunistic observation of this species was made during Phase 2 of the survey, when a single bird was observed flying over the creek (22º46'15"S, 119º19'40"E). The lack of observations at other times during the survey suggest that Eastern Great Egret is either uncommon or not regular within the study area.

6.1.4.3 Rainbow Bee-eater *Merops ornatus*

Distribution: This species occurs through the majority of the western third of Western Australia, usually where free water is readily available.

Ecology: This species forages aerially for insects and nests in burrows in the ground (Johnstone and Storr 1998). It occurs in a variety of habitats that are generally well watered, lightly wooded with suitable (sandy) soil for nesting and a tall stratum of vegetation for perching.

Occurrence in study area: This species was observed on numerous occasions opportunistically and whilst conducting systematic avifauna surveys throughout the study area (Table 6.4). This species, which is very common in the bioregion, is likely to be a breeding resident or non-breeding visitor to the region (Johnstone and Storr 1998), with Weeli Wolli Creek providing attractive wetter habitat with ample tall trees from which to forage.

Table 6.4: Locations of Rainbow Bee-eater records in the Pocket and Billiard South study area.

	Site	Latitude	Longitude
Phase 1	YBL002P	22º44'29"S	119º20'40"E
	YBL006P	22º50'52"S	119º16'30"E
	YBL008F	22º48'27"S	119º16'56"E
	YBL09E	22º46'59"S	119º17'18"E
	YBL010E	22º50'07"S	119º15'30"E
	YBLBird01	22º47'40"S	119º18'07"E
	YBLBird02	22º46'50"S	119º18'45"E
	YBLBird03	22º44'51"S	119º20'06"E
	YBLOPP	22º47'01"S	119º17'23"E
	YBLOPP	22º50'03"S	119º16'28"E
	YBLOPP	22º47'23"S	119º15'52"E
Phase 2	YBL002P	22º44'29"S	119º20'40"E
	YBL09E	22º46'59"S	119º17'18"E
	YBLBird05	22º46'09"S	119º19'04"E
	YBLOPP	22º46'04"S	119º19'04"E
	YBLOPP	22º47'39"S	119º18'07"E

6.2 Conservation Significant Fauna Potentially Occurring

Table 6.5 summarises the conservation significant species that have been recorded historically from the study area and from the locality (within 40 km) surrounding the study area. For each species, the likelihood of occurrence currently within the study area was assessed by giving consideration to last known records, distributions and availability of preferred habitat within the study area.

On this basis, the following species were considered likely to occur:

- Orange Leaf-nosed Bat, *Rhinonicteris aurantius* (Schedule 1/Vulnerable);
- Peregrine Falcon, *Falco peregrinus* (Schedule 4);
- Pilbara Barking Gecko, *Underwoodisaurus seorsus* (Priority 1);
- Blind Snake, *Anilios ganei* (Priority 1);
- Ghost Bat, *Macroderma gigas* (Priority 4);
- Bush Stone-curlew, *Burhinus grallarius* (Priority 4); and,
- Common Greenshank, *Tringa nebularia* (Schedule 3, Migratory).

The following species were considered to have the potential for occurrence:

- Northern Quoll, *Dasyurus hallucatus* (Schedule 1/Endangered);
- Australian Painted Snipe, *Rostratula australis* (Schedule 1)
- Grey Falcon, *Falco hypoleucos* (Schedule 1)*;*
- Cattle Egret, *Ardea ibis* (Schedule 3, Migratory);

The following species were considered to be unlikely to occur:

- Night Parrot, *Pezoporus occidentalis* (Schedule 1, Endangered)*;*
- Crest-tailed Mulgara, *Dasycercus cristicauda* (Schedule 1, Vulnerable);
- Bilby, *Macrotis lagotis* (Schedule 1, Vulnerable);
- Short-tailed Mouse, *Leggadina lakedownensis* (Priority 4);
- Long-tailed Dunnart, *Sminthopsis longicaudata* (Priority 4); and,
- Oriental Plover, *Charadrius veredus* (Schedule 3, Migratory).

One species was considered to not occur in the study area:

- Northern Marsupial Mole, *Notoryctes caurinus* (Schedule 1, Endangered);

Table 6.5: Conservation significant species returned from the desktop review and their likelihood of occurrence in the study area.

Class	Conservation Status								
Common Name/ Species Name	WC Act/ DPaW	EPBC Act	NatureMap (<40km)	EPBC PMD*	ALA (<40km)	Records within 10 km	Preferred Habitat	Habitat Available in Study Area?	Likelihood of Occurrence
Mammals									
Crest-tailed Mulgara *Dasycercus cristicauda*	Schedule 1	Vulnerable	-	-		Biota (2002a, 2002b), although see Section 6.1.1	Sand ridges with an understorey dominated by *Triodia.*	✗	Unlikely to occur
Northern Quoll *Dasyurus hallucatus*	Schedule 1	Endangered	✔	✔		Biota (2002a, 2011a)	Many records from the Pilbara bioregion originate from rocky habitats, ridges and free faces particularly when in contact with dense vegetation along drainage areas, and from boulder tors of the Abydos-Woodstock Plain.	✔	May potentially occur
Short-tailed Mouse *Leggadina lakedownensis*	Priority 4		-	-		Biota (2004a, 2005a)	Cracking clay, native grasslands and surrounding habitat.	✗	Unlikely to occur
Long-tailed Dunnart *Sminthopsis longicaudata*	Priority 4					Biota (2004c)	Records have come from plateaus near breakaways and screes, and rugged boulder strewn screes, often in areas with little vegetation.	✔	Unlikely to occur
Bilby *Macrotis lagotis*	Schedule 1	Vulnerable	-	✔	-	-	Sandy soils covered with spinifex grassland (mainly *Triodia basedowii*), with an over-storey of low shrubs dominated by Acacia species.	✔	Unlikely to occur
Northern Marsupial Mole *Notoryctes caurinus*	Schedule 1	Endangered	-	✔	-	-	Well vegetated sand dunes and sandy soils.	✗	Would not occur
Ghost Bat *Macroderma gigas*	Priority 4		✔	-	✔	Biota (2002a, 2012a)	Breakaways adjacent to large drainage lines, deep caves in Banded Iron Formation ranges.	✔ (Foraging)	Likely to occur
Orange Leaf-nosed Bat *Rhinonicteris aurantius*	Schedule 1	Vulnerable	✔	✔		Biota (2013c)(2013b)	Breakaways adjacent to large drainage lines, deep caves in Banded Iron Formation ranges.	✔ (Foraging)	Likely to occur
Reptiles									
Pilbara Barking Gecko *Underwoodisaurus seorsus*	Priority 1		✔			Biota (2012a)	Associated with rocky ridges, slopes and gullies.	✔	Likely to occur
Blind Snake *Anilios ganei*	Priority 1		✔	-	✔	Biota (2004a)(2004b)	Few records, however, occurs in a wide variety of habitats.	✔	Likely to occur
Avifauna									
Night Parrot *Pezoporus occidentalis*	Schedule 1	Endangered		✔		-	Dense, low vegetation often associated with *Triodia* hummock grasslands and areas dominated by samphire or areas where these two habitats are juxtaposed.	✔	Unlikely to occur
Peregrine Falcon *Falco peregrinus*	Schedule 4		✔	-	✔	Ninox (1994) Biota (2004a, 2004b, 2005a, 2013c)	Wide range of habitats including forest, woodlands, wetlands and open country.	✔	Likely to occur
Bush Stone-curlew *Burhinus grallarius*	Priority 4		-	-	✔	Biota (2004a, 2004b)	Sparsely grassed, lightly timbered forest or woodland.	✔	Likely to occur
Grey Falcon *Falco hypoleucos*	Schedule 1		-	-	✔	-	Wide range of habitats in the arid zone but appears to be least rare in lightly wooded coastal and riverine plains.	✔	May potentially occur
Common Greenshank *Tringa nebularia*	Schedule 3	Migratory	✔	-	-	Biota (2013b)	Sheltered coastal habitats and terrestrial ephemeral wetlands.	✔	Likely to occur
Australian Painted Snipe *Rostratula australis*	Schedule 1		✔	✔			Wetland areas with dense screening vegetation.	✔	May potentially occur
Cattle Egret *Ardea ibis*	Schedule 3	Migratory		✔	-	-	Standing shallow freshwater.	✔	May potentially occur
Oriental Plover *Charadrius veredus*	Schedule 3	Migratory		✔	-	-	Numerous, including: open plains, bare, rolling country, muddy or sandy wastes near inland swamps or tidal mudflats, bare claypans, margins of coastal marshes, grassy airfields, lawns and coastal dunes.	✔	Unlikely to occur

* PMD = Protected matters database

6.3 Conservation Significant Species Likely to Occur

6.3.1 Schedule 1 / Vulnerable Species

6.3.1.1 Orange Leaf-nosed Bat, *Rhinonicteris aurantius*

Distribution: While *Rhinonicteris aurantius* occurs from the Pilbara region in Western Australia to Queensland, the Pilbara form is geographically restricted to the Pilbara and Gascoyne regions by a wide expanse of desert (DSEWPaC 2008). Colonies are scattered throughout the landscape and known from mines of the eastern Pilbara, throughout the Hamersley Range and from sandstone formations south of the Hamersley Range (Department of the Environment 2015). Confirmed collections, sightings or records of roost sites are known from Red Hill Station, Turee Creek Station, Klondyke Queen gold mine near Marble Bar, Karratha, Millstream, Tom Price-Marandoo, Comet mine, Bamboo Creek, Copper Hills (near Nullagine) and the Barlee Range Nature Reserve.

Ecology: The Orange Leaf-nosed Bat has short fur, small ears and a distinguishing fleshy, diamond-shaped nose-leaf surrounding the nostrils. The orange fur visible on the front of its body appears darker on the back, where the fur is brown-tipped (Strahan 1995, Department of the Environment 2015). Orange Leaf-nosed Bat are sensitive to human intrusion to their roost (Department of the Environment 2015). The Orange Leaf-nosed Bat is an opportunistic feeder on moths and beetles throughout the year, as well as flying termites during the wet season. Mating occurs in July, followed by a gestation period of five months with single young is born in December or January (Churchill 2008). The Orange Leaf-nosed Bat is a poor thermoregulator and is very susceptible to dehydration. For this reason it requires deep caves, small crevices within deep caves or horizontal mine shafts that have stable, warm and humid microclimates for permanent roost sites (Department of the Environment 2015). For the Orange Leaf-nosed Bat, these parameters are 28-32°C and 96-100% humidity during the dry season (Churchill 2008).

Likelihood of Occurrence: This species may potentially forage within the study area, however it would not be expected to roost in the study area due to a lack of suitable cave habitat. A single call of this species was recorded from a survey approximately 7 km northwest of the study area (Biota 2013c), but no calls were recorded within the study area, despite extensive surveying.

6.3.2 Schedule 4 Species

6.3.2.1 Peregrine Falcon, *Falco peregrinus*

Distribution: The Peregrine Falcon has an almost cosmopolitan distribution across Australia, but is absent from most deserts and the Nullarbor Plain (Johnstone and Storr 1998).

Ecology: This species inhabits a wide range of habitats including forest, woodlands, wetlands and open country (Pizzey and Knight 2007). The Peregrine Falcon, like other birds of prey, is a relatively long-lived species, with low reproductive rates and low population density. These factors, combined with the fact that they are a top end predator and limited by their prey, make them particularly vulnerable to human impact.

Likelihood of Occurrence: This species has been recorded within the vicinity (10 km) of the study area previously (Table 6.5), and large trees adjacent to creekline/riverine areas may provide potential nesting and foraging habitat. The species is considered likely to occur within the study area.

6.3.3 Priority 1 Species

6.3.3.1 Pilbara Barking Gecko, *Underwoodisaurus seorsus*

Distribution: The Pilbara Barking Gecko is a Hamersley Range endemic that was discovered in 2006 but has only recently been described (Doughty and Oliver 2011). It was initially thought to be an isolated population of its more southerly relative, the Barking Gecko *Underwoodisaurus milii* (Menz and Cullen 2006) before morphological and molecular analysis showed it to be taxonomically distinct. To date there are very few records of this species, which occurs in a band

from north of Tom Price in the western Hamersley to West Angelas mine in the south-east (Doughty and Oliver 2011).

Ecology: The habitats used by this species vary in their topography and vegetation but are usually associated with rocky ridges, slopes and gullies.

Likelihood of Occurrence: This species has been recorded within the vicinity of the study area (Table 6.5), and as suitable habitat is present within the study area, this species is considered likely to occur.

6.3.3.2 Blind Snake, *Anilios ganei*

Distribution: This blind snake is poorly collected, being represented by only 39 records throughout Western Australia. This species is distributed from Pannawonica in the west, to Millstream in the north, to Newman in the southeast.

Ecology: The records collected to date indicate that the blind snake may be associated with moist gorges and gullies (Wilson and Swan 2008) but they have also been recorded from mulga woodland and rocky scree slopes. The ecology of this species is poorly known, but it is likely that as with most blind snakes, they would mostly inhabit topsoil, termitaria and ant nests. Blind snake diet typically consists of the eggs, larvae and pupae of ants (Storr et al. 2002).

Likelihood of Occurrence: This species has been recorded previously from within the vicinity of the study area (records from 2004; Table 6.5), and is likely to be present in suitable habitat.

6.3.4 Priority 4 Species

6.3.4.1 Ghost Bat, *Macroderma gigas*

Distribution: Previously distributed across most of inland and northern Australia, but now restricted to the tropical north of the continent (Churchill 1998). Occurs in a broad range of habitats, with their distribution being influenced by the availability of suitable caves and mines for roost sites (Churchill 1998). The distribution of Ghost Bats is fragmented, with each population showing some genetic differentiation (Armstrong and Wilmer 2004, Biota 2004d). Populations in the Pilbara bioregion appear to be isolated from those in the Kimberley and Northern Territory. A study by McKenzie and Bullen (2009) found that the Ghost Bat is more common than previously thought.

Ecology: Ghost Bats are efficient predators of small birds, mammals, reptiles and large insects, and they have highly developed echolocation, visual and hearing systems (Churchill 1998). Vocalisations audible to humans are used in their complex social interactions (Churchill 1998). Bats forage over large distances, with ranges of ~60 ha, and the size of their foraging area is probably inversely related to the productivity of their landscape. Bats are known to have overlapping ranges (Churchill 1998). Scat material from *M. gigas* is quite distinctive and can be used to identify temporary roosts or feeding sites.

Likelihood of Occurrence: This species has been recorded within the vicinity of the study area recently from 9km south (Biota 2012a), where a cave containing scats was located. This species has potential to utilise habitats within the study area, but no potential roost caves were noted.

6.3.4.2 Bush Stone-curlew, *Burhinus grallarius*

Distribution: This species is widespread in Australia and southern New Guinea. It remains common in tropical Australia, but has declined considerably in temperate Australia and has disappeared from many regions (Marchant and Higgins 1993).

Ecology: The Bush Stone-curlew is primarily nocturnal and inhabits sparsely grassed, lightly timbered forest or woodland, often in areas where fallen timber can provide concealment during the day. It is most easily detected by calls, which are given most frequently in Spring (Marchant and Higgins 1993). Breeding season extends from July to January, with eggs laid directly on the ground or in a small scrape (Johnstone and Storr 1998). This species is a generalist terrestrial

feeder, primarily eating invertebrates, particularly beetles, but also small lizards, frogs, snakes, vegetation and seeds (Marchant and Higgins 1993).

Likelihood of Occurrence: This species has been recorded previously from within the vicinity of the study area (Table 6.5) and suitable habitat, such as low open woodlands associated with drainage lines, is available within the study area, therefore this species is considered likely to occur.

6.3.5 Schedule 3 / Migratory Species

6.3.5.1 Common Greenshank, *Tringa nebularia*

Distribution: This species does not breed in Australia, however it occurs in well-watered regions throughout Western Australia (Johnstone and Storr 1998).

Ecology: Found in a wide variety of shallow inland wetlands and sheltered coastal habitat (Johnstone and Storr 1998). It is a visitor to these habitats year round, where it feeds on insects and small molluscs (Johnstone and Storr 1998).

Likelihood of Occurrence: This species has been recorded previously within the vicinity of the study area (Table 6.5), and may be present on occasion in drainage line habitats with water.

6.4 Conservation Significant Species Potentially Occurring

6.4.1 Schedule 1 / Endangered Species

6.4.1.1 Northern Quoll, *Dasyurus hallucatus*

Distribution: The Northern Quoll currently occurs in three broad zones of northern Australia including the Northern Territory, Queensland and the Pilbara. The species occurs in the northerly portion of Northern Territory, with the westernmost records near the WA border and the south-easternmost records from Borroloola (DSEWPaC 2012b). In Queensland, populations of the species have shown a severe decline from their former distribution and are highly fragmented. Records are still known from areas south of Rockhampton, as far north as Cooktown and as far west as near Carnarvon Range National Park (DSEWPaC 2012b). It occurs in all subregions of the Pilbara bioregion, and is also known from a number of offshore islands in Western Australia including Adolphus, Augustus, Berthier, Bigge, Boongaree, Caffarelli, Capstan, Carlia, Dolphin, Hidden, Koolan, Purrungku, Sir Fredrick, Uwins and Wollaston Islands (Biota 2009c); (DSEWPaC 2012b). In the Pilbara, records of the Northern Quoll extend east to the Little Sandy Desert (How et al. 2009) and south to near Newman, but the species is most common in the northern Pilbara closer to the coast.

Ecology: Although known to occur in a variety of habitats across its range, the Northern Quoll is most abundant in rocky country and in open eucalypt forest within 150 km of the coast (Strahan 1983, 1995). In the Pilbara, the Northern Quoll is considered to favour rocky gorges, boulder piles, breakaways and hills (usually of high relief and often along drainage lines) for denning purposes, where it utilises spaces between rocks or in log or tree hollows (Biota 2009c). Previously completed records frequency analysis (Biota 2009a, 2012d) has shown that these critical habitat types are commonly associated with the Capricorn, Macroy, Robe and Newman land systems in the Pilbara bioregion. These land systems include basalt hills, mesas, major drainage channels, low and high plateaux, lower slopes and stony plains (van Vreeswyk et al. 2004). Adjacent plains and vegetated areas provide habitats suitable for foraging and dispersal of young (van Dyck and Strahan 2008), but are considered to be of less importance for the purpose of the species' conservation.

The Northern Quoll is the smallest, most arboreal and most aggressive of the four Australian quoll species (Strahan 1995). It is predominantly a carnivore with a varied diet of small invertebrates and vertebrates, including termites, grasshoppers, beetles, moths, lizards, birds, snakes, small mammals and frogs, as well as figs, other fleshy fruit and carrion (Oakwood 1997, Biota 2010c). In particular, it is known to prey on the Common Rock-rat *Zyzomys argurus* (Strahan 1995); probably

a primary prey item in the Pilbara region (Biota 2013f). Female Northern Quolls seem to outnumber males in most populations. While about one third of females tend to remain in the area they were born, most males disperse by six to eight months of age, and some males in areas are merely transients (Strahan 1983). This species is short-lived, with both sexes reaching maturity at 11 months (Biota 2010c). Male Northern Quolls usually die after one breeding season, which has been documented as May-July in the tropics. This, coupled with the fact that females typically only breed once per year, makes local populations of this species vulnerable to extinction (DSEWPaC 2012b).

Likelihood of Occurrence: There are few records from the locality surrounding the study area (Table 6.5), indicating that while the species may be present, it does not occur in high numbers. Despite targeted surveys within the study area using cage traps (192 total trap nights),Elliott traps (1155 total trap nights) and camera traps (total of 22 trap nights) (Biota 2009a, 2014c), it has not been detected. However, potentially suitable habitat is present within the study area, suggesting that it has potential to occur.

6.4.1.2 Night Parrot, *Pezoporus occidentalis*

Distribution: Very little is known about the distribution of the Night Parrot as only two of the 23 specimens ever collected of this species were from the 20th century; one from the Gascoyne region in WA in 1912 and the other in western Queensland in 1990 (FMG 2005). Several dedicated surveys for the Night Parrot have so far failed to locate a confirmed extant population in the Pilbara, however the species was sighted near Minga Well near the Fortescue Marsh in 2005 (Davis and Metcalf 2008). Its current distribution is thought to be limited to the inland southeast Pilbara and western Queensland (DSEWPaC 2012d).

Ecology: The Night Parrot grows from 22 to 25 cm in length and has a wingspan from 44 to 46 cm. It has a bright green body with black and yellow bars, spots and streaks, bright yellow belly and black wing periphery and tail, which is the same for the male and female parrots (DSEWPaC 2012c). The species is data deficient, but the reliable sightings have recorded birds occurring singly, in pairs and occasionally in small groups of four to eight (DSEWPaC 2012c). The diet of the Night Parrot is thought to comprise grass seeds, especially those of *Triodia*, and green plant material. It is thought to be a nocturnal species, frequenting sources of water at night (DSEWPaC 2012c). Although poorly known, the life expectancy of individuals is estimated at 10 years. The nest is said to be made up of a few small sticks and possibly *Triodia* leaves, built into a tunnel-like structure in a *Triodia* hummock or small bush (DSEWPaC 2012c).

The Night Parrot prefers arid and semi-arid regions characterised by dense, low vegetation (DSEWPaC 2012c). Confirmed records have described the parrot's habitat as *Triodia* grasslands on stony or sandy substrates, particularly when in association with samphire and chenopod shrublands, including genera such as *Atriplex*, *Maireana* and *Bassia,* on the border of salt lakes and creeks (DSEWPaC 2012c)

Likelihood of Occurrence: This species has not been recorded within the study area, or within 40 km of the study area. It is difficult to gauge the probability of this species occurring within the study area given a lack of records, however on the basis of habitat preference, some suitable habitat is present within the study area (see Table 4.9 for locations), suggesting this species has potential to occur.

6.4.2 Schedule 1 Species

6.4.2.1 Grey Falcon, *Falco hypoleucos*

Distribution: The Grey Falcon is endemic to Australia, where it is widespread but rare throughout the arid zone. This species occurs in the northern half of Western Australia, typically north of 26ºS (Johnstone and Storr 1998). It is a resident or nomadic visitor to inland parts of Australia (Pizzey and Knight 2007), but its movements are poorly understood.

Ecology: The Grey Falcon mainly inhabits lightly wooded coastal and riverine plains (Johnstone and Storr 1998) and may also occur near wetlands where surface water attracts prey. In the Pilbara, the Grey Falcon is mostly recorded from the coastal plain between the de Grey and

Ashburton Rivers (Storr 1984). Prey primarily comprises birds, especially parrots and pigeons, taken using high-speed chases and stoops; reptiles and mammals are also taken. It breeds in trees, such as *Eucalyptus* spp., typically in the abandoned nests of crows and butcherbirds (Marchant and Higgins 1993, Johnstone and Storr 1998). Eggs have been recorded in July and August but its breeding season is not certain.

Likelihood of Occurrence: While not recorded in the study area, this species has been recorded within 40 km. This species has potential to hunt in the study area periodically, and could potentially breed in taller eucalypts associated with the Weeli Wolli drainage system.

6.4.2.2 Australian Painted Snipe, *Rostratula australis*

Distribution: This species has been recorded from wetland areas in all states of Australia, although it is most common in eastern Australia (Department of the Environment 2014b).

Ecology: The Australian Painted Snipe is a wading bird with a long, pinkish coloured bill. It is generally observed singly or in pairs. This species generally inhabits shallow terrestrial freshwater wetlands with emergent grasses, sedges, rushes and reeds. Breeding habitat is characterised by shallow wetlands with bare wet mud and small islands within wetlands (Department of the Environment 2014b). The Australian Painted Snipe breeds year round when wetland conditions are favourable (Marchant and Higgins 1993). A substantial and sustained decline in numbers of the Australian Painted Snipe has been observed since the 1950s, and was thought to largely be the result of degradation and alteration of wetland habitats (Garnett and Crowley 2000, Rogers et al. 2005).

Likelihood of Occurrence: While not recorded in the study area, this species has been recorded within 40 km (NatureMap database). Wetland habitats are present year-round, therefore this cryptic species was considered to have potential for occurrence.

6.4.3 Schedule 3 / Migratory Species

6.4.3.1 Cattle Egret, *Ardea ibis*

Distribution: The Cattle Egret is largely associated with pastures and wetlands (Simpson and Day 2004), with scattered records from the Pilbara coming from areas surrounding the Fortescue Marshes and other wetland areas.

Ecology: This species primarily uses shallow open fresh wetlands with low emergent vegetation and abundant aquatic flora. It forages most often away from water in low lying grasslands, pastures and croplands, where it feeds on insects, frogs, reptiles and small mammals (Marchant and Higgins 1993).

Likelihood of Occurrence: this species may utilise damp grasslands adjacent to Weeli Wolli Creek following flooding, but is not expected to be a regular visitor in the study area.

6.5 Conservation Significant Species Unlikely to Occur

6.5.1 Schedule 1 / Endangered Species

6.5.1.1 Northern Marsupial Mole, *Notoryctes caurinus*

Distribution: This species is sparsely distributed across much of arid Australia in sandy desert area (Menkhorst and Knight 2011).

Ecology: This species is adapted to living underground where it burrows through sand. It has no functional eyes, small ear holes and its body is covered in a dense, fine, uniformly golden-brown fur. It primarily lives in sand dunes and sandy soils along river flats, where they forage on ants, beetle larvae and arthropods (Menkhorst and Knight 2011).

Likelihood of Occurrence: There are very few records of this species, with most recorded from over a decade ago from the eastern Pilbara, Gibson Desert and Kimberley region (NatureMap database). Habitat for this species is not present within the study area; therefore this species is unlikely to occur.

6.5.2 Schedule 1 / Vulnerable Species

6.5.2.1 Crest-tailed Mulgara, *Dasycercus cristicauda*

Distribution: This species is known to inhabit the slopes and crests of sand ridges in the southern Simpson Desert and the adjoining Tirari and Strzelecki Deserts in southern Northern Territory and northern South Australia (van Dyck and Strahan 2008). Historic records indicate it occurred from the Canning Stock route in central Western Australia and from Ooldea and along the Nullabor Plain at Fisher and Rawlinna (Pavey et al. 2011).

Ecology: The Crest-tailed Mulgara is generally more brightly coloured and bigger (65 – 185 g) than the Brush-tailed Mulgara, and has a dorsal fin-like crest of the black hairs on the tail (van Dyck and Strahan 2008). Unlike the Brush-tailed Mulgara, this species has eight nipples (Woolley 2005). Little detailed ecological work has been carried out on this species, although it is likely to be similar to the Brush-tailed Mulgara. Previous knowledge suggested that this species is strongly associated with the presence of the sandhill canegrass, *Zygochloa paradoxa*, as burrows were found at the base of this grass (van Dyck and Strahan 2008). Contrary to this, a study by Pavey and colleagues (2011), determined that gradients in *Triodia* cover might be more important than the presence/absence of the canegrass. It appeared that *Triodia*, like canegrass, functioned to stabilise sand required for burrow structural integrity.

Likelihood of Occurrence: Before recent and morphological reviews resulted in the recognition of two distinct species, *D. cristicauda* was recorded from the locality during previous surveys (Biota 2002a, 2002b). Current knowledge would suggest that these records are in fact more likely to be *D. blythi.* The preferred habitat of this species is also not available within the study area, suggesting that it is unlikely to occur.

6.5.2.2 Bilby, *Macrotis lagotis*

Distribution: Historically found across most of arid and semi-arid Australia, the Bilby is now restricted to the deserts of central Australia including the Tanami, Gibson and Great Sandy Deserts, the east Pilbara and south to Warburton in Western Australia. Western Australian populations are found in the inland Pilbara, northern Great Sandy Desert, the south-western Kimberley and the Gibson Desert (DSEWPaC 2012d).

Ecology: The Bilby is a rabbit-sized marsupial covered in long, soft, blue-grey fur and is quite delicate in appearance. Distinguishing features of this marsupial are its large rabbit-like ears, long pointed snout, black tail with a white tip, and delicate hind limbs with the hind foot lacking a first toe (Strahan 1995, Pavey 2006, DSEWPaC 2012d). The species has strong forelimbs with stout claws, making it a powerful burrower and well equipped to dig for food. Their diet typically comprises seeds, bulbs, fruit, insects, larvae and fungi, found primarily through their sharp senses of hearing and smell (Strahan 1995). The occurrence of this species is strongly influenced by the availability of sandy substrates (where burrowing is easier), areas of higher rainfall and higher temperatures (i.e. higher productivity areas and conditions that are unfavourable for foxes), and in some parts of its range, fire age is thought to influence species occurrence (DSEWPaC 2012d). Habitat near areas that have been recently burnt (one year ago or less) appear to be favoured by the Bilby (DSEWPaC 2012d).

Likelihood of Occurrence: There have been no records of this species within the study area or its locality, but potentially suitable habitats are present, particularly sandy areas in the northwest. The lack of records however, despite extensive surveying, suggests that the likelihood of occurrence of this species in the study area is low.

6.5.3 Priority 4 Species

6.5.3.1 Short-tailed Mouse, *Leggadina lakedownensis*

Distribution: Prior to 1997, only two specimens of this species had been collected, however the number of records of this species has increased substantially since this time (Cooper et al. 2003). In Western Australia the distribution includes the Pilbara and Kimberley regions (Menkhorst and Knight 2011).

Ecology: The Lakeland Downs Mouse is known to occur in areas of open tussock and hummock grassland, *Acacia* shrubland and savannah woodland, on sandy soils and cracking clays (Morris et al. 2008). This species has been recorded on cracking clay communities from Cape Preston (60 km west of Dampier) in the west to the northern flanks of the Fortescue Marshes in the east (Halpern Glick Maunsell and Biota 2000). These records suggest that the primary mainland habitat comprises areas of cracking clay and adjacent habitats, although this species has also been recorded from hilltops and sandy coastal areas near Onslow.

Likelihood of Occurrence: This species has been recorded in close proximity to the study area previously (Table 6.5), although very little of its core habitat is present within the study area, and it is therefore considered unlikely to occur.

6.5.3.2 Long-tailed Dunnart, *Sminthopsis longicaudata*

Distribution: The Long-tailed Dunnart inhabits rocky, rugged habitat from the Pilbara and adjacent upper Gascoyne region east to the central Northern Territory and South Australia (Menkhorst and Knight 2011).

Ecology: This species is nocturnal, and its diet includes a variety of invertebrates. Females in captivity give birth to up to five young between the months of October and December (McKenzie et al. 2008). Records of this species have come from plateaus near breakaways and screes, and rugged boulder strewn screes, often in areas with little vegetation. This species was once considered to be rare and possibly threatened, however, research has shown that it is relatively common and widespread but is restricted to a specific habitat (Burbidge 2004).

Likelihood of Occurrence: This species has been recorded in proximity to the study area previously (Table 6.5), however this record was from a decade ago. Preferred habitat of this species is present within the study area, however lack of recent records would suggest that this species is unlikely to occur in the study area.

6.5.4 Schedule 3 / Migratory Species

6.5.4.1 Oriental Plover, *Charadrius veredus*

Distribution: This species is a non-breeding visitor to Australia where it occurs along coastal and inland areas in northern Australia, predominantly north of the Fortescue Marsh (BirdLife Australia 2014).

Ecology: This species prefers open areas such as plains, bare, rolling country, muddy or sandy wastes near inland swamps or tidal mudflats; bare claypans, margins of coastal marshes; grassy airfields, lawns and coastal dune areas (Pizzey and Knight 2007).

Ecology: This species has not been recorded from the study area previously and suitable habitat is largely absent from the study area, only occurring following a fire. The species is thought to be unlikely to occur within the study area.

6.6 NES Species Habitat Mapping

In general terms, the study area was considered to be largely unsuitable for Northern Quoll, with a few small areas found that would have a low likelihood of providing habitat, that is, potential den locations in proximity to water and foraging opportunities (Figure 6.2). The habitat values of the study area as a whole are probably limited to potential dispersal area for Northern Quoll.

The Weeli Wolli Creek system with its series of semi-permanent pools and extensive riparian vegetation represents preferred habitat for Pilbara Olive Python, and this species was recorded in this habitat (Figure 6.2). Preferred habitat in this sense means that it provides areas of shelter in close proximity to foraging areas. During hot and humid conditions, dispersal throughout the study area is possible and, as for Northern Quoll, the study area as a whole is considered to be dispersal habitat for the species.

Weeli Wolli Creek was also considered to be potential foraging habitat for Orange Leaf-nosed Bat, although none were recorded. There was no evidence of roost caves suitable for the species despite extensive searches along the ridgelines of the study area. Consequently, while the study area as a whole could be considered to be dispersal habitat for the species, it was not considered to have any roosting or foraging habitat present. In addition, there is no evidence that a roost occurs within 15 km of the study area (the maximum foraging distance of individuals (Biota 2013h)).

Similarly, the spinifex plains in the north of the study area may represent potential foraging area for Night Parrot, but the spinifex was not old enough to create the large, continuous clumps required to provide suitable nesting locations and the study area as a whole does not provide preferred habitat for the species.

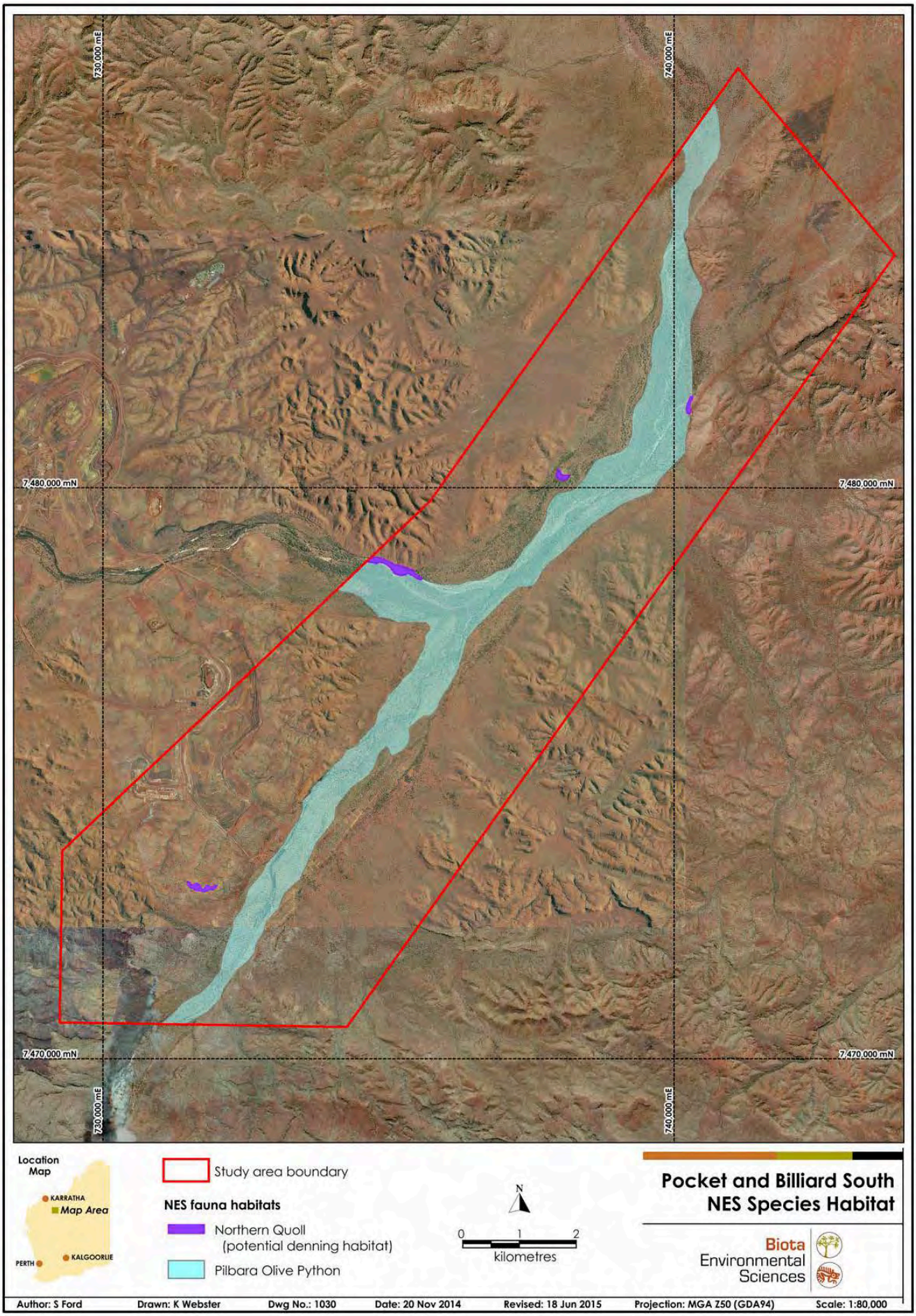


Figure 6.2: NES species habitat mapping.

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7.0 Short Range Endemic Fauna Results

7.1 Fauna Recorded in Study Area

The survey recorded taxa from two invertebrate groups: mygalomorph spiders and pseudoscorpions. The locations of these records are illustrated in Figure 7.1.

7.1.1 Myglamorph Species: *Aganippe* 'MYG086'

A previous environmental survey in the north of the study area (URS Australia 2012) reportedly recorded specimens of the potential SRE, *Aganippe* 'MYG086'. Searches during Phase 1 and 2 were performed in the same location as these records were reportedly found in, however no specimens were located. The specimens located during the previous environmental survey had been lodged with the WA Museum, and were submitted to Helix along with specimens collected during this survey for genetic analysis, to assign them to a species (as no genetic material was taken originally). These specimens were successfully sequenced, and were assigned to the species 'I80' (family Idiopidae), which has not been collected previously from the wider Pilbara Mygalomorph study (Helix 2012).

However, upon plotting the locations of these museum specimens (species I80) from museum record coordinates, it was found that they originated 40 km northwest and 60 km east of the study area. Because the species I80 was not detected during this survey, and known records of this species are located some distance outside of the study area in different habitat, it is considered unlikely that this species occurs within the study area.

7.1.2 Mygalomorph Spiders

Nineteen specimens (11 from Phase 1, eight from Phase 2) were collected from the Pocket and Billiards South study area (this study). Genetic analysis of the specimens detected five putative species from two families (Table 7.1).

All species detected have been found previously outside of the study area (Table 7.1).

The Maximum Spanning Distance (MSD), Minimum Spanning Area (MSA) and SRE status of each species is outlined in Table 7.1 and each putative species is further described in Sections 7.1.2.1 - 7.1.2.5. This analysis was based on the locations of all records of this species supplied by the Western Australian Museum.

Table 7.1: Putative species recorded from the Pocket and Billiard South study area.

Family Molecular Species	No of Specimens (Phase)	Sites collected from	No of Sites collected from	Found outside project area?	Maximum Spanning Distance (km)	Minimum Spanning Area (km^2)	SRE Status
Idiopidae I53	3 (P1)	YBLSRE01	1	Y	42.3	0.54	Potential SRE
Nemesiidae N42	2 (P1), 1 (P2)	YBLSRE01, YBL005P, YBLSRE15	3	Y	17.65	106.39	Potential SRE
Nemesiidae N44	2 (P1), 6 (P2)	YBLSRE04, YBLSRE14, YBLSRE19, YBLSRE20	4	Y	20.25	26.47	Potential SRE
Nemesiidae N16	4 (P1)	YBLSRE08, YBLSRE10, YBL007P	3	Y	176.2	14,042	Not an SRE
Nemesiidae N1	1 (P2)	YBLSRE15	1	Y	296.9	14,412	Not an SRE

7.1.2.1 Idiopidae 'I53'

Distribution:
Species I53 is known from four other specimens in the Pilbara; three collected at Yandi (approximately 80.5 km north-northwest of Newman) and one collected from Koodaideri (approximately 122 km northwest of Newman). It currently has a known MSD of 42.3 km and a MSA of 0.54 km^2.

Habitat: Species I53 has been collected from hummock grasslands.

SRE Status: The current known distribution of this putative species is less than 10,000 km^2; therefore it is considered a potential SRE in accordance with the criteria outlined in Table 4.15.

7.1.2.2 Nemesiidae 'N42'

Distribution: This species is known from 20 individuals collected across 11 separate localities between 80 and 90 km northwest of Newman. It has also been recorded within 10 km of the study area during previous surveys (Biota 2011c, 2013e). It has a MSD of 17.65 km and a MSA of 106.39 km^2.

Habitat: Species N42 has been collected from stony plains, ridges, lower slopes and alluvial floodplains.

SRE Status: Based on current records, this species qualifies as a potential SRE.

7.1.2.3 Nemesiidae 'N44'

Distribution: A total of 22 specimens of Species N44 have been collected from the Pilbara region across seven separate locations. It has also been recorded from within 10 km of the study area during a previous survey (Biota 2011c). The records are separated by a MSD of 20.25 km and occupy an area of 26.47 km^2.

Habitat: Species N44 is known from Loamy soils along Weeli Wolli Creek.

SRE Status: Based on the current spread of records, Species N44 qualifies as a potential SRE.

7.1.2.4 Nemesiidae 'N16'

Distribution: Species N16 is broadly distributed through the southern central Pilbara and is known from 221 specimens collected from 184 separate localities that are separated by a MSD of 176.2 km, and has a MSA of 14,042 km^2. This species has been recorded within 10 km of the study area from a number of previous surveys (Biota 2011b, 2011c, 2013c, 2013d).

Habitat: Species N16 have been collected from red shallow loams or red earthy loams in narrow drainage floors and from adjacent landforms (e.g., low slopes and stony plains) where suitable soil profile exists. Associated vegetation units include Acacia woodlands and *Triodia* hummock grasslands.

SRE Status: Species N16 has a distribution larger than 10,000 km^2 and, on that basis, does not qualify as an SRE.

7.1.2.5 Nemesiidae 'N1'

Distribution: Species N1 is known from 108 individuals collected across 71 locations in the Pilbara. It has a MSD of 296.9 km and based on current data, it occupies a MSA of 14,412 km^2. This species has been recorded during a number of previous surveys conducted within 10 km of the study area (Biota 2011b, 2011c, 2013c, 2013d, 2013e).

Habitat: Species N1 is associated with clayey soils in *Acacia aneura* dominated communities as well as clay loams on alluvial fans and broad floodplains.

SRE Status: Species N1 has a distribution larger than 10,000 km^2 and, on that basis, does not qualify as an SRE.

7.1.3 Pseudoscorpions

One pseudoscorpion specimen belonging to the *Beierolpium* genus (family Olpiidae) was recorded during the survey from within leaf litter. This species has been recorded previously during surveys conducted within 10 km of the survey area (Biota 2011b, 2012c, 2013c, 2013d). This group requires further taxonomic investigation before its SRE status can be determined.

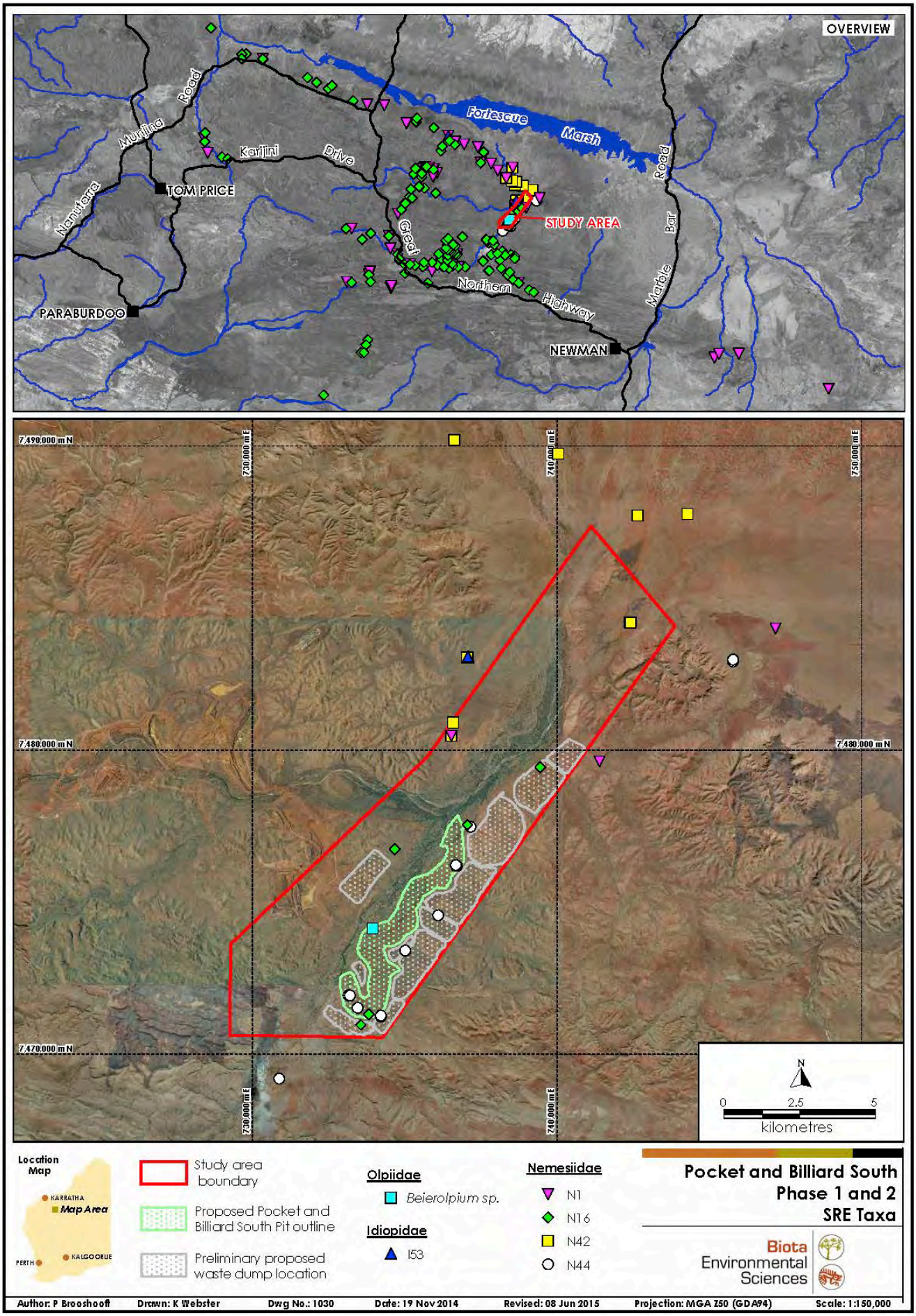

Figure 7.1: Locations of SRE taxa recorded from the Pocket and Billiard South study area.

8.0 Conclusions

The review of the information available for terrestrial fauna within the Pocket and Billiard South study area conducted by Biota (2013a) recommended that additional fauna sampling in the northern and western portions of the study area, coinciding predominantly with the Newman, McKay and Urandy land systems, was required. These land systems do not intersect the Weeli Wolli Creek system. This survey addressed that zoological knowledge gap and added considerably to the understanding of the terrestrial assemblage of the study area, particularly in respect to vertebrate groups such as reptiles, as outlined in a separate report integrating this and other reports on the terrestrial fauna of the study area (Biota 2014e).

Eight conservation significant vertebrate taxa were recorded using survey techniques tailored to each species. Additional trapping effort targeted at Northern Quolls in areas identified as having the greatest potential to support the species continued to be unsuccessful and the study area as a whole was considered to be largely unsuitable for the species, with only minimal potential denning habitat available. Additionally, despite extensive searching, no caves suitable for Ghost Bat or Orange Leaf-nosed Bat colonies were found. While the area represents possible foraging area for these species, the lack of suitable roosts reduces their likelihood of occurrence, and they were not recorded. On the other hand, extensive suitable habitat is available for Pilbara Olive Python in riparian vegetation associated with the Weeli Wolli Creek system and the species has been confirmed as occurring.

Mulgara burrows were recorded within the study area, however no direct captures of species were made, therefore it remains uncertain whether the burrows belonged to the Crest-tailed Mulgara (*Dasycercus cristicauda*) or the Brush-tailed Mulgara (*Dasycercus blythi*). The Crest-tailed Mulgara has previously been recorded within 10 km of the study area, although recent genetic and morphological reviews would suggest these records were in fact more likely to be *D. blythi.* Based on current knowledge of the genetic and morphological differences between the two species, coupled with habitat preferences and distribution, it was assumed that the burrows recorded during this survey belonged to the Priority 4 listed *D. blythi.*

Targeted searches for SRE taxa yielded records of several invertebrate species considered to be potential SREs. All of the taxa recorded have documented distributions that extend outside of the Pocket and Billiard South study area.

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9.0 Glossary

ALA	Atlas of Living Australia
Biota	Biota Environmental Sciences
EIA	Environmental Impact Assessment
Elliott Trap	A collapsible aluminium box trap
EPA	Environmental Protection Authority
EPBC Act 1999	Federal *Environmental Protection and Biodiversity Conservation Act 1999*
Helix	Helix Molecular Solutions
IBRA	Interim Biogeographic Regionalisation for Australia
MSA	Minimum Spanning Area
MSD	Maximum Spanning Distance
NES	Species of National Environmental Significance
Non-volant mammals	Ground dwelling mammals
NRS	National Reserve System
Opportunistic record	A species recorded by non-systematic sampling methods
Passerine	Of the order Passeriformes, also known as a perching bird
PBS	Pocket and Billiard South
Study area	The area in which the fauna survey was conducted; Pocket and Billiard South
SM2	A model of Song Meter by Wildlife Acoustics
Speciose	Rich in number of species
SRE	Short Range Endemic fauna
Systematic sampling	Sampling using trapping (including pitfall traps, Elliott traps or funnel traps)
Volant mammals	Bats

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Appendix 1

Potential Species List Compiled from the Database and Literature Searches

Mammals

Family / Species Name	Common Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2002b)	Biota (2004a), Biota (2004b)	Biota (2004a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2009a)	Biota (2011)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Tachyglossidae																			
Tachyglossus aculeatus	Short-beaked Echidna			•					•										
Dasyuridae																			
Dasycercus cristicauda	Crest-tailed Mulgara	S1					•	•											
Dasycercus sp. (blythi or cristicauda)	Brush-tailed Mulgara or Crest-tailed Mulgara	P4/S1																	•
Dasykaluta rosamondae	Little Red Kaluta			•	•				•	•		•	•		•	•			•
Dasyurus hallucatus	Northern Quoll	S1	•	•			•							•					
Ningaui timealeyi	Pilbara Ningaui			•	•				•	•		•			•	•			•
Sminthopsis longicaudata	Long-tailed Dunnart	P4								•									
Sminthopsis macroura	Stripe-faced Dunnart			•	•					•					•	•			•
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart			•	•				•	•					•				•
Planigale ingrami	Long-tailed Planigale			•	•										•	•			
Ningaui ridei	Wongai Ningaui			•	•						•								
Pseudantechinus woolleyae	Woolley's Pseudantechinus			•	•													•	
Sminthopsis hirtipes	Hairy-footed Dunnart			•															
Sminthopsis ooldea	Ooldea Dunnart			•	•														
Thylacomyidae																			
Macrotis lagotis	Bilby, Dalgyte	S1	•																
Notoryctidae																			
Notoryctes caurinus	Northern Marsupial Mole	S1	•																
Macropodidae																			
Macropus robustus	Euro			•	•	•			•	•		•			•	•		•	•
Macropus rufus	Red Kangaroo, Marlu			•	•	•			•	•	•	•							•
Petrogale rothschildi	Rothschild's Rock-wallaby			•											•	•		•	•
Muridae																			
Leggadina lakedownensis	Short-tailed Mouse	P4							•	•									
Mus musculus	House Mouse		•	•	•	•	•		•	•			•	•	•				•
Pseudomys chapmani	Western Pebble-mound Mouse	P4		•	•	•				•		•			•	•	•		•
Pseudomys delicatulus	Delicate Mouse									•									
Pseudomys desertor	Desert Mouse			•	•		•		•	•					•	•			•
Pseudomys hermannsburgensis	Sandy Inland Mouse			•	•	•	•		•	•		•	•		•	•		•	•
Zyzomys argurus	Common Rock-rat			•	•	•	•		•			•			•	•	•	•	•
Notomys alexis	Spinifex Hopping-mouse			•	•						•								•
Leporidae																			
Oryctolagus cuniculus	Rabbit		•																
Canidae																			
Canis lupus			•	•		•				•	•				•	•			
Canis lupus dingo	Dingo				•						•						•		•
Vulpes vulpes	Red Fox		•																
Felidae																			
Felis catus	Cat		•	•		•				•	•						•	•	
Equidae																			
Equus asinus	Donkey		•							•		•							
Equus caballus	Horse		•	•						•						•			•
Camelus dromedarius	Dromedary, Camel		•	•		•				•						•			
Bos taurus	European Cattle			•		•					•	•			•	•			

Bats

Family / Species Name	Common Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Emballonuridae																
Taphozous georgianus	Common Sheathtail-bat			•	•		•	•		•	•	•	•	•	•	•
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat			•	•			•	•	•	•	•	•		•	•
Taphozous hilli	Hill's Sheathtail-bat			•	•								•			
Hipposideridae																
Rhinonicteris aurantius	Orange Leafnosed-bat	S1	•	•									•			
Megadermatidae																
Macroderma gigas	Ghost Bat	P4		•	•		•					•				
Molossidae																
Tadarida australis	White-striped Freetail-bat			•	•		•	•	•		•	•	•		•	
Chaerephon jobensis	Northern Freetail-bat			•	•		•	•	•	•		•	•	•	•	•
Mormopterus loriae	Little Northern Freetail-bat						•									
Mormopterus beccarii	Beccari's Freetail-bat			•	•			•		•		•	•		•	•
Pteropodidae																
Pteropus scapulatus	Little Red Flying-fox							•								
Vespertilionidae																
Nyctophilus arnhemensis	Arnhem Land Long-eared Bat						•									
Chalinolobus gouldii	Gould's Wattled Bat			•	•	•	•	•	•	•	•	•	•	•	•	•
Scotorepens greyii	Little Broad-nosed Bat			•	•	•	•	•	•	•	•	•	•	•	•	•
Vespadelus finlaysoni	Finlayson's Cave Bat			•	•	•	•	•	•	•	•	•	•	•	•	•
Nyctophilus geoffroyi	Lesser Long-eared Bat			•	•				•	•		•	•		•	•
Scotorepens balstoni	Inland Broad-nosed Bat				•				•							
Chalinolobus morio	Chocolate Wattled Bat			•	•					•		•	•		•	•
Nyctophilus daedalus	Northwestern Long-eared Bat			•	•								•			

Reptiles

Family / Species Name	Common Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2009a)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Cheluidae																	
Chelodina steindachneri	Flat-shelled Turtle												•				
Carphodactylidae																	
Nephrurus levis									•								
Nephrurus wheeleri				•	•		•			•			•	•			•
Underwoodisaurus seorsus	Pilbara Barking Gecko	P1		•									•				
Diplodactylidae																	
Crenadactylus ocellatus	Clawless Gecko			•	•								•				
Diplodactylus conspicillatus	Fat-tailed Gecko			•	•	•	•		•	•							•
Diplodactylus mitchelli								•									
Diplodactylus pulcher				•	•								•				
Diplodactylus savagei	Southern Pilbara Beak-faced Gecko			•	•		•	•					•	•			
Lucasium stenodactylum				•	•	•	•	•	•	•	•		•	•			•
Lucasium wombeyi				•	•								•	•			
Oedura marmorata	Marbled Velvet Gecko			•	•	•		•			•			•	•		
Rhynchoedura ornata	Western Beaked Gecko			•	•	•	•	•		•			•	•			•
Strophurus elderi				•	•				•	•			•				
Strophurus jeanae				•	•					•							•
Strophurus wellingtonae				•	•				•	•			•				•
Gekkonidae																	
Gehyra pilbara				•	•	•								•			
Gehyra punctata				•	•		•	•	•	•	•		•	•			•
Gehyra purpurascens				•	•												
Gehyra variegata				•	•	•	•	•	•	•			•	•			•
Heteronotia binoei	Bynoe's Gecko			•	•	•		•	•	•			•	•			•
Heteronotia spelea	Pilbara Cave Gecko			•	•			•					•	•			
Pygopodidae																	
Delma butleri				•													•
Delma elegans				•	•												
Delma haroldi				•	•				•								
Delma nasuta				•	•		•	•	•	•	•		•	•			
Delma pax				•	•			•	•	•	•		•	•			•
Delma tincta				•	•		•	•	•				•	•			•
Lialis burtonis				•	•			•	•	•			•	•			•
Pygopus nigriceps				•	•		•		•	•			•				
Agamidae																	
Amphibolurus longirostris				•	•	•				•			•	•			•
Ctenophorus caudicinctus	Ring-tailed Dragon			•	•	•	•	•	•	•	•		•	•			•
Ctenophorus isolepis	Military Dragon			•	•	•	•		•	•	•		•	•			•
Ctenophorus nuchalis	Central Netted Dragon			•	•	•		•		•							•
Ctenophorus reticulatus	Western Netted Dragon			•	•				•								•
Diporiphora amphiboluroides	Mulga Dragon				•				•				•	•			
Diporiphora valens	Southern Pilbara Tree Dragon			•										•			
Pogona minor				•	•	•		•	•	•			•	•			•
Tympanocryptis cephalus	Pebble Dragon			•	•												

Family / Species Name	Common Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2009a)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Egerniidae																	
Cyclodomorphus melanops	Slender Blue-tongue			•	•		•		•	•	•		•	•			•
Egernia cygnitos	Western Pilbara Spiny-tailed Skink			•	•												
Egernia depressa	Southern Pygmy Spiny-tailed Skink			•	•												
Egernia formosa				•	•	•	•	•					•	•			•
Egernia pilbarensis	Pilbara Skink					•											
Tiliqua multifasciata	Central Blue-tongue			•	•		•		•	•			•	•			•
Tiliqua rugosa										•							
Eugongylidae																	
Carlia munda				•	•	•	•	•	•	•	•		•	•			•
Carlia triacantha				•	•			•	•				•	•			•
Cryptoblepharus buchananii				•	•												
Cryptoblepharus plagiocephalus				•	•	•						•					
Cryptoblepharus ustulatus				•	•								•	•	•		•
Menetia greyii				•	•	•	•		•		•		•	•			•
Menetia surda				•	•								•				
Morethia ruficauda				•	•	•	•	•	•	•			•	•	•		•
Proablepharus reginae				•	•		•		•	•							
Sphenomorphidae																	
Ctenotus ariadnae				•	•				•	•							•
Ctenotus atlas				•													
Ctenotus duricola				•	•	•		•	•	•	•		•	•			•
Ctenotus grandis				•	•			•	•				•				•
Ctenotus hanloni				•	•				•	•	•	•					
Ctenotus helenae				•	•	•			•	•			•	•			•
Ctenotus leonhardii				•							•						
Ctenotus pantherinus	Leopard Ctenotus			•	•	•	•	•	•	•	•		•	•			•
Ctenotus piankai									•								
Ctenotus quattuordecimlineatus				•													
Ctenotus rubicundus				•	•		•	•	•		•		•	•			
Ctenotus rutilans				•	•								•	•			
Ctenotus saxatilis	Rock Ctenotus			•	•	•	•	•	•	•			•	•	•		•
Ctenotus schomburgkii				•	•		•		•	•			•	•			•
Ctenotus serventyi				•	•				•	•							•
Ctenotus uber				•													
Eremiascincus pallidus	Western Narrow-banded Skink			•	•												
Eremiascincus richardsonii	Broad-banded Sand Swimmer			•									•	•			
Lerista amicorum				•	•												
Lerista bipes				•					•	•							•
Lerista jacksoni				•													
Lerista labialis				•	•	•				•							•
Lerista macropisthopus				•													
Lerista muelleri				•	•			•	•	•			•	•			•
Lerista neander				•	•								•				
Lerista timida				•	•												
Lerista verhmens				•													

Family / Species Name	Common Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2009a)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Lerista zietzi				•	•		•							•			
Notoscincus ornatus				•	•	•		•	•								
Varanidae																	
Varanus acanthurus	Spiny-tailed Monitor			•	•		•	•	•	•			•	•			•
Varanus brevicauda	Short-tailed Pygmy Monitor			•	•				•	•			•	•			•
Varanus bushi	Pilbara Mulga Monitor			•	•								•				•
Varanus caudolineatus				•	•												
Varanus eremius	Pygmy Desert Monitor			•	•			•	•	•		•					•
Varanus giganteus	Perentie			•	•				•								•
Varanus gilleni	Pygmy Mulga Monitor									•							
Varanus gouldii	Bungarra or Sand Monitor			•	•	•				•				•			•
Varanus panoptes	Yellow-spotted Monitor			•	•				•	•			•	•			•
Varanus pilbarensis	Pilbara Rock Monitor			•	•	•	•						•	•	•		•
Varanus tristis	Racehorse Monitor			•	•	•	•	•		•		•	•	•			•
Typhlopidae																	
Anilios ammodytes				•	•				•	•				•			•
Anilios ganei		P1		•	•			•									
Anilios grypus				•	•			•	•	•			•	•			•
Anilios hamatus				•	•								•				
Anilios waitii				•	•												
Boidae																	
Antaresia perthensis	Pygmy Python			•	•				•	•			•	•			•
Antaresia stimsoni	Stimson's Python			•	•								•	•			•
Aspidites melanocephalus	Black-headed Python			•										•			
Liasis olivaceus barroni	Pilbara Olive Python	S1	•	•	•					•							•
Elapidae																	
Acanthophis wellsi	Pilbara Death Adder			•	•												•
Brachyurophis approximans				•	•			•	•	•			•				•
Demansia psammophis	Yellow-faced Whipsnake			•	•		•	•	•	•	•			•			•
Demansia rufescens	Rufous Whipsnake			•									•	•			•
Furina ornata	Moon Snake			•					•				•	•			
Parasuta monachus				•	•		•			•	•		•	•			•
Pseudechis australis	Mulga Snake			•	•				•			•	•	•		•	•
Pseudonaja mengdeni	Western Brown Snake			•	•								•	•			•
Pseudonaja modesta	Ringed Brown Snake			•	•			•					•	•	•		
Pseudonaja nuchalis	Gwardar; Northern Brown Snake			•						•							
Suta fasciata	Rosen's Snake			•	•			•	•	•			•				
Suta punctata	Spotted Snake			•				•	•								

Amphibians

Family / Species Name	Common Name	Conservation Status	EPBC	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2009a)	Biota (2012a)	Biota (2013b)	Biota (2012b)	Biota (2014c)	This Survey
Hylidae																	
Cyclorana maini	Sheep Frog					•		•	•	•	•		•	•			•
Cyclorana platycephala	Water-holding Frog												•				
Litoria rubella	Little Red Tree Frog						•	•	•	•	•	•	•	•			•
Limnodynastidae																	
Neobatrachus sutor	Shoemaker Frog												•				
Notaden nichollsi	Desert Spadefoot								•								
Myobatrachidae																	
Uperoleia saxatilis	Pilbara Toadlet							•	•	•			•	•			•

Avifauna

Family / Common Name	Species Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2014c)	This Survey
Casuariidae															
Emu	*Dromaius novaehollandiae*			•	•	•		•	•	•		•	•	•	•
Phasianidae															
Stubble Quail	*Coturnix pectoralis*								•		•				
Brown Quail	*Coturnix ypsilophora*			•	•				•						•
Anatidae															
Plumed Whistling-duck	*Dendrocygna eytoni*			•	•										
Australian Shelduck	*Tadorna tadornoides*			•	•										
Australian Wood Duck	*Chenonetta jubata*			•	•										
Grey Teal	*Anas gracilis*			•	•			•		•	•				
Pacific Black Duck	*Anas superciliosa*			•	•			•	•	•			•		•
Hardhead	*Aythya australis*			•	•										
Podicipedidae															
Australasian Grebe	*Tachybaptus novaehollandiae*			•	•										
Hoary-headed Grebe	*Poliocephalus poliocephalus*				•										
Columbidae															
Common Bronzewing	*Phaps chalcoptera*			•	•	•		•	•			•	•		•
Crested Pigeon	*Ocyphaps lophotes*			•	•	•		•	•	•	•	•	•		•
Spinifex Pigeon	*Geophaps plumifera*			•	•	•		•	•	•	•	•	•		•
Diamond Dove	*Geopelia cuneata*			•	•	•		•	•	•	•	•	•		•
Peaceful Dove	*Geopelia striata*			•	•	•		•	•	•	•	•			•
Podargidae															
Tawny Frogmouth	*Podargus strigoides*			•	•			•	•			•	•		
Eurostopodidae															
Spotted Nightjar	*Eurostopodus argus*			•	•	•		•				•	•		•
Aegothelidae															
Australian Owlet-nightjar	*Aegotheles cristatus*			•	•	•		•	•			•	•		•
Apodidae															
Fork-tailed Swift	*Apus pacificus*	S3/M	•	•					•						•
Anhingidae															
Australasian Darter	*Anhinga novaehollandiae*			•	•							•	•		•
Phalacrocoracidae															
Little Pied Cormorant	*Microcarbo melanoleucos*				•						•				
Little Black Cormorant	*Phalacrocorax sulcirostris*			•	•										
Pied Cormorant	*Phalacrocorax varius*			•									•		
Pelecanidae															
Australian Pelican	*Pelecanus conspicillatus*			•	•			•					•		
Ciconiidae															
Black-necked Stork	*Ephippiorhynchus asiaticus*							•	•						
Ardeidae															
White-necked Heron	*Ardea pacifica*			•	•			•		•					•
Eastern Great Egret	*Ardea modesta*	S3/M	•	•					•						•
Cattle Egret	*Ardea ibis*	S3/M	•												
White-faced Heron	*Egretta novaehollandiae*			•	•	•		•	•		•		•		
Little Egret	*Egretta garzetta*				•										
Nankeen Night-Heron	*Nycticorax caledonicus*			•				•					•		

Family / Common Name	Species Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2014c)	This Survey
Threskiornithidae															
Straw-necked Ibis	*Threskiornis spinicollis*			•	•				•						•
Yellow-billed Spoonbill	*Platalea flavipes*			•	•										
Accipitridae															
Black-shouldered Kite	*Elanus axillaris*			•	•				•						•
Square-tailed Kite	*Lophoictinia isura*			•					•						
Black-breasted Buzzard	*Hamirostra melanosternon*							•	•	•	•				•
Whistling Kite	*Haliastur sphenurus*			•	•	•		•	•	•	•	•	•		•
Black Kite	*Milvus migrans*			•	•			•	•			•	•		•
Brown Goshawk	*Accipiter fasciatus*			•	•	•		•	•	•			•		•
Collared Sparrowhawk	*Accipiter cirrocephalus*			•	•	•		•	•			•			•
Spotted Harrier	*Circus assimilis*			•	•	•		•	•	•		•	•		•
Swamp Harrier	*Circus approximans*			•	•				•						
Wedge-tailed Eagle	*Aquila audax*			•	•			•	•				•		
Little Eagle	*Hieraaetus morphnoides*			•	•			•	•		•				•
Falconidae															
Nankeen Kestrel	*Falco cenchroides*			•	•	•		•	•	•	•	•	•		•
Brown Falcon	*Falco berigora*			•	•	•		•	•	•	•	•	•		•
Australian Hobby	*Falco longipennis*			•	•	•		•	•			•	•		•
Grey Falcon	*Falco hypoleucos*	S1			•										
Black Falcon	*Falco subniger*								•						
Peregrine Falcon	*Falco peregrinus*	S4		•	•	•		•	•				•		
Rallidae															
Purple Swamphen	*Porphyrio porphyrio*														•
Spotless Crake	*Porzana tabuensis*														•
Black-tailed Native-hen	*Tribonyx ventralis*				•										
Eurasian Coot	*Fulica atra*							•		•					
Otididae															
Australian Bustard	*Ardeotis australis*	P4		•	•	•		•	•	•		•	•	•	•
Burhinidae															
Bush Stone-curlew	*Burhinus grallarius*	P4			•			•							
Recurvirostridae															
Black-winged Stilt	*Himantopus himantopus*			•	•										
Charadriidae															
Oriental Plover	*Charadrius veredus*	S3/M	•												
Black-fronted Dotterel	*Elseyornis melanops*			•	•	•		•	•	•	•		•		•
Red-kneed Dotterel	*Erythrogonys cinctus*				•										•
Rostratulidae															
Australian Painted Snipe	*Rostratula australis*	S1	•	•											
Scolopacidae															
Common Greenshank	*Tringa nebularia*	S3/M		•									•		
Turnicidae															
Little Button-quail	*Turnix velox*			•	•	•		•	•	•		•	•		•
Cacatuidae															
Galah	*Eolophus roseicapillus*			•	•	•		•	•			•	•		•
Little Corella	*Cacatua sanguinea*			•	•	•		•	•	•	•	•	•		•
Cockatiel	*Nymphicus hollandicus*			•	•			•	•	•		•	•		•

Family / Common Name	Species Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2014c)	This Survey
Psittacidae															
Australian Ringneck	*Barnardius zonarius*			•	•	•	•			•		•	•		•
Mulga Parrot	*Psephotus varius*			•	•		•								•
Budgerigar	*Melopsittacus undulatus*			•	•	•		•	•	•		•	•		•
Bourke's Parrot	*Neopsephotus bourkii*				•				•						
Elegant Parrot	*Neophema elegans*								•						
Night Parrot	*Pezoporus occidentalis*	S1		•											
Cuculidae															
Pheasant Coucal	*Centropus phasianinus*			•	•				•		•				
Horsfield's Bronze-Cuckoo	*Chalcites basalis*			•	•	•		•	•	•	•	•	•		•
Black-eared Cuckoo	*Chalcites osculans*			•			•	•	•	•					•
Pallid Cuckoo	*Cacomantis pallidus*			•	•			•	•	•	•	•			
Strigidae															
Barking Owl	*Ninox connivens*			•	•	•		•		•			•		•
Southern Boobook	*Ninox novaeseelandiae*			•	•	•		•				•	•		•
Tytonidae															
Eastern Barn Owl	*Tyto javanica*			•	•			•							•
Halcyonidae															
Blue-winged Kookaburra	*Dacelo leachii*			•	•	•		•	•	•	•		•		•
Red-backed Kingfisher	*Todiramphus pyrrhopygius*			•	•	•		•	•	•	•	•	•		
Sacred Kingfisher	*Todiramphus sanctus*			•	•	•		•	•	•		•	•		•
Meropidae															
Rainbow Bee-eater	*Merops ornatus*	S3/M	•	•	•	•	•	•	•	•	•	•	•		•
Climacteridae															
White-browed Treecreeper	*Climacteris affinis*						•								
Black-tailed Treecreeper	*Climacteris melanura*				•										
Ptilonorhychidae															
Spotted Bowerbird	*Ptilonorhynchus maculatus*			•	•										
Western Bowerbird	*Ptilonorhynchus guttatus*				•			•				•	•		•
Maluridae															
Splendid Fairy-wren	*Malurus splendens*				•		•								
White-winged Fairy-wren	*Malurus leucopterus*			•		•		•	•	•		•	•		•
Variegated Fairy-wren	*Malurus lamberti*			•	•	•	•	•	•	•	•	•	•		•
Rufous-crowned Emu-wren	*Stipiturus ruficeps*			•				•	•	•					
Striated Grasswren	*Amytornis striatus*			•	•			•	•						
Acanthizidae															
Redthroat	*Pyrrholaemus brunneus*			•	•		•		•						
Weebill	*Smicrornis brevirostris*			•	•	•	•	•	•	•	•	•	•		•
Western Gerygone	*Gerygone fusca*			•	•	•		•	•	•	•	•	•		•
Slaty-backed Thornbill	*Acanthiza robustirostris*			•	•	•	•		•						
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*			•	•							•			
Chestnut-rumped Thornbill	*Acanthiza uropygialis*			•	•	•	•	•	•	•		•			•
Inland Thornbill	*Acanthiza apicalis*			•	•		•			•		•	•		•
Southern Whiteface	*Aphelocephala leucopsis*			•	•		•		•						
Pardalotidae															
Red-browed Pardalote	*Pardalotus rubricatus*			•	•	•		•	•	•	•	•	•		•
Striated Pardalote	*Pardalotus striatus*			•	•	•	•	•	•		•	•	•		•

Family / Common Name	Species Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2014c)	This Survey
Meliphagidae															
Pied Honeyeater	*Certhionyx variegatus*			•					•						
Singing Honeyeater	*Lichenostomus virescens*			•	•	•	•	•	•	•	•	•	•		•
White-eared Honeyeater	*Lichenostomus leucotis*						•								
Grey-headed Honeyeater	*Lichenostomus keartlandi*				•	•		•	•	•	•	•	•		•
White-plumed Honeyeater	*Lichenostomus penicillatus*			•	•	•		•	•	•	•	•	•		•
White-fronted Honeyeater	*Purnella albifrons*					•		•							•
Yellow-throated Miner	*Manorina flavigula*			•	•	•	•	•	•	•	•	•	•		•
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*			•	•		•	•	•	•	•	•	•		•
Grey Honeyeater	*Conopophila whitei*			•								•			•
Crimson Chat	*Epthianura tricolor*			•	•	•		•	•			•	•		•
Black Honeyeater	*Sugomel niger*			•	•			•	•	•		•			
Brown Honeyeater	*Lichmera indistincta*			•	•	•		•	•	•	•	•	•		•
Black-chinned Honeyeater	*Melithreptus gularis*			•	•			•	•	•		•	•		•
Pomatostomidae															
Grey-crowned Babbler	*Pomatostomus temporalis*			•	•	•		•	•	•	•	•	•		•
White-browed Babbler	*Pomatostomus superciliosus*			•	•		•		•			•			
Eupetidae															
Chestnut-breasted Quail-thrush	*Cinclosoma castaneothorax*			•	•		•		•						
Chiming Wedgebill	*Psophodes occidentalis*			•	•										
Neosittidae															
Varied Sittella	*Daphoenositta chrysoptera*				•		•	•	•	•					
Campephagidae															
Ground Cuckoo-shrike	*Coracina maxima*			•					•			•	•		
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*			•	•	•	•	•	•	•	•	•	•		•
White-winged Triller	*Lalage sueurii*			•	•	•		•	•	•		•	•		•
Pachycephalidae															
Rufous Whistler	*Pachycephala rufiventris*			•	•	•	•	•	•	•	•	•	•		•
Grey Shrike-thrush	*Colluricincla harmonica*			•	•	•	•	•	•	•	•	•	•		•
Crested Bellbird	*Oreoica gutturalis*			•	•	•	•	•	•	•	•	•	•		•
Artamidae															
Masked Woodswallow	*Artamus personatus*			•	•	•			•		•	•	•		•
Black-faced Woodswallow	*Artamus cinereus*			•	•			•	•	•	•	•	•		•
Little Woodswallow	*Artamus minor*			•	•			•		•	•	•	•		•
Grey Butcherbird	*Cracticus torquatus*			•	•	•	•	•	•	•	•	•			•
Pied Butcherbird	*Cracticus nigrogularis*			•	•	•	•	•	•	•	•	•	•		•
Australian Magpie	*Cracticus tibicen*			•	•	•	•	•	•	•	•	•	•		•
Grey Currawong	*Strepera versicolor*						•								
Rhipiduridae															
Grey Fantail	*Rhipidura albiscapa*			•	•		•	•	•	•	•	•	•		
Willie Wagtail	*Rhipidura leucophrys*			•	•	•		•	•	•	•	•	•		•
Corvidae															
Australian Raven	*Corvus coronoides*						•						•		
Little Crow	*Corvus bennetti*			•	•				•		•	•			
Torresian Crow	*Corvus orru*			•	•	•		•	•		•	•	•	•	•
Monarchidae															
Magpie-lark	*Grallina cyanoleuca*			•	•	•		•	•	•	•	•	•		•

Family / Common Name	Species Name	Conservation Status	EPBC PMD	NatureMap + 40km	ALA + 40km	Ninox Wildlife Consulting (1994)	Biota (2002a)	Biota (2004a), Biota (2004b)	Biota (2005a), Biota (2004c)	Biota (2005b)	Biota (2010a), Biota (2010b)	Biota (2012a)	Biota (2013b)	Biota (2014c)	This Survey
Petroicidae															
Red-capped Robin	*Petroica goodenovii*			•	•	•	•	•	•	•	•	•	•		•
Hooded Robin	*Melanodryas cucullata*			•	•	•		•	•	•	•	•	•		•
Western Yellow Robin	*Eopsaltria griseogularis*						•								
Alaudidae															
Horsfield's Bushlark	*Mirafra javanica*			•	•								•		•
Acrocephalidae															
Australian Reed-Warbler	*Acrocephalus australis*			•	•			•					•		•
Megaluridae															
Rufous Songlark	*Cincloramphus mathewsi*			•	•	•		•	•	•	•	•	•		•
Brown Songlark	*Cincloramphus cruralis*			•	•			•	•			•	•		
Spinifexbird	*Eremiornis carteri*			•	•			•	•	•		•	•		•
Hirundinidae															
White-backed Swallow	*Cheramoeca leucosterna*														•
Welcome Swallow	*Hirundo neoxena*				•										
Fairy Martin	*Petrochelidon ariel*			•	•			•		•		•	•		
Tree Martin	*Petrochelidon nigricans*			•	•	•		•	•	•	•	•	•		•
Nectariniidae															
Mistletoebird	*Dicaeum hirundinaceum*			•	•	•	•	•	•	•	•	•			•
Estrildidae															
Zebra Finch	*Taeniopygia guttata*			•	•	•		•	•	•	•	•	•		•
Star Finch	*Neochmia ruficauda*	P4		•	•			•			•				•
Painted Finch	*Emblema pictum*			•	•	•		•	•	•	•	•	•		•
Motacillidae															
Australasian Pipit	*Anthus novaeseelandiae*			•	•	•		•	•				•		

Appendix 2

NatureMap Database Search Results

NatureMap Species Report

Created By penny brooshooft on 31/10/2014

Kingdom	Animalia
Current Names Only	Yes
Core Datasets Only	Yes
Species Group	Amphibians
Method	'By Circle'
Centre	119°18' 36" E,22°47' 08" S
Buffer	39km
Group By	Species Group

Species Group	Species	Records
Amphibian	7	360
TOTAL	**7**	**360**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Amphibian					
1.	25375	*Cyclorana maini (Sheep Frog)*			
2.	25376	*Cyclorana platycephala (Water-holding Frog)*			
3.	25392	*Litoria rubella (Little Red Tree Frog)*			
4.	25427	*Neobatrachus sutor (Shoemaker Frog)*			
5.	25432	*Pseudophryne douglasi (Gorge Toadlet)*			
6.	25445	*Uperoleia russelli (Northwest Toadlet)*			
7.	41428	*Uperoleia saxatilis (Pilbara Toadlet)*			

Conservation Codes
T - Rare or likely to become extinct
X - Presumed extinct
IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3
4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

NatureMap Species Report

Created By penny brooshooft on 31/10/2014

Kingdom	Animalia
Current Names Only	Yes
Core Datasets Only	Yes
Species Group	Reptiles
Method	'By Circle'
Centre	119°18' 36" E,22°47' 08" S
Buffer	39km
Group By	Species Group

Species Group	Species	Records
Reptile	139	5270
TOTAL	**139**	**5270**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Reptile					
1.	25332	*Acanthophis wellsi (Pilbara Death Adder)*			
2.	30833	*Amphibolurus longirostris (Long-nosed Dragon)*			
3.	25318	*Antaresia perthensis (Pygmy Python)*			
4.	25448	*Antaresia stimsoni (Stimson's Python)*			
5.	25319	*Antaresia stimsoni subsp. orientalis (Stimson's Python)*			
6.	25241	*Antaresia stimsoni subsp. stimsoni (Stimson's Python)*			
7.	25320	*Aspidites melanocephalus (Black-headed Python)*			
8.	25331	*Brachyurophis approximans (North-western Shovel-nosed Snake)*			
9.	25015	*Carlia munda (Shaded-litter Rainbow Skink)*			
10.	25017	*Carlia triacantha (Desert Rainbow Skink)*			
11.	25456	*Crenadactylus ocellatus (Clawless Gecko)*			
12.	24919	*Crenadactylus ocellatus subsp. horni (Clawless Gecko)*			
13.	24921	*Crenadactylus ocellatus subsp. rostralis (Clawless Gecko)*			
14.	30893	*Cryptoblepharus buchananii*			
15.	25020	*Cryptoblepharus plagiocephalus*			
16.	30892	*Cryptoblepharus ustulatus*			
17.	25458	*Ctenophorus caudicinctus (Ring-tailed Dragon)*			
18.	24865	*Ctenophorus caudicinctus subsp. caudicinctus (Ring-tailed Dragon)*			
19.	25459	*Ctenophorus isolepis (Crested Dragon, Military Dragon)*			
20.	24874	*Ctenophorus isolepis subsp. citrinus (Crested Dragon, Military Dragon)*			
21.	24875	*Ctenophorus isolepis subsp. gularis (Central Military Dragon)*			
22.	24876	*Ctenophorus isolepis subsp. isolepis (Crested Dragon, Military Dragon)*			
23.	24882	*Ctenophorus nuchalis (Central Netted Dragon)*			
24.	24886	*Ctenophorus reticulatus (Western Netted Dragon)*			
25.	25025	*Ctenotus ariadnae*			
26.	25026	*Ctenotus atlas*			
27.	25036	*Ctenotus duricola*			
28.	25462	*Ctenotus grandis*			
29.	25041	*Ctenotus grandis subsp. grandis*			
30.	25043	*Ctenotus grandis subsp. titan*			
31.	25044	*Ctenotus hanloni*			
32.	25045	*Ctenotus helenae*			
33.	25052	*Ctenotus leonhardii*			
34.	25463	*Ctenotus pantherinus (Leopard Ctenotus)*			
35.	25060	*Ctenotus pantherinus subsp. acripes (Leopard Ctenotus)*			
36.	25064	*Ctenotus pantherinus subsp. ocellifer (Leopard Ctenotus)*			
37.	25065	*Ctenotus pantherinus subsp. pantherinus (Leopard Ctenotus)*			
38.	25066	*Ctenotus quattuordecimlineatus*			
39.	25072	*Ctenotus rubicundus*			
40.	25071	*Ctenotus rutilans*			
41.	25073	*Ctenotus saxatilis (Rock Ctenotus)*			
42.	25074	*Ctenotus schomburgkii*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
43.	25077	*Ctenotus serventyi*			
44.	25465	*Ctenotus uber (Spotted Ctenotus)*			
45.	25086	*Cyclodomorphus branchialis (Gilled Slender Blue-tongue Skink)*		T	
46.	25466	*Cyclodomorphus melanops (Slender Blue-tongue)*			
47.	25089	*Cyclodomorphus melanops subsp. elongatus (Slender Blue-tongue)*			
48.	25090	*Cyclodomorphus melanops subsp. melanops (Slender Blue-tongue)*			
49.	24997	*Delma butleri*			
50.	24998	*Delma elegans*			
51.	25000	*Delma haroldi*			
52.	25001	*Delma nasuta*			
53.	25002	*Delma pax*			
54.	25004	*Delma tincta*			
55.	25468	*Demansia psammophis (Yellow-faced Whipsnake)*			
56.	25295	*Demansia psammophis subsp. cupreiceps (Yellow-faced Whipsnake)*			
57.	25297	*Demansia rufescens (Rufous Whipsnake)*			
58.	24926	*Diplodactylus conspicillatus (Fat-tailed Gecko)*			
59.	24940	*Diplodactylus pulcher*			
60.	24944	*Diplodactylus savagei (Southern Pilbara Beak-faced Gecko)*			
61.	24899	*Diporiphora valens (Southern Pilbara Tree Dragon)*			
62.	41406	*Egernia cygnitos (Western Pilbara Spiny-tailed Skink)*			
63.	25092	*Egernia depressa (Southern Pygmy Spiny-tailed Skink)*			
64.	25094	*Egernia formosa*			
65.	43381	*Eremiascincus pallidus (Western Narrow-banded Skink, Narrow-banded Sand Swimmer)*			
66.	25109	*Eremiascincus richardsonii (Broad-banded Sand Swimmer)*			
67.	25301	*Furina ornata (Moon Snake)*			
68.	24956	*Gehyra pilbara*			
69.	24958	*Gehyra punctata*			
70.	24957	*Gehyra purpurascens*			
71.	24959	*Gehyra variegata*			
72.	24961	*Heteronotia binoei (Bynoe's Gecko)*			
73.	-18513	*Heteronotia sp.*			
74.	24962	*Heteronotia spelea (Desert Cave Gecko)*			
75.	30926	*Lerista amicorum*			
76.	25125	*Lerista bipes*			
77.	30929	*Lerista jacksoni*			
78.	25146	*Lerista labialis*			
79.	25151	*Lerista macropisthopus subsp. fusciceps*			
80.	25155	*Lerista muelleri*			
81.	25156	*Lerista neander*			
82.	42411	*Lerista timida*			
83.	30925	*Lerista verhmens*			
84.	25183	*Lerista zietzi*			
85.	25005	*Lialis burtonis*			
86.	25238	*Liasis olivaceus subsp. barroni (Pilbara Olive Python)*		T	
87.	-18483	*Lucasium sp.*			
88.	30933	*Lucasium stenodactylum*			
89.	30934	*Lucasium wombeyi*			
90.	25184	*Menetia greyii*			
91.	25491	*Menetia surda*			
92.	25187	*Menetia surda subsp. surda*			
93.	25495	*Morethia ruficauda*			
94.	25193	*Morethia ruficauda subsp. exquisita*			
95.	25498	*Nephrurus wheeleri*			
96.	24972	*Nephrurus wheeleri subsp. cinctus*			
97.	25499	*Notoscincus ornatus*			
98.	25197	*Notoscincus ornatus subsp. ornatus*			
99.	24976	*Oedura marmorata (Marbled Velvet Gecko)*			
100.	25254	*Parasuta monachus*			
101.	25510	*Pogona minor (Dwarf Bearded Dragon)*			
102.	24907	*Pogona minor subsp. minor (Dwarf Bearded Dragon)*			
103.	24908	*Pogona minor subsp. mitchelli (Dwarf Bearded Dragon)*			
104.	25199	*Proablepharus reginae*			
105.	25261	*Pseudechis australis (Mulga Snake)*			
106.	42416	*Pseudonaja mengdeni (Western Brown Snake)*			
107.	25263	*Pseudonaja modesta (Ringed Brown Snake)*			
108.	25264	*Pseudonaja nuchalis (Gwardar, Northern Brown Snake)*			
109.	25009	*Pygopus nigriceps*			
110.	25270	*Ramphotyphlops ammodytes*			
111.	25276	*Ramphotyphlops ganei (blind snake)*		P1	

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
112.	25277	*Ramphotyphlops grypus*			
113.	25279	*Ramphotyphlops hamatus*			
114.	25288	*Ramphotyphlops waitii*			
115.	24982	*Rhynchoedura ornata (Western Beaked Gecko)*			
116.	24927	*Strophurus elderi*			
117.	24932	*Strophurus jeanae*			
118.	24949	*Strophurus wellingtonae*			
119.	25269	*Suta fasciata (Rosen's Snake)*			
120.	25307	*Suta punctata (Spotted Snake)*			
121.	25202	*Tiliqua multifasciata (Central Blue-tongue)*			
122.	30814	*Tympanocryptis cephalus (Pebble Dragon)*			
123.	24983	*Underwoodisaurus milii (Barking Gecko)*			
124.	41426	*Underwoodisaurus seorsus (Pilbara Barking Gecko)*		P1	
125.	25209	*Varanus acanthurus (Spiny-tailed Monitor)*			
126.	25210	*Varanus brevicauda (Short-tailed Pygmy Monitor)*			
127.	30825	*Varanus bushi (Pilbara Mulga Monitor)*			
128.	25211	*Varanus caudolineatus*			
129.	25212	*Varanus eremius (Pygmy Desert Monitor)*			
130.	25216	*Varanus giganteus (Perentie)*			
131.	25218	*Varanus gouldii (Bungarra or Sand Monitor)*			
132.	25524	*Varanus panoptes (Yellow-spotted Monitor)*			
133.	25222	*Varanus panoptes subsp. panoptes*			
134.	25223	*Varanus panoptes subsp. rubidus*			
135.	25224	*Varanus pilbarensis (Pilbara Rock Monitor)*			
136.	25526	*Varanus tristis (Racehorse Monitor)*			
137.	25227	*Varanus tristis subsp. tristis (Racehorse Monitor)*			

Conservation Codes
T - Rare or likely to become extinct
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IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3
4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

NatureMap Species Report

Created By penny brooshooft on 31/10/2014

Kingdom	Animalia
Current Names Only	Yes
Core Datasets Only	Yes
Species Group	Mammals
Method	'By Circle'
Centre	119°18' 36" E,22°47' 08" S
Buffer	39km
Group By	Species Group

Species Group	Species	Records
Mammal	45	1401
TOTAL	**45**	**1401**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Mammal					
1.	24251	*Bos taurus (European Cattle)*	Y		
2.	24254	*Camelus dromedarius (Dromedary, Camel)*	Y		
3.	25454	*Canis lupus (Dog, Dingo)*	Y		
4.	24039	*Canis lupus subsp. dingo (Dingo)*	Y		
5.	30883	*Canis lupus subsp. familiaris (Dog)*	Y		
6.	24181	*Chaerephon jobensis (Northern Freetail-bat)*			
7.	24186	*Chalinolobus gouldii (Gould's Wattled Bat)*			
8.	24187	*Chalinolobus morio (Chocolate Wattled Bat)*			
9.	24091	*Dasykaluta rosamondae (Little Red Kaluta)*			
10.	24092	*Dasyurus geoffroii (Chuditch, Western Quoll)*		T	
11.	24093	*Dasyurus hallucatus (Northern Quoll)*		T	
12.	24258	*Equus caballus (Horse)*	Y		
13.	24041	*Felis catus (Cat)*	Y		
14.	24180	*Macroderma gigas (Ghost Bat)*		P4	
15.	25489	*Macropus robustus (Euro)*			
16.	24135	*Macropus robustus subsp. erubescens (Euro, Biggada)*			
17.	24136	*Macropus rufus (Red Kangaroo, Marlu)*			
18.	24182	*Mormopterus beccarii (Beccari's Freetail-bat)*			
19.	24223	*Mus musculus (House Mouse)*	Y		
20.	24094	*Ningaui ridei (Wongai Ningaui)*			
21.	24095	*Ningaui timealeyi (Pilbara Ningaui)*			
22.	24224	*Notomys alexis (Spinifex Hopping-mouse)*			
23.	25500	*Nyctophilus bifax (Eastern Long-eared Bat)*			Y
24.	42365	*Nyctophilus daedalus (Northwestern Long-eared Bat)*			
25.	24194	*Nyctophilus geoffroyi (Lesser Long-eared Bat)*			
26.	24144	*Petrogale rothschildi (Rothschild's Rock-wallaby)*			
27.	24101	*Planigale ingrami (Long-tailed Planigale)*			
28.	24106	*Pseudantechinus woolleyae (Woolley's Pseudantechinus)*			
29.	24233	*Pseudomys chapmani (Western Pebble-mound Mouse, Ngadji)*		P4	
30.	24235	*Pseudomys desertor (Desert Mouse)*			
31.	24237	*Pseudomys hermannsburgensis (Sandy Inland Mouse)*			
32.	43368	*Rhinonicteris aurantia (Orange Leafnosed-bat)*		T	
33.	24174	*Saccolaimus flaviventris (Yellow-bellied Sheathtail-bat)*			
34.	24200	*Scotorepens greyii (Little Broad-nosed Bat)*			
35.	24114	*Sminthopsis hirtipes (Hairy-footed Dunnart)*			
36.	24116	*Sminthopsis macroura (Stripe-faced Dunnart)*			
37.	24117	*Sminthopsis ooldea (Ooldea Dunnart)*			
38.	24120	*Sminthopsis youngsoni (Lesser Hairy-footed Dunnart)*			
39.	24207	*Tachyglossus aculeatus (Short-beaked Echidna)*			
40.	24185	*Tadarida australis (White-striped Freetail-bat)*			
41.	24175	*Taphozous georgianus (Common Sheathtail-bat)*			
42.	24176	*Taphozous hilli (Hill's Sheathtail-bat)*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
43.	24205	*Vespadelus finlaysoni (Finlayson's Cave Bat)*			
44.	24248	*Zyzomys argurus (Common Rock-rat)*			
45.	-18210	*Zyzomys sp.*			Y

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NatureMap Species Report

Created By penny brooshooft on 31/10/2014

Kingdom	Animalia
Current Names Only	Yes
Core Datasets Only	Yes
Species Group	Invertebrates
Method	'By Circle'
Centre	119°18' 36" E,22°47' 08" S
Buffer	39km
Group By	Species Group

Species Group	Species	Records
Invertebrate	36	318
TOTAL	**36**	**318**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Invertebrate					
1.	-11832	*Amblyomma triguttatum*			
2.	-13644	*Aname mellosa*			
3.	-1868	*Argiope protensa*			
4.	-1883	*Arthrorhabdus paucispinus*			
5.	-13287	*Asadipus yundamindra*			
6.	-12352	*Austrostrophus stictopygus*			
7.	-12563	*Cavisternum clavatum*			
8.	-1815	*Cormocephalus strigosus*			
9.	-1832	*Cormocephalus turneri*			
10.	-1890	*Ethmostigmus curtipes*			
11.	-12996	*Fissarena castanea*			
12.	-12184	*Hesperomomonia humphreysi*			
13.	-12416	*Heteropoda marillana*			Y
14.	-13175	*Hoggicosa bicolor*			
15.	-12042	*Leptasteron platyconductor*			
16.	-13606	*Missulena faulderi*			Y
17.	-12044	*Missulena langlandsi*			
18.	-11835	*Mituliodon tarantulinus*			
19.	-12751	*Pediana horni*			
20.	-12410	*Phryssonotus novaehollandiae*			
21.	-12743	*Pilbarascutigera incola*			
22.	-13508	*Prethopalpus maini*			
23.	-13590	*Prethopalpus pearsoni*			Y
24.	-1789	*Scolopendra laeta*			
25.	-1942	*Scolopendra morsitans*			
26.	-12424	*Spinasteron cavasteroides*			
27.	-12426	*Spinasteron waldockae*			
28.	-13387	*Synsphyronus gracilis*			
29.	-12698	*Synsphyronus heptatrichus*			
30.	-13010	*Tamopsis fickerti*			
31.	-12262	*Trachyspina mundaring*			
32.	-12413	*Tyrannochthonius aridus*			
33.	-13578	*Unixenus attemsi*			
34.	-12972	*Urodacus butleri*			
35.	-12983	*Urodacus megamastigus*			
36.	-12550	*nr Encoptarthria sp. B01*			Y

Conservation Codes
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3 - Priority 3
4 - Priority 4

Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area

5 - Priority 5

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NatureMap
Mapping Western Australia's biodiversity

NatureMap Species Report

Created By penny brooshooft on 31/10/2014

Kingdom	Animalia
Current Names Only	Yes
Core Datasets Only	Yes
Species Group	Birds
Method	'By Circle'
Centre	119°18' 36" E,22°47' 08" S
Buffer	39km
Group By	Species Group

Species Group	Species	Records
Bird	177	7948
TOTAL	**177**	**7948**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Bird					
1.	24559	*Acanthagenys rufogularis (Spiny-cheeked Honeyeater)*			
2.	24260	*Acanthiza apicalis (Broad-tailed Thornbill, Inland Thornbill)*			
3.	24261	*Acanthiza chrysorrhoa (Yellow-rumped Thornbill)*			
4.	24264	*Acanthiza robustirostris (Slaty-backed Thornbill)*			
5.	24265	*Acanthiza uropygialis (Chestnut-rumped Thornbill)*			
6.	25535	*Accipiter cirrocephalus (Collared Sparrowhawk)*			
7.	24281	*Accipiter cirrocephalus subsp. cirrocephalus (Collared Sparrowhawk)*			
8.	25536	*Accipiter fasciatus (Brown Goshawk)*			
9.	25755	*Acrocephalus australis (Australian Reed Warbler)*			
10.	25544	*Aegotheles cristatus (Australian Owlet-nightjar)*			
11.	25647	*Amytornis striatus (Striated Grasswren)*			
12.	24540	*Amytornis striatus subsp. whitei (Striated Grasswren)*			
13.	24312	*Anas gracilis (Grey Teal)*			
14.	24316	*Anas superciliosa (Pacific Black Duck)*			
15.	25553	*Anhinga melanogaster (Darter)*			
16.	24332	*Anhinga melanogaster subsp. novaehollandiae (Darter)*			
17.	25670	*Anthus australis (Australian Pipit)*			
18.	24599	*Anthus australis subsp. australis (Australian Pipit)*			
19.	25528	*Aphelocephala leucopsis (Southern Whiteface)*			
20.	25554	*Apus pacificus (Fork-tailed Swift)*		IA	
21.	24285	*Aquila audax (Wedge-tailed Eagle)*			
22.	25538	*Aquila morphnoides (Little Eagle)*			
23.	41324	*Ardea modesta (Eastern Great Egret)*		IA	
24.	24340	*Ardea novaehollandiae (White-faced Heron)*			
25.	24341	*Ardea pacifica (White-necked Heron)*			
26.	24610	*Ardeotis australis (Australian Bustard)*		P4	
27.	25566	*Artamus cinereus (Black-faced Woodswallow)*			
28.	24352	*Artamus cinereus subsp. melanops (Black-faced Woodswallow)*			
29.	24355	*Artamus minor (Little Woodswallow)*			
30.	24356	*Artamus personatus (Masked Woodswallow)*			
31.	24318	*Aythya australis (Hardhead)*			
32.	25715	*Cacatua roseicapilla (Galah)*			
33.	24725	*Cacatua roseicapilla subsp. assimilis (Galah)*			
34.	24726	*Cacatua roseicapilla subsp. roseicapilla (Galah)*			
35.	25716	*Cacatua sanguinea (Little Corella)*			
36.	24728	*Cacatua sanguinea subsp. sanguinea (Little Corella)*			
37.	42307	*Cacomantis pallidus (Pallid Cuckoo)*			
38.	25600	*Centropus phasianinus (Pheasant Coucal)*			
39.	24564	*Certhionyx variegatus (Pied Honeyeater)*			
40.	24373	*Charadrius melanops (Black-fronted Dotterel)*			
41.	24321	*Chenonetta jubata (Australian Wood Duck, Wood Duck)*			
42.	24431	*Chrysococcyx basalis (Horsfield's Bronze Cuckoo)*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
43.	24434	*Chrysococcyx osculans (Black-eared Cuckoo)*			
44.	24833	*Cincloramphus cruralis (Brown Songlark)*			
45.	24834	*Cincloramphus mathewsi (Rufous Songlark)*			
46.	25580	*Cinclosoma castaneothorax (Chestnut-breasted Quail-thrush)*			
47.	24288	*Circus approximans (Swamp Harrier)*			
48.	24289	*Circus assimilis (Spotted Harrier)*			
49.	25675	*Colluricincla harmonica (Grey Shrike-thrush)*			
50.	24613	*Colluricincla harmonica subsp. rufiventris (Grey Shrike-thrush)*			
51.	24361	*Coracina maxima (Ground Cuckoo-shrike)*			
52.	25568	*Coracina novaehollandiae (Black-faced Cuckoo-shrike)*			
53.	24362	*Coracina novaehollandiae subsp. novaehollandiae (Black-faced Cuckoo-shrike)*			
54.	24363	*Coracina novaehollandiae subsp. subpallida (Black-faced Cuckoo-shrike)*			
55.	24416	*Corvus bennetti (Little Crow)*			
56.	25593	*Corvus orru (Torresian Crow)*			
57.	24418	*Corvus orru subsp. cecilae (Western Crow)*			
58.	25701	*Coturnix ypsilophora (Brown Quail)*			
59.	24420	*Cracticus nigrogularis (Pied Butcherbird)*			
60.	25595	*Cracticus tibicen (Australian Magpie)*			
61.	24422	*Cracticus tibicen subsp. dorsalis (White-backed Magpie)*			
62.	24423	*Cracticus tibicen subsp. tibicen (Black-backed Magpie)*			
63.	25596	*Cracticus torquatus (Grey Butcherbird)*			
64.	25547	*Dacelo leachii (Blue-winged Kookaburra)*			
65.	24304	*Dacelo leachii subsp. leachii (Blue-winged Kookaburra)*			
66.	24325	*Dendrocygna eytoni (Plumed Whistling Duck)*			
67.	25607	*Dicaeum hirundinaceum (Mistletoebird)*			
68.	24470	*Dromaius novaehollandiae (Emu)*			
69.	25540	*Elanus caeruleus (Black-shouldered Kite)*			
70.	24631	*Emblema pictum (Painted Finch)*			
71.	24570	*Epthianura tricolor (Crimson Chat)*			
72.	24837	*Eremiornis carteri (Spinifex-bird)*			
73.	24368	*Eurostopodus argus (Spotted Nightjar)*			
74.	25621	*Falco berigora (Brown Falcon)*			
75.	24471	*Falco berigora subsp. berigora (Brown Falcon)*			
76.	25622	*Falco cenchroides (Australian Kestrel)*			
77.	24472	*Falco cenchroides subsp. cenchroides (Australian Kestrel)*			
78.	25623	*Falco longipennis (Australian Hobby)*			
79.	24474	*Falco longipennis subsp. longipennis (Australian Hobby)*			
80.	25624	*Falco peregrinus (Peregrine Falcon)*		S	
81.	42314	*Gavicalis virescens (Singing Honeyeater)*			
82.	24401	*Geopelia cuneata (Diamond Dove)*			
83.	25585	*Geopelia striata (Zebra Dove)*			
84.	24403	*Geopelia striata subsp. placida (Peaceful Dove)*			
85.	24404	*Geophaps plumifera (Spinifex Pigeon)*			
86.	24272	*Gerygone (fusca) mungi (Desert Gerygone)*			
87.	25530	*Gerygone fusca (Western Gerygone)*			
88.	24271	*Gerygone fusca subsp. fusca (Western Gerygone)*			
89.	-13988	*Gerygone fusca subsp. mungi*			
90.	24443	*Grallina cyanoleuca (Magpie-lark)*			
91.	24295	*Haliastur sphenurus (Whistling Kite)*			
92.	24296	*Hamirostra isura (Square-tailed Kite)*			
93.	25734	*Himantopus himantopus (Black-winged Stilt)*			
94.	24489	*Hirundo ariel (Fairy Martin)*			
95.	25629	*Hirundo nigricans (Tree Martin)*			
96.	24492	*Hirundo nigricans subsp. nigricans (Tree Martin)*			
97.	24572	*Lacustroica whitei (Grey Honeyeater)*			
98.	24367	*Lalage tricolor (White-winged Triller)*			
99.	25661	*Lichmera indistincta (Brown Honeyeater)*			
100.	24582	*Lichmera indistincta subsp. indistincta (Brown Honeyeater)*			
101.	24690	*Macronectes giganteus (Southern Giant Petrel)*		P4	
102.	25651	*Malurus lamberti (Variegated Fairy-wren)*			
103.	24544	*Malurus lamberti subsp. assimilis (Variegated Fairy-wren)*			
104.	25652	*Malurus leucopterus (White-winged Fairy-wren)*			
105.	24549	*Malurus leucopterus subsp. leuconotus (White-winged Fairy-wren)*			
106.	24548	*Malurus leucopterus subsp. leucopterus (Dirk Hartog Is. White-winged Fairy-wren)*		T	
107.	24583	*Manorina flavigula (Yellow-throated Miner)*			
108.	25665	*Melithreptus gularis (Black-chinned Honeyeater)*			
109.	24589	*Melithreptus gularis subsp. laetior (Black-chinned Honeyeater)*			
110.	24736	*Melopsittacus undulatus (Budgerigar)*			
111.	24598	*Merops ornatus (Rainbow Bee-eater)*		IA	
112.	25542	*Milvus migrans (Black Kite)*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
113.	24298	*Milvus migrans subsp. affinis (Black Kite)*			
114.	25545	*Mirafra javanica (Horsfield's Bushlark, Singing Bushlark)*			
115.	24302	*Mirafra javanica subsp. horsfieldii (Horsfield's Bushlark, Singing Bushlark)*			
116.	25685	*Neochmia ruficauda (Star Finch)*			
117.	24639	*Neochmia ruficauda subsp. clarescens (Star Finch)*			
118.	25747	*Ninox connivens (Barking Owl)*			
119.	24819	*Ninox connivens subsp. connivens (Barking Owl (southwest pop P2), Barking Owl)*		P2	
120.	25748	*Ninox novaeseelandiae (Boobook Owl)*			
121.	24820	*Ninox novaeseelandiae subsp. boobook (Boobook Owl)*			
122.	25564	*Nycticorax caledonicus (Rufous Night Heron)*			
123.	24350	*Nycticorax caledonicus subsp. hilli (Rufous Night Heron)*			
124.	24742	*Nymphicus hollandicus (Cockatiel)*			
125.	24407	*Ocyphaps lophotes (Crested Pigeon)*			
126.	24618	*Oreoica gutturalis (Crested Bellbird)*			
127.	25680	*Pachycephala rufiventris (Rufous Whistler)*			
128.	24624	*Pachycephala rufiventris subsp. rufiventris (Rufous Whistler)*			
129.	25543	*Pandion haliaetus (Osprey)*			
130.	24627	*Pardalotus rubricatus (Red-browed Pardalote)*			
131.	25682	*Pardalotus striatus (Striated Pardalote)*			
132.	24628	*Pardalotus striatus subsp. murchisoni (Striated Pardalote)*			
133.	24629	*Pardalotus striatus subsp. uropygialis (Striated Pardalote)*			
134.	24630	*Pardalotus striatus subsp. westraliensis (Striated Pardalote)*			
135.	24648	*Pelecanus conspicillatus (Australian Pelican)*			
136.	24658	*Petroica cucullata (Hooded Robin)*			
137.	24659	*Petroica goodenovii (Red-capped Robin)*			
138.	24667	*Phalacrocorax sulcirostris (Little Black Cormorant)*			
139.	25699	*Phalacrocorax varius (Pied Cormorant)*			
140.	24409	*Phaps chalcoptera (Common Bronzewing)*			
141.	24841	*Platalea flavipes (Yellow-billed Spoonbill)*			
142.	24748	*Platycercus varius (Mulga Parrot)*			
143.	25721	*Platycercus zonarius (Australian Ringneck, Ring-necked Parrot)*			
144.	24751	*Platycercus zonarius subsp. zonarius (Port Lincoln Parrot)*			
145.	25703	*Podargus strigoides (Tawny Frogmouth)*			
146.	24683	*Pomatostomus superciliosus (White-browed Babbler)*			
147.	25706	*Pomatostomus temporalis (Grey-crowned Babbler)*			
148.	24684	*Pomatostomus temporalis subsp. rubeculus (Grey-crowned Babbler)*			
149.	24390	*Psophodes occidentalis (Western Wedgebill, Chiming Wedgebill)*			
150.	24757	*Ptilonorhynchus maculatus subsp. guttatus (Western Bowerbird)*			
151.	24758	*Ptilonorhynchus nuchalis subsp. nuchalis (Great Bowerbird)*			
152.	42341	*Ptilotula penicillatus (White-plumed Honeyeater)*			
153.	24278	*Pyrrholaemus brunneus (Redthroat)*			
154.	24453	*Rhipidura (fuliginosa) albicauda (White-tailed Fantail)*			
155.	-14063	*Rhipidura albicauda*			
156.	25613	*Rhipidura fuliginosa (Grey Fantail)*			
157.	24451	*Rhipidura fuliginosa subsp. alisteri (Grey Fantail)*			
158.	25614	*Rhipidura leucophrys (Willie Wagtail)*			
159.	24454	*Rhipidura leucophrys subsp. leucophrys (Willie Wagtail)*			
160.	24777	*Rostratula benghalensis subsp. australis (Australian Painted Snipe)*		T	
161.	30948	*Smicrornis brevirostris (Weebill)*			
162.	25656	*Stipiturus ruficeps (Rufous-crowned Emu-wren)*			
163.	24556	*Stipiturus ruficeps subsp. ruficeps (Rufous-crowned Emu-wren)*			
164.	42310	*Sugomel niger (Black Honeyeater)*			
165.	25705	*Tachybaptus novaehollandiae (Australasian Grebe, Black-throated Grebe)*			
166.	24331	*Tadorna tadornoides (Australian Shelduck, Mountain Duck)*			
167.	30870	*Taeniopygia guttata (Zebra Finch)*			
168.	30871	*Taeniopygia guttata subsp. castanotis (Zebra Finch)*			
169.	24845	*Threskiornis spinicollis (Straw-necked Ibis)*			
170.	42351	*Todiramphus pyrrhopygius (Red-backed Kingfisher)*			
171.	25549	*Todiramphus sanctus (Sacred Kingfisher)*			
172.	24309	*Todiramphus sanctus subsp. sanctus (Sacred Kingfisher)*			
173.	24808	*Tringa nebularia (Common Greenshank)*		IA	
174.	24851	*Turnix velox (Little Button-quail)*			
175.	25762	*Tyto alba (Barn Owl)*			
176.	24852	*Tyto alba subsp. delicatula (Barn Owl)*			

Conservation Codes
T - Rare or likely to become extinct
X - Presumed extinct
IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3

Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area

4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

Appendix 3

EPBC Protected Matters Database Search Results

Australian Government

Department of the Environment

EPBC Act Protected Matters Report

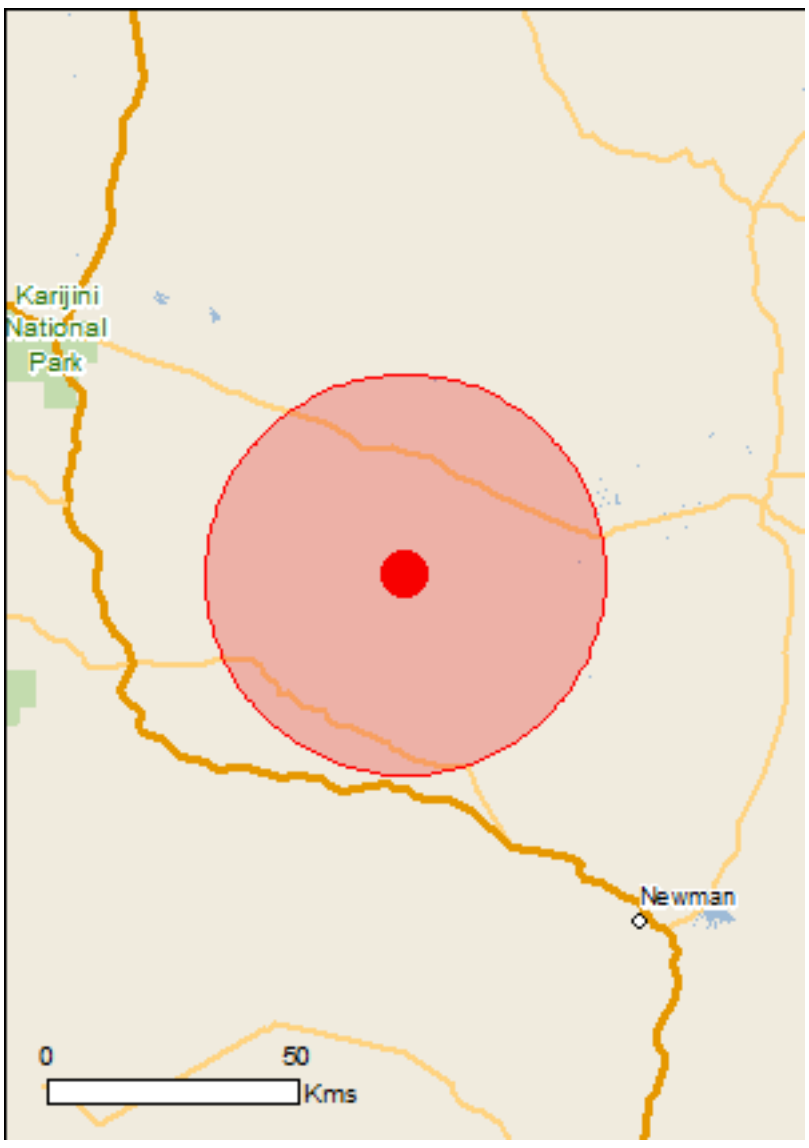
This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 31/10/14 11:54:24

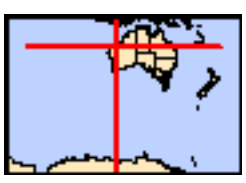
Summary
Details
Matters of NES
Other Matters Protected by the EPBC Act
Extra Information
Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates

Buffer: 40.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Areas:	None
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	8
Listed Migratory Species:	6

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place and the heritage values of a place on the Register of the National Estate.

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	6
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

Place on the RNE:	1
State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	10
Nationally Important Wetlands:	1
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat likely to occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Mammals		
Dasyurus hallucatus Northern Quoll [331]	Endangered	Species or species habitat likely to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Notoryctes caurinus Kakarratul, Northern Marsupial Mole [295]	Endangered	Species or species habitat likely to occur within area
Rhinonicteris aurantia (Pilbara form) Pilbara Leaf-nosed Bat [82790]	Vulnerable	Species or species habitat known to occur within area
Plants		
Lepidium catapycnon Hamersley Lepidium, Hamersley Catapycnon [9397]	Vulnerable	Species or species habitat likely to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies) [66699]	Vulnerable	Species or species habitat known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Migratory Wetlands Species		
Ardea alba Great Egret, White Egret [59541]		Species or species habitat known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat likely to occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Species or species habitat known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat likely to occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Extra Information

Places on the RNE [Resource Information]

Note that not all Indigenous sites may be listed.

Name	State	Status
Natural		
Fortescue Marshes	WA	Indicative Place

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Mammals		
Camelus dromedarius Dromedary, Camel [7]		Species or species habitat likely to occur within area
Canis lupus familiaris Domestic Dog [82654]		Species or species habitat likely to occur within area
Equus asinus Donkey, Ass [4]		Species or species habitat likely to occur within area
Equus caballus Horse [5]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		

Name	Status	Type of Presence
Cenchrus ciliaris		
Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area
Parkinsonia aculeata		
Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, Horse Bean [12301]		Species or species habitat likely to occur within area

Nationally Important Wetlands [Resource Information]

Name	State
Fortescue Marshes	WA

Coordinates

-22.78556 119.31

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World Heritage and Register of National Estate properties, Wetlands of International Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Department of Environment, Climate Change and Water, New South Wales
-Department of Sustainability and Environment, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment and Natural Resources, South Australia
-Parks and Wildlife Service NT, NT Dept of Natural Resources, Environment and the Arts
-Environmental and Resource Management, Queensland
-Department of Environment and Conservation, Western Australia
-Department of the Environment, Climate Change, Energy and Water
-Birds Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-SA Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
-State Forests of NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Appendix 4

Atlas of Living Australia Database Results

Non-Volant Mammals

Family	Species Name	Common Name
Canidae	*Canis lupus dingo*	Dingo
Dasyuridae	*Dasykaluta rosamondae*	Little Red Kaluta
Dasyuridae	*Ningaui ridei*	Wongai Ningaui
Dasyuridae	*Ningaui timealeyi*	Pilbara Ningaui
Dasyuridae	*Planigale ingrami*	Long-tailed Planigale
Dasyuridae	*Pseudantechinus woolleyae*	Woolley's Pseudantechinus
Dasyuridae	*Sminthopsis macroura*	Stripe-faced Dunnart
Dasyuridae	*Sminthopsis ooldea*	Ooldea Dunnart
Dasyuridae	*Sminthopsis youngsoni*	Lesser Hairy-footed Dunnart
Macropodidae	*Macropus robustus*	Euro
Macropodidae	*Macropus rufus*	Red Kangaroo, Marlu
Muridae	*Mus musculus*	House Mouse
Muridae	*Notomys alexis*	Spinifex Hopping-mouse
Muridae	*Pseudomys chapmani*	Western Pebble-mound Mouse
Muridae	*Pseudomys desertor*	Desert Mouse
Muridae	*Pseudomys hermannsburgensis*	Sandy Inland Mouse
Muridae	*Zyzomys argurus*	Common Rock-rat

Volant Mammals

Family	Species Name	Common Name
Emballonuridae	*Saccolaimus flaviventris*	Yellow-bellied Sheathtail-bat
Emballonuridae	*Taphozous georgianus*	Common Sheathtail-bat
Emballonuridae	*Taphozous hilli*	Hill's Sheathtail-bat
Megadermatidae	*Macroderma gigas*	Ghost Bat
Molossidae	*Chaerephon jobensis*	Northern Freetail-bat
Molossidae	*Mormopterus beccarii*	Beccari's Freetail-bat
Molossidae	*Tadarida australis*	White-striped Freetail-bat
Vespertilionidae	*Chalinolobus gouldii*	Gould's Wattled Bat
Vespertilionidae	*Chalinolobus morio*	Chocolate Wattled Bat
Vespertilionidae	*Nyctophilus daedalus*	Northwestern Long-eared Bat
Vespertilionidae	*Nyctophilus geoffroyi*	Lesser Long-eared Bat
Vespertilionidae	*Scotorepens balstoni*	Inland Broad-nosed Bat
Vespertilionidae	*Scotorepens greyii*	Little Broad-nosed Bat
Vespertilionidae	*Vespadelus finlaysoni*	Finlayson's Cave Bat

Reptiles

Family	Species Name	Common Name
Elapidae	*Acanthophis wellsi*	Pilbara Death Adder
Agamidae	*Amphibolurus longirostris*	
Typhlopidae	*Anilios ammodytes*	
Typhlopidae	*Anilios ganei*	
Typhlopidae	*Anilios grypus*	
Typhlopidae	*Anilios hamatus*	
Typhlopidae	*Anilios waitii*	
Boidae	*Antaresia perthensis*	Pygmy Python
Boidae	*Antaresia stimsoni*	Stimson's Python
Elapidae	*Brachyurophis approximans*	
Eugongylidae	*Carlia munda*	
Eugongylidae	*Carlia triacantha*	
Diplodactylidae	*Crenadactylus ocellatus*	Clawless Gecko
Eugongylidae	*Cryptoblepharus buchananii*	
Eugongylidae	*Cryptoblepharus plagiocephalus*	

Eugongylidae	*Cryptoblepharus ustulatus*	
Agamidae	*Ctenophorus caudicinctus*	Ring-tailed Dragon
Agamidae	*Ctenophorus isolepis*	Military Dragon
Agamidae	*Ctenophorus nuchalis*	Central Netted Dragon
Agamidae	*Ctenophorus reticulatus*	Western Netted Dragon
Sphenomorphidae	*Ctenotus ariadnae*	
Sphenomorphidae	*Ctenotus duricola*	
Sphenomorphidae	*Ctenotus grandis*	
Sphenomorphidae	*Ctenotus hanloni*	
Sphenomorphidae	*Ctenotus helenae*	
Sphenomorphidae	*Ctenotus pantherinus*	Leopard Ctenotus
Sphenomorphidae	*Ctenotus rubicundus*	
Sphenomorphidae	*Ctenotus rutilans*	
Sphenomorphidae	*Ctenotus saxatilis*	Rock Ctenotus
Sphenomorphidae	*Ctenotus schomburgkii*	
Sphenomorphidae	*Ctenotus serventyi*	
Egerniidae	*Cyclodomorphus melanops*	Slender Blue-tongue
Pygopodidae	*Delma elegans*	
Pygopodidae	*Delma haroldi*	
Pygopodidae	*Delma nasuta*	
Pygopodidae	*Delma pax*	
Pygopodidae	*Delma tincta*	
Elapidae	*Demansia psammophis*	Yellow-faced Whipsnake
Diplodactylidae	*Diplodactylus conspicillatus*	Fat-tailed Gecko
Diplodactylidae	*Diplodactylus pulcher*	
Diplodactylidae	*Diplodactylus savagei*	Southern Pilbara Beak-faced Gecko
Agamidae	*Diporiphora amphiboluroides*	Mulga Dragon
Egerniidae	*Egernia cygnitos*	Western Pilbara Spiny-tailed Skink
Egerniidae	*Egernia depressa*	Southern Pygmy Spiny-tailed Skink
Egerniidae	*Egernia formosa*	
Sphenomorphidae	*Eremiascincus pallidus*	Western Narrow-banded Skink
Gekkonidae	*Gehyra pilbara*	
Gekkonidae	*Gehyra punctata*	
Gekkonidae	*Gehyra purpurascens*	
Gekkonidae	*Gehyra variegata*	
Gekkonidae	*Heteronotia binoei*	Bynoe's Gecko
Gekkonidae	*Heteronotia spelea*	Pilbara Cave Gecko
Sphenomorphidae	*Lerista amicorum*	
Sphenomorphidae	*Lerista labialis*	
Sphenomorphidae	*Lerista muelleri*	
Sphenomorphidae	*Lerista neander*	
Sphenomorphidae	*Lerista timida*	
Sphenomorphidae	*Lerista zietzi*	
Pygopodidae	*Lialis burtonis*	
Boidae	*Liasis olivaceus barroni*	Pilbara Olive Python
Agamidae	*Amphibolurus longirostris*	
Diplodactylidae	*Lucasium stenodactylum*	
Diplodactylidae	*Lucasium wombeyi*	
Eugongylidae	*Menetia greyii*	
Eugongylidae	*Menetia surda*	
Eugongylidae	*Morethia ruficauda*	
Carphodactylidae	*Nephrurus wheeleri*	
Sphenomorphidae	*Notoscincus ornatus*	
Diplodactylidae	*Oedura marmorata*	Marbled Velvet Gecko
Elapidae	*Parasuta monachus*	
Agamidae	*Pogona minor*	

Agamidae	*Pogona minor*	
Eugongylidae	*Proablepharus reginae*	
Elapidae	*Pseudechis australis*	Mulga Snake
Elapidae	*Pseudonaja mengdeni*	Western Brown Snake
Elapidae	*Pseudonaja modesta*	Ringed Brown Snake
Pygopodidae	*Pygopus nigriceps*	
Diplodactylidae	*Rhynchoedura ornata*	Western Beaked Gecko
Diplodactylidae	*Strophurus elderi*	
Diplodactylidae	*Strophurus jeanae*	
Diplodactylidae	*Strophurus wellingtonae*	
Elapidae	*Suta fasciata*	Rosen's Snake
Egerniidae	*Tiliqua multifasciata*	Central Blue-tongue
Agamidae	*Tympanocryptis cephalus*	Pebble Dragon
Varanidae	*Varanus acanthurus*	Spiny-tailed Monitor
Varanidae	*Varanus brevicauda*	Short-tailed Pygmy Monitor
Varanidae	*Varanus bushi*	Pilbara Mulga Monitor
Varanidae	*Varanus caudolineatus*	
Varanidae	*Varanus eremius*	Pygmy Desert Monitor
Varanidae	*Varanus giganteus*	Perentie
Varanidae	*Varanus gouldii*	Bungarra or Sand Monitor
Varanidae	*Varanus pilbarensis*	Pilbara Rock Monitor
Varanidae	*Varanus panoptes*	Yellow-spotted Monitor
Varanidae	*Varanus tristis tristis*	Racehorse Monitor

Amphibians

Family	Species Name	Common Name
Myobatrachidae	*Uperoleia saxatilis*	Pilbara Toadlet
Myobatrachidae	*Pseudophryne douglasi*	Gorge Toadlet
Hylidae	*Litoria rubella*	Little Red Tree Frog
Hylidae	*Cyclorana maini*	Sheep Frog

Avifauna

Family	Common Name	Species Name
Casuariidae	Emu	*Dromaius novaehollandiae*
Phasianidae	Brown Quail	*Coturnix ypsilophora*
Anatidae	Plumed Whistling-duck	*Dendrocygna eytoni*
Anatidae	Australian Shelduck	*Tadorna tadornoides*
Anatidae	Australian Wood Duck	*Chenonetta jubata*
Anatidae	Grey Teal	*Anas gracilis*
Anatidae	Pacific Black Duck	*Anas superciliosa*
Anatidae	Hardhead	*Aythya australis*
Podicipedidae	Australasian Grebe	*Tachybaptus novaehollandiae*
Podicipedidae	Hoary-headed Grebe	*Poliocephalus poliocephalus*
Columbidae	Common Bronzewing	*Phaps chalcoptera*
Columbidae	Crested Pigeon	*Ocyphaps lophotes*
Columbidae	Spinifex Pigeon	*Geophaps plumifera*
Columbidae	Diamond Dove	*Geopelia cuneata*
Columbidae	Peaceful Dove	*Geopelia striata*
Podargidae	Tawny Frogmouth	*Podargus strigoides*
Eurostopodidae	Spotted Nightjar	*Eurostopodus argus*
Aegothelidae	Australian Owlet-nightjar	*Aegotheles cristatus*
Anhingidae	Australasian Darter	*Anhinga novaehollandiae*
Phalacrocoracidae	Little Pied Cormorant	*Microcarbo melanoleucos*
Phalacrocoracidae	Little Black Cormorant	*Phalacrocorax sulcirostris*
Pelecanidae	Australian Pelican	*Pelecanus conspicillatus*

Ardeidae	White-necked Heron	*Ardea pacifica*
Ardeidae	White-faced Heron	*Egretta novaehollandiae*
Ardeidae	Little Egret	*Egretta garzetta*
Threskiornithidae	Straw-necked Ibis	*Threskiornis spinicollis*
Threskiornithidae	Yellow-billed Spoonbill	*Platalea flavipes*
Accipitridae	Black-shouldered Kite	*Elanus axillaris*
Accipitridae	Whistling Kite	*Haliastur sphenurus*
Accipitridae	Black Kite	*Milvus migrans*
Accipitridae	Brown Goshawk	*Accipiter fasciatus*
Accipitridae	Collared Sparrowhawk	*Accipiter cirrocephalus*
Accipitridae	Spotted Harrier	*Circus assimilis*
Accipitridae	Swamp Harrier	*Circus approximans*
Accipitridae	Wedge-tailed Eagle	*Aquila audax*
Accipitridae	Little Eagle	*Hieraaetus morphnoides*
Falconidae	Nankeen Kestrel	*Falco cenchroides*
Falconidae	Brown Falcon	*Falco berigora*
Falconidae	Australian Hobby	*Falco longipennis*
Falconidae	Grey Falcon	*Falco hypoleucos*
Falconidae	Peregrine Falcon	*Falco peregrinus*
Rallidae	Black-tailed Native-hen	*Tribonyx ventralis*
Otididae	Australian Bustard	*Ardeotis australis*
Burhinidae	Bush Stone-curlew	*Burhinus grallarius*
Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*
Charadriidae	Black-fronted Dotterel	*Elseyornis melanops*
Charadriidae	Red-kneed Dotterel	*Erythrogonys cinctus*
Turnicidae	Little Button-quail	*Turnix velox*
Cacatuidae	Major Mitchell's Cockatoo	*Lophochroa leadbeateri*
Cacatuidae	Galah	*Eolophus roseicapillus*
Cacatuidae	Little Corella	*Cacatua sanguinea*
Cacatuidae	Cockatiel	*Nymphicus hollandicus*
Psittacidae	Australian Ringneck	*Barnardius zonarius*
Psittacidae	Mulga Parrot	*Psephotus varius*
Psittacidae	Budgerigar	*Melopsittacus undulatus*
Psittacidae	Bourke's Parrot	*Neopsephotus bourkii*
Cuculidae	Pheasant Coucal	*Centropus phasianinus*
Cuculidae	Horsfield's Bronze-cuckoo	*Chalcites basalis*
Cuculidae	Pallid Cuckoo	*Cacomantis pallidus*
Strigidae	Barking Owl	*Ninox connivens*
Strigidae	Southern Boobook	*Ninox novaeseelandiae*
Tytonidae	Eastern Barn Owl	*Tyto javanica*
Halcyonidae	Blue-winged Kookaburra	*Dacelo leachii*
Halcyonidae	Red-backed Kingfisher	*Todiramphus pyrrhopygius*
Halcyonidae	Sacred Kingfisher	*Todiramphus sanctus*
Meropidae	Rainbow Bee-eater	*Merops ornatus*
Climacteridae	Black-tailed Treecreeper	*Climacteris melanura*
Ptilonorhychidae	Spotted Bowerbird	*Ptilonorhynchus maculatus*
Ptilonorhychidae	Western Bowerbird	*Ptilonorhynchus guttatus*
Maluridae	Splendid Fairy-wren	*Malurus splendens*
Maluridae	Variegated Fairy-wren	*Malurus lamberti*
Maluridae	Striated Grasswren	*Amytornis striatus*
Acanthizidae	Redthroat	*Pyrrholaemus brunneus*
Acanthizidae	Weebill	*Smicrornis brevirostris*
Acanthizidae	Western Gerygone	*Gerygone fusca*
Acanthizidae	Slaty-backed Thornbill	*Acanthiza robustirostris*
Acanthizidae	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*
Acanthizidae	Chestnut-rumped Thornbill	*Acanthiza uropygialis*
Acanthizidae	Inland Thornbill	*Acanthiza apicalis*
Acanthizidae	Southern Whiteface	*Aphelocephala leucopsis*
Pardalotidae	Red-browed Pardalote	*Pardalotus rubricatus*
Pardalotidae	Striated Pardalote	*Pardalotus striatus*

Meliphagidae	Singing Honeyeater	*Lichenostomus virescens*
Meliphagidae	Grey-headed Honeyeater	*Lichenostomus keartlandi*
Meliphagidae	White-plumed Honeyeater	*Lichenostomus penicillatus*
Meliphagidae	Yellow-throated Miner	*Manorina flavigula*
Meliphagidae	Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*
Meliphagidae	Crimson Chat	*Epthianura tricolor*
Meliphagidae	Black Honeyeater	*Sugomel niger*
Meliphagidae	Brown Honeyeater	*Lichmera indistincta*
Meliphagidae	Black-chinned Honeyeater	*Melithreptus gularis*
Pomatostomidae	Grey-crowned Babbler	*Pomatostomus temporalis*
Pomatostomidae	White-browed Babbler	*Pomatostomus superciliosus*
Eupetidae	Chestnut-breasted Quail-thrush	*Cinclosoma castaneothorax*
Eupetidae	Chiming Wedgebill	*Psophodes occidentalis*
Neosittidae	Varied Sittella	*Daphoenositta chrysoptera*
Campephagidae	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*
Campephagidae	White-winged Triller	*Lalage sueurii*
Campephagidae	White-winged Triller	*Lalage sueurii*
Pachycephalidae	Rufous Whistler	*Pachycephala rufiventris*
Pachycephalidae	Grey Shrike-thrush	*Colluricincla harmonica*
Pachycephalidae	Crested Bellbird	*Oreoica gutturalis*
Artamidae	Masked Woodswallow	*Artamus personatus*
Artamidae	Black-faced Woodswallow	*Artamus cinereus*
Artamidae	Little Woodswallow	*Artamus minor*
Artamidae	Grey Butcherbird	*Cracticus torquatus*
Artamidae	Pied Butcherbird	*Cracticus nigrogularis*
Artamidae	Australian Magpie	*Cracticus tibicen*
Rhipiduridae	Grey Fantail	*Rhipidura albiscapa*
Rhipiduridae	Willie Wagtail	*Rhipidura leucophrys*
Corvidae	Little Crow	*Corvus bennetti*
Corvidae	Torresian Crow	*Corvus orru*
Monarchidae	Magpie-lark	*Grallina cyanoleuca*
Petroicidae	Red-capped Robin	*Petroica goodenovii*
Petroicidae	Hooded Robin	*Melanodryas cucullata*
Alaudidae	Horsfield's Bushlark	*Mirafra javanica*
Acrocephalidae	Australian Reed-warbler	*Acrocephalus australis*
Megaluridae	Rufous Songlark	*Cincloramphus mathewsi*
Megaluridae	Brown Songlark	*Cincloramphus cruralis*
Megaluridae	Spinifexbird	*Eremiornis carteri*
Hirundinidae	Welcome Swallow	*Hirundo neoxena*
Hirundinidae	Fairy Martin	*Petrochelidon ariel*
Hirundinidae	Tree Martin	*Petrochelidon nigricans*
Nectariniidae	Mistletoebird	*Dicaeum hirundinaceum*
Estrildidae	Zebra Finch	*Taeniopygia guttata*
Estrildidae	Star Finch	*Neochmia ruficauda*
Estrildidae	Painted Finch	*Emblema pictum*
Motacillidae	Australasian Pipit	*Anthus novaeseelandiae*

Appendix 5

Bat Call WA Reports

Yandicoogina fauna survey Phase 1, Pilbara WA, March 2014

Echolocation Survey of Bat Activity.

Prepared for Biota Environmental Sciences

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Issue B
3 April 2014

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Document Revision History

Date	Issue	Revision History
2 April 2014	Issue A	Initial draft prepared for Biota
3 April 2014	Issue B	Draft B with initial comments added

Summary
Microbat species presence, with an estimate of activity level, is presented for eight recording nights at Yandicoogina in the Pilbara, WA. Biota Environmental Sciences carried out an echolocation based survey during March 2014. Bat Call WA has reviewed the recordings made and provided species lists for the bats present.

Seven species of echolocating microbats were recorded including rare *Chalinolobus morio*. No Orange Leaf-nosed Bat, Pilbara form (*Rhinonicteris aurantia*) or Ghost Bat (*Macroderma gigas*) calls were detected.

Habitats
Four sites for the survey were chosen by Biota. Details of the sites are presented in Table 1. Three are along the Weeli Wolli Creek riparian zone and the fourth is on Marillana Creek a short distance upstream. The locations of the sites are shown in relation to the locality's features in Figure 1.

Characteristics of the calls recorded are presented in Table 2.

Bat Fauna
A microbat assemblage of seven insectivorous species was confirmed as present at the study sites, Tables 2 and 3. Each of the insectivorous species is has previously been detected along Weeli Wolli Creek. *Chalinolobus morio* is known from this locality and upstream on both Weeli Wolli and Marillana Creeks.

Species activity levels were low to high, which is expected for the study area habitat and the time of year, see criteria below.

Survey Timing, Moon Phase and Weather
The echolocation survey was conducted between 13th and 17th March 2014. Sampling evenings were warm and mostly dry with minimum overnight temperatures around 25^{O}C. Some rain fell on the night of the 16th. The moon in this period was full. These conditions correspond to typical levels of bat echolocation detection for the season.

Survey Team
A team of Biota ecologists conducted the bat sampling work. Bob Bullen of Bat Call WA completed analysis of echolocation recordings.

Sampling
The survey consisted of completing a total of eight overnight bat sound recordings, beginning at twilight, at four locations within the survey area. The recordings were "continuous" (Hyder *et al.* 2010) made using a SM2BAT SongMeter (Wildlife Acoustics Inc, USA). The jumper and audio settings used for the SM2BAT followed the manufacturer's recommendations for bat detection contained in the user manual (Wildlife Acoustics 2010). Selectable filters and triggers were also set using the manufacturer's recommendations, see also Table 4. Table 2 provides details of the methods used by date and site.

For the recordings, once reformatted as .wav files, COOL EDIT 2000 (Now available as AUDITION from Adobe Systems Inc.) was used to display each sequence for identification. Calls were identified manually. Only good quality call sequences were

used. Details of calls analysed are provided in Table 2 as recommended by Australasian Bat Society (ABS 2006). Reference data for the species identified are available in Bullen and McKenzie 2002, McKenzie and Bullen 2003 and McKenzie and Bullen 2009.

Bat activity was then characterised as “Low”, “Medium” or “High” based on the rate of call sequences recorded.

- Low species activity is referred when a species is recorded with call spacing less often than ten minutes,
- Medium species activity refers to call recordings more often than 10 minutes but less often than two minutes apart for a at least an hour followed by sporadic records for the remainder of the session.
- High species activity refers to call recording more often than two minutes apart for at least two hours followed by reasonably regular records for the remainder of the session.

Survey Limitations

The sites surveyed were accessible on foot and the SM2, using an omnidirectional microphone, was set on the ground with the microphone horizontal. Species are unlikely to be under-represented as a result.

Bat species density away from cave or adit entrances is impossible to estimate from echolocation records. Bat activity is therefore substituted as an approximate guide to the relative numbers of each species using the study area.

References

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Wildlife Acoustics (2010). Song Meter User Manual, Model SM2, with Song Meter SM2BAT 192kHz Stereo or 384kHz Mono Ultrasonic Recorders addendum.

Table 1 Site Specific details.

Site	Date	Recording Time	Habitat	Latitude	Longitude
YBLSM2-03	13 to 15 March	Three overnight recordings using SM2 SN 12791	Ephemeral waterhole on creek line	22^{O} 43’ 10”	119^{O} 20’ 20”
YBLSM2-04	15 to 16 March	Two overnight recordings using SM2 SN 11040	Marillana Ck riparian zone	22^{O} 46’ 58”	119^{O} 17’ 18”
YBLSM2-06	16 to 17 March	Two overnight recordings using SM2 SN 12791	Weeli Wolli Ck riparian zone	22^{O} 48’ 15”	119^{O} 17’ 41”
YBLSM2-07	17 March	One overnight recordings using SM2 SN 11040	Weeli Wolli Ck riparian zone	22^{O} 47’ 38”	119^{O} 18’ 07”

Table 2: Summary of Echolocation call characteristics for microbat species present.

Genus species Authority	Common name	Typical F_{peakC} kHz	Ave. Q	Typical Duration msec	Typical Call Shape
Chaerephon jobensis (Miller 1902)	Northern free-tailed bat	22	5	8 - 15	Shallow FM
Chalinolobus gouldii (Grey 1841)	Gould's wattled bat	32	10	7 - 11	FM
Chalinolobus morio (Grey 1841)	Chocolate wattled bat	50	10	7	FM
Mormopterus beccarii (Peters 1881)	Beccari's free-tailed bat	26	10	8 - 13	Shallow FM
Nyctophilus geoffroyi Leach 1821	Lesser long-eared bat	45	3	5	Steep FM
Scotorepens greyii (Gray 1843)	Little broad-nosed bat	38	10	7 - 13	FM
Vespadelus finlaysoni (Kitchener, Jones and Caputi 1987)	Inland cave bat	55	14	4 - 8	FM

Note: FpeakC and Q are defined in McKenzie and Bullen 2003, 2009.

Table 3. Microbat lists obtained presented by detector and night.

Site	Date	*Chaerephon jobensis*	*Chalinolobus gouldii*	*Chalinolobus morio*	*Mormopterus beccarii*	*Nyctophilus geoffroyi*	*Scotorepens greyii*	*Vespadelus finlaysoni*
YBLSM2-03	13 March	Low	High	Low	Low	Low	High	High
YBLSM2-03	14 March	Low	High		Med		High	Low
YBLSM2-03	15 March	Low	High		Low		High	Low
YBLSM2-04	15 March	Low	Low				Low	Low
YBLSM2-04	16 March	Low	Low				Low	Low
YBLSM2-06	16 March	Low	Med				Med	Low
YBLSM2-06	17 March	Low	High		Low		High	Low
YBLSM2-07	17 March	Low	Low		Low		Low	

Table 4 SM2 Audio settings used during survey.

Parameter	Setting
Sample rate	384,000 kHz
Channel used	Left
Compression protocol	WAC0 (12 bit audio samples)
Gain - left channel	0.00
Digital high pass filter Left channel	fs/48 (giving 8 kHz minimum frequency)
Digital low pass filter Left channel	Off
Triggering level Left channel	6SNR (adaptive +6 dB triggering)
Triggering window Left channel	1.0 sec.

Note: These settings are as recommended in Wildlife Acoustics (2010) except the high pass filter. This is set lower to 8kHz to record any *Tadarida australis* that may be present

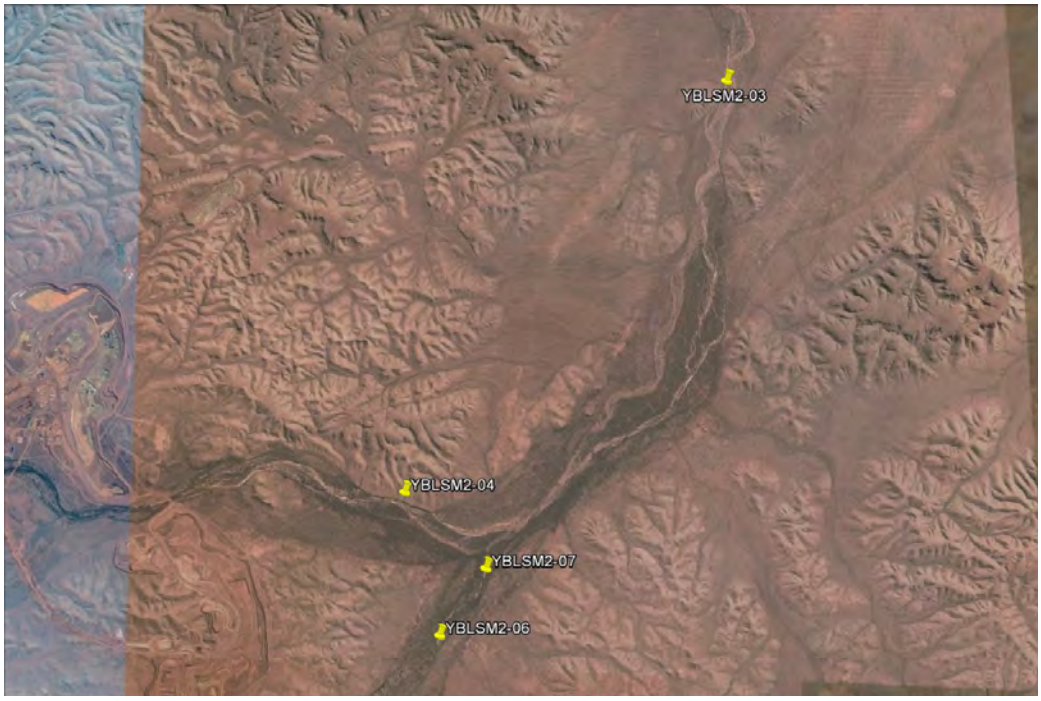

Figure 1. Detector Sites in relation to features in the study area.

Appendix 6

Helix Molecular Solutions Molecular Analysis Reports

Helix
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28 April, 2014

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Via email

Re. Report on the molecular systematics of Mygalomorphae from Yandi Billiards

Dear Stewart,

Following is a summary of the results for the Yandi Billiards collections. We detected six distinct genetic lineages in two families of Mygalomorphae (Idiopidae, Nemesiidae). The six Mygalomorphae lineages likely represent five putative species, four of which have been detected previously in the Pilbara.

Thank you once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Jason Kennington
Helix Molecular Solutions Pty Ltd

Background
Extensive molecular work has been conducted on the trap-door spider fauna of Western Australia (Helix 2012a). The resulting dataset provides a molecular framework that can be used to provide a regional context for localised sampling.

The present study involved the collection and sequencing of 66 Mygalomorphae specimens from the Yandi Billiards site in order to assess their relationships to the existing sequencing records for more than 2200 specimens from the Pilbara.

The new Yandi Billiards Mygalomorphae sequences were added to the existing sequence dataset to assign specimens to existing lineages and species or to identify new lineages/species.

Executive Summary
- Sixteen specimens from Yandi Billiards were sequenced for COXI.
- A DNA sequence was obtained from all 16 of the specimens.
- Phylogenetic analysis of the 16 new specimens revealed the presence of six distinct genetic lineages (two Idiopidae and four Nemesiidae).
- The six lineages represent five putative species, four of which have been detected previously in the Pilbara.

Methods
The specimens were sequenced and analysed as previously described (Helix 2012b), with the following changes:

In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) tree was constructed from the 16 new sequences in order to identify the number of unique lineages present. Representatives from each lineage were then used in a model-based phylogenetic analysis along with 76 reference specimens of Mygalomorphae as described below.

Model-based phylogenetic analysis was performed using the lineages of Mygalomorphae detected among the new specimens and a sub-set of reference lineages (N=76) that were selected based on the criteria that they showed ≤15% sequence divergence from at least one of the new lineages. The reference lineages represented two families of Mygalomorphae detected in the Pilbara (Idiopidae, Nemesiidae). Lineages detected in the present study were assumed to belong to a previously detected lineage when they shared a single common ancestor, were well-supported by posterior probabilities (≥0.95), and differed from one another by ≤3% sequence divergence.

Results
Preliminary analysis
The NJ analyses placed the 16 new specimens into six distinct genetic lineages (haplotypes or clusters of highly similar haplotypes separated from other such clusters by long branch lengths; Figure 1). The analysis revealed the presence of two lineages of Idiopidae and four lineages of Nemesiidae. The number of individuals in each lineage ranged from 2 to 5 (Figure 1; Table 1).

Mean genetic distances between individuals within the Yandi Billiards lineages detected in the NJ analysis ranged from 0.0 to 1.2% sequence divergence (Table 2). The two lineages of Idiopidae differed from one another by a mean sequence divergence of 13.6% and the four lineages of Nemesiidae differed from one another by between 3.4 and 20.4% mean sequence divergence (Table 3).

Phylogenetic analyses
Model-based phylogenetic analysis was performed using the six lineages detected among the new Yandi Billiards specimens and 76 reference lineages that were ≤ 15% divergent from at least one of the new lineages (Figures 2; 3). The GTR+G model of sequence evolution was used for the Idiopidae tree and the GTR+I+G model was used for the Nemesiidae tree, with the Idiopidae tree running for 1 $\times 10^6$ generations and the Nemesiidae tree running for 25 $\times 10^6$ generations. Specimens were assumed to belong to the same lineage as a reference

specimen when they shared a single common ancestor, were well-supported by posterior probabilities (≥0.95), and differed from one another by ≤3% sequence divergence.

Of the six Mygalomorphae lineages detected in the present study, two (represented by FY9 and FY5) were placed in well-supported lineages that also contained reference specimens, NO and NR, respectively (Figure 3). The remaining four lineages were assumed to represent new lineages, because they showed >3% sequence divergence from the reference specimens (assigned to the new lineages IEF and IEG (Figure 2) and NIB and NIC (Figure 3).

Genetic differentiation between haplotypes and lineages

The two lineages of Idiopidae differed from the reference specimens by between 4.2 and 16.3% sequence divergence (Table 4). In particular, lineage the new Yandi Billiards lineage IEG showed a relatively high similarity to lineage IBL, differing from that lineage by 4.2% sequence divergence (Table 4).

The four lineages of Nemesiidae differed from the reference specimens by between 2.7 and 24.5% sequence divergence (Table 5). In particular, two lineages showed a high genetic similarity to reference lineages. Yandi Billiards lineage NO differed from the reference lineage of NO by 2.7% sequence divergence, and Yandi Billiards lineage NR differed from the reference lineage of NR by 2.7% sequence divergence (Table 7).

Conclusions

Taxonomic implications

The number of lineages and putative species in each family, as assessed using standard methods (Helix, 2012a), may be summarised as follows:

Idiopidae (two lineages, two putative species)

Eight specimens of Idiopidae were sequenced and all were assigned to new lineages (IEF and IEG). The former lineage was assigned to an existing species I53, while the latter was assigned to a new species, I80.

Nemesiidae (four lineages, three putative species)

Eight specimens of Nemesiidae were sequenced, and four of these were assigned to two existing lineages (NO and NR) and species (N42 and N44 respectively). The remaining four specimens were assigned to two new lineages (NIB and NIC). Both new lineages were assigned to the existing species N16.

Distributions of lineages and species

Both of the lineages of Idiopidae detected at Yandi Billiards were new. One of the lineages was assigned to the previously detected species I53, which has been detected at Koodaideri (Table 6). The remaining species of Idiopidae detected at Yandi Billiards (I80) has not been detected previously.

Two (NO and NR) of the four of the lineages of Nemesiidae collected at Yandi Billiards have been detected previously. Lineage NO has been detected at xxx and lineage NR has been detected at xxz. All four lineages were assigned to species that have detected previously in the Pilbara. Species N16 has been detected at 17 sites in the Pilbara (Table 6). Species N42 has been detected at Jinidi to Mainline Rail and Marillana, and species N44 has been detected at Jinidi to Mainline Rail (Table 6).

In summary, six lineages of Mygalomorphae belonging to two families (Idiopidae and Nemesiidae) were detected at Yandi Billiards. These lineages may be grouped into five putative species, four of which have been detected previously at reference sites and one of which is new.

References

Helix 2012a. Report on the Molecular systematics of Mygalomorphae from the Pilbara. Unpublished report, prepared for Biota Environmental Sciences, 31 January.

Helix Molecular Solutions (2012b). Molecular systematics of invertebrates from Koodaideri. Unpublished report, prepared for Biota Environmental Sciences, 25 April.

Table 1. Specimens used in this study, and the genetic lineage and putative species to which they were assigned based on variation at the COXI gene. * = new lineage or species.

Helix ID	Specimen ID	Taxon	Lineage/Species
FY1	M20140313.YBLSRE01-01	Idiopidae	IEG*/I53
FY2	M20140313.YBLSRE01-02	Idiopidae	IEG*/I53
FY3	M20140313.YBLSRE01-03	Idiopidae	IEG*/I53
FY4	M20140313.YBLSRE01-04	Nemesiidae	NO/N42
FY5	M20140315.YBLSRE04-01	Nemesiidae	NR/N44
FY6	M20140315.YBLSRE04-02	Nemesiidae	NR/N44
FY7	M20140316.YBLSRE08-01	Nemesiidae	NIB*/N16
FY8	M20140317.YBLSRE10-01	Nemesiidae	NIB*/N16
FY9	M20140317.YBL005P-01	Nemesiidae	NO/N42
FY10	M20140317.YBL007P-01	Nemesiidae	NIC*/N16
FY11	M20140317.YBL007P-02	Nemesiidae	NIC*/N16
FY12	T114601	Idiopidae	IEF*/I80*
FY13	T114602	Idiopidae	IEF*/I80*
FY14	T114603	Idiopidae	IEF*/I80*
FY15	T114604	Idiopidae	IEF*/I80*
FY16	T114605	Idiopidae	IEF*/I80*

Table 2. Mean distance (D) and standard error (s.e.) within lineages and the number (N) of individuals assigned to that lineage, detected in the Neighbour-Joining analysis. rep= haplotype chosen to represent the lineage in the model-based phylogenetic analysis.

Lineage	N	D	s.e.	rep
1	5	0.005	0.002	FY16
2	3	0.002	0.002	FY2
3	2	0.009	0.005	FY8
4	2	0.000	0.000	FY11
5	2	0.012	0.006	FY9
6	2	0.009	0.005	FY5

Table 3. Mean distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Mygalomorphae detected at Yandi Billiards in the Neighbour Joining analysis.

Lineage	1	2	3	4	5	6
1		0.018	0.020	0.022	0.022	0.021
2	0.136		0.020	0.019	0.020	0.022
3	0.217	0.210		0.009	0.021	0.020
4	0.213	0.212	0.034		0.020	0.018
5	0.202	0.194	0.204	0.191		0.018
6	0.218	0.221	0.187	0.173	0.127	

Table 4. Pairwise distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Idiopidae detected in the present study and selected reference lineages. Distances between the Yandi Billiards lineages and the reference lineages are highlighted in yellow.

Lineage	FY2	FY16	IAH	IAJ	IAL	IBB	IBD	IB	IBL	IBS	IBW	IBX	ICB	ICC	ICR	ICW	IY	IDT	IDU	IDX
FY2		0.018	0.019	0.019	0.017	0.017	0.017	0.019	0.010	0.018	0.018	0.019	0.019	0.018	0.017	0.018	0.017	0.020	0.019	0.019
FY16	0.133		0.020	0.018	0.018	0.016	0.016	0.015	0.019	0.018	0.016	0.019	0.019	0.018	0.019	0.016	0.018	0.019	0.019	0.017
IAH	0.163	0.139		0.020	0.016	0.018	0.017	0.019	0.018	0.017	0.019	0.017	0.018	0.017	0.016	0.018	0.020	0.019	0.019	0.019
IAJ	0.158	0.147	0.166		0.017	0.017	0.017	0.017	0.018	0.019	0.016	0.017	0.019	0.016	0.016	0.019	0.020	0.021	0.019	0.017
IAL	0.147	0.150	0.150	0.130		0.018	0.018	0.020	0.017	0.016	0.016	0.017	0.018	0.016	0.016	0.019	0.019	0.019	0.018	0.017
IBB	0.127	0.122	0.161	0.130	0.136		0.012	0.014	0.018	0.016	0.016	0.018	0.017	0.018	0.017	0.017	0.018	0.022	0.021	0.016
IBD	0.144	0.139	0.163	0.136	0.139	0.061		0.016	0.018	0.018	0.017	0.016	0.019	0.016	0.015	0.019	0.017	0.022	0.021	0.017
IB	0.152	0.130	0.172	0.125	0.152	0.083	0.102		0.019	0.019	0.018	0.018	0.017	0.018	0.016	0.019	0.019	0.021	0.021	0.019
IBL	0.042	0.125	0.144	0.141	0.141	0.130	0.141	0.147		0.018	0.017	0.018	0.019	0.018	0.015	0.017	0.017	0.018	0.020	0.019
IBS	0.166	0.150	0.147	0.166	0.127	0.150	0.175	0.180	0.161		0.019	0.020	0.020	0.016	0.015	0.019	0.018	0.017	0.017	0.016
IBW	0.141	0.127	0.158	0.139	0.144	0.155	0.169	0.172	0.136	0.150		0.016	0.015	0.016	0.017	0.017	0.017	0.020	0.018	0.017
IBX	0.139	0.127	0.152	0.139	0.152	0.139	0.155	0.155	0.139	0.158	0.108		0.013	0.012	0.019	0.016	0.017	0.019	0.020	0.017
ICB	0.144	0.139	0.183	0.150	0.155	0.141	0.172	0.150	0.147	0.180	0.119	0.061		0.017	0.019	0.018	0.019	0.020	0.020	0.019
ICC	0.133	0.122	0.150	0.141	0.139	0.141	0.147	0.150	0.144	0.144	0.111	0.086	0.122		0.016	0.018	0.016	0.017	0.019	0.018
ICR	0.130	0.147	0.158	0.111	0.130	0.111	0.116	0.100	0.127	0.161	0.139	0.161	0.163	0.130		0.018	0.016	0.020	0.019	0.019
ICW	0.136	0.125	0.133	0.144	0.139	0.139	0.152	0.152	0.122	0.161	0.125	0.125	0.133	0.133	0.155		0.018	0.019	0.019	0.017
IY	0.152	0.150	0.147	0.150	0.152	0.155	0.163	0.166	0.150	0.155	0.144	0.152	0.191	0.130	0.141	0.144		0.018	0.020	0.018
IDT	0.158	0.141	0.150	0.161	0.136	0.166	0.186	0.163	0.144	0.147	0.150	0.150	0.169	0.133	0.155	0.136	0.152		0.013	0.019
IDU	0.139	0.139	0.150	0.166	0.136	0.155	0.175	0.175	0.144	0.155	0.152	0.150	0.169	0.133	0.150	0.147	0.158	0.061		0.020
IDX	0.130	0.111	0.136	0.125	0.122	0.122	0.130	0.141	0.114	0.144	0.122	0.116	0.144	0.133	0.133	0.114	0.144	0.133	0.141	

Table 5 (attached). Pairwise distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Nemesiidae detected in the present study and selected reference lineages. Distances between the Yandi Billiards lineages and the reference lineages are highlighted in yellow.

Table 6. Putative species (defined as groups of lineages that form well-supported clades and differ by <9.5% sequence divergence) identified for each family and the distinct genetic lineages that compose them. *= new species or lineage this study.

Species	Composite lineages	Distribution
Idiopidae		
I53	IBL, IEG*	Koodaideri, Yandi Billiards
I80*	IEF*	Yandi Billiards
Nemesiidae		
N16	NB, NEP, NEQ, NFR – NFV, NG, NGU, NFE, NIB*, NIC*	Jinidi, Hope Downs, South Parmelia, Jinayri, Southern Flank to Jinidi Rail, Newman, Koodaideri, Koodaideri West Corridor, Area C, Hamersley Range, Mudlark, West Angeles, Tom Price, Jinidi to Mainline Rail, Juna Downs Station, Area C West, Koodaideri Southern Corridor, Yandi Billiards
N42	NO	Jinidi to Mainline Rail, Marillana, Yandi Billiards
N44	NR	Jinidi to Mainline Rail, Yandi Billiards

Figure 1. Neighbour-joining analysis of the 16 specimens of Mygalomorphae from Yandi Billiards. Numbers on nodes correspond to bootstrap support over 2000 iterations; values < 50% not shown. Scale bar= genetic distance. The six specimens selected to represent each lineage (labelled 1 – 6) are highlighted in yellow.

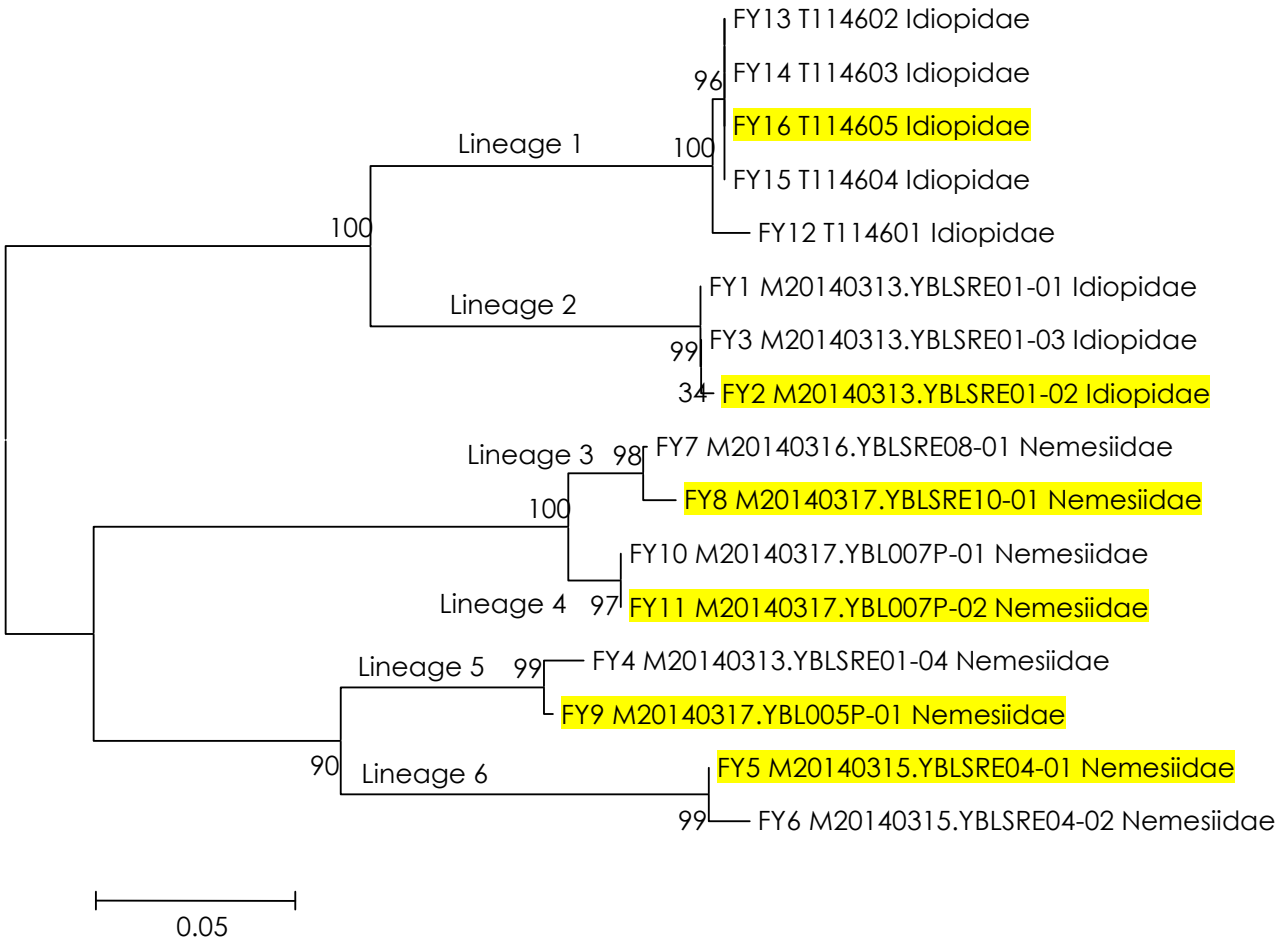


Figure 2. Bayesian analysis of COXI haplotypes of Idiopidae from Yandi Billiards. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Lineages from the present study are highlighted in yellow. Scale bar= number of substitutions per site. Clades that are well supported and whose composite lineages differ by ≤ 9.5%, or which have met these criteria in previous studies, are enclosed by red boxes.

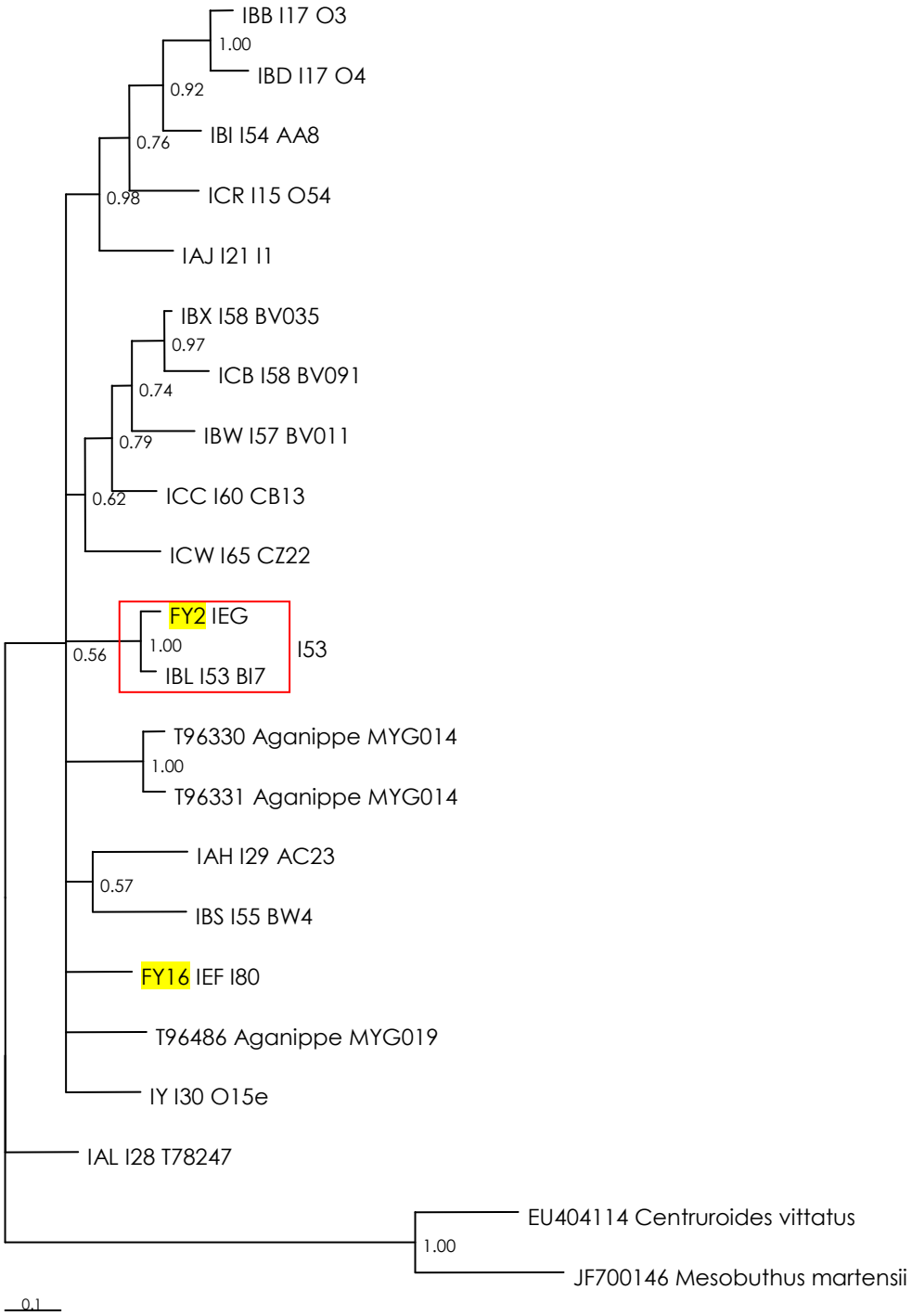
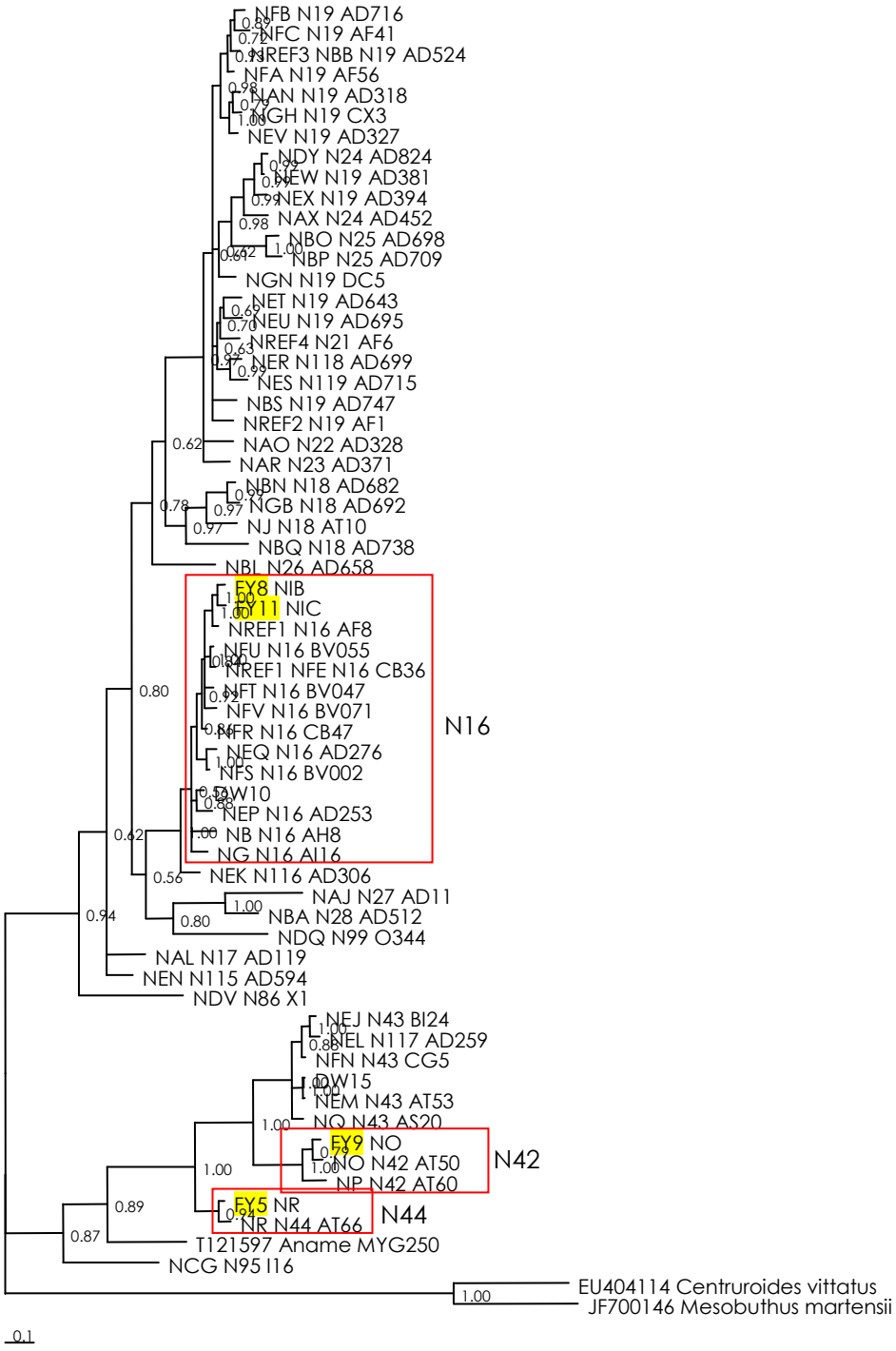


Figure 3. Bayesian analysis of COXI haplotypes of Nemesiidae from Yandi Billiards. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Lineages from the present study are highlighted in yellow. Scale bar= number of substitutions per site. Clades that are well supported and whose composite lineages differ by ≤ 9.5%, or which have met these criteria in previous studies, are enclosed by red boxes.



Helix
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Solutions

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1 November, 2014

Stewart Ford
Biota Environmental Sciences Pty. Ltd.
Level 1, 228 Carr Place,
Leederville, WA 6007, AUSTRALIA

Via email

Re. Report on the molecular systematics of Mygalomorphae from Yandi Billiards phase II

Dear Stewart,

Following is a summary of the results for the Yandi Billiards collections from phase II. We detected three distinct genetic lineages in the family Nemesiidae. The three lineages likely represent three putative species, all of which have been detected previously in the Pilbara.

Thank you once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Jason Kennington
Helix Molecular Solutions Pty Ltd

Background
Extensive molecular work has been conducted on the trap-door spider fauna of Western Australia (Helix 2012a). The resulting dataset provides a molecular framework that can be used to provide a regional context for localised sampling.

The present study involved the collection and sequencing of eight additional Mygalomorphae specimens from the Yandi Billiards site in order to assess their relationships to the existing sequencing records for more than 2200 specimens from the Pilbara.

The new Yandi Billiards Mygalomorphae sequences were added to the existing sequence dataset to assign specimens to existing lineages and species or to identify new lineages/species.

Executive Summary
- Eight specimens from Yandi Billiards were sequenced for COXI.
- A DNA sequence was obtained from all eight specimens.
- Phylogenetic analysis of the eight new specimens revealed the presence of three distinct genetic lineages in the family Nemesiidae.
- The three lineages represent three putative species, all of which have been detected previously in the Pilbara.

Methods
The specimens were sequenced and analysed as previously described (Helix 2012b), with the following changes:

In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) tree was constructed from the eight new sequences in order to identify the number of unique lineages present. Representatives from each lineage were then used in a model-based phylogenetic analysis along with 40 reference specimens of Mygalomorphae as described below.

Model-based phylogenetic analysis was performed using the lineages of Mygalomorphae detected among the new specimens and a sub-set of reference lineages (N=40) that were selected based on the criteria that they showed ≤15% sequence divergence from at least one of the new lineages. The reference lineages represented one family of Mygalomorphae detected in the Pilbara (Nemesiidae). Lineages detected in the present study were assumed to belong to a previously detected lineage when they shared a single common ancestor, were well-supported by posterior probabilities (≥0.95), and differed from one another by ≤3% sequence divergence.

Results
A 686 bp fragment of COXI was obtained from all eight specimens.

Preliminary analysis
The NJ analyses placed the eight new specimens into three distinct genetic lineages (haplotypes or clusters of highly similar haplotypes separated from other such clusters by long branch lengths; YB2-1, YB2-2, YB2-3; Figure 1). The number of individuals in each lineage ranged from one to six (Figure 1; Table 1).

Mean genetic distance between individuals within the Yandi Billiards lineage YB2-1 detected in the NJ analysis was 1.2% sequence divergence; the remaining two lineages contained only single individuals (Table 2). The three lineages differed from one another by between 10.8 and 18.7% mean sequence divergence (Table 3).

Phylogenetic analyses
Model-based phylogenetic analysis was performed using the three lineages detected among the new Yandi Billiards phase II specimens and 40 reference lineages that were ≤ 15% divergent from at least one of the new lineages (Figure 2). The GTR+I+G model of sequence evolution was used for the tree, with the tree running for 25 $\times 10^6$ generations. Specimens were assumed to belong to the same lineage as a reference specimen when they shared a single

common ancestor, were well-supported by posterior probabilities (≥0.95), and differed from one another by ≤3% sequence divergence.

All three Mygalomorphae lineages detected in the present study were placed in lineages that also contained reference specimens. Lineage GT4 was placed in a lineage containing reference lineage NO (=species N42), GT5 was placed in a lineage containing reference lineage NAC (=species N1) and GT8 was placed in a lineage containing reference lineage NR (=species N44; Figure 2).

Genetic differentiation between haplotypes and lineages

The three lineages of Nemesiidae differed from the reference specimens by between 1.1 and 24.7% sequence divergence (Table 4). In particular, all three lineages showed high genetic similarities to reference lineages. Yandi Billiards lineage YB2-2 (represented by GT4) differed from the reference lineage NO by 2.2% sequence divergence, Yandi Billiards lineage YB2-3 (GT5) differed from the reference lineage NAC by 1.1% sequence divergence and Yandi Billiards lineage YB2-1 (GT8) differed from the reference lineage NR by 2.2% sequence divergence (Table 4).

Conclusions

Taxonomic implications

The number of lineages and putative species in each family, as assessed using standard methods (Helix, 2012a), may be summarised as follows:

Nemesiidae (three lineages, three putative species)

Eight specimens of Nemesiidae were sequenced, and all were assigned to three existing lineages (NO, NR and NAC) and species (N42, N44 and N1, respectively).

Distributions of lineages and species

All three of the lineages of Nemesiidae collected at Yandi Billiards during phase II have been detected previously in the Pilbara. Both lineages NO and NR have been detected at Jinidi to Mainline Rail and Yandi Billiards phase I, and lineage NAC has been detected at Marillana and Koodaideri. All three lineages were assigned to species that have detected previously in the Pilbara. Species N1 has been detected previously at 14 sites in the Pilbara (Table 5). Species N42 has been detected at Jinidi to Mainline Rail and Marillana as well as previously at Yandi Billiards phase I, and species N44 has been detected at Jinidi to Mainline Rail as well as previously at Yandi Billiards, phase I (Table 5).

In summary, three lineages of Mygalomorphae belonging to the family Nemesiidae were detected at Yandi Billiards during phase II. These lineages may be grouped into three putative species, all of which have been detected previously at reference sites.

References

Helix 2012a. Report on the Molecular systematics of Mygalomorphae from the Pilbara. Unpublished report, prepared for Biota Environmental Sciences, 31 January.

Helix Molecular Solutions (2012b). Molecular systematics of invertebrates from Koodaideri. Unpublished report, prepared for Biota Environmental Sciences, 25 April.

Table 1. Specimens used in this study, and the genetic lineage and putative species to which they were assigned based on variation at the COXI gene.

Specimen ID	Family	Helix ID	Lineage/Species
M20140913-YBLSRE20-01	Nemesiidae	GT1	NR/N44
M20140913-YBLSRE20-02	Nemesiidae	GT2	NR/N44
M20140913-YBLSRE20-03	Nemesiidae	GT3	NR/N44
M20140914-YBLSRE21-01	Nemesiidae	GT4	NO/N42
M20140914-YBLSRE21-02	Nemesiidae	GT5	NAC/N1
M20140917-YBLSRE25-01	Nemesiidae	GT6	NR/N44
M20140917-YBLSRE25-02	Nemesiidae	GT7	NR/N44
M20140918-YBLSRE26-01	Nemesiidae	GT8	NR/N44

Table 2. Mean distance (D) and standard error (s.e.) within lineages and the number (N) of individuals assigned to that lineage, detected in the Neighbour-Joining analysis. rep= haplotype chosen to represent the lineage in the model-based phylogenetic analysis. Na=not analysed because n=1.

Lineage	N	D	s.e.	rep
YB2-1	6	0.012	0.002	GT8
YB2-2	1	na	na	GT4
YB2-3	1	na	na	GT5

Table 3. Mean distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Mygalomorphae detected at Yandi Billiards phase II in the Neighbour Joining analysis.

Lineage	YB2-1	YB2-2	YB2-3
YB2-1		0.011	0.013
YB2-2	0.108		0.012
YB2-3	0.183	0.187	

Table 4 (attached). Pairwise distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Nemesiidae detected in the present study and selected reference lineages. Distances between the Yandi Billiards lineages and the reference lineages are highlighted in yellow.

Table 5. Putative species (defined as groups of lineages that form well-supported clades and differ by <9.5% sequence divergence) detected in the present study, the distinct genetic lineages that compose them and their distributions.

Species	Composite lineages	Distribution
Nemesiidae		
N1	NA, NAC, NBD, NEI, NFM, NFP, NH, NI	South Parmelia, Jinayri, 113 km, 114 km and 118 km NW of Newman, Koodaideri, Koodaideri Southern Corridor, Area C, Mudlark, Juna Downs Station, Area C West, Davidson Creek, Marillana, Jimblebar, Yandi Billiards phase II
N42	NO, NP	Jinidi to Mainline Rail, Marillana, Yandi Billiards phase I and II
N44	NR	Jinidi to Mainline Rail, Yandi Billiards phase I and II

Figure 1. Neighbour-joining analysis of the eight specimens of Mygalomorphae from Yandi Billiards phase II. Numbers on nodes correspond to bootstrap support over 2000 iterations; values < 50% not shown. Scale bar= genetic distance. The three specimens selected to represent each lineage (labelled YB2-1 – YB2-3) are highlighted in yellow.

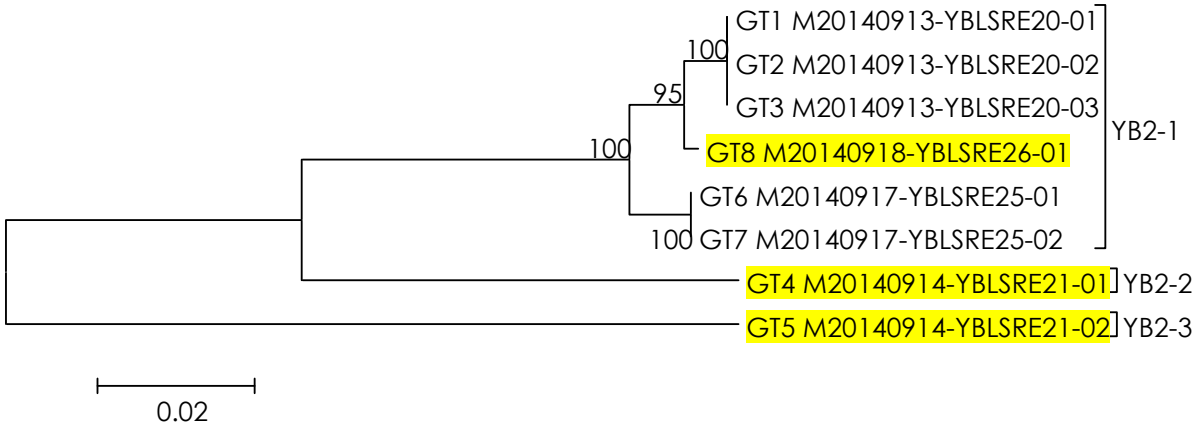
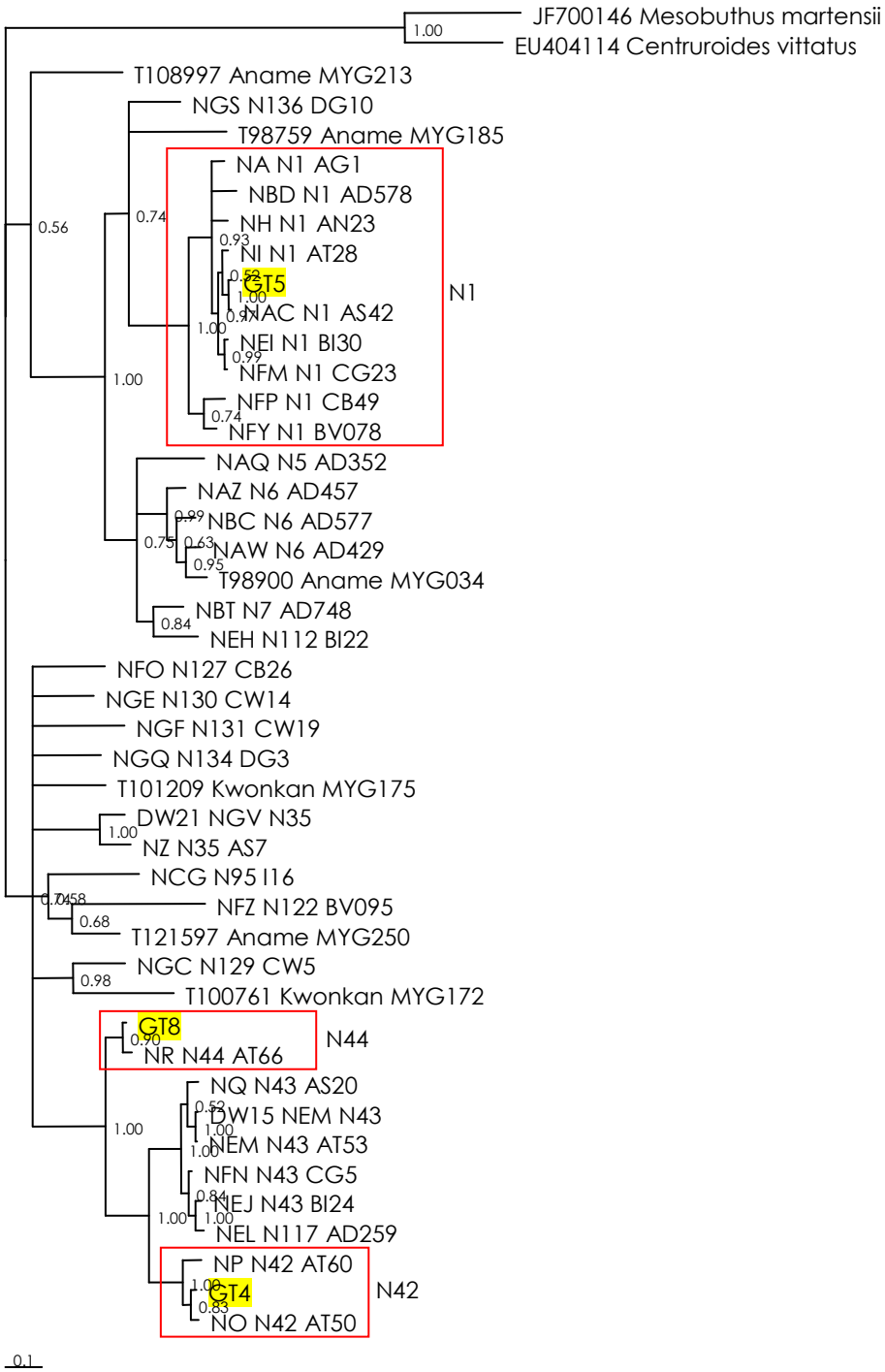


Figure 2. Bayesian analysis of COXI haplotypes of Nemesiidae from Yandi Billiards Phase II. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Lineages from the present study are highlighted in yellow. Scale bar= number of substitutions per site. Clades that are well supported and whose composite lineages differ by ≤ 9.5%, or which have met these criteria in previous studies, are enclosed by red boxes.



Appendix 7

Regulation 17: Licence to Take Fauna for Scientific Purposes

DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
Telephone: 08 9334 0333
Facsimile: 08 9334 0242

Correspondence: **Locked Bag 30**
Bentley Delivery Centre WA 6983

PERSON NO. SF009991
167264

DATE OF ISSUE 27/08/2014
VALID FROM 05/09/2014
DATE OF EXPIRY 19/09/2014

LICENSING OFFICER

LICENSEE: DR SS FORD (STEWART STEPHEN)
ADDRESS BIOTA ENVIRONMENTAL SCIENCES
PO BOX 155
LEEDERVILLE WA 6903

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DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

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Telephone: 08 9334 0333
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Correspondence: **Locked Bag 30**
Bentley Delivery Centre WA 6983

PAGE NO. 1
SF009991
PERSON NO. 167264

RECEIPT NO. **AMOUNT**
$0.00

WILDLIFE CONSERVATION ACT 1950
REGULATION 17
LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

DIRECTOR GENERAL

CONDITIONS

1 THE LICENSEE SHALL COMPLY WITH THE PROVISIONS OF THE WILDLIFE CONSERVATION ACT AND REGULATIONS AND ANY NOTICES IN FORCE UNDER THIS ACT AND REGULATIONS.

2 UNLESS SPECIFICALLY AUTHORISED IN THE CONDITIONS OF THIS LICENCE OR OTHERWISE IN WRITING BY THE DIRECTOR GENERAL, SPECIES OF FAUNA DECLARED AS LIKELY TO BECOME EXTINCT, RARE OR OTHERWISE IN NEED OF SPECIAL PROTECTION SHALL NOT BE CAPTURED OR OTHERWISE TAKEN.

3 NO FAUNA SHALL BE TAKEN FROM ANY NATURE RESERVE, WILDLIFE SANCTUARY, NATIONAL PARK, MARINE PARK, TIMBER RESERVE OR STATE FOREST WITHOUT PRIOR WRITTEN APPROVAL OF THE DIRECTOR GENERAL. NO FAUNA SHALL BE TAKEN FROM ANY OTHER PUBLIC LAND WITHOUT THE WRITTEN APPROVAL OF THE GOVERNMENT AUTHORITY MANAGING THAT LAND.

4 NO ENTRY OR COLLECTION OF FAUNA TO BE UNDERTAKEN ON ANY PRIVATE PROPERTY OR PASTORAL LEASE WITHOUT THE CONSENT IN WRITING OF THE OWNER OR OCCUPIER, OR FROM ANY ABORIGINAL RESERVE WITHOUT THE WRITTEN APPROVAL OF THE DEPARTMENT OF INDIGENOUS AFFAIRS.

5 NO FAUNA OR THEIR PROGENY SHALL BE RELEASED IN ANY AREA WHERE IT DOES NOT NATURALLY OCCUR, NOR BE HANDED OVER TO ANY OTHER PERSON OR AUTHORITY UNLESS APPROVED BY THE DIRECTOR GENERAL, NOR SHALL THE REMAINS OF SUCH FAUNA BE DISPOSED OF IN SUCH MANNER AS TO CONFUSE THE NATURAL OR PRESENT DAY DISTRIBUTION OF THE SPECIES.

6 THIS LICENCE AND THE WRITTEN PERMISSION REFERRED TO AT CONDITIONS 3 & 4 MUST BE CARRIED BY THE LICENSEE OR AUTHORISED AGENT AT ALL TIMES FOR THE PURPOSE OF PROVING THEIR AUTHORITY TO TAKE FAUNA WHEN QUESTIONED AS TO THEIR RIGHT TO DO SO BY A WILDLIFE OFFICER, ANY OTHER STATE OR LOCAL GOVERNMENT EMPLOYEE OR ANY MEMBER OF THE PUBLIC.

7 **********ANY INTERACTION INVOLVING GAZETTED THREATENED FAUNA THAT MAY BE HARMFUL AND/OR INVASIVE MAY REQUIRE APPROVAL FROM THE DEPT OF SUSTAINABILITY, ENVIRONMENT, WATER, POPULATION & COMMUNITIES PH 02 6274 1111. INTERACTION WITH SUCH SPECIES IS CONTROLLED BY THE COMMONWEALTH GOVERNMENT'S "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999" & "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION REGULATIONS 2000" AS WELL AS DPaW'S WILDLIFE CONSERVATION ACT & REGULATIONS.**********

8 NO BIOPROSPECTING INVOLVING THE REMOVAL OF SAMPLE AQUATIC AND TERRESTRIAL ORGANISMS (BOTH FLORA AND FAUNA) FOR CHEMICAL EXTRACTION AND BIOACTIVITY SCREENING IS PERMITTED TO BE CONDUCTED WITHOUT SPECIFIC WRITTEN APPROVAL BY THE DIRECTOR GENERAL OF DPaW.

9 FURTHER CONDITIONS (NUMBERED 1 TO 4) ARE ATTACHED.

PURPOSE LEVEL 2 FAUNA SURVEY BY SYSTEMATIC TRAPPING (ELLIOTT, FUNNEL AND DRY PITFALL TRAPS), TARGETED TRAPPING AND SEARCHES FOR CONSERVATION SIGNIFICANT SPECIES (NORTHERN QUOLL, ORANGE LEAF-NOSED BAT, PILBARA OLIVE PYTHON, NIGHT PARROT, MULGARA), ECHOLOCATION CALL RECORDERS, HARP NETS, REMOTE CAMERAS, AND SHORT RANGE ENDEMIC (SRE) TARGETED SEARCHES, AT THE YANDI BILLIARDS PROJECT AREA 90KM NORTHWEST OF NEWMAN, FOR RIO TINTO PTY LTD.

AUTHORISED PERSONS
PENNY BROOSHOOFT
DANIEL KAMIEN
JASON ALEXANDER
TIM SACHSE
CHRIS COLE

WILDLIFE CONSERVATION REGULATIONS 1970

Regulation 17:- Licence to Take Fauna for Scientific Purposes

FURTHER CONDITIONS (OF LICENCE NUMBER SF00 9991)

1. The licensee shall take fauna only in the manner stated on the endorsed Regulation 17 licence application form and endorsed related correspondence.

2. Except in the case of approved lethal traps, the licensee shall ensure that measures are taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be deployed so as to prevent exposure of trapped animals to ants and debilitating weather conditions and inspected at regular intervals throughout each day of their use. At the conclusion of research all markers etc and signs erected by the licensee and all traps shall be removed, all pitfalls shall be refilled or capped and the study area returned to the condition it was in prior to the research/capture program. During any break in research, cage traps should be removed and pitfalls either removed, capped or filled with sand.

3. No collecting is to be undertaken in areas where it would impinge on pre-existing scientific research programs.

4. Any form of colour marking of birds or bats shall only be undertaken in accordance with the requirements of the Australian Bird and Bat Banding Scheme.

5. Any inadvertently captured specimen of fauna which is declared as likely to become extinct, rare or otherwise in need of special protection is to be released immediately at the point of capture. Where such a specimen is injured or deceased, the licensee shall contact Department of Parks and Wildlife licensing staff at Kensington (08 9219 9831) for advice on disposal. Records are to be kept of any fauna so captured and details included in the report required under further condition 6 below.

6. Within one month of the expiration of this licence, the holder shall submit an electronic return detailing the locality, site, geocode, date and number of each species captured, sighted or vouchered during the currency of the licence, into the Department of Parks and Wildlife Fauna Survey Database (FSD). A copy of any paper, report or thesis resulting from the research shall on completion be lodged with the Director General. If a renewal of this licence is required, the licensee shall submit a written progress report for activities undertaken during this licence period prior to the expiry of this licence.

7. Not more than ten specimens of any one protected species shall be taken and removed from any location less than 20km apart. Where exceptional circumstances make it necessary to take large series in order to obtain adequate statistical data the collector will proceed with circumspection and justify their actions to the Director General in advance.

8. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected which represents a significant extension of geographic range shall be donated on request to the Western Australian Museum.

9. To prevent any unnecessary collecting in this State, all specimens and material collected under the authority of this license shall, on request, be loaned to the Western Australian Museum. Also, the unused portion or portions of any specimen collected under the authority of this license shall be offered for donation to the Western Australian Museum or made available to other scientific workers if so required.

Appendix 8

Threatened Fauna Statutory Framework

Commonwealth EPBC Act 1999

Fauna species of national environmental significance are listed under the Commonwealth *EPBC Act 1999*, and may be classified as 'critically endangered', 'endangered', 'vulnerable' or 'lower risk', which are consistent with IUCN categories (IUCN 2013).

Critically Endangered (CR): a taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future.

Endangered (EN): a taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future.

Vulnerable (VU): a taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future.

Lower Risk (LR): a taxon is Lower Risk when it has been evaluated, does not satisfy the criteria for any of the categories Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories:

1. Conservation Dependent (CD). Taxa which are the focus of a continuing taxon-specific or habitat-specific conservation program targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within a period of five years.
2. Near Threatened (NT). Taxa which do not qualify for Conservation Dependent, but which are close to qualifying for Vulnerable.
3. Least Concern (LC). Taxa which do not qualify for Conservation Dependent or Near Threatened.

Migratory species are also protected under the *EPBC Act 1999* as species of national environmental significance (DSEWPaC 2013). Migratory species are those animals that migrate to Australia and its external territories, or pass through or over Australian waters during their annual migrations (DSEWPaC 2013). The list of migratory species consists of those species listed under the following international conventions:

1. Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention);
2. China-Australia Migratory Bird Agreement (CAMBA);
3. Japan-Australia Migratory Bird Agreement (JAMBA); and,
4. Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA).

Western Australian Wildlife Conservation Act 1950

Classification of rare and endangered fauna under the state *Wildlife Conservation (Specially Protected Fauna) Notice 2013* (State of Western Australia 2013), recognises four distinct schedules of taxa:

Schedule 1: taxa that are rare or likely to become extinct and are declared to be fauna in need of special protection.

Schedule 2: taxa that are presumed to be extinct and are declared to be fauna in need of special protection.

Schedule 3: birds that are subject to an agreement between the government of Australia and the governments of Japan, China and the Republic of Korea relating to

the protection of migratory birds, and birds in danger of extinction, which are declared to be fauna in need of special protection.

Schedule 4: taxa that are in need of special protection, otherwise than for the reasons mentioned above in Schedules (1), (2) and (3).

Department of Parks and Wildlife Priority Fauna

In addition, the Department of Parks and Wildlife maintains a list of Priority species that have not been assigned statutory protection under the *Wildlife Conservation Act 1950*. Species on this list are considered to be of conservation priority because there is insufficient information to make an assessment of their conservation status or they are considered to be rare but not threatened and are in need of monitoring. Under this list, species are classified according to five Priority categories:

Priority One: Taxa with few, poorly known populations on threatened lands
Taxa which are known from few specimens or sight records from one or a few localities on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, active mineral leases. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Two: Taxa with few, poorly known populations on conservation lands
Taxa that are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Three: Taxa with several, poorly known populations, some on conservation lands
Taxa that are known from few specimens or sight records from several localities, some of which are on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Four: Taxa in need of monitoring
Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands.

Priority Five: Taxa in need of monitoring
Taxa that are not considered threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

DSEWPaC (2013). *Environment Protection and Biodiversity Conservation Act 1999* Species Profile and Threats Database [WWW Document]. Retrieved from http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl.

IUCN (2013). IUCN Red List of Threatened Species. Version 2013.2. [WWW Document]. Retrieved January 9, 2014, from http://www.iucnredlist.org/.

State of Western Australia (2013). Wildlife Conservation (Specially Protected Fauna) Notice 2013. *Western Australian Government Gazette* 170:4320–4331.

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RIO TINTO IRON ORE

BILLIARDS SOUTH PRE-FEASIBILITY STUDY

REVIEW OF SURFACE WATER MODELLING

Issue 1

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RIO TINTO IRON ORE

BILLIARDS SOUTH PRE-FEASIBILITY STUDY
Review of Surface Water Modelling

Executive Summary

The present study by Rio Tinto has been undertaken to investigate and develop a concept design for a flood protection levee along Weeli Wolli Creek that would enable the recovery of the Billiards South ore deposit. To support this conceptual review a RORB hydrologic model and TUFLOW hydraulic model have been developed. The work undertaken by Rio Tinto has demonstrated that construction of a levee along Weeli Wolli Creek is feasible and the results have been used to inform the levee design. The RORB and TUFLOW flood modelling results have also been used to inform an ecohydrology study to identify the likely changes to surface water flow regime and the effects on riparian vegetation along Weeli Wolli Creek as a result of development of the Pocket and Billiard South deposits within the Yandicoogina mine.

The results of this peer review indicate suggest that:

- The RORB modelling undertaken is fit for purpose.
- Although some minor improvements can be made to the TUFLOW flood model, the modelling undertaken and results are also considered fit for purpose.

The recommended improvements presented in this report should be implemented during the next phase of the Project to further develop the levee design in more detail.

Disclaimer

This report has been prepared on behalf of and for the exclusive use of Rio Tinto Iron Ore, and is subject to and issued in accordance with the agreement between Rio Tinto Iron Ore and WorleyParsons. WorleyParsons accepts no liability or responsibility whatsoever for any use of or reliance upon this report by any third party.

Project: 201012-00527 – BILLIARDS SOUTH PRE-FEASIBILITY STUDY
Review of Surface Water Modelling

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1. INTRODUCTION

Rio Tinto's Yandicoogina Operation is located approximately 80 km northwest of Newman near the intersection of Marillana Creek, Phil's Creek, Yandicoogina Creek and Weeli Wolli Creek (*refer* **Figure 1.1**). The Billiard South Deposit, which incorporates the Pocket Deposit, runs parallel to Weeli Wolli Creek upstream of its confluence with Marillana Creek. Some sections of the deposit also intersect Weeli Wolli Creek itself.

Although the extent of mining will be constrained by the natural flood extent, development of the deposit will have some impact on the riparian zone and has the potential to encroach into the floodplain of the Weeli Wolli Creek if flood protection infrastructure is provided.

A Flood Study has been undertaken by Rio Tinto as part of the Pre-Feasibility Phase of the Project to characterise both the pre-development and proposed operational flow conditions for Weeli Wolli Creek. The Flood Study is based on the results of hydrologic modelling of catchment runoff using RORB and hydrodynamic modelling of flood conditions using the TUFLOW software package. Results from the TUFLOW modelling have been used to assist in the design a flood protection levee for the Pocket and Billiard South Operations. The results have also been used to inform an ecohydrology study which is aimed at identifying the likely changes to surface water flow regime and the effects on riparian vegetation along Weeli Wolli Creek as a result of development of the Pocket and Billiard South deposits.

An independent review of the RORB and TUFLOW flood modelling has been requested due to the location of the proposed development within the floodplain and the potential risks associated with the flooding of Weeli Wolli Creek. This report documents the outcomes of a review of the RORB and TUFLOW flood modelling undertaken by Rio Tinto.

2. PREVIOUS INVESTIGATIONS

A number of previous studies have been undertaken that relate to management of water and the environment in Weeli Wolli Creek, Marillana Creek and Yandicoogina Creeks as a result of the nearby mining operations. The most relevant of these, and the subject of this review, are:

- *'Weeli Wolli Creek Ecohydrology - Yandicoogina Pocket and Billiard South Pre-Feasability Study'* (*Rio Tinto, 2015*); and,
- *'Weeli Wolli Creek Hydrology and Floodplain Assessment - Yandicoogina Billiard South Order of Magnitude Study'* (*Rio Tinto, 2013*).

A number of other hydrologic and hydraulic modelling investigations have also been carried out in the vicinity of the site. Each of the studies that have involved hydraulic modelling is discussed in the following sections.

2.1 IRON VALLEY PROJECT SURFACE WATER STUDY (URS 2012)

URS was commissioned by Iron Ore Holdings Ltd to undertake a surface water assessment for the Iron Valley Tenement, which is located near to the Billiards Deposit and Weeli Wolli Creek. The purpose of the study was to undertake modelling of the works that would be required to protect the operation of the mine form flooding and stormwater. The investigation involved the development and application of a 2D hydraulic model using the TUFLOW software.

2.2 YANDI SUSTAINING PROJECT DETAILED HYDROLOGY (STORMWATER) STUDY (BG&E 2012)

BG&E Pty Ltd was engaged by Rio Tinto Iron Ore to undertake a detailed stormwater study for the Yandi Sustaining Project. The investigation involved the development of a two-dimensional hydraulic model of Marillana Creek upstream of its confluence with Yandicoogina Creek. The model was developed using MIKE 21 and used a 5 m rectangular grid. The terrain was based on LiDAR data, while surface roughness was delineated from available aerial photography. Structures such as culverts were modelled as linked MIKE 11 1D elements.

2.3 WEELI WOLLI CREEK HYDROLOGY AND FLOODPLAIN ASSESSMENT - YANDICOOGINA BILLIARD SOUTH ORDER OF MAGNITUDE STUDY (RIO TINTO 2013)

This study was undertaken by Rio Tinto to determine the flood extents and hydraulic characteristics of flood flows in the vicinity of the Billiards South Deposit. Options for positioning flood protection levees to enable the recovery of ore from the Billiards South Deposit are discussed. The hydraulic modelling that was developed as part of this investigation is discussed in further detail in **Section 2** of this report.

The modelling undertaken as part of this study led to the identification of recommendations for the location and extent of levees that would be required to protect the mine from flooding.

Three levee options were investigated and are referred to as the Pillar Levee, the Maximum Extraction Levee and the Conservative Extraction Levee. The location and extent of each of the three levee options is shown in **Figure 1.1** and are described as follows:

- The Pillar levee option, which could be constructed in conjunction with either the conservative or the maximum recovery levees to protect the Pocket mining operation on the Western side of the Weeli Wolli Creek floodplain. Depending on the option chosen this levee would have an average height of between 1.3 m and 2.8 m.
- The Conservative Extraction Levee which extends along the eastern side of Weeli Wolli Creek with an average crest height of 3.1 m.
- The Maximum Extraction Levee which facilitates the maximum recovery of the Billiards South ore deposit. This levee would be 4.1 m high on average and would require nearly twice the volume of fill to construct relative to the Conservative Extraction Levee.

In all scenarios an allowance for 0.5 m of freeboard was incorporated into the levee crest height.

2.4 WEELI WOLLI CREEK ECOHYDROLOGY - YANDICOOGINA POCKET AND BILLIARD SOUTH PRE-FEASABILITY STUDY (RIO TINTO 2015)

This pre-feasibility study built on the understanding of the hydrologic and hydraulic processes developed as part of the *'Weeli Wolli Creek hydrology and floodplain assessment - Yandicoogina Billiard South Order of Magnitude Study'* (*Rio Tinto 2013*). It involved more detailed flood modelling to assess each of the three levee options considered by Rio Tinto in its 2013 Report. However, in this phase of investigation, the Pillar Levee is always considered in conjunction with one of the levees on the eastern side of Weeli Wolli Creek.

In this investigation, four options for crossing Weeil Wolli Creek are considered as summarised below:

- The conservative and Pillar Levee with eight 3.6 m diameter pipe culverts in the low flow channel and two 2.1 m diameter pipes in the high flow channel.
- The conservative and Pillar Levee with a 22 m wide 3.6m high box culvert bridge in the low flow channel and two 2.1 m diameter pipes in the high flow channel.
- The maximum recovery and Pillar Levee with eight 3.6 m diameter pipe culverts in the low flow channel.
- The conservative and Pillar Levee with a 22 m wide 3.6m high box culvert bridge in the low flow channel.

In all cases some flow over the road way is intended during flood events.

3. HYDROLOGIC MODELLING

Rio Tinto prepared the study report (RTIO-PDE-0117748_Weeli Wolli Creek hydrology and floodplain assessment) dated 17 December 2013 which documents the outcomes of RORB runoff routing modelling and TUFLOW 2D hydraulic modelling (Rio Tinto, 2013). The modelling was undertaken to define the hydrological regime and natural flow conditions of the creek and to investigate conceptual flood mitigation options to facilitate safe mining of the Billiard South deposits within the Weeli Wolli Creek floodplain.

RORB is considered to be an appropriate software package for modelling flood hydrology as it is event based rather than a continuous simulation model. The RORB runoff routing software was originally developed by Eric Laurensen and Russell Mein at Monash University and is widely used throughout the Australia.

3.1 CATCHMENT AND NETWORK DELINEATION

The Weeli Wolli Creek catchment includes the catchment of Marillana Creek, the main tributary of Weeli Wolli Creek. The GIS-based delineations of the model catchment, its subcatchments and the connecting stream network were checked by comparing them with watersheds and streamlines generated from ASTER digital elevation data. The ASTER GDEM is a product of METI and NASA. **Figure 3.1** shows the modelled subcatchments and stream network overlaid with the ASTER-based subcatchment and streamline delineations. While there were several discrepancies, the most significant were attributed to errors in the ASTER generated delineation and none were considered to be significant in affecting outcomes from the RORB model. **Table 3.1** summarizes the subcatchment comparisons.

The routes of the link-node routing network, representing the dendritic stream flow lines, were also confirmed initially by comparison with the ASTER-based streamlines. Significant discrepancies were verified by reference to Google Earth imagery. All of the significant discrepancies in the network were attributed to lack of channel definition in the ASTER DEM. The network routes used in the model were therefore verified.

In the RORB model network there appeared to be a number of redundant nodes located at subcatchment outlets. While the presence of these subcatchment outlet nodes, where located near the edge of the Billiard deposit, may have provided information on local subcatchment flood flows entering the mine, the redundant nodes higher in the Marillana Creek and Weeli Wolli catchments appeared to add unnecessary complexity to the model. Ultimately, however the presence of these nodes would not adversely affect the results obtained from the model.

The storage characteristics used for the Munjina Claypan could not be verified due to a lack of detailed topographic and definition data available to the reviewer.

Table 3.1 Assessment of Subcatchment Delineation

Sub-catchment	Area (ASTER), km²	Area (Model), km²	%Diff	Comments	Model Status
M01	106.63	105.13	1.4%		OK.
M02	252.30	258.66	2.5%	5.4km² less subcatchment at ASTER watershed.	OK.
M03	242.62	247.35	1.9%	6.9km² extra subcatchment at ASTER watershed.	OK.
M04	116.19	102.91	12.9%	ASTER Boundary with M03 ill-defined.	OK.
M05	94.02	91.70	2.5%		OK.
M06	62.21	61.44	1.3%		OK.
M07	81.70	82.65	1.1%		OK.
M08	92.77	92.57	0.2%		OK.
M09	113.71	113.00	0.6%		OK.
M10	47.11	46.39	1.5%		OK.
M12	98.55	99.07	0.5%		OK.
M13	210.86	215.80	2.3%		OK.
M14	61.02	57.37	6.4%	Numerous peripheral differences with ASTER	OK.
M15	16.09	16.70	3.7%		OK.
M16	48.28	52.95	8.8%	ASTER Boundary with M17 ill-defined.	OK.
M17	220.56	220.69	0.1%		OK.
M18	296.25	283.13	4.6%	7.3km² extra subcatchment at ASTER watershed.	OK.
M19	30.25	24.22	24.9%	ASTER Boundary with surrounding subcatchments ill-defined.	OK.
M20	53.52	58.39	8.3%	ASTER Boundary with M19, M05 and M03 ill-defined.	OK.
WW01	201.24	212.23	5.2%	ASTER Boundary with watershed, WW06 and WW11 ill-defined. Small (2.2 km²) outflowing subcatchment included in model.	OK.
WW02	108.63	109.88	1.1%		OK.
WW03	83.72	87.48	4.3%	Small 2.7 km² valley catchment correctly included in WW03 model.	OK.
WW04	48.36	46.87	3.2%	Small 2.7km² valley catchment included in WW03.	OK.
WW05	232.91	212.24	9.7%	Small 7.2km² valley catchment with indeterminate discharge direction not included. Could go either east (into WW05) or west, off-model. Small 1.8km² catchment correctly excluded from WW05 (passes to WW06).	OK.
WW06	132.71	128.60	3.2%	6.6km² subcatchment correctly excluded, passing to WW01. 1.8km² subcatchment correctly included in model (refer to WW05).	OK.
WW07	87.47	90.89	3.8%	South east corner ill-defined. 4.5km² sub-catchment included in model (conservative).	OK.

Sub-catchment	Area (ASTER), km²	Area (Model), km²	%Diff	Comments	Model Status
WW08	204.06	242.66	15.9%	South east corner ill-defined. 439.0km² subcatchment included in model (conservative).	OK.
WW09	128.25	131.37	2.4%		OK.
WW10	47.15	51.39	8.3%	4.8km² subcatchment correctly included (refer to WW11)	OK.
WW11	135.70	124.01	9.4%	4.8km² subcatchment assigned to WW11. 3.6km² and 2.2km² subcatchments correctly excluded (see WW01, WW04), the latter affected by mining infrastructure.	OK.
WW12	17.27	17.63	2.1%		OK.
WW13	73.38	70.81	3.6%		OK.
WW14	46.32	46.35	0.1%		OK.
WW15	19.39	19.19	1.0%		OK.
WW16	27.77	28.72	3.3%		OK.
WW17	29.55	29.44	0.4%		OK.
WW18	24.44	25.90	5.6%	4.8km² subcatchment correctly included (refer to WW21)	OK.
WW19	22.80	24.68	7.6%	Northern (outlet) end ill-defined; 1.1km² subcatchment correctly included in model (refer to WW20). 1.0km² subcatchment at southern end correctly included (refer to WW20).	OK.
WW20	29.71	33.91	12.4%	5.3km² subcatchment correctly included at eastern and southern watershed. 1.1km² subcatchment correctly excluded (refer to WW19)	OK.
WW21	42.00	41.97	0.1%		OK.
TOTALS	3987.5	4006.3	0.5%	Very good overall comparison of catchment areas.	OK.

3.2 MODEL CALIBRATION

The Initial Loss (IL) – Continuing Loss (CL) loss model adopted for calibration is consistent with guidance in Australian Rainfall and Runoff for the Pilbara Region. Calibration was based on a number of observed flood events using gauged streamflow records from Flat Rocks (708001) on Marillana Creek and from Tarina (708013) and Waterloo Bore (708014) on Weeli Wolli Creek. Corresponding rainfall data for those events was obtained from records for Munjina (505004), Flat Rocks (505011), Wonmunna (507012), Tarina (505040) and Waterloo Bore (505041). Rainfall records from Munjina (in the upper reaches of Marillana Creek) and Wonmunna (in the upper reaches of Weeli Wolli Creek) do not appear to have been used in the calibration. Rainfall from the remaining three stations appears to have been distributed to the modelled subcatchments based on Thiessen polygons (Voronoi tessellation) constructed from the gauge locations.

Flood events from 25 February 1995, 8 January 1997, 15 December 1999 and 25 January 2003 were used for model calibration, with a further gauged event from 1 March 2009 used for validation. The estimated annual exceedance probability (AEP) of the floods produced by these events ranged from 50% (1/3/2009 at Flat Rocks gauge) to 1% (12/12/1999 at Tarina gauge).

The four input values used in the RORB calibration process were kc (an empirical coefficient representing the relative delay time of the catchment), m (the reach storage exponent), IL and CL. For this study, a value of 0.8 was adopted for m, in accordance with the recommendations of the RORB User Manual and guidance from Australian Rainfall and Runoff (AR&R).

Examination of the calibration plots presented in the Weeli Wolli Creek hydrology and floodplain assessment report (Rio Tinto, 2013) indicated that the calculated peak flows were well matched with the observed values. Hydrograph shapes generally appeared to be well matched, with consistent trends in both rising and falling legs of the hydrographs at the gauged locations. Times-to-peak was compared well in the modelled results.

Two of the calibration models, chosen arbitrarily, were examined in more detail to test the sensitivity of the calibration to each of the parameters in isolation.

3.2.1 December 1999 Calibration

The December 1999 event at Flat Rocks (10% - 5% AEP) yielded calibration values of 19, 80 and 14.8 for kc, IL and CL respectively. The flow peaks were well-matched with only slight lag in timing of the modelled peak. The model appeared to be relatively insensitive to moderate changes in IL, possibly due to the significant losses and buffering effects of storage upstream at the Munjina Flats. The model appeared responsive to changes in both kc and CL, with the storage exponent m fixed at 0.8. Hydrograph shapes were reasonably consistent with the observed curve at Flat Rocks exhibiting the greater volume.

At Tarina gauge (2% - 1% AEP), the calibrated values were 21, 45 and 11.1 for kc, IL and CL respectively. The magnitude and timing of the flow peaks were well-matched. The model at this site appeared sensitive to changes in kc, less sensitive to IL and very sensitive to changes in CL. Modelled hydrograph shapes and volumes were reasonably consistent.

At Waterloo Bore gauge (5% - 2% AEP) the values were 19, 105 and 5.5. The magnitude and timing of the flow peaks again were well-matched. At this site, the model was sensitive to changes in kc and CL and again appeared less sensitive to IL.

Overall the calibrated hydrographs appeared to be a good match to the observed flows. The parameters kc and CL appeared to have greatest influence on the modelled flows.

3.2.2 February 1995 Flood Calibration

At Flat Rocks (5% - 2% AEP) the calibration yielded values of 9, 20 and 5.2 for kc, IL and CL respectively. The flow peaks were well-matched with only slight lag in timing of the modelled peak.

While the model appeared to be insensitive to IL values below 50mm and only moderately sensitive to kc, it exhibited significant response to changes in CL.

At Tarina gauge (20% AEP), the calibrated values for kc, IL and CL were 28, 70 and 8.7. The magnitude and timing of the flow peaks were well-matched. The model at this site appeared somewhat sensitive to changes in kc, insensitive to IL below 50mm and sensitive to changes in CL. Modelled hydrograph shapes and volumes appeared to be reasonably consistent.

At Waterloo Bore gauge (5% AEP) the values were 21, 54 and 0. The magnitude of the flow peaks again were well-matched, however the observed flows seemed to lag behind the modelled curve. While the rising limbs of the hydrographs were similar, the modelled recession limb occurred more rapidly than the observed resulting in some underestimation of flow volume. At this site, the model appeared to be sensitive to changes to all parameters, kc, IL and CL.

For this event, the calibrated hydrographs appeared to be a reasonable match to the observed flows.

3.2.3 Verification Run

The verification run (1 March 2009 event) using the adopted parameters (based on averages from the various calibration runs) exhibited good agreement between the observed peak flow values and the calculated peak flows at each gauge site. Rate of rise of the main hydrograph peaks were reasonably well approximated and volumes of flow appeared consistent for each gauged site.

3.2.4 Calibration of IL and CL

Rather than using the calibrated values for the loss parameters IL and CL, which were determined from observed storm and flood data, these parameters were recalibrated for design storms events of a range of AEP's. The values of the parameters IL and CL were recalibrated to match the peak flows at the gauge sites with the expected peak flow values determined from annual series flood frequency analysis (FFA) of the observed streamflow datasets.

It was evident that there were no distinct trends the calibrated values of either IL or CL with observed event AEP, so recalibration of these parameters against the FFA expected flow values would appear appropriate to reflect the likely variability of both IL and CL with storm (and hence flood) AEP.

Comparison was made in the Weeli Wolli Creek hydrology and floodplain assessment report (Rio Tinto, 2013) with model results at the gauges determined using the published loss values recommended in AR&R. The report concluded that use of the AR&R values tended to overestimate the flood peaks determined for this catchment. This conclusion is supported on the basis of the FFA results presented figures 8-4 (Flat Rocks), 8-5 (Tarina) and 8-6 (Waterloo Bore) of the report (Rio Tinto, 2013).

Ultimately the ranges of the loss values adopted for the design flood simulations (see Table 8-3 of Rio Tinto, 2013) are reasonably consistent with the ranges of values determined in the calibration of observed events.

3.3 RARE DESIGN FLOOD ESTIMATION

For estimation of rare flood events (0.5 to 0.05% AEP) adoption of areal design rainfalls using the published CRC-FORGE data for Western Australia would appear appropriate, particularly where design durations are 24-hours or longer, as appears to be the case at each of the gauge locations (see Tables 8-3 and 10-3 of Rio Tinto, 2013) and at principal points of interest at Billiard South and the Marillana Creek confluence (see Table 9-1 of Rio Tinto, 2013). The recalibrated loss parameters for the design rare events are substantially lower than those used for the 1% AEP design modelling which is more likely to overestimate than underestimate the resulting flood flows and again is considered to be a reasonable approach for the purposes of design.

4. HYDRAULIC MODELLING

Rio Tinto developed a 2D hydrodynamic model that has been used to assess potential levee options aimed at protecting mining operations associated with the Billiards South Deposit. The hydrodynamic model was developed using the TUFLOW software which is a GIS driven 2D hydraulic modelling package that is widely used within Australia and around the world to simulate flooding. GIS tools are used to process the available base data, such as LiDAR derived terrain information or vegetation mapping, into a model capable of accurately simulating a variety of flood events.

4.1 BASE DATA

The TUFLOW model was developed using LiDAR derived terrain data, vegetation mapping and aerial photography. This data was used in conjunction with ground based survey, site inspections and historic records of previous flood events to create a model capable of reliably simulating flood behaviour along Weeli Wolli Creek and its floodplain.

4.1.1 LiDAR

The LiDAR data used as a basis for the TUFLOW model was captured by Fugro Spatial Solutions Pty Ltd. The data was captured between the 12th December 2011 and the 17th May 2012 by an aircraft flying at approximately 1400 m above ground level. The full metadata report is reproduced in **Appendix A**.

In conjunction with the aerial survey, Fugro Spatial Solutions Pty Ltd collected 57 ground control points, of which 3 points are within the model domain. Comparisons between the LiDAR and the ground control points show the standard deviation of returns is 0.09 m vertically and 0.18 m horizontally. The average vertical deviation is 0.055 m, while the maximum vertical error is +0.143 m. This suggests that there are no systematic errors in the LiDAR data set, and that the LiDAR data provides a reliable representation of the terrain.

However, LiDAR may not always accurately capture features underneath heavy vegetation, in steep or enclosed terrain, or where there may have been buildings or standing water. These features may be of greater hydraulic interest. Due to the location of the ground control points comparisons between ground control points and the terrain surface produced by the LiDAR data do not always give a good indication of the suitability of the data for hydraulic modelling.

A sample of the LiDAR data that has been used to develop the TUFLOW model is shown in **Figure 4.1**. A detailed examination of high resolution contours shows that the creek and overbank floodplain are clearly resolved in the LiDAR data set.

There are some areas where vegetation may be confusing the interpretation of the laser returns, however these areas are limited in extent and do not materially affect the resolution of the waterways or other hydraulic features.

Areas that were covered with water at the time of the data collection would have been filtered from the laser returns, and hence no terrain data is available in these locations. Subsequent processing was undertaken using interpolated data to fill in these areas. However, the waterways were substantially dry during the survey collection, and so there are only limited areas where data is missing for this reason and where interpolation was required.

4.1.2 Aerial Photographs

Aerial photographs were available for use in developing the TUFLOW model. These photos are visible in **Figure 1.1**. A broader scale photograph with a 0.5 m resolution was used to aid model development, together with a photograph extending over the Billiards South Deposit which has a 0.3 m resolution. Metadata is not available to indicate the time or date of capture.

These photographs clearly show features within the Weeli Wolli Creek floodplain. Floodplain features such as vegetation, roads, creeks and waterway extent and structures are all clearly visible across the modelling domain.

4.1.3 Site Inspection

Multiple site inspections were undertaken by Rio Tinto staff in and around the TUFLOW model domain area. Site inspections were undertaken on the following days:

- 24th June 2014
- 25th June 2014
- 2nd July 2014
- 11th July 2014
- 12th July 2014
- 13th November 2014

A range of Site Photos was gathered during the site inspections. Some of these are contained in **Appendix B**, which also includes a map showing the location and orientation of each photo. Most of these photos are concentrated around the Billiards South deposit, and show in channel, overbank and overland floodplain areas. They have been used in conjunction with the aerial photographs, publications documenting floodplain roughness and previous experience to determine appropriate energy loss coefficients for use on the Weeli Wolli Creek floodplain.

4.1.4 Historic Flood Level Information

No historic flood level information is available for Weeli Wolli Creek or its tributaries Marillana Creek or Yandicoogina Creek. It is noted that significant flooding did occur in January 2012, however no flood marks were recorded in the vicinity of the Billiards South Development. Without records of historic floods it is not possible to undertake reliable calibration of the flood model.

4.2 MODEL SETUP

Two versions of the TUFLOW hydraulic model were developed by 2D modelling specialists within Rio Tinto. The model used for the *Weeli Wolli Creek Hydrology and Floodplain Assessment – Yandicoogina Billiard South Order of Magnitude Study*, is based on a 40 m grid. The model was developed using TUFLOW version 2013-12-AC-iDP-w64, which is a double precision, 64 bit version of the software.

A separate a 5 m grid based TUFLOW model was developed for the *Weeli Wolli Creek Ecohydrology - Yandicoogina Pocket and Billiard South Pre-Feasibility Study*. Two versions of the TUFLOW modelling software were used in this study. TUFLOW version 2013-12-AC-iDP-w64 was used where the model includes the crossing of Weeli Wolli Creek. Where the model does not include the creek crossing, version 2013-12-AC-iSP-w64 was used with the GPU solver. The GPU solver operates using a different numerical scheme to the regular version of TUFLOW, and as such has different requirements.

4.2.1 Model Configuration and Parameters

For the most part model parameters have been left as the default values for version 2013-12-AC-iDP-w64. In general, the default values within TUFLOW are set to produce reasonable simulation results, and as such, there is often little reason to vary from these defaults. The default configuration for all TUFLOW settings is documented in BMT WBM (*2010*). However the timestep, cell wet / dry depth and eddy viscosity have all been explicitly set in the set-up file.

The 40 m model time step has been set at 10 seconds, which results in a maximum Courant number of 3.05 for the 0.2% AEP base case simulation. Mass errors are also less than 1% once starting conditions are allowed for. Both of these values are within the guidelines advised by the TUFLOW manual. There is no other evidence of numerical instabilities in the modelling, and hence the selected timestep can be considered appropriate.

The 5 m model time step has been set at 1.25 seconds with the creek crossing, which results in a maximum Courant number of approximately 3.05 as before for the 0.2% AEP base case simulation. Mass errors are also still less than 1% once starting conditions are allowed for, which indicates that the selected time step is appropriate. The versions of the model without the creek crossing have used adaptive timestepping.

The cell wet / dry depth is set at 0.002 m, which is the recommended value for main stream flood simulations, although it is greater than the minimum value of 0.0002 m. As a result cells will drop out of the simulation once the depth of water is less than 0.002 m, and this may contribute to the mass error. However, with the exception of direct rainfall simulations, the default value of 0.002 m is normally appropriate. As stated above the mass balance does not present a concern.

The Smagorinsky turbulence model has been used to simulate the hydrodynamic viscosity. This is a Large Eddy Simulation (LES) turbulence model that is commonly adapted for flood and estuary models, and calculates the effect of eddy viscosity from the local velocity field in the model. The recommended values have been used in the turbulence model, with a constant co-efficient of 0.1 and a Smagorinsky coefficient of 0.2.

Due to the coarse (40 m) grid, the effects of eddy viscosity are not expected to be a major factor in the simulated hydrodynamics. As the Smagorinsky turbulence model calculates the effect of eddy viscosity form the velocity field, there is little reason to change the coefficient from the recommended default values in most circumstances. However, the 40 m grid may be supressing the calculation of viscosity effects.

4.2.2 TUFLOW Model Terrain Resolution

The terrain used by the TUFLOW model is based on the LiDAR data-set discussed in **Section 4.1.1**. TUFLOW samples the terrain at half the grid resolution to allow for cells to be partially blocked. As a 40 m grid has been used, TUFLOW effectively samples the terrain at 20 m intervals. With the 5 m grid the floodplain is sampled at 2.5 m intervals.

Figure 4.2 shows a comparison of the difference in a cross section located across the main channel of Weeli Wolli Creek, as well as a side tributary, near the Pillar Levee. The LiDAR data used to make this cross-section is shown in **Figure 4.1**.

From this comparison it is evident that the 40 m TUFLOW model has not been able to sample the details of the main channel as well as the main channel. The depth of the main channel is reduced, while the channel bank heights and steepness are also reduced. The smaller side tributary is not captured by the TUFLOW model. Flatter overbank areas are however reproduced reasonably well by the TUFLOW model.

As a result of the differences in the terrain between the available LiDAR and the 40 m grid TUFLOW model, the 40 m grid TUFLOW model may not have the ability to accurately capture the impacts on the hydrodynamics of in channel flow as well as the impacts of small features such as road embankments.

However, once flooding covers the floodplain to a substantial depth, the TUFLOW model does captures the flow area available across the entire floodplain.

These issues are addressed with the 5m grid TUFLOW model. **Figure 4.2** shows that most of the detail of the floodplain is captured by the 5 m grid.

4.2.3 Model Representation of Proposed Levees

As 40 m grid resolution TUFLOW model has sampled the terrain on a 20 m interval, it is possible for the simulation grid to sample the terrain either side of narrow structures such as the proposed levees. As a result there are circumstances where the proposed levees may not be properly represented in the model.

In the post development modelling, the levees have been incorporated as 'thin' lines. These lines raise the elevation in a continuous string in a path defined by the line. The crests of the levees have been raised above the simulated terrain by a uniform amount. Inspection of the post-development model shows that there are no gaps where water may flow through the levee.

However, this approach may not capture the side slopes of the levee embankment. The effect of the not fully representing the side slopes of the levees is expected to be minor in terms of its impact on flood levels. However, it may mean that the velocity information extracted from the model is less reliable that desired for use in designing scour protection systems that may be required, especially where high velocity conditions exist. It may be appropriate to refine the model in these areas when and if it is used to provide criteria for levee and scour protection system design.

4.2.4 Model Representation of the Creek Crossing

The crossing of Weeli Wolli Creek has used 1D elements linked to the 2D model domain. This approach allows the energy losses associated with the structure to be carefully controlled. The 1D results show the simulation to be stable, and as such the model is accurately simulating the structures that have been specified.

As the culverts are modelled in 1D, entry and exit losses are assigned to the inlet and outlet of the culverts. A value of 0.5 has been used for the inlet losses, while a value of 1.0 has been assumed for the exit loss. These are typical loss energy loss values and are appropriate in the majority of circumstances.

However, for some inlet and outlet arrangements it is recommended that these losses be adjusted (*Queensland Department of Energy and Water Supply, 2013*). For example, in cases where the pipe inlet protrudes from the embankment, the inlet loss should be increased. In cases where the flow leaving the outlet is constrained, there may be scope to decrease the loss values.

In addition to inlet an outlet losses, TUFLOW applies a contraction coefficient to the pipe or culvert inlets to account for the effects of the vena-contracta. For circular pipes a contraction coefficient of 1.0 has been used. For the box culvert sections a height contraction of 0.6 and a width contraction of 0.9 has been applied. As these are large culverts these values may be more conservative than required.

4.2.5 Boundary Conditions and Model Extent

The location of the boundary conditions is shown in **Figure 4.3**. All inflow boundaries are flow hydrographs exported from RORB, while both of the outflow boundaries are normal depth boundaries where the energy slope has been specified.

The downstream boundaries are located over 10 km from the Billiards South deposit, while the upstream boundary is over 1km from the end of the proposed levee. The two downstream boundaries both contain bends which result in flow running parallel to the boundary for a distance.

The boundaries should be located such that the flow is approximately perpendicular to the boundary. However, in this instance this does not appear to have affected the results at Billiards South.

A plot of the water level profile through the model domain for the 0.5% AEP flood is shown in **Figure 4.4**. The energy slope is approximately equal to the water surface slope, and this is shown to be approximately equal to the bed slope. Such conditions suggest that using a normal depth boundary at the downstream end of the model is appropriate.

The bed slope is uniform throughout the model domain, with a slope of 0.0026. This compares with an energy slope of 0.00286 and 0.00295 used in the model. As the water surface profile is reasonably uniform throughout the model domain, and as the sites of interest are sufficiently far from the downstream boundaries the modelled boundary slopes are reasonable.

Downstream of the Billiards South development there is a proposed Fortescue Metals Group (FMG) development. As part of this development a levee is to be constructed, and this may create a backwater that will affect the Billiards South development. As **Figure 4.4** shows the backwater for the 0.5% AEP does not extend to the Billiards South Levee.

4.2.6 Effect of Grid Resolution

While the initial modelling has been undertaken using a 40 m grid, recent modelling has been conducted using a 5 m grid. The reduction in grid size has resulted in changes to both flood level and flow velocity. This change may be as a result of any or all of the following factors:

- Increased definition of the terrain allowing greater conveyance in the identified water ways and defined flood channels
- Increase in the definition of the terrain effectively increases roughness
- Improved definition of the velocity field affecting the calculation of viscosity effects and allowing the formation of eddies.

The impact on peak flood levels is shown in **Figure 4.5**. The reduction in grid size has resulted in a mean increase of 0.1 m, although the water levels are reduced by up to 0.5 m and are increased by up to 0.5 m. Along the length of the proposed levee (*maximum extraction option*) the peak flood levels are increased by up to 0.1 m. The largest variations are noted where Marillana Creek enters the model domain.

The variations in water level, combined with differences in the terrain used in the simulation, have resulted in areas becoming inundated which were not previously inundated, while some areas which were inundated are now no longer inundated as shown by the yellow and purple mapping in **Figure 4.5**.

The impact that the reduction in grid size has had on velocity is shown in **Figure 4.6**. **Figure 4.6** shows that across the majority of the floodplain the impact on velocity is extremely minor. However, there is a notable change in the vicinity of the main channels.

The standard deviation in velocity as a result of the reduction in grid size is 0.28 m/s, while the maximum change in velocity is 4.1 m/s. Along the levee (*maximum extraction option*), the velocities may be increased by up to 0.7 m/s or reduced by 1.0 m/s as a result of the reduction in grid size.

As the velocity along the levee varies between 1.4 m/s and 4.8 m/s (*Maximum Recovery Levee with Pillar Levee Option*), the variation in velocity associated with the different grid size may alter the type and extent of the scour protection required along the levee embankment. It is recommended that velocity and shear stress criteria adopted for design of the levee and associated scour protection be based on the results of simulations undertaken using the 5 m grid resolution TUFLOW model.

4.2.7 Model Roughness

Model roughness has been determined based on Land Unit Classifications (*Van Vreeswyk et al., 2004*), aerial photographs, and literature (*Arcement & Schneider, 1989*). The roughness distribution is shown in **Figure 4.7**.

The site inspection photographs (*refer* **Appendix B**), along with the aerial photographs show that the creek channel contains only minimal vegetation at the northern portion of the of the model domain where Weeli Wolli Creek flows towards Fortescue Marsh (*refer* **Photo B1).** However the vegetation that is present consists of mature trees that will have a disproportionate effect on flow due to their location and rigidity**.** Further south, nearer the Billiards development area, the creek resembles a pool and riffle system, with gravel bars and some vegetation separating present between pools of standing water. In all instances there is significant vegetation, though not excessively thick, on the creek banks.

The floodplain is covered with vegetation that varies from moderate, which is inclusive of grasses and shrubs but very few trees, to thick with a substantial number of trees (*refer* **Photo B6).** Gulleys and other watercourses attract a greater density of vegetation. Due to the terrain, vegetation in these areas will have a greater influence on flood flows and hence the roughness should be weighted accordingly.

It is understood that the roughness delineation used has been based on vegetation mapping. The use of vegetation mapping has enabled the floodplain roughness to be mapped in detail. Major hydraulic features such as the creek channel, thick overbank and moderate overbank vegetation are all delineated. Graded roads are also included in the roughness distribution used. A small area of the model domain has not been assigned a roughness values, and this area will be assigned a value of 0.045 as this is the default roughness set in this particular model.

However, the roughness does not always follow the patterns of vegetation visible in the aerial photographs. Along the creek channel the creek and immediate overbank areas are commonly covered by the same roughness polygon, which will apply the same roughness to the relatively clear creek channel and relatively heavily vegetated creek banks. In other instances it is apparent that there are flood channels that have been swept clear of vegetation that are included within polygons that correspond to thick vegetation.

Table 4.1 lists the materials roughness values adopted and the apparent conditions that each refers to, based on overlaying the roughness distribution over the aerial photographs (*refer* **Figure 4.7**). Also listed for comparison is the expected range that the roughness co-efficient would fall in for a 2D model from the Australian Rainfall (ARR) and Runoff Project 15 Stage 1 and 2 Draft Report (*Babister & Barton 2012*).

From **Table 4.1** is apparent that in many instances the adopted roughness co-efficients fall below the range recommended by ARR Project 15. The ARR Project 15 Stage 1 and 2 Draft Report does not specify what roughness value should be used for a given set of conditions, but rather, it gives the range of values used by water resources engineers to achieve calibration over a variety of other 2D numerical flood models in Australian catchments.

It is not necessary for the adopted roughness co-effients to fall inside range nominated by ARR in every instance. However any instance where the adopted value does fall outside of the nominated range should be carefully justified. Consideration should be given to other factors which may be altering roughness calibration process, for example, hydrologic factors, the presence or absence of hydraulic structures or changes in the nature and type of vegetation.

For the comparison, the modelling undertaken as part of BG&E (*2012*) applied a roughness co-efficient of 0.08 for densely vegetated areas, 0.06 for moderately vegetated areas, 0.05 for lightly vegetated areas, and 0.04 for cleared areas. As the model domain used in BG&E (*2012*) is located very close to the model domain used by Rio Tinto (*2013*), and both are 2D modelling studies, the roughness values are comparable between the two models. The modelling undertaken in URS (2012) applies a uniform roughness of 0.04 across waterways and the floodplain. However the modelling approach is not comparable as Rio Tinto (*2013*) has delineated the roughness based on the vegetation present while URS (*2012*) have not.

Sensitivity tests with a higher roughness demonstrated that increasing the roughness coefficients do have a significant effect on flood levels. **Figure 4.8** shows the impact that a 20% increase in roughness has on the 0.5% AEP flood levels. Along the length of the proposed levee the water level increased by up 0.4 m. However, the range recommended by ARR is in many instances more than 20% greater, and hence the results of this sensitivity test may understate the effect that a revised roughness will have on flood levels.

Table 4.1 COMPARISON BETWEEN BILLIARDS TUFLOW MODEL AND ARR PROJECT 15 RECOMMENDED RANGE

Roughness co-efficient	TUFLOW Material IDs	Description	ARR Recommended Range
0.022	24	Unsealed Roads	0.02 to 0.03
0.025	16	Non- floodplain areas with some minimal vegetation (grassed)	0.03 to 0.05
0.028	20, 23	Non- floodplain areas with minimal vegetation (grassed)	0.03 to 0.05
0.030	4, 7, 14	Non- floodplain areas with moderate vegetation (shrubs)	0.05 to 0.07
0.032	19	Mine site – roads and materials stockpile (industrial, not conducive to flood conveyance)	0.2 to 0.5
0.035	3, 6, 21	Creek channels and immediate overbank area with vegetation	0.04 to 0.1
0.040	13, 18	Floodplain areas with moderate vegetation (shrubs)	0.05 to 0.07
0.045	2, 9, 25	Floodplain areas with moderate vegetation (shrubs)	0.05 to 0.07
0.047	11, 12	Floodplain areas with thick vegetation (trees)	0.07 to 0.12
0.050	1, 8, 17, 22	Floodplain areas with thick vegetation (trees)	0.07 to 0.12
0.052	10	Floodplain areas with thick vegetation (trees)	0.07 to 0.12
0.055	5	Floodplain areas with thick vegetation (trees)	0.07 to 0.12
0.060	15	Floodplain areas with thick vegetation (trees)	0.07 to 0.12

4.2.8 Hydraulic Structures

The modelling produced by Rio Tinto contained no hydraulic structures such as culverts of bridges. In the base case modelling, there is a road that crosses Weeli Wolli Creek, however **Photo B4** shows this road crossing to be by way of a ford, and as such no hydraulic structure is present.

No structures have been incorporated into the post development modelling either. While it is proposed to construct a crossing of Weeli Wolli Creek to connect to the Existing facilities at the Yandicoogina Mine, the details of this crossing are yet to be determined.

Some sensitivity testing has been undertaken on the effect that the crossing may have on the TUFLOW model results. The potential impacts of the crossing are shown in **Figure 4.9**. The inclusion of the crossing has increased water levels upstream of the bridge by as much as 1.5 m. The extent of the impact is however limited.

4.3 REVIEW OF RESULTS

4.3.1 Flood Level and Velocity

A review of base case results has been carried out, with an example of the velocity and depth shown in **Figure 4.10**. In all cases the results were as expected, with greatest velocities and greatest depths noted in the creek channels.

WaterRide has been used to examine the flows through the model. Hydrographs are consistent with expectations through the model. Some attenuation is noted due to storage effects in in the flood plain; however mass is conserved throughout the model domain.

4.3.2 Impact of the Levees

The impact of the maximum recovery levee and Pillar levee on flood levels during the 0.5% AEP event is shown in **Figure 4.11**. The construction of both levees may increase flood levels by up to 2.4 m. The construction of both levees creates a funnel through which the floodwater is forced.

Due to the effect of funnelling the flow between the levees, velocities are increased by up to 3 m/s in the vicinity of the Billiards development (*refer* **Figure 4.12**). As velocity in this area is between 2 m/s and 3 m/s the effect of the levees has been to double the velocity while also increasing the depth by up to 50%.

As a result, the model will have a greater sensitivity to the effect of roughness. In the St Venant's equations, depth reduces the effect of roughness by the 4/3rd power. Velocity however increases the effect of roughness with the 2nd power. In a natural channel this will result in changes in water level due to variations in roughness that are greater than sensitivity testing on the base case would suggest.

5. CONCLUSIONS

5.1 SUMMARY

The present study by Rio Tinto has been undertaken to investigate and develop a concept design for a flood protection levee along Weeli Wolli Creek that would enable the recovery of the Billiards South ore deposit. A RORB hydrologic model and TUFLOW hydraulic model have been developed to support this conceptual review.

The work undertaken by Rio Tinto has demonstrated that construction of a levee along Weeli Wolli Creek is feasible and the results have been used to inform the levee design. The flood modelling results have also been used to inform an ecohydrology study to identify the likely changes to surface water flow regime and the effects on riparian vegetation along Weeli Wolli Creek as a result of development of the Pocket and Billiard South deposits.

The results of this peer review indicate that although some minor improvements could be made to the flood model(s), the 5 m grid TUFLOW model is considered to be 'fit for purpose'. Furthermore, the results that have been derived from the modelling are considered to provide a reliable representation of flow conditions during major flooding of Weeli Wolli Creek, and are therefore suitable for the assessment of environmental impacts and for use in the development of concept designs for the proposed flood protection levee. The minor improvements to the model that are outlined in this report can be implemented during the next phase of the Project to further support the detail design of the levee.

5.2 'FIT FOR PURPOSE' ASSESSMENT OF TUFLOW MODEL

5.2.1 Model Set-up

A peer review of the TUFLOW hydraulic model(s) developed by Rio Tinto has established that the models are based on reliable data. LiDAR terrain data, aerial photographs and site inspection photographs have all been used to assist in developing the TUFLOW model and in the determination of key model parameters such as roughness. Examination of this base data sources it to be of a good quality and to be representative of the Weeli Wolli Creek and its floodplain.

The TUFLOW model that has been developed from these data sources is, for the most part, set up in accordance with the recommendations made by BMT WBM (2010). Where model parameters are unspecified the appropriate TUFLOW default settings are used. Where model parameters have been specified these are within the range expected for a model of this type. While the location of the downstream boundary could be improved this does not have a notable impact on the modelling results at the Billiards South Levee for those design flood scenarios that have been tested.

The original modelling was based on a 40 m grid. This grid resolution compromised the ability of the TUFLOW model to reliably simulate the hydrodynamics in some areas. The 40 m grid did not allow the terrain to be sampled correctly, and as a result the depth of the

main channel that was simulated is less than it should be. However, the development of a finer resolution TUFLOW model based on a 5 m grid addressed this issue.

Sensitivity testing undertaken by Rio Tinto showed that reducing the model resolution from 40 m to 5 m increases peak flood levels throughout the model domain. Along the proposed levee, the reduction in grid size results in an increase in peak 1% AEP flood level of 0.1 m, on average.

Velocities are also changed, with increases of up to 0.7 m/s and decreases of up to 1.0 m/s noted in the vicinity of the Billiards South development. This change in velocity may influence the design of the required scour protection.

Where there is a crossing of the Weeli Wolli Creek included in the model, a linked 1D element has been used. The general arrangement and operation of these structures in the simulation is satisfactory, and can be considered to serve as an accurate representation of the structure that has been specified. However, once further details regarding the specific design of these crossings is known, values for the entry loss, exit loss and flow contraction should be reviewed.

5.2.2 Model Parameters

The model roughness used in TUFLOW can have a significant effect on the flood level results. The roughness used for this project has been assigned on the basis of vegetation mapping, and clearly delineates major features such as the creek channels or pockets of thick vegetation. This is appropriate provided consideration is given to whether the adopted grid resolution suitably “picks-up” vegetation or obstructions that are smaller than the model grid. For example, in the creek channel it is possible that each grid cell has captured part of the creek channel and part of the overbank area. A roughness that accounts for this partial obstruction should be derived.

The method for estimation of roughness coefficients used in this study is based on Arcement & Schneider (*1989*). Arcement & Schneider (*1989*) break down the selection of roughness into the following components:

- A base value for a straight, uniform and smooth channel in natural materials
- A correction for the effect of surface irregularities
- A correction for variations in the size and shape of the channel cross-section or floodplain
- A correction for obstructions in the channel or floodplain
- A correction for the effect of vegetation in the channel or floodplain
- A factor applied for the sinuosity of the channel.

The base roughness values have been determined appropriately from site inspection and the coefficients developed by Arcement & Schenider (*1989*) have been applied. Therefore, roughness parameters adopted in the modelling are considered to be ‘fit for purpose’ for

environmental impact assessment and for the provision of parameters (*e.g., velocity and shear stress*) that will be required to inform the levee design at a pre-feasibility level.

5.3 RECOMMENDATIONS FOR FUTURE STUDIES

It is recommended that the following data be gathered, if available, for use in validating the results of the flood modelling:

- Stream gauging data for Weeli Wolli Creek.
- Available flood level marks from any significant flood events.

If available, this data should be used to validate the flood model for existing scenario conditions.

For future work is recommended that the TUFLOW modelling be modified in the following ways:

(i) All simulations aimed at deriving hydraulic parameters for levee design should be based on application of the 5 m grid TUFLOW model. .

(ii) The downstream boundary conditions should be moved closer to the site of interest to reduce simulation run time.

(iii) The model roughness values should be revisited to ensure alignment with recommendations made in the ARR Project 15 Stage 1 Report and Stage 2 Draft Report, and should be re-assessed for the area within 500 metres of the flood protection levee to ensure the coefficients recommended by Arcement & Schneider (*1989*) have been employed. The levee design should be re-evaluated during the next phase of the project based on the results of this more detailed assessment of roughness values.

(iv) The Creek Crossing should be reviewed and the TUFLOW model updated as required once details of the proposed crossing design are made available.

6. REFERENCES

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FIGURES

FIGURE 1.1

FMG Development

Levees associated with the FMG development

Drains to Fortescue Marsh

Weeli Wolli Creek

Billiards South

Marilana Creek

Conservative extraction levee option

Maximum extraction levee option

Pillar Levee

LEGEND

- Creeks and waterways
- Extent of the TUFLOW model
- Billiards Deposit
- Extent of proposed works

Levee Options

- Conservative levee
- Maximum extraction levee
- Pillar levee
- FMG levee

N

0 1 2 3 4 5 km

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LOCATION OF THE PROPOSED SITE AND THE BILLIARDS SOUTH DEPOSIT

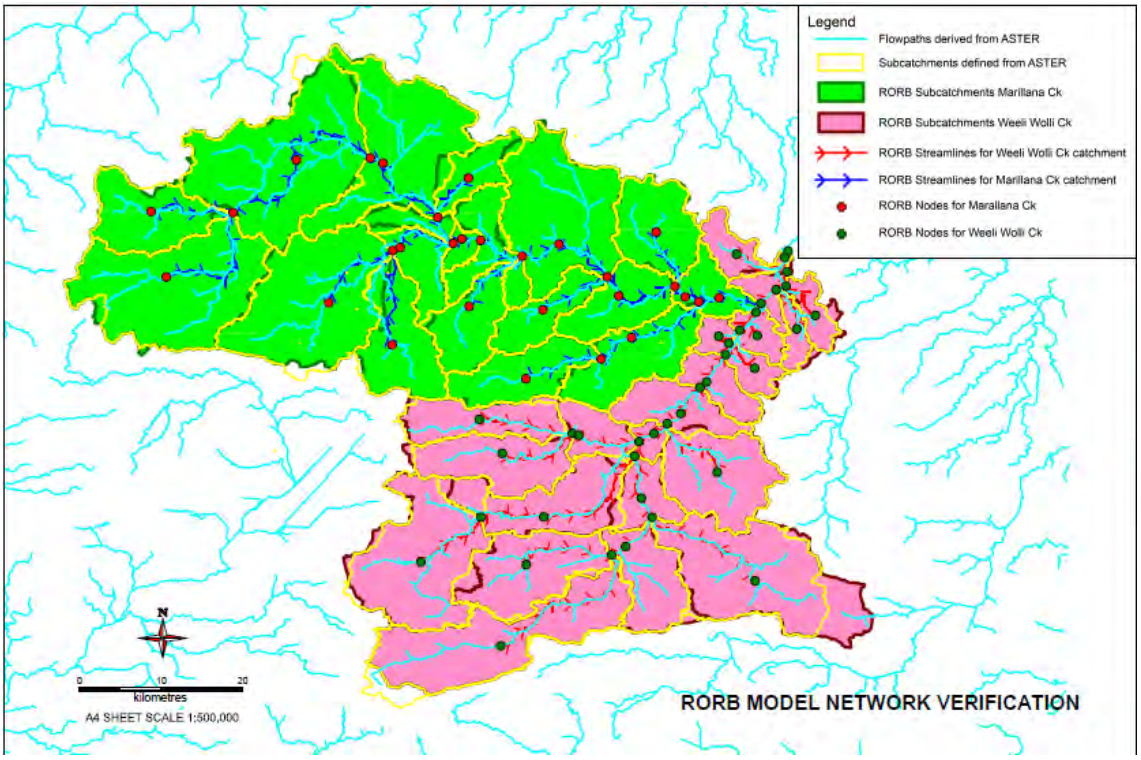
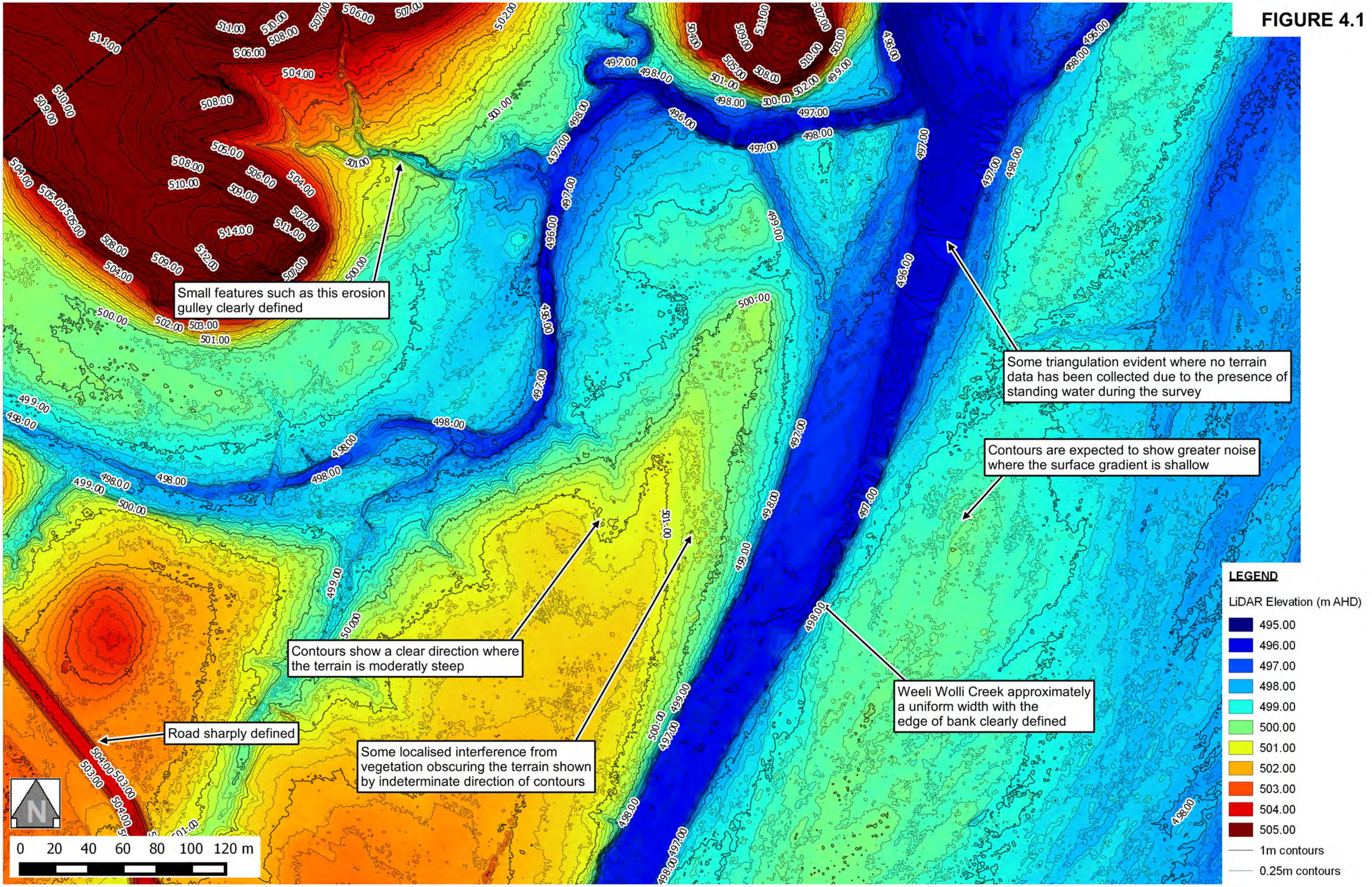


Figure 3.1 RORB Model Network Verification

FIGURE 4.1



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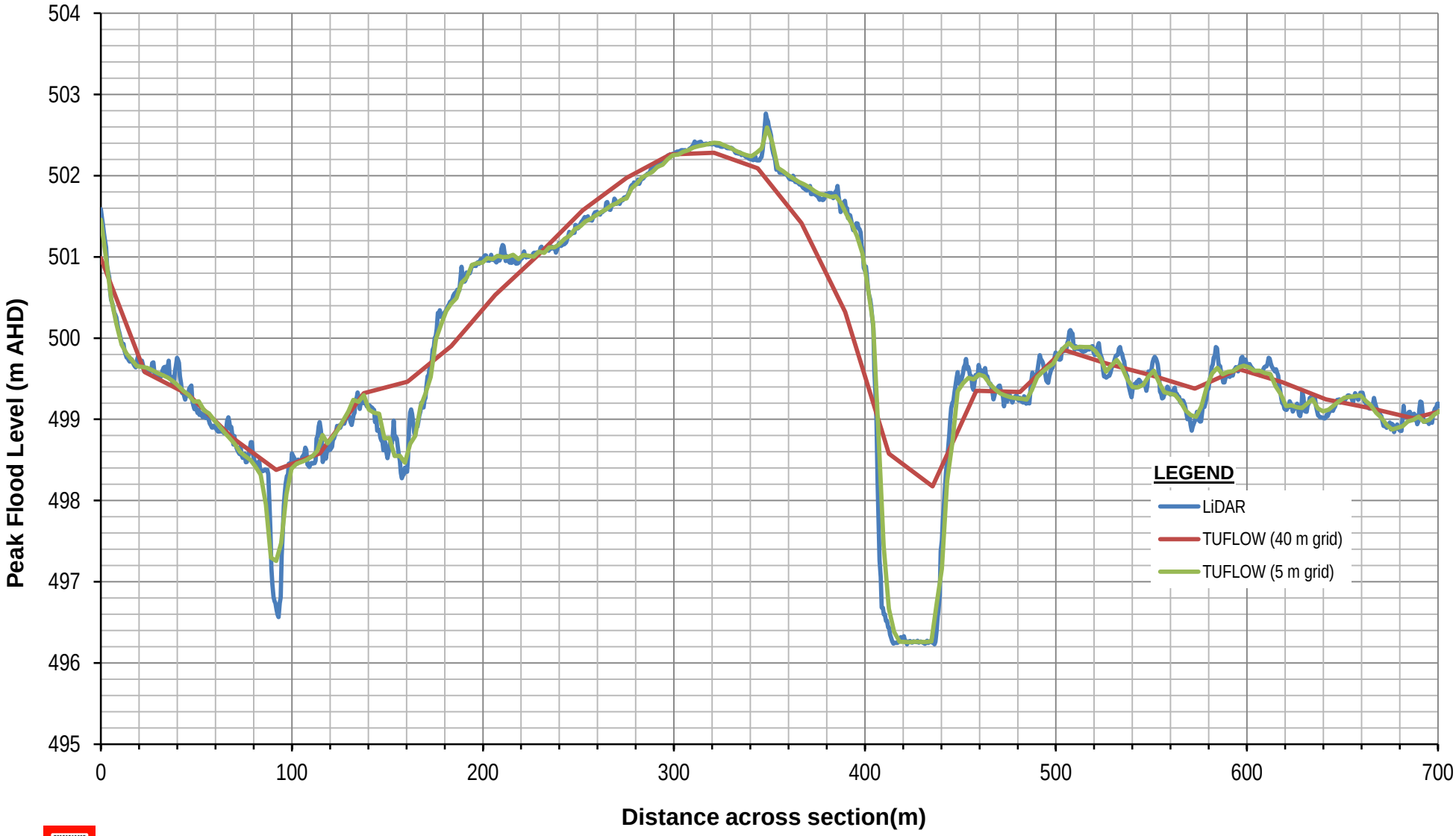
LiDAR DATA USED IN THE PREPARATION OF THE TUFLOW MODEL

FIGURE 4.2



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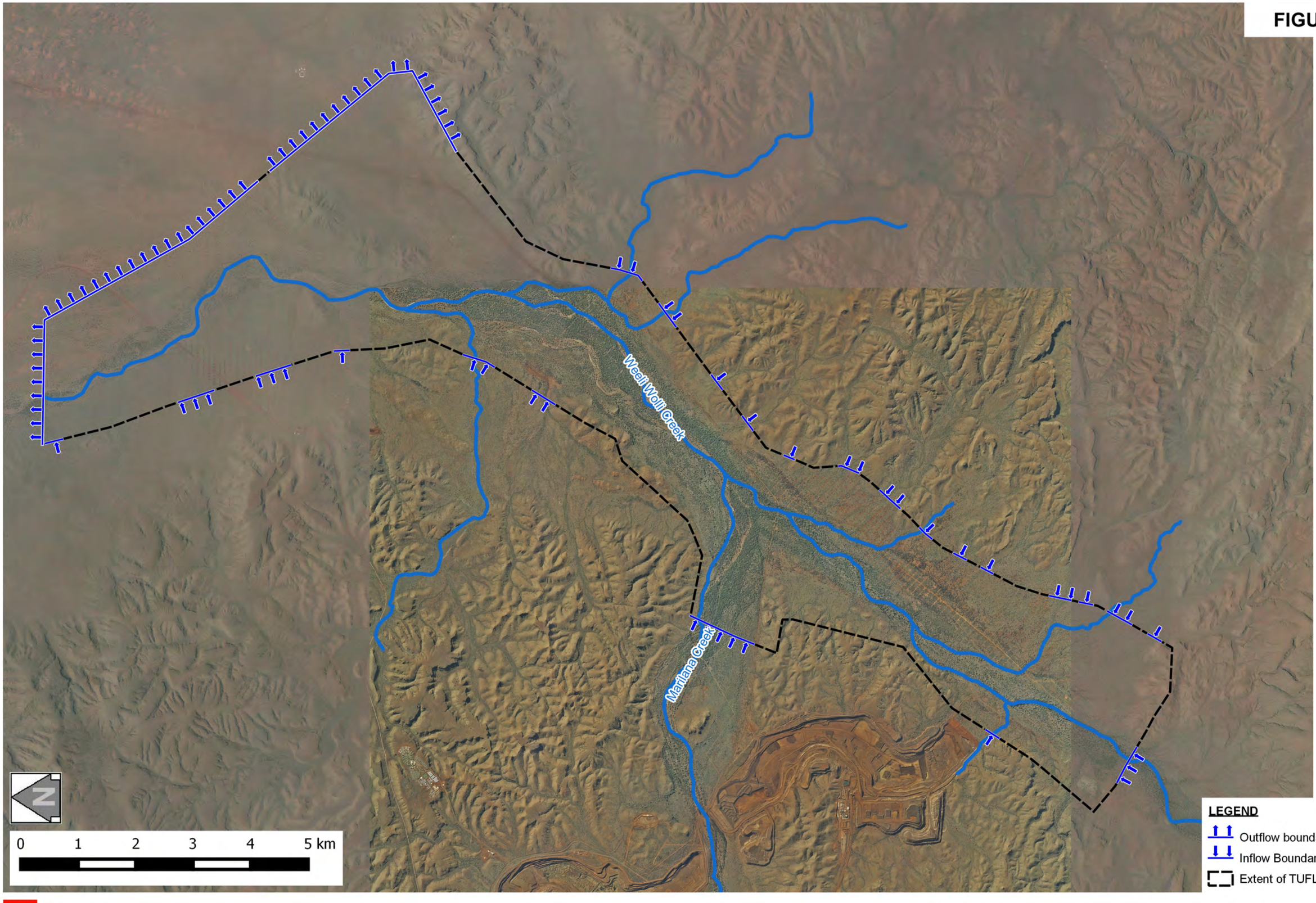
COMPARISON BETWEEN THE LIDAR DATA AND THE TERRAIN MODEL USED BY TUFLOW

FIGURE 4.3



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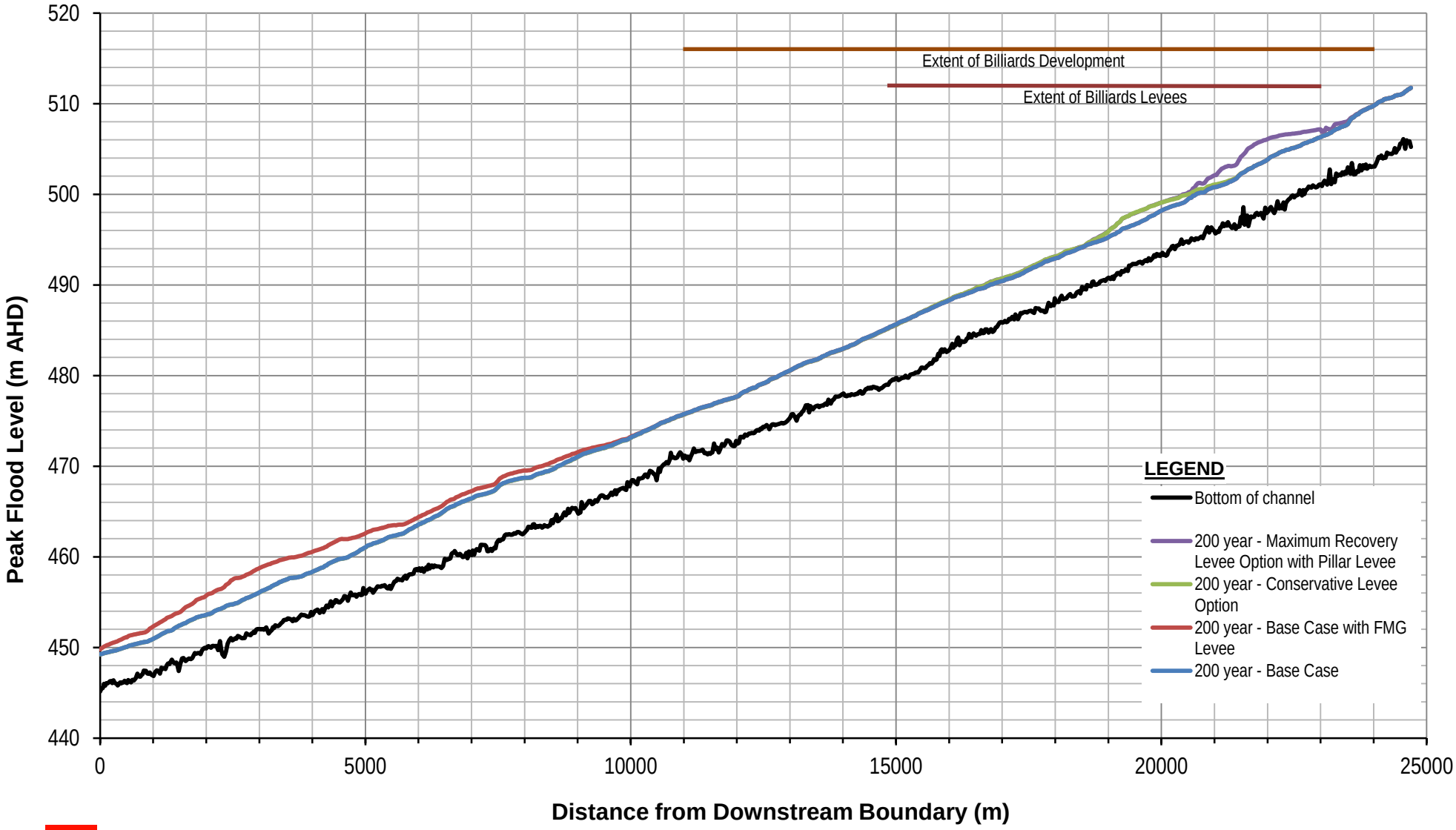
LOCATION OF THE TUFLOW BOUNDARY CONDITIONS

FIGURE 4.4



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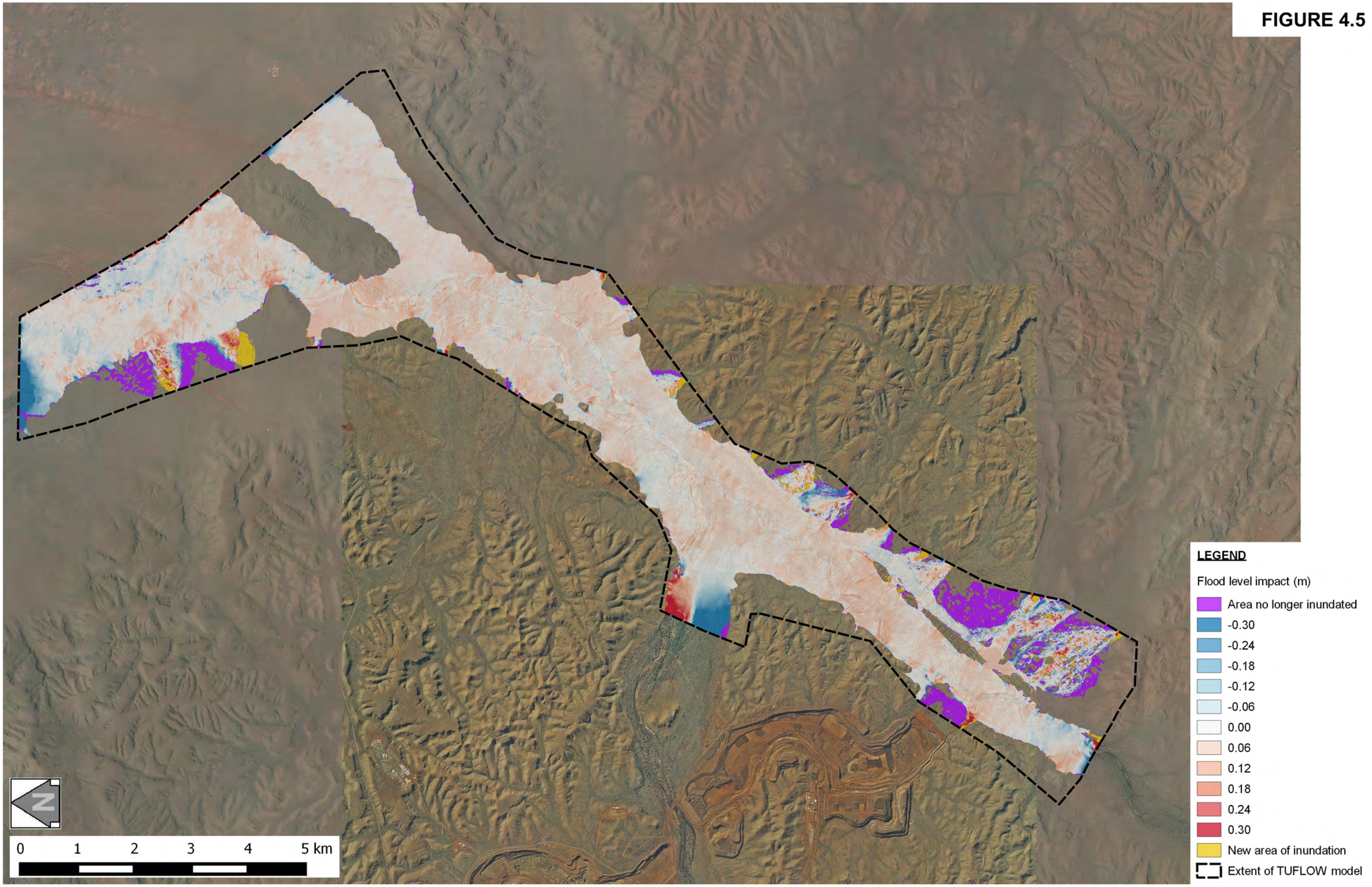
PEAK FLOOD LEVEL PROFILE TO THE 0.5% AEP FLOOD EVENT

FIGURE 4.5



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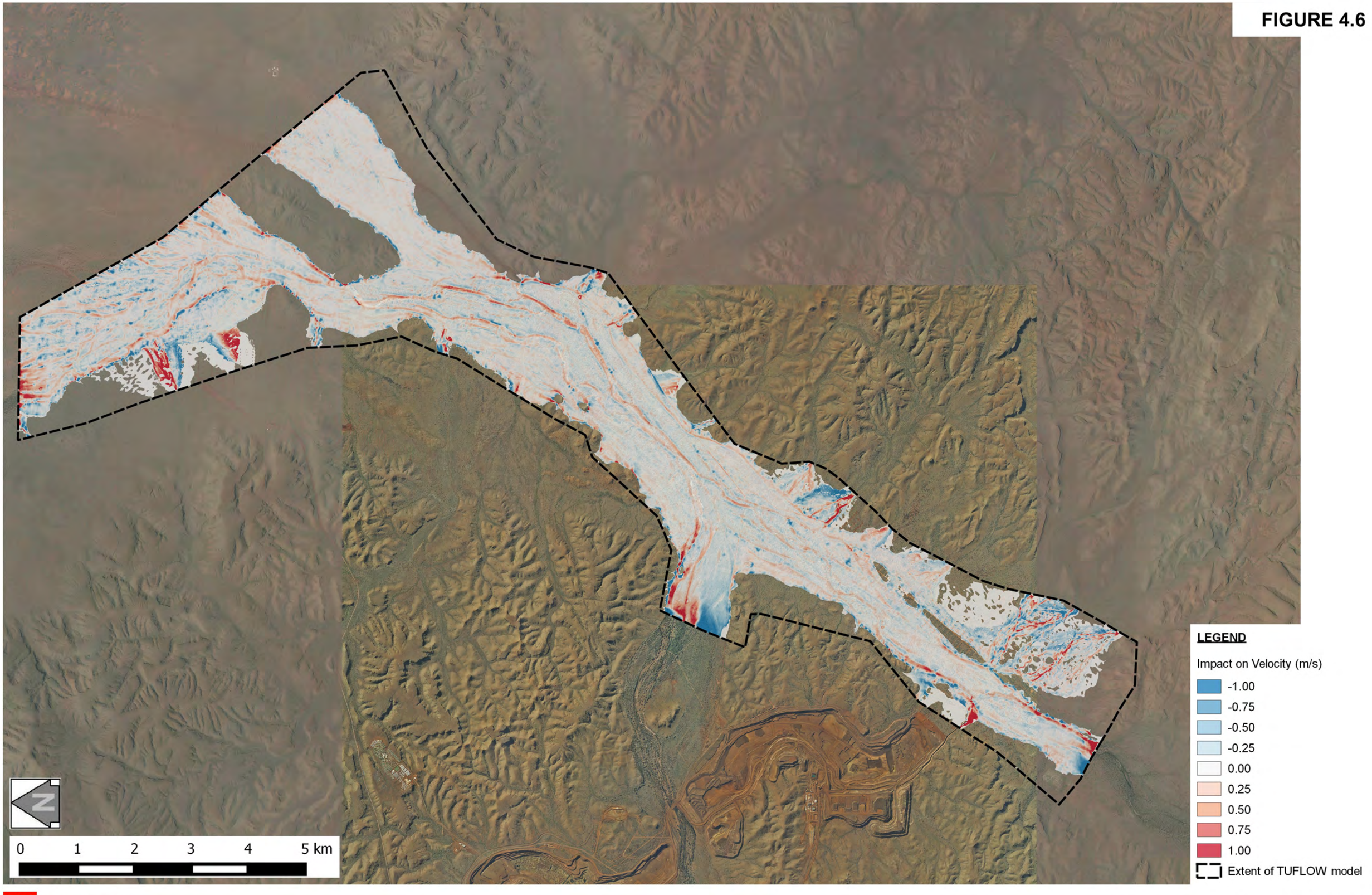
IMPACT OF REDUCING THE GRID FROM 40 m TO 5 m ON 0.5% AEP FLOOD LEVELS (BASE CASE CONDITIONS)

FIGURE 4.6



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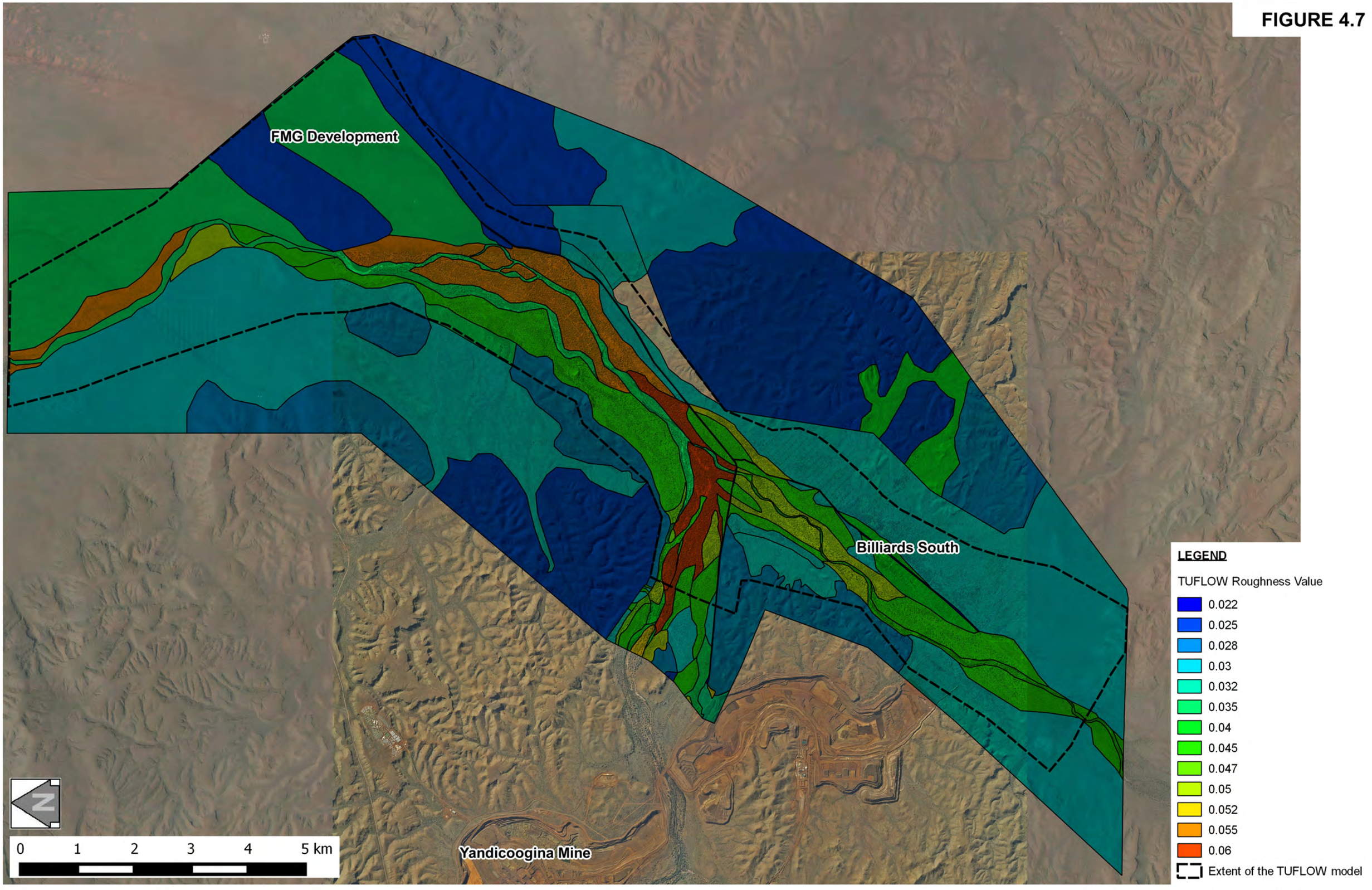
IMPACT OF REDUCING THE GRID FROM 40 m TO 5 m ON 0.5% AEP FLOOD VELOCITY (BASE CASE CONDTIONS)

FIGURE 4.7



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DELINEATION OF SURFACE ROUGHNESS USED IN THE BILLIARDS SOUTH TUFLOW MODEL

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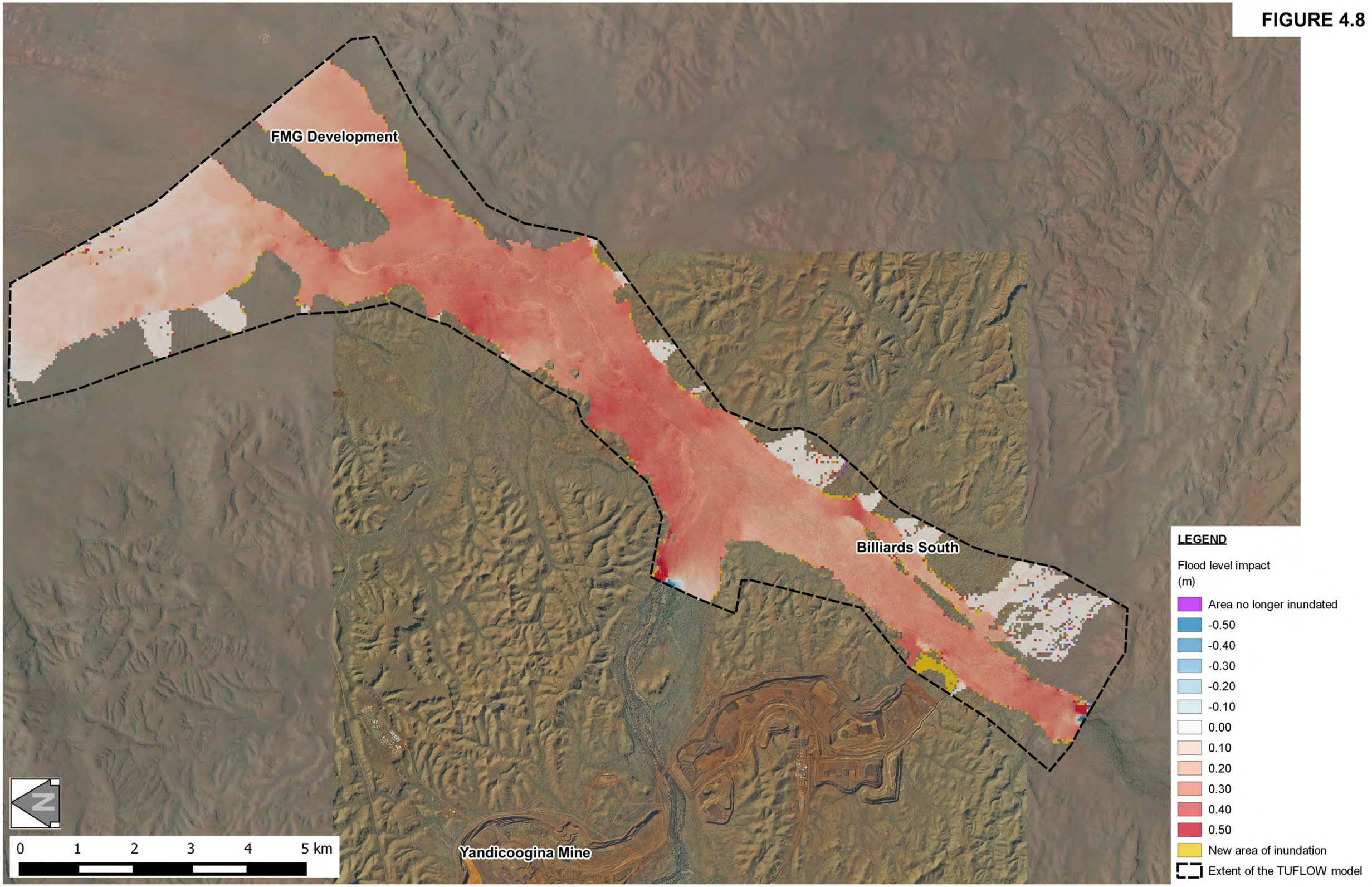
FIGURE 4.8



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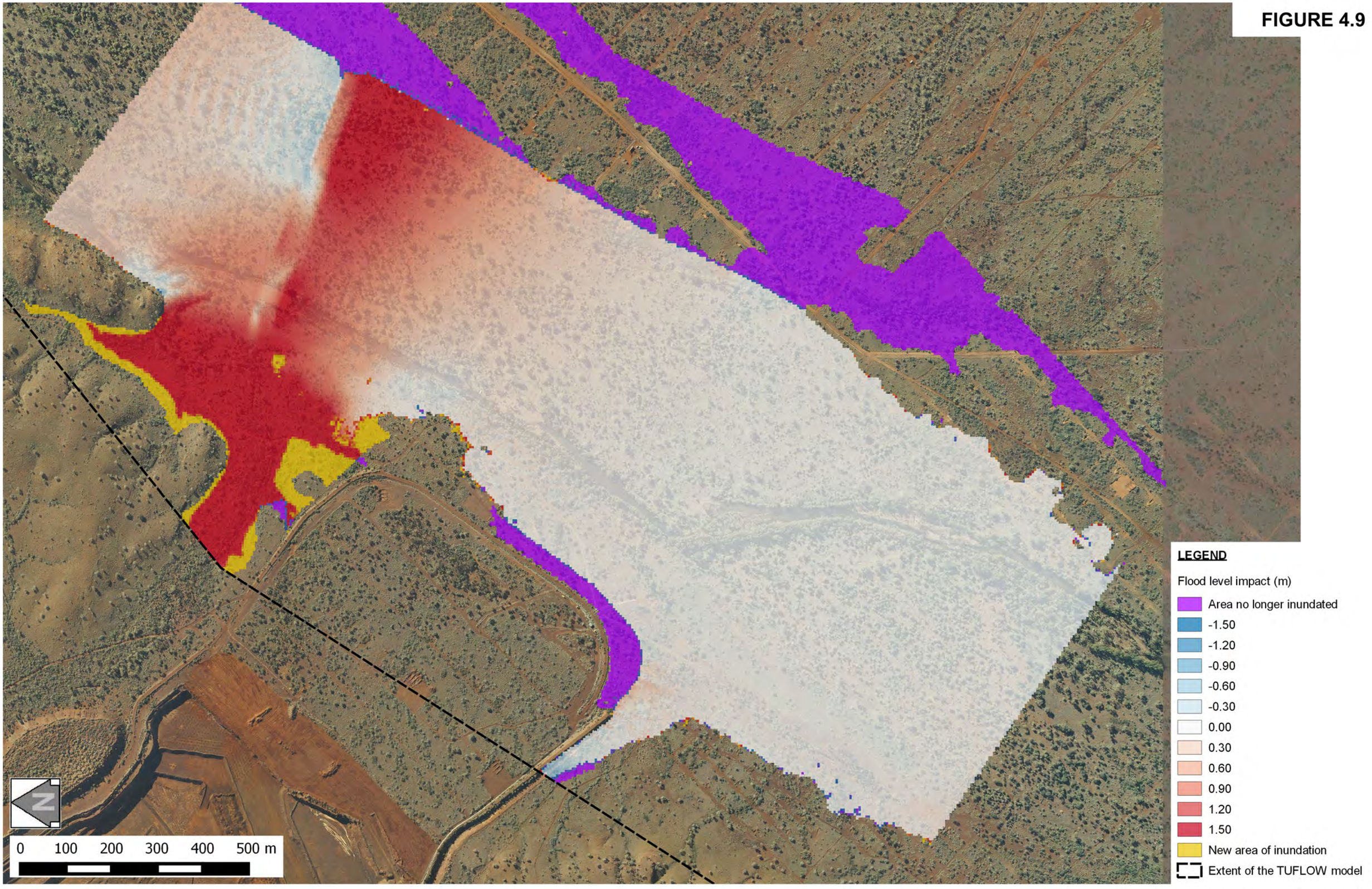
IMPACT OF A 20% INCREASE IN ROUGHNESS ON THE 0.5% AEP FLOOD EVENT (BASE CASE CONDITIONS)

FIGURE 4.9



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IMPACT OF INCLUDING A CROSSING OF WEELI WOLLI CREEK ON THE 0.5% AEP FLOOD LEVELS

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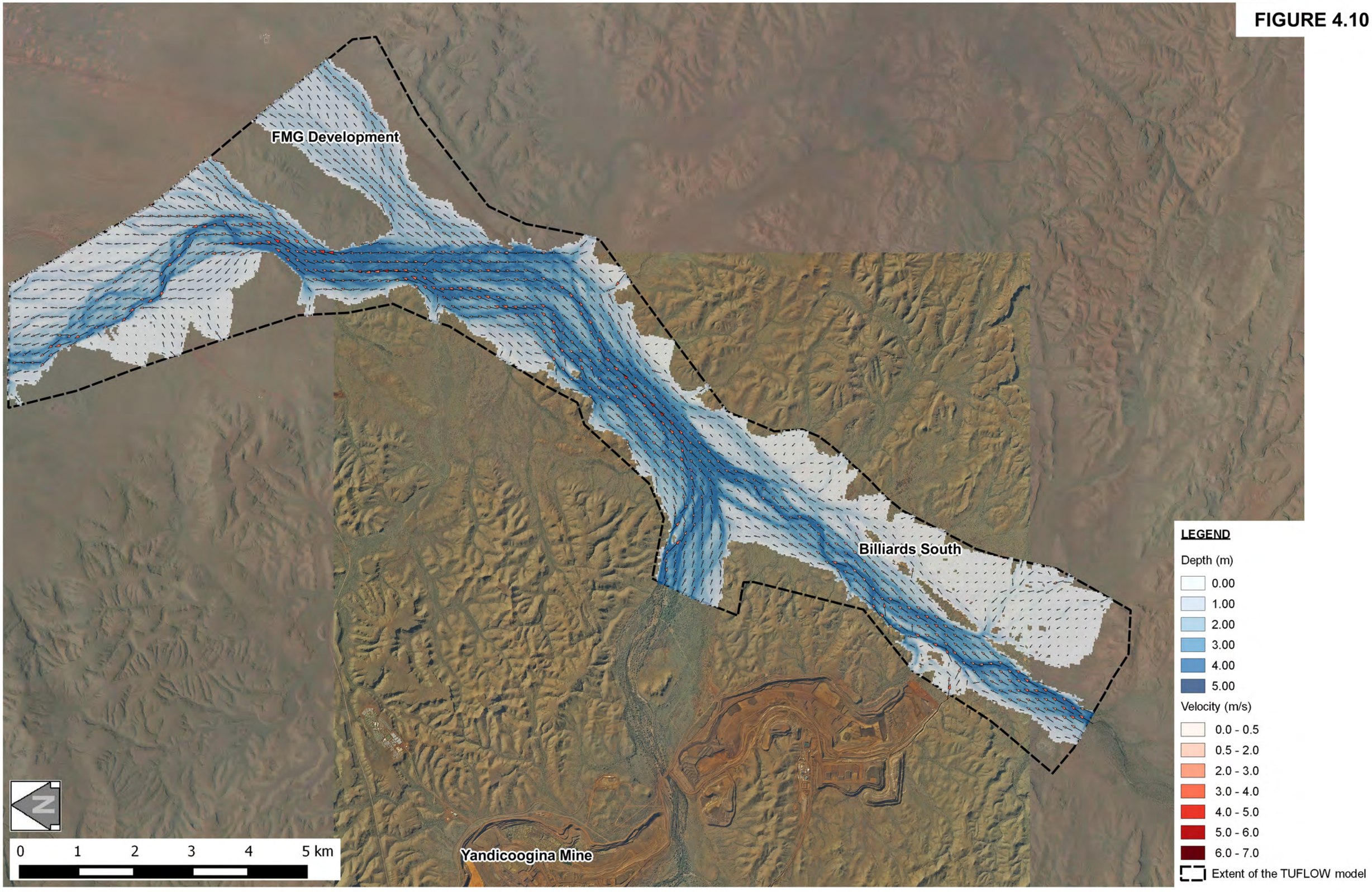
FIGURE 4.10



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PEAK FLOOD DEPTH AND VELOCITY FOR THE 0.5% AEP

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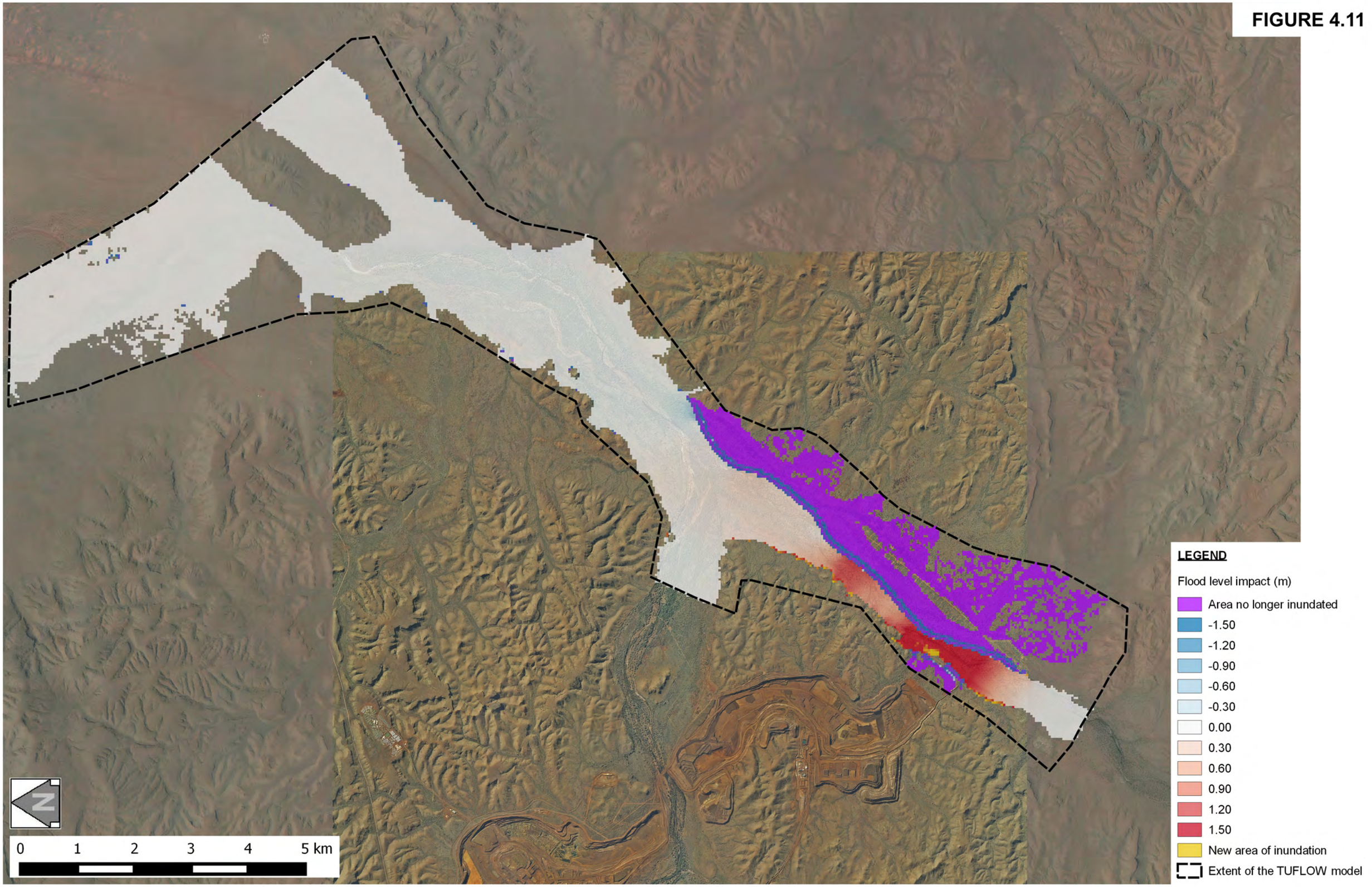
FIGURE 4.11



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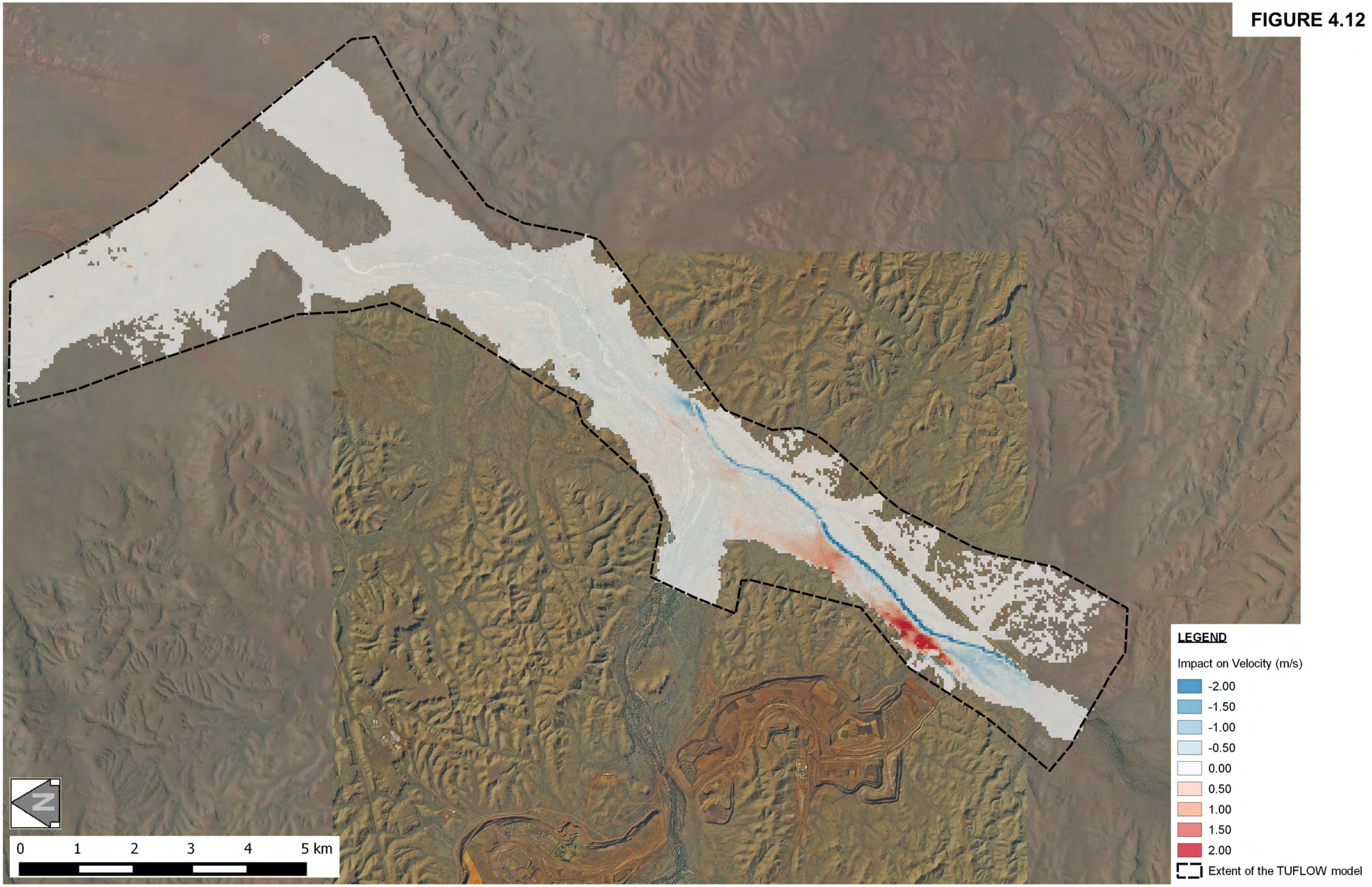
IMPACT OF THE MAXIMUM RECOVERY LEVEE AND PILLAR LEVEE ON 0.5% AEP FLOOD LEVELS

FIGURE 4.12



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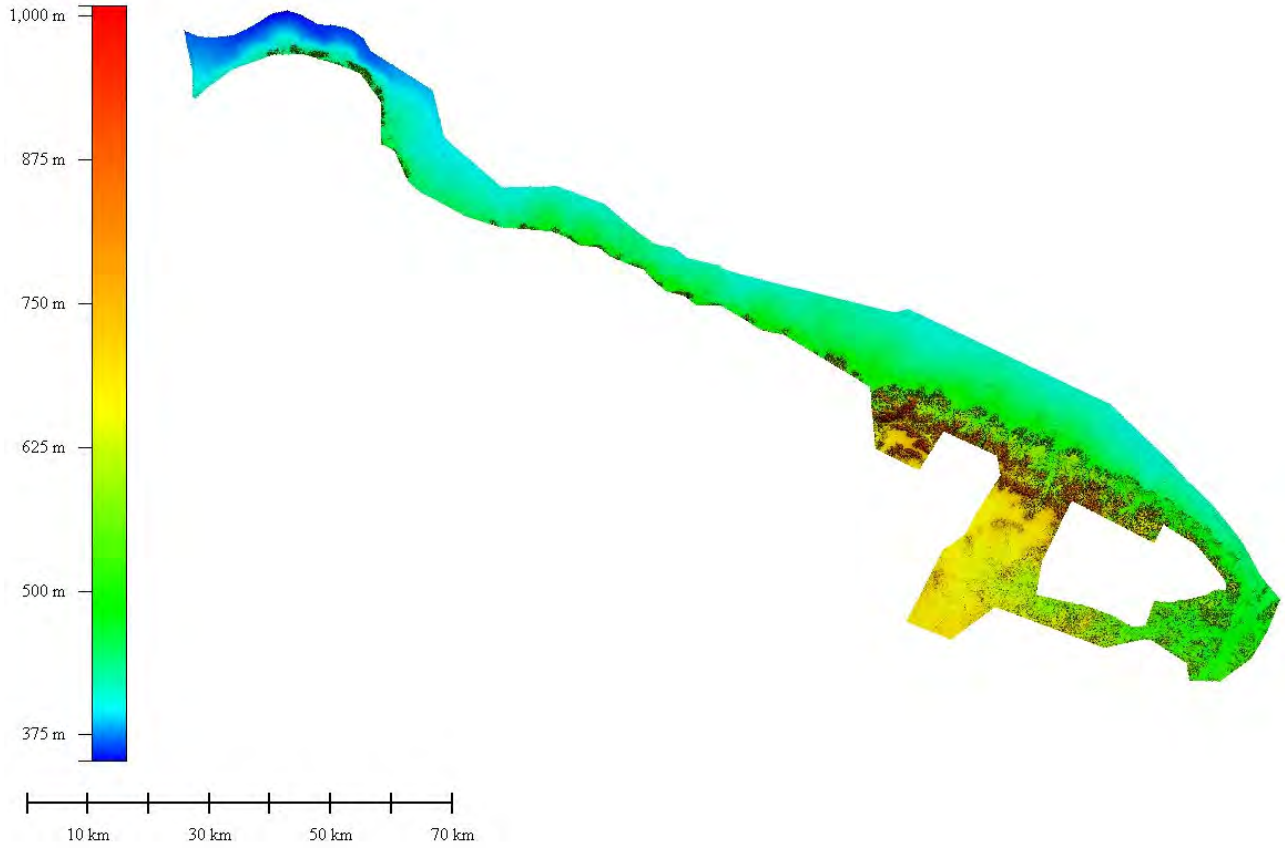
IMPACT OF THE MAXIMUM RECOVERY LEVEE AND PILLAR LEVEE ON 0.5% AEP FLOOD VELOCITY

APPENDIX A
LIDAR METADATA REPORT

Record ID	Record
Metadata Filename	22496001_RioTinto_Koodaideri_and_Extension_20140710_Metadata
Metadata Language	English
Metadata Character Set	ASCII
Metadata Point of Contact	Owen Temby [Project Manager] Fugro Spatial Solutions Pty Ltd 18 Prowse Street, West Perth, WA, 6005 Telephone: +61 8 92824100 o.temby@fugro.com
Metadata Date Stamp	10 July 2014
Dataset Title and Graphic Overview Koodaideri – Fortescue, Main Area and Extended Areas 	
Dataset Reference Date	May-12
Dataset Description Abstract	Koodaideri Extension LiDAR derived products
Dataset Language	English
Dataset Character Set	ASCII and binary
Dataset Topic Category	DEM and Contours
Geographic Location Description	Western Australia
Geographic Bounding Box	WEST LONGITUDE = 117° 37' 10" E NORTH LATITUDE = 21° 51' 28" S EAST LONGITUDE = 119° 23' 16" E SOUTH LATITUDE = 22° 52' 36" S
Acquisition Start Date	12th December 2011
Acquisition End Date	17th May 2012
Sensor Type Name	Leica ALS50-2
Sensor/Lens serial ID	SN031
Flying Height (AGL)	1400m

INS / IMU Used	IPAS10
Number of Runs	239
Swath Width (meters)	992m
Flight Direction	Non-Cardinal
Side Overlap (%)	20
Output Data Format	Classified ALS Point Cloud in LAS1.2 format 5m DEM, Ground and Model Keypoints in DGN and ASCII XYZ 50cm Contours in DGN 1km Tile Index and tile edited index in shape and dxf Flightlines DGN
Horizontal Datum	GDA94
Vertical Datum	AHD as defined by AUSGeoid09 v1.01
Map Projection	MGA Zone 50 South
Dz Validation Summary <u>Description of GCPs</u> Horizontal Datum / Coordinate System : GDA94 / MGA94 Zone 50 Vertical Datum – AHD Laser Z : Represent LiDAR data height values (triangulation of closest three Ground points within 3m of Control point position) Known Z : Represent Control Point heights values Dz : Difference between the elevation values of Control points and Laser points.	

Number	Easting	Northing	Known Z	Laser Z	Dz
KD_001	565845.006	7571507.860	390.470	390.480	+0.010
KD_002	564024.576	7577637.547	368.930	369.000	+0.070
KD_003	582429.050	7579774.996	357.936	357.940	+0.004
KD_004	598347.351	7571670.262	378.609	378.660	+0.051
KD_005	607957.246	7559070.323	394.059	394.050	-0.009
KD_006	604883.010	7566110.606	388.771	388.830	+0.059
KD_007	605169.957	7551698.238	428.587	428.530	-0.057
KD_008	610262.230	7547183.629	448.751	448.710	-0.041
KD_009	677733.040	7531945.784	416.287	416.310	+0.023
KD_010	673401.167	7521120.068	512.600	512.580	-0.020
KD_011	677650.453	7509844.459	652.249	652.240	-0.009
KD_012	572035.563	7576014.120	364.683	364.670	-0.013
KD_013	590368.200	7572948.379	427.358	427.420	+0.062
KD_014	728064.762	7503284.602	420.229	420.320	+0.091
KD_015	742272.344	7484496.209	462.825	462.880	+0.055
KD_016	741210.115	7479617.760	481.185	481.220	+0.035
KD_017	733328.011	7471388.819	515.153	515.250	+0.097
KD_018	722003.653	7478200.614	529.316	529.400	+0.084
KD_019	737742.043	7486929.100	476.652	476.690	+0.038
KD_020	724292.334	7496819.183	601.071	601.180	+0.109
KD_021	717600.572	7497265.119	722.631	722.660	+0.029
KD_022	717096.418	7497691.653	564.817	564.770	-0.047
KD_023	715489.289	7480438.489	593.638	593.760	+0.122
KD_024	698990.141	7484590.185	636.571	636.600	+0.029
KD_025	685100.768	7480317.737	674.990	675.040	+0.050
KD_026	681141.273	7522001.780	456.728	456.820	+0.092
KD_028	692213.215	7518054.044	479.151	479.190	+0.039
KD_029	706044.437	7520057.618	412.637	412.660	+0.023
KD_030	703983.950	7513031.124	479.821	479.910	+0.089
KD_031	718512.387	7507488.115	429.784	429.780	-0.004
KD_032	708630.144	7482366.623	617.372	617.440	+0.068
KD_033	691206.243	7483274.330	661.184	661.130	-0.054
KD_034	735605.566	7493569.249	444.913	444.820	-0.093
KD_035	736445.433	7477380.814	488.382	488.300	-0.082
KD_036	582204.723	7576736.708	393.215	393.280	+0.065
KD_037	730203.265	7479950.421	516.148	516.230	+0.082
KD_038	716608.402	7514039.691	413.368	413.380	+0.012
KD_039	717527.781	7476763.301	561.873	561.940	+0.067
KD_040	689645.035	7478029.683	690.727	690.790	+0.063
KD_041	724818.797	7505466.501	415.837	415.780	-0.057
KD_042	638188.810	7541554.006	446.593	446.560	-0.033
KD_043	687084.093	7479092.466	676.784	676.860	+0.076
KD_044	688970.841	7526324.541	412.924	412.980	+0.056
KD_045	628306.199	7550476.248	409.921	409.890	-0.031
KD_046	620539.139	7548429.732	429.318	429.320	+0.002
KD_047	661014.595	7533598.812	432.275	432.330	+0.055
KD_048	633043.835	7542874.032	456.204	456.310	+0.106
KD_049	644667.942	7540458.352	417.363	417.370	+0.007
KD_050	645011.678	7536329.211	467.741	467.800	+0.059
KD_051	658035.671	7529606.180	491.677	491.740	+0.063
KD_052	697824.419	7497948.985	678.870	678.950	+0.080
KD_053	693585.413	7492084.822	655.966	656.040	+0.074
MBC172	614395.778	7549939.785	415.678	415.650	-0.028
PYRAMID31	565798.641	7573583.701	382.284	382.310	+0.026
RHL64	667916.612	7526175.353	467.218	467.340	+0.122
RHL70	730954.334	7501852.845	419.844	419.790	-0.054
XH40	709024.242	7511060.641	469.253	469.110	-0.143

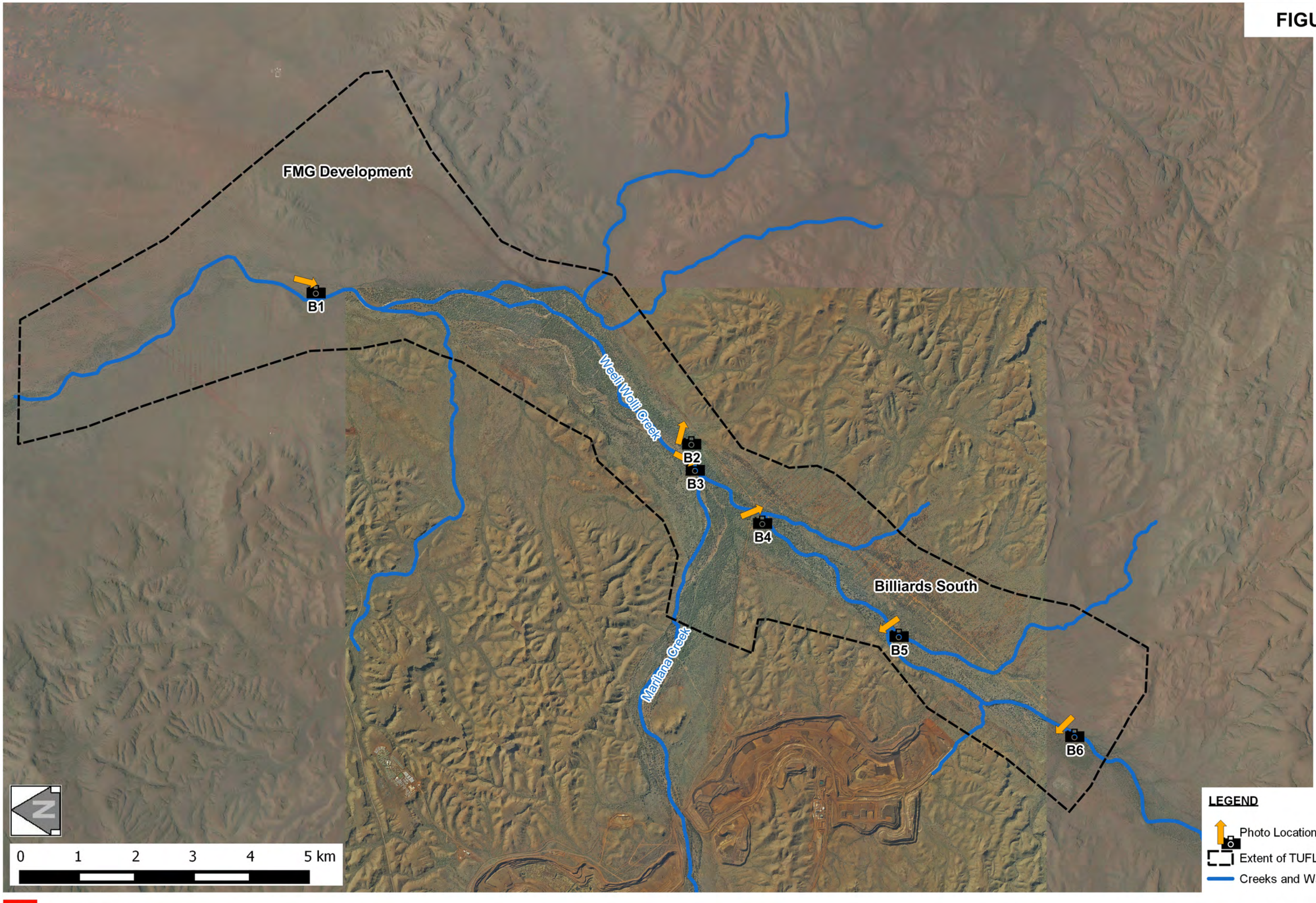
Average dz	+0.028
Minimum dz	-0.143
Maximum dz	+0.122
Average magnitude	0.055
Root mean square	0.064
Std deviation	0.058

Spatial Accuracy - Height	0.09m @ 67 % CI
Spatial Accuracy - Plan	0.18m @ 67 % CI
Surface Type	Various
Average Point Separation	Target spacing 2.1 pt/m^2
Laser Return Types	All Returns
Data Thinning	None
Laser Footprint Size (meters)	0.32
Data Tile size (km 2)	1km^2
Processing / Derivation Lineage	**Ground Classifications** Fugro Spatial Solutions Pty Ltd aim is to select those points that are part of a clean ground surface, which might not be 100% of the ground hits. This results in a cleaner dataset, without compromising on terrain detail and accuracy. Ground filtering algorithms, tailored for this project, data type and terrain type, are applied to the full dataset. The ground filtered dataset is then visually checked by an operator, and incorrectly classified data is corrected or the ground filtering algorithm is adjusted and then visually checked. For the verification of the ground classifications, intensity imagery is used as a backdrop image. All data was reviewed for ground classification at level 2 classification. **Classified point cloud las 1.2** A merge of ground and non-ground data, in LAS file format. Ground in class 2 and non ground in class1. Classification 2 for ground has been performed. **Ground in DGN and XYZ** This dataset consists of every point that is part of the classified ground surface. The data is level 2 classified. **Bare Earth DEM in DGN** A 5m DEM has been generated from the LiDAR ground surface. The method of deriving the height for each grid point is by triangulation between the three nearest LiDAR ground points. **Model Keypoints in DGN and XYZ** A resampled ground dataset, consisting of only those points that actually contribute to the shape of the terrain (+/- 15cm), with a minimum point density of 1 point every 10m. **Contours 50cm in DGN** From the model keypoints, triangles are built. At 0.5m intervals in height, points or interpolated points on triangle edges with the same height are connected using smoothed curved lines. The lines for each height interval are then merged to become the final contours. **Note:** Returns on water have not been removed from the (classified) point clouds. Gridded datasets have been interpolated across voids (up to 500m in diameter) caused by either no-return due to water bodies, or removal of buildings, vegetation or other above ground features. Contour datasets are interpolated across voids, and contours across water bodies have not been removed or clipped. All data has been cut into 1km tiles, where the file name prefix corresponds with the Lower Left coordinate of the block.

Limitations of Data	This data has not been field tested for completeness or accuracy.
Conditions of Supply	1. This Metadata file is always to be stored with the unaltered data contained in this volume. 2. Any supplied data is to be used only for the purpose for which it was commissioned and in accordance with the terms of engagement. 3. Use of any supplied data for purposes other than those stated is entirely at the risk of the Client.

APPENDIX B
SITE INSPECTION PHOTOGRAPHS

FIGURE B1



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LOCATION OF SITE PHOTOS

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Photo B1: Weeli Wolli Creek at the north end of the model domain

Photo B2: Weeli Wolli Creek floodplain

Photo B3: Weeli Wolli Creek downstream of the confluence with Yandicoogina Creek

Photo B4: Weeli Wolli Creek upstream of the confluence with Yandicoogina Creek

Photo B5: Weeli Wolli Creek upstream of the confluence with Yandicoogina Creek

Photo B6: Weeli Wolli Creek at the upstream (south) end of the domain

Biota Environmental Sciences

Yandi Vegetation and Flora Integration Report

Prepared for Rio Tinto

March 2015

Biota Environmental Sciences

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Yandi Vegetation and Flora Integration Report

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1.0 Summary

Rio Tinto's Yandicoogina (Yandi) iron ore project is located approximately 90 km northwest of Newman, in the Pilbara region of Western Australia. Since its construction in 1997, the Yandi project has expanded from the original mine at Junction Central to a number of other developments including Junction South East, Junction South West and Oxbow. Hamersley Iron Pty Ltd – Yandi Pty Ltd (Hamersley Iron) plans to further sustain the operations at Yandi mine. This includes the development of the Channel Iron Deposits at Pocket and Billiard South (PBS), located approximately 7 km east of the existing Yandi mine, and within the existing Yandi Operations development envelope (as per Ministerial Statement 914). The proposed PBS development is being formally assessed under the WA *Environmental Protection Act 1986* at a Public Environmental Review level of assessment.

Biota Environmental Sciences was commissioned in 2014 to integrate the existing vegetation and flora data for the Yandi PBS area into the wider dataset for the broader Yandi locality, to produce a supporting document for the environmental impact assessment of the PBS development. This report documents the combined results of the PBS Level 2 vegetation and flora survey, together with 14 other separate studies located within the Yandi integration development envelope (the 19,351 ha area as per Ministerial Statement 914, which is hereafter referred to as the study area).

Detailed vegetation mapping had already been prepared for over 63% of the study area. Vegetation types described from different surveys were standardised and the mapping was extended over the entire study area in order to produce a single consolidated vegetation map. A total of 30 vegetation types have been described for the study area. These vegetation types are associated with four landscape categories: major creeklines and tributaries; minor creeklines, floodplains and valleys; hills, ridges and breakaways; and plains. Most of the vegetation was in Excellent to Good Condition, except for the creekline and floodplain vegetation; this ranged from Very Good to Very Poor, as some areas were affected by weed invasion and minor disturbance from cattle.

None of the vegetation types observed in the study area represent Threatened Ecological Communities or Priority Ecological Communities. Vegetation similar to that recorded for the study area is well represented in the broader locality. Four riparian vegetation types (C1, C2, C3 and C5) represent good condition riparian vegetation associated with Marillana Creek and Weeli Wolli Creek, which are two of the major ephemeral creek systems in the locality. These vegetation types are considered to be of local conservation significance.

A total of 548 native vascular flora taxa from 173 genera and 53 families have been recorded from the study area to date. This species richness is within the range expected for an area of this size in that locality.

One Threatened species, *Lepidium catapycnon,* was recorded from the study area. A total of 4,211 individuals of this species were recorded from 81 locations, forming 11 separate populations. It occurred on rocky hills and slopes, with the majority of the populations being recorded from vegetation type H1. Additional habitat suitable for *L. catapycnon* occurred in the study area, not all of which has been systematically searched, and it is possible that other populations occur. All hills and slopes of the study area could comprise suitable habitat for *L. catapycnon*, especially areas that have been burnt recently or have a substrate of rocky ironstone shale, however vegetation type H1 remains the most prospective unit for this species. The majority of the proposed PBS development will be located in valleys and drainage areas, rather than on the hills and slopes.

Five Priority flora species were recorded from the study area:

- *Rostellularia adscendens* var. *latifolia* (Priority 3) has been recorded from three locations on a floodplain (vegetation type F1), comprising a total of 13 individuals in two populations. One of these populations (two individuals) has since been cleared.
- *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) was recorded from three locations, comprising a total of five individuals in two populations. One population was recorded from the bank of Marillana Creek, which has since been cleared (number of individuals for this population not supplied), and the remaining population was recorded from a rocky ridgeline (vegetation type H5).
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) was recorded from one location on a plain adjacent to Marillana Creek (vegetation type P2). The number of individuals at this location was not recorded.
- *Goodenia nuda* (Priority 4) was recorded from 21 locations on floodplains (vegetation type F1), creeklines (vegetation type C2) and plains (vegetation type P6, P2 and P3), with a total of 154 individuals forming 11 separate populations.
- *Rhynchosia bungarensis* (Priority 4) was recorded from two locations, which represented one population in vegetation type P5. The number of individuals was not recorded, and one of these locations has since been cleared.

One additional Priority flora species, *Stylidium weeliwolli* (Priority 2), may potentially occur in the study area in the wetter areas along Weeli Wolli Creek or Marillana Creek (vegetation type C1). While it has not been recorded from the study area to date, there is a known population 1.3 km west and the suitable habitat in the study area has not been systematically searched through its entirety. As *Stylidium weeliwolli* is a very small annual herb, additional survey effort under optimal conditions would be required to determine whether it is present in the study area.

A total of 36 introduced flora species (weeds) have been recorded from the study area. Weeds were most densely distributed around areas of development and disturbance, and along creeklines and floodplains in the study area. **Argemone ochroleuca* (Mexican Poppy) is the only species listed as a declared pest for WA under the *Biosecurity and Agriculture Management Act 2007*. **Cenchrus ciliaris* (Buffel Grass) was the most prolific weed observed in the study area. This species formed dense populations along sections of creek banks and floodplains, frequently in association with **Cenchrus setiger* (Birdwood Grass). Both **Cenchrus* species are serious environmental weeds.

2.0 Introduction

2.1 Project Background

Hamersley Iron currently operates the Yandi iron ore mine as part of its Pilbara Iron operations. The Yandi mine is situated approximately 90 km northwest of Newman in the Pilbara region of Western Australia (Figure 2.1). Construction of the original Yandi mine, Junction Central (YJC), started in 1997 with the first shipment of ore occurring in 1999. An expansion to existing mining developments was approved in 2005 in the form of Junction South East (JSE). A number of other expansions have subsequently been approved, including at the Junction South West (JSW) and Oxbow deposits (YOX) (Figure 2.1). The Yandi operations have been approved under Ministerial Statement 914 (MS914).

Hamersley Iron plans to further sustain the operations at the Yandi mine. The proposed expansion includes the Channel Iron Deposits at PBS, located approximately 7 km east of the existing Yandi mine within the existing Yandi Operations development envelope (as per MS914; see Figure 2.1). A level 2 vegetation and flora survey has already been completed over the proposed PBS development area (Biota 2014a). The proposed PBS development is now being formally assessed under the WA *Environmental Protection Act 1986* at a Public Environmental Review (PER) level of assessment. In order to assist with the environmental impact assessment (EIA), Biota Environmental Sciences (Biota) was commissioned to integrate the Yandi PBS vegetation and flora surveys into a broader reference framework for the wider locality.

The combined extent of the different mining developments represents the overall Yandi integration development envelope as specified under MS914, which is hereafter referred to as the study area (see Figure 2.1). The study area covers a total of 19,351 ha.

2.2 Purpose and Scope of this Report

This report has been prepared as a supporting document for an EIA of the Yandi PBS development. It consolidates all data from the individual studies completed for various components of the broader Yandi study area into a consistent format, and provides a structured framework and integrated summary of the data from the individual studies. In this form, the entire dataset from the Yandi surveys can be analysed together to provide a more informed view of the botanical values of the overall study area. Consequently, combined records of flora species of conservation significance and the potential impacts of development of the PBS deposits can be placed into a better context to support the forthcoming EIA.

Additionally, vegetation mapping that has been prepared for different parts of the study area at different times and at different scales was reviewed and revised where necessary, so that one consolidated map could be presented for the entire study area. The description of vegetation types in the study area has been strengthened through the analysis of a larger floristic dataset.

The following tasks were specifically required to be completed for this study:

- identification of all relevant surveys completed to date within the integration study area;
- integration, mapping unit standardisation and spatial joining of vegetation mapping completed for the Yandi PBS survey area (Biota 2014a) with existing recent vegetation mapping of the broader Yandi locality;
- examination of older vegetation mapping from the broader Yandi locality to assess whether it could be aligned with the integrated map for the study area;
- specific mapping and area estimates of riparian vegetation types across the entire extent of the study area;

- re-analysis of all flora quadrat data from the PBS survey area and comparison of the wider Yandi locality quadrat dataset with selected data from other sites in the broader subregion to place these floristic groups into better context; and
- collation and updating of all records and mapping of Threatened and Priority flora and introduced flora (weed) populations from the integration study area[1].

[1] The framework for conservation significance ranking of species in Western Australia is provided in Appendix 1.

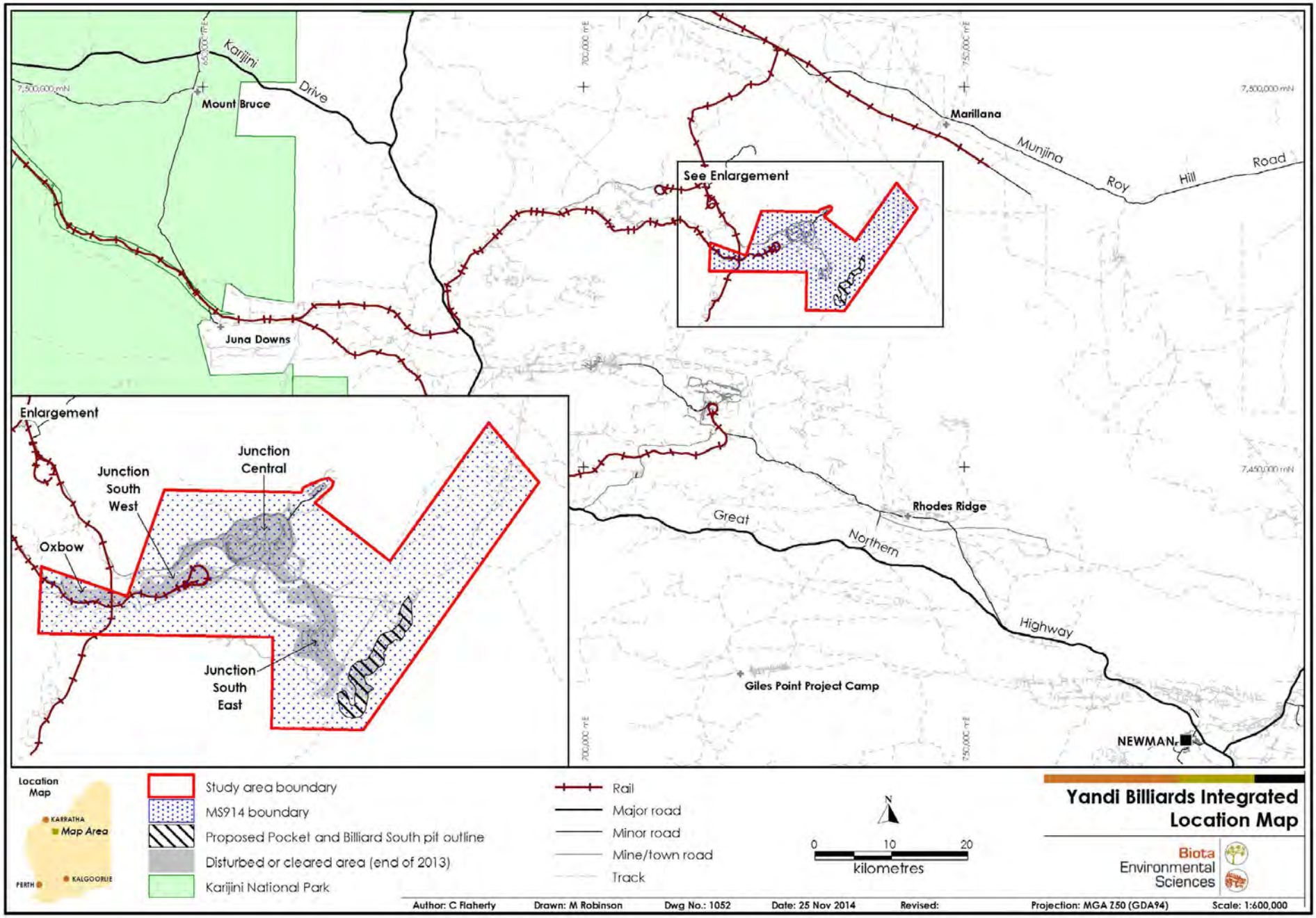

Figure 2.1: Location of the study area and the MS914 boundary.

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3.0 Methodology

3.1 Survey Data Used

The collated Yandi vegetation and flora data used in this report were sourced from 15 separate studies, some of which involved multiple survey phases. The spatial extent of these survey areas is displayed in Figure 3.1. Note that "survey area" has been used to refer to these individual areas within the broader study area.

Table 3.1 provides a brief description of each survey and summarises the data available from each survey that contribute to the overall dataset for the study area. A review of the combined data from these surveys shows that:

- 12,226 ha (63%) of the study area has been subject to detailed vegetation and flora surveys, which have included detailed vegetation mapping and establishment of quadrats[2] and relevés to validate the vegetation types (Biota 2005, 2009a, 2009b, 2010a, 2011a, 2014a, 2014b, 2014c);
- 2,880 ha (15%) of the study area has been subject to historical vegetation and flora surveys, for which vegetation mapping was completed, however the descriptions provided are at a very broad scale and there are no quadrat data available to validate the vegetation types (Mattiske 1995a, 1995b, 1995c);
- 1,533 ha (8%) of the study area remains unsurveyed; and
- 2,711 ha (14%) of the study area is cleared or disturbed[3] (see Figure 3.2).

Some survey areas overlap and in some cases vegetation mapping presented in the individual reports have been updated and integrated in subsequent reports. Where survey areas overlap, the most recent revisions of mapping boundaries are presented. The method of integration of existing data into a consolidated vegetation map of the study area is detailed in Section 3.5.

Details on the individual survey teams and weather conditions are provided in the relevant reports for the surveys listed in Table 3.1. A summary of the survey methods used and the combined sampling effort is provided in Section 3.3.

3.2 Additional Flora Data Sourced for the Study Area

In addition to the vegetation and flora data obtained from the studies outlined in Section 3.1, a search of Rio Tinto's internal flora database was requested for the study area.

Any additional records of introduced flora (weeds) and conservation significant flora from surveys not reviewed in this report (e.g. from non-baseline surveys such as weed monitoring and rare flora clearances) are also listed in this report in order to present a comprehensive and up-to-date record of flora for the study area.

2 Some of which have been seasonally sampled.

3 This estimate was based on the Rio Tinto December 2013 disturbance layer and does not include additional areas mapped as disturbed within individual survey areas, which are included in Section 4.3.

Table 3.1: Summary of Yandi vegetation and flora surveys contributing to the overall Yandi Integration study area dataset.

Study (Reference)	Area Surveyed Within Study Area (Total Area of Survey)	Survey Description Survey Timing (Conditions for Plant Growth[4])	Available Data
Yandi Billiards – Phase 1 and Phase 2 (Yandi PBS) (Biota 2014a)	8,640 ha (8,640 ha)	Two phase (seasonal) vegetation and flora survey of the PBS survey area to expand the existing data for the area to a Level 2 standard. 8 – 20 March 2014 (favourable); 7 – 11 July 2014 and 14 July 2014 (favourable).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Yandi JSW/Oxbow Vegetation and Flora Integration Report (Biota 2014b)	2,133 ha (2,192 ha)	Integration of existing data with a further botanical survey to provide additional information on the values associated with the JSW and YOX survey areas. 27 February – 4 March 2012 (favourable).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Yandi Additional Areas (Biota 2014c)	2,807 ha (2,828 ha)	Establish additional quadrats to validate vegetation mapping of additional areas around the JSW and YOX deposits to match the project footprint. 12 – 18 June 2012 (favourable).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Yandicoogina Additional Vegetation Mapping (Biota 2011a)	2,806 ha (3,030 ha)	Mapping of additional areas around the JSW and YOX deposits to match the project footprint. 29 November – 3 December 2010 (unfavourable).	• Mapping notes. • Detailed vegetation mapping. • Conservation significant flora and weeds. • Vegetation condition assessment. • Species list.
Vegetation and Flora Surveys of the Oxbow and Junction South West Deposits, near Yandicoogina (Biota 2010a)	YOX: 665 ha (725 ha) JSW: 1,460 ha (1,460 ha)	Two phase (seasonal) vegetation and flora survey of the JSW and YOX survey areas. YOX: 27 July-6 August 2008 (unfavourable); 3-9 June 2009 (favourable). JSW: 4 – 16 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
A Flora and Vegetation Survey of the Billiards Deposit, near Yandi (Biota 2009a)	1,512 ha (1,512 ha)	Two phase (seasonal) vegetation and flora survey of the Billiards survey area. 11 – 20 June 2007 (unfavourable); 27 July – 6 August 2008 (unfavourable); 3 – 9 June 2009 (favourable).	• Quadrats/relevés/mapping notes. • Weed records. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.

[4] Determined by assessing the amount of rainfall received prior to the survey dates; listed as "unknown" if rainfall data from Marillana Station (the closest recording station to the study area) were not available for the specific survey period.

Study (Reference)	Area Surveyed Within Study Area (Total Area of Survey)	Survey Description Survey Timing (Conditions for Plant Growth[4])	Available Data
Yandicoogina Waste Dumps, Topsoil Stockpiles and Haulroads Native Vegetation Clearing Permit Report (Biota 2009b)	406 ha (406 ha)	Single phase vegetation and flora survey of four development areas to support a Native Vegetation Clearing Permit. 4 – 7 September 2008 (unfavourable).	• Conservation significant flora records. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Vegetation Mapping and Rare Flora Searches of Yandi Backfill Hill (Biota 2005)	189 ha (189 ha)	Vegetation mapping and systematic rare flora searches of the Yandi Backfill Hill survey area. 31 May – 2 June 2005 (unfavourable)	• Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Yandi Expansion Vegetation and Flora Survey (Biota 2004a)	2,245 ha (2,245 ha)	Single phase vegetation and flora survey of the Yandi Expansion area, near the YJC deposit. 30 August – 5 September 2004 (unfavourable)	• Quadrats/relevés. • Conservation significant flora and weeds. • Detailed vegetation mapping. • Vegetation condition assessment. • Species list.
Flora and Vegetation Survey of the Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b)	1,492 ha (3,977 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor Extension through the Hamersley Range. April 2003 (favourable)	• Quadrats. • Weed records. • Detailed vegetation mapping. • Species list.
Vegetation and Flora of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002)	805 ha (2,774 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridor from Port Hedland to Weeli Wolli. 25 April – 14 May 2001 (favourable) 29 May – 10 June 2001 (favourable)	• Quadrats. • Weed records. • Vegetation mapping. • Species list.
Hope Downs Rail Corridors Biological Surveys (Halpern Glick Maunsell 2000a)	2,594 ha (16,420 ha)	Single phase vegetation and flora survey of the Hope Downs Rail Corridors. 25 November – 3 December 1999 (unfavourable)	• Quadrat. • Vegetation mapping. • Species list.
Flora and Vegetation: Yandicoogina Junction Area (Mattiske 1995a)	3,591 ha (3,745 ha)	Single phase vegetation and flora survey of the YJC survey area. January and March 1994 (unknown) February 1995 (unknown)	• Detailed vegetation mapping.
Flora and Vegetation: Northern Transport Corridor, Yandicoogina Junction Project Area (Mattiske 1995b)	3,035 ha (24,703 ha)	Single phase vegetation and flora survey of the Yandi Northern Transport Corridor. February 1995 (unknown)	• Detailed vegetation mapping.
Flora and Vegetation: Southern Transport Corridor, Yandicoogina Junction Project Area (Mattiske 1995c)	2,450 ha (30,103 ha)	Single phase vegetation and flora survey of the Southern Transport Corridor. January and March 1994 (unknown) February 1995 (unknown)	• Detailed vegetation mapping.

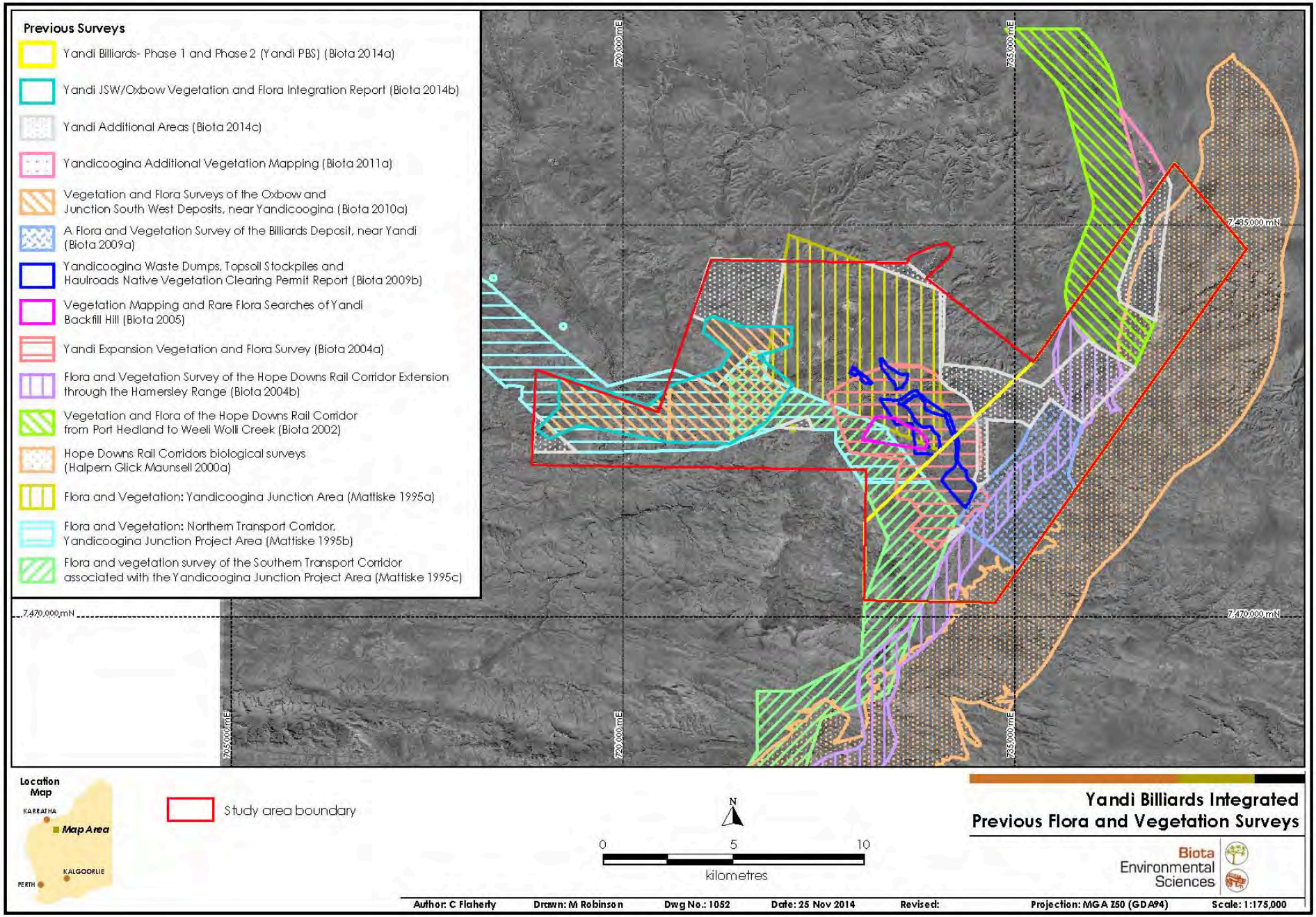

Figure 3.1: Flora and vegetation surveys conducted over the study area.

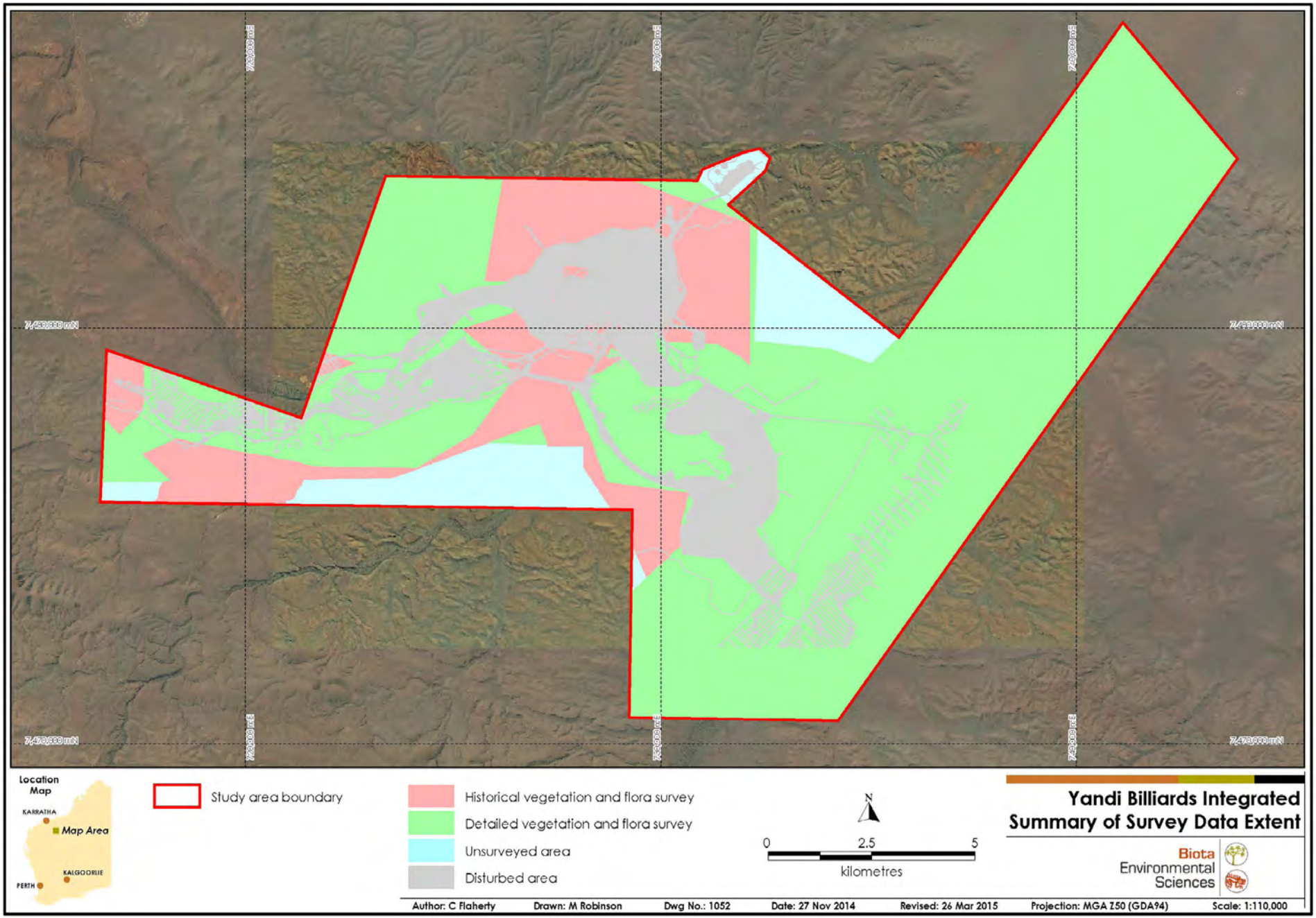

Figure 3.2: Different levels of survey effort across the study area.

3.3 Summary of Survey Methods

The vegetation and flora surveys completed by Biota within the study area used essentially the same sampling methods. This approach comprised a combination of qualitative description and mapping of vegetation types and vegetation condition (Section 3.3.1), systematic sampling of flora using standard floristic survey quadrats (Section 3.3.2), and targeted searches and opportunistic sampling for additional flora, particularly species of conservation significance and weeds (Section 3.3.3).

The field surveys were generally completed in accordance with relevant Environmental Protection Authority (EPA) policies and guidelines, specifically:

- EPA Position Statement No. 3: "*Terrestrial Biological Surveys as an Element of Biodiversity Protection*" (EPA 2002); and
- EPA Guidance Statement No. 51 "*Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia*" (EPA 2004).

A statement of limitations is provided in Section 3.7.

3.3.1 Vegetation Description and Mapping

Detailed vegetation mapping was completed over nine separate surveys and extends over 12,226 ha (63%) of the study area (see Section 3.1).

Vegetation types identified from aerial photography were ground-truthed during foot traverses in the respective survey areas. The boundaries of the survey area were uploaded onto hand-held Global Positioning System (GPS) units to ensure that the correct areas were traversed. Vegetation descriptions for each vegetation type observed in the field were recorded at all quadrats and relevés (see Section 3.3.2), and also in a series of mapping notes[5]. Typical information recorded at the mapping note locations included notes on the habitat, landscape and vegetation type, usually with a representative photograph and often with opportunistic specimen collections to supplement the species list. Over 600 mapping notes have been made during the recent surveys at Yandi (see Table 3.1 in Section 3.1). Locations of these mapping notes are presented in Figure 3.3.

Vegetation descriptions for the study area were based on the height and estimated cover value of dominant species using Aplin's (1979) modification of the vegetation classification of Specht (1970) (see Appendix 2). Descriptions were made for each vegetation type observed in the field, and vegetation boundaries identified from aerial photography were ground-truthed during foot traverses through the survey area.

The vegetation types were described at the sub-association level (level VI as per the National Vegetation Information System, or NVIS)[6]. The sub-association level includes information about the dominant growth form, height and cover for up to five species in all layers/sub-strata observed (e.g. *Eucalyptus victrix, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland).

Similar vegetation descriptions were grouped to establish the vegetation types for the study area. Vegetation descriptions that shared a suite of perennial species with a similar range of cover values were considered to be alike.

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5 Mapping notes are sampling sites conducted over an area of smaller scale than a quadrat or relevé; these notes are typically brief, with only dominant and commonly associated species being recorded. Mapping notes are taken primarily during foot traverses of an area, with the objective of detecting boundaries and changes in vegetation types.

6 http://www.environment.gov.au/erin/nvis/publications/avam/section-2-1.html

Two coding systems are presented in this report to refer to the individual vegetation types:

1. An alphabetic code was assigned to represent the dominant flora species from the tallest stratum to the lowest stratum. Each dominant species was given a unique code by using an abbreviation of the genus to capital letter(s) followed by an abbreviation of the species to lower case letter(s) (e.g. EvAciAcMgCEc denotes a vegetation type dominated by *Eucalyptus victrix, Acacia citrinoviridis, Acacia coriacea* subsp*. pendens, Melaleuca glomerata and *Cenchrus ciliaris*). This coding enables vegetation types from different studies to be quickly compared, however it can sometimes result in long and unwieldy codes.
2. To aid interpretation, each vegetation type was also assigned an alpha-numeric code as a unique precursor to the species-driven code (e.g. C3: EvAciAcMgCEc for the third creekline sub-association). This short code is used to refer more simply to the individual vegetation types in this report.

Although some of the vegetation types were first drafted in the field, the majority of the vegetation mapping was completed in the office after the fieldwork was completed. Field data and aerial imagery were studied to determine boundaries of vegetation types, which were then mapped to an appropriate scale. The maps were created and consolidated using GIS software (QGIS and MapInfo), and point locations of sampling sites, conservation significant flora and weeds were added. All maps in this report were produced by Melissa Robinson (Biota) using the MapInfo package (version 11).

Summarised descriptions of the vegetation types are provided in Appendix 3, while their distribution is mapped in Appendix 4.

3.3.2 Establishment and Assessment of Flora Quadrats and Relevés

Permanently marked quadrats (flora sampling sites of a fixed area) were preferentially used as the primary method to gather quantitative data on floristic composition. Most quadrats established were 50 m x 50 m in size. This quadrat area of 2,500 m^2 is recognised as providing an adequate sample of species presence for Pilbara vegetation, and is the standard quadrat size for botanical survey work in the region (Clarke 2009). Where a square quadrat was unsuitable for capturing the vegetation type (e.g. along narrow creeklines), a rectangular quadrat of equivalent area (e.g. 25 m x 100 m) was established instead. In most cases, the quadrats were permanently marked using steel fence droppers on at least three corners. An optical square and measuring tapes were used to accurately position the quadrat boundaries.

In cases where quadrats could not be established (e.g. due to the small size or irregular shape of the habitat), these locations were instead surveyed as relevés. A relevé is an unbounded flora sampling site with a similar area to a standard quadrat; essentially the same information is recorded as for a quadrat, however the sampling of flora is typically not as thorough. Relevé sampling was usually undertaken if the vegetation type had a linear or irregular shape (e.g. along creeklines), making establishment of a standard quadrat in a single vegetation type difficult.

The following information was recorded for each quadrat and relevé (raw data are appended to each of the relevant survey reports):

- Location: Universal Transverse Mercator (UTM) coordinates in WGS84 datum in Zone 50, recorded to an accuracy of typically ±5 m using a handheld GPS unit; coordinates were recorded for all four corners of a quadrat and for the centre point of a relevé;
- Vegetation description: a broad description based on the height and estimated cover value of dominant species (Aplin 1979; see Appendix 2);
- Habitat description: a description of the landform and other relevant habitat details (e.g. aspect);
- Broad soil type: a description of the soil colour, texture and any stony surface mantle;
- Fire history: approximate time since last fire, where applicable;

- Vegetation condition ranking: considering evidence of grazing, physical disturbance, weed invasion etc. (after Trudgen 1988; see Appendix 2);
- The estimated percent foliar cover of each flora species present within the quadrat, or in the vicinity (within a ~30 m radius) of the centre point of the relevé; and
- A colour photograph of each site (usually taken from the northwest corner of a quadrat).

Data are available from a total of 209 quadrats and 35 relevés that have been sampled in the study area. A summary of the quadrats and relevés in the study area is provided in Table 3.2, while their locations are indicated in Figure 3.3 and on the vegetation maps in Appendix 4. Due to the overlap of some of the 15 survey areas, some sampling sites were presented in more than one of the survey reports. Quadrat and relevé numbers in Table 3.2 have been assigned based on the source survey during which each site was initially established. Therefore for some of the surveys, this does not reflect the total number of quadrats that were located within the survey area as described in the original report. Mattiske (1995a, 1995b, 1995c) established a total of 296 sites, however only a subset of these were located within the study area. As no data were provided in the respective reports, these sites have not been considered further in this report.

A subset of 83 quadrats (approximately 40% of the quadrats sampled in the study area) were effectively seasonally sampled; that is, surveyed over two phases, with at least one survey phase completed when conditions were favourable for plant growth (i.e. following adequate rainfall). Some quadrats previously established by Biota (2009a, 2010a) were sampled over two phases, however both seasons were unfavourable for plant growth. These quadrats were not considered as being effectively seasonally sampled, as it is likely that some species would not have been present or identifiable at the time of both survey phases (e.g. annual daisies that would germinate mostly after late winter rains, other herbs, annual grasses, etc.). Some quadrats were established during one survey and resampled during a different survey. The numbers presented in Table 3.2 display the seasonally sampled quadrats in each of the source survey areas, regardless of whether resampling occurred during the source survey or a separate survey.

Thirty-one quadrats and one relevé have subsequently been cleared for mine expansion or establishment of roads or drill tracks (see Section 4.3).

Table 3.2: Total number of quadrats and relevés located in the study area that were established during each survey.

Survey Area (Reference)	Survey Code	Number of Quadrats		Number of Relevés
		Not Seasonally Sampled	Seasonally Sampled	
Yandi Billiards (PBS) (Biota 2014a)	BIL	19	30	7
Yandi JSW/Oxbow Integration (Biota 2014b)	YVI	15	0	1
Yandi Junction South West (Biota 2010a)	YSW	15	4	1
Yandi Oxbow (Biota 2010a)	OXB	0	11	0
Yandi Billiards (Biota 2009a)	YBI	15	21	15
Yandi Additional Areas (Biota 2014c)	YAQ	21	7	5
Yandi Expansion (Biota 2004a)	YEX	33	6	6
Hope Downs Rail Corridor Extension through the Hamersley Range (Biota 2004b)	HDA	6	3	0
Hope Downs Rail Corridor from Port Hedland to Weeli Wolli Creek (Biota 2002)	H	1	1	0
Hope Downs Rail Corridors Biological Surveys (Halpern Glick Maunsell 2000a)	WW	1	0	0
	Total	126	83	35

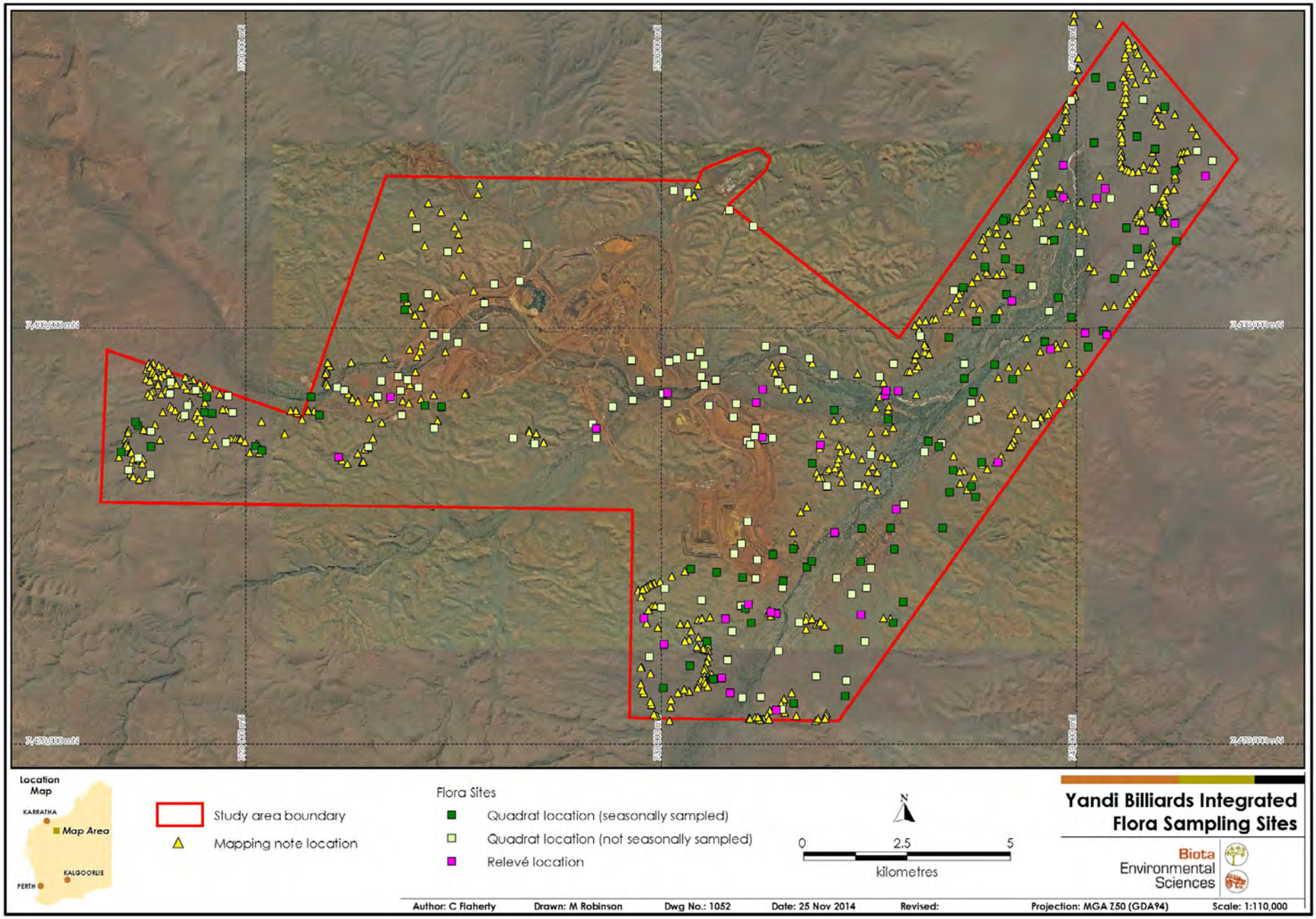

Figure 3.3: Quadrat, relevé and mapping note locations in the study area.

3.3.3 Targeted Searches for Conservation Significant Flora and Weeds

Searches for conservation significant flora were not conducted systematically over the entire study area. Only one of the surveys that was reviewed for the study area (a survey of Yandi Backfill Hill; Biota 2005) included systematic searches for conservation significant flora (see Section 3.1).

However, all surveys reviewed for this report included opportunistic searches for conservation significant flora. These were conducted within quadrats and relevés, and during foot traverses while conducting vegetation mapping and travelling between sites. Track logs of foot traverses are only available for the most recent survey in the study area and are provided in the relevant report (Biota 2014a). Another indication of the proportion of the study area that was assessed opportunistically is provided by the spatial coverage of the quadrats, relevés and mapping notes recorded during the field surveys (see Figure 3.3).

All locations of conservation significant flora were recorded using a GPS unit (WGS84 datum). Wherever possible, the number of individuals, habitat and associated plant species were also recorded. Voucher specimens were collected for confirmation, and also for lodgement with the WA Herbarium (as appropriate).

Similar information was recorded during the foot traverses for introduced flora species (weeds), and any additional native flora species that had not been previously recorded in the area were noted as opportunistic collections. A list of all vascular flora species recorded in the study area is provided in Appendix 5.

3.4 Specimen Identification, Nomenclature and Data Entry

Identification of vascular flora specimens was conducted in the field or in the office following the field survey. In cases where a plant specimen was common and known to the botanist, the identification was confirmed and noted in the field. If the species was difficult to determine without microscopic examination, belonged to a recognised species complex, was poorly collected or otherwise unusual, a voucher specimen was collected.

Voucher specimens were identified by using flora keys, consulting appropriate publications, checking voucher reference collections, and comparing the specimens to the collections held at the WA Herbarium. Biota botanists identified most specimens, the majority of which were confirmed by Michi Maier, with external assistance sought as necessary. Data from older surveys in the study area were reviewed, and specimen identifications were checked and amended as necessary to reflect recent taxonomic changes. Various taxonomic specialists were consulted to provide assistance or confirm the identifications of difficult plant groups (see Table 3.3).

Table 3.3: Taxonomic specialists that have identified difficult taxa from the study area.

Specialist (Affiliation)	Taxa Examined	Survey/s
Malcolm Trudgen (M.E. Trudgen and Associates)	Fabaceae, Poaceae, Malvaceae and other difficult taxa	All surveys
Bruce Maslin (WA Herbarium)	*Acacia.*	Biota (2002, 2004b)
Bryan Simon (Queensland Herbarium)	*Triodia, Cymbopogon, Aristida* and *Eriachne*	Biota (2002)
Lyn Craven (Australian National Herbarium, Canberra)	*Halgania*	Biota (2004b)
Allen Lowrie	*Stylidium*	Biota (2002)
Leigh Sage (Department of Parks and Wildlife)	*Goodenia*	Biota (2002)
Paul G. Wilson (WA Herbarium)	Asteraceae and Chenopodiaceae	Biota (2002)
Ryonen Butcher (WA Herbarium)	*Tephrosia*	Biota (2014a)
Andrew Perkins (WA Herbarium)	Conservation significant species and atypical specimens of various taxa	Biota (2014a)

Nomenclature was checked against the current listing of scientific names recognised by the WA Herbarium. All data were entered into a Microsoft Access Vegetation Database structure held internally at Biota. The database model employed by Biota was developed by Ted Griffin (private consultant) at the request of Malcolm Trudgen (M.E. Trudgen and Associates).

3.5 Mapping Integration and Standardising of Vegetation Types

In order to prepare an integrated map based on all of the vegetation mapping available for the study area, it was necessary to attempt to standardise some of the vegetation types that were described in the different surveys by the different authors. As Biota had conducted the majority of the survey work in the study area in a consistent way, and given that for most areas the vegetation types used across the different projects were kept consistent, Biota's more recent mapping units were used as the basis for the vegetation mapping over the entire study area.

Some vegetation mapping completed by Biota (2000, 2004a, 2005, 2009b) was revised and updated where necessary. The changes made were generally minor and included some amendments to a few vegetation descriptions, so that they reflected the vegetation types used consistently over the study area; and some changes to mapping boundaries, so that the vegetation units displayed seamlessly across the boundaries of the different survey areas. It was necessary to update a number of vegetation descriptions due to some updates made to the identification of *Triodia*: specimens that were previously thought to be *Triodia lanigera* in the Yandi area have been re-identified as *T. basedowii,* while the taxon previously designated by the informal name "*Triodia* aff. *basedowii*" is now recognised as *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835).

The areas of historical mapping by Mattiske (1995a, 1995b, 1995c) were reviewed, however it was determined that it was not possible to integrate this mapping with the more recent, detailed mapping of the surrounds completed by Biota. Some of the historic vegetation types were described at a considerably broader level than the vegetation types described more recently for the study area (e.g. 'Low shrubland of mixed *Acacia* species' (Mattiske 1995a), which is a broad floristic formation equivalent to NVIS Level III). Additionally, some of the mapping boundaries appeared to be spatially inaccurate, as they did not correspond to the landforms apparent on aerial photography. While numerous flora sites were sampled during these surveys, no data were provided in any of the reports. As these areas of historical vegetation mapping could not be validated with any quantitative flora site data, we were unable to accurately translate these vegetation types to the corresponding more detailed units used for the study area. For these reasons it was decided that the historical mapping would not be presented or further discussed in this report.

Instead the existing detailed mapping and corresponding vegetation types were extended over these areas through a desktop exercise using aerial photography and information from the surrounding areas that had been mapped. This was also done for the areas where no mapping had been completed, in order to produce a single consolidated vegetation map for the entire study area. The extended vegetation mapping should provide a reasonable indication of vegetation in these areas. However, mapping boundaries would need to be ground-truthed in the field and flora quadrats would need to be established to support the vegetation types mapped, in order for this mapping to be considered suitable to support an EIA (as outlined in Guidance Statement No. 51 of EPA 2004).

The consolidated vegetation map for the study area is presented in Appendix 4. Not all surveys within the study area were completed at a Level 2 standard (as outlined in EPA 2004) and vegetation mapping was completed with varying levels of survey effort across the study area. A discussion of the level of confidence in the vegetation mapping presented in this report is provided in Section 4.2.

3.6 Floristic Analysis

In order to examine the relationships between the floristic composition of the sampling sites in the study area compared to a selection of sites from the broader locality (within 100 km of the study area), cluster analyses were carried out using the PRIMER software package. The dataset included 868 quadrats and 101 detailed relevés, comprising:

- 209 quadrats and 21 relevés assessed within the current study area by several studies (including Halpern Glick Maunsell 2000a, Biota 2004a, 2009a, 2010a, 2014a, 2014b, 2014c); together with three additional quadrats in close proximity that were treated as "inside the study area" for the purposes of the current analysis: YVI03 (40 m outside), YAQ28 (60 m outside) and YAQ26 (420 m outside);
- 16 quadrats and three relevés from the Hamersley Range section of the Hope Downs rail corridor (Biota 2004b);
- 26 quadrats and one relevé from the Chichester Range section of the Hope Downs rail corridor (Biota 2004c);
- 41 quadrats and one relevé from the Juna Downs section of the Hope Downs rail corridor (Biota 2006a);
- 13 quadrats from Rio Tinto's Bellbird – Juna Downs rail corridor (Biota 2008), and 15 quadrats from an addendum to this corridor (Biota 2009c);
- 348 quadrats and 23 relevés from various survey areas associated with Koodaideri, including the Koodaideri Lease Area, Western Rail Corridor, Southern Infrastructure Corridor and Northern Extension (summarised in Biota 2012a);
- 52 quadrats and 13 relevés from Fortescue Metal Group's Stage A rail corridor (Biota 2004d);
- nine quadrats and 10 relevés from BHP Billiton's Jinidi-Mindy survey area (Biota 2011b);
- 67 quadrats and eight relevés from BHP Billiton's Southern Flank-Jinidi survey area (2012b);
- 24 quadrats and 16 relevés from Deposits E and F at West Angelas (Biota 2006b);
- 35 quadrats from the West Angelas gas plant and pipeline corridor (Biota 2010b); and
- 10 quadrats and five relevés from Deposit F at West Angelas (Biota 2014d).

A full list of the sites and their source studies is provided in Table 1 in Appendix 8, with each site within the study area attributed with its alpha-numeric vegetation code (Section 3.3.1) and broad habitat. Note that five sites sampled in the locality were excluded from the dataset after an initial screening analysis, as they were found to be significant outliers that precluded presentation of the analysis results for the remaining sites. These outlier sites were HDDRELG in a herbland on a granite outcrop (Biota 2004c); FMG15 and FMG16 in samphire shrublands associated with the Fortescue Marsh, FMG61 in a *Triodia longiceps* hummock grassland on a low-lying plain containing patches of clay, and FMG20f in a mixed herbland on a clay plain (all from Biota 2004d).

A combined species list was created from all of the sites and reviewed for errors or inconsistencies in nomenclature. Both annual and perennial vascular flora species were included. The data were screened to remove or take into account records with the potential to substantially bias the results. This included:

- Weed species other than **Cenchrus* were excluded, as these were often linked to location (particularly the presence of disturbance factors, such as cattle) rather than specifically to the vegetation type. **Cenchrus ciliaris* and **C. setiger* were retained and were combined and treated as "**Cenchrus* spp.", as these provided a significant cover in some areas and now formed part of the vegetation structure.
- Fungi and non-vascular flora records were excluded from the dataset, as these were not systematically sampled.
- Records that could represent different taxa across multiple projects (e.g. "*Euphorbia* sp.") were excluded.

- Where it was considered that multiple taxa may represent the same species, these were all referred to a single taxon identification code in the dataset, and thus treated as a single entity in the subsequent analyses. For example, the records of sterile soft spinifex that were assigned to *Triodia* sp. (*epactia/pungens*) were amalgamated with *T. epactia* and *T. pungens*; records of *Scaevola parvifolia* and its two subspecies were amalgamated, as there appeared to be crossover of characters; and all forms of Mulga (*Acacia aneura* complex) were referred back to the species in the broad sense, as names from old projects were not consistent with the recent taxonomic revision by Maslin and Reid (2012).
- Finally, singleton species (those occurring in only one site) were removed to reduce noise in the dataset, unless they were characteristic of a particular habitat (e.g. *Astrotricha hamptonii*).

Where a site had been sampled more than once, the Phase 1 and Phase 2 data were amalgamated. Where the estimated cover value for a particular species differed between survey phases, the larger of the two estimates was retained.

For the resulting list of species, two matrices were then generated:

- percentage foliar cover of each species at each site; and
- presence / absence of each species at each site.

Two additional matrices were generated from the above by removing annual species that would only be recorded under optimal sampling conditions. These matrices were used to investigate potential bias in the dataset caused by sampling during different seasonal conditions for different projects.

The screened site by species data were imported into PRIMER. Percentage foliar cover values were square-root transformed to reduce the influence of high abundance species on the similarity analyses. A resemblance matrix was then constructed using the Bray-Curtis similarity index, which produces a similarity value for all pairs of sites based on their species composition and transformed abundances.

The resultant resemblance matrix was then run through PRIMER's CLUSTER routine, using group average linkage to construct a dendrogram grouping the survey sites into clusters based on similarity in species composition. Two analyses were run, the first including data for both perennial and annual flora species, and the second using data for perennial species only. Analyses were run using all sites from the study area, and using all sites in the dataset. The resemblance matrix was used to generate Non-metric Multi-Dimensional Scaling (NMDS) ordination plots to assist with visualising the groupings amongst sites based on flora composition. Due to the size of the dataset (969 sites), site clusters were not tested for significance using the similarity profile permutation test (SIMPROF) and it was not possible to reproduce the dendrogram from the overall analysis. Representative outputs are instead presented as NMDS plots in Appendix 8. The full outputs from the analyses are available for inspection if required.

3.7 Limitations of this Study

As this report collates data from 15 studies, the limitations outlined in the reports for each individual study also apply here. The main limitations affecting the study that should be taken into account include:

- Some sections of the individual survey areas were not ground-truthed or systematically sampled. The habitats and vegetation types within each survey area were therefore not equally sampled, and sampling effort was not equal amongst the contributing surveys (see Section 3.1 and Figure 3.2). This particularly applies to the areas indicated as 'Low - moderate' and 'High' vegetation mapping confidence in Figure 4.1.
- EPA Guidance Statement 51 (EPA 2004) states that a Level 2 vegetation and flora survey should comprise a seasonal survey component. Not all of the component surveys within the study area included a seasonal component to meet Level 2 standards (see Table 3.1 and Figure 4.1), and

resampling of existing quadrats was therefore a key task for the more recent survey work. Over the entire study area, approximately 40% of the quadrats established have been effectively seasonally sampled (see Section 3.3.2 and Figure 3.3), and the more recent component surveys generally have a higher proportion (e.g. approximately 56% of quadrats within the PBS survey area have been resampled). While resampling of all established quadrats would be ideal, it has been acknowledged that a 'High' level of satisfaction can be reached from resampling a proportion of quadrats (approximately 25–50%) if the initial survey was completed under appropriate seasonal conditions (EPA and DEC 2012, p. 123). The level of quadrat resampling within the study area is therefore adequate.

- Survey timing has a significant effect on the flora species recorded from any area. The various studies were conducted at different times of year and following different rainfall regimes. While most of the survey work included at least one phase that followed adequate rainfall, the timing of some of the surveys was not optimal for recording annual or cryptic perennial species (see Table 3.1).
- While some opportunistic records of fungi were made (see species list in Appendix 5), fungi and non-vascular flora were not specifically surveyed, as is typical for surveys of this nature.
- The vegetation types for the individual survey areas were defined through a combination of quadrat and relevé data, mapping notes recorded in the field, and the interpretation of aerial photography. Interpretation of vegetation from aerial photography can be difficult and mapping notes are recorded as point data, which provide only an indication of vegetation boundaries. The existing mapping therefore provides a spatial representation of the vegetation of the individual survey areas, and vegetation boundaries should be treated as indicative rather than absolute.
- Vegetation mapping has been extrapolated to unsurveyed sections of the study area. Vegetation boundaries were based on landforms apparent on aerial photography, combined with information inferred from nearby areas of vegetation mapping. Vegetation types and mapping boundaries in these areas have not been ground truthed, and should only be used to provide a general indication of the vegetation in these areas (see Section 4.2 for a broad indication of the level of confidence in the vegetation mapping).
- Vegetation type C1 includes riparian vegetation of the wettest parts of the local creek systems, but does not distinguish between areas dominated by *Melaleuca argentea* and *Eucalyptus camaldulensis.* The former species occurred in stands along Marillana Creek and Weeli Wolli Creek but was not continuous through this vegetation type.
- The majority of the information presented in this mapping integration has been acquired post-mining. Consequently, the vegetation types present and their spatial extent are likely to have been altered through clearing for mining development and the effects of mine water discharge into the local creek system.
- Four vegetation types (H8, H9, H10 and H11) were described from a single quadrat only. These vegetation types have a very small area of representation (see Appendix 4).
- The results of the floristic analysis reflect the dataset utilised, and analysis using different or additional sites may result in a somewhat different interpretation. Quadrat data for the Pilbara region is typically patchily distributed and concentrated in development areas, and not all vegetation types are equally well sampled.

4.0 Vegetation of the Study Area

4.1 Overview of Vegetation Types

Four landscape categories were identified for the study area:

- major creeklines and tributaries;
- minor creeklines, floodplains and valleys;
- hills, ridges and breakaways; and
- plains.

A total of 30 vegetation types were mapped for the study area over the four landform categories. Some of the older vegetation types were updated to an equivalent unit so that mapping was kept consistent over the entire study area (see Section 3.5). All vegetation types are summarised in Appendix 3 (for full descriptions, refer to the individual supporting survey reports).

4.1.1 Major Creeklines and Tributaries

A total of five vegetation types mapped in the study area were associated with creeklines that supported true riparian vegetation, as characterised by the presence of the tree species *Eucalyptus camaldulensis* (River Red Gum), *E. victrix* (Coolibah) and/or scattered stands of *Melaleuca argentea* (Cadjeput). This vegetation was associated with Marillana Creek and Weeli Wolli Creek, which represent two major, regionally significant creeklines in the Pilbara. Weeli Wolli Creek is situated adjacent to the proposed PBS area, while Marillana Creek flows through the YJC, JSW and YOX developments. The confluence of the two creeks is situated immediately to the north of the proposed PBS development.

The wettest parts of these creeklines supported vegetation type C1, which comprised riparian woodlands containing varying proportions of *Eucalyptus camaldulensis* subsp. *refulgens* and/or scattered stands of *Melaleuca argentea,* sometimes with *E. victrix* also present. A tall shrubland of species such as *Melaleuca glomerata* and *Acacia coriacea* subsp. *pendens* (Weeping Wirewood) was typically also present, and patches of *Typha domingensis* (Bulrush) and sedges such as *Cyperus vaginatus* (Stiff-leaf Sedge) often occurred in these areas.

The scoured, rocky beds of the major creeks supported occasional trees of *Eucalyptus victrix* and shrubs of *Acacia citrinoviridis* (River Jam), *A. coriacea* subsp. *pendens* and *Melaleuca glomerata* (vegetation type C3). Buffel Grass (**Cenchrus ciliaris*) also occurred in these areas as scattered individuals, while the low shrubs *Indigofera monophylla* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) were common.

Major tributaries of Marillana and Weeli Wolli Creeks (vegetation types C2, C4, C5 and some parts of C3) supported *Eucalyptus victrix* low trees, occasionally with *Corymbia hamersleyana* (Hamersley Bloodwood) in the upstream reaches of vegetation type C2. A tall shrub or low woodland stratum typically consisted of mixed *Acacia* species, *Grevillea wickhamii* (Wickham's Grevillea) and occasionally *Atalaya hemiglauca* (Whitewood). Vegetation types C2 and C5 supported several native species of tussock grasses in the understorey, while C3 and C4 were dominated by **Cenchrus ciliaris*.

4.1.2 Minor Creeklines, Floodplains and Valleys

A total of five vegetation types were associated with minor creeklines, floodplains and valleys in the study area.

Minor creeklines and the smaller tributaries of Marillana and Weeli Wolli Creeks (vegetation types F1 and F3) were typically in better condition than the main channels, with **Cenchrus ciliaris* being

considerably less abundant or absent. The floristic composition of these smaller creeklines varied depending on their location and size. The overstorey typically comprised scattered trees to a low open woodland of *Eucalyptus leucophloia* (Snappy Gum) or *Corymbia hamersleyana* over an open to closed tall shrubland of mixed species such as *Acacia tumida* var. *pilbarensis* (Pilbara Pindan Wattle), *A. ancistrocarpa* (Fitzroy Wattle), *A. bivenosa* (Two-veined Wattle) and *Grevillea wickhamii*. The understorey of these creeks varied from grasslands dominated by *Eriachne tenuiculmis* and *Themeda triandra* (Kangaroo Grass), to hummock grasslands dominated by *Triodia pungens* (Soft Spinifex) or various other spinifex species, particularly *T. wiseana* (Limestone Spinifex) and *T.* sp. Shovelanna Hill (S. van Leeuwen 3835).

Floodplains of Marillana and Weeli Wolli Creeks had a substrate of sandy or silty loams and supported open to dense woodlands dominated by *Acacia citrinoviridis* over an understorey of **Cenchrus ciliaris* tussock grassland (vegetation type F2). **Cenchrus ciliaris* formed dense infestations in vegetation type F2, affecting the overall condition of this vegetation (see Section 4.3). Other typical trees and shrubs in these areas included occasional *Acacia pruinocarpa* (Western Gidgee) and *Atalaya hemiglauca*. Some of the floodplains provided habitat for the Priority flora species *Rostellularia adscendens* var. *latifolia* (Priority 3) and *Goodenia nuda* (Priority 4) (see Section 5.4.2). Other floodplain vegetation types in the study area were associated with more minor creeklines, or with floodouts and valleys, which were often fed by minor creeklines that flowed through low hills (vegetation types F4 and F5). These vegetation types typically comprised a *Corymbia hamersleyana* low open woodland over a mixed *Acacia* shrub stratum with *Triodia pungens* hummock grasses and common tussock grasses including *Aristida holathera* var. *holathera* and *Paraneurachne muelleri* (Northern Mulga Grass).

4.1.3 Hills, Ridges, Gorges and Breakaways

A total of 11 vegetation types were associated with hills, ridges, gorges or breakaways in the study area.

The low stony hills had a near-continuous surface cover of cobbles, pebbles and gravel over sandy loams, and were generally dominated by hummock grasslands of *Triodia wiseana* and/or *T.* sp. Shovelanna Hill (S. van Leeuwen 3835), with the latter tending to be more dominant on elevated hill crests. Occasional low trees and shrubs were present including *Eucalyptus leucophloia, Hakea chordophylla, Acacia inaequilatera* (Baderi) and *Grevillea wickhamii*. The two major hill and hillslope vegetation types (H1 and H2) covered approximately 96% of the hills mapped for the study area and 45% of the entire study area. These vegetation types were also the main habitat for the Threatened species, *Lepidium catapycnon* (see Section 5.4).

Other vegetation types that were recorded less broadly through the hills, ridges, gorges and breakaways of the study area included:

- Some hilltops and slopes had a distinct shrubland stratum of *Acacia arida* (vegetation types H3 and H4). *Eucalyptus leucophloia* was the dominant tree species in vegetation type H3 and *Corymbia hamersleyana* was the dominant tree species in vegetation type H4.
- Several rocky ridges and breakaways situated on large rocky hills were mapped separately (vegetation type H5). This vegetation was characterised by very steep, often vertical, rocky slopes and rocky outcrops with skeletal soil. *Eucalyptus leucophloia* and *Corymbia ferriticola* were found growing out of crevices in the rocks. *Eremophila latrobei* subsp. *filiformis* and several species of *Senna* formed a shrub stratum. Several species of native tussock grasses were present in the understorey, including *Themeda* sp. Mt Barricade (M.E. Trudgen 2471), a species typically restricted to rocky habitats. The Priority 3 species *Sida* sp. Barlee Range (S. van Leeuwen 1642), which has a similar preferred habitat comprising skeletal soil in rocky areas, was also recorded from this vegetation type (see Section 5.4.2).
- *Acacia bivenosa* was found occasionally as an open shrubland on some slopes and hilltops, along with *Eucalyptus leucophloia* and *Triodia wiseana* (vegetation type H6).

- Low stony hills fringing Marillana Creek supported *Eucalyptus leucophloia* scattered low trees over an *Acacia pruinocarpa* tall open shrubland and a mixed hummock grassland of *Triodia wiseana* and *T. pungens* (vegetation type H7).
- A tall shrubland of *Acacia monticola* (Gawar) was found on a single area of hillslope (vegetation type H8), occurring over a mixed hummock grassland of *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) and *T. wiseana*.
- Two gorges in the study area were sufficiently large to map separately (vegetation type H9). These were dominated by *Corymbia hamersleyana* low trees over a shrub layer of *Gossypium robinsonii* (Wild Cotton), *Androcalva luteiflora* (Yellow-flowered Rulingia), *Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* and tussock grasses including *Themeda triandra* and *Cymbopogon ambiguus* (Scentgrass).
- *Eremophila fraseri* subsp. *fraseri* (Burra) was found on some isolated low hills, where it occurred over *Triodia pungens* with either *Acacia inaequilatera* (vegetation type H10) or *Grevillea pyramidalis* subsp. *leucadendron* (Caustic Bush) (vegetation type H11).

4.1.4 Plains

A total of nine vegetation types were associated with stony plains of the study area.

Vegetation occurring on the pebbly to stony plains typically comprised scattered low trees to a low open woodland of *Corymbia hamersleyana* or *Eucalyptus leucophloia*, sometimes with *E. gamophylla* (Twin-leaf Mallee), over scattered shrubs to an open shrubland of various wattle species, particularly *Acacia ancistrocarpa, A. bivenosa, A. citrinoviridis, A. inaequilatera*, *A. pachyacra, A. pruinocarpa, A. pyrifolia* (Ranji), *A. sclerosperma* subsp. *sclerosperma* (Limestone Wattle) and *A. synchronicia* (Bardi Bush) (vegetation types P1 to P5 and P9). The understorey was typically a hummock grassland, with *Triodia pungens, T. longiceps* (Giant Grey Spinifex), *T. wiseana* or *T. basedowii* (Lobed Spinifex; formerly identified as *T. lanigera*) dominating different areas. Some areas of plains in the study area provided habitat for Priority flora including the Priority 3 species *Themeda* sp. Hamersley Station (M.E. Trudgen 11431), and *Goodenia nuda* and *Rhynchosia bungarensis* (both Priority 4).

Other vegetation types that occurred over the plains in the study area included:

- The *Acacia "aneura"* (Mulga) complex was dominant in one vegetation type (P6) that occurred in several stands across the alluvial plains adjacent to Weeli Wolli Creek. Mulga species also occurred as scattered individuals (i.e. as a non-dominant species) over the plains and some hillslopes in the study area. Vegetation type P6 was dominated by shrubs of *Acacia aptaneura*[7], *Eremophila forrestii* subsp. *forrestii* and *E. lanceolata* and mixed grasses including *Triodia longiceps*, *Aristida pruinosa* (Gulf Feathertop Wiregrass) and sometimes **Cenchrus ciliaris* and **C. setiger* (Birdwood Grass). Several populations of the Priority 4 species, *Goodenia nuda,* were located in this vegetation (see Section 5.4.2).
- *Eremophila fraseri* subsp. *fraseri* (Burra) was a dominant shrub on some small areas of plain with a calcrete substrate (vegetation type P7). These areas supported either a mixed tussock grassland, with the dominant species comprising *Aristida contorta* (Bunched Kerosene Grass), *Enneapogon polyphyllus* (Leafy Nineawn), *Eragrostis eriopoda* (Woollybutt Grass) and *Paraneurachne muelleri* (Northern Mulga Grass), or a *Triodia wiseana* hummock grassland.
- *Triodia schinzii* was present along with *Eucalyptus gamophylla* and *Acacia inaequilatera* in one area of gently sloping pediment slopes at the base of a range of low hills (vegetation type P8).

[7] All Mulga specimens collected from the previous surveys were assigned names based on the recent taxonomic revision completed by Maslin and Reid (2012); older specimens were re-determined as necessary.

4.2 Vegetation Mapping Confidence

The various surveys completed previously in the study area utilised differing methodologies and had differing levels of survey effort. In addition, some areas of mapping were prepared solely from interpretation of aerial photography in combination with information extrapolated from adjacent mapping, and have not been ground-truthed. This results in variable levels of confidence (see Figure 4.1) in the final integrated vegetation map generated for the study area (as presented in Appendix 4).

Figure 4.1 provides a broad indication of our level of confidence in the accuracy of the vegetation mapping presented in this report. This is a function of various factors including the age of the mapping, the level of survey effort completed and the amount of site data available to validate the vegetation types and boundaries. The areas indicated in Figure 4.1 as a 'Very High' level of mapping confidence correspond to surveys that were completed at a Level 2 standard (as outlined in EPA (2004) Guidance Statement No. 51) and which included a seasonal component.

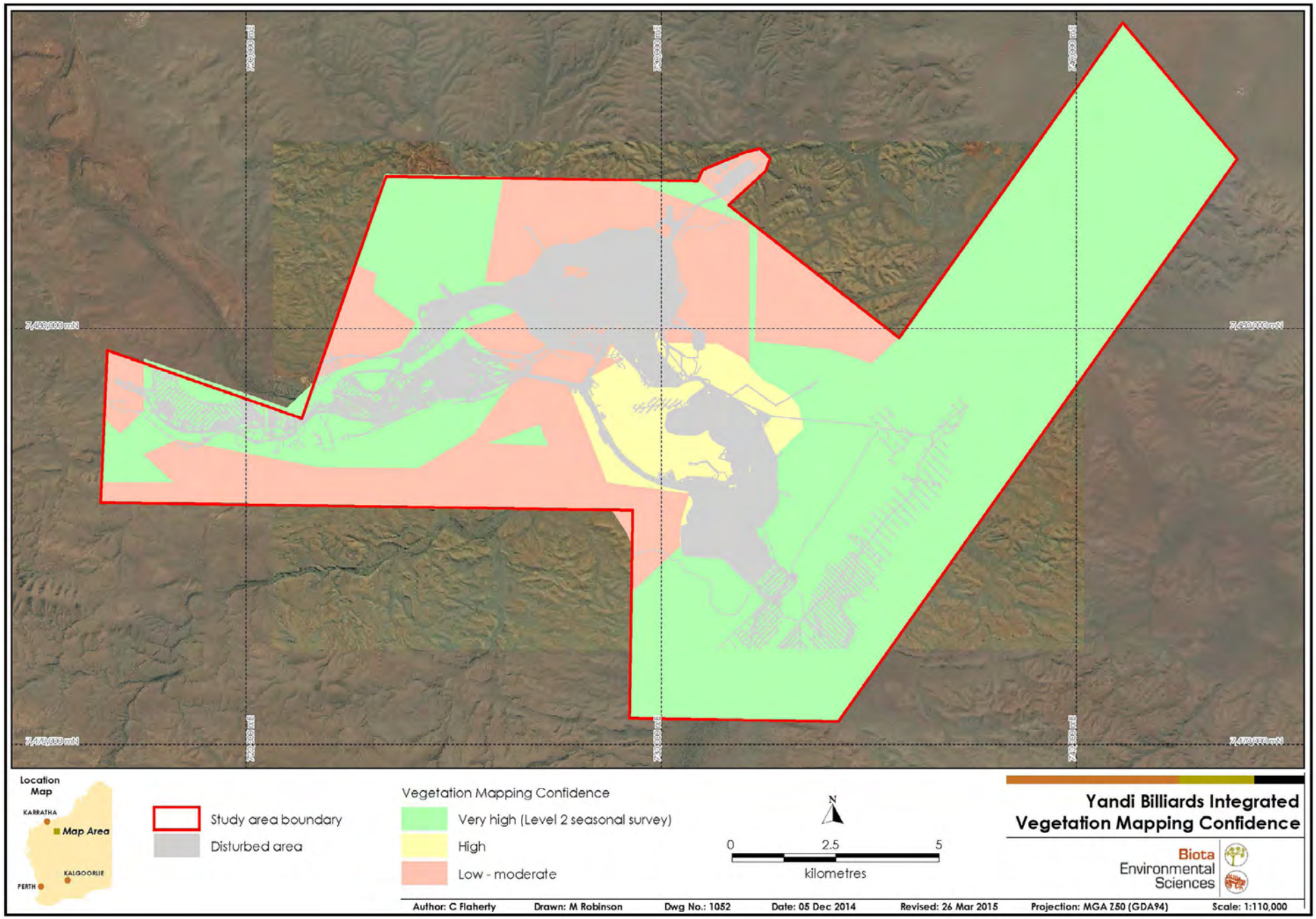

Figure 4.1: Broad indication of the level of confidence in the accuracy of the vegetation mapping presented in this report.

4.3 Vegetation Condition

Vegetation condition mapping for the study area is presented in Appendix 6. The vegetation condition ranking was based on the weed density, human impact, feral animals and livestock activities, and the perceived structural integrity of the vegetation as a whole. Appendix 2 presents the vegetation condition scale from Trudgen (1988) that was used to determine the vegetation condition rankings.

A total of 2,770 ha (approximately 14%) of the study area was mapped as Disturbed, which is equivalent to a Completely Degraded vegetation condition (Trudgen 1988). These areas comprised, mine pits, haul roads, exploration tracks and drill pads, as well as buildings and infrastructure associated with the existing approved Yandi mines (see Figure 4.1 and Appendix 4). The extents of these areas were largely based on Rio Tinto's December 2013 disturbance footprint layer, however some additional areas identified as disturbed on aerial photography were also mapped as disturbed. At the time of the second phase of the PBS field survey (July 2014; Biota 2014a), additional drill lines were being cleared on the eastern side of Weeli Wolli Creek, south of the confluence with Marillana Creek. These new drill lines were not mapped as disturbed areas, as they were too recent to be visible on aerial photography or captured in the Rio Tinto December 2013 disturbance footprint layer. A total of 31 quadrats and one relevé have been cleared since they were first established in the study area (see Table 4.1).

Table 4.1: Sites in the study area that have been cleared.

Vegetation Type	Quadrats/Relevés that Have Been Cleared	
	Total Number	Site Name and Reference
C2: EvChAtuGwTErCYpERtTHt	1	YSW01 (Biota 2010a).
C4: EvAciAprAThCEc	1	H051 (Biota 2002).
C5: EvAbAaAmERItTHt	1	YSW19S (Biota 2010a).
F3: ElChAtuAaAbGwTspp	4	YEX07, YEX11, YEX34, YEX-G (Biota 2004a).
H1: ElHcAiGwTsps	6	YEX10, YEX13, YEX18, YEX24, YEX36, YSW13 (Biota 2004a).
H7: ElAprTwTp	1	YVI05 (Biota 2014b).
H11: GpERfTp	1	YSW02 (Biota 2010a).
P1: ElEgAprAbAaAdTwTpTsps	2	YEX05 (Biota 2004a), YVI04 (Biota 2014b).
P2: ChAprAiAsclApaTp	3	YEX14 (Biota 2004a), YBI26 (Biota 2009a), YAQ29 (Biota 2014c).
P3: AprAciAiAsclTlo	1	HDA14 (Biota 2004b).
P4: AprAsyAiTw	5	HDA07, HDA15 (Biota 2004b), YEX03, YEX32 (Biota 2004a), YBI19 (Biota 2009a).
P5: ElEgAbAaTb	2	HDA12 (Biota 2004b),YEX33 (Biota 2004a).
P6: AapERfoERI/g	2	YEX09, YEX12 (Biota 2004a).
P9: ChEgAiAaAprPcTb	2	YEX31, YEX33 (Biota 2004a).
Total	32	

The remaining 86% of the study area represents intact vegetation that ranged from Excellent to Very Poor condition (see Appendix 6). The main disturbance factors in the study area were weed invasion and disturbance from livestock (cattle) including grazing, tracks, trampled vegetation and scats. It was noted during some of the surveys (e.g. Biota 2004a, 2014a) that some areas of hills and slopes were burnt. Fire is a natural process in the Pilbara region and natural fire regimes are not considered as part of the overall assessment of vegetation condition.

Dense weed infestations and high cattle activity were generally restricted to the creeklines and floodplains of the study area (Sections 4.1.1 and 4.1.2). **Cenchrus ciliaris* (Buffel Grass; Plate 4.1) was the most prolific weed in these habitats, sometimes occurring together with **C. setiger* (Birdwood Grass). **Cenchrus* species were present as a continuous population along the edges of Weeli Wolli and Marillana Creeks and on some adjacent floodplains. Where the **Cenchrus* formed a closed tussock grassland, a low number of native species was recorded in the understorey. Given the aggressive, invasive nature of these grasses, it is probable that the

abundance of **Cenchrus* species will increase over time in areas of suitable habitat, and these weed populations may also spread to surrounding areas. Dispersal may be aided by factors such as flowing water, cattle activity, and clearing for tracks and other infrastructure; all of which are already present in the study area.

Several other weed species were found in the creeklines of the study area, but these were usually present as scattered individuals only (see Section 5.6 for more information on the weeds in the study area). While most creekline and floodplain vegetation types were rated as being in Very Good to Good condition, some parts of vegetation types C4 and F2 were rated as Very Poor due to the high weed cover (greater than 70% cover) and evidence of extensive grazing and trampling by cattle (Plate 4.2).

Plate 4.1: **Cenchrus ciliaris*, the most prolific weed species in the study area.

Plate 4.2: Creekline vegetation in the study area with a dense **Cenchrus ciliaris* understorey grazed by cattle.

The hills, ridges and breakaways of the study area (Section 4.1.3) were mostly in Excellent condition and free from any form of disturbance. However, some vegetation types (H7, H9 and H10) contained occasional individuals of **Cenchrus ciliaris,* which had dispersed from nearby creekline or floodplain areas; these resulted in scaling down of the condition rating to Very Good or Good.

The plains of the study area (Section 4.1.4) also contained some weed species, which again did not usually occur as dense populations. Occasionally a very open tussock grassland of **Cenchrus ciliaris* was present, usually on plains adjacent to creeklines or floodplains. Evidence of cattle was also occasionally noted on the plains. The condition of the majority of the vegetation of the plains therefore ranged from Good to Excellent. Vegetation type P3 was generally in Very Good condition except for some parts that were rated as Poor due to a higher level of weed invasion.

4.4 Results of Floristic Clustering Analysis

There was a reasonable correspondence between the floristic groups identified through the PRIMER analyses and the vegetation types described for the study area, although these were not exact. This is as expected, given that floristic composition of vegetation varies along a continuum, while the classification of sample sites into vegetation types is an attempt to impose a framework of distinct groups incorporating vegetation structure.

The floristic analyses based on only the perennial species resulted in the closest match to the described vegetation sub-associations, as would be expected given that the latter were defined primarily on the abundance of the dominant species, which tended to be perennials. Figure 1 in Appendix 8 shows the similarity of sites from the study area based on the percent cover of perennial species only.

In the analysis of the total dataset, the sites from the current study area clustered with other sites from the broader locality on the basis of their floristic composition (see Figure 2 in Appendix 8). This was true whether all species or only perennial species were considered, and whether percent foliar cover or only presence / absence data were used, although the actual site clusters frequently changed (compare Figures 2 and 3 in Appendix 8).

Overall, sites from the current study area were most similar to sites from the nearby Koodaideri and Southern Flank/Jinidi-Mindi areas, and least similar to the more distant sites from West Angelas and the Bellbird to Juna Downs area (Figure 3 in Appendix 8). The degree of geographic patterning evident is relatively high, when it is considered that the dataset spans only a 100 km radius around the current study area. Similar fine-scale geographic patterns have been observed elsewhere in the Pilbara (M. Maier, Biota, pers. obs.).

As expected, the underlying landform was strongly linked to floristic composition (Figure 4 in Appendix 8). Sites located on stony hills (vegetation codes with an "H" prefix) tended to cluster separately on the basis of their floristic composition from sites in major creeks (vegetation codes with a "C" prefix; see Appendix 3). Sites on stony plains (vegetation codes with a "P" prefix) and in minor drainages and on floodplains (vegetation codes with an "F" prefix) were more variable floristically, being distributed between these two broad groupings (Figure 4 in Appendix 8). This is as expected, given that the topographic position of the plains landform is intermediate between the hills and drainages; and that water availability, which strongly influences the species present, declines markedly along this gradient.

Figure 5 in Appendix 8 shows the NMDS plot based on percent foliar cover of perennial species only for the entire dataset. This shows again the clear patterning evident for some vegetation types, particularly C1-C5, H1-H3 and P5-P6, although sites in these vegetation types were frequently spread across more than one floristic group.

At a nominal 30% level of similarity, several floristic groups contained sites only from the current study area when the percent foliar cover data of perennial species were considered (groups z, at, az, bc, bd and be; see Table 1 in Appendix 8). However, only one such group was evident when presence/absence data were considered (group h; Table 1 in Appendix 8), and this group contained an entirely different site. Different groupings were again evident when annual and perennial species were considered together (Table 1 in Appendix 8). This means that there were no floristic groups at the 30% level containing only sites from the study area that were supported by all of the analyses, and thus none of the floristic groups are considered likely to be restricted to the study area.

4.5 Vegetation of Conservation Significance

4.5.1 Threatened Ecological Communities and Priority Ecological Communities

Threatened Ecological Communities (TECs) are described by the Department of Parks and Wildlife as "biological (flora or fauna) assemblages occurring in a particular habitat, which are under threat of modification or destruction from various processes" (DEC 2010a). TECs listed by the Department of Parks and Wildlife are significant at the State level and are protected as Environmentally Sensitive Areas under the WA *Environmental Protection Act 1986*.

Two TECs are listed for the Pilbara bioregion: the '*Themeda* grasslands on cracking clays (Hamersley Station, Pilbara)' and the 'Ethel Gorge aquifer stygobiont community' (Department of Parks and Wildlife 2014a). Twenty-three of the 69 TECs listed in Western Australia are also nationally recognised and listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act). These do not include either of the two TECs listed for the Pilbara bioregion. The Ethel Gorge stygobiont TEC is approximately 77 km southeast of the study area, while the nearest area of the *Themeda* grasslands TEC is approximately 140 km northwest. Neither TEC is therefore relevant to the study area.

Priority Ecological Communities (PECs) include possible TECs that do not meet survey criteria or are not adequately defined (DEC 2010a). These are added to the Department of Parks and Wildlife's PEC list under Priorities 1 (highest priority), 2 and 3. Ecological Communities that are: 1) adequately known; 2) are rare but not threatened, or meet criteria for Near Threatened; or 3) have been recently removed from the threatened list, are placed in Priority 4. Conservation dependent ecological communities are placed in Priority 5.

Thirty PECs are listed for the Pilbara bioregion (Department of Parks and Wildlife 2014b). The nearest PECs to the study area are the Priority 1 'Weeli Wolli Spring community', located approximately 7 km to the south; and two sand dunes supporting the Priority 3 'Vegetation of sand dunes of the Hamersley Range/Fortescue Valley' PEC, one located approximately 5 km to the east and the other 5 km to the northwest of the study area. In addition, the Priority 1 'Fortescue Marsh (Marsh Land System)' PEC occurs in the broader locality; the marsh itself is located approximately 27 km north of the study area, and is surrounded by fringing vegetation. None of these mapped occurrences of PECs would be directly impacted by the proposed development.

None of the vegetation units defined for the study area represent TECs listed under either the Commonwealth EPBC Act or the WA *Environmental Protection Act 1986,* nor do they represent PECs listed by the Department of Parks and Wildlife.

4.5.2 Other Communities of Local Conservation Significance

The then Department of Conservation and Land Management listed TECs and also compiled a list of other "ecosystems at risk" as part of the biodiversity audit of each IBRA subregion (May and McKenzie 2003). When the PEC listing process was subsequently established, the ecosystems at risk in each subregion that were considered to be of the highest conservation significance were then listed under this process.

One ecosystem at risk identified for the Hamersley and Fortescue Plains subregions of the Pilbara bioregion (see Kendrick 2003a, 2003b) is relevant to the study area:

- 'All major ephemeral water courses' in the Hamersley subregion were listed as an ecosystem at risk by Kendrick (2003a). These water courses were described as supporting "*Eucalyptus* forests with a shrubby understorey", which were considered to be under threat of degradation from weed invasion and grazing and trampling by feral herbivores (Kendrick 2003a).

This ecosystem at risk was not subsequently identified as a PEC by the Department of Parks and Wildlife, however significant drainages are widely recognised as being of importance to the functioning of the local ecosystem. Groundwater drawdown could also potentially impact such vegetation if it includes phreatophytic flora, which are species that are primarily or totally reliant on groundwater to meet their physiological water requirements. It is generally accepted that the common Pilbara riparian species *Melaleuca argentea* and *Eucalyptus camaldulensis* are phreatophytic (Thorburn et al. 1993, O'Grady et al. 2005). *Melaleuca argentea,* in particular, occurs only where there is water permanently at or near the ground surface (within 5 m; Ecosystems Research Group 2012). In contrast, *Eucalyptus camaldulensis* appears to utilise surface water when available, with greater proportions of groundwater used in drier months of the year (see for example Halpern Glick Maunsell 2000b). It should be noted that discharge of dewatering water may also promote the growth or recruitment of phreatophytic species.

Five vegetation types comprising a total of 2,313 ha (11.9%) of the study area have been mapped as riparian vegetation associated with Marillana Creek and Weeli Wolli Creek, which are two of the major ephemeral creek systems for the locality. These creek systems are at risk of degradation from a variety of factors, including development, groundwater drawdown, frequent fires, grazing and weed invasion. Four of the five riparian vegetation units have been identified as being of local conservation significance (Table 4.2).

Two of the riparian vegetation types (C1 and C4) comprised woodlands associated with Marillana Creek and Weeli Wolli Creek. With regards to the two woodland vegetation types:

- Vegetation type C1 was in Good condition; although several weed species were recorded, there were no dense infestations that could have an impact on native flora diversity. This vegetation also supported both *Melaleuca argentea* and *Eucalyptus camaldulensis*, two species that could be affected by groundwater drawdown (and also potentially discharge) from the adjacent mining operations. Similar vegetation to unit C1 is widespread in major creek systems through the Pilbara, including the Robe River, Hardey River, Caves Creek/Duck Creek and Marillana Creek/Weeli Wolli Creek systems. This vegetation is therefore considered significant at a local, rather than regional, scale.
- While vegetation type C4 also occurred in the major creeklines of the study area (mainly on the broad floodplains of Weeli Wolli and Marillana Creek), it has been extensively degraded by the invasion of **Cenchrus ciliaris* (often together with **C. setiger*) in the understorey and the condition was rated as Good to Very Poor. This vegetation has therefore already been substantially impacted by the processes threatening riparian vegetation, and is not considered to be of particular conservation significance.

Three other vegetation types (C2, C3 and C5) comprised riparian vegetation along these same major creek systems, but featured only scattered trees of *Eucalyptus victrix*. These vegetation types did not typically support the phreatophytic species present in C1, but were in Good to Very Good condition, with **Cenchrus* spp. generally present only as scattered individuals rather than a continuous understorey. Similar vegetation assemblages are widespread in major creek systems through the Pilbara including tributaries of the Beasley River, and in the Caves Creek/Duck Creek, Hardey River and Marillana Creek/Weeli Wolli Creek systems. These vegetation types are thus again considered significant at a local, rather than regional, scale.

Table 4.2: Riparian vegetation types in the study area.

Vegetation Code	Vegetation Description	Area (ha)	Percentage of the Study Area
Woodlands of *Eucalyptus camaldulensis, E. victrix* or *Melaleuca argentea*			
C1: EcEvMaMgAc (local significance)	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland	318.1	1.6%
C4: EvAciAprAThCEc (degraded by Buffel Grass invasion)	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland	1,395.5	7.2%
Scattered trees of *Eucalyptus victrix*			
C2: EvChAtuGwTErCYpERItTHt (local significance)	*Eucalyptus victrix, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* subsp. *hispidula* tall shrubland over *Tephrosia rosea* low shrubland over *Cymbopogon ambiguus*, *C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	191.8	1.0%
C3: EvAciAcMgCEc (local significance)	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	381.6	2.0%
C5: EvAbAaAmERItTHt (local significance)	*Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	26.0	0.1%
	Total	2,313 ha	11.9%

4.5.3 Other Conservation Values

All of the habitats in the study area are widespread in the locality, and none of the vegetation types appear to be restricted in distribution on the basis of their floristic composition (see Section 4.4).

The remaining vegetation types in the study area are therefore considered to be of low conservation significance, being representative of the vegetation occurring in similar habitats throughout the local area. This is not meant to imply that the vegetation in the study area is of no conservation value, as all intact native vegetation is inherently valuable (DEWHA 2010).

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5.0 Flora of the Study Area

5.1 Overview

A total of 548 native vascular flora taxa from 173 genera and 53 families were recorded from the study area, based on all survey effort to date. This includes one Threatened species (discussed in Section 5.4) and five Priority flora species (discussed in Section 5.4.2). A total of 36 introduced flora species were also recorded (see Section 5.6). A list of all species recorded in the study area, and in each individual survey area, is provided in Appendix 5.

Table 5.1 presents the total number of species in various taxonomic groups for each survey area. These totals represent flora recorded from each individual survey conducted previously in the current study area. Where only a portion of the survey area overlapped the current study area, only the relevant subset of the total species recorded is presented. Species lists were reviewed and taxa have been updated to reflect current taxonomy as necessary.

Table 5.1: Total number of vascular plant families, genera and species recorded in the study area.

Category	Total for Component Survey Areas												Study Area Total
	Biota (2014a)	Biota (2014b)	Biota (2014c)	Biota (2011a)	Biota (2010a)	Biota (2009a)	Biota (2009b)	Biota (2005)	Biota (2004a)	Biota (2004b)	Biota (2002)	HGM (2000)	
Native Species	454	321	289	74	YOX: 206 YSW: 264	244	201	116	319	194	69	16	548
Genera	154	136	124	37	YOX: 103 YSW: 121	108	95	57	138	94	57	12	173
Families	47	46	45	23	YOX: 39 YSW: 44	40	39	30	48	33	24	9	53
Threatened Flora Species	1	1	0	0	YOX: 1 YSW: 0	0	1	0	0	0	0	0	1
Priority Flora Species	2	2	0	1	YOX: 0 YSW: 1	0	0	0	2	0	0	0	5
Weed Species	18	17	12	1	YOX: 12 YSW: 11	6	10	1	14	11	3	0	36

5.2 Dominant Families and Genera

The dominant families and genera (native taxa only) recorded from the study area are presented in Table 5.10. These are typical of the most well represented families and genera in the Pilbara bioregion.

Table 5.2: Dominant plant families and genera in the study area.

Family	No. of Native Taxa	Genus	No. of Native Taxa
Fabaceae	114	*Acacia*	51
Poaceae	90	*Senna*	24
Malvaceae	59	*Sida*	16
Asteraceae	28	*Euphorbia*	15
Amaranthaceae	24	*Ptilotus*	14

5.3 Species Richness – Regional Context

Species richness tends to vary on a logarithmic scale with the size of the survey area. However, the array of habitats (and therefore vegetation types) present also has a large influence on the number and type of species recorded, as different habitats provide a greater variety of ecological niches that can be occupied by a greater number of different species. The shape of the survey area may also influence the number of species recorded, with long linear survey areas tending to intersect a greater variety of habitats and, depending on the length, sometimes different biogeographic regions.

Figure 5.1 plots the number of vascular flora species against the area surveyed for the overall Yandi integration study area, as well as the main component survey areas at Yandi[8]. Five other flora and vegetation surveys in the Pilbara region are also plotted to provide a comparison: Western Turner Syncline (Biota 2013), Koodaideri Mining Lease (Biota 2012c), Koodaideri Northern Extension Area (Biota 2012d), Koodaideri Southern Infrastructure Corridor (Biota 2012e) and Southern Flank to Jinidi Rail Corridor (Biota 2012b).

When compared to the other survey areas, the total number of native flora in the individual component survey areas within Yandi are in the range expected for areas of similar size in this locality (this includes the Yandi PBS survey area of Biota 2014a). The species richness of the overall Yandi integration study area is slightly higher, but still within the range expected for a survey area of that size; this is probably due to the larger number of habitats and high level of survey effort in this area.

8 Species richness from Biota (2002, 2004b) and Halpern Glick Maunsell (2000a) not shown, as only a small portion of these survey areas overlaps the current study area.

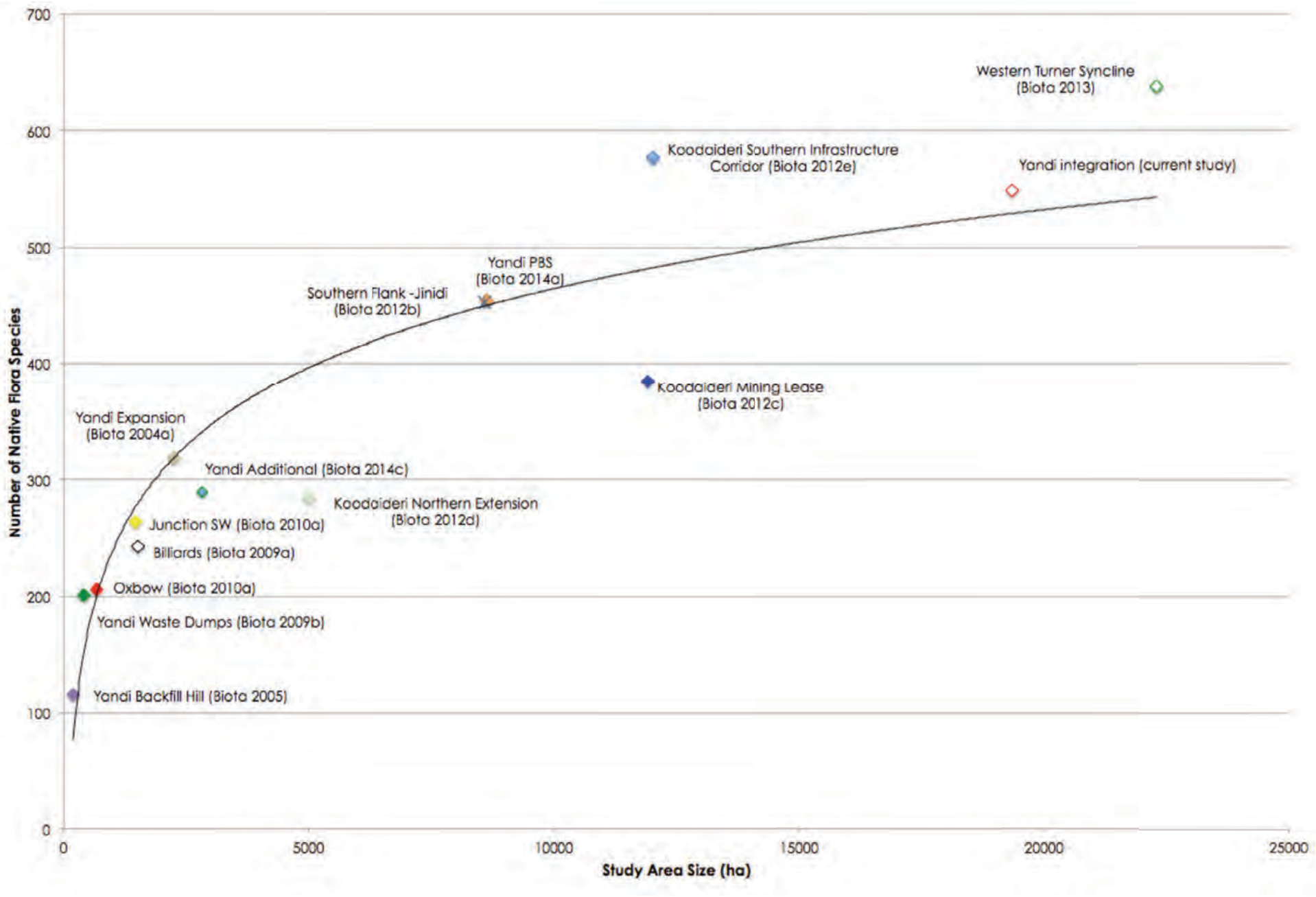

Figure 5.1: The number of native taxa recorded from the different surveys completed in the Yandi study area compared to other surveys in the locality.

Table 5.3: Threatened and Priority flora species occurring in the study area.

Species	Source Survey and Number of Records													Total No. of Records
	Biota (2014a)	Biota (2014b)	Biota (2014c)	Biota (2011a)	Biota (2010a)	Biota (2009a)	Biota (2009b)	Biota (2005)	Biota (2004a)	Biota (2004b)	Biota (2002)	HGM (2000a)	Other	
Threatened														
Lepidium catapycnon (Hamersley Lepidium)	26	1	1	0	1	0	1	0	0	0	0	0	51	81
Priority 3														
Rostellularia adscendens var. *latifolia*	0	2	0	0	0	0	0	0	0	0	0	0	1	3
Sida sp. Barlee Range (S. van Leeuwen 1642)	2	0	0	0	0	0	0	0	1	0	0	0	0	3
Themeda sp. Hamersley Station (M.E. Trudgen 11431)	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Priority 4														
Goodenia nuda	9	10	0	1	1	0	0	0	0	0	0	0	0	22
Rhynchosia bungarensis	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Total No. of Conservation Significant Species	3	3	1	1	2	0	1	0	2	0	0	0	3	111

5.4 Flora of Conservation Significance

A combined total of six species of conservation significance were recorded from the study area (Table 5.3). These comprise one Threatened species, *Lepidium catapycnon* (see Section 5.4.1), and five species of Priority flora (see Section 5.4.2).

In addition, three vascular flora taxa are potentially of some conservation interest. These species are discussed briefly in Section 5.4.3.

5.4.1 Threatened Flora

Three Threatened flora species (*Aluta quadrata, Lepidium catapycnon* and *Thryptomene wittweri*) are known from the Pilbara bioregion. *Lepidium catapycnon* and *Thryptomene wittweri* are listed as Threatened flora under the Commonwealth EPBC Act as well as the WA *Wildlife Conservation Act 1950*. *Aluta quadrata* has only recently been listed in WA (State of Western Australia 2012) and is currently only recognised as Threatened under the *Wildlife Conservation Act 1950.*

It should be noted that *Lepidium catapycnon* has been proposed to be removed from the State Threatened flora listing for a number of years, due to the relatively large number of populations that have been identified. The Department of Parks and Wildlife has apparently recently nominated this species to the WA Threatened Species Scientific Committee for delisting, however the results of this nomination are not yet known (J. Naaykens, Rio Tinto, pers. comm. 2015).

With regards to these three Threatened species:

- *Thryptomene wittweri* would not occur in the study area as no suitable habitat is present (mountains greater than 1,000 m elevation).
- *Aluta quadrata* is restricted to the southern flanks of the range of hills around Paraburdoo and, given its localised distribution, would not occur in the study area.
- *Lepidium catapycnon* (Hamersley Lepidium) has been recorded from the study area.

Lepidium catapycnon (Hamersley Lepidium) is a woody perennial herb to low shrub, which typically occurs in hummock grasslands on skeletal soils on the slopes of low to moderate-sized stony hills (Plate 5.1), occasionally extending onto the surrounding stony plains. It is frequently recorded in association with the Newman land system. This relatively short-lived species is often recorded from areas that have been recently disturbed, apparently persisting for only a few years.

Lepidium catapycnon was recorded from 81 locations in the study area, forming 11 separate populations[9] (Table 5.4). Over 4,211 individuals have been found in the study area to date (the number of individuals was not supplied for some records, and these are not included in the total). Locations are displayed on the vegetation mapping in Appendix 4.

All *Lepidium catapycnon* populations were located on the hills and slopes of the study area. Most populations (all except Populations 5 and 8) were associated with vegetation type H1, which typically occurred on a rocky, shale-covered surface (Plate 5.1). Populations 5 and 8 were located in vegetation types H6 and H2 respectively. Two of the records of *L. catapycnon* made from Population 5 were from an area that had been disturbed, and several records from Populations 3 were from hillslopes that were recently burnt (within 2-3 years; Plate 5.2). As noted previously, both fire and ground disturbance appear to promote recruitment in this species. While both adult and juvenile plants were noted in Populations 3 and 4, a higher proportion of juvenile plants were noted in Population 3 than in Population 4, where the fire age was estimated at 4-5 years (Biota 2014a). Two of the older records of *L. catapycnon* were revisited during a later survey but were not able to be found (see Table 5.4). It is possible that these populations have senesced after a period of years where no recruitment had occurred.

9 Plants more than 500 m from a known population were considered to be a new population (as per DEC 2010b).

Plate 5.1: A mature *Lepidium catapycnon* plant (left) and its preferred habitat of stony hillslopes with a shale surface (right).

Plate 5.2: Location of *Lepidium catapycnon* recorded by Biota (2010a, 2014b) at the base of the powerline tower (left), and a recently burnt hillslope within the *L. catapycnon* Population 3 (right).

Lepidium catapycnon occurs over a broad range through the Pilbara, extending from northwest of Tom Price across to Newman (Department of Parks and Wildlife 2014c). Over 30 populations are known, including one population in the conservation estate of the Karijini National Park, and some of these populations number in the hundreds to over a thousand individuals (M. Maier, Biota, pers. obs.). The 11 populations recorded in the study area are located within the known range of the species. The populations within the study area would therefore not be considered to be of regional significance, and would be unlikely to be of local significance.

Based on the vegetation mapped for the study area, considerable additional suitable habitat for *Lepidium catapycnon* occurs in the study area, not all of which has been searched. It is therefore possible that this species occurs at other locations within the study area. All hills and slopes of the study area (vegetation types H1-H11; totalling 9,074.6 ha) could potentially comprise suitable habitat for *L. catapycnon*, especially areas that have been burnt recently or have rocky ironstone shale slopes. However, most populations were recorded in vegetation type H1 and this vegetation type (2,840.3 ha) remains the most prospective unit for this species. Given the nature of the Channel Iron Deposits, the majority of the Yandi development would likely occur in the valleys and drainage areas rather than on the hilltops and slopes.

Table 5.4: All records of the Threatened species, *Lepidium catapycnon*, located in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	No. of Individuals
Population 1	Biota (2009b)	7-Sep-08	733172	7475074	171 †
	Biota (2014a)	10-Jul-14	733185	7475117	3
	Rio Tinto (2014a)	14-Aug-14	733576	7475131	1
		14-Aug-14	733586	7475137	2
		14-Aug-14	733586	7475148	1
		14-Aug-14	733586	7475153	2
		14-Aug-14	733586	7475152	1
		14-Aug-14	733580	7475148	1
		14-Aug-14	733580	7475147	1
		14-Aug-14	733564	7475141	6
		14-Aug-14	733598	7475176	3
		14-Aug-14	733167	7475500	22
		14-Aug-14	733333	7475573	1
		14-Aug-14	733342	7475579	1
		14-Aug-14	733861	7475659	21
		14-Aug-14	733850	7475672	3
		14-Aug-14	733657	7475773	1
		14-Aug-14	733641	7476283	9
		14-Aug-14	733668	7476299	39
		14-Aug-14	734250	7476289	31
		14-Aug-14	733564	7475134	1
		14-Aug-14	733567	7475135	2
Population 2	Hamersley Iron (2006)	Not supplied	732596	7470785	Not supplied †
Population 3	Biota (2014a)	8-Jul-14	733334	7470806	50
		8-Jul-14	733363	7470663	1
		8-Jul-14	733370	7470785	23
		8-Jul-14	733373	7470723	10
		8-Jul-14	733373	7470739	3
		8-Jul-14	733373	7470762	33
		8-Jul-14	733374	7470867	10
		8-Jul-14	733390	7470691	20
		10-Jul-14	733399	7470826	24
		10-Jul-14	733776	7470609	17
		9-Jul-14	733911	7470603	27
		9-Jul-14	733928	7470625	18
		10-Jul-14	733942	7470609	32
		9-Jul-14	733947	7470645	80
		9-Jul-14	733947	7470675	50
		10-Jul-14	733968	7470690	27
Population 4	Biota (2014a)	14-Jul-14	735843	7473347	30
		14-Jul-14	735870	7473373	5
		14-Jul-14	735946	7473354	1
		14-Jul-14	735962	7473331	10
		14-Jul-14	736005	7473311	85
		14-Jul-14	736038	7473307	72
		14-Jul-14	736060	7473302	13
		14-Jul-14	736141	7473312	111
		14-Jul-14	736176	7473323	22
	Rio Tinto (2014a)	Not supplied	736039	7473306	Not supplied
		Not supplied	736129	7473331	Not supplied
		Not supplied	736131	7473304	Not supplied
		Not supplied	736162	7473317	Not supplied
Population 5	Biota (2010a, 2014b)	29-Jul-08	720262	7477224	1
	Opportunistic records made by Mr E. Thoma, Rio Tinto (no report)	17-Oct-12	720263	7477221	1
		17-Oct-12	720314	7477152	23
Population 6	Biota (2014c) (opportunistic record made outside the survey area for that report)	14-Jun-12	732031	7481987	1
Population 7	Rio Tinto (2014b)	20-Feb-14	724302	7478477	1

Population	Source	Date	Easting (mE)	Northing (mN)	No. of Individuals
	Hamersley Iron (2002)	Not supplied	724313	7478495	40
	Hamersley Iron (2003a)	Not supplied	724316	7478448	Not supplied
Population 8	Rio Tinto (2003)	Not supplied	727334	7478420	91
		Not supplied	727266	7478488	127
	Hamersley Iron (2003b)	Not supplied	727350	7478429	Not supplied
		Not supplied	727284	7478500	Not supplied
	Hamersley Iron (2003a)	Not supplied	727332	7478415	Not supplied
		Not supplied	727265	7478481	Not supplied
Population 9	Biota (2005)	Not supplied	727961	7478265	Not supplied
	Hamersley Iron (2005)	Not supplied	727934	7478396	200
		Not supplied	727905	7478370	200
		Not supplied	728018	7478385	200
		Not supplied	728029	7478375	200
		Not supplied	728006	7478400	200
		Not supplied	727990	7478276	200
		Not supplied	727920	7478339	200
		Not supplied	727933	7478261	200
		Not supplied	727975	7478327	200
		Not supplied	728051	7478272	200
		Not supplied	727964	7478378	200
		Not supplied	728021	7478331	200
		Not supplied	727996	7478397	200
		Not supplied	728043	7478356	200

† Population not found in 2014 during the PBS survey.

5.4.2 Priority Flora

The previous surveys have recorded five Priority flora species from the study area. These are described briefly below:

- *Rostellularia adscendens* var. *latifolia* (Priority 3)
  This herb to low shrub with purple-violet flowers (Plate 5.3) occurs in a broad range of habitats, but is most frequently recorded in drainage areas and low-lying areas on plains (Department of Parks and Wildlife 2014c). Two populations of this species totalling 13 individuals were recorded in the study area (Table 5.5). Population 1 was recorded approximately 60 m north of Marillana Creek, but this location has since been cleared for the JSW mine. Population 2 occurred on the floodplain of a major tributary of Marillana Creek (vegetation type F1).

  Table 5.5: All records of *Rostellularia adscendens* var. *latifolia* (Priority 3) in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	No. of Individuals
Population 1	Rio Tinto rare flora survey	10-Mar-02	724687	7479780	2
Population 2	Biota (2014b)	01-Mar-12	718797	7478505	10
		02-Mar-12	718790	7478459	1

  This taxon has a broad distribution across the Pilbara (over 400 km, extending from the Brockman locality to the Oakover River), with five populations known from Karijini National Park (Department of Parks and Wildlife 2014c). Several records of *Rostellularia adscendens* var. *latifolia* were made during a recent survey on a floodplain of Marillana Creek to the north of the YOX development, just outside the study area (Biota 2014e). Given that there are several records in the Yandi locality and that the study area lies within the broad range of this species, these populations are not considered to be either regionally or locally significant.

  It is possible that additional populations occur in the study area. The most prospective vegetation for this species would be vegetation type F1 (418.4 ha) and vegetation type F2 (314.6 ha).

- *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3)
  This spreading shrub (Plate 5.4) grows to 0.5 m tall and produces yellow flowers in August. It typically occurs on steep slopes with red skeletal soils and exposed rock, often in gorges and gullies. Two populations of this species were recorded in the study area (Table 5.6). Population 1 was recorded from the bank of Marillana Creek, in between the YJC and JSW developments. This location has since been cleared for a haul road. The two other records were made south of the proposed PBS development from a rocky ridgeline (vegetation type H5). The first record, of three individuals, was located near the southern boundary of the study area. The second record, of two individuals, was made approximately 10 m outside the study area boundary. At both of these locations, the plants were growing out of the side of a free face at the top of a steep, shale-covered hillslope.

Table 5.6: All records of *Sida* sp. Barlee Range (S. van Leeuwen 1642) in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	No. of Individuals
Population 1	Biota (2004a)	02-Sep-04	731037	7478616	Not supplied
Population 2	Biota (2014a)	09-Jul-14	733697	7470558	3
		09-Jul-14	733720	7470548	2¥

¥ NB. 10 m south of the study area boundary.

Sida sp. Barlee Range (S. van Leeuwen 1642) is known from a number of locations throughout the Hamersley Range, extending over a range of approximately 250 km from Brockman to 36 km southeast at Coondiner Creek (Department of Parks and Wildlife 2014c). Numerous additional locations have been recorded approximately 30 km northwest at Koodaideri (Biota 2012a). The hills of the study area would contain considerable areas of suitable habitat and the low number of records of this species from the study area is likely a reflection of survey effort rather than an actual indication of this species' distribution. The individuals recorded from the study area would be unlikely to be considered regionally or locally significant.

The preferred habitat for *Sida* sp. Barlee Range (S. van Leeuwen 1642) comprises exposed rock in gullies and gorges, and vegetation type H5 (27.6 ha) and vegetation type H9 (13.8 ha) are therefore considered to represent the most prospective vegetation types to support further populations of this species in the study area.

Plate 5.3: *Rostellularia adscendens* var. *latifolia* (photo not from study area).

Plate 5.4: *Sida* sp. Barlee Range (S. van Leeuwen 1642) growing out of a rocky free face in the study area.

- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3)
  This tussock grass (Plate 5.5) grows to 1.8 m tall and is typically associated with red clay pans where it may form dense grasslands, however there are occasional records of small populations or isolated individuals from creeks and floodplains. It differs from the more common and widespread *Themeda triandra* by its larger size, sturdier culms and pale bluish colouring (*T. triandra* has yellowish colouring). One record of this species has been made in the study area (Table 5.8) from vegetation type P2, approximately 160 m north of Marillana Creek in between the YJC and JSW developments.

Table 5.7: All records of *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	No. of Individuals
Population 1	Biota (2004a)	02-Sep-04	731034	7479113	Not supplied

Themeda sp. Hamersley Station (M.E. Trudgen 11431) has a broad distribution over the Pilbara region. It has been recorded near Karratha and as far south as West Angelas, with dense grasslands occurring on the plains of Hamersley Station. Records have also been made in the Millstream-Chichester and Karijini National Parks (Department of Parks and Wildlife 2014c). The study area is located within the known range of this species. While only one record has been made in the study area, several populations are known from Koodaideri (Biota 2012e), which is situated to the north of Yandi. This record of *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) from the study area is therefore unlikely to be regionally or locally significant.

It is possible that additional isolated individuals of this species may occur in the study area. Floodplains such as vegetation units F1 (414.8 ha) and F2 (314.6 ha) or plains adjacent to Marillana and Weeli Wolli Creek would provide the most prospective habitats for this species.

- *Goodenia nuda* (Priority 4)

This erect to ascending, slender herb (Plate 5.6) grows to 50 cm tall, with yellow flowers and narrow, pale green glaucous leaves (Department of Parks and Wildlife 2014c). This species is typically found growing near creeklines and in wet areas. A total of 154 individuals from 11 separate populations were recorded from the study area (Table 5.8). *Goodenia nuda* was recorded in the east of the study area from Mulga woodlands (vegetation type P6; Populations 7, 8, 10 and 11) and plains (vegetation types P2 and P3; Population 9 and six individuals from population 7) located adjacent to Weeli Wolli and Marillana creeks. Two records were made in the JSW area; two records north of the JSW development in a tributary of Marillana Creek (vegetation types C2 and F1; Population 2) and the other record on a floodplain south of Marillana Creek (vegetation type F1; Population 1). The remaining records (Populations 3, 4, 5 and 6) were from the YOX area from a floodplain along a tributary of Marillana Creek (vegetation type F1).

Table 5.8: All records of *Goodenia nuda* in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	Number of Individuals
Population 1	Biota (2010a)	01-Aug-08	725105	7479657	Unknown
Population 2	Biota (2011a)	30-Nov-10	725630	7483464	4
Population 3	Biota (2014b)	01-Mar-12	718797	7478505	50
		02-Mar-12	718793	7478356	1
Population 4	Biota (2014b)	02-Mar-12	718374	7477952	5
		02-Mar-12	718389	7477939	4
		02-Mar-12	718463	7477854	1
		02-Mar-12	718553	7477896	1
Population 5	Biota (2014b)	02-Mar-12	718051	7477266	1
		02-Mar-12	718015	7477266	8
Population 6	Biota (2014b)	02-Mar-12	717409	7477045	2
		02-Mar-12	717380	7477017	1
Population 7	Biota (2014a)	18-Mar-14	737054	7477706	6
		18-Mar-14	737185	7477606	2
		18-Mar-14	737185	7477540	26
		18-Mar-14	737274	7477733	1
Population 8	Biota (2014a)	15-Mar-14	736668	7477105	8
		16-Mar-14	736668	7477149	23
Population 9	Biota (2014a)	16-Mar-14	734166	7478025	4
Population 10	Biota (2014a)	17-Mar-14	735517	7475188	1
Population 11	Biota (2014a)	16-Mar-14	734807	7474388	5

Goodenia nuda has a broad distribution; most records occur over a range of approximately 500 km through the Pilbara bioregion, from Mardie Station on the coast to the eastern section of the Fortescue Valley (Department of Parks and Wildlife 2014c). Populations are known from Karijini and Millstream-Chichester National Parks. There is also an outlying record from the Canning Stock Route in the Gascoyne bioregion (Department of Parks and Wildlife 2014c).

Given the known range and the number of populations that occur in the study area, the records of *Goodenia nuda* are not considered to be regionally or locally significant.

It is possible that additional populations of this species occur in the study area. A large number of individuals are already known from the study area and this species is a small, often inconspicuous, herb. It would particularly be expected to occur on floodplains such as vegetation types F1 (414.8 ha) and F2 (314.6 ha). While F1 is the most prospective vegetation type for this species, it could also be found on the banks of creeklines or on plains.

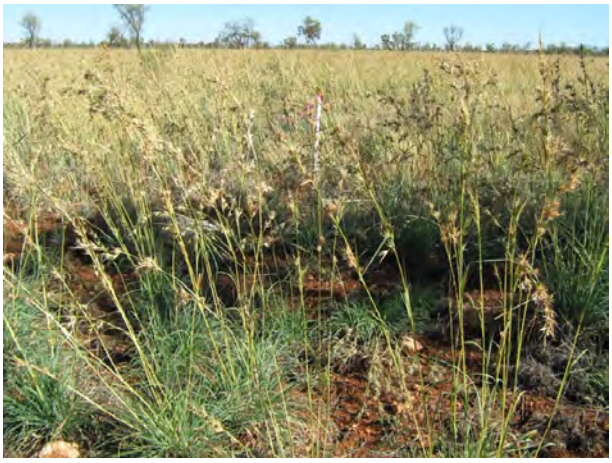

Plate 5.5: *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (photo not from the study area).

Plate 5.6: *Goodenia nuda* inflorescence (photo not from the study area).

- *Rhynchosia bungarensis* (Priority 4)

This compact, prostrate creeper to low shrub (Plate 5.7) grows to 50 cm in height and has very resinous trifoliate leaves (Department of Parks and Wildlife 2014c). It has been recorded growing in pebbly, shingly coarse sand amongst boulders, in flowlines, on floodplains and in rocky gullies. One population was recorded in the study area, however the number of individuals was not provided (Table 5.9). The first location was in a small remnant of vegetation type P5 adjacent to the YJC development. The second location in the YJC development has since been cleared for a haul road.

Table 5.9: All records of *Rhynchosia bungarensis* in the study area.

Population	Source	Date	Easting (mE)	Northing (mN)	Number of Individuals
Population 1	Hamersley Iron (2003c)	Not supplied	728416	7480090	Unknown
		Not supplied	728557	7480244	Unknown

Rhynchosia bungarensis is known from a number of locations and has a broad distribution across the Pilbara. Populations are known from Karijini, Millstream-Chichester, Barlee Range and Cape Range National Parks. The population recorded in the study area is on the eastern edge of this species range. Several populations (together totalling 1,000+ individuals) have also been recorded from Koodaideri, which is situated to the north of Yandi (Biota 2012a). The population of *Rhynchosia bungarensis* in the study area is therefore not considered to be regionally or locally significant.

It is possible that additional populations occur in the study area, with the most prospective habitats for this species being the rocky beds of moderate-sized creeklines supporting vegetation types C2 (191.8 ha), C4 (1,395.5 ha) and C5 (26.0 ha) and gorges supporting vegetation types such as H9 (13.8 ha).

Plate 5.7: *Rhynchosia bungarensis* (photo not from the study area).

Although no records are known, one additional Priority flora species may potentially occur in the study area:

- *Stylidium weeliwolli* (Priority 2)
  This annual herb grows to 25 cm tall and produces pink flowers between August and September. This species has a relatively broad range through the Pilbara and Gascoyne bioregions, extending over more than 330 km, but is only infrequently recorded. This is probably partly due to its small and delicate stature, and also a reflection of the habitats in which it occurs (on floodplains, in seasonally damp or wet areas including root mats of *Melaleuca*, and in seepages around granite rocks). In the Pilbara, this species occurs mainly along major watercourses.

  There are two records of *Stylidium weeliwolli* from the Yandi locality: from a tributary of Marillana Creek (approximately 1.3 km from the western end of the study area), and from the vicinity of Weeli Wolli Springs in Weeli Wolli Creek (the closest record is approximately 9 km upstream of the study area). As these records are in close proximity and are located upstream in the respective creek systems, it is considered possible that this species occurs in the study area, with the most prospective habitat being the wetter parts of Marillana Creek and Weeli Wolli Creek (vegetation type C1). The small size and annual nature of this herb makes it difficult to locate, and further survey effort (systematic searches through prospective habitat) under optimal conditions would be required to determine whether this species does in fact occur.

5.4.3 Other Flora of Conservation Significance

Three flora taxa of interest were recorded from the study area. These are described briefly below:

- *Eulalia* sp. (Three Rivers Station, B. Forsyth AQ6789133)
  This currently undescribed species of *Eulalia* (Plate 5.8) was recorded from four locations within the study area (Biota 2014a, 2014c) including two records from a plain (vegetation type P2), one record from a floodplain (vegetation type F1) and one record from a minor creekline (vegetation type F4). Dr. Ken Tinley first collected this species in 2008 on Three Rivers Homestead (approximately 290 km south of Yandi) and the phrase name *Eulalia* sp. (Three Rivers Station) was applied (Bryan Simon, Queensland Herbarium, pers. comm. 2012). *Eulalia* sp. (Three Rivers Station) differs from the common *Eulalia* species occurring in the Pilbara (*E. aurea*) by its broader leaves, elongated rhizomes and the inflorescences remaining closed at maturity (Simon and Alfonso 2012). Currently, the phrase name is not recognised on FloraBase or Australia's Virtual Herbarium, however a formal description of *Eulalia* sp. (Three Rivers Station) is being progressed by Rachel Butler (Biota) and Mr. Malcolm Trudgen (M.E. Trudgen and Associates).

  This species has a broad range extending over approximately 380 km from the Pilbara to the Gascoyne bioregion, and it has been recorded from other surveys in the locality including at West Angelas (Biota 2014f) and Koodaideri (Biota 2012a). It is likely that this taxon has been under-collected given its similarity to *Eulalia aurea*. The populations in the study area are therefore unlikely to be considered either regionally or locally significant.

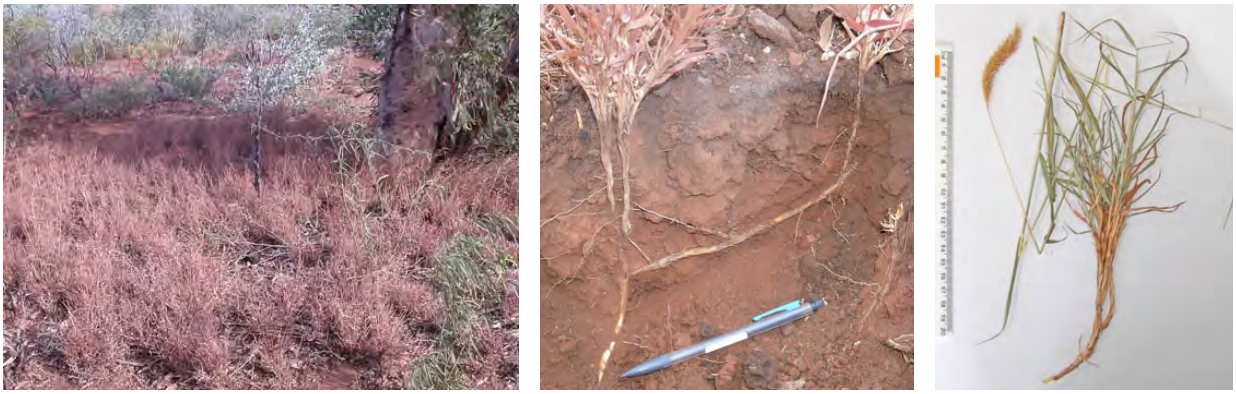

Plate 5.8: *Eulalia* sp. (Three Rivers Station, B. Forsyth AQ6789133): growth form, underground rhizome and pressed specimen.

- *Glycine* sp. aff. *arenaria*
  This creeper with apparent affinities to *Glycine arenaria* was collected from a single site in Marillana Creek (vegetation type C1), in between the YJC and the JSW developments (Biota 2014b). This taxon was identified by Malcolm Trudgen (M.E. Trudgen and Associates), who described it as uncommon in the Pilbara. To date, no specimens of *G. arenaria* have been vouchered from outside the Northern Kimberley. The voucher specimen collected by Biota was submitted to the WA Herbarium for lodgement in February 2013, but is believed to be still awaiting incorporation to the collection. This record may be regionally significant, however this cannot be determined until the taxonomy of this specimen is resolved.
- *Goodenia nuda/triodiophila*
  Two collections that could not be confidently identified as being either *Goodenia triodiophila* or the Priority 4 species *Goodenia nuda* (see Section 5.4.2) were recorded from a floodplain along a tributary of Marillana Creek near the YOX development (vegetation type F1). The two specimens collected represented a population of 33 individuals. Both of these collections were determined as unresolved by Malcolm Trudgen and have been submitted to the WA Herbarium for lodgement. The difficulty in identifying these specimens is most likely due to the poor quality of the material and even if they do represent the Priority 4 *Goodenia nuda*, they are unlikely to be locally or regionally significant records (see Section 5.4.2).

5.5 Poorly Collected, Variable or Incompletely Resolved Taxa

Some apparent range extensions were recorded, which are considered likely to represent poorly collected taxa (*Euphorbia australis* var. *australis, Glycine* sp. aff. *arenaria, Heliotropium glabellum Peripleura hispidula* var. *hispidula* and *Sida* sp. A. Kimberley Flora (P.A. Fryxell &L.A. Craven 3900); see Appendix 7). In addition, some variable taxa that were distinguished with informal names in previous reporting are referred to in this document as single entities but with the suffix “sens. lat.”, meaning ‘in the broad sense’ (see Appendix 7). Two taxa (*Portulaca oleracea/intraterranea* and *Sorghum plumosum* var. *plumosum*) recorded from the study area have not been conclusively resolved due to a lack of taxonomic framework (see Appendix 7). None of these taxa are currently considered to be of conservation significance.

5.6 Introduced Flora Species (Weeds)

A total of 36 introduced flora species have been recorded from the study area to date. This includes the 22 species recorded from the component vegetation and flora surveys (see Section 3.1) and an additional 14 species that were recorded during other surveys (i.e. records from Rio Tinto’s database of introduced flora).

Table 5.10 presents the total number of locations from which each weed was recorded. These locations are mapped in Appendix 6. Weeds were most densely distributed around areas of development and disturbance, and also along creeklines and floodplains in the study area. These records are indicative only, as the entire area was not searched, thus resulting in an

underestimation of the actual weed presence in the area. It is noteworthy that some of these locations have subsequently been cleared. Descriptions of each weed species and co-ordinates for each weed record are provided in the individual survey reports.

None of the weeds recorded are listed as Weeds of National Significance (Thorp and Lynch 2000)[10]. However, **Argemone ochroleuca* (Mexican Poppy) is listed under the WA *Biosecurity and Agriculture Management Act 2007* (the BAM Act) as a declared pest for the whole of WA in category C3 (management).

The Department of Parks and Wildlife currently applies an alternative ranking system to weed species within each management region, called the Weed Prioritisation Process (Department of Parks and Wildlife 2013). None of the weed species recorded in the study area are ranked as Very High or High management priorities for the Pilbara region. However, it should be noted that for some species (e.g. **Cenchrus* spp.), this is a result of their low feasibility of control, rather than a reflection of their perceived invasiveness.

Ricinus communis* is listed as an 'Alert' species, meaning that while it is known from the Pilbara region it does not occur on land managed by the Department of Parks and Wildlife (Department of Parks and Wildlife 2013). While the management priority of **Acetosa vesicaria* is ranked by the Department of Parks and Wildlife (2013) as Medium, most other species recorded in the study area are ranked as Low or Negligible. It is noted that further assessment is required to rank **Chloris virgata.* Several species that are uncommon or not known from the Pilbara (Catharanthus roseus, Lactuca serriola, *Sonchus asper, *Lotus sp., *Oxalis corniculata, *Cenchrus clandestinus, *Paspalum dilatatum* and **Typha orientalis*) had no ranking.

[10] For the current listing of Weeds of National Significance, go to http://www.weeds.org.au/WoNS/

Table 5.10: Introduced species recorded from the study area.

Species (Common Name)	Source Survey and Number of Locations													Total No. of Locations
	Biota (2014a)	Biota (2014b)	Biota (2014c)	Biota (2011a)	Biota (2010a)	Biota (2009a)	Biota (2009b)	Biota (2005)	Biota (2004a)	Biota (2004b)	Biota (2002)	HGM (2000a)	Rio Tinto Database	
Family: Amaranthaceae														
**Aerva javanica* (Kapok)	11	0	5	0	0	1	0	0	0	0	0	0	88	105
**Alternanthera pungens* (Khaki Weed)	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Family: Apocynaceae														
**Catharanthus roseus* (Pink Periwinkle)	0	0	0	0	0	0	0	0	0	0	0	0	5	5
Family: Asteraceae														
**Bidens bipinnata* (Bipinnate Beggartick)	12	9	1	0	5	4	0	0	4	3	0	0	83	121
**Conyza bonariensis* (Flaxleaf Fleabane)	0	0	0	0	2	0	1	0	2	0	0	0	48	53
**Flaveria trinervia* (Speedy Weed)	2	5	0	0	3	2	0	0	7	1	0	0	14	34
**Lactuca serriola* (Prickly Lettuce)	0	0	0	0	0	0	0	0	0	0	0	0	6	6
**Sigesbeckia orientalis* (Indian Weed)	1	0	0	0	1	0	0	0	0	1	0	0	1	4
**Sonchus asper* (Rough Sowthistle)	0	0	0	0	0	0	0	0	0	0	0	0	7	7
**Sonchus oleraceus* (Common Sowthistle)	0	1	1	0	0	2	1	0	3	1	0	0	127	136
**Tridax procumbens* (Tridax)	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Family: Brassicaceae														
**Sisymbrium irio* (London Rocket)	0	0	0	0	0	0	0	0	2	0	0	0	0	2
**Sisymbrium orientale* (Indian Hedge Mustard)	0	0	0	0	1	1	1	0	0	0	0	0	8	11
Family: Cucurbitaceae														
**Citrullus lanatus* (Pie Melon)	0	0	0	0	0	0	0	0	0	0	0	0	5	5
**Citrullus* aff. *lanatus*	0	1	0	0	0	0	0	0	0	0	0	0	0	1
**Citrullus colocynthis*	0	0	0	0	1	0	0	0	0	0	0	0	44	45
Family: Euphorbiaceae														
**Euphorbia hirta* (Asthma Plant)	0	0	0	0	0	0	0	0	0	0	0	0	66	66
**Ricinus communis* (Castor Oil Plant)	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Family: Fabaceae														
**Lotus* sp.	0	0	0	0	0	0	0	0	0	0	0	0	2	2
**Vachellia farnesiana* (Mimosa Bush)	1	2	3	0	5	1	1	0	2	1	0	0	59	75
Family: Malvaceae														
**Malvastrum americanum* (Spiked Malvastrum)	8	1	4	0	6	16	1	0	13	4	0	0	113	166

Species (Common Name)	Source Survey and Number of Locations													Total No. of Locations
	Biota (2014a)	Biota (2014b)	Biota (2014c)	Biota (2011a)	Biota (2010a)	Biota (2009a)	Biota (2009b)	Biota (2005)	Biota (2004a)	Biota (2004b)	Biota (2002)	HGM (2000a)	Rio Tinto Database	
Family: Oxalidaceae														
**Oxalis corniculata* (Yellow Wood Sorrel)	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Family: Papaveraceae														
**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)	0	0	4	0	2	3	1	0	5	0	0	0	63	78
Family: Poaceae														
**Cenchrus ciliaris* (Buffel Grass)	76	7	23	9	12	29	3	1	18	6	2	0	491	677
**Cenchrus clandestinus* (Kikuyu Grass)	0	0	0	0	0	0	0	0	0	0	0	0	1	1
**Cenchrus setiger* (Birdwood Grass)	28	0	6	0	0	13	0	0	0	1	2	0	72	122
**Chloris barbata* (Purpletop Chloris)	0	0	0	0	0	0	0	0	0	0	0	0	86	86
**Chloris virgata* (Feathertop Rhodes Grass)	0	0	0	0	0	0	1	0	0	0	0	0	12	13
**Cynodon dactylon* (Couch Grass)	0	1	0	0	0	0	0	0	1	0	0	0	29	31
**Paspalum dilatatum*	0	0	0	0	0	0	0	0	0	0	0	0	1	1
**Setaria verticillata* (Whorled Pigeon Grass)	12	3	2	0	7	10	1	0	4	2	2	0	34	77
Family: Polygonaceae														
**Acetosa vesicaria* (Ruby Dock)	0	0	0	0	3	0	3	0	2	0	0	0	149	157
Family: Solanaceae														
**Datura leichhardtii* (Native Thornapple)	0	0	0	0	0	0	0	0	2	2	0	0	1	5
**Solanum nigrum* (Black Berry Nightshade)	0	0	0	0	2	1	1	0	3	0	0	0	27	34
Family: Typhaceae														
**Typha orientalis* (Bulrush)	0	0	0	0	0	0	0	0	0	0	0	0	16	16
Family: Zygophyllaceae														
**Tribulus terrestris* (Caltrop)	9	0	0	0	1	0	0	0	0	1	0	0	7	18
Total No. of Weed Species	10	9	9	1	14	12	11	1	14	11	3	0	34	

6.0 Key Findings and Discussion

6.1 Survey Effort

A large proportion (63%) of the Yandi Integration study area has been surveyed for vegetation and flora values at a detailed level. An additional 15% of the study area has been subject to historical vegetation and flora surveys, however the flora data associated with these surveys were not provided in the relevant reports and could therefore not be used as part of this study. The broad level at which these vegetation types were described, coupled with the absence of any flora data to verify the units, prevented the integration of this vegetation mapping with the more recent surveys. Consequently, this mapping is not discussed in detail or presented in this report. These areas, together with the 8% of the study area that remains unsurveyed, were mapped as a desktop exercise using aerial photography and information extrapolated from adjacent mapping. The resulting vegetation mapping should be viewed as indicative only (refer to Figure 4.1) and would need to be ground-truthed and validated with flora sampling sites.

A total of 209 quadrats and 35 relevés have been sampled in the study area to date. All vegetation types were sampled by at least one flora site, and all but four vegetation types (H8, H9, H10 and H11) were sampled by two or more flora sites. Quadrats were more numerous around the newer development areas (YJC, YSW and YOX) and the proposed PBS deposit.

Seasonal sampling of quadrats is a requirement for a Level 2 flora and vegetation survey as per EPA (2004). It has been acknowledged that a 'High' level of satisfaction can be reached from resampling a proportion of quadrats (approximately 25–50%) if the initial survey was completed under appropriate seasonal conditions (EPA and DEC 2012, p. 123). Seasonally sampled quadrats were completed for the Billiards/PBS, JSW and YOX survey areas, however no quadrats were resampled for the Yandi Expansion survey, located in the centre of the study area near the existing YJC. A subset of 83 (40%) of the total number of quadrats were seasonally sampled. The proportion of quadrats resampled was higher for the more recent surveys (e.g. approximately 56% of quadrats were resampled within the PBS survey area). Further discussion of the proposed PBS development is provided in Section 6.4.

6.2 Vegetation of Conservation Significance

A total of 30 vegetation types have been described for the study area, none of which represent TECs or PECs. This is considered to be within the range expected for a study area of this size in this locality, taking into account the habitats present and the scale at which the vegetation mapping was completed. None of the vegetation types are considered to be restricted to the study area.

Four riparian vegetation types (C1, C2, C3 and C5) are considered to be of local conservation significance: these were all associated with Marillana Creek and Weeli Wolli Creek, which are major ephemeral water courses for the locality. Vegetation type C1 comprised a woodland of riparian Eucalypts with scattered stands of *Melaleuca argentea*. Although creeklines are susceptible to weed invasion and disturbance from grazing herbivores, this vegetation type was in Good condition, with only scattered weeds and limited disturbance from cattle. Due to the presence of two phreatophytic tree species (*Eucalyptus camaldulensis* and *Melaleuca argentea*) as dominant species, vegetation type C1 would be most susceptible to changes in groundwater depth causes by dewatering and discharge associated with below water table mining. Vegetation types C2, C3 and C5 were dominated by only scattered trees of *Eucalyptus victrix,* but were similarly in Good to Very Good condition. Similar vegetation assemblages are widespread throughout the Pilbara in several major creek systems, and these vegetation types would therefore be of significance at the local, rather than regional, scale.

A total of 2,770 ha (approximately 14%) of the study area was mapped as Disturbed. The vegetation in the remaining sections of the study area was ranked between Excellent and Very Poor condition. The main disturbance factor noted was invasion by weeds. Most weed species occurred as

scattered individuals, however **Cenchrus ciliaris* (sometimes together with **C. setiger*) formed dense populations causing degradation in some creeklines and floodplains. Cattle were present in the study area but were generally restricted to creekline and floodplain habitat. Some damage caused by grazing and trampling was noted, and this was more prevalent in the vegetation that was extensively invaded by **Cenchrus* spp.

Two vegetation types associated with Weeli Wolli Creek and Marillana Creek were degraded by these disturbances, comprising vegetation types C4 (rated Good to Very Poor) and F2 (rated Poor to Very Poor). All other vegetation types in the study area have inherent value as relatively intact and good quality examples of native vegetation, but are not considered to have any elevated conservation value beyond this.

6.3 Flora of Conservation Significance

A total of 548 native flora species have been recorded from the study area. This total is in the range expected for a study area of this size in this locality.

One Threatened flora species, *Lepidium catapycnon* (Hamersley Lepidium), has been recorded. This species was recorded from 81 locations on the hills and slopes of the study area (vegetation types H1, H2 and H6), comprising a total of 4,211 individuals in nine separate populations. All hills and slopes of the study area could provide potential suitable habitat for further populations of this species, however as most populations occurred in vegetation type H1 (2,840.3 ha), this is considered the most prospective habitat for this species. The two other Threatened species listed for the Pilbara (*Aluta quadrata* and *Thryptomene wittweri*) would not occur in the study area due to a lack of suitable habitat and their relatively restricted distributions in the Pilbara (south-facing gullies near Paraburdoo, and the crests and upper slopes of a mountain in Karijini National park, respectively).

Five Priority flora species have been recorded from the study area:

- *Rostellularia adscendens* var. *latifolia* (Priority 3) was recorded from three locations on a floodplain (vegetation type F1), comprising two populations with a total of 13 individuals. One of these populations (of two individuals) has since been cleared.
- *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) was recorded from three locations, comprising two populations with a total of five individuals. One population was recorded from the bank of Marillana Creek, which has now been cleared (the number of individuals in this population was not recorded). The remaining population was recorded from a rocky ridgeline (vegetation type H5).
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3) was recorded from one location on a plain adjacent to Marillana Creek (vegetation type P2); the number of individuals was not recorded.
- *Goodenia nuda* (Priority 4) was recorded from 21 locations from floodplains (vegetation type F1), creeklines (vegetation type C2) and plains (vegetation type P6, P2 and P3). A total of 154 individuals were recorded from 11 separate populations.
- *Rhynchosia bungarensis* (Priority 4) was recorded from two locations forming one population in vegetation type P5; the number of individuals was not recorded. One of these locations has since been cleared.

One other Priority species, *Stylidium weeliwolli* (Priority 2), could potentially occur in the study area. This delicate ephemeral herb could potentially occur in vegetation type C1 along Marillana Creek and Weeli Wolli Creek, although it has not been recorded to date. This species typically occurs in permanent or seasonally wet areas, but would only be recorded under optimal conditions. There are two records of this species from the Yandi locality, with the closest being 1.3 km upstream of the study area.

The remainder of the species recorded for the study area are considered to be typical for this part of the Pilbara region. The flora of the study area is therefore representative of the locality.

A total of 36 weed species were recorded in the study area. None of the weeds recorded are listed as Weeds of National Significance (Thorp and Lynch 2000). However, **Argemone ochroleuca* (Mexican Poppy) is listed under the BAM Act as a declared pest for the whole of WA in category C3 (management). **Cenchrus ciliaris* (often together with **C. setiger*) was the most prolific weed in the study area and formed dense infestations in some floodplains and creeklines.

6.4 Proposed PBS Development

A Level 2 vegetation and flora survey has been completed in the Billiards area for the proposed PBS development (see Figure 2.1; details of this survey are provided in Biota (2014a)). These vegetation and flora data form part of a wider dataset, which has been compiled from several vegetation and flora surveys that have been completed in the Yandi integration study area. The main findings of the PBS survey can be placed into a better context when viewed as part of the overall Yandi study area.

In general, the vegetation and flora values found within the PBS survey area are consistent with the wider dataset for the Yandi integration study area. Most vegetation types and vascular flora species recorded in the PBS area have also been recorded in the other survey areas at Yandi (see Sections 4.1 and 5.1). The species richness of the PBS survey area is within the range expected for a survey area of this size in the locality, and is comparable to the other survey areas within the Yandi study area (see Section 5.3).

The two Priority flora that occur in the PBS survey area, *Sida* sp. Barlee Range (S. van Leeuwen 1642) (Priority 3) and *Goodenia nuda* (Priority 4), have both been recorded from other locations in the Yandi integration study area. The populations in the area would not be expected to represent regionally or locally significant populations (see Section 5.4.2).

Four populations of the Threatened species, *Lepidium catapycnon,* are currently known to occur in the PBS survey area (Populations 1 to 4), two of which are located in proposed preliminary waste dump locations (Biota 2014a). No *L. catapycnon* individuals are currently located within the proposed PBS pit. An additional five *L. catapycnon* populations occur outside the proposed PBS development area, with nine populations in total occurring in the Yandi integration study area. The number of individuals within the PBS development area is relatively low compared to the wider Yandi area (a total of 1,097 individuals occur in the PBS development area, compared with 3,085 individuals outside the PBS development area in the wider Yandi integration study area). There are also a large number of records of this species from the broader locality and some of the populations comprise hundreds to over a thousand individuals (see Section 5.4).

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7.0 Glossary and Acronyms

*	Used prior to a species name to denote a weed species.
Alluvial	Loose, unconsolidated (not cemented together into a solid rock) soil or sediments, which have been eroded, reshaped by water in some form, and redeposited in a non-marine setting.
Anabranching	An anabranching river consists of multiple channels separated by vegetated (sometimes semi-permanent) alluvial islands.
Annual (plant)	A plant that lives for only one year.
BAM Act	The WA *Biosecurity and Agriculture Management Act 2007.*
Conservation Significant	A plant that is recognised to be rare, unusual, new or poorly sampled; may have a formally assigned conservation ranking (see Appendix 1 for more on the WA conservation framework).
Culm	The stem of a grass or sedge.
EPA	Environmental Protection Authority of Western Australia.
EPBC Act	The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*
Ephemeral	A plant that lives a very short time; less than one year, usually less than six months.
Floodout	An area of land, usually adjacent to a river or major drainage system, that receives water during periods of overbank flow associated with normal or extreme flood events. Can be situated at the end of the drainage line.
Flora keys	Botanical publications containing a series of questions regarding the characteristics of plants, aiding in the identification of different taxa.
Foot Traverse	Consists of walking through an area to confirm or note vegetation boundaries or to search for flora (usually sampling a narrow corridor/cross section of vegetation).
Free face	A vertical or near vertical landform element situated part way up a slope but not comprising the entire slope.
GIS	Geographic Information System.
GPS	Global Positioning System.
PEC	Priority Ecological Community (see Appendix 1 for more on the WA conservation framework).
Perennial	A plant that lives for more than two growing seasons.
Phreatophytic	A species that is primarily or totally reliant on groundwater to meet its physiological water requirements.
Priority flora	Flora species listed by the Department of Parks and Wildlife as requiring additional information to properly evaluate their conservation significance; see Appendix 1 for more on the WA conservation framework.
sens. lat.	Abbreviation of *sensu lato* (Latin), meaning “in the broad sense”.
sp. (plural: spp.)	Abbreviation of “species”.
Stratum (plural: strata)	A horizontal level of vegetation defined by growth form (and sometimes height); e.g. low trees, tall trees, tussock grasses, hummock grasses.
subsp.	Abbreviation of “subspecies”.
Taxon (plural: taxa)	A taxonomic entity, typically at species level or below.
TEC	Threatened Ecological Community (see Appendix 1 for more on the WA conservation framework).

Threatened flora	Flora species protected by legislation, either listed under the Commonwealth EPBC Act or the WA *Wildlife Conservation Act 1950* (species formerly known as Declared Rare Flora); see Appendix 1 for more on the WA conservation framework.
var.	Abbreviation of “variety”.

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Appendix 1

Framework for Conservation Significance Ranking of Communities and Species in WA

A. Definitions, Categories and Criteria for Threatened and Priority Ecological Communities

1. General Definitions

Ecological Community
A naturally occurring biological assemblage that occurs in a particular type of habitat.

Note: The scale at which ecological communities are defined will often depend on the level of detail in the information source, therefore no particular scale is specified.

A threatened ecological community (TEC) is one which is found to fit into one of the following categories; "presumed totally destroyed", "critically endangered", "endangered" or "vulnerable".

Possible threatened ecological communities that do not meet survey criteria are added to DPaW's Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

An assemblage is a defined group of biological entities.

Habitat is defined as the areas in which an organism and/or assemblage of organisms lives. It includes the abiotic factors (e.g. substrate and topography), and the biotic factors.

Occurrence: a discrete example of an ecological community, separated from other examples of the same community by more than 20 metres of a different ecological community, an artificial surface or a totally destroyed community.

By ensuring that every discrete occurrence is recognised and recorded future changes in status can be readily monitored.

Adequately Surveyed is defined as follows:
"An ecological community that has been searched for thoroughly in most likely habitats, by relevant experts."

Community structure is defined as follows:
"The spatial organisation, construction and arrangement of the biological elements comprising a biological assemblage" (e.g. *Eucalyptus salmonophloia* woodland over scattered small shrubs over dense herbs; structure in a faunal assemblage could refer to trophic structure, e.g. dominance by feeders on detritus as distinct from feeders on live plants).

Definitions of Modification and Destruction of an ecological community:

Modification: "changes to some or all of ecological processes (including abiotic processes such as hydrology), species composition and community structure as a direct or indirect result of human activities. The level of damage involved could be ameliorated naturally or by human intervention."

Destruction: "modification such that reestablishment of ecological processes, species composition and community structure within the range of variability exhibited by the original community is unlikely within the foreseeable future even with positive human intervention."

Note: Modification and destruction are difficult concepts to quantify, and their application will be determined by scientific judgement. Examples of modification and total destruction are cited below:

Modification of ecological processes: The hydrology of Toolibin Lake has been altered by clearing of the catchment such that death of some of the original flora has occurred due to dependence on fresh water. The system may be bought back to a semblance of the original state by redirecting saline runoff and pumping waters of the rising underground watertable away to restore the hydrological balance. Total destruction of downstream lakes has occurred due to hydrology being altered to the point that few of the original flora or fauna species are able to tolerate the level of salinity and/or water logging.

Modification of structure: The understorey of a plant community may be altered by weed invasion due to nutrient enrichment by addition of fertiliser. Should the additional nutrients be removed from the system the balance may be restored, and the original plant species better able to compete. Total destruction may occur if additional nutrients continue to be added to the system causing the understorey to be completely replaced by weed species, and death of overstorey species due to inability to tolerate high nutrient levels.

Modification of species composition: Pollution may cause alteration of the invertebrate species present in a freshwater lake. Removal of pollutants may allow the return of the original inhabitant species. Addition of

residual highly toxic substances may cause permanent changes to water quality, and total destruction of the community.

Threatening processes are defined as follows:
"Any process or activity that threatens to destroy or significantly modify the ecological community and/or affect the continuing evolutionary processes within any ecological community."

Examples of some of the continuing threatening processes in Western Australia include: general pollution; competition, predation and change induced in ecological communities as a result of introduced animals; competition and displacement of native plants by introduced species; hydrological changes; inappropriate fire regimes; diseases resulting from introduced micro-organisms; direct human exploitation and disturbance of ecological communities.

Restoration is defined as returning an ecological community to its pre-disturbance or natural state in terms of abiotic conditions, community structure and species composition.

Rehabilitation is defined as the re-establishment of ecological attributes in a damaged ecological community although the community will remain modified.

2. Definitions and Criteria for Presumed Totally Destroyed, Critically Endangered, Endangered and Vulnerable Ecological Communities

ECOLOGICAL COMMUNITIES

Presumed Totally Destroyed (PD)
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future.

An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant and either of the following applies (A or B):

A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats or

B) All occurrences recorded within the last 50 years have since been destroyed

Critically Endangered (CR)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated.

An ecological community will be listed as Critically Endangered when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting any one or more of the following criteria (A, B or C):

A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% and either or both of the following apply (i or ii):

   i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years);

   ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated.

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

   i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years);

   ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes;

   iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes.

C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

Endangered (EN)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as Endangered when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement and either or both of the following apply (i or ii):

   i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

   ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, and one or more of the following apply (i, ii or iii):

   i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

   ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

   iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

Vulnerable (VU)
An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as Vulnerable when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting any one or more of the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

3. Definitions and Criteria for Priority Ecological Communities

PRIORITY ECOLOGICAL COMMUNITY LIST
Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. These three categories are ranked in order of priority for survey and/or definition of the community, and evaluation of conservation status, so that consideration can be given to their declaration as threatened ecological communities. Ecological Communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Priority One: Poorly-known ecological communities
Ecological communities with apparently few, small occurrences, all or most not actively managed for conservation (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) and for which current threats exist. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.

Priority Two: Poorly-known ecological communities
Communities that are known from few small occurrences, all or most of which are actively managed for conservation (e.g. within national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc.) and not under imminent threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.

Priority Three: Poorly known ecological communities

(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or:

(ii) communities known from a few widespread occurrences, which are either large or within significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or;

(iii) communities made up of large, and/or widespread occurrences, that may or not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes.

Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.

Priority Four: Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring.

(a) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands.

(b) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.

(c) Ecological communities that have been removed from the list of threatened communities during the past five years.

Priority Five: Conservation Dependent ecological communities
Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Department of Parks and Wildlife

CONSERVATION CODES

for Western Australian Flora and Fauna

T: **Threatened species -** Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.

X: **Presumed extinct species -** Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora (which may also be referred to as Declared Rare Flora).

Species* which have been adequately searched for and there is no reasonable doubt that the last individual has died, and have been gazetted as such.

IA: **Migratory birds protected under an international agreement -** Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Birds that are subject to an agreement between governments of Australia and Japan, China and The Republic of Korea relating to the protection of migratory birds and birds in danger of extinction.

S: **Other specially protected fauna -** Specially protected under the *Wildlife Conservation Act 1950,* listed under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Threatened Fauna and Flora are further recognised by the Department according to their level of threat using IUCN Red List criteria. For example Carnaby's Cockatoo *Calyptorynchus latirostris* is specially protected under the *Wildlife Conservation Act 1950* as a threatened species with a ranking of endangered.

Ranking:

CR: Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.

EN: Endangered – considered to be facing a very high risk of extinction in the wild.

VU: Vulnerable - considered to be facing a high risk of extinction in the wild.

A list of the current rankings can be downloaded from the Listing of species and ecological communities webpage http://dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/84-listing-of-species-and-ecological-communities .

Species that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Species that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Conservation Dependent species are placed in Priority 5.

1: Priority One: Poorly-known species

Species that are known from one or a few collections or sight records (generally less than five), all on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, Shire, rail reserves and Main Roads WA road, gravel and soil reserves, and active mineral leases and under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes.

2: Priority Two: Poorly-known species

Species that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc. Species may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes.

3: Priority Three: Poorly-known species

Species that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them.

4: Priority Four: Rare, Near Threatened and other species in need of monitoring

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.
(b) Near Threatened. Species that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.
(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

5: Priority Five: Conservation Dependent species

Species that are not threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

*Species includes all taxa (plural of taxon - a classificatory group of any taxonomic rank, e.g. a family, genus, species or any infraspecific category i.e. subspecies, variety or forma).

Appendix 2

Vegetation Structural Classes and Condition Scale

Vegetation Structural Classes*

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970):

- Aplin T.E.H. (1979). The Flora. Chapter 3 In O'Brien, B.J. (ed.) (1979). *Environment and Science*. University of Western Australia Press;
- Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum*, Suppl. No. 3;
- Specht R.L. (1970). Vegetation. In: *The Australian Environment*. 4th edn (Ed. G.W. Leeper). Melbourne.

Vegetation Condition Scale*

E = Excellent (=Pristine of BushForever) Pristine or nearly so; no obvious signs of damage caused by the activities of European man.
VG = Very Good (= Excellent of BushForever) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Sonchus oleraceus* or **Citrullus* spp., or occasional vehicle tracks.
G = Good (= Very Good of BushForever) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Cenchrus* spp.
P = Poor (= Good of BushForever) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Cenchrus* spp.
VP = Very Poor (= Degraded of BushForever) Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species such as **Prosopis* spp.
D = Completely Degraded (= Completely Degraded of BushForever) Areas that are completely or almost completely without native species in the structure of their vegetation; i.e. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 3

Summary of Vegetation Types Recorded in the Study Area

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
Vegetation of Major Creeklines and Tributaries						
C1: EcEvMaMgAc	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea*¥, *M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland ¥ *M. argentea* was not continuous through this vegetation type but rather occurred as scattered stands.	318.1	Scoured creekbeds and channels in the wetter parts of Marillana and Weeli Wolli Creeks; throughout the study area, except in the northeast.	9 quadrats: OXB06^, YAQ22, YEX16, YEX21, YEX39, YBI23, YBI30S^, YSW08, YVI06.	Very Good to Good.	
C2: EvChAtuGwTErCYpERItTHt	*Eucalyptus victrix,* (*Corymbia hamersleyana*¥) scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon ambiguus, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland ¥ *C. hamersleyana* was a dominant species in tributaries but not in the main channels of Marillana Creek.	191.8	Creekbeds of Marillana Creek, (south of the YJC mine) and major tributaries of Marillana and Weeli Wolli Creeks throughout the study area.	6 quadrats: BIL02^, BIL31^, OXB16^, YEX25, YSW01 (cleared), YVI09.	Very Good to Good.	
C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses	381.6	Anabranching creekbeds found along the main channel of Weeli Wolli Creek and some channels in the eastern parts of Marillana Creek. Also occurred in two major tributaries of Marillana Creek.	4 quadrats: BIL30^, YEX28, YBI01^, YSW04. 2 relevés: YEX-K, YBI-RRWB.	Very Good.	

11 ^ denotes that the quadrat has been seasonally sampled. See Table 3.2 for the study that each site code (BIL, YEX, etc.) relates to.

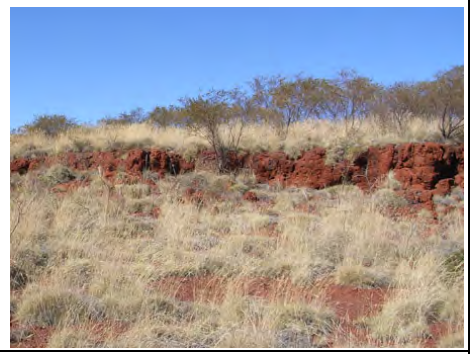
Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland	1,395.5	Creek banks and floodplains of the major channels of Marillana and Weeli Wolli Creeks throughout the study area. Also occurred in two tributaries of Weeli Wolli Creek near the proposed PBS development.	13 quadrats: HAD09^, H050^, H051 (cleared), YAQ12^, YAQ13, YAQ21, YBI02, YBI03, YBI04, YBI08^, YEX02^, YEX17, YEX29. 5 relevés: YAQ-CSRA, YBI-RBMK, YBI-RPHB, YBI-RPHA, YEX-M.	Good to Very Poor.	
C5: EvAbAaAmERltTHt	*Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland	26.0	Several major tributaries feeding into Marillana Creek around the JSW and YJC mines.	2 quadrats: YVI15, YSW19S^.	Very Good.	
Vegetation of Minor Creeklines, Floodplains and Valleys						
F1: ChAtuGwTp	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland	414.8	Floodplains and minor creeklines throughout the study area.	13 quadrats: BIL16^, OXB04^, YAQ03, YAQ05, YAQ20, YBI20^, YBI25, YBI35S^, YSW05, YSW18S^, YVI11, YVI12, YVI13. 3 relevés: BIL-RCFC, BILRSWA, YBIRBME.	Very Good to Good.	

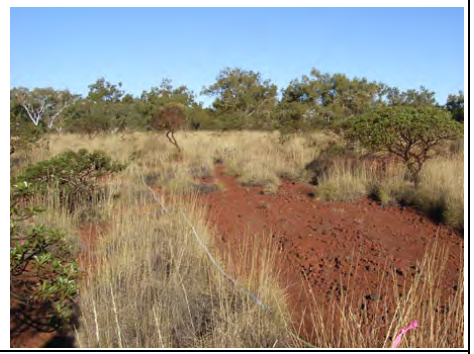
Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
F2: AprAciCEc	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland	314.6	Floodplains and some minor tributaries of Weeli Wolli Creek.	4 quadrats: BIL23^, BIL24^, YAQ30^, YEX38^. 4 relevés: YAQ-CSRC, YAQ-CSRD, YBI-RBMF, YBIRBMH.	Poor to Very Poor.	
F3: ElChAtuAaAbGwTspp	*Eucalyptus leucophloia, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland	260.8	Minor creeklines flowing between low hills. Mainly distributed around the JSW and YJC mines.	7 quadrats: BIL35^, BIL36^, YEX07 (cleared), YEX08^, YEX11 (cleared), YEX26, YEX34 (cleared). 2 relevés: YAQ-RPLA, YEX-G.	Good.	
F4: ChAtuAaPcAtenBONeARh PAmTp	*Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland.	41.7	Occurred north of the proposed PBS development on the west side of Weeli Wolli Creek, on a floodout that was located on a plain and fed by minor creeklines flowing through low hills to the east.	3 quadrats: BIL11^, BIL14, BIL46^.	Very Good.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
F5: ChAciAaAiSENsppTp	*Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland.	31.4	Occurred near the proposed PBS development, east of Weeli Wolli Creek in a small area of floodplains and floodouts.	2 quadrats: BIL21^, BIL47.	Good.	
Vegetation of Hills, Ridges, Gorges and Breakaways						
H1: ElHcAiGwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland	2,840.3	Widespread throughout the study area on elevated hill crests and some rocky hill slopes.	38 quadrats: BIL05, BIL17, BIL19, BIL20, BIL28, BIL34, BIL37, BIL43, OXB01^, OXB05^, OXB10^, OXB11^, YAQ01, YAQ07, YAQ09, YAQ10, YAQ11, YAQ14, YAQ25, YAQ27, YBI18, YBI31S^, YBI33S^, YEX01^, YEX06^, YEX10 (cleared), YEX13 (cleared), YEX18 (cleared), YEX24 (cleared), YEX30, YEX35, YEX36 (cleared), YEX37, YSW03, YSW13, YSW15, YVI07, YVI14. 1 relevé: YVI-RMMA.	Excellent.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
H2: ElAiTwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland	5,841.6	Widespread throughout the study area on rolling stony hills and slopes.	25 quadrats: BIL03, BIL15^, BIL26, BIL27, BIL29, BIL39^, BIL40, BIL44, HDA16, HDA24^, OXB02^, YAQ02, YAQ04, YAQ06, YAQ08, YAQ15, YAQ18, YAQ19, YBI05^, YBI32S^, YBI36^, YSW06^, YSW17S^, YVI01, YVI02. 1 relevé: BIL-RCFA.	Excellent.	
H3: ElGwAarTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland	210.4	Slopes and crests of a range of low stony hills northeast of the proposed PBS development.	2 quadrats: BIL01^, BIL06^. 1 relevé: BIL-RPCA.	Excellent.	
H4: ChAarTspsTw	*Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland	74.3	Crests of two low stony hills northeast of the proposed PBS development.	2 quadrats: BIL04^, YBI24^.	Excellent.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
H5: ElCfERlmTHspp	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis, Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade (M.E. Trudgen 2471), *T. triandra* open tussock grassland	27.6	Found throughout the study area on narrow ridgelines with free face and breakaway slopes.	4 relevés: BIL-RCFB, BIL-RCFD, YEX-F, YEX-J.	Very Good.	
H6: ElAbTw	*Eucalyptus leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland	7.4	Slopes and crests of some hills near the JSW and YOX mines.	2 quadrats: OXB13^, YSW20S^.	Excellent.	
H7: ElAprTwTp	*Eucalyptus leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana, T. pungens* open hummock grassland	32.9	Low stony hills, mainly fringing Marillana Creek near the YOX and JSW mines.	4 quadrats: YSW09, YSW16, YVI05 (cleared), YVI16.	Very Good	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
H8: AmoTspsTw	*Acacia monticola* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* closed hummock grassland	1.2	Recorded from a single area along a breakaway on a hillslope, near Marillana Creek. It has since been dissected by drill lines associated with the JSW mine.	1 quadrat: YSW14.	Excellent.	
H9: ChGOrANlAtuGwTHtCYa	*Corymbia hamersleyana* scattered low trees over *Gossypium robinsonii, Androcalva luteiflora, Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* shrubland over *Themeda triandra, Cymbopogon ambiguus* open tussock grassland	13.8	Recorded in a single gorge southwest of the YOX mine. Also mapped from two other similar-sized gorges (one near the Yandi camp and the other south of the Oxbow deposit), however these areas have not been ground-truthed.	1 quadrat: OXB03.	Very Good.	
H10: AiERfTp	*Acacia inaequilatera* scattered tall shrubs over *Eremophila fraseri* subsp. *fraseri* scattered shrubs over *Triodia pungens* very open hummock grassland	25.0	Located on a single hill adjacent to Marillana Creek, north of the JSE mine.	1 quadrat: YAQ17.	Good.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
H11: GpERfTp	*Grevillea pyramidalis* subsp. *leucadendron, Eremophila fraseri* tall open shrubland over *Triodia pungens* hummock grassland	0.1	Recorded from a single area of low stony hill on the northern side of Marillana Creek, near the JSW mine. The extent of this vegetation has been reduced through clearing for the mine.	1 quadrat: YSW02 (cleared).	Excellent.	
Vegetation of Stony Plains						
P1: ElEgAprAbAaAdTwTpTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland	395.9	Undulating colluvial plains throughout the study area.	11 quadrats: BIL38^, BIL39, OXB03^, OXB09^, YEX05 (cleared), YSW07, YSW11, YSW12, YVI04 (cleared), YVI08, YVI10. 1 relevé: YSW-RBMA.	Excellent to Very Good.	
P2: ChAprAiAsclApaTp	*Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland	1,065.3	Occurred broadly over plains in the eastern half of the study area, fringing the floodplain on the southern side of Marillana Creek and on both sides of Weeli Wolli Creek.	14 quadrats: BIL07^, BIL08, BIL09, BIL10^, YAQ16^, YAQ24, YAQ29, YBI10^, YBI26, YEX14 (cleared), YEX19, YEX20, YEX23, YEX27. 2 relevés: YBI-RBMC, YBI-RBMD.	Good.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
P3: AprAciAiAsclTlo	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland	177.9	Occurred along either side of Weeli Wolli Creek, fringing the floodplains along the central section of the creek.	3 quadrats: HDA14 (cleared), YBI11^, YBI17^. 1 relevé: YBI-RBMJ.	Very Good (some small areas Poor).	
P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland	352.1	Occurred in the southern half of the study area along Weeli Wolli Creek, where it fringed the floodplains on both sides of the creek.	6 quadrats: HDA07 (cleared), HDA15 (cleared), YBI19 (cleared), YEX03 (cleared), YEX04^, YEX32 (cleared). 1 relevé: YAQ-CSRB	Excellent to Good.	
P5: ElEgAbAaTb	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland	1547.2	Occurred broadly over the stony plains of the Billiards area along either side of Weeli Wolli Creek, and also in small areas around the JSW and YJC mines.	18 quadrats: BIL18, BIL33^, HDA12 (cleared), YAQ23^, YBI06^, YBI07^, YBI09^, YBI14, YBI16, YBI21, YBI22, YBI27^, YBI28, YBI29, YBI34S^, YEX15, YEX33 (cleared), WW30. 4 relevés: YBI-RBMA, YBIRBMB, YBI-RROA, YEX-N.	Excellent to Good.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
P6: AapERfoERl/g	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland	144.1	Occurred only in the Billiards area, mainly in narrow stands adjacent to the floodplains along Weeli Wolli Creek; several small patches of this vegetation also occurred on plains and hill crests.	8 quadrats: BIL32^, HDA08^, HDA13, YBI12^, YBI13, YBI15^, YEX09 (cleared), YEX12 (cleared). 2 relevés: BIL-RSPA, YBI-RBMI.	Good.	
P7: ERf/g	*Eremophila fraseri* subsp. *fraseri* open shrubland over mixed very open grassland	35.6	Occurred on three small areas of plain with a calcrete substrate near the proposed PBS development.	2 quadrats: BIL25^, BIL48. 1 relevé: YBI-RBMG.	Good.	
P8: EgAiTs	*Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland	32.4	Gently sloping pediment slopes and colluvial plains at the base of a range of low hills north of the proposed PBS development.	2 quadrats: BIL22^, BIL42^.	Excellent.	

Vegetation Code	Vegetation Description	Area (ha)	Distribution	Flora Sampling Sites[11]	Vegetation Condition	Photograph
P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland	380.1	Occurred broadly over the plains on the western side of Weeli Wolli Creek, north of Marillana Creek.	6 quadrats: BIL12^, BIL13, BIL41^, BIL45^, YEX31 (cleared), YEX33 (cleared).	Very Good.	

Appendix 4

Vegetation Mapping and Locations of Conservation Significant Flora

Vegetation of Yandi Billiards Integrated

Vegetation of Major Creeklines and Tributaries

C1: EcEvMaMgAc	*Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* woodland over *Melaleuca argentea, M. glomerata, Acacia coriacea* subsp. *pendens* low open woodland
C2: EvChAtuGwTErCYp-ERItTHt	*Eucalyptus victrix,* (*Corymbia hamersleyana*) scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall shrubland over *Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) low shrubland over *Cymbopogon mbiguous, C. procerus, Eriachne tenuiculmis, Themeda triandra* very open tussock grassland
C3: EvAciAcMgCEc	*Eucalyptus victrix* scattered trees over *Acacia citrinoviridis, A. coriacea* subsp. *pendens, Melaleuca glomerata* tall open shrubland over **Cenchrus ciliaris* scattered tussock grasses
C4: EvAciAprAThCEc	*Eucalyptus victrix* open woodland over *Acacia citrinoviridis, A. pruinocarpa, Atalaya hemiglauca* low woodland over **Cenchrus ciliaris* tussock grassland
C5: EvAbAaAmERItTHt	*Eucalyptus victrix* scattered low trees over *Acacia bivenosa, A. ancistrocarpa, A. maitlandii* tall open shrubland over *Eriachne tenuiculmis, Themeda triandra* very open tussock grassland

Vegetation of Minor Creeklines, Floodplains and Valleys

F1: ChAtuGwTp	*Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* tall open shrubland over *Triodia pungens* hummock grassland
F2: AprAciCEc	*Acacia pruinocarpa, A. citrinoviridis* tall open shrubland over **Cenchrus ciliaris* tussock grassland
F3: ElChAtuAaAbGwTspp	*Eucalyptus leucophloia, Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *A. ancistrocarpa, A. bivenosa, Grevillea wickhamii* tall open scrub over mixed *Triodia* hummock grassland
F4: ChAtuAaPcAtenBONe-ARhPAmTp	*Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open shrubland over *A. ancistrocarpa, Petalostylis cassioides, A. tenuissima* open shrubland over *Bonamia erecta* very open herbland over *Aristida holathera* var. *holathera, Paraneurachne muelleri* very open tussock grassland and *Triodia pungens* very open hummock grassland
F5: ChAciAaAiSENsppTp	*Corymbia hamersleyana* scattered low trees over *Acacia citrinoviridis, A. ancistrocarpa, A. inaequilatera* tall open shrubland over *Senna* spp. open shrubland over *Triodia pungens* open hummock grassland

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Vegetation of Yandi Billiards Integrated

Vegetation of Hills, Ridges, Gorges and Breakaways

H1: ElHcAiGwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Hakea chordophylla, Acacia inaequilatera, Grevillea wickhamii* tall open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
H2: ElAiTwTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana*, (*T.* sp. Shovelanna Hill (S. van Leeuwen 3835)) open hummock grassland
H3: ElGwAarTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Grevillea wickhamii* tall open shrubland over *Acacia arida* shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835) open hummock grassland
H4: ChAarTspsTw	*Corymbia hamersleyana* scattered low trees over *Acacia arida* open shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* hummock grassland
H5: ElCfERImTHspp	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola* scattered low trees over *Eremophila latrobei* subsp. *filiformis, Senna* spp. scattered shrubs over *Cymbopogon ambiguus, Eriachne mucronata, Themeda* sp. Mt Barricade (M.E. Trudgen 2471), *T. triandra* open tussock grassland
H6: ElAbTw	*Eucalyptus leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland
H7: ElAprTwTp	*Eucalyptus leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana, T. pungens* open hummock grassland
H8: AmoTspsTw	*Acacia monticola* tall shrubland over *Triodia* sp. Shovelanna Hill (S. van Leeuwen 3835), *T. wiseana* closed hummock grassland
H9: ChGOrANlAtuGw-THtCYa	*Corymbia hamersleyana* scattered low trees over *Gossypium robinsonii, Androcalva luteiflora, Acacia tumida* var. *pilbarensis*, *Grevillea wickhamii* subsp. *hispidula* shrubland over *Themeda triandra, Cymbopogon ambiguus* open tussock grassland
H10: AiERfTp	*Acacia inaequilatera* scattered tall shrubs over *Eremophila fraseri* subsp. *fraseri* scattered shrubs over *Triodia pungens* very open hummock grassland
H11: GpERfTp	*Grevillea pyramidalis* subsp. *leucadendron, Eremophila fraseri* tall open shrubland over *Triodia pungens* hummock grassland

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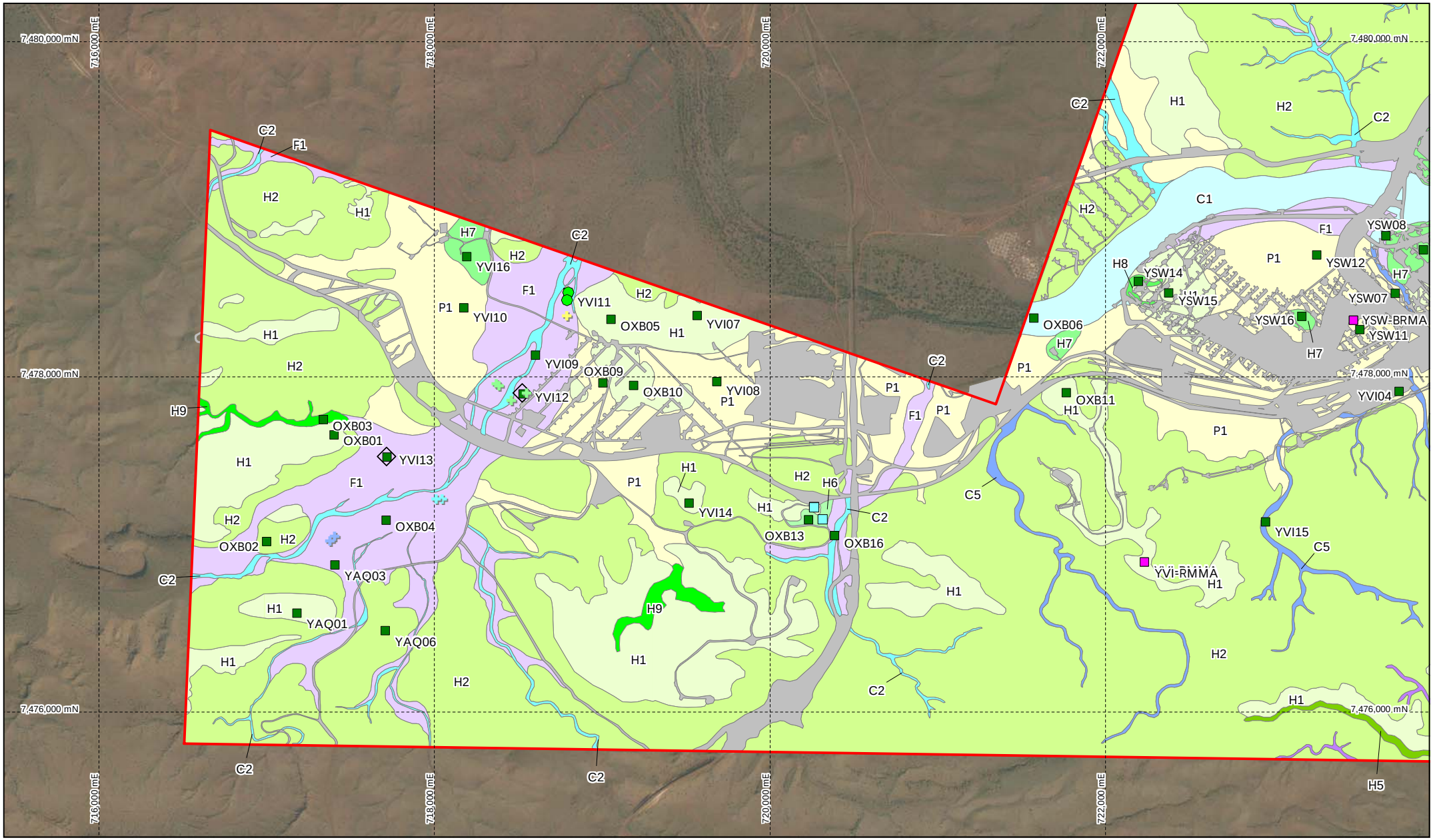
Vegetation of Yandi Billiards Integrated

Vegetation of Stony Plains

P1: ElEgAprAbAaAd-TwTpTsps	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia pruinocarpa* scattered tall shrubs over *A. bivenosa, A. ancistrocarpa, A. dictyophleba* shrubland over *Triodia wiseana, T. pungens*, *T.* sp. Shovelanna Hill (S. van Leeuwen 3835) hummock grassland
P2: ChAprAiAsclApaTp	*Corymbia hamersleyana, Acacia pruinocarpa* scattered low trees over *A. inaequilatera, A. sclerosperma* subsp. *sclerosperma, A. pachyacra* tall open shrubland over *Triodia pungens* hummock grassland
P3: AprAciAiAsclTlo	*Acacia pruinocarpa* low open woodland over *A. citrinoviridis, A. inaequilatera, A. sclerosperma* subsp. *sclerosperma* open shrubland over *Triodia longiceps* hummock grassland
P4: AprAsyAiTw	*Acacia pruinocarpa* low open woodland over *A. synchronicia, A. inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland
P5: ElEgAbAaTb	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia bivenosa, A. ancistrocarpa* open shrubland over *Triodia basedowii* open hummock grassland
P6: AapERfoERI/g	*Acacia aptaneura* low open forest over *Eremophila forrestii* subsp. *forrestii* open shrubland over *E. lanceolata* low open shrubland over mixed very open grassland
P7: ERf/g	*Eremophila fraseri* subsp. *fraseri* open shrubland over mixed very open grassland
P8: EgAiTs	*Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera* scattered tall shrubs over *Triodia schinzii* hummock grassland
P9: ChEgAiAaAprPcTb	*Corymbia hamersleyana* scattered low trees over *Eucalyptus gamophylla* scattered low mallees over *Acacia inaequilatera, A. ancistrocarpa, A. pruinocarpa* tall open shrubland over *Petalostylis cassioides* open shrubland over *Triodia basedowii* open hummock grassland



Yandi Billiards Integrated Vegetation Map 1

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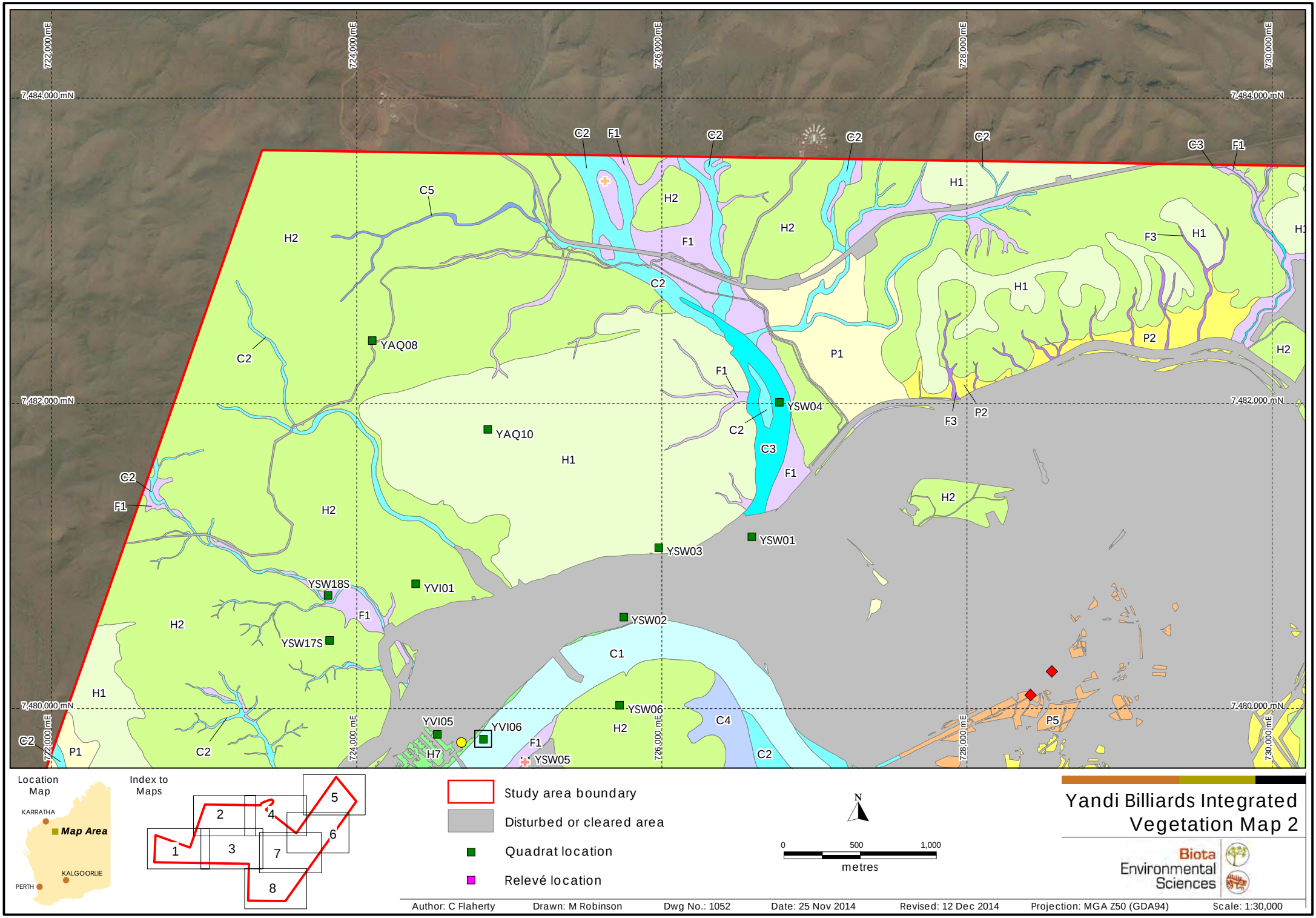
Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 25 Nov 2014 | Revised: | Projection: MGA Z50 (GDA94) | Scale: 1:30,000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Location Map
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Study area boundary
Disturbed or cleared area
Quadrat location
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Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 1052
Date: 25 Nov 2014
Revised: 12 Dec 2014
Projection: MGA Z50 (GDA94)
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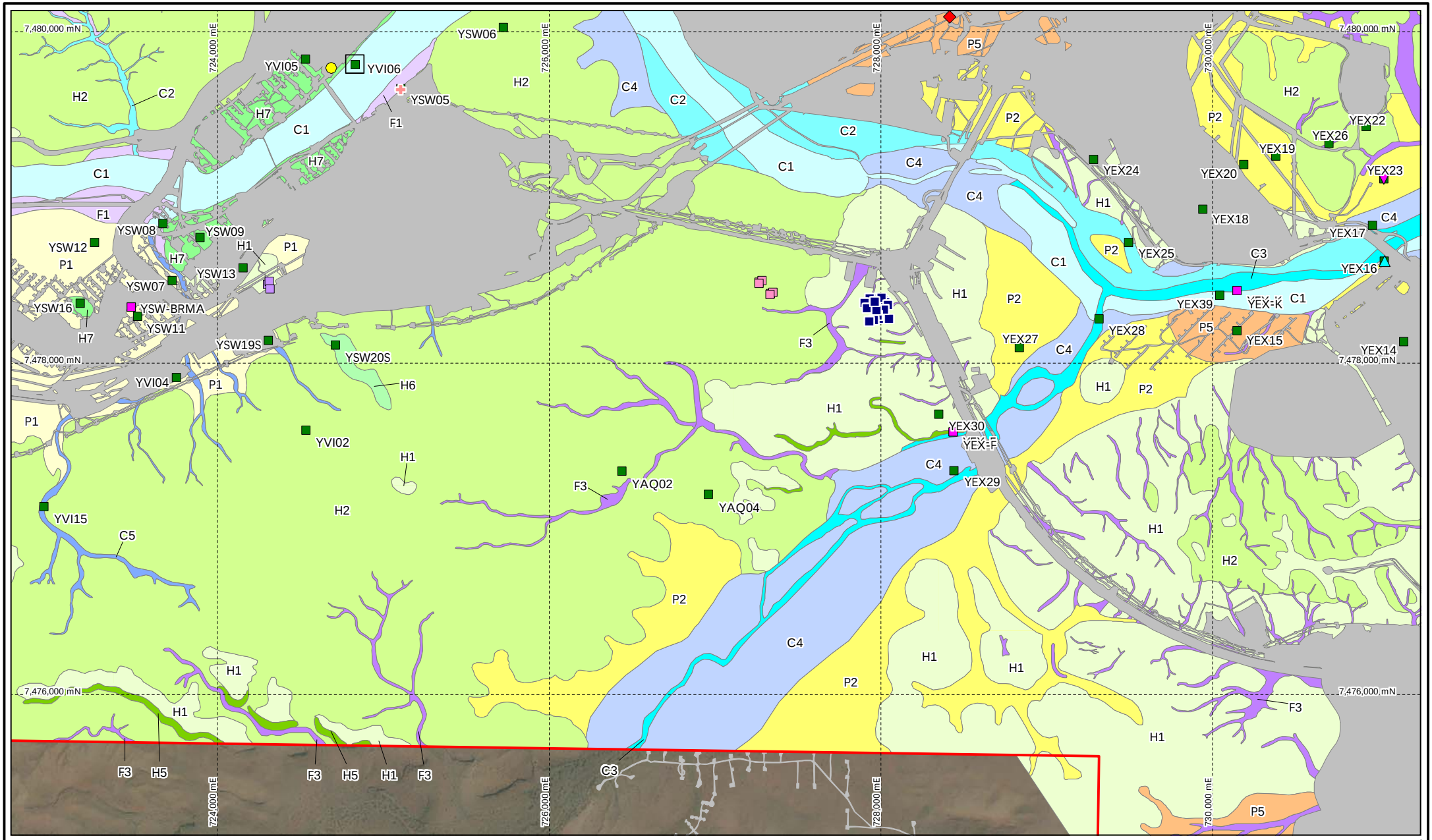
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Quadrat location
Relevé location
Location Map
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KALGOORLIE
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Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 1052
Date: 25 Nov 2014
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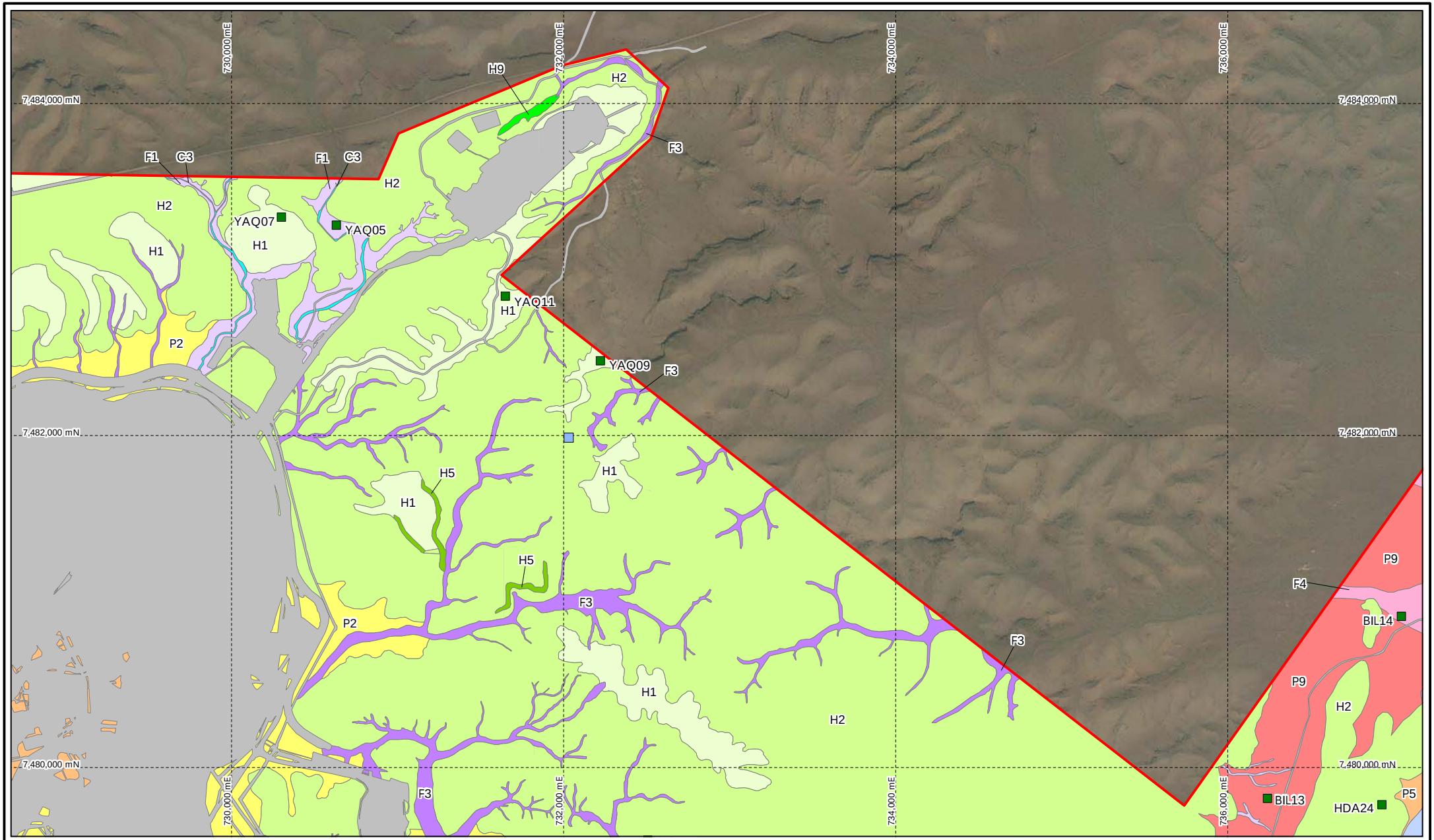

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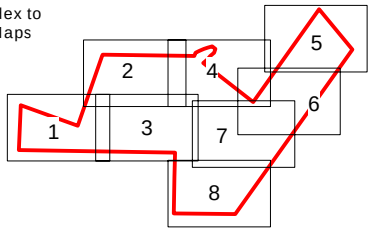

Study area boundary

Disturbed or cleared area

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Relevé location

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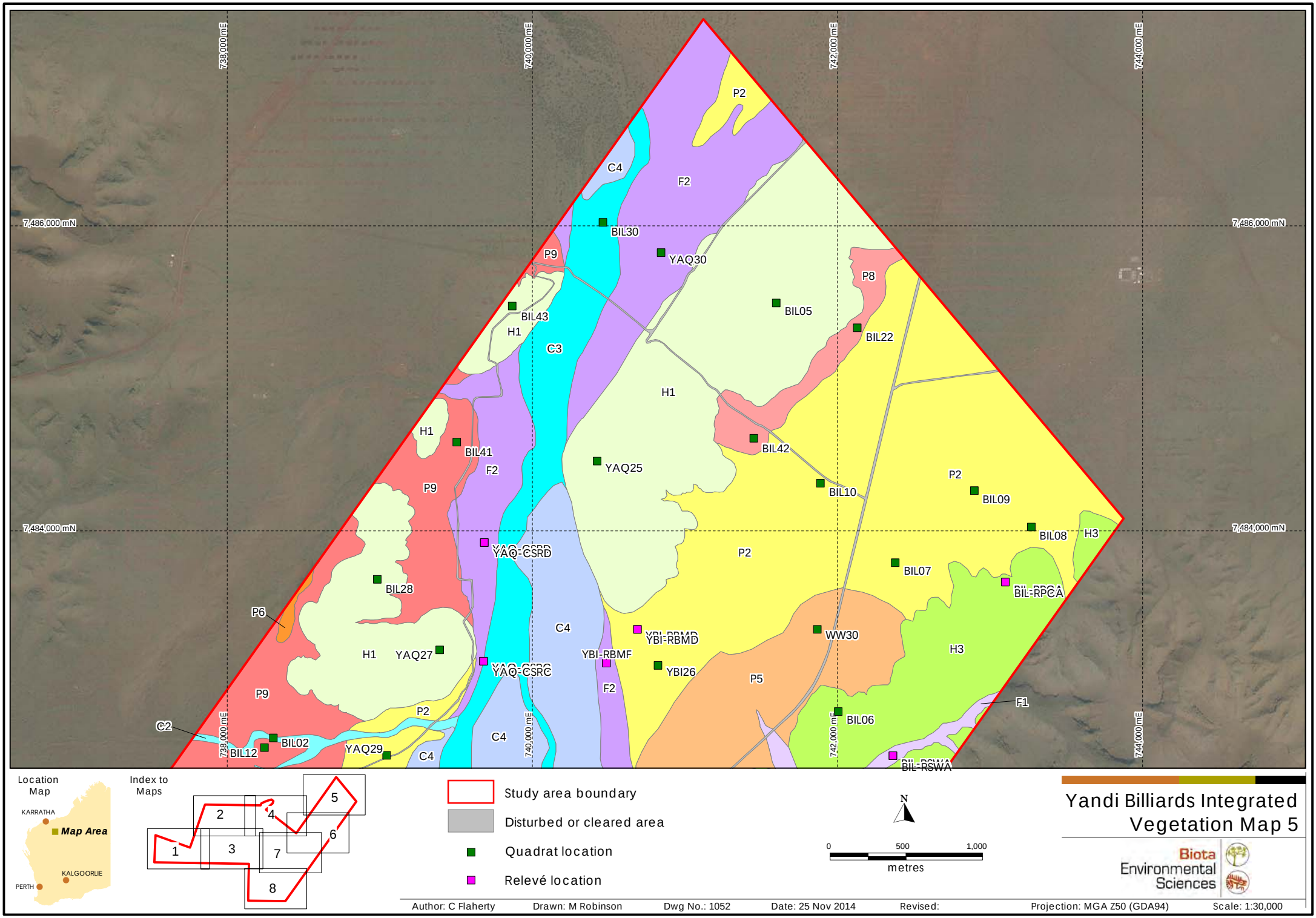
metres

Yandi Billiards Integrated Vegetation Map 4

Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 25 Nov 2014 | Revised: | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps

Study area boundary

Disturbed or cleared area

Quadrat location

Relevé location

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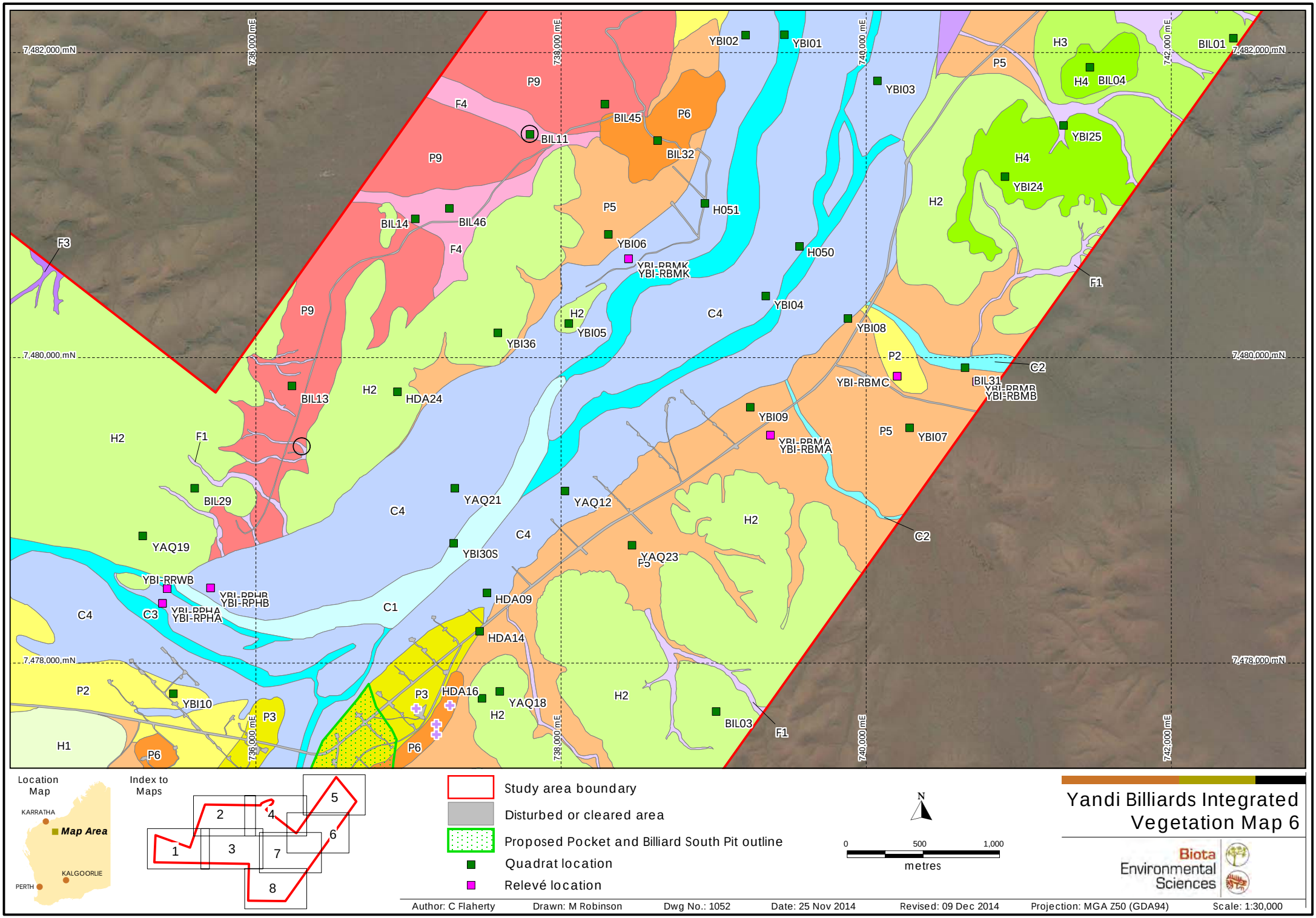
metres

Yandi Billiards Integrated Vegetation Map 5

Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 25 Nov 2014 | Revised: | Projection: MGA Z50 (GDA94) | Scale: 1:30,000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BIL03
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Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Index to Maps
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Study area boundary
Disturbed or cleared area
Proposed Pocket and Billiard South Pit outline
Quadrat location
Relevé location
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metres
Yandi Billiards Integrated Vegetation Map 6
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 1052
Date: 25 Nov 2014
Revised: 09 Dec 2014
Projection: MGA Z50 (GDA94)
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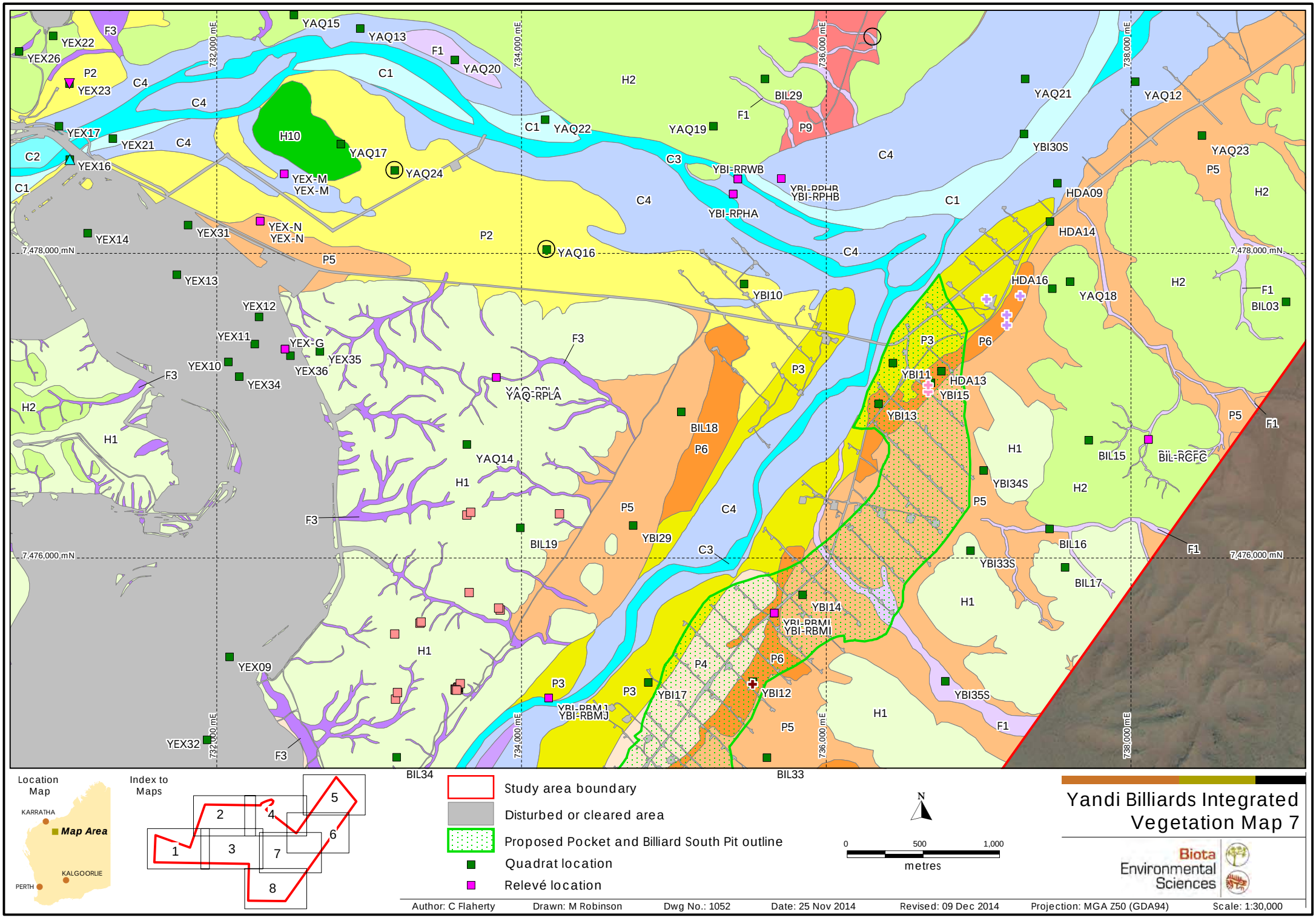

Location Map

Index to Maps

Study area boundary

Disturbed or cleared area

Proposed Pocket and Billiard South Pit outline

Quadrat location

Relevé location

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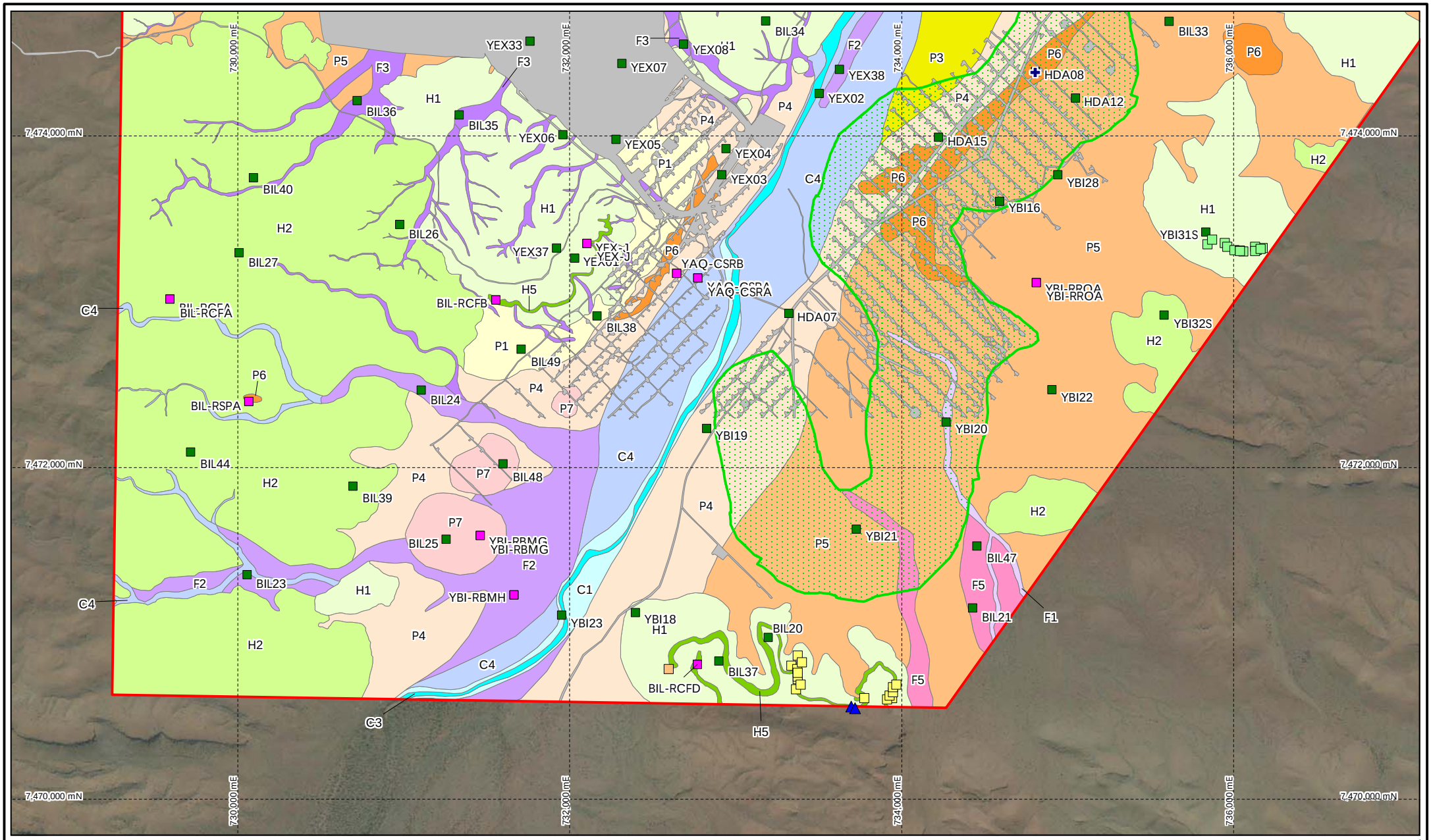
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Map 7

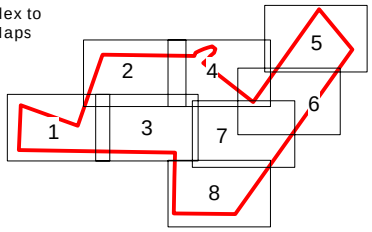
Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 25 Nov 2014 | Revised: 09 Dec 2014 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed or cleared area

Proposed Pocket and Billiard South Pit outline

Quadrat location

Relevé location

N

0 500 1,000

metres

Yandi Billiards Integrated Vegetation Map 8

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Appendix 5

Vascular Flora Species Recorded in the Study Area

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Family: Acanthaceae														
Dicladanthera forrestii	X	X	X		X		X	X		X		X		
Dipteracanthus australasicus subsp. *australasicus*	X	X			X			X		X	X	X		
Rostellularia adscendens var. *clementii*		X			X					X				
Rostellularia adscendens var. *latifolia* (Priority 3)		X												
Family: Aizoaceae														
Trianthema glossostigmum	X		X				X	X		X				
Trianthema pilosum	X						X	X		X				
Zaleya galericulata subsp. *galericulata*	X		X											
Family: Amaranthaceae														
Achyranthes aspera	X	X	X		X					X	X	X		
**Aerva javanica*	X		X				X							X
Alternanthera angustifolia	X													
Alternanthera denticulata	X													
Alternanthera nana	X	X			X	X	X	X		X	X			
Alternanthera nodiflora	X									X				
**Alternanthera pungens*														X
Amaranthus cuspidifolius	X	X			X	X		X						
Amaranthus undulatus	X	X	X		X	X	X			X		X		
Gomphrena affinis subsp. *pilbarensis*	X													
Gomphrena cunninghamii	X	X	X		X	X	X	X	X	X	X	X		
Gomphrena kanisii							X							
Ptilotus aervoides	X	X			X		X			X	X			
Ptilotus astrolasius	X	X	X		X	X	X	X	X	X	X			
Ptilotus auriculifolius	X	X	X		X	X	X		X	X				
Ptilotus calostachyus	X	X	X	X	X	X	X	X	X	X				
Ptilotus clementii	X	X	X		X	X		X		X	X			
Ptilotus fusiformis	X	X	X		X	X				X				
Ptilotus gaudichaudii subsp. *gaudichaudii*	X						X			X	X			
Ptilotus helipteroides	X		X				X	X		X	X			
Ptilotus incanus									X					
Ptilotus nobilis subsp. *nobilis*	X	X	X	X	X	X	X	X		X	X			
Ptilotus obovatus var. *obovatus*	X	X	X	X	X	X	X	X	X	X	X	X		
Ptilotus polystachyus	X	X	X		X		X	X		X	X			
Ptilotus roei	X									X				

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Ptilotus rotundifolius	X	X	X		X	X	X	X	X	X	X			
Family: Apocynaceae														
**Catharanthus roseus*														X
Cynanchum floribundum		X				X								
Rhyncharrhena linearis	X	X	X		X			X						
Sarcostemma viminale subsp. *australe*										X				
Tylophora flexuosa	X													
Family: Araliaceae														
Astrotricha hamptonii		X				X								
Trachymene oleracea subsp. *oleracea*	X	X	X		X	X	X	X		X				
Family: Asteraceae														
**Bidens bipinnata*	X	X	X		X	X	X			X	X			X
Blumea tenella	X						X							
Calotis hispidula		X				X								
Calotis plumulifera	X									X				
Centipeda minima subsp. *macrocephala*	X	X	X							X	X			
Chrysocephalum apiculatum	X	X	X		X	X		X	X	X				
Chrysocephalum gilesii	X									X				
Chrysocephalum pterochaetum	X						X							
**Conyza bonariensis*		X			X			X		X				X
**Flaveria trinervia*	X	X	X		X	X				X	X			X
Helichrysum luteoalbum	X		X							X				
Ixiochlamys cuneifolia	X		X							X				
**Lactuca serriola*														X
Olearia fluvialis		X	X		X	X				X				
Peripleura arida	X						X			X				
Peripleura hispidula var. *hispidula*	X		X											
Peripleura obovata		X			X					X				
Peripleura virgata		X			X	X								
Pluchea dentex	X	X	X		X			X		X				
Pluchea dunlopii	X	X			X		X	X		X				
Pluchea ferdinandi-muelleri	X	X			X		X			X				
Pluchea rubelliflora	X	X	X	X	X	X	X	X		X		X		
Pluchea tetranthera		X			X	X				X				
Pterocaulon sphacelatum	X	X	X		X		X				X	X	X	

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Pterocaulon sphaeranthoides								X	X					
Rhodanthe citrina					X									
Rhodanthe floribunda	X									X				
Rhodanthe margarethae		X				X		X		X				
**Sigesbeckia orientalis*	X	X				X					X			X
**Sonchus asper*														X
**Sonchus oleraceus*	X	X	X					X		X	X			X
Streptoglossa bubakii	X	X	X		X		X			X	X			
Streptoglossa decurrens	X	X	X			X	X	X		X	X			
Streptoglossa odora	X										X			
**Tridax procumbens*														X
Vittadinia dissecta var. *hirta*							X							
Family: Boraginaceae														
Heliotropium chrysocarpum	X	X	X			X		X						
Heliotropium cunninghamii	X	X	X		X	X	X			X	X			
Heliotropium glabellum	X		X											
Heliotropium heteranthum	X													
Heliotropium inexplicitum	X	X	X		X		X			X	X			
Heliotropium pachyphyllum	X	X	X		X	X	X	X		X	X			
Heliotropium aff. *pachyphyllum*			X											
Heliotropium tanythrix	X													
Heliotropium tenuifolium	X	X	X	X	X	X		X		X				
Heliotropium sp. (*tenuifolium/cunninghamii*; sterile)		X												
Trichodesma zeylanicum var. zeylanicum	X	X	X		X	X	X		X	X	X	X		
Family: Brassicaceae														
Lepidium catapycnon (Threatened)	X	X				X		X						
Lepidium muelleri-ferdinandii		X			X			X		X				
Lepidium oxytrichum	X									X				
Lepidium pedicellosum	X													
Lepidium phlebopetalum	X	X			X		X	X		X				
Lepidium pholidogynum	X										X			
Lepidium platypetalum										X				
**Sisymbrium irio*										X				
**Sisymbrium orientale*	X	X	X			X		X						X

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Family: Campanulaceae														
Lobelia arnhemiaca	X	X	X					X	X	X				
Wahlenbergia tumidifructa	X	X	X		X					X				
Family: Capparaceae														
Capparis lasiantha	X								X					
Capparis spinosa var. *nummularia*	X		X				X			X		X		
Family: Caryophyllaceae														
Polycarpaea corymbosa var. *corymbosa*	X	X	X		X	X	X	X		X				
Polycarpaea holtzei	X	X	X		X	X	X	X		X	X			
Polycarpaea longiflora	X	X	X		X	X	X	X	X	X		X		
Family: Celastraceae														
Stackhousia intermedia			X											
Family: Chenopodiaceae														
Dysphania cristata	X										X			
Dysphania kalpari	X							X		X	X			
Dysphania melanocarpa forma *melanocarpa*	X						X			X	X	X		
Dysphania plantaginella	X		X				X							
Dysphania rhadinostachya (sterile; subsp. not determined)	X	X	X		X	X	X	X						
Dysphania rhadinostachya subsp. *inflata*	X													
Dysphania rhadinostachya subsp. *rhadinostachya*	X		X				X			X	X			
Dysphania sp. (sterile; insufficient material for further determination)	X	X												
Enchylaena tomentosa var. *tomentosa*	X		X				X	X		X	X	X		
Maireana planifolia	X	X			X		X	X		X	X			
Maireana planifolia x *villosa*	X									X	X			
Maireana villosa	X	X	X				X			X	X			
Rhagodia eremaea	X		X					X	X	X	X	X		
Salsola australis	X	X	X			X		X		X	X			
Sclerolaena cornishiana	X	X	X		X		X	X		X	X	X		
Sclerolaena costata		X			X									
Sclerolaena eriacantha	X									X				
Family: Cleomaceae														
Cleome viscosa	X	X	X	X	X	X	X	X	X	X	X	X		

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Family: Convolvulaceae														
Bonamia erecta	X	X	X		X	X	X	X	X	X			X	
Bonamia pannosa	X								X	X				
Bonamia sp. Dampier (A.A. Mitchell PRP 217)	X	X	X		X	X	X	X	X	X	X			
Convolvulus clementii	X						X			X	X			
Duperreya commixta	X	X	X			X	X	X	X	X		X		
Evolvulus alsinoides (sterile; var. not determined)	X							X						
Evolvulus alsinoides var. *decumbens*	X	X	X		X	X				X		X		
Evolvulus alsinoides var. *villosicalyx*	X	X	X		X	X	X	X		X	X			
Ipomoea muelleri	X	X	X		X	X	X	X		X				
Ipomoea polymorpha	X													
Operculina aequisepala	X													
Polymeria ambigua	X	X	X		X	X	X	X		X	X			
Family: Cucurbitaceae														
**Citrullus colocynthis*		X				X								X
**Citrullus lanatus*														X
**Citrullus* aff. *lanatus*		X												
Cucumis melo	X		X				X							X
Cucumis variabilis	X	X	X		X	X	X	X	X	X	X			
Family: Cyperaceae														
Bulbostylis barbata	X	X	X		X	X	X	X		X	X			
Bulbostylis turbinata	X	X				X				X	X			
Cyperus cunninghamii subsp. *cunninghamii*	X													
Cyperus difformis	X									X				
Cyperus iria	X									X				
Cyperus ixiocarpus	X		X											
Cyperus squarrosus	X													
Cyperus vaginatus	X	X	X	X	X	X		X						
Eleocharis atropurpurea	X													
Eleocharis geniculata										X				
Fimbristylis dichotoma	X	X	X		X	X	X			X	X			
Fimbristylis microcarya	X													
Fimbristylis simulans	X	X	X		X	X	X			X	X			
Schoenoplectus subulatus	X									X				

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Family: Droseraceae														
Drosera indica		X												
Family: Elatinaceae														
Bergia pedicellaris										X				
Bergia trimera					X					X				
Family: Euphorbiaceae														
Adriana tomentosa var. *tomentosa*							X							
Euphorbia australis (insufficient material for further determination)	X	X			X	X		X			X			
Euphorbia australis var. *australis*	X													
Euphorbia australis var. *erythrantha*	X	X	X		X		X			X	X			
Euphorbia australis var. *hispidula*	X	X								X				
Euphorbia australis var. *subtomentosa*	X	X	X		X	X	X	X	X	X	X	X		
Euphorbia biconvexa	X	X	X		X	X	X				X			
Euphorbia boophthona	X	X	X		X	X		X		X	X			
Euphorbia coghlanii	X		X						X					
Euphorbia drummondii	X													
**Euphorbia hirta*														X
Euphorbia tannensis subsp. *eremophila*	X	X	X		X	X	X			X	X			
Euphorbia trigonosperma	X	X	X				X			X				
Euphorbia vaccaria var. *vaccaria*			X							X				
Euphorbia sp. (*biconvexa/coghlanii/trigonosperma*; sterile)	X	X			X					X				
Euphorbia sp. (*coghlanii/trigonosperma*)	X	X	X		X	X				X		X		
Euphorbia sp. (insufficient material for further determination)	X	X			X	X	X							
**Ricinus communis*														X
Family: Fabaceae														
Acacia adoxa var. *adoxa*	X	X	X	X	X	X	X	X	X	X	X			
Acacia adsurgens	X		X				X			X				
Acacia ampliceps		X			X	X								
Acacia ancistrocarpa	X	X	X	X	X	X	X	X	X	X	X		X	
Acacia ancistrocarpa x *arida*	X													
Acacia ancistrocarpa x *trachycarpa*		X				X		X						
Acacia aneura								X						
Acacia aptaneura	X		X	X	X		X	X		X	X			

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Acacia aptaneura x *ayersiana*	X													
Acacia aptaneura x *incurvaneura*	X									X	X			
Acacia aptaneura x *macraneura*	X									X				
Acacia aptaneura x (unknown hybrid)	X						X			X				
Acacia aff. *aptaneura*				X						X				
Acacia arida	X			X			X							
Acacia arida x *hilliana*	X						X							
Acacia ayersiana	X		X				X			X	X			
Acacia bivenosa	X	X	X	X	X	X	X	X	X	X	X			
Acacia bivenosa (wispy/weeping form)	X		X					X			X			
Acacia catenulata	X						X			X				
Acacia citrinoviridis	X	X	X	X	X		X	X	X	X	X	X		
Acacia colei var. *colei*										X				
Acacia coriacea subsp. *pendens*	X	X	X	X	X	X	X	X	X	X	X	X		
Acacia dictyophleba	X	X	X	X	X	X	X	X	X	X	X		X	
Acacia elachantha	X	X			X	X	X	X		X				
Acacia hamersleyensis								X						
Acacia hilliana	X	X	X	X	X	X	X	X	X	X	X			
Acacia inaequilatera	X	X	X	X	X	X	X	X	X	X	X		X	
Acacia kempeana	X													
Acacia ligulata			X											
Acacia maitlandii	X	X	X	X	X	X		X	X	X				
Acacia marramamba	X								X					
Acacia monticola	X	X	X	X	X	X		X						
Acacia pachyacra	X	X	X	X	X	X	X	X	X	X			X	
Acacia pruinocarpa		X	X	X	X	X	X	X	X	X	X		X	
Acacia pteraneura				X										
Acacia pyrifolia (var. not determined)	X			X				X	X	X				
Acacia pyrifolia var. *morrisonii*	X	X	X											
Acacia pyrifolia var. *pyrifolia*	X	X	X		X	X	X							
Acacia rhodophloia								X						
Acacia sclerosperma subsp. *sclerosperma*	X		X	X			X	X		X	X			
Acacia sclerosperma hybrid	X		X											
Acacia sericophylla	X									X				
Acacia sibirica	X						X	X		X				

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Acacia spondylophylla	X			X			X							
Acacia synchronicia	X	X	X	X	X		X	X	X	X	X			
Acacia tenuissima	X	X	X		X		X	X	X					
Acacia tetragonophylla	X	X			X	X								
Acacia trudgeniana	X		X											
Acacia tumida var. *pilbarensis*	X	X	X	X	X	X	X	X	X	X	X			
Acacia wanyu				X										
Acacia sp. (insufficient material for further determination)		X			X									
Alysicarpus muelleri	X	X	X		X									
Crotalaria medicaginea var. *neglecta*	X	X	X		X	X	X	X		X	X			
Crotalaria novae-hollandiae subsp. *novae-hollandiae*	X		X						X	X				
Cullen lachnostachys	X													
Cullen leucanthum					X			X		X				
Cullen leucochaites	X	X	X		X		X	X	X	X				
Cullen martinii	X													
Dichrostachys spicata										X				
Glycine canescens	X	X	X		X	X	X			X	X	X		
Glycine sp. aff. *arenaria*		X												
Glycine tabacina		X												
Gompholobium oreophilum	X						X	X		X				
Indigofera colutea	X	X	X		X									
Indigofera georgei	X		X				X	X		X				
Indigofera linifolia	X		X								X			
Indigofera linnaei	X	X			X	X								
Indigofera monophylla	X	X	X	X	X	X	X	X	X	X	X	X		
Indigofera rugosa	X	X	X		X		X		X	X				
Isotropis atropurpurea	X	X	X		X	X		X		X				
**Lotus* sp.														X
Mirbelia viminalis		X			X									
Petalostylis cassioides	X						X							
Petalostylis labicheoides	X	X	X					X		X				
Rhynchosia minima	X	X	X		X	X	X	X	X	X	X	X		
Senna artemisioides subsp. ? *oligophylla* x *S. glaucifolia*		X												

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Senna artemisioides subsp. *helmsii*	X	X	X	X	X	X	X	X	X	X	X	X		
Senna artemisioides subsp. *oligophylla*	X	X	X	X	X	X	X		X	X	X			
Senna artemisioides subsp. *oligophylla* x subsp. *helmsii*	X	X	X		X		X	X		X	X			
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)	X	X	X		X		X	X						
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035) *x* subsp. *helmsii*	X													
Senna artemisioides subsp. *oligophylla* x *S. glutinosa* subsp. *glutinosa*	X	X	X											
Senna artemisioides subsp. x *artemisioides*	X	X	X		X			X		X	X			
Senna ferraria	X		X				X		X					
Senna glaucifolia			X											
Senna glutinosa subsp. *glutinosa*	X	X	X			X	X	X	X	X	X			
Senna glutinosa subsp. *glutinosa* x subsp. x *luerssenii*	X	X	X				X		X					
Senna glutinosa subsp. *glutinosa* x subsp. *pruinosa*	X								X					
Senna glutinosa subsp. *glutinosa* x *S. stricta*	X													
Senna glutinosa subsp. *glutinosa* x		X												
Senna glutinosa subsp. x *luerssenii*	X	X	X			X		X		X	X			
Senna glutinosa subsp. *pruinosa*	X	X	X	X		X		X		X	X			
Senna glutinosa subsp. *pruinosa* x subsp. ? *glutinosa*	X										X			
Senna glutinosa subsp. *pruinosa* x	X													
Senna notabilis	X	X	X	X	X	X	X	X	X	X	X			
Senna sericea	X						X	X						
Senna venusta		X				X		X	X					
Senna sp. Meekatharra (E. Bailey 1-26)	X						X				X			
Senna sp. (insufficient material for further determination)	X	X	X		X									
Sesbania cannabina	X		X											
Swainsona decurrens			X							X				
Swainsona formosa	X		X											
Swainsona kingii	X									X				
Swainsona maccullochiana	X													
Tephrosia arenicola										X				

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Tephrosia oxalidea	X	X	X		X	X		X		X				
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	X	X	X	X	X	X	X	X	X	X		X		
Tephrosia spechtii		X	X			X		X						
Tephrosia supina	X	X					X		X					
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	X	X	X		X	X	X			X				
Tephrosia sp. Fortescue (A.A. Mitchell 606)	X	X	X		X	X	X			X				
Tephrosia sp. Newman (A.A. Mitchell PRP 29)	X		X							X				
Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)	X		X				X			X	X			
Tephrosia sp. (insufficient material for further determination)		X												
**Vachellia farnesiana*	X	X	X		X	X	X	X		X	X			X
Vigna lanceolata var. *lanceolata*		X	X		X					X				
Family: Goodeniaceae														
Dampiera candicans	X	X	X	X	X	X	X	X	X	X	X			
Goodenia forrestii		X			X			X						
Goodenia lamprosperma	X		X	X	X					X				
Goodenia microptera	X	X	X		X	X	X	X	X	X	X	X		
Goodenia muelleriana	X	X	X	X	X	X	X		X	X	X			
Goodenia nuda (Priority 4)	X	X		X	X									
Goodenia nuda/triodiophila		X												
Goodenia prostrata	X						X				X			
Goodenia stellata	X									X				
Goodenia stobbsiana	X	X	X	X	X	X	X	X	X	X	X			
Goodenia triodiophila	X	X	X		X	X	X	X	X	X	X			
Goodenia vilmoriniae										X				
Scaevola amblyanthera var. *centralis*	X		X											
Scaevola browniana subsp. *browniana*	X	X	X											
Scaevola parvifolia subsp. *pilbarae*	X	X			X	X	X	X	X	X	X			
Scaevola spinescens	X	X	X		X			X						
Family: Gyrostemonaceae														
Codonocarpus cotinifolius	X	X	X		X	X	X	X	X	X				
Family: Haloragaceae														
Haloragis gossei (sterile; var. not determined)	X	X			X		X			X				

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Haloragis gossei var. *gossei*	X							X		X	X			
Family: Lamiaceae														
Clerodendrum floribundum var. *angustifolium*	X	X	X		X	X		X	X	X				
Dicrastylis cordifolia	X	X	X				X	X		X	X			
Spartothamnella teucriiflora	X													
Family: Lauraceae														
Cassytha capillaris		X			X									
Cassytha filiformis	X													
Family: Loranthaceae														
Amyema hilliana	X		X				X			X		X		
Amyema miquelii										X				
Amyema sp. (sterile; insufficient material for further determination)		X			X	X								
Diplatia grandibractea	X													
Lysiana casuarinae										X				
Family: Lythraceae														
Ammannia baccifera	X		X							X				
Ammannia multiflora	X									X				
Family: Malvaceae														
Abutilon amplum	X		X											
Abutilon cryptopetalum	X										X			
Abutilon fraseri subsp. *fraseri*	X	X	X		X					X	X			
Abutilon lepidum sens. lat.	X	X	X		X	X	X	X	X	X	X			
Abutilon leucopetalum	X													
Abutilon macrum	X	X	X		X	X	X			X	X	X		
Abutilon otocarpum	X	X	X		X	X	X	X		X	X	X		
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	X	X	X		X	X		X		X				
Abutilon sp. Pilbara (W.R. Barker 2025)	X	X	X		X	X		X		X				
Abutilon sp. (insufficient material for further det.)	X										X			
Androcalva luteiflora	X	X	X	X	X	X		X	X	X				
Corchorus crozophorifolius	X	X	X	X	X	X	X	X		X	X	X		
Corchorus laniflorus										X				
Corchorus lasiocarpus (insufficient material to determine subsp.)	X	X			X			X			X			
Corchorus lasiocarpus subsp. *lasiocarpus*	X	X	X		X	X	X	X	X	X				

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Corchorus lasiocarpus subsp. *parvus*	X	X	X		X	X	X			X				
Corchorus sidoides (insufficient material to determine subsp.)	X		X								X			
Corchorus sidoides subsp. *sidoides*	X						X				X			
Corchorus sidoides subsp. *vermicularis*	X						X							
Corchorus tectus	X						X	X		X			X	
Corchorus tridens	X	X	X				X				X			
Corchorus sp. (insufficient material for further determination)	X													
Gossypium australe	X	X	X	X	X	X	X	X	X	X	X			
Gossypium robinsonii	X	X	X	X	X	X	X	X	X	X		X		
Gossypium sturtianum var. *sturtianum*	X									X				
Hibiscus brachychlaenus	X									X				
Hibiscus burtonii	X	X	X		X		X	X		X	X			
Hibiscus coatesii	X	X	X		X	X	X	X		X				
Hibiscus goldsworthii	X	X				X			X	X				
Hibiscus leptocladus	X		X				X		X					
Hibiscus sturtii (var. not determined)	X	X			X	X							X	
Hibiscus sturtii var. *campylochlamys*	X	X	X		X	X	X	X	X	X	X			
Hibiscus sturtii var. *grandiflorus*	X						X							
Hibiscus sturtii var. *platychlamys*	X	X	X		X	X	X	X		X	X			
Hibiscus sp. Mt Robinson (G. Byrne 3537)	X													
Hibiscus sp. (insufficient material for further determination)	X	X				X								
Keraudrenia nephrosperma	X						X	X						
Keraudrenia velutina subsp. *elliptica*	X	X	X		X	X	X			X				
**Malvastrum americanum*	X	X	X		X	X	X	X		X	X			X
Melhania oblongifolia	X	X	X		X	X	X	X		X	X	X		
Sida arenicola	X	X	X		X		X	X	X	X				
Sida arsiniata	X	X			X		X			X	X			
Sida cardiophylla	X	X	X		X		X		X	X	X			
Sida echinocarpa	X	X	X		X	X	X	X		X	X			
Sida ectogama	X													
Sida fibulifera sens. lat.	X	X	X		X	X	X	X		X	X			
Sida platycalyx	X													
Sida rohlenae subsp. *rohlenae*			X											

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Sida sp. A Kimberley Flora (P.A. Fryxell & L.A. Craven 3900)										X				
Sida sp. Articulation below (A.A. Mitchell PRP 1605)		X	X			X			X					
Sida sp. Barlee Range (S. van Leeuwen 1642) (Priority 3)	X									X				
Sida sp. Excedentifolia (J.L. Egan 1925)	X	X				X		X						
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	X	X	X		X	X	X	X		X	X			
Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)	X	X	X		X	X	X	X		X	X	X		
Sida sp. verrucose glands (F.H. Mollemans 2423)	X	X	X		X	X	X	X						
Sida sp. (insufficient material for further determination)		X			X									
Triumfetta clementii	X	X			X									
Triumfetta leptacantha		X				X								
Triumfetta maconochieana	X	X				X		X		X				
Waltheria indica	X	X	X		X	X	X	X	X	X	X	X		
Family: Marsileaceae														
Marsilea hirsuta					X									
Family: Menispermaceae														
Tinospora smilacina		X				X		X	X					
Family: Molluginaceae														
Mollugo molluginea	X	X	X	X	X	X	X	X	X	X	X			
Family: Moraceae														
Ficus brachypoda	X	X	X			X			X	X				
Family: Myrtaceae														
Calytrix carinata	X	X	X		X	X		X	X	X	X			
Corymbia candida	X	X	X		X		X	X	X	X	X			
Corymbia deserticola subsp. *deserticola*	X	X	X		X									
Corymbia ferriticola	X	X					X							
Corymbia hamersleyana	X	X	X	X	X	X	X	X	X	X	X		X	
Eucalyptus camaldulensis subsp. *refulgens*	X	X	X		X	X				X				
Eucalyptus gamophylla	X	X	X	X	X	X	X	X	X	X				
Eucalyptus leucophloia subsp. *leucophloia*	X	X	X	X	X	X	X	X	X	X	X			
Eucalyptus victrix	X	X	X	X	X	X		X	X	X	X	X		
Eucalyptus xerothermica	X	X	X					X		X	X			

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Melaleuca argentea	X	X	X			X				X				
Melaleuca glomerata	X	X	X	X	X	X			X	X				
Family: Nyctaginaceae														
Boerhavia burbidgeana	X													
Boerhavia coccinea	X	X	X		X	X	X			X	X	X		
Boerhavia gardneri	X									X				
Boerhavia repleta	X										X			
Family: Oleaceae														
Jasminum didymum subsp. *lineare*	X	X	X	X	X	X	X	X	X	X				
Family: Oxalidaceae														
**Oxalis corniculata*														X
Family: Papaveraceae														
**Argemone ochroleuca* subsp. *ochroleuca*	X	X	X		X	X				X				X
Family: Phrymaceae														
Peplidium sp. E Evol. Fl. Fauna Arid Aust. (A.S. Weston 12768)										X				
Family: Phyllanthaceae														
Notoleptopus decaisnei (insufficient material to determine variety)		X			X	X		X						
Notoleptopus decaisnei var. *decaisnei*	X	X	X							X	X	X		
Notoleptopus decaisnei var. *orbicularis* (A.B. Craig 428)	X	X	X											
Phyllanthus erwinii	X	X	X		X	X	X			X	X	X		
Phyllanthus maderaspatensis	X	X	X	X	X	X	X	X		X	X	X		
Phyllanthus reticulatus							X							
Family: Plantaginaceae														
Stemodia grossa	X	X	X	X	X	X	X	X		X	X	X		
Family: Poaceae														
Acrachne racemosa	X						X					X		
Amphipogon sericeus	X	X	X		X	X	X	X		X				
Aristida contorta	X	X	X		X	X	X	X		X	X	X		
Aristida holathera var. *holathera*	X	X	X		X	X	X	X	X	X	X			
Aristida hygrometrica	X													
Aristida inaequiglumis	X	X	X		X		X		X	X	X			
Aristida ingrata	X	X			X	X								
Aristida latifolia	X									X	X			

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Aristida pruinosa	X		X				X							
Aristida sp. (insufficient material for further determination)	X						X							
Bothriochloa ewartiana	X	X			X		X				X			
Brachyachne prostrata	X													
**Cenchrus ciliaris*	X	X	X	X	X	X	X	X	X	X	X	X		X
**Cenchrus clandestinus*														X
**Cenchrus setiger*	X		X				X				X	X		X
Chloris pectinata	X										X			
**Chloris barbata*														X
**Chloris virgata*								X						X
Chloris sp. (insufficient material for further determination)		X			X									
Chrysopogon fallax	X	X	X		X	X	X	X		X	X			
Cymbopogon ambiguus	X	X	X	X	X	X	X	X	X	X	X	X		
Cymbopogon obtectus	X	X	X		X	X	X	X	X	X	X			
Cymbopogon procerus	X	X	X		X	X				X				
Cymbopogon sp. (sterile; insufficient material for further determination)	X	X	X		X									
**Cynodon dactylon*		X								X				X
Dactyloctenium radulans	X										X			
Dichanthium sericeum subsp. *humilius*	X	X				X	X			X				
Digitaria brownii	X	X	X		X	X	X			X		X		
Digitaria ctenantha	X	X	X		X	X	X			X		X		
Elytrophorus spicatus										X				
Enneapogon caerulescens	X	X	X		X	X	X	X		X				
Enneapogon lindleyanus	X	X	X		X	X	X			X				
Enneapogon polyphyllus	X	X	X		X	X	X	X		X	X	X		
Enneapogon robustissimus	X	X	X		X		X	X		X		X		
Enneapogon sp. (insufficient material for further determination)			X		X									
Enteropogon ramosus	X	X	X		X		X			X	X			
Eragrostis cumingii	X	X	X		X	X	X	X		X	X	X		
Eragrostis desertorum	X													
Eragrostis dielsii	X									X				
Eragrostis elongata	X	X	X											

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Eragrostis eriopoda	X	X	X		X	X	X	X		X	X		X	
Eragrostis falcata	X													
Eragrostis leptocarpa	X									X				
Eragrostis pergracilis	X									X	X			
Eragrostis setifolia	X	X			X						X			
Eragrostis tenellula	X	X	X		X		X			X	X	X		
Eragrostis xerophila	X						X							
Eriachne aristidea	X	X	X		X	X	X	X	X	X	X		X	
Eriachne lanata	X	X	X		X			X	X	X				
Eriachne mucronata (form not determined)		X	X					X		X				
Eriachne mucronata (arid form) (MET 12 736)	X	X	X				X		X	X				
Eriachne mucronata (typical form)	X	X	X	X	X	X	X			X	X	X		
Eriachne pulchella	X	X	X		X	X	X	X		X	X	X		
Eriachne tenuiculmis	X	X	X	X	X	X		X	X	X				
Eulalia aurea	X	X	X		X	X	X	X		X	X			
Eulalia sp. (Three Rivers Station, B. Forsyth AQ6789133)	X		X											
Heteropogon contortus										X				
Iseilema dolichotrichum	X		X											
Iseilema macratherum	X										X			
Iseilema membranaceum	X	X			X		X							
Iseilema vaginiflorum	X									X				
Panicum effusum	X													
Paraneurachne muelleri	X	X	X	X	X	X	X	X	X	X	X	X		
Paspalidium basicladum	X						X			X				
Paspalidium clementii	X	X	X		X	X	X			X	X	X		
Paspalidium constrictum		X	X		X					X				
Paspalidium rarum	X		X											
Paspalidium tabulatum		X				X								
**Paspalum dilatatum*														X
Perotis rara	X	X	X		X	X	X			X	X	X		
Schizachyrium fragile	X	X	X		X	X	X	X		X				
Setaria dielsii	X	X	X		X	X				X				
Setaria surgens	X	X								X				
**Setaria verticillata*	X	X	X		X	X	X	X		X	X	X		X

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Sorghum plumosum var. *plumosum*	X	X	X			X								
Sporobolus actinocladus										X				
Sporobolus australasicus	X	X	X		X	X	X	X		X	X	X		
Themeda triandra	X	X	X	X	X	X	X	X	X	X	X	X		
Themeda sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3)										X				
Themeda sp. Mt Barricade (M.E. Trudgen 2471)	X													
Tragus australianus	X	X			X						X	X		
Triodia angusta	X		X											
Triodia basedowii	X	X	X		X		X	X	X	X	X			
Triodia biflora		X												
Triodia brizoides	X	X	X	X										
Triodia epactia	X							X				X		
Triodia longiceps	X	X	X		X		X	X		X	X	X		
Triodia pungens	X	X	X	X	X	X	X	X	X	X	X	X	X	
Triodia schinzii	X		X											
Triodia wiseana	X	X	X	X	X	X	X	X	X	X	X			
Triodia sp. Shovelanna Hill (S. van Leeuwen 3835)	X	X	X	X	X	X	X	X	X	X	X			
Tripogon loliiformis	X	X			X									
Triraphis mollis	X	X	X		X		X			X				
Urochloa holosericea subsp. *velutina*	X													
Urochloa occidentalis var. *occidentalis*	X		X											
Urochloa piligera	X	X	X		X						X			
Urochloa subquadripara	X													
Yakirra australiensis var. *australiensis*	X	X			X									
Family: Polygalaceae														
Polygala glaucifolia	X	X	X		X	X				X	X			
Family: Polygonaceae														
**Acetosa vesicaria*	X	X			X	X		X		X				X
Family: Portulacaceae														
Calandrinia ptychosperma	X		X				X			X	X			
Calandrinia sp. (insufficient material for further determination)	X													
Portulaca filifolia	X													
Portulaca intraterranea	X	X												

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Portulaca oleracea/intraterranea	X	X	X		X	X	X			X	X	X		
Portulaca pilosa	X						X			X	X			
Family: Proteaceae														
Grevillea berryana	X								X					
Grevillea pyramidalis subsp. *leucadendron*	X	X			X	X			X					
Grevillea wickhamii (sterile; subsp. not determined)		X	X	X	X	X		X	X	X				
Grevillea wickhamii subsp. *aprica*		X	X							X				
Grevillea wickhamii subsp. *hispidula*	X	X	X		X	X	X			X	X			
Grevillea wickhamii subsp. *macrodonta*		X												
Hakea chordophylla	X	X	X	X	X	X	X	X	X	X	X			
Hakea lorea subsp. *lorea*	X	X	X	X	X	X	X	X	X	X	X		X	
Family: Pteridaceae														
Cheilanthes austrotenuifolia								X						
Cheilanthes brownii	X	X			X	X								
Cheilanthes contigua	X	X	X			X								
Cheilanthes lasiophylla								X						
Cheilanthes sieberi subsp. *pseudovellea*	X													
Cheilanthes sieberi subsp. *sieberi*	X	X		X	X		X	X		X				
Family: Rubiaceae														
Oldenlandia crouchiana	X	X	X		X	X				X				
Psydrax latifolia	X						X			X	X			
Psydrax suaveolens	X						X							
Spermacoce brachystema	X						X				X			
Synaptantha tillaeacea var. *tillaeacea*	X	X				X					X	X		
Family: Santalaceae														
Anthobolus leptomerioides	X	X	X		X		X	X		X				
Santalum lanceolatum	X	X			X	X			X	X				
Santalum spicatum	X										X			
Family: Sapindaceae														
Alectryon oleifolius subsp. *oleifolius*	X													
Atalaya hemiglauca	X	X	X	X		X	X	X	X	X	X	X	X	
Dodonaea coriacea	X	X	X			X	X	X	X	X	X			
Dodonaea lanceolata var. *lanceolata*	X						X				X			
Dodonaea petiolaris	X									X				

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Dodonaea viscosa	X		X											
Family: Scrophulariaceae														
Eremophila forrestii subsp. *forrestii*	X						X	X		X	X			
Eremophila forrestii x *latrobei*	X	X			X									
Eremophila fraseri subsp. *fraseri*	X	X	X		X			X	X	X				
Eremophila jucunda subsp. *pulcherrima*	X						X							
Eremophila lanceolata	X						X				X			
Eremophila latrobei subsp. *filiformis*	X	X			X	X	X	X		X	X			
Eremophila latrobei subsp. *glabra*	X	X			X		X		X					
Eremophila latrobei subsp. *latrobei*	X	X						X						
Eremophila longifolia	X	X	X		X	X	X	X		X	X			
Family: Solanaceae														
**Datura leichhardtii*	X									X	X			X
Nicotiana benthamiana	X	X			X					X				
Nicotiana occidentalis subsp. *obliqua*	X									X				
Nicotiana occidentalis subsp. *occidentalis*	X	X			X	X	X				X			
Nicotiana rosulata	X						X							
Nicotiana simulans	X		X				X							
Solanum centrale										X				
Solanum cleistogamum	X									X				
Solanum elatius	X		X				X				X			
Solanum gabrielae										X				
Solanum horridum	X	X	X		X	X	X	X	X	X	X	X		
Solanum lasiophyllum	X	X	X		X	X	X	X	X	X	X	X	X	
**Solanum nigrum*	X		X		X	X	X	X		X				X
Solanum phlomoides	X	X	X	X	X	X	X	X	X	X		X		
Solanum sp. (insufficient material for further determination)	X		X											
Family: Surianaceae														
Stylobasium spathulatum	X	X	X		X		X	X		X				
Family: Typhaceae														
Typha domingensis	X	X	X	X				X		X				
**Typha orientalis*														X
Family: Violaceae														
Hybanthus aurantiacus	X	X	X	X	X	X	X	X	X	X	X			

Species (Ordered by Family)	Biota 2014a	Biota 2014b	Biota 2014c	Biota 2011	Biota 2010 (JSW)	Biota 2010 (YOX)	Biota 2009a	Biota 2009b	Biota 2005	Biota 2004a	Biota 2004b	Biota 2002	HGM 2000	Rio Tinto Database
Family: Zygophyllaceae														
Tribulopis angustifolia	X	X									X			
Tribulus astrocarpus	X										X	X		
Tribulus hirsutus	X	X	X		X	X			X		X			
Tribulus macrocarpus	X	X	X		X	X	X			X	X			
Tribulus platypterus	X	X	X			X								
Tribulus suberosus	X	X	X	X	X	X	X	X	X	X				
**Tribulus terrestris*	X	X									X			X
Tribulus sp. (insufficient material for further determination)	X													
Zygophyllum eichleri	X	X			X		X							

Opportunistic Fungi Records from the Study Area	
Family Sclerodermataceae	*Pisolithus albus*
Family Polyporaceae	*Pycnoporus coccineus*
Family Agaricaceae	*Podaxis pistillaris*

Appendix 6

Vegetation Condition Mapping and Weed Locations

Introduced Flora

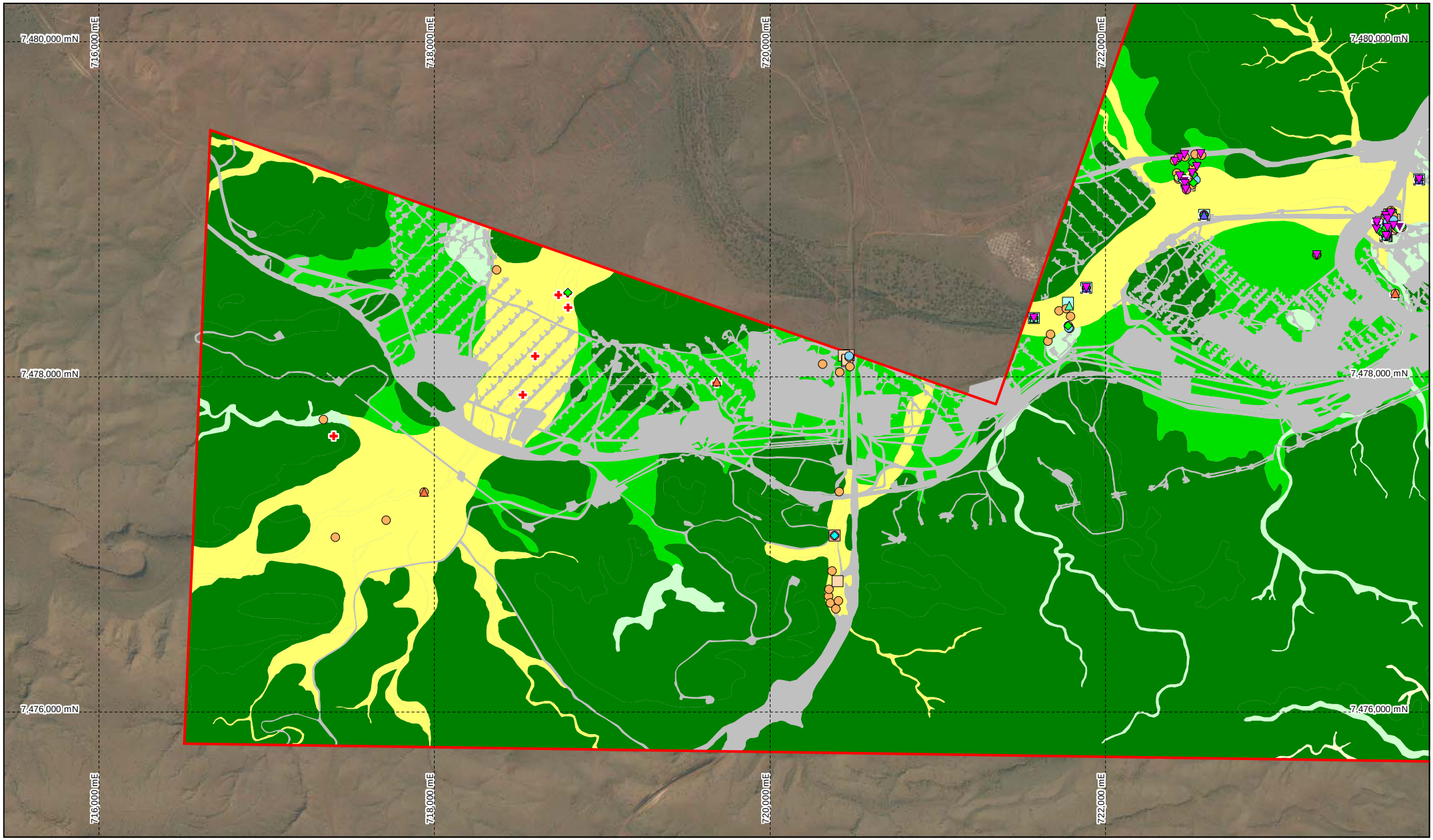
- *Acetosa vesicaria
- *Aerva javanica
- *Alternanthera pungens
- *Argemone ochroleuca subsp. ochroleuca
- *Bidens bipinnata
- *Catharanthus roseus
- *Cenchrus ciliaris
- *Cenchrus clandestinus
- *Cenchrus setiger
- *Chloris barbata
- *Chloris virgata
- *Citrullus colocynthis
- *Citrullus aff. lanatus
- *Citrullus lanatus
- *Conyza bonariensis
- *Cynodon dactylon
- *Datura leichhardtii
- *Euphorbia hirta
- *Flaveria trinervia
- *Lactuca serriola
- *Lotus sp.
- *Malvastrum americanum
- *Oxalis corniculata
- *Paspalum dilatatum
- *Ricinus communis
- *Setaria verticillata
- *Sigesbeckia orientalis
- *Sisymbrium irio
- *Sisymbrium orientale
- *Solanum nigrum
- *Sonchus asper
- *Sonchus oleraceus
- *Tribulus terrestris
- *Tridax procumbens
- *Typha orientalis
- *Vachellia farnesiana

Vegetation Condition

- Excellent
- Excellent to Very Good
- Excellent to Good
- Very Good
- Very Good to Good
- Good
- Good to Very Poor
- Poor to Very Poor

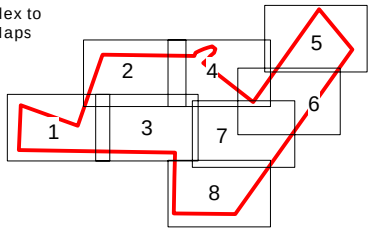
Vegetation Condition Scale and Introduced Flora Records for the Yandi Billiards Integrated Vegetation Condition Maps

Biota Environmental Sciences



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

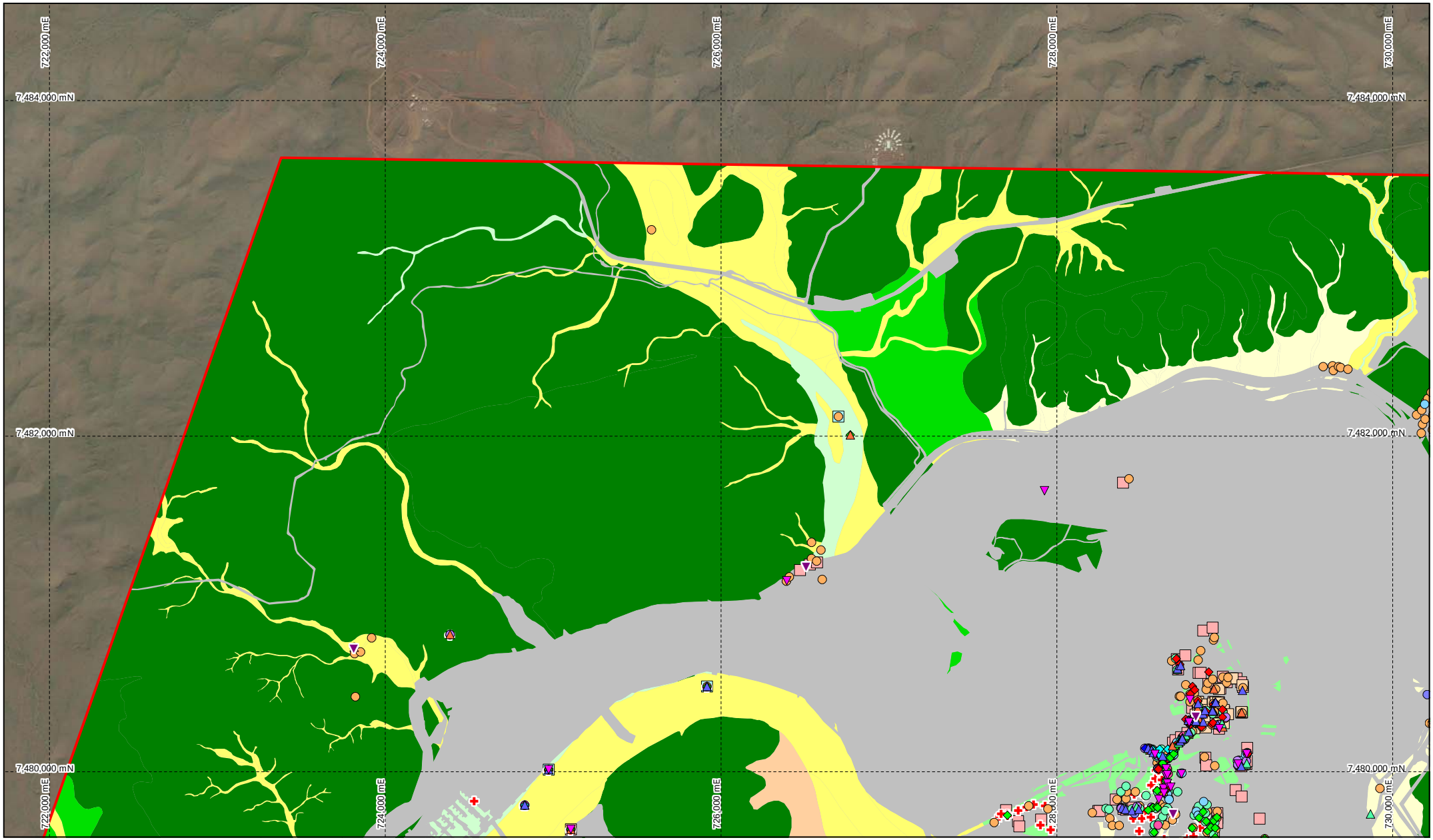
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 1

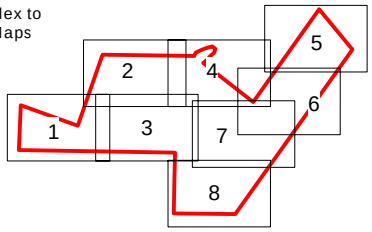
Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

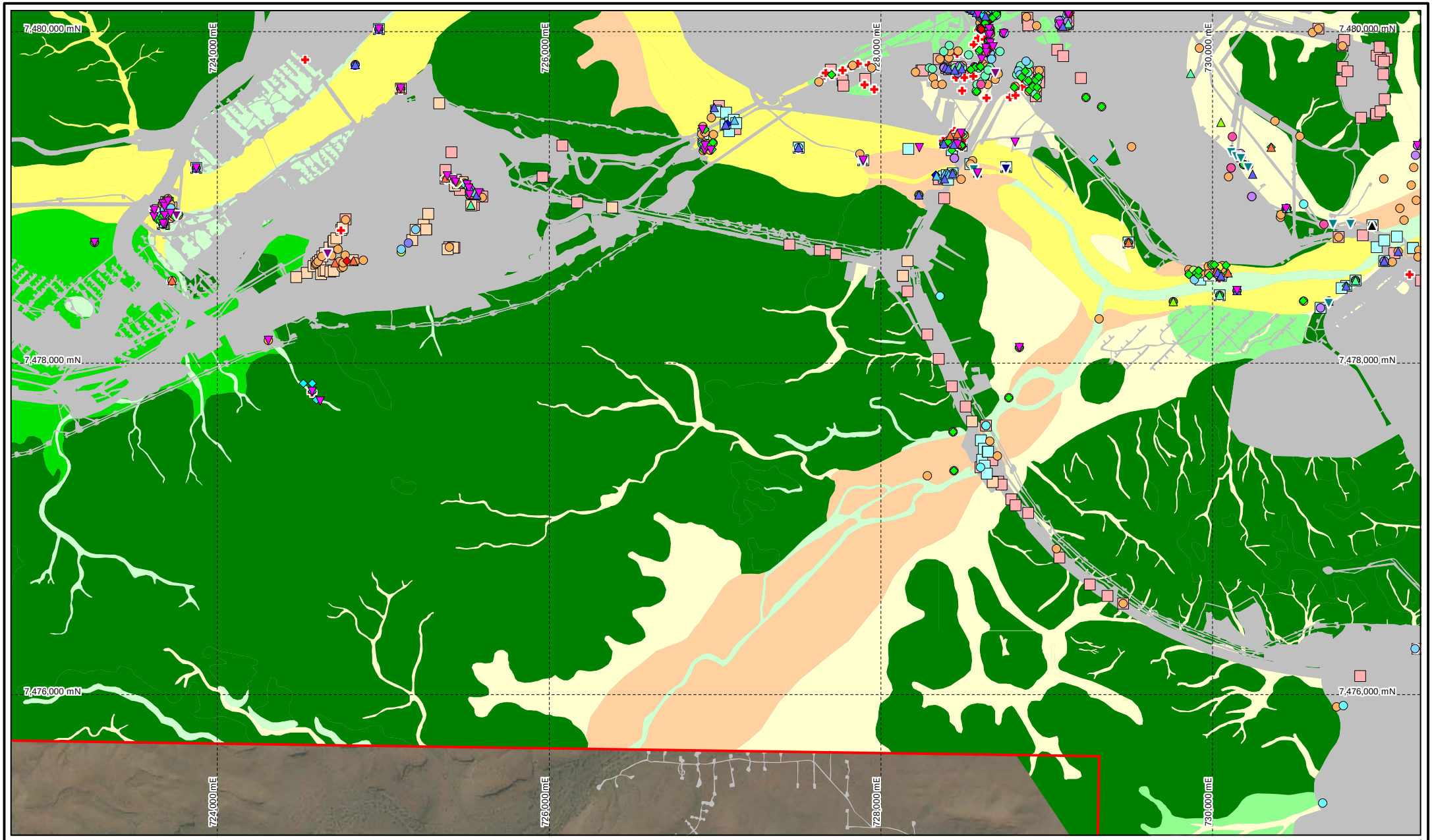
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 2

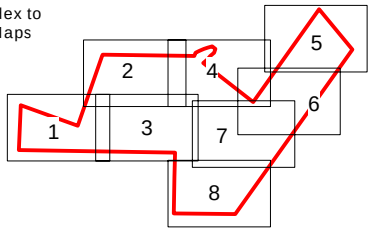
Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

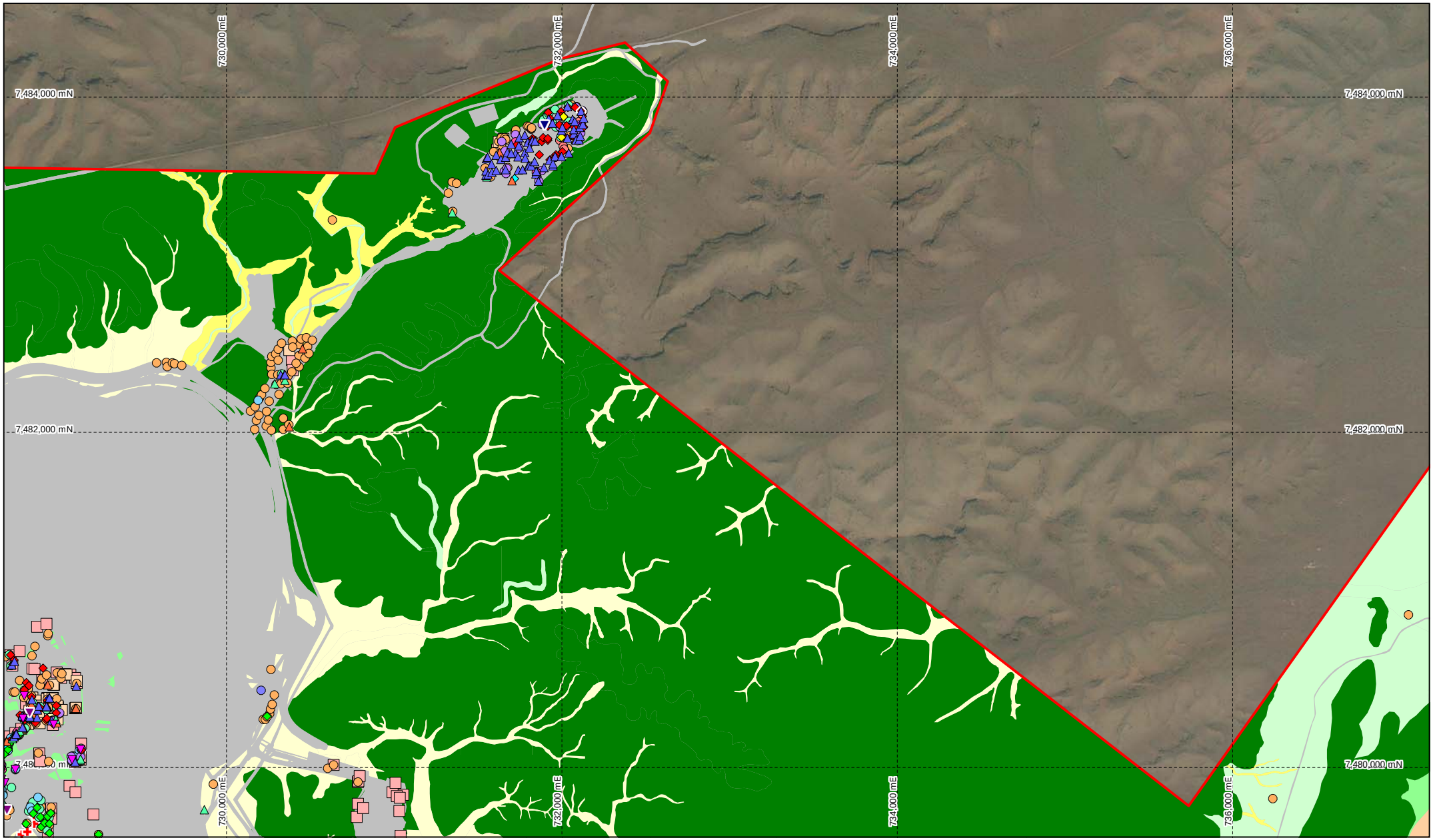
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 3

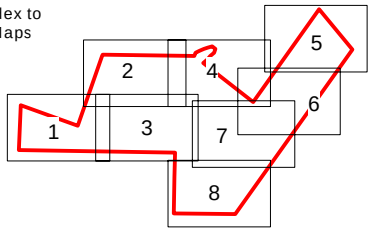
Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

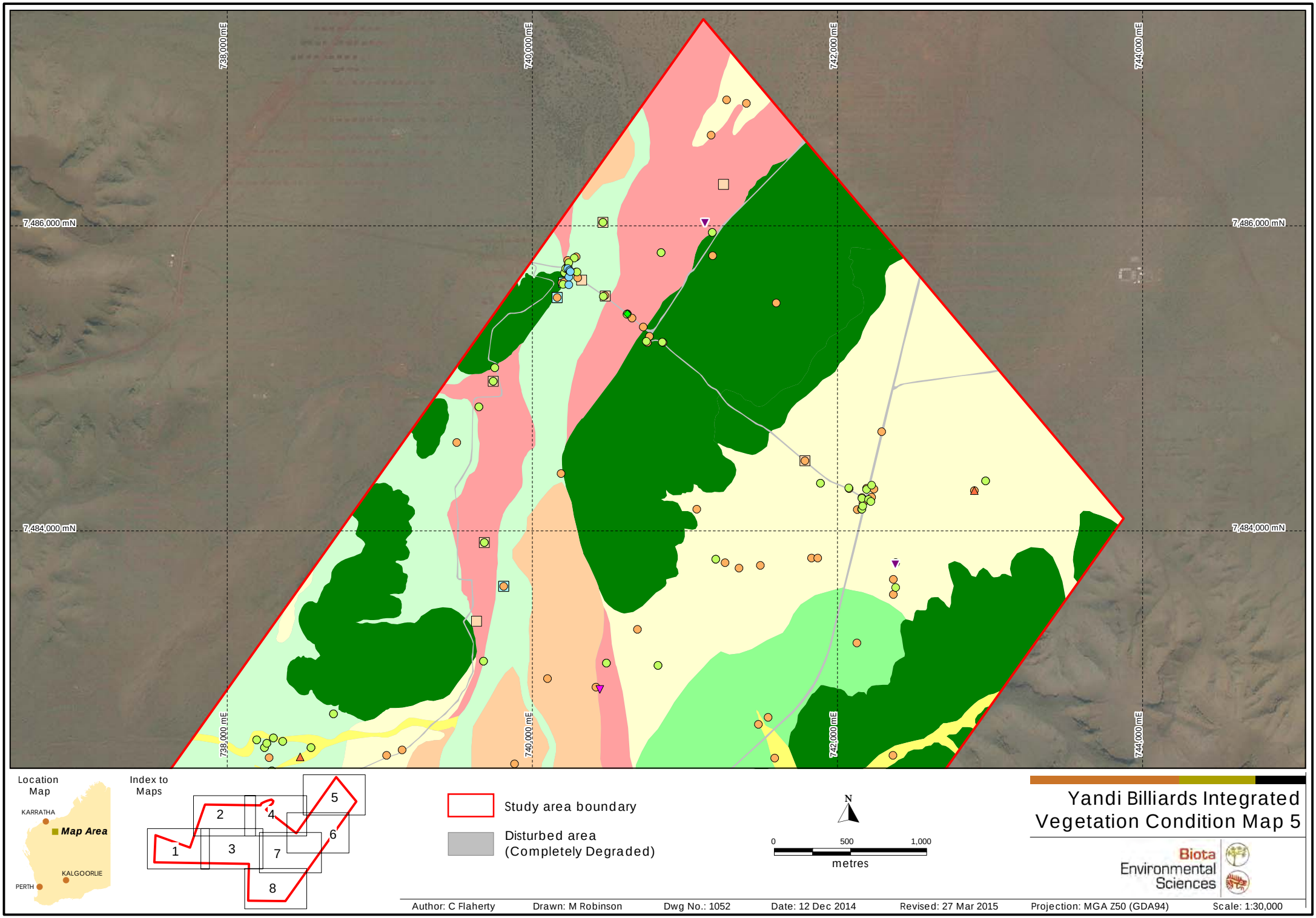
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 4

Biota Environmental Sciences

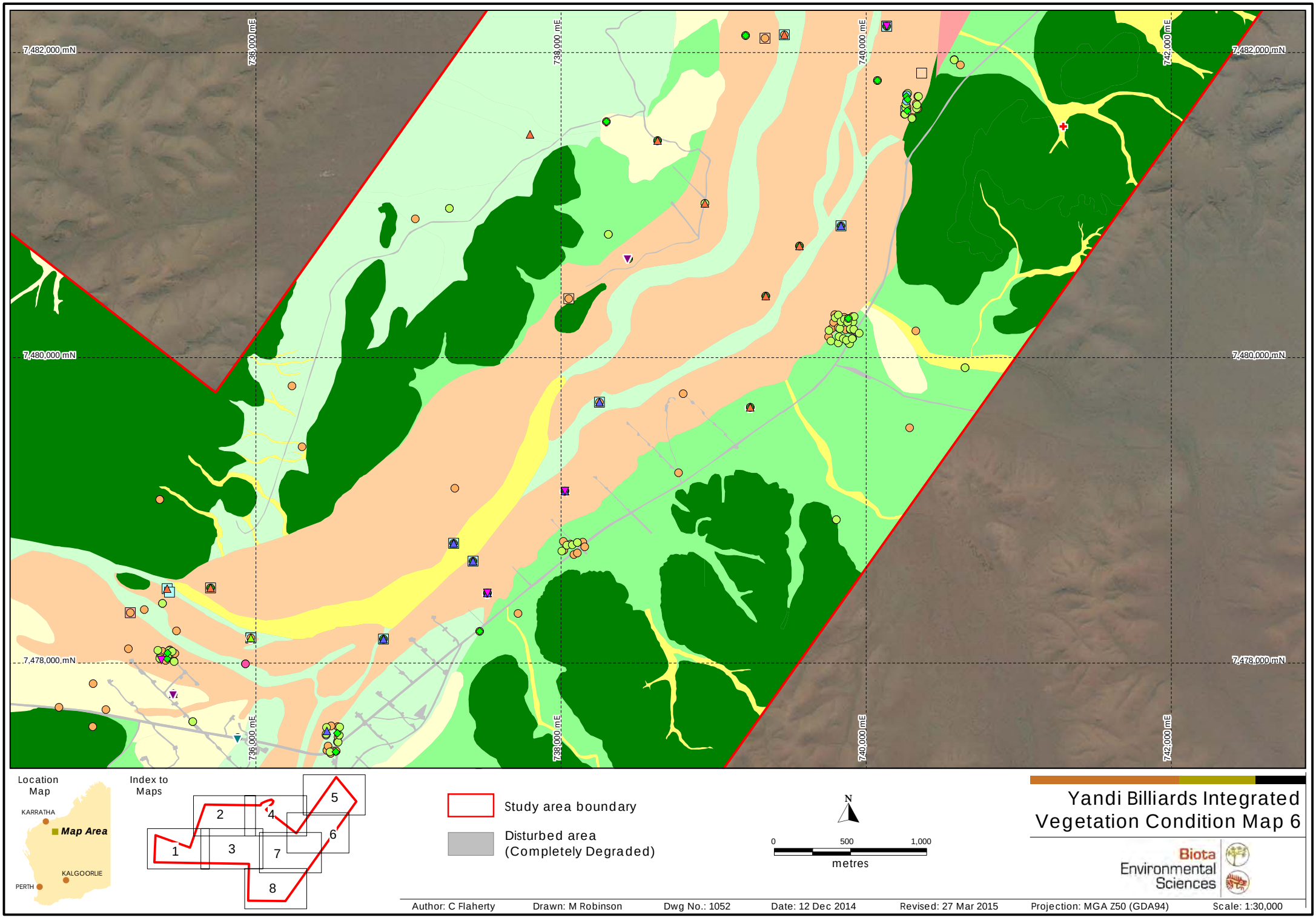
Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000

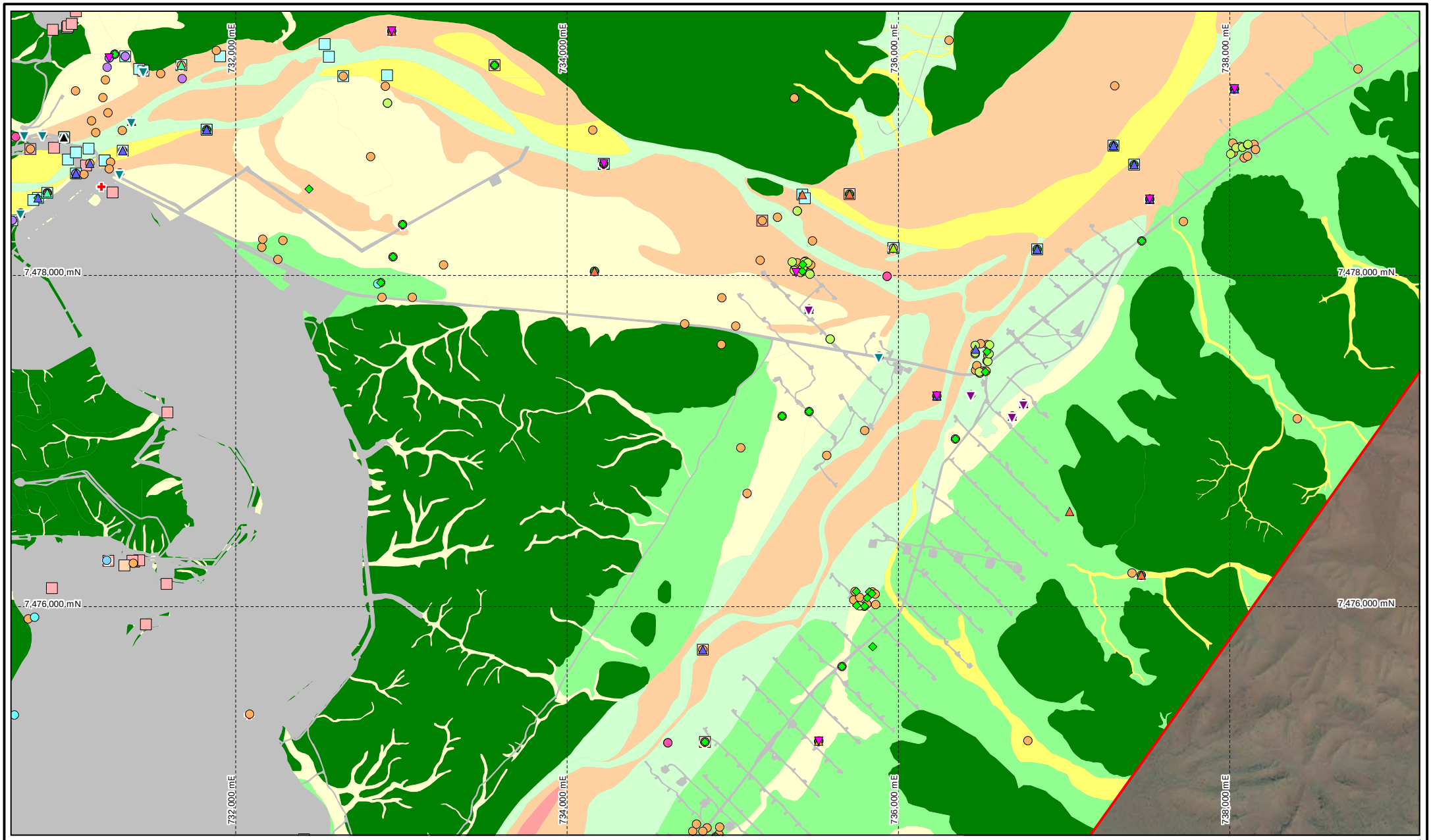


Yandi Billiards Integrated Vegetation Condition Map 5

Biota Environmental Sciences

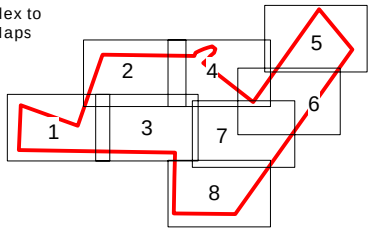
Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000


7,482,000 mN
7,480,000 mN
7,478,000 mN
736,000 mE
738,000 mE
740,000 mE
742,000 mE
Location Map
KARRATHA
Map Area
KALGOORLIE
PERTH
Index to Maps
1
2
3
4
5
6
7
8
Study area boundary
Disturbed area (Completely Degraded)
N
0
500
1,000
metres
Yandi Billiards Integrated Vegetation Condition Map 6
Biota Environmental Sciences
Author: C Flaherty
Drawn: M Robinson
Dwg No.: 1052
Date: 12 Dec 2014
Revised: 27 Mar 2015
Projection: MGA Z50 (GDA94)
Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

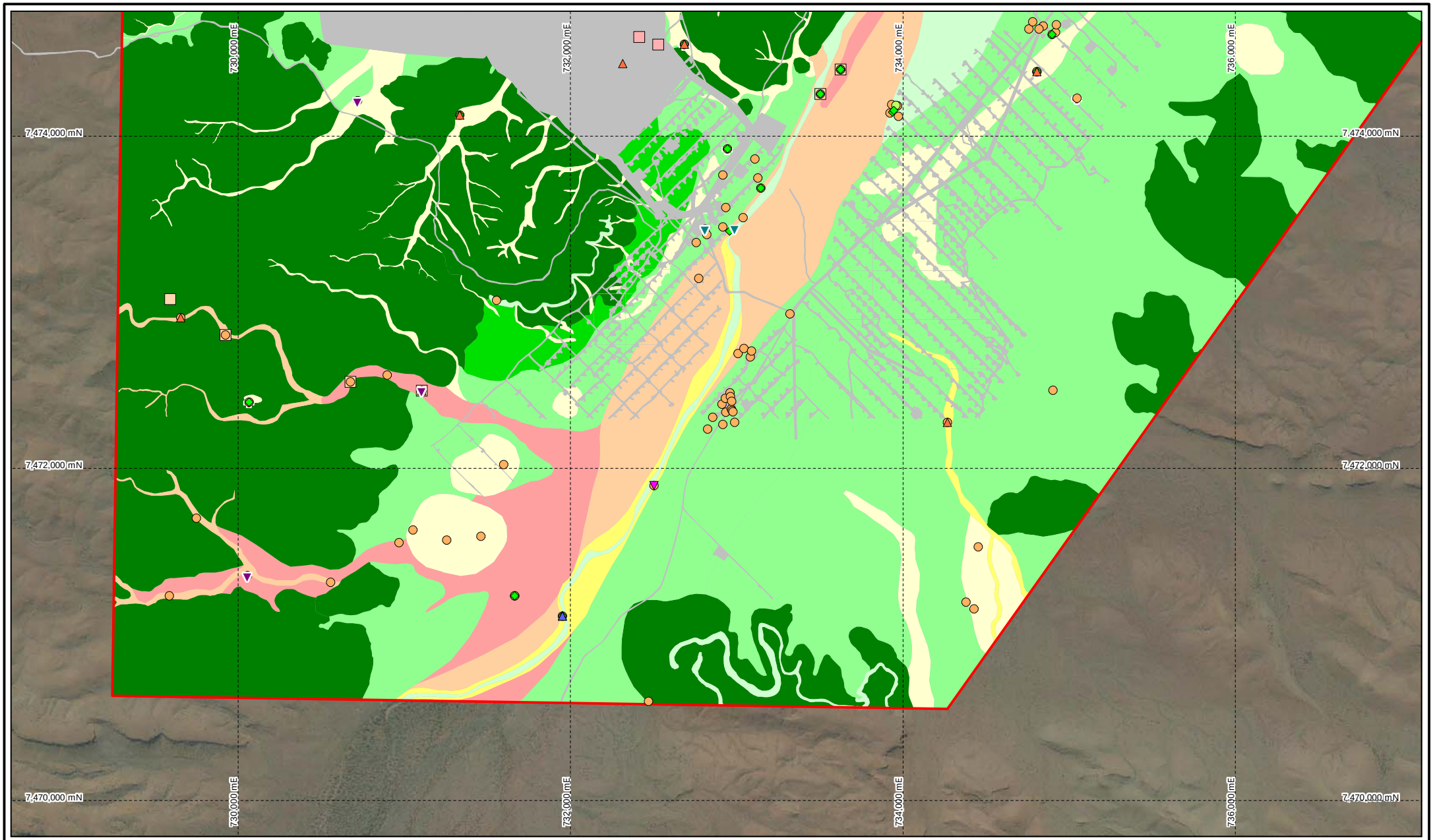
0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 7

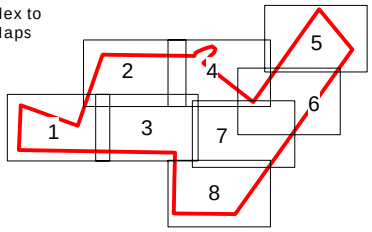
Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000



Location Map

Index to Maps



Study area boundary

Disturbed area (Completely Degraded)

N

0 500 1,000

metres

Yandi Billiards Integrated Vegetation Condition Map 8

Biota Environmental Sciences

Author: C Flaherty | Drawn: M Robinson | Dwg No.: 1052 | Date: 12 Dec 2014 | Revised: 27 Mar 2015 | Projection: MGA Z50 (GDA94) | Scale: 1:30,000

Appendix 7

Poorly Collected, Variable or Incompletely Resolved Taxa

Taxon	Reason	Specimen Lodged with WA Herbarium?
Poorly Collected Taxa		
Euphorbia australis var. *australis*	The current vouchered specimens of this taxon are predominantly from coastal locations, with only one vouchered record from the central Pilbara. Two specimens keying to *Euphorbia australis* var. *australis* were collected from the study area, both of which were confirmed by Andrew Perkins (taxonomist with the WA Herbarium).	Yes
Glycine sp. aff. *arenaria*	One specimen of a creeper with affinities to *G. arenaria* was collected. To date, no specimens of *G. arenaria* have been vouchered from outside the northern Kimberley (see Section 5.4.3).	Yes
Heliotropium glabellum	Five specimens keying to *Heliotropium glabellum* were collected from the study area. Although this species is widespread through the Kimberley, it is uncommon in the Pilbara, with only a few voucher records from the far east of the region.	Yes
Peripleura hispidula var. *hispidula*	A single specimen keying to *Peripleura hispidula* var. *hispidula* was collected from the study area, however this taxon had not previously been considered to occur in WA. Equivalent material has been recorded from other survey areas in the Pilbara, including near West Angelas (Biota 2014d), and has been confirmed as this taxon by Andrew Perkins (taxonomist with the WA Herbarium).	Yes
Sida sp. A Kimberley Flora (P.A. Fryxell & L.A. Craven 3900)	One specimen identified as this species was collected from the study area. This species occurs largely in the Kimberley, with one record known from the Pilbara (in the Bungaroo Valley near Pannawonica, approximately 300 km from the study area).	Yes
**Sisymbrium irio*	This weed species is known from much of the south west and central WA but there are currently no vouchered specimens from the Pilbara region. This species has been previously recorded in the region (Biota unpubl. data).	No; voucher specimen rejected.
Variable Taxa		
Abutilon lepidum	Three apparently undescribed entities in this species were identified by Malcolm Trudgen (M.E. Trudgen and Associates) amongst material from the study area, all of which are widespread and not believed to be of conservation significance: *Abutilon* aff. *lepidum* (1) (MET 15352), *A.* aff. *lepidum* (2) (MET 15970) and *A.* aff. *lepidum* (4). For the purpose of this report, they are recognised as one entity: *Abutilon lepidum* sens. lat.	Yes: *A.* aff. l*epidum* (4).
**Citrullus* aff. *lanatus*	One specimen collected from the study area was identified by Malcolm Trudgen (M.E. Trudgen and Associates) to represent a variation of **Citrullus lanatus.* The specimen was sterile and a juvenile with the cotyledons still present.	Yes
Eriachne mucronata	Two forms of *Eriachne mucronata* were present in the study area: the 'typical form' (culms with sparse erect hairs), and one designated as 'arid form' (which has white woolly hairs on the culms). Both forms are widespread in the Pilbara bioregion and commonly collected. Although not formally recognised, they have been treated as separate entities for this report since they are clearly distinguishable.	No
Gossypium australe	Two apparently undescribed forms of *Gossypium* were recorded from the study area: *G. australe* (Burrup Peninsula form) and *G. australe* (Whim Creek form). These entities are widespread in the Pilbara. For the purpose of this report they have been recognised as a single entity: *Gossypium australe*.	No
Heliotropium pachyphyllum	One specimen was collected from the study area that has characters intermediate between *H. pachyphyllum* and *H. ovalifolium*. This entity is designated *Heliotropium* aff. *pachyphyllum* in this report.	Yes

Taxon	Reason	Specimen Lodged with WA Herbarium?
Hibiscus coatesii	Considerable variation is observed within Pilbara specimens of this taxon. Two apparently undescribed entities were identified from the study area, both of which are widespread: *Hibiscus* aff. *coatesii* (MET 16,542) and *H.* aff. *coatesii* (site 664). For the purpose of this report, they are recognised as a single entity: *Hibiscus coatesii.*	Yes: *H.* aff. *coatesii* (site 664).
Hibiscus sturtii	Considerable variation is observed within the Pilbara specimens of this taxon. One apparently undescribed taxon, *Hibiscus* aff. sturtii (HD7-11), was identified from the study area. This entity is widespread and for the purpose of this report is recognised as *Hibiscus sturtii*.	No
Indigofera monophylla	Several forms of *Indigofera monophylla* were identified by Malcolm Trudgen (M.E. Trudgen and Associates) amongst the specimens from the study area. All forms are considered to be widespread in the Pilbara. For the purpose of this report, the different forms of *Indigofera monophylla* have not been distinguished and they are referred to as a single entity.	Yes: brown calyx form and small leaflet form.
Polymeria ambigua	One taxon that represents a variation of *P. ambigua* was recorded from the study area: *Polymeria* aff. *ambigua* (PAN 26B-20). For the purpose of the report, this entity is designated as *P. ambigua*.	Yes
Senna artemisioides subsp. *oligophylla* (thinly sericeous form MET 15,035)	This taxon is a form of *Senna artemisioides* subsp. *oligophylla* recognised by Malcolm Trudgen (M.E. Trudgen and Associates), which can be distinguished by the very appressed hairs on the leaflets. Although not formally recognised, this taxon has been included in this report because it appears distinctly different from *S. artemisioides* subsp. *oligophylla* and is easily recognised. It also occurred in the study area as a hybrid with *Senna artemisioides* subsp. *helmsii*.	No
Sida echinocarpa	One taxon that represents a variation of *Sida echinocarpa* was recorded from the study area*: Sida* aff. *echinocarpa* (MET 15,350). For the purpose of this report, this entity is designated as *S. echinocarpa.*	Yes
Sida fibulifera sens. lat.	*Sida fibulifera* is a recognised species complex. In past surveys, six apparently undescribed entities were identified from the study area: *Sida* aff. *fibulifera* (FMG 125-20), *S.* aff. *fibulifera* (HD12-39), *S.* aff. *fibulifera* (HD237-9), *S.* aff. *fibulifera* (oblong; MET 15 220), *S.* aff. *fibulifera* (site 1394) and *Sida* aff. *fibulifera* (prostrate A.A. Mitchell 3 572). None of these taxa are considered to be rare, and it is likely that more entities exist within this group. For the purpose of this report, all entities have been assigned to *Sida fibulifera* sens. lat.	No
Triodia basedowii	Following a discussion with Dr Matthew Barrett (Kings Park and Botanic Garden), all specimens of *Triodia lanigera* collected from the study area have been re-determined as *T. basedowii*. A relevant specialist taxonomist will be consulted for further confirmation.	No
Incompletely Resolved Taxa		
Goodenia nuda/triodiophila	Two collections of *Goodenia* could not be confidently distinguished between these two species (see Section 5.4.3).	Yes
Portulaca oleracea/Portulaca intraterranea	The taxonomy of "*Portulaca oleracea*" in the Pilbara is currently unresolved. It is not clear whether specimens from this region with weakly developed tubercles on the seeds belong to *Portulaca oleracea, P. intraterranea* and/or one or more undescribed taxa (S. Dillon, WA Herbarium, pers. comm. 2012). For the purposes of this report, all specimens have been allocated to "*Portulaca oleracea/P. intraterranea*", with the exception of a single specimen that was confirmed as *P. intraterranea* by Andrew Perkins (WA Herbarium taxonomist). The latter specimen was conspicuously different to the other specimens designated as "*Portulaca oleracea/intraterranea*", having seeds with very prominent elongated tubercles with star-shaped bases.	Yes

Taxon	Reason	Specimen Lodged with WA Herbarium?
Sorghum plumosum var. *plumosum*	One specimen collected from the study area that was identified as *Sorghum plumosum* var. *plumosum* by Malcolm Trudgen (M.E. Trudgen and Associates) was noted to have some unusual features for this species. The taxonomy of this genus is in need of review.	No. Specimen was of poor quality but was returned to Malcolm Trudgen for future reference.

Appendix 8

Selected PRIMER Inputs and Outputs

Table 1: Sites included in the PRIMER dataset. † Floristic groups containing sites only from the Yandi study area are highlighted in green.

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
ADD05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bf
ADD06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	bb
ADD07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	az	an	at
ADD09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ah	az	bc	bb
ADD13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD46	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD53	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	az	an	at
ADD54	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	az	an	at
ADD55	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD56	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	ay	an	av
ADD57	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
ADD58	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	bb
ADD59	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD60	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bn
ADD61	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD62	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
ADD63	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ah	bc	bc	bb
ADD70	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
ADD71	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
ADD-RCAA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
BEL01	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	y	bi	ag
BEL02	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	y	bi	ag
BEL03	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	ac	bc	aj
BEL04	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	bb
BEL05	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bb	aj
BEL06	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	aj
BEL07	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	ag
BEL08	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	ac	bc	ag
BEL09	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	y	bi	az
BEL10	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	ac	bm	az
BEL11	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	ak	o	by
BEL12	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	k	u	f	ae
BEL13	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bh	ar	h	ai
BEL14	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	af	ar	at	ah
BEL15	Quadrat	Biota (2009c)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bi	ar	h	ag
BELJ13	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	ag
BELJ14	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	c	bm	b
BELJ15	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	at	o	bs
BELJ16	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	ac	bi	ag

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
BELJ17	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	w	o	ag
BELJ18	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	w	bi	ag
BELJ19	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bi	ad	j	s
BELJ20	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	y	bi	ag
BELJ21	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aa	ac	bi	ag
BELJ22	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	v	ac	as	ag
BELJ24	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	m	bc	u	aq
BELJ25	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	af	ae	at	t
BELJ26	Quadrat	Biota (2008)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bi	aq	j	bp
BIL01	Quadrat	Biota (2014a)	Inside	Yandi	H3	Hill	bb	af	o	bm
BIL02	Quadrat	Biota (2014a)	Inside	Yandi	C2	Major creek	al	bc	az	bb
BIL03	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bb	am	o	bo
BIL04	Quadrat	Biota (2014a)	Inside	Yandi	H4	Hill	bb	am	o	bo
BIL05	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	ay	w	n	bo
BIL06	Quadrat	Biota (2014a)	Inside	Yandi	H3	Hill	bb	am	o	bm
BIL07	Quadrat	Biota (2014a)	Inside	Yandi	P2	Stony plain	ak	az	bc	bb
BIL08	Quadrat	Biota (2014a)	Inside	Yandi	P2	Stony plain	au	ay	an	at
BIL09	Quadrat	Biota (2014a)	Inside	Yandi	P2	Stony plain	ak	az	bc	bb
BIL10	Quadrat	Biota (2014a)	Inside	Yandi	P2	Stony plain	ak	az	bc	bb
BIL11	Quadrat	Biota (2014a)	Inside	Yandi	F4	Minor creek/floodplain	al	bc	az	bb
BIL12	Quadrat	Biota (2014a)	Inside	Yandi	P9	Stony plain	al	bc	az	bb
BIL13	Quadrat	Biota (2014a)	Inside	Yandi	P9	Stony plain	au	ay	an	at
BIL14	Quadrat	Biota (2014a)	Inside	Yandi	F4	Minor creek/floodplain	al	bc	az	bb
BIL15	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bb	am	o	bn
BIL16	Quadrat	Biota (2014a)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
BIL17	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL18	Quadrat	Biota (2014a)	Inside	Yandi	P5	Stony plain	au	ay	an	bb
BIL19	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL20	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL21	Quadrat	Biota (2014a)	Inside	Yandi	F5	Minor creek/floodplain	ak	bc	az	bb
BIL22	Quadrat	Biota (2014a)	Inside	Yandi	P8	Stony plain	ar	ay	ak	at
BIL23	Quadrat	Biota (2014a)	Inside	Yandi	F2	Minor creek/floodplain	n	bc	t	bb
BIL24	Quadrat	Biota (2014a)	Inside	Yandi	F2	Minor creek/floodplain	n	bc	t	bb
BIL25	Quadrat	Biota (2014a)	Inside	Yandi	P7	Stony plain	bd	az	bh	bb
BIL26	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bi	am	j	bo
BIL27	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bi	bc	j	av
BIL28	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL29	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bb	am	o	bo
BIL30	Quadrat	Biota (2014a)	Inside	Yandi	C3	Major creek	s	bc	ah	aq
BIL31	Quadrat	Biota (2014a)	Inside	Yandi	C2	Major creek	ak	bc	az	bb
BIL32	Quadrat	Biota (2014a)	Inside	Yandi	P6	Stony plain	ae	az	bm	bb
BIL33	Quadrat	Biota (2014a)	Inside	Yandi	P5	Stony plain	au	ay	an	at
BIL34	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL35	Quadrat	Biota (2014a)	Inside	Yandi	F3	Minor creek/floodplain	al	bc	az	bb
BIL36	Quadrat	Biota (2014a)	Inside	Yandi	F3	Minor creek/floodplain	ak	bc	bc	bb
BIL37	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL38	Quadrat	Biota (2014a)	Inside	Yandi	P1	Stony plain	bb	am	o	bn

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							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
BIL39	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bb	am	o	bo
BIL40	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bi	ap	j	ay
BIL41	Quadrat	Biota (2014a)	Inside	Yandi	P9	Stony plain	au	ay	an	at
BIL42	Quadrat	Biota (2014a)	Inside	Yandi	P8	Stony plain	ar	ay	ak	at
BIL43	Quadrat	Biota (2014a)	Inside	Yandi	H1	Hill	bb	am	o	bo
BIL44	Quadrat	Biota (2014a)	Inside	Yandi	H2	Hill	bi	ap	j	bi
BIL45	Quadrat	Biota (2014a)	Inside	Yandi	P9	Stony plain	au	ay	an	at
BIL46	Quadrat	Biota (2014a)	Inside	Yandi	F4	Minor creek/floodplain	al	bc	az	bb
BIL47	Quadrat	Biota (2014a)	Inside	Yandi	F5	Minor creek/floodplain	ak	bc	az	bb
BIL48	Quadrat	Biota (2014a)	Inside	Yandi	P7	Stony plain	bi	ae	j	ax
BIL49	Quadrat	Biota (2014a)	Inside	Yandi	P1	Stony plain	bb	am	o	bn
BIL-RCFA	Relevé	Biota (2014a)	Inside	Yandi	H2	Hill	bc	bc	y	av
BIL-RCFB	Relevé	Biota (2014a)	Inside	Yandi	H5	Hill	ap	w	ar	bu
BIL-RCFC	Relevé	Biota (2014a)	Inside	Yandi	F1	Minor creek/floodplain	am	bc	az	av
BIL-RCFD	Relevé	Biota (2014a)	Inside	Yandi	H5	Hill	ap	am	ar	bu
BIL-RPCA	Relevé	Biota (2014a)	Inside	Yandi	H3	Hill	bb	am	o	bo
BIL-RSPA	Relevé	Biota (2014a)	Inside	Yandi	P6	Stony plain	ae	w	bl	ay
BIL-RSWA	Relevé	Biota (2014a)	Inside	Yandi	F1	Minor creek/floodplain	bc	bc	ay	bb
FMG10	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ay	an	at
FMG12	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ay	an	at
FMG13	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	f	f	bq	l
FMG14	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	f	ap	m
FMG17	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	az
FMG18	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	f	az	bm	az
FMG19	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	az
FMG20	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	c	a	c	d
FMG22	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	ay	bc	an
FMG23	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	p	i	ab	am
FMG24	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	q	i	ab	am
FMG38	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	au	ap	m
FMG40	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	f	f	bq	l
FMG41	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	d	ap	m
FMG42	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	bb
FMG43	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ay	an	at
FMG44	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	bb
FMG45	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	bb
FMG46	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ai	ay	bd	at
FMG47	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ax	an	at
FMG48	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aq	ay	ai	at
FMG49	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	al	bc	az	bb
FMG50	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ay	an	at
FMG51	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	g	az	s	ba
FMG52	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	s	ba
FMG53	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aq	ay	ai	at
FMG54	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	az
FMG55	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	bm	az
FMG56	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	an

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							% Cover	Pres/Abs	% Cover	Pres/Abs
FMG57	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bh
FMG58	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	a	a	c	d
FMG59	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	b	a	c	d
FMG60	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	au	ap	k
FMG63	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	ay	an	at
FMG64	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bb	am	o	bo
FMG65	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aq	ay	ai	at
FMG66	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aj	az	bc	bb
FMG67	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	am	am	bo
FMG68	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	az	ba	bb
FMG69	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bn
FMG70	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	k	q	f	i
FMG71	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	a	a	c	d
FMG72	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	am	bc	az	bw
FMG73	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bn
FMG74	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	q	i	ab	am
FMG75	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bh
FMG84	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bn
FMG85	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	w	bm	az
FMG97	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	k	u	f	j
FMG98	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aj	y	bl	cb
FMG101	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ar	ag	aj	an
FMG102	Quadrat	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bh
FMG-BE	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ae	az	s	ba
FMG-BF	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	m	j	p
FMG-KC	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	n	az	t	ba
FMG-KD	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	k	q	f	j
FMG-KE	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	d	c	a	a
FMG-KF	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	f	g	bo	c
FMG-KG	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	f	g	a	d
FMG-KH	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	d	c	a	d
FMG-MJ	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	k	q	f	h
FMG-RA	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	n	av	t	bb
FMG-RB	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	aq	aw	ai	x
FMG-RD	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	aj	j	bl
FMG-RE	Relevé	Biota (2004d)	Outside	FMG rail / Hope Downs rail	not coded	not coded	y	o	aa	am
H050	Quadrat	HGM (2000a)	Inside	Yandi	C4	Major creek	n	bc	t	aq
H051	Quadrat	HGM (2000a)	Inside	Yandi	C4	Major creek	n	av	t	bb
HDA01	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	bc	ap	aw
HDA02	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	l	ae	ao	t
HDA03	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	t	bc	ax	bb
HDA04	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	ae	j	u
HDA05	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	am	bc	az	bw
HDA06	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bb	am	o	bo
HDA07	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P4	Stony plain	bi	az	j	ax
HDA08	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P6	Stony plain	ae	az	bm	bb
HDA09	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	C4	Major creek	n	av	t	aw

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							% Cover	Pres/Abs	% Cover	Pres/Abs
HDA10	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	w	n	g	o
HDA11	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	o	bc	ad	aq
HDA12	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P5	Stony plain	ae	az	bg	bb
HDA13	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P6	Stony plain	ae	az	bm	bb
HDA14	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P3	Stony plain	ak	az	at	bb
HDA15	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	P4	Stony plain	bi	az	j	ax
HDA16	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	H2	Hill	bb	am	o	bo
HDA17	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	al	j	bn
HDA18	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bb	am	o	bo
HDA19	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	ae	j	u
HDA20	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	t	bc	ah	aq
HDA21	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ab	w	q	ay
HDA22	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	am	j	bn
HDA23	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	am	j	bn
HDA24	Quadrat	Biota (2004b)	Inside	FMG rail / Hope Downs rail	H2	Hill	bb	am	o	bn
HDA25	Quadrat	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	am	bc	az	bb
HDARELA	Relevé	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	an	bc	z	ac
HDARELB	Relevé	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	r	j	ac	e
HDARELM	Relevé	Biota (2004b)	Outside	FMG rail / Hope Downs rail	not coded	not coded	w	n	v	o
HDD01	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	c	a	b	d
HDD02	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	a	a	c	d
HDD03	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	av	bb
HDD04	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	w	bc	x	aq
HDD05	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	r	i	ae	ao
HDD06	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	w	bc	x	aq
HDD07	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	aj	j	bf
HDD08	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	q	i	ae	ao
HDD09	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bh
HDD11	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bc
HDD12	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bc
HDD13	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	c	a	b	d
HDD14	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	ai	bc	q
HDD15	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	bc	x	aq
HDD16	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	u	bc	ah	aq
HDD17	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	an	j	bf
HDD18	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bh
HDD19	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	bc	j	aq
HDD20	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	q	i	ae	ao
HDD21	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ar	ag	ak	an
HDD22	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	u	bc	ah	aq
HDD23	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bh
HDD24	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	ak	aj	bc	bd
HDD25	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bh
HDD26	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	bi	aj	j	bf
HDD27	Quadrat	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	au	aj	an	bh
HDDRELB	Relevé	Biota (2004c)	Outside	FMG rail / Hope Downs rail	not coded	not coded	r	i	ae	ao
JD02	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	y	bl	ah

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
JD13	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	ah	o	br
JD23	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	y	bl	ah
JD30	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ad	y	bl	ak
JD31	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JD32	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ba	am	n	bs
JD33	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	aa	bj	ah
JD34	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JD35	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bl	ah
JD36	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	ah
JD37	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bi	ao	j	bk
JD38	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bf	ae	d	t
JD39	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bi	y	h	ah
JD40	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JD41	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ai	ar	at	bs
JD42	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bl	ah
JD43	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	u	bl	ae
JD44	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	k	u	f	ae
JD45	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	aa	bj	ah
JD46	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JD47	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	k	u	f	ae
JD48	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	l	d	ap	ae
JD49	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	x	bl	ak
JD50	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	at	o	bz
JD51	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bl	ah
JD52	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	y	bl	ah
JD53	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	y	bc	af
JD54	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	y	bj	ah
JD55	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	ar	o	bs
JD56	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	ar	o	bs
JD57	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	ar	bc	bs
JD58	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	y	bl	ah
JD59	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	aa	bc	ah
JD60	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	y	bl	ah
JD61	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JD62	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	l	aa	ap	ah
JD63	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ae	y	bl	ah
JD64	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	k	u	f	ae
JD65	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	aj	am	bc	ah
JD66	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ai	ar	bd	bs
JD-MA	Relevé	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	bb	am	o	bs
JINM01	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ba	bc	n	bw
JINM02	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	ak	o	j
JINM03	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	af	o	bo
JINM04	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	an	j	bi
JINM05	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	p	bc	ag	aq
JINM06	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	an	o	bm
JINM07	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
JINM08	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bo
JINM09	Quadrat	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	au	ay	an	at
JINM-REA	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	am	ba	az	as
JINM-RMA	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ab	x	q	w
JINM-RMB	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	am	bc	az	bw
JINM-RMC	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	e	ba	r	ar
JINM-RMD	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	am	ba	az	as
JINM-RME	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	af	o	bg
JINM-RMF	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	am	o	aq	bt
JINM-RMG	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ak	bc	bc	aq
JINM-RMH	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ae	l	bm	r
JINM-RMI	Relevé	Biota (2011b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	am	o	aq	bt
KAD01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aw	am	l	bo
KAD02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KAD07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KAD08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	am	an	bo
KAD09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bf
KAD11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bl	bb
KAD15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KAD16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KAD-RCEA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KAD-RPSA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	am	bc	az	bb
KCC01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCC02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KCC03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCC04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	bb
KCC05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCC06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	at
KCC07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KCC08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	at
KCC09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KCC10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCC101	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KCC102	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	av
KCC103	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	aq	o	bm
KCC12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCC14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCW01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	am	an	at
KCW03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCW04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCW05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at

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							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KCW06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	az	an	at
KCW08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCW12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KCW14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KCW17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	bb
KCW19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	aa	bm	al
KCW24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	az	an	at
KCW27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KCW28	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW29	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KCW31	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KCW33	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bc	bb
KCW35	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW37	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KCW39	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KEA01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn
KEA02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	k	w	f	bv
KEA03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	bc	an	bb
KEA04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bf
KEA05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bf
KEA06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	av
KEA07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KEA08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KEA09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KEA10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KEA11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	at
KEA12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KEA13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	an	bb
KEA16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KEA17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KEA18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	av
KEA20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KEA21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KEA23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	av
KEA24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn
KEA26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	am	an	at
KEA27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KEA28	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA29	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KEA30	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KEA31	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KEA32	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	bc	an	bb
KEA33	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KEA34	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	av
KEA-RCFA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOC01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KOC02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	aq
KOC09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	u	bc	af	aq
KOC12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bg	am	i	bo
KOC13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	u	bc	af	aq
KOC14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	at	bb
KOC16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	z	bm	az
KOC17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KOC18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KOC19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	y	j	bb
KOC20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	at	bb
KOC21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bs
KOC22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ar	bm	az
KOC23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ar	o	bs
KOC24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ad	ac	bk	az
KOC25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC28	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bg	am	i	bo
KOC29	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ar	o	bs
KOC30	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC31	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ai	ar	bd	bs
KOC32	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	t	bc	ax	aq
KOC33	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bg	bc	i	bn

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KOC34	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	t	bc	ax	aq
KOC35	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC36	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	z	bm	az
KOC37	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ar	o	bs
KOC38	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC39	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ar	h	bs
KOC40	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	z	bm	az
KOC41	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	v
KOC42	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	s
KOC43	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	aq	h	bq
KOC44	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aa	y	bi	ag
KOC45	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ap	j	bl
KOC46	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ai	ar	bd	bs
KOC47	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	s	bc	ah	aq
KOC48	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	s
KOC49	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ap	j	bl
KOC50	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aj	ar	bc	bq
KOC51	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ah	o	bd
KOC52	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bo
KOC53	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC55	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC60	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	v
KOC61	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	l	bc	aw	bb
KOC62	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ai	ar	bd	bs
KOC63	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	ar	h	bs
KOC64	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ar	o	bq
KOC65	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	at	bs
KOC-RCFA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	t	bc	u	aq
KOC-RPLA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bb	bc	av
KOC-RPLB	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bo
KOC-RPLC	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC-RPLD	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOC-RPLE	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	av	bw
KOC-RPLF	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KOC-RPLG	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ac	ac	bl	bb
KOC-RPLH	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	ac	bm	az
KOC-RPLI	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ar	o	bs
KOC-RPLJ	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ar	h	ca
KOC-RPLK	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	s	bc	ah	aq
KOC-RRBA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	u	bc	af	aq
KOD01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOD02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	bb
KOD03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	ac
KOD05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KOD07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KOD08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KOD10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOD11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	al	j	bn
KOD12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aj	v	bc	bo
KOD13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ap	bc	ar	bn
KOD14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bg	bc	i	bn
KOD16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ap	bc	az	bb
KOD17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	bb
KOD18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	r	bc	ad	aq
KOD18BANK	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	r	bc	ad	aq
KOD19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	r	k	ad	f
KOD20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	av
KOD22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOD23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	am	bc	az	bb
KOD25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KOD28	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD29	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn
KOD30	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KOD31	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD32	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD33	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD35	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD36	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	t	ac
KOD37	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD38	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KOD39	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD40	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KOD41	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bn
KOD42	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOD43	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD44	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bb	bc	bb
KOD45	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOD46	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD47	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD48	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD49	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	al	j	bn
KOD50	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD51	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD52	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD53	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD54	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	bc	i	bn

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
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							% Cover	Pres/Abs	% Cover	Pres/Abs
KOD55	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD56	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn
KOD57	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOD58	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bo
KOD59	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	bc	bb
KOD60	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD61	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bn
KOD62	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD63	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOD-RJF	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ap	bc	ar	bx
KOD-RPA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ap	bc	ar	bx
KOE01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	as	ay	al	at
KOE02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KOE03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOE04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOE05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOE06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aj	az	bm	bb
KOE07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOE11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOE13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aj	az	bc	bb
KOE14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	an	j	bf
KOE15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOE16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KOE17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOE20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	e	az	r	a
KOE21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	az	h	bb
KOE22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	h	e	bp	l
KOE23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	n	az	bm	bb
KOE24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	n	az	bm	bb
KOE25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOE28	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE29	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOE30	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE31	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOE32	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE33	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOE34	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOE35	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOE36	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KOI01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	al	bc	az	bb
KOI07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	aj	bc	f	bf
KOI08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ax	am	l	bo
KOI09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOI12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOOC01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	o	bo
KOOC02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOOC03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOOC04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KOOC05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KOOC-RRWA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	am	ar	az	au
KOW43	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOW45	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOW55	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	az	j	bb
KOW105	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOW106	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KOW107	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KOW-RPLC	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	am	bc	az	bb
KSV01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	at	bb
KSV02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KSV03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	ar	at	bb
KSV04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KSV05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KSV06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ai	ar	bd	bs
KSV07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	aq	o	bq
KSV08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	am	j	bo
KSV09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	ar	h	bs
KSV10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	aq	j	bq
KSV11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	v
KSV12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ad	j	v
KSV13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	z	bm	az
KSV14	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	u	bc	ah	aq
KSV15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	z	bm	az
KSV16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	ar	h	ag
KSV17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KSV18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	aq	h	bq
KSV19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bs
KSV20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ap	j	bi
KSV21	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ai	ar	bd	bb
KSV22	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	af	aa	bm	bb

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
KSV23	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	s	bc	ah	aq
KSV24	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	ar	h	ag
KSV25	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bh	ar	h	ag
KSV26	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	k	aq	f	bl
KSV27	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ar	j	bq
KSV-RCAA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	am	ao	az	av
KSV-RRBA	Relevé	Biota (2012a)	Outside	Koodaideri	not coded	not coded	t	bc	ax	aq
KWRCS05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KWRCS06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KWRCS07	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	bc	bb
KWRCS08	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KWRCS09	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	az	bb
KWRCS10	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	bc	az	bb
KWRCS11	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	bb
KWRCS12	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	au	ay	an	at
KWRCS13	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	s	av	ah	aq
KWRCS15	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	at
KWRCS16	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KWRCS17	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KWRCS18	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KWRCS19	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	am	o	bo
KWRCS20	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bb	ay	o	at
KWV01	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	ba
KWV02	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ae	az	bm	ba
KWV03	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	bi	ay	j	at
KWV04	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	ay	bd	at
KWV05	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bc	bb
KWV06	Quadrat	Biota (2012a)	Outside	Koodaideri	not coded	not coded	ak	az	bd	at
OXB01	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
OXB02	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bl
OXB03	Quadrat	Biota (2014b)	Inside	Yandi	H9	Hill (gorge)	ap	bc	az	bn
OXB04	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
OXB05	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	az	am	m	bo
OXB06	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
OXB09	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	ak	bc	bc	bb
OXB10	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
OXB11	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
OXB13	Quadrat	Biota (2014b)	Inside	Yandi	H6	Hill	bi	am	j	bn
OXB16	Quadrat	Biota (2014b)	Inside	Yandi	C2	Major creek	al	bc	az	aq
SFJ01	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	af	y	bm	bb
SFJ02	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ03	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ04	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	bb
SFJ05	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	t	bc	ax	bb
SFJ06	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ07	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	bn
SFJ08	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	t	j	bj

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							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
SFJ09	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	bb
SFJ10	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bg	bc	at	bb
SFJ11	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	l	bc	aw	bb
SFJ12	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ae	aa	bm	bb
SFJ13	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	ar	o	bs
SFJ14	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	ak	o	bq
SFJ15	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ16	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ae	aa	bm	bb
SFJ17	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	af	bc	at	bb
SFJ18	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	k	t	f	bj
SFJ19	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bq
SFJ20	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ21	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	aj	w	bb	az
SFJ22	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	ak	o	by
SFJ23	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	bb
SFJ24	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ25	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	w	o	al
SFJ26	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	al
SFJ27	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	l	aa	ap	bb
SFJ28	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bo
SFJ29	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ae	y	bm	bb
SFJ30	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ31	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ai	am	bd	bs
SFJ32	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ33	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	s	bc	ah	aq
SFJ34	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ35	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bf	ae	ao	t
SFJ36	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	o	bc	aw	bb
SFJ37	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ38	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	l	bc	ao	bb
SFJ39	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ40	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	af	y	bm	bb
SFJ41	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ42	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	l	aa	ap	bb
SFJ43	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ44	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ45	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	aj	aa	bc	bb
SFJ46	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ47	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ48	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	al
SFJ49	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	o	bc	aw	bb
SFJ50	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	o	bc	aw	bb
SFJ51	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	af	bc	at	bb
SFJ52	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ53	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ54	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ55	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u

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							% Cover	Pres/Abs	% Cover	Pres/Abs
SFJ56	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	al
SFJ57	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	t	j	bj
SFJ58	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ59	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ60	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	y	bm	bb
SFJ61	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	al
SFJ62	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	m	bc	aw	bb
SFJ63	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ64	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	w	n	bs
SFJ65	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	t	j	bj
SFJ66	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	am	o	bs
SFJ67	Quadrat	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bi	ae	j	u
SFJ-RMMA	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	w	o	bs
SFJ-RMMB	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	aj	s	bb	bv
SFJ-RMMC	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	aj	aa	bc	ad
SFJ-RMMD	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	l	b	ao	ad
SFJ-RMME	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	bb	an	o	bm
SFJ-RMMF	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	m	bc	u	aq
SFJ-RMMG	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	m	bc	aw	bb
SFJ-RMMH	Relevé	Biota (2012b)	Outside	Southern Flank / Jinidi-Mindi	not coded	not coded	ac	y	bl	al
WAF01	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	af	ar	at	ah
WAF02	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	ac	y	bl	bs
WAF03	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	af	ar	at	ah
WAF04	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	bb	y	o	bs
WAF05	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	aa	y	bi	bs
WAF06	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	bb	as	o	bs
WAF07	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	aa	y	bi	bs
WAF08	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	bb	as	o	bs
WAF09	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	af	am	at	ah
WAF11	Quadrat	Biota (2014d)	Outside	West Angelas	not coded	not coded	bb	ak	o	by
WAF-RCBA	Relevé	Biota (2014d)	Outside	West Angelas	not coded	not coded	ao	s	au	bx
WAF-RCBB	Relevé	Biota (2014d)	Outside	West Angelas	not coded	not coded	ae	y	bl	aj
WAF-RCBC	Relevé	Biota (2014d)	Outside	West Angelas	not coded	not coded	ao	s	au	bx
WAF-RPSA	Relevé	Biota (2014d)	Outside	West Angelas	not coded	not coded	af	bc	av	bw
WAF-RPSB	Relevé	Biota (2014d)	Outside	West Angelas	not coded	not coded	af	bc	av	bw
WAG03	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	x	p	bf	g
WAG04	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	p	bf	g
WAG05	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	aa	bc	aj
WAG06	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	s	f	cb
WAG07	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	y	be	ai
WAG08	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	y	be	ai
WAG09	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ae	ac	bf	g
WAG10	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	aa	bc	be
WAG11	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	aa	bc	g
WAG12	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	s	bc	ah	aq
WAG13	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	p	bf	g
WAG14	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	t	bc	u	bw

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							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
WAG15	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ak	at	av	bz
WAG16	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	p	bf	g
WAG17	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	m	bc	u	bw
WAG18	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	s	bc	ai
WAG19	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ae	aa	bl	aj
WAG20	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	s	f	cb
WAG21	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aa	y	bi	ai
WAG22	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	av	at	e	bz
WAG23	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	an	bc	z	bw
WAG24	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	ah	f	be
WAG25	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ae	p	bl	g
WAG26	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	at	f	bz
WAG27	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	s	bc	bx
WAG28	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ai	at	bd	bz
WAG29	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aa	y	bi	ai
WAG30	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ae	y	bl	aj
WAG31	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	m	aa	u	bw
WAG32	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ae	aa	bl	aj
WAG33	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	ac	y	be	be
WAG34	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	at	f	bz
WAG35	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	y	bc	af
WAG36	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	k	at	f	bz
WAG37	Quadrat	Biota (2010b)	Outside	West Angelas	not coded	not coded	aj	aa	u	bw
WES01	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	ak	ar	ba	ah
WES02	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	ae	ab	bl	ah
WES03	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	ae	ab	bl	ah
WES06	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	i	ab	bn	ah
WES07	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	ak	o	by
WES08	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	ak	bb	by
WES08E	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bi	s	g	bx
WES09	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	y	bl	ah
WES10	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	y	bc	ah
WES11	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	am	o	bs
WES12	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	af	ar	at	ah
WES13	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	y	bc	ah
WES14	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	am	o	bs
WES15	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	ak	bb	by
WES16	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	ai	ar	at	bx
WES17	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	ab	bl	ah
WES18	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	am	o	bs
WES19	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES20	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	af	ar	at	bx
WES21	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	am	o	bs
WES22	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	af	ar	at	ah
WES23	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	af	ar	at	ah
WES24	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	y	o	bs
WES26	Quadrat	Biota (2006b)	Outside	West Angelas	not coded	not coded	bi	s	g	bx

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							% Cover	Pres/Abs	% Cover	Pres/Abs
WES-A	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	ak	bb	by
WES-B	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES-C	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	bb	at	o	bz
WES-F	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES-G	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	af	s	at	bx
WES-H	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	b	bb	ad
WES-I	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	y	bc	ah
WES-J	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	j	r	p	n
WES-K	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES-L	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES-M	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	ab	bk	ah
WES-O	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	ay	ak	k	by
WES-P	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	au	bx
WES-Q	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	bx
WES-R	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	aj	s	bb	by
WES-T	Relevé	Biota (2006b)	Outside	West Angelas	not coded	not coded	ac	y	be	al
WW30	Quadrat	HGM (2000a)	Inside	Yandi	P5	Stony plain	ak	aw	bc	bd
WWJD06	Quadrat	Biota (2006a)	Outside	Bellbird-Juna rail / Juna Downs	not coded	not coded	ac	x	bi	af
YAQ01	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ02	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	av
YAQ03	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	ao	bc	av
YAQ04	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	am	j	bh
YAQ05	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
YAQ06	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bh
YAQ07	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ08	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bh
YAQ09	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ10	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ11	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ12	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	bc	t	aq
YAQ13	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YAQ14	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ15	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	az	am	m	bn
YAQ16	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	bc	az	bb
YAQ17	Quadrat	Biota (2014b)	Inside	Yandi	H10	Hill	z	bb	bh	ay
YAQ18	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bb	am	o	bo
YAQ19	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bb	am	o	bo
YAQ20	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
YAQ21	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YAQ22	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	s	bc	ah	aq
YAQ23	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	bo
YAQ24	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	az	bc	bb
YAQ25	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ26	Quadrat	Biota (2014b)	Inside	Yandi	C3	Major creek	s	bc	ah	aq
YAQ27	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YAQ28	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YAQ29	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	al	bc	az	bb

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
YAQ30	Quadrat	Biota (2014b)	Inside	Yandi	F2	Minor creek/floodplain	n	av	t	y
YAQ-CSRA	Relevé	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	aa
YAQ-CSRB	Relevé	Biota (2014b)	Inside	Yandi	P4	Stony plain	bi	az	j	at
YAQ-CSRC	Relevé	Biota (2014b)	Inside	Yandi	F2	Minor creek/floodplain	al	av	t	aa
YAQ-CSRD	Relevé	Biota (2014b)	Inside	Yandi	F2	Minor creek/floodplain	n	av	t	aa
YAQ-RPLA	Relevé	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	ap	bc	az	bn
YAQ-RPLB	Relevé	Biota (2014b)	Inside	Yandi	F2	Minor creek/floodplain	n	aw	t	y
YBI01	Quadrat	Biota (2014b)	Inside	Yandi	C3	Major creek	s	bc	ah	aq
YBI02	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YBI03	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YBI04	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YBI05	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	am	j	ay
YBI06	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	az	an	bb
YBI07	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YBI08	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	az	bc	bb
YBI09	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	az	an	bb
YBI10	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	n	az	bc	bb
YBI11	Quadrat	Biota (2014b)	Inside	Yandi	P3	Stony plain	l	az	ap	bb
YBI12	Quadrat	Biota (2014b)	Inside	Yandi	P6	Stony plain	ae	az	bm	bb
YBI13	Quadrat	Biota (2014b)	Inside	Yandi	P6	Stony plain	l	az	ap	bb
YBI14	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	at	ay	ba	at
YBI15	Quadrat	Biota (2014b)	Inside	Yandi	P6	Stony plain	ae	az	bm	bb
YBI16	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YBI17	Quadrat	Biota (2014b)	Inside	Yandi	P3	Stony plain	l	bc	ap	bb
YBI18	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bb	am	o	bo
YBI19	Quadrat	Biota (2014b)	Inside	Yandi	P4	Stony plain	bi	az	j	ax
YBI20	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
YBI21	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YBI22	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YBI23	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	s	bc	ah	aq
YBI24	Quadrat	Biota (2014b)	Inside	Yandi	H4	Hill	bb	am	o	bo
YBI25	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	am	bc	az	bn
YBI26	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	aw	bc	y
YBI27	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YBI28	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	at	ay	an	at
YBI29	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	am	an	bn
YBI30S	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
YBI31S	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YBI32S	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bb	aq	o	bp
YBI33S	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YBI34S	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	am	an	bn
YBI35S	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	al	bc	az	bb
YBI36	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bb	am	o	bn
YBI-RPHA	Relevé	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	z
YBI-RPHB	Relevé	Biota (2014b)	Inside	Yandi	C4	Major creek	n	av	t	ab
YBI-RROA	Relevé	Biota (2014b)	Inside	Yandi	P5	Stony plain	ab	w	q	ay
YBI-RRWB	Relevé	Biota (2014b)	Inside	Yandi	C3	Major creek	s	h	ah	ap

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
YEX01	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX02	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	bc	t	aq
YEX03	Quadrat	Biota (2014b)	Inside	Yandi	P4	Stony plain	be	az	bg	bb
YEX04	Quadrat	Biota (2014b)	Inside	Yandi	P4	Stony plain	ae	az	bm	bb
YEX05	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bb	am	o	bo
YEX06	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX07	Quadrat	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	al	bc	at	bb
YEX08	Quadrat	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	al	bc	at	bb
YEX09	Quadrat	Biota (2014b)	Inside	Yandi	P6	Stony plain	ae	az	bl	bb
YEX10	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX11	Quadrat	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	af	az	at	bb
YEX12	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bb	w	o	bn
YEX13	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX14	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bb	am	o	at
YEX15	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	bo
YEX16	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
YEX17	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	n	bc	t	aq
YEX18	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bn
YEX19	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	az	ba	bb
YEX20	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	af	bc	at	ao
YEX21	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	u	bc	ah	aq
YEX22	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	am	j	bn
YEX23	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	bc	ba	bb
YEX24	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bn
YEX25	Quadrat	Biota (2014b)	Inside	Yandi	C2	Major creek	u	bc	ah	aq
YEX26	Quadrat	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	ai	ar	bd	bb
YEX27	Quadrat	Biota (2014b)	Inside	Yandi	P2	Stony plain	ak	az	ba	bb
YEX28	Quadrat	Biota (2014b)	Inside	Yandi	C3	Major creek	s	bc	ah	aq
YEX29	Quadrat	Biota (2014b)	Inside	Yandi	C4	Major creek	m	bc	az	aq
YEX30	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bn
YEX31	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	ay	an	at
YEX32	Quadrat	Biota (2014b)	Inside	Yandi	P4	Stony plain	be	az	bg	bb
YEX33	Quadrat	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	az	an	bb
YEX34	Quadrat	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	am	bc	az	bb
YEX35	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX36	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bh
YEX37	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YEX38	Quadrat	Biota (2014b)	Inside	Yandi	F2	Minor creek/floodplain	l	bc	ap	bb
YEX39	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
YEX-G	Relevé	Biota (2014b)	Inside	Yandi	F3	Minor creek/floodplain	bb	am	o	bo
YEX-M	Relevé	Biota (2014b)	Inside	Yandi	C4	Major creek	m	av	w	z
YEX-N	Relevé	Biota (2014b)	Inside	Yandi	P5	Stony plain	au	az	an	bb
YSW01	Quadrat	Biota (2014b)	Inside	Yandi	C2	Major creek	u	bc	ah	aq
YSW02	Quadrat	Biota (2014b)	Inside	Yandi	H11	Hill	ak	w	bb	bn
YSW03	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YSW04	Quadrat	Biota (2014b)	Inside	Yandi	C2	Major creek	u	bc	ah	aq
YSW05	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	bc	aw	aq

Site	Site Type	Reference Report	Inside / Outside Study Area	Broad Project Area	Veg Code (sites inside study area only)	Habitat	Floristic Group at 30% Similarity Level †			
							Perennials only		All species	
							% Cover	Pres/Abs	% Cover	Pres/Abs
YSW06	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YSW07	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	ak	bc	bc	bb
YSW08	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
YSW09	Quadrat	Biota (2014b)	Inside	Yandi	H7	Hill	aj	am	bc	bn
YSW11	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bi	am	j	bn
YSW12	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	ag	az	bm	bb
YSW13	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	az	am	m	bo
YSW14	Quadrat	Biota (2014b)	Inside	Yandi	H8	Hill	az	am	m	bn
YSW15	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	az	am	m	bn
YSW16	Quadrat	Biota (2014b)	Inside	Yandi	H7	Hill	az	am	m	bn
YSW17S	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bn
YSW18S	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	bc	bc	bb
YSW19S	Quadrat	Biota (2014b)	Inside	Yandi	C5	Major creek	u	bc	ax	bb
YSW20S	Quadrat	Biota (2014b)	Inside	Yandi	H6	Hill	bi	am	j	bn
YVI01	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bi
YVI02	Quadrat	Biota (2014b)	Inside	Yandi	H2	Hill	bi	ap	j	bi
YVI03	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bb	am	o	bn
YVI04	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bi	aq	j	bl
YVI05	Quadrat	Biota (2014b)	Inside	Yandi	H7	Hill	bi	am	j	bn
YVI06	Quadrat	Biota (2014b)	Inside	Yandi	C1	Major creek	r	bc	ah	aq
YVI07	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YVI08	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	bb	ar	o	bn
YVI09	Quadrat	Biota (2014b)	Inside	Yandi	C2	Major creek	u	bc	ah	bb
YVI10	Quadrat	Biota (2014b)	Inside	Yandi	P1	Stony plain	ak	bc	bc	bb
YVI11	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	bc	az	bb
YVI12	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	bc	az	bb
YVI13	Quadrat	Biota (2014b)	Inside	Yandi	F1	Minor creek/floodplain	ak	bc	bc	bb
YVI14	Quadrat	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bo
YVI15	Quadrat	Biota (2014b)	Inside	Yandi	C5	Major creek	u	bc	ax	bb
YVI16	Quadrat	Biota (2014b)	Inside	Yandi	H7	Hill	bi	am	j	bo
YVI-RMMA	Relevé	Biota (2014b)	Inside	Yandi	H1	Hill	bb	am	o	bn

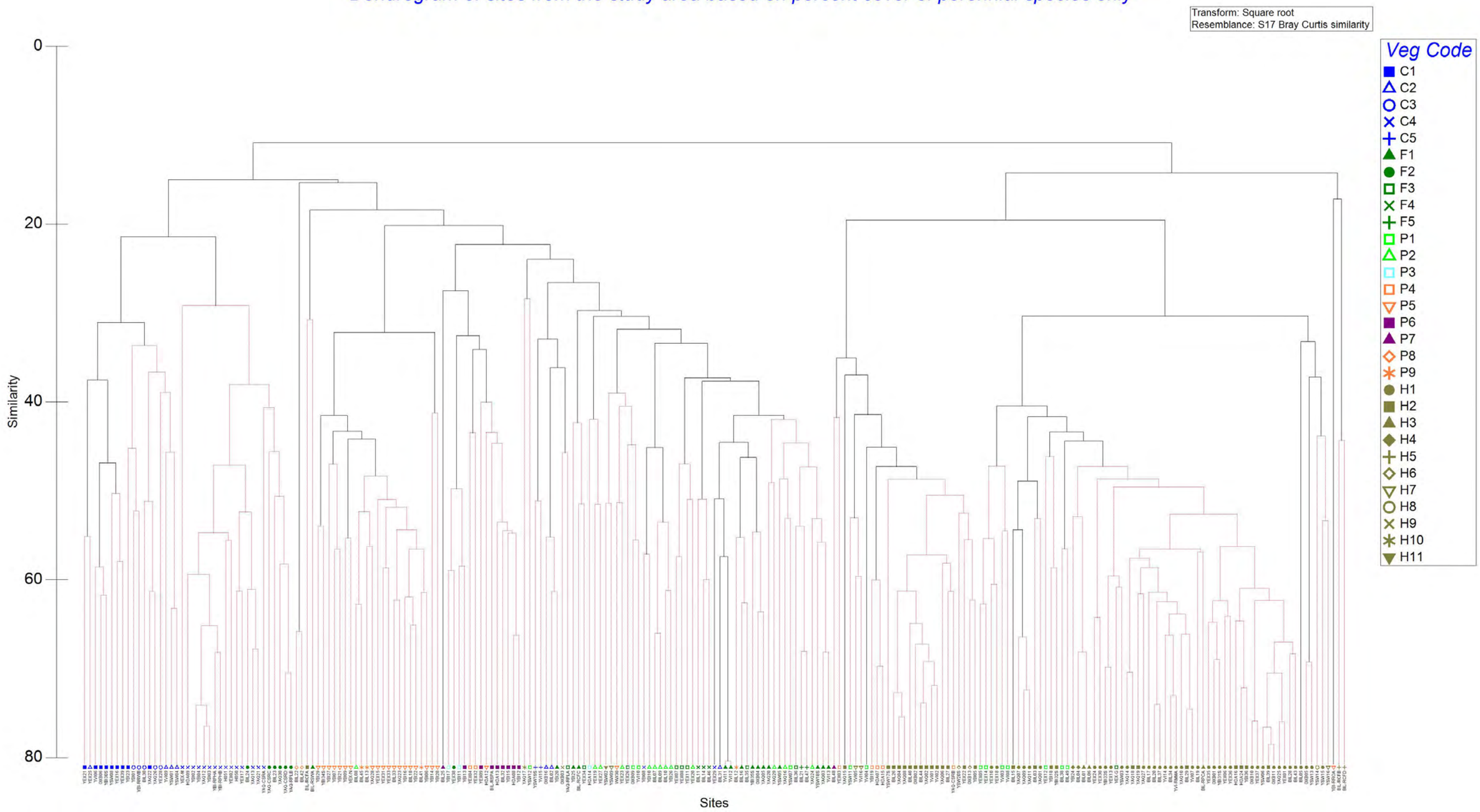

Figure 1: Dendrogram based on percent foliar cover of perennial species in sites from the Yandi study area.
Adjacent sites connected by red lines are not significantly floristically different, as determined by the SIMPROF test.

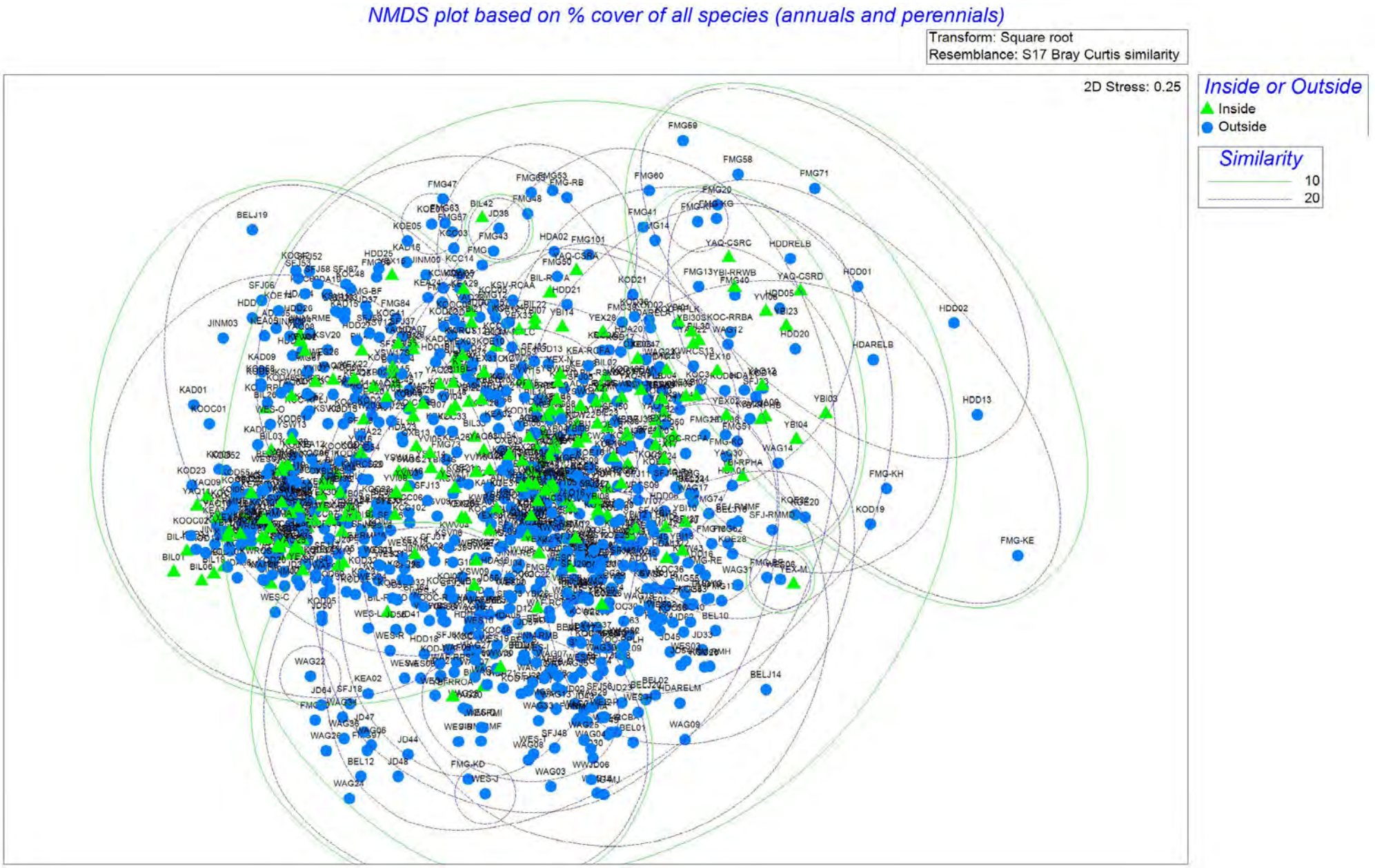

Figure 2: NMDS plot based on the percent foliar cover of all species, showing sites inside and outside the current study area.

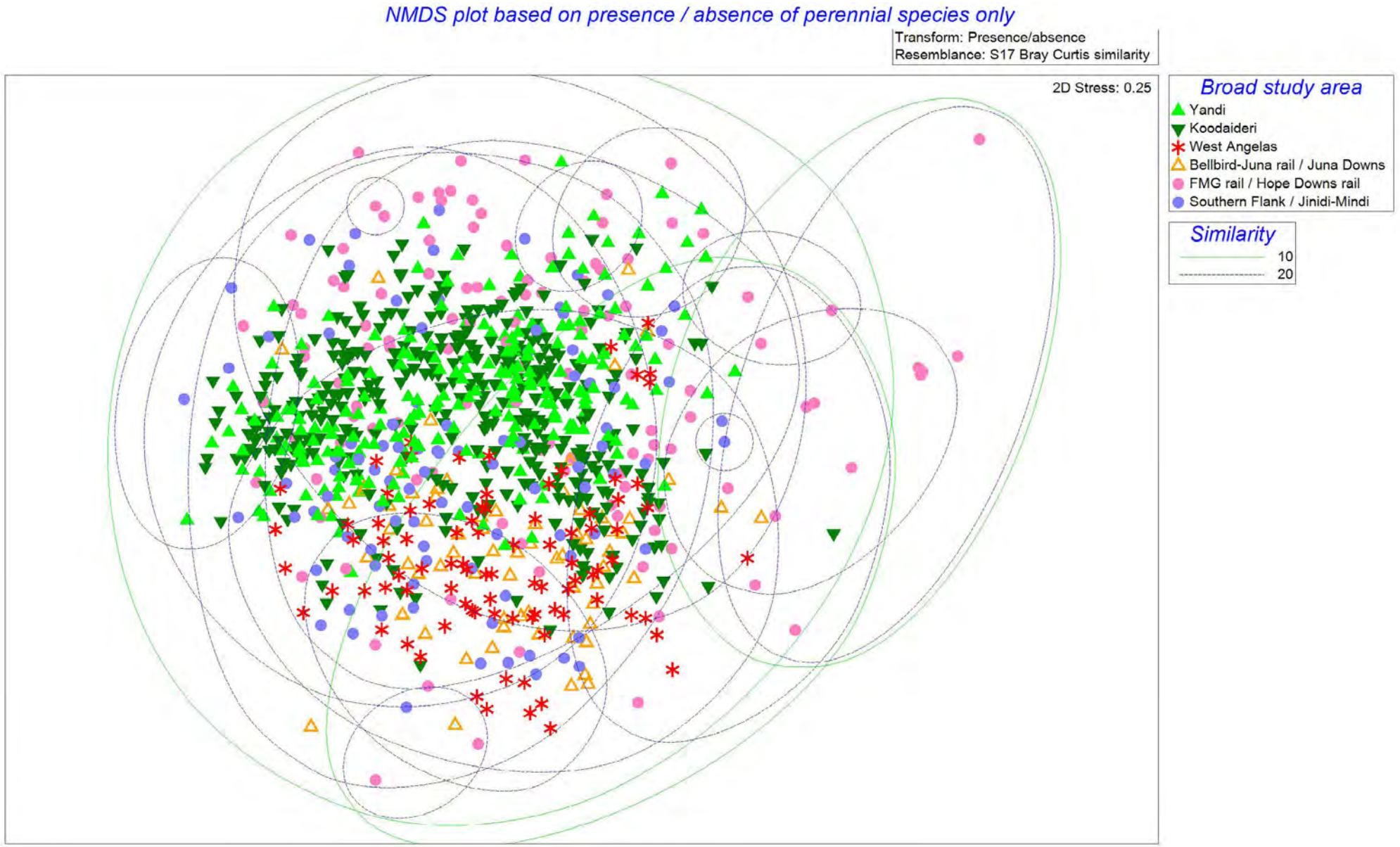

Figure 3: NMDS plot based on the presence / absence of perennial species only, with sites coded by the broad study area.

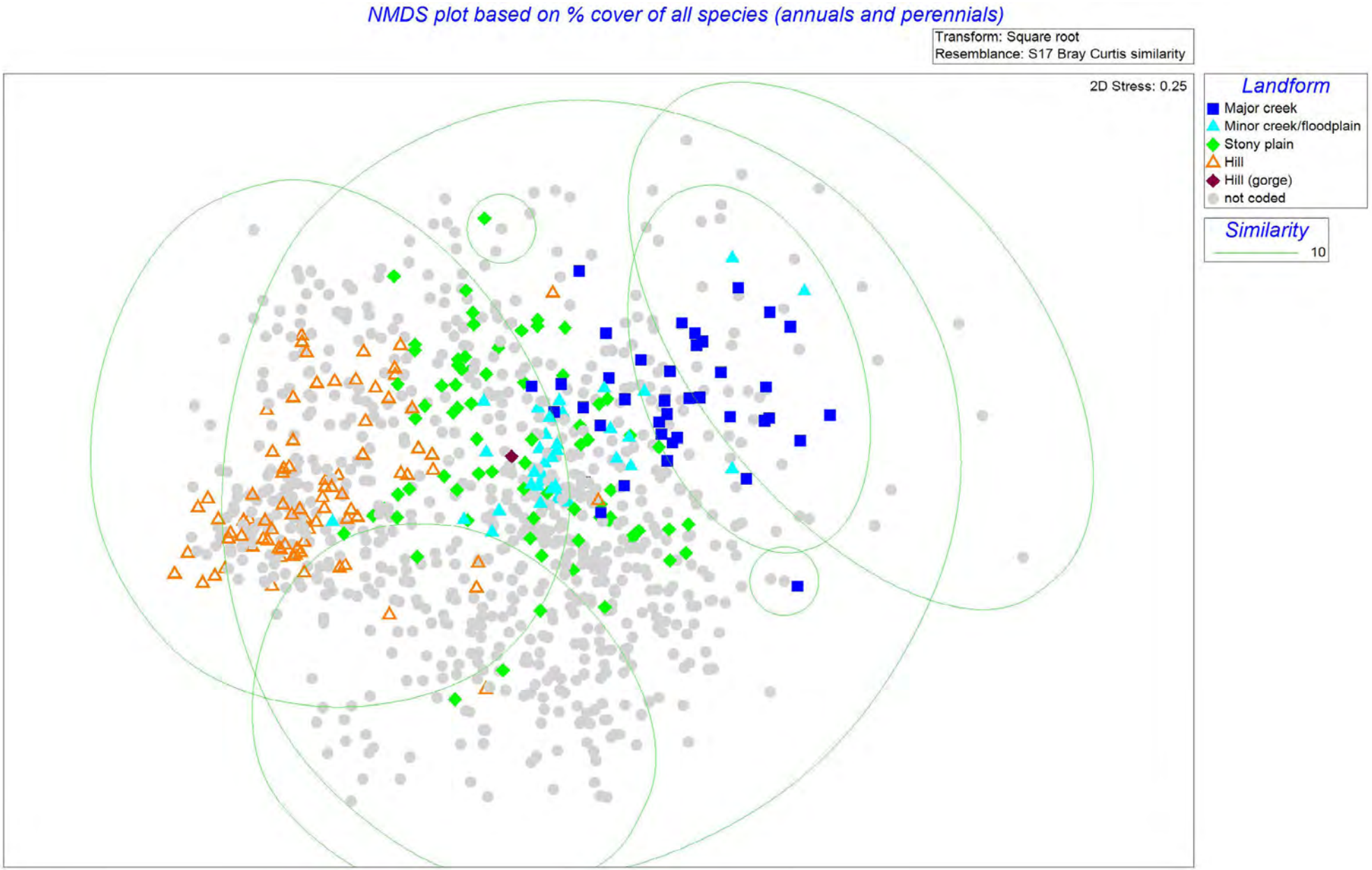

Figure 4: NMDS plot based on the percent foliar cover of all species, with sites in the study area coded by landform.

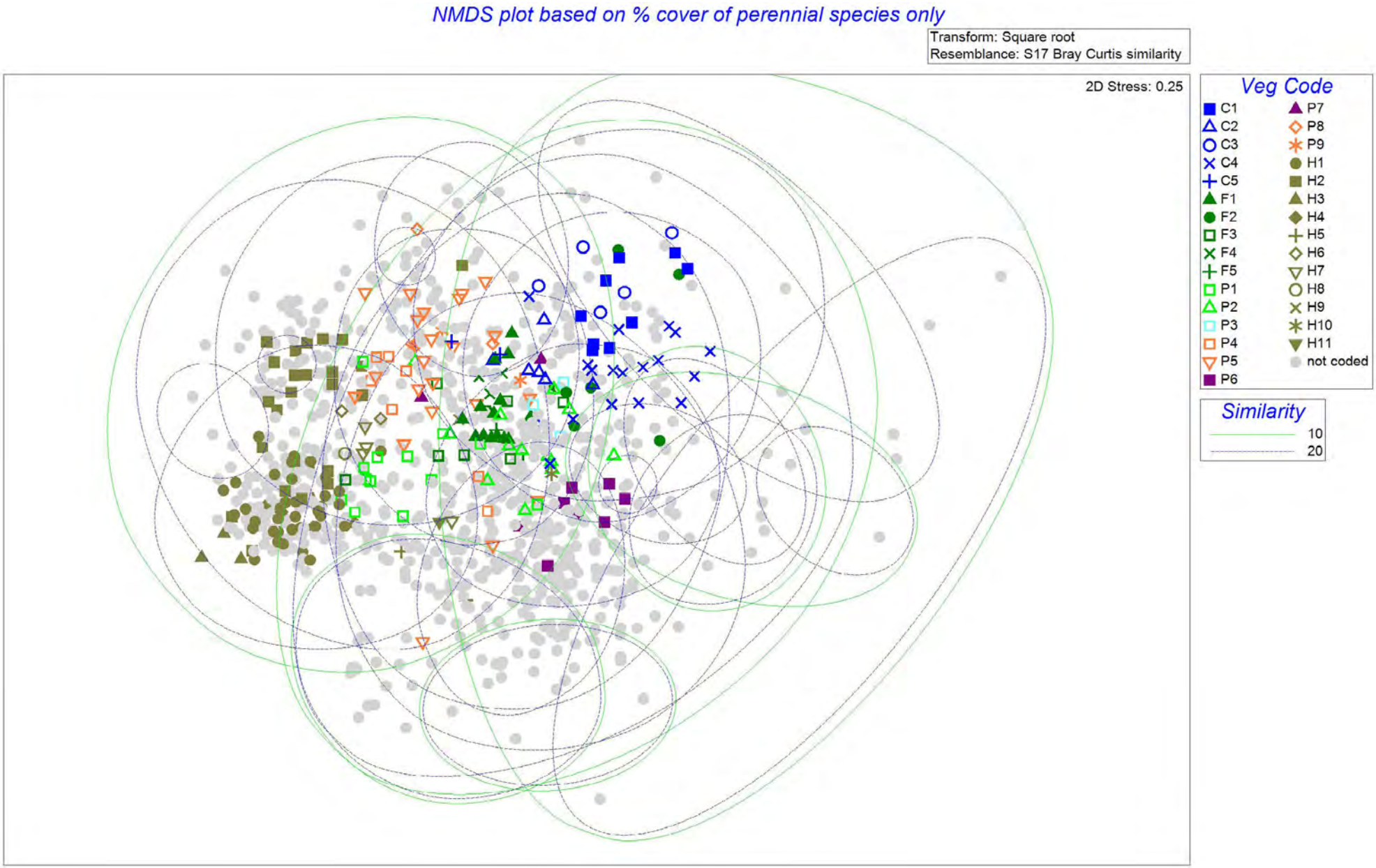

Figure 5: NMDS plot based on the percent foliar cover of perennial species only, with sites in the study area coded by vegetation type (see Appendix 3 for explanations of codes).

Rio Tinto Significant Species Management Plan

Document Owner:	**Environment Manager, Approvals**
Document Revision:	September 2014

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1. Scope

1.1 Rio Tinto Operations

Rio Tinto's Iron Ore business in Western Australia includes several wholly owned subsidiaries and joint venture initiatives in the Pilbara region of north-west Western Australia. The Rio Tinto Iron Ore WA operations include assets owned by Hamersley Iron, Robe River Iron Associates and Hamersley Hope Management Services.

The operations include a network of open cut mines, shipping terminals and a connecting heavy freight rail network (Figure 1-1). Ore is generally mined, crushed and screened at source, and then transported by rail to port facilities where it is stockpiled, sorted and shipped to customers.

As part of these combined operations Rio Tinto is responsible for managing mines, infrastructure and supporting assets. Rio Tinto also undertakes exploration for new ore bodies, and extensions to existing orebodies; Greenfield and Brownfield expansions, and provides corporate and site services.

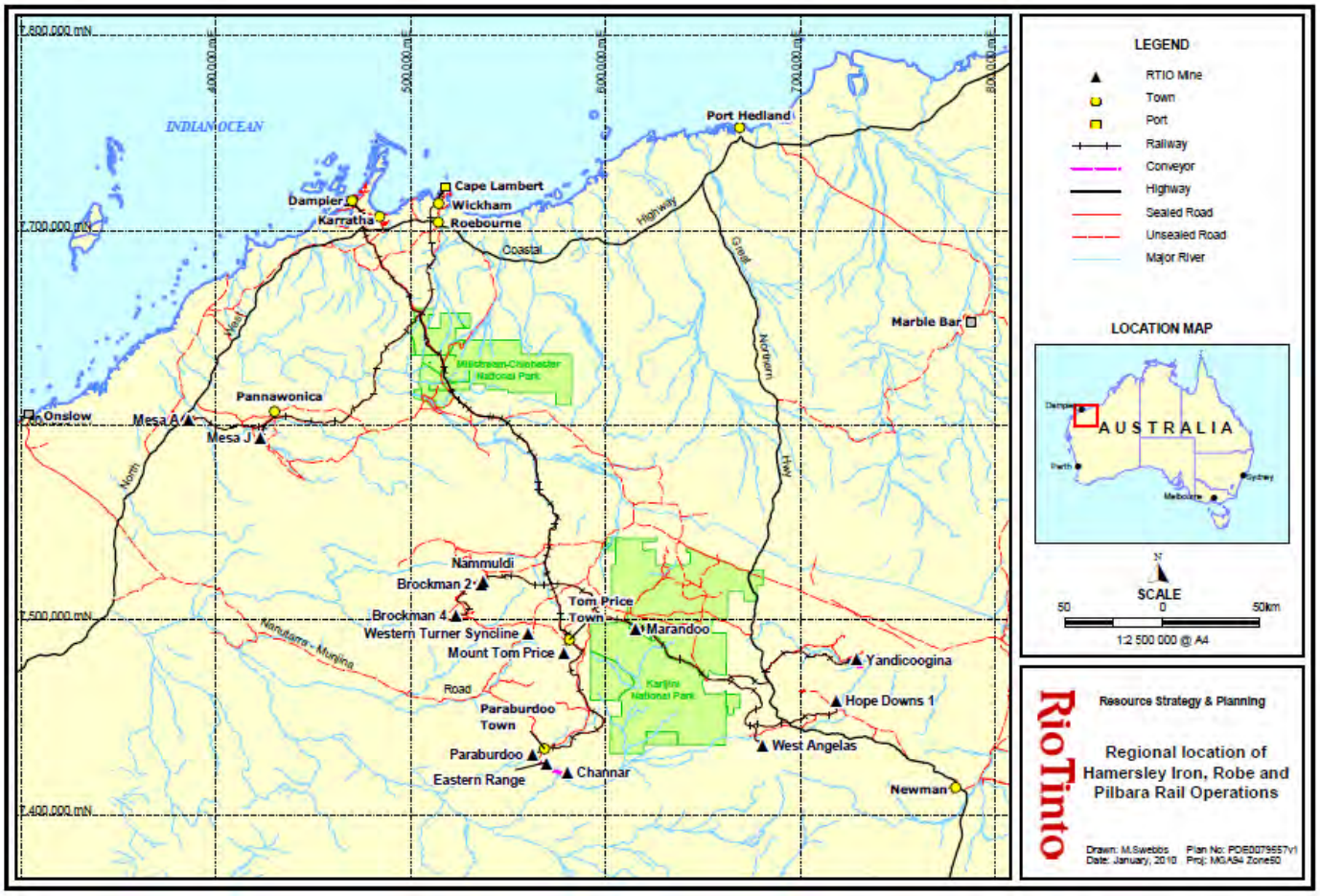

Figure 1-1 Rio Tinto Iron Ore Operations in WA

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1.2 EPBC Act

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. These conservation assets are defined in the EPBC Act as matters of national environmental significance. The EPBC Act is administered by the Commonwealth Department of Department of the Environment (DoE).

Threatened fauna and flora listed under the EPBC Act are described as species of National Environmental Significance (**NES**), including the categories endangered, critically endangered, conservation dependant, vulnerable, extinct in the wild and extinct.

1.3 Management Plan Purpose

This Significant Species Management Plan (**SSMP**) provides the framework for Rio Tinto to minimise impacts to Pilbara populations of significant species from activities associated with its iron ore mining operations. The scope of the SSMP includes expansions to Rio Tinto's existing operations and new mining and infrastructure projects. The key elements of the management plan include:

- a summary of the broad aspects of Rio Tinto's operations with the potential to impact Pilbara populations of species of national environmental significance;
- a concise summary of the general distribution, ecology, conservation status and threatening processes for species of national environmental significance relevant to Rio Tinto's operations in the Pilbara;
- an updated consolidation of all readily available records of these species in the Pilbara region, and a comparison of this with database results for the species from the EPBC Act 1999 Protected Matters Search Tool;
- an overview of the broad scale management measures that Rio Tinto will use to minimise impacts to species of national environmental significance; and
- site specific management measures and local scale species information where species of national environmental significance are at elevated risk from Rio Tinto operations.

The purpose of the plan is to meet Commonwealth requirements and to communicate Rio Tinto's management measures for species of national environmental significance to relevant stakeholders. Where relevant this plan will operate in conjunction with any Rio Tinto site specific Environment Management Plans. The SSMP has been developed in accordance with relevant provisions of the EPBC Act and Western Australian *Environmental Protection Act 1986* (EP Act). The DoE and the WA Environmental Protection Authority (EPA) are the relevant federal and state administering authorities of these acts respectively.

1.4 Review schedule

The plan will be reviewed and updated regularly in response to changing legislation, EPA and DoE policies, changes in the conservation status of MNES, changes in key threatening processes, and RIO TINTO's new and expanding operations. Regular revisions are a component of an adaptive management approach, and will provide for the incorporation of new scientific knowledge and management techniques as these become available.

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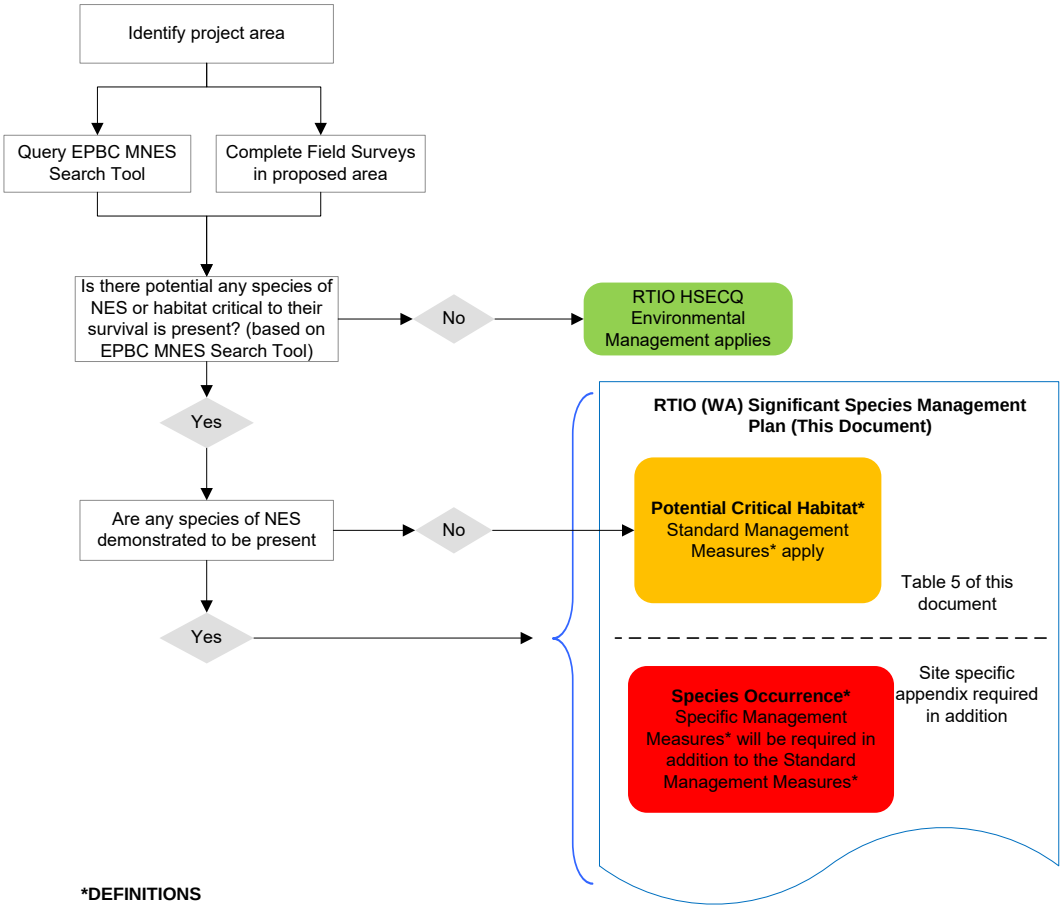
2. Application of the SSMP

The way in which the SSMP is applied will depend on the specific context of each new or expanded Rio Tinto project. The framework for implementing the SSMP is described in Figure 2-1, which demonstrates how different components of the plan are relevant for different situations.

This SSMP also sits within the broader context of current Rio Tinto environmental management policies, programs and procedures within an overall Health, Safety, Environment and Quality (HSEQ) Management System. This relationship is described in Figure 2-2.



***DEFINITIONS**

Potential Critical Habitat: Habitat critical to the survival of the species of NES, but species not proven to be present
Species Occurrence: species is proven to be present in the critical habitat

Standard Management Measures: RTIO (WA)'s standard management measures to minimise impact to species of NES in the RTIO (WA) Significant Species Management Plan
Specific Management Measures: Further management measures RTIO (WA) will undertake that are specific to individual species and individual projects in the RTIO (WA) Significant Species Management Plan

Figure 2-1 How the RTIO (WA) Significant Species Management Plan works

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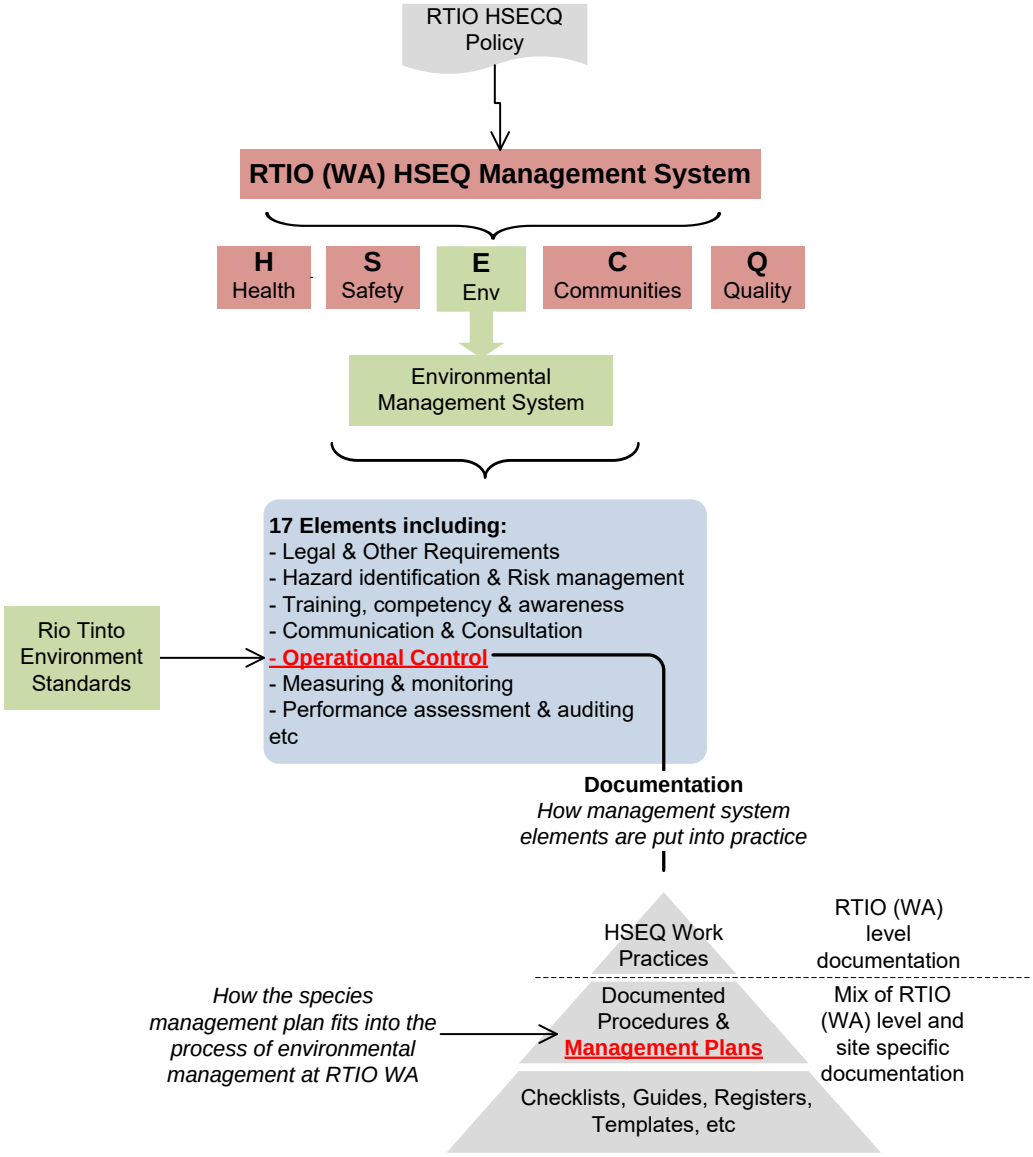

Figure 2-2 Environmental Management at RTIO (WA)

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3. Rio Tinto Environmental Management

Rio Tinto aims to conduct its business in an efficient and environmentally responsible manner that is compatible with stakeholder expectations. Rio Tinto recognises that environmental responsibilities go beyond those required under statutory regulations. As part of their commitment, Rio Tinto has a Health, Safety, Environment and Quality (HSEQ) Policy endorsed by management that is the guiding document for driving environmental management, and provides context and direction for continuous improvement (Figure 2-2).

3.1 Environmental Management System

Rio Tinto operates under an Environmental Management System (EMS), contained within the Health, Safety, Environment, Communities and Quality (HSECQ) Management System. It provides a structured framework for developing an EMS based on an organisational policy and management objectives, which take into account legal requirements and information about significant environmental aspects. The Standard places emphasis on securing management commitment and appropriately allocating resources for the establishment of systems to reduce environmental risk. Key elements include assessing environmental risk and legal requirements (including requirements under state and federal acts), developing objectives and targets, training, operational control, corrective actions, audits and review.

The Rio Tinto EMS includes systems for managing environmental incidents which could include potential and actual impacts on species of national environmental significance. The EMS requires internal reporting, investigation, and review of incidents to determine if they require reporting to relevant authorities and any remedial actions. These processes allow Rio Tinto to minimise harm to the environment, and ensure all incidents are recorded, trends noted, and corrective actions determined.

The Rio Tinto EMS includes induction and training requirements. The induction program includes information on all aspects of environmental management including responsibilities, legal requirements and Rio Tinto's expectations. In particular the induction program includes information on the potential for mining activities to affect flora, fauna and habitat, fauna encounter procedures, and feral animal and weed control. The induction program is designed to ensure employees and contractors understand environmental risks and legal requirements associated with their roles.

The Rio Tinto EMS is audited on an annual basis and where auditing finds management actions are not effective, the audits may recommend changes to procedures and systems. Environmental performance and compliance with commitment and conditions is reported in Annual Environment Reports. The Department of Environment Regulation (DER) Audit Branch may undertake regular audits in conjunction with these reports. The EMS is reviewed annually to ensure its continuing suitability, adequacy and effectiveness.

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3.2 Approvals Request System

In addition to the EMS, Rio Tinto maintains an Approvals Request System for all ground disturbance activities. This is a coordination process, administered by a company Approvals Coordination Officer, which prior to the commencement of any work ensures:

- relevant biological surveys are complete;
- relevant heritage survey are complete; and
- appropriate government regulatory approvals are in place.

After these checks are made, an Approvals Permit is issued which may contain specific conditions based on results of surveys or approval requirements. The process minimises the risk of disturbing any protected areas and assists Rio Tinto in complying with legal and social requirements.

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4. Aspects and Impacts

Various aspects of Rio Tinto's activities have the potential to impact on species of national environmental significance. Rio Tinto's management objectives for species of national environmental significance are to:

- avoid areas of high sensitivity where practicable;
- minimise impacts by appropriate design and operation; and
- mitigate potential impacts through rehabilitation

Table 4-1 Aspects of Rio Tinto activities with the potential to impact on species of national environmental significance

Aspect	Potential Impacts	Type & Potential Duration of Impact*	Management Objective
Clearing & Disturbance	- Critical and/or peripheral habitat decreased, altered or fragmented - Populations decreased, altered or fragmented	Direct Medium term	Maintain the abundance, species diversity, geographic distribution and productivity of significant habitat or flora populations, by avoiding or minimising clearing, and utilising appropriate engineering and management of areas to be cleared
			Progressively restore habitat for flora and fauna, particularly areas of habitat for significant species/ populations, and develop self sustaining, non-polluting final landforms to support ecosystems
Spread of weed species	- Critical and/or peripheral habitat altered - Populations altered or displaced	Indirect Long term	Minimise the introduction and spread of weed species to significant flora and fauna habitat and populations
Increase in feral animals	- Direct Mortality - Increased competition	Indirect Long term	Minimise the effect of feral animals on native terrestrial fauna by controlling spread and mitigating impacts through management
Dust generation	- Critical and/or peripheral habitat altered - Populations decreased or altered	Indirect Short term	Protect significant fauna habitat and vegetation by controlling dust emissions
Direct MNES encounter	- Direct Mortality	Direct Short term	Protect native fauna by avoiding species / ecological communities with conservation significance wherever practicable; utilising engineering designs, management controls, education of site personnel and traffic management
Changes to hydrology and hydrogeology	- Critical and/or peripheral habitat decreased or altered - Populations decreased or altered	Cumulative Long term	Maintain the quantity and quality of water to protect existing and potential values, including ecosystem maintenance, flow paths and water quality.
Altered fire regimes	- Critical and/or peripheral habitat altered - Populations altered	Indirect Medium term	Protect significant habitat from fire where beneficial and minimise fire occurring from human activities

*Potential Duration of impact:
- Short term: impact limited to discrete phase of mining
- Medium: life of mine
- Long term: impact extends beyond closure

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5. Management measures

5.1 Standard management

Standard management measures for species of national environmental significance are described in Table 5-1. Rio Tinto will adopt these management measures at all operations where there is:

- Potential for species of national environmental significance to be present; or
- Potential for critical habitat of species of national environmental significance.

These standard management measures apply to the following species:

- Northern Quoll (*Dasyurus hallucatus*)
- Pilbara Leaf-Nosed Bat (*Rhinonicteris aurantia)*
- Pilbara Olive Python (*Liasis olivaceus barroni*)
- Hamersley Lepidium (*Lepidium catapycnon*)
- Greater Bilby (*Macrotis lagotis*)

Table 5-1 Management Measures for species of national environmental significance

Aspect	Action	Rio Tinto Accountability	References	Species applies to
Clearing & Disturbance	Baseline surveys (following EPA guidance statements) will be completed in all areas with planned mining developments and infrastructure.	- Environment Manager Approvals	- Approvals Request system	- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-Nosed Bat - Greater Bilby - Hamersley Lepidium
	Location of species of NES and their habitats identified within and adjacent to Rio Tinto project boundaries will be recorded on the Rio Tinto GIS database.	- Environment Manager Approvals		
	Proposed clearing and disturbance will be assessed through the Rio Tinto Approvals Request System.	- Environment Manager Approvals - Site, Project, Study & Exploration Managers		
	The Rio Tinto Approvals Request System will ensure: - disturbance remains within approved boundaries - clearing is minimised to meet specific demands - planned clearing is adjusted where possible to avoid disturbance of significant areas - planned clearing meets legal obligations.	- Environment Managers Approvals, Operation & Expansions - Site, Project, Study & Exploration Managers		
	All areas to be cleared will be demarcated prior to disturbance.	- Site, Project, Study & Exploration Managers		

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	Completion criteria will be developed as part of the closure and rehabilitation plan to provide the basis for functioning habitat post mining.	- Water & Closure Manager	- Closure plans	
Spread of weed species	Weed management measures will be implemented in accordance with Rio Tinto's EMS Weed management Strategy and equipment hygiene procedures to ensure weeds are controlled and recorded and equipment is cleaned to minimise the spread of weeds.	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Weed Management Strategy	- Northern Quoll - Pilbara Olive Python - Greater Bilby - Hamersley Lepidium
Increase in feral animals	Feral animal control will be undertaken by: • prohibiting feeding animals • prohibiting keeping pets • appropriate waste disposal for food scraps and other wastes as per the Rio Tinto EMS waste management guidelines • regular feral animal reduction programs	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Wildlife Interaction Guidelines - Waste Management Treatment, Storage & Disposal Guidelines	- Northern Quoll - Pilbara Olive Python - Greater Bilby
Dust generation	Dust control measures (including road watering, water sprays and dust suppression systems) will be used to minimise dust from sites	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Cleaner air management plan	- Hamersley Lepidium
Direct MNES encounter / sighting	A register of any MNES encountered on site will be developed and maintained. This will include GIS locations, and MNES status (alive/dead).	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Wildlife Interaction Guidelines - Waste Management Treatment, Storage & Disposal Guidelines	- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-Nosed Bat - Greater Bilby
	Native fauna encountered on site will be given the opportunity to move on if there is no threat to personnel safety in doing so.			
	Fauna (including injured fauna) encountered on site will be handled and transported in accordance with Rio Tinto's Wildlife interaction guidelines.			
	Feeding of native fauna, hunting, keeping of firearms or pets on site will be prohibited	- Site, Project, Study & Exploration Managers	- Rio Tinto induction program	- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-Nosed Bat - Greater Bilby - Hamersley Lepidium
	Appropriate speed limits for mining equipment and light vehicles will be implemented, sign-posted and enforced, and communicated via education of site personnel			

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	Vehicles will remain on designated roads and will not be permitted off designated roads unless in the case of emergency. Location of any significant roost sites adjacent to the operations will be demarcated and access prohibited to all personnel.	- Site, Project, Study & Exploration Managers		- Pilbara Leaf-Nosed Bat
Changes to hydrology and hydrogeology	Taking water only from points licensed by the DoW and remaining within licence limits. Storing, handling and disposing of effluent in accordance with the environmental licence Adhering to site specific Groundwater, Surface Water and Drainage Management Plans where applicable Adhering to discharge conditions Installing appropriate hydrocarbon bunding and management practices at hydrocarbon use and storage facilities	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Existing site management plans - Licences	- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-Nosed Bat - Greater Bilby - Hamersley Lepidium
Altered Fire Regimes	Control fires caused by operations Minimise risk of fire from ignition sources	- Environment Managers Operations & Expansions - Site, Project, Study & Exploration Managers	- Emergency management procedures - Weed Management Plan - Hot work Standard	- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-Nosed Bat - Greater Bilby - Hamersley Lepidium

5.2 Site specific management measures

In addition to the above measures, further specific measures may need to be undertaken at Rio Tinto operations in the event that there is confirmation of species of national environmental significance present.

Site specific measures will be matched to local scale environmental protection and threat mitigation requirements. These will be addressed in detail in the site specific addendums to this management plan. These further management measures will predominantly focus on minimisation of impact on potential critical habitat through appropriate design and construction.

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6. Contingency

Threatening processes are continually monitored and assessed by Rio Tinto, along with consultation with appropriate government agencies, including the Department of Parks and Wildlife (DPaW), OEPA and DoE. If the status of any species or threatening process changes, Rio Tinto will consult with the relevant agency and update the management plan where required.

7. Monitoring

Rio Tinto is committed to designing and implementing monitoring programs specific at its operations to meet all regulatory requirements. In special cases monitoring will be designed to enable an assessment of the effectiveness of flora and fauna management measures. An example of considerations to be addressed by Rio Tinto monitoring programs is shown below.

Table 7-1 Monitoring Requirements

Sources of monitoring requirements	- Ministerial conditions - Licence requirements - Referral requirements - Part IV assessment commitments - Rio Tinto requirements
Monitoring and Survey guidelines	- EPA guidance note 56 (Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia) - EPA guidance note 51 (Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia) - EPA Technical Guide – Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment - Significant Impact guidelines 1.1 Matters of National Environmental Significance - Species significant guidelines issued by DoE eg EPBC Act policy Referral guidelines for the Northern Quoll *Dasyurus hallucatus*
Purpose of monitoring	- Collection of baseline data - Knowledge gain - Measurement of impacts on matters of National Environmental Significance - Determination of trigger values to change practices on site - Determine effectiveness of management measures
Reporting of monitoring	- Present findings and trends in the Annual Environment Report - Identify and understand impacts and cumulative impacts - Identify trigger values and responses required for exceedance of trigger values - Trigger updates to management plan where required - Include justification for survey methodology - Include discussion on scientific reliability of surveys

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8. Significant Species descriptions

8.1 Northern Quoll (*Dasyurus hallucatus*)

Biology

The Northern Quoll is a medium-sized dasyurid marsupial, with adult weight ranging from 300 to 1,200 g. It is considered a partially arboreal and aggressive carnivore, preying on a varied diet of small invertebrates and vertebrates, including lizards, birds, snakes, small mammals and frogs (Oakwood 2000). It is also known to feed on fleshy fruit and carrion. The Northern Quoll is mostly nocturnal, although crepuscular (dusk and dawn) activity also occurs.

The Northern Quoll is short-lived, with both sexes maturing at approximately 11 months. Females reproduce only once each year and males typically undergo die-off after mating (Dickman and Braithwaite 1992, Oakwood 2000). The timing of breeding varies across the species range but typically occurs between July and September. In the Kimberley bioregion of Western Australia breeding has been recorded between July and August while in the Pilbara bioregion breeding has also been recorded in September (How et al. 2009), (Biota, 2009).

The home range size and density of Northern Quoll populations is poorly understood across the species range. In Savanna populations the home range of male Northern Quolls may extend over 100 hectares and encompass numerous female territories (Oakwood 2000). There is some suggestion that rocky habitats such as those commonly found in the Pilbara bioregion support denser populations of quolls (DoE 2014) and as such the size of home ranges may be smaller in these habitats.

Habitat preferences

A regional analysis completed by Biota (2009), found that the majority of Northern Quoll records from the Pilbara region came from land systems containing rocky hills, mesas, plateaux, drainages and granite tor fields. When dispersing, foraging or seeking mates, the species may also utilise other parts of the landscape and as a result occurs in a wide variety of habitats across its range (Hill & Ward 2010).

The species is known to occupy denning and shelter sites located amongst rock crevices, hollow logs, goanna burrows, termite mounds and human dwellings (Hill & Ward 2010). Many records from the Pilbara bioregion have come from mesa, plateaux and breakaway features abutting large creeks (Garth Humphreys, Biota Environmental Sciences, pers. obs.) and from boulder tors of the Abydos-Woodstock Plain (How et al. 1991), (Biota, 2009).

Distribution

The Northern Quoll's (*Dasyurus hallucatus*) distribution is discontinuous across northern Australia and is restricted to six main areas:

- Top end of the Northern Territory;
- North of Cape York;
- The Atherton-Cairns area,
- The Carnarvon Range-Bowen area of Queensland (Menkhorst 2001),
- The northwest Kimberley and
- The Pilbara region of Western Australia (Braithwaite and Griffiths 1994)

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The Northern Quoll also occurs on numerous islands off the Australian coast (Abbott and Burbidge 1995, Burbidge and McKenzie 1978; How et al. 2006).

In the Pilbara bioregion the Northern Quoll is widely distributed and has been recorded from all four subregions of the Pilbara bioregion. A total of 245 records of the Northern Quoll are known from locations across the extent of the bioregion (Figure 8.1-1). Population density varies across the region, with reliable populations occurring in several areas including the Robe River valley, rocky areas inland of Port Hedland and the Abydos-Woodstock plain. The species appears to occur at lower frequency across other parts of the Pilbara and density of populations appears to wane toward the southeast of the region. Population numbers and spatial extent also contracts and expands interannually, presumably in response to seasonal conditions, related abundance of prey species and fire regimes.

Threats

The National Recovery Plan for the Northern Quoll (Hill & Ward 2010) identifies a variety of threats to regional Northern Quoll populations throughout the species range. These threats include; Cane Toads, feral predators, inappropriate fire regimes, habitat degradation and destruction, weeds, disease, hunting and population isolation (Hill & Ward 2010).

The most significant threat to the Northern Quoll in Queensland, the Northern Territory and the Kimberley bioregion of Western Australia is the invasion of the Cane Toad *Bufo marinus*. The Cane Toad does not occur in the Pilbara bioregion and current modelling suggests it is not expected to become established in inland areas of the Pilbara (Urban et al. 2007, DoE 2014).

Specific threats to the Pilbara regional population of the Northern Quoll are thought to include:

- Predation by feral predators
- Inappropriate fire regimes
- Pastoralism
- Habitat clearing and modification

Conservation Status

Dasyurus hallucatus is specially protected under both State and Federal legislation. The species is listed as Schedule 1 (‘Endangered’) under the *Western Australian Wildlife Conservation Act 1950- 1979* and is also listed as ‘Endangered’ under both the Commonwealth *EPBC Act 1999* and the IUCN Red List.

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8.2 Pilbara Olive Python (*Liasis olivaceus barroni*)

Biology

The Pilbara Olive Python (*Liasis olivaceus barroni)* is an olive brown/pale fawn python growing to 2.5m. The diet includes birds, reptiles, and mammals as large as rock wallabies (Wilson and Swan 2008, Pearson 1993). Breeding commences in June - August, with males travelling distances of several kilometres in search of mates. Eggs are laid in October and juveniles hatch in summer, following which they disperse. Adults may occupy very large home ranges, up to approximately 450 ha in size (Pearson 2006).

Habitat preferences

Restricted to gorges and escarpments in the Pilbara and Gascoyne, this species shows a preference for rocky habitats near water, particularly where permanent or semi-permanent rock pools are present. Individuals may shelter in deep rock crevices.

Distribution

The olive python is endemic to Western Australia, occurring in a restricted region within the Pilbara and Gascoyne regions (Wilson and Swan 2008). It is distributed throughout most rocky areas of the Pilbara bioregion, including the Burrup Peninsula, throughout the Hamersley and Chichester Ranges, parts of the eastern Pilbara and Barlee Range Nature Reserve. Based on the Department of Parks and Wildlife's (**DPaW**) NatureMap database and Rio Tinto data, there are 48 records of this species spanning the majority of the bioregion (Figure 8.2-1). Known populations occur in association with rockpiles on the Burrup Peninsula, mesas of the Robe River valley and the Millstream spring system (Pearson 1993), though it appears to occur in lower density across suitable habitat in the majority of the bioregion.

Threats

Identified threatening processes for the Pilbara Olive Python include:

- predation of individual pythons by feral cats and foxes (particularly juveniles);
- predation of python prey species by foxes (competition); and
- habitat loss due to resources development (especially on Burrup Peninsula) (Pearson 2006).

Other impacts on the species include the loss of individuals due to road kills and deliberate killing of individuals due to misidentification as a venomous species (Pearson 2006).

Conservation Status

The species is listed as 'Vulnerable' under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. At State level, the Pilbara Olive Python is also listed under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 2010.

It should be noted that in 2003, a publication by the then Department of Conservation and Land Management (May and Mackenzie 2003) concluded that this species was not under threat at regional scale. Pearson (1993) also commented that a large proportion of the species' habitat in the Pilbara region was well represented in the conservation estate in Karijini National Park.

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8.3 Hamersley Lepidium (*Lepidium catapycnon*)

Biology

Hamersley Lepidium is a short lived perennial herb or shrub up to 40 cm high, with stems that zigzag. (Mattiske & Assoc., 1994; Brown et al., 1998). The leaves are small, linear, terete, and succulent (Hewson, 1981). White flowers occur as a dense head at the tips, and the life cycle is that of a pioneer ephemeral, with flowering from August to January (Hewson, 1981; Brown et al., 1998).

It should be noted that *Lepidium catapycnon* superficially resembles *L. platypetalum Hewson*; both have distinctive linear, more or less terete leaves, however *L. catapycnon* is defined by its characteristically zigzag shaped branches (Hewson, 1981).

Habitat preferences

Lepidium catapycnon is found in the following preferred habitats:

- stony hill slopes such as the uplands of the Hamersley Range plateau;
- skeletal soils;
- open woodland in usually hilly areas, more frequently on south facing slopes; and
- hill hummock grasslands

It tends to be displaced by maturing *Triodia sp*. (Spinifex), re-appearing after fires. It has also been found on road-verges and cuttings (Hewson, 1981).

In previous Rio Tinto vegetation surveys *Lepidium catapycnon* has often been found in association with *Eucalyptus sp*. over mixed *Acacia sp*. shrubland over *Triodia sp*. hummock grassland vegetation stands. The most common associated species are *Eucalyptus leucophloia*, *Eucalyptus xerothermica*, *Triodia wiseana*, *Triodia basedowii*, *Acacia bivenosa*, and *Acacia pruinocarpa*.

Distribution

Lepidium catapycnon is endemic to Western Australia and found in the Pilbara. Records are from around Newman, Wittenoom, Weeli Wolli creek and West Angelas.

DPaW's maintained database NatureMap indicates 44 records of *Lepidium catapycnon*. However, the Rio Tinto database lists 230 known recordings, with some stands containing approximately 1000 plants.

The species' extent of occurrence is approximately 10 280 km^2. There are insufficient data available to determine the area of occurrence although this species has now been recorded within Karijini National Park (Figure 8.3-1).

The distribution of this species is not known to overlap with any EPBC Act-listed threatened ecological community.

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Lepidium catapycnon is found on stony hill slopes such as the uplands of the Hamersley Range plateau (Figure 8.3-1)

Threats

Potential threats to the *L. catapycnon* include road works, as many populations are on or adjacent to frequently graded mining/exploration tracks (Brown et al., 1998), clearing, and invasion of the introduced Ruby Dock (*Acetosa vesicaria*), which may displace populations in some areas.

Conservation Status

Lepidium catapycnon is specially protected under both State and Federal legislation. The species is listed as 'Declared Rare Flora' under the *Western Australian Wildlife Conservation Act 1950* and is also listed as 'Vulnerable' under the Commonwealth EPBC Act 1999.

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8.4 Pilbara Leaf Nosed Bat (*Rhinonicteris aurantius)*

Biology

The Pilbara Leaf Nosed Bat (*Rhinonicteris aurantius)* is a moderate sized bat with short fur, relatively small ears and a fleshy noseleaf structure surrounding the nostrils. It has bright orange fur on the front of the body and the back appears darker because of brownish tips on the fur this also. Morphologically smaller than the northern form of this species, the nocturnal Pilbara Leaf-nosed Bat has a head and body length ranging from 40.8 – 47.4 mm, with an average of 42.7 mm (van Dyck and Strahan 2008).

Rhinonicteris aurantia are opportunistic in their diet, with prey primarily consisting of moths, beetles and termites, but supplemented with other insects (Churchill 2008).

Mating occurs in July, with females giving birth to solitary young in late December or early January. Young grow rapidly until weaning in February, with females becoming sexually mature in their first year at about seven months, although males do not mature until their second year.

Habitat preferences

The local distribution of the Pilbara Leaf-nosed Bat is mostly strongly influenced by the suitability of roost caves (hot and with a high humidity level) rather than habitat type. Many deeper caves that provide a suitable microclimate arise in Brockman Iron Formation ranges (Armstrong 2000, 2001), and there is a general association of the species records with this geology type (Figure 8.2-1). Foraging habitat appears to be diverse and not a restricting factor.

In the Pilbara, core roost sites are thought to be restricted to caves where at least semi-permanent water is nearby (Armstrong 2000, 2001, Churchill 2008). While they typically occur in caves, significant roosts have also become established in man-made structures such as abandoned mines in the Pilbara region (Churchill 1991, Dr Norm McKenzie, DPaW, unpubl. data). This includes confirmed roosts in the northern Pilbara at Lalla Rookh, Klondyke Queen (Armstrong 2010) and Bamboo Creek amongst others (DoE 2014).

Distribution

The Pilbara form of *Rhinonicteris aurantia* is found across the Pilbara bioregion and also just inside the Gascoyne bioregion at Barlee Range Nature Reserve.

Historically, individual R. aurantia have been recorded from a range of locations across the Pilbara since 1925. The Department of Environment and Conservation's Pilbara Biological Survey found *Rhinonicteris aurantia* to be more common than previously supposed, with numerous records from three of the four Pilbara sub-regions (McKenzie and Bullen 2009). The exception was the Fortescue subregion, which lacks suitable roost caves. Colonies of the species are scattered throughout the landscape in the Pilbara, and permanent roosts are known from abandoned mines and exploration adits in the eastern Pilbara, throughout the Hamersley Range and from sandstone formations south of the Hamersley Range. These colonies represent central points of population density, with individuals foraging out at distances of tens of kilometres. Pilbara colonies

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contain relatively small numbers of individuals, ranging from a few individuals to a few hundred, with 30 being a typical Pilbara roost size.

Threats

DoE (2014) lists nine threats to the conservation status of the Pilbara Leaf-nosed Bat:

- Heat and water loss: the species is known for its poor ability to maintain body temperature and water. Consequently, where roosts are disturbed the risk and/or rate of mortality may increase;
- Mine collapse: resulting in direct mortality;
- Flooding: resulting in destruction of roost sites and possibly direct mortality;
- Natural predators: direct mortality resulting from predators such as the Ghost Bat *Macroderma gigas*;
- Mine development: may result in the destruction of roost sites;
- Blasting in adjacent workings: resulting in abandoning of roost sites by bats;
- Human entry of roosts: resulting in animals abandoning the site;
- Roadkills: direct mortality resulting from increased vehicle activity; and
- Site rehabilitation.

Conservation status

Rhinonicteris aurantius is listed as Schedule 1 ('Vulnerable') under the Western Australian *Wildlife Conservation Act 1950 - 1979* and is also listed as 'Vulnerable' under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. It is currently listed as 'Least Concern' under the IUCN Red List, however it should be noted that this listing includes the both the Kimberley and Northern Territory populations.

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10. List of Site Specific Appendices

- Yandicoogina

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Figures

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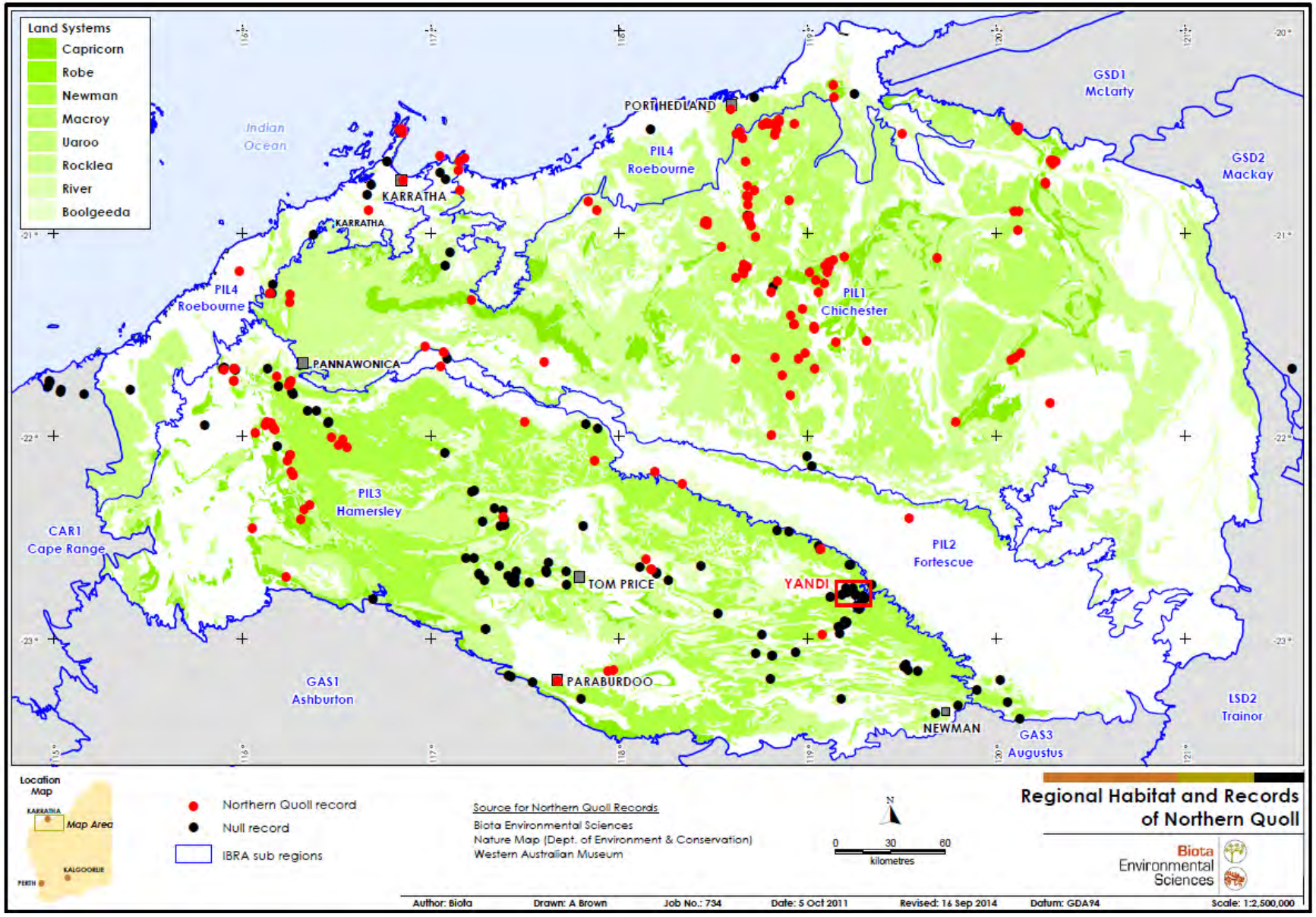

Figure 8.1-1 Distribution of Northern Quoll (*Dasyurus hallucatus)* records in the Pilbara.

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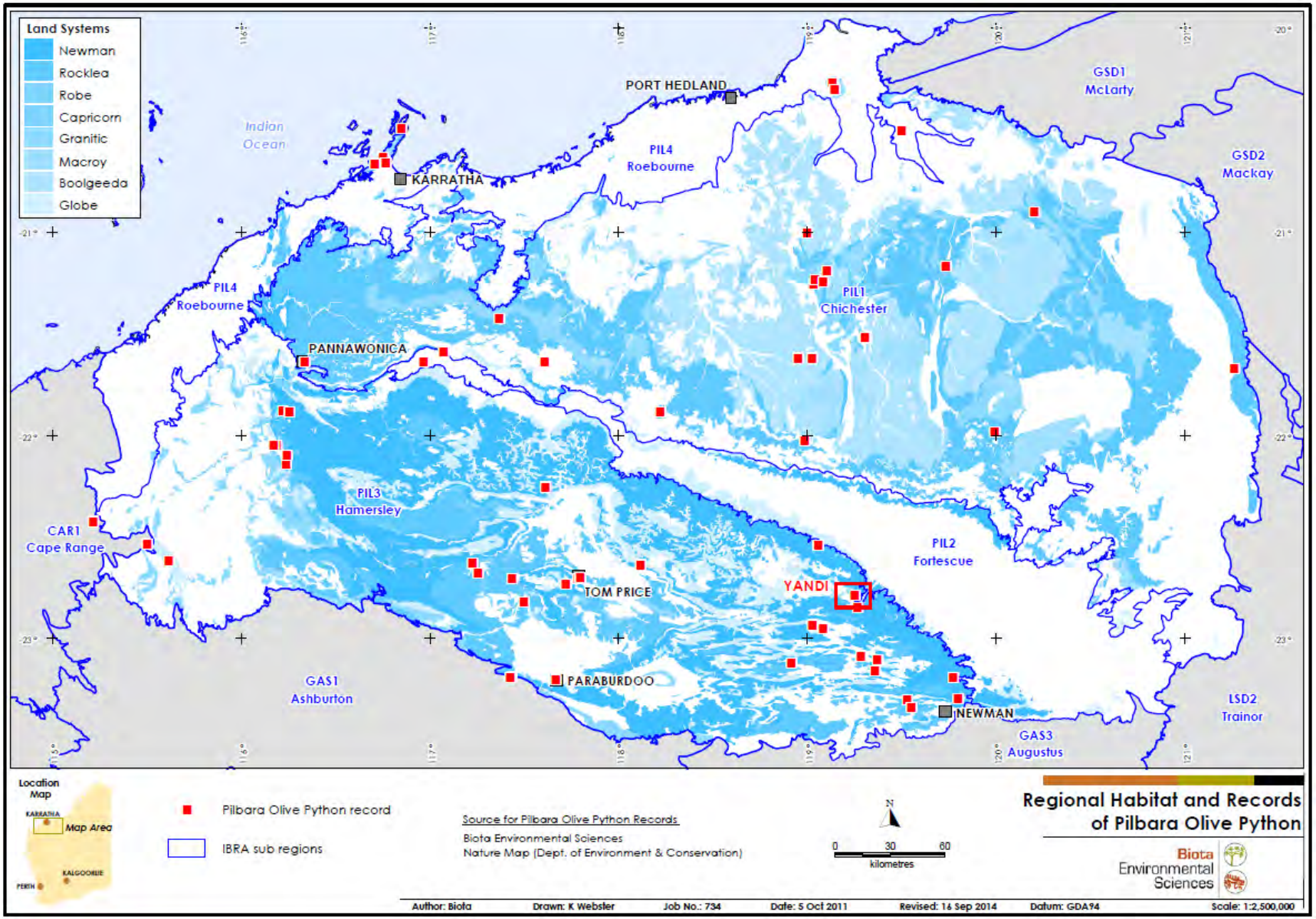

Figure 8.2-1 Distribution of Pilbara Olive Python (*Liasis olivaceus barroni*) records in the Pilbara.

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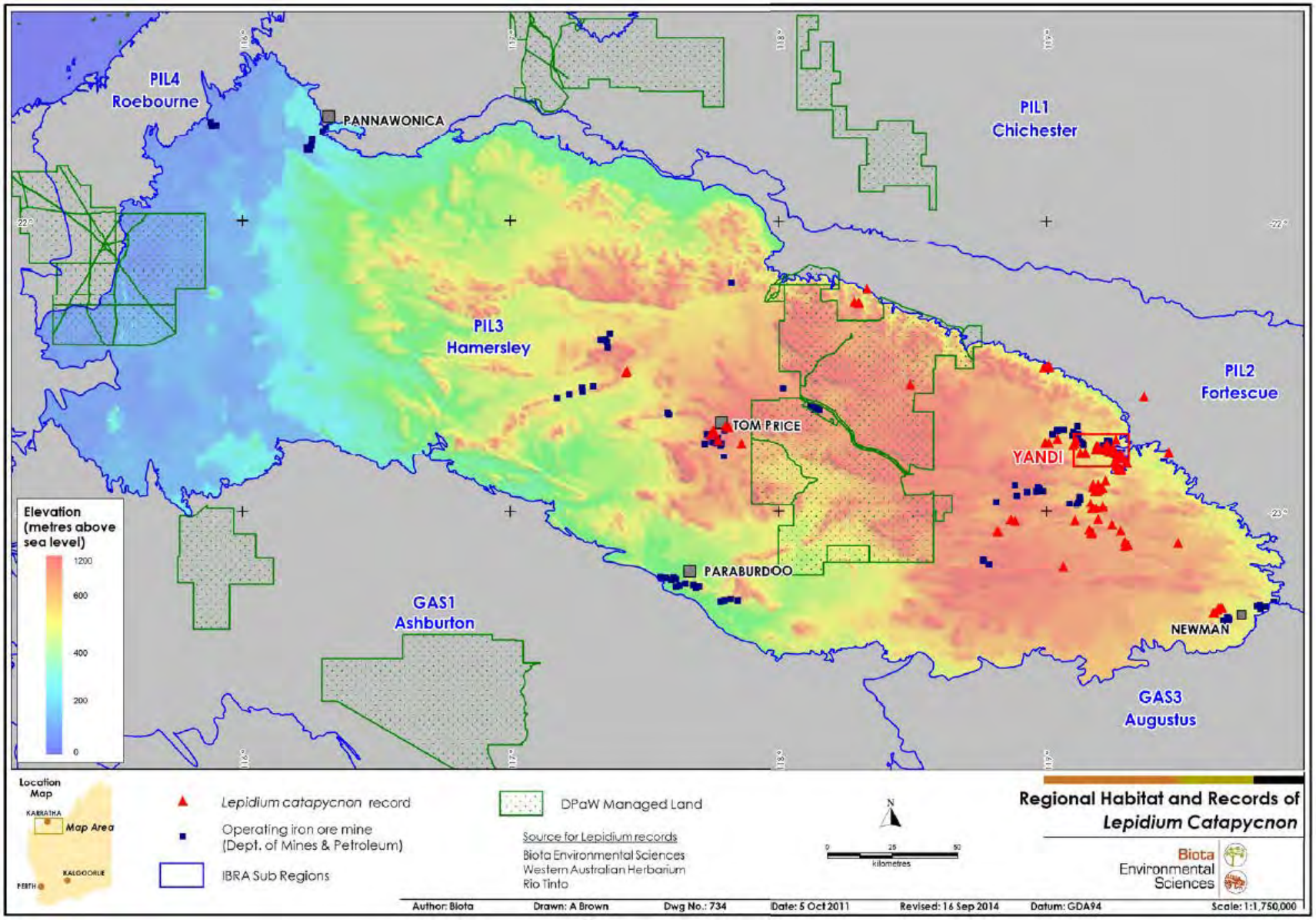

Figure 8.3-1 Distribution of Hamersley Lepidium (*Lepidium catapycnon*) in the Pilbara.

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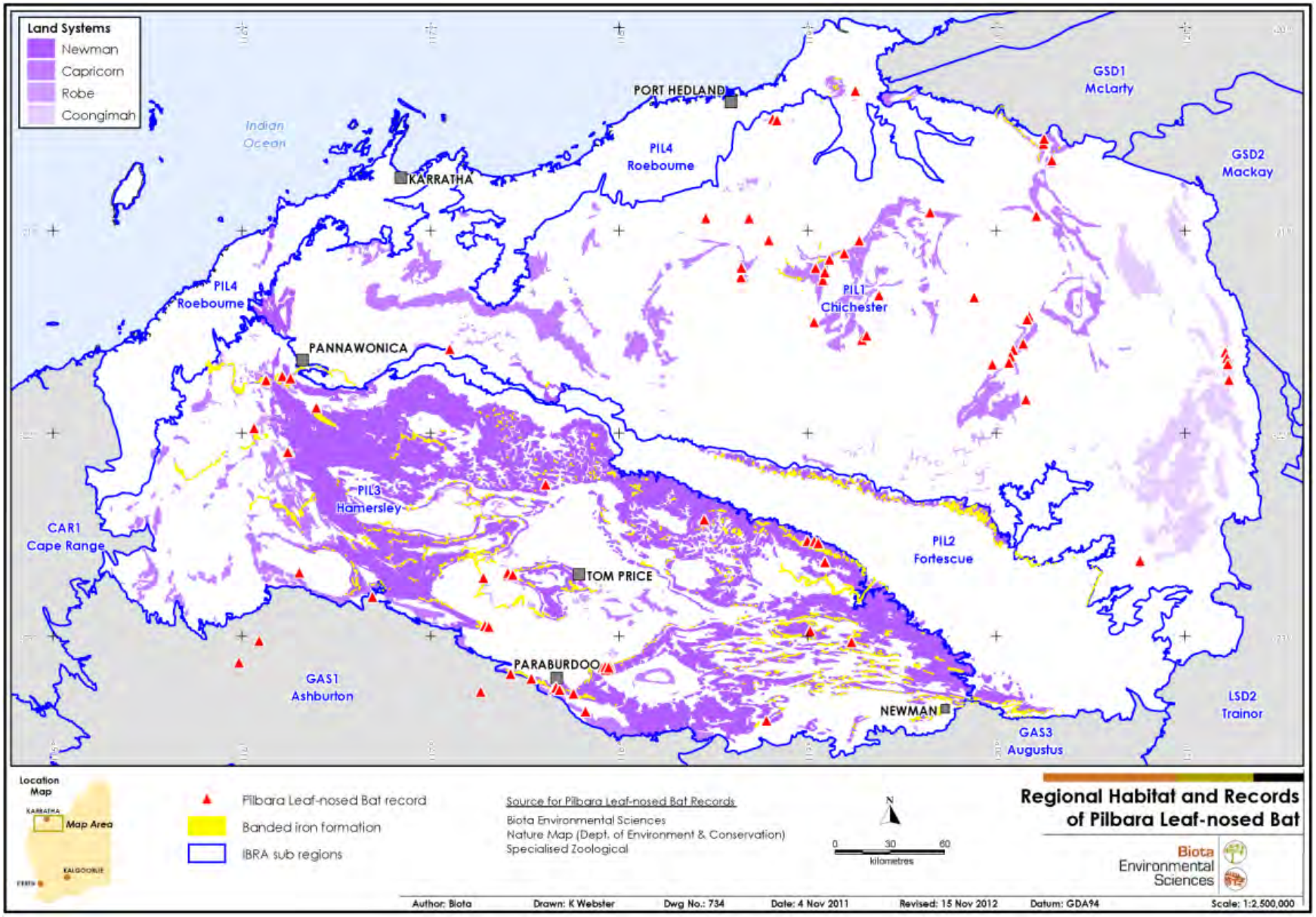

Figure 8.4-1 Distribution of Pilbara Leaf-nosed Bat (*Rhinonicteris aurantius*) records in the Pilbara

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Yandicoogina Significant Species Management Plan Addendum

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Document Owner:	**Environment Manager, Approvals**
Document Revision:	September 2014

1. Purpose

This plan is a site specific addendum to the Rio Tinto (WA) Significant Species Management Plan (**SSMP**), to manage potential impacts to species of National Environmental Significance (**NES**) protected under the *Environment Protection and Biodiversity Conservation Act 1999* (**EPBC Act**). This document must be read as an addendum to the Rio Tinto (WA) SSMP.

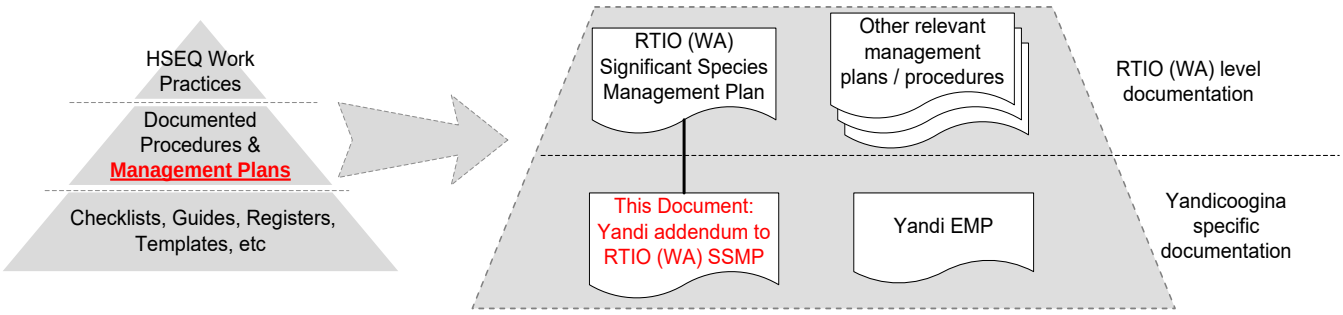

Figure 1-1 Relationship of Significant Species Management documents

Four species of NES occur, or have potential to occur in the vicinity of the Pocket and Billiard South Proposal:

- Pilbara Olive Python (*Liasis olivaceus barroni*) – known to occur
- Hamersley Lepidium (*Lepidium catapycnon*) – known to occur
- Northern Quoll (*Dasyurus hallucatus*) – potentially occurs
- Pilbara Leaf Nosed Bat (*Rhinonicteris aurantius*) – potentially occurs

The Proposal is unlikely to cause significant impacts to populations of these species, although it is possible impact to individuals of some species may occur.

2. Site context

The Yandicoogina operation is located approximately 90 km north-west of Newman in the eastern Pilbara region of Western Australia. Yandicoogina comprises a number of existing open-cut iron ore operations (and associated railway and infrastructure): Junction Central (approved in 1996) and Junction South east (JSE) (approved in 2005), and the more recent Junction South west (JSW) and Oxbow deposits (approved in 2012).

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An additional operation, the Pocket and Billiard South Project (the **Proposal**), will augment and ultimately replace the existing Yandicoogina operations as ore is eventually depleted from the existing mine pits. The Proposal requires clearing of up to 2,800 ha of native vegetation within a broader Yandicoogina Operations Development Envelope, and as the majority of the deposit occurs below the water table, dewatering of an additional ~30 GL/annum will be required to enable mining of the PBS deposit. Surplus water discharge in excess of operational requirements will be discharged to an ephemeral watercourse (Marillana Creek), which intersects Weeli Wolli Creek approximately 2 km downstream. Options for alternate surplus water management options are currently being investigated.

The Proposal has been determined to require assessment at a Public Environmental Review level under the Western Australian *Environmental Protection Act 1986*.

The Yandicoogina Mine area is within the Fortescue Botanical District of the Eremaean Botanical Province, as defined by Beard (1975), and is located near the boundary of the Hamersley and Fortescue sub-regions of the Pilbara Biogeographic Region as defined by the Interim Biogeographic Regionalisation for Australia (Environment Australia 2000). The majority of the Proposal area is typical of the Hamersley sub-region where the major creek systems (Marillana, Yandicoogina and Weeli Wolli Creek) form part of the Fortescue sub-region (Biota 2004a).

3. Potential Impacts on species of NES

Potential short term impacts of the Proposal that may affect individuals of species of NES, if present in the Proposal area include:

- Direct loss of habitat and fragmentation due to clearing;
- Alteration of surface hydrological regimes;
- Injury or mortality of fauna struck by vehicles;
- Spatial and temporal increase in suitable foraging habitat due to dewatering discharge.

Potential long term impacts that may affect individuals of species of NES, if present in the Proposal area include:

- Direct loss of habitat due to clearing and altered landforms;
- Alteration of surface hydrological regimes due to altered landforms;
- Indirect habitat disturbance by introduction of weed and pest species;
- Degradation of riparian habitat along the section of Weeli Wolli Creek within and adjacent to The PBS Mine pit due to mining and dewatering;
- Potential impacts on water dependent communities as a result of closure and creek system return from perennial to ephemeral regime
- Alteration of aquifer properties and groundwater chemistry resulting from post mining landform.

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Potential cumulative impacts to flora and fauna of NES by the Proposal and surrounding mining projects include:

- Direct loss of habitat due to clearing and altered landforms;
- Alteration of surface hydrological regimes due to altered landforms;
- Direct habitat disturbance on the Weeli Wolli creek system by release of surplus dewater by Yandicoogina, BHPBIO Yandicoogina and Hope Downs 1 operations
- Altered hydrology of the Fortescue Marsh, if combined dewatering discharge should ever inadvertently reach the marsh. Modelling studies indicate that potential discharges into Weeli Wolli Creek from mining project in the upper catchment are projected to cease ~23 km south of the southern edge of the Fortescue Marsh.

4. Site specific management objectives

Management objectives to minimise the potential impact of the Proposal on NES species are detailed in Table 5-1, and the following items are identified:

- Management measures/commitments that will ensure the Proposal achieves these objectives, comprising:
    - standard management measures for NES species as detailed in Table 5-1 of the SSMP;
    - site specific management measures for NES species as detailed in Table 6-1;
    - other relevant environmental management commitments that are part of the proposal being assessed under Part IV of the *Environmental Protection Act 1986* (WA) (**EP Act**) by the Environmental Protection Authority (**EPA**);
- Expected or known requirements under State legislation that will ensure specified management measures/commitments are implemented.

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Table 5-1 Yandicoogina Management Objectives for species of national environmental significance and mechanisms to achieve

Aspect	Rio Tinto overarching objective	PBS objective	Management measures/commitments	State legislative requirements to implement management measures/commitments [1]
Clearing and disturbance	Maintain the abundance, species diversity, geographic distribution and productivity of significant habitat or flora populations, by avoiding or minimising clearing, and utilising appropriate engineering and management of areas to be cleared.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • Additional site specific management measures (Table 6-1). Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The Ministerial Statement (**MS**) authorising the Proposal under Part IV of the *Environmental Protection Act 1986* (WA) (**EP Act**) is expected to maintain or impose Revised Conditions to MS914 that; • Limit the area of clearing to 2800ha within the Project Area; • Limit the extent of clearing of any vegetation or habitat considered significant by State government agencies; • Require implementation of the Proposal as assessed by the EPA, including management commitments associated with this objective.

Aspect	Rio Tinto overarching objective	PBS objective	Management measures/commitments	State legislative requirements to implement management measures/commitments [1]
	Progressively restore habitat for flora and fauna, particularly areas of habitat for significant species/populations, and develop self-sustaining, non-polluting final landforms to support ecosystems.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • A Closure Plan for the Proposal has been developed, in accordance with the Rio Tinto Closure Standard and the Guidelines for Preparing Mine Closure Plans (DMP/EPA 2011). The Closure Plan specifies closure objectives that are aligned with this overarching objective, and management measures to achieve closure objectives. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected to maintain or impose Revised Conditions to MS914 that; • Require EPA approval of a Closure Plan that meets the requirements of the Guidelines for Preparing Mine Closure Plans (DMP/EPA 2011); • Require progressive implementation of the Closure Plan (including rehabilitation) during the operational stage of the Proposal; • Require ongoing review and update of the Closure Plan, with periodic review by State government agencies during the operational stage of the Proposal; • Require approval by State government agencies of a final Closure Plan prior to closure of the operation.
Spread of weed species	Minimise the introduction and spread of weed species to significant flora and fauna habitat and populations.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • A site specific Weed Action Plan has been developed and will be implemented, in accordance with the requirements of the RTIO (WA) Weed Management Strategy. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected maintain or impose Revised Conditions to MS914 that require weed management and monitoring to ensure no increase in diversity or abundance of weed species due to Proposal implementation.
Increase in feral animals	Minimise the impact of feral animals by controlling their spread and mitigate impacts through feral animal management.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • Management measures (aligned with standard SSMP management measures) are part of the Proposal being assessed under Part IV of the EP Act. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected to maintain or impose Revised Conditions to MS914 that require implementation of the Proposal as assessed by the EPA, including management commitments associated with this objective.

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Aspect	Rio Tinto overarching objective	PBS objective	Management measures/commitments	State legislative requirements to implement management measures/commitments [1]
Dust generation	Protect significant fauna habitat and vegetation by controlling dust emissions.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • Management measures (aligned with standard SSMP management measures) are part of the Proposal being assessed under Part IV of the EP Act. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected to maintain or impose Revised Conditions to MS914 that require implementation of the Proposal as assessed by the EPA, including management commitments associated with this objective. The Licence to operate the Primary Crusher under Part V of the EP Act will impose conditions as deemed necessary by the Department of Environment Regulation (**DER**) to control/manage dust emissions.
Direct MNES encounter	Protect native fauna by avoiding species / ecological communities with conservation significance wherever practicable; utilising engineering designs, management controls, education of site personnel and traffic management.	• Overarching Rio Tinto objective.	• Standard management measures (SSMP Table 5-1); • Additional site specific management measures (Table 6-1); • Management measures (aligned with standard SSMP management measures) are part of the Proposal being assessed under Part IV of the EP Act. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected maintain or impose Revised Conditions to MS914 that require implementation of the Proposal as assessed by the EPA, including management commitments associated with this objective.

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Aspect	Rio Tinto overarching objective	PBS objective	Management measures/commitments	State legislative requirements to implement management measures/commitments [1]
Changes to hydrology and hydrogeology	Maintain the quantity and quality of water to protect existing and potential values, including ecosystem maintenance, flow paths and water quality.	• Overarching Rio Tinto objective; • Pit voids do not cause significant adverse impacts on the regional groundwater resource, or environmental values of the PBS area.	• Standard management measures (SSMP Table 5-1); • A Closure Plan for the Proposal has been developed, in accordance with internal Rio Tinto Closure practices and the Guidelines for Preparing Mine Closure Plans (DMP/EPA 2011). The Closure Plan specifies closure objectives that are aligned with this overarching objective, and management measures to achieve closure objectives. • A specific closure objective in relation to pit voids is specified (refer objective column), and measures to achieve are detailed in the Closure Plan. The PBS pit void is proposed to be left with a number of pit lakes, with investigations to date indicating the lake should not cause significant environmental impacts. Additional management measures for JSW & Oxbow: • EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected to maintain or impose Revised Conditions to MS914 that: • Require EPA approval of a Closure Plan that meets the requirements of the Guidelines for Preparing Mine Closure Plans (DMP/EPA 2011); • Require progressive implementation of the Closure Plan (including rehabilitation) during the operational stage of the Proposal; • Require ongoing review and update of the Closure Plan, with periodic review by State government agencies during the operational stage of the Proposal; • Require approval by State government agencies of a final Closure Plan prior to closure of the operation.
Altered fire regimes	Protect significant habitat from fire where beneficial, and minimise fire occurring from human activities.	• Overarching Rio Tinto objective.	Standard management measures (SSMP Table 5-1); Management measures (aligned with standard SSMP management measures) are part of the Proposal being assessed under Part IV of the EP Act. Additional management measures for JSW & Oxbow: EPBC Decision Notice 2011/5815 (Refer to Section 9)	The MS authorising the Proposal under Part IV of the EP Act is expected to maintain or impose Revised Conditions to MS914 that require implementation of the Proposal as assessed by the EPA, including management commitments associated with this objective.

[1] *To be periodically updated to align with conditions of State legislative approvals for the Proposal*

5. Site-specific management measures

In addition to the standard management measures in Table 5-1 of the SSMP, further specific measures apply at Yandicoogina (for the existing JSW and Oxbow Project and the PBS Proposal) (Table 6-1) where there is confirmation of species of NES present.

These further management measures apply to the following species:

- Pilbara Olive Python (*Liasis olivaceus barroni*) – known to occur
- Hamersley Lepidium (*Lepidium catapycnon*) – known to occur
- Northern Quoll (*Dasyurus hallucatus*) – potentially occurs
- Pilbara Leaf-nosed Bat (*Rhinonicteris aurantius*) – potentially occurs

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Table 6-1 Management Measures at Yandicoogina for species of NES

All management measures as listed in Table 5-1 of this document (RTIO (WA) Significant Species management plan

All management measures as listed in the Yandicoogina Iron Ore Operations Environmental Management Program 2013 (EMP):
• Surface Water Discharge Monitoring and Management Plan
• Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan
• Weed Monitoring Plan
• Yandicoogina Life of Mine Closure Plan
• Yandicoogina Threatened Species Offset Plan
• Yandicoogina Significant Species Management Plan
• Guidelines:
  ○ EMP 01 – Dust Management Guideline (E2)
  ○ EMP 02 – Acid Rock Drainage Management Guideline (E3)
  ○ EMP 03 – Greenhouse Gas Management Guideline (E4)
  ○ EMP 04 – Hazardous Materials Management Guideline (E5)
  ○ EMP 05 – Noise Management Guideline (E6)
  ○ EMP 06 – Non-Mineral Waste Management Guideline (E7)
  ○ EMP 07 – Mineral Waste Management Guideline (E8)
  ○ EMP 08 – Aboriginal Heritage Management Guideline (E9)
  ○ EMP 09 – Waste Water and Effluent Management Guideline
  ○ EMP 10 – Subterranean Fauna Management Guideline
  ○ EMP 11 – Significant Species Management Guideline
  ○ EMP 12 – Non Threatened Native Fauna Management Guideline
  ○ EMP 13 – Fire Management Guideline

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Additional Management Measures:				
Aspect	**Action**	**RTIO (WA) Accountability**	**References**	**Species applies to**
Clearing & Disturbance	Ensure any sightings or potential records of NES species encountered by the workforce during clearing operations are reported to site Environmental Advisors and recorded in a register. Site environmental inductions & educational posters utilised to raise awareness of NES species and specify protocols for reporting sightings.	All employees and contractors		- Northern Quoll - Pilbara Olive Python - Hamersley Lepidium
	Obtain botanical confirmation of any reported and previously undocumented populations of Hamersley Lepidium within the operations area. Map extent of population and carry out adaptive review of existing management and design for Yandi operations.	Environment Managers Operations & Expansions		- Hamersley Lepidium
	Targeted surveys will be undertaken to identify any significant species, habitat or communities for any new projects/expansions - investigate ways to minimise or avoid the clearing of significant species if identified - riparian vegetation will be managed as per the Vegetation and Groundwater Dependent Ecosystems Monitoring and Management plan.	Environment Managers Operations & Expansions		- Northern Quoll - Pilbara Olive Python - Pilbara Leaf-nosed Bat - Hamersley Lepidium
Direct MNES encounter	Follow the Yandicoogina Pilbara Olive Python relocation protocol for any individuals encountered within the Yandi operational area. This should comprise measures for safe capture of individuals, temporary storage and suitable habitat release areas outside of the Yandi operations.	Environment Managers, Operations & Expansions	RTIO Wildlife interaction guidelines	- Pilbara Olive Python
	Native animals encountered onsite will be given the opportunity to move on if there is no threat to personnel safety in doing so. All animal strikes by vehicles will be recorded and documented.	All employees and contractors		- Northern Quoll - Pilbara Olive Python

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6. Surveys & Monitoring

Based on detailed knowledge of the occurrence of NES species and potential core habitat in the PBS area, and the implementation of standard and additional site specific management measures (SSMP Table 5-1; Table 6-1 herein), the PBS Proposal will not result in significant impact on population or species of NES, or potential 'core' habitat for NES species, at a local or regional scale.

Therefore, in addition to regular monitoring requirements at Yandicoogina within the broader Development Envelope (including the monitoring conditions of EPBC 2011/5815 for JSW and Oxbow), monitoring will comprise recording of any future sightings of species of NES in the both the PBS Proposal area and surrounds and recording the extent of potential core habitat cleared during Proposal implementation. These additional monitoring actions are described in table 7-1.

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Table 7-1 Monitoring at Yandicoogina for species of NES

Refer to Yandicoogina Expansion Northern Quoll Position Paper (Biota, 2010)
Refer to Yandicoogina Targeted Northern Quoll Survey (Biota, 2014b)
Refer to Yandicoogina Iron Ore Operations Environmental Management Program 2013 (EMP) (RTIO 2013)
Refer to Yandicoogina Junction South West and Oxbow Iron Ore Project EPBC Decision Notice 2011/5815

Additional Monitoring Measures:

Species Targeted	Design / Guidelines	Purpose	Reporting & Review
Northern Quoll	Presence monitoring for the Northern Quoll comprising the use of automatic infrared cameras deployed in suitable habitat for the species at Yandi.	To identify whether this species does use the Yandicoogina area as habitat, whether any populations exist in the general area, and when this species is present at Yandi during the life of the operations. If camera records indicate a potential increase in the local population, then consideration may be given to a targeted survey.	- Annual Environmental Report - Review of monitoring results after 5 years to interpret, recommend and assess future requirements - Review habitat for changes in vegetation condition
Hamersley Lepidium	Monitoring of dust levels for known populations adjacent to operational areas. This will be complemented by systematic monitoring of the populations of Hamersley Lepidium at selected sites. Local populations outside of the influence of the operations will also be similarly monitored to distinguish project effects from regional stochastic change.	To collect data on any change in Hamersley Lepidium population density or condition in relation to measured dust levels. These data will inform both site management procedures and future assessment of ecological risk for Hamersley Lepidium in relation to dust deposition.	- Annual Environmental Report - Review of monitoring results after 5 years to interpret, recommend and assess future requirements
Pilbara Olive Python	Maintain a site register of number of individuals relocated under the relocation protocol during the life of the operation.	To collect data on total number of python records within the Yandi operations over time.	- Annual Environmental Report - Review of monitoring results after 5 years to interpret, recommend and assess future requirements - Review habitat for changes in vegetation condition
Riparian Vegetation	Tree health monitoring program	Continue existing tree health monitoring program	- Annual Environmental Report - Ongoing review of monitoring results to interpret, recommend and assess future requirements

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7. References

Biota 2010, *Yandicoogina Targeted Northern Quoll Survey*, Unpublished report prepared by Biota Environmental Sciences Pty Ltd for Rio Tinto, December 2009

Biota 2014a *Yandi Billiards – Phase 2 Interim Report on Conservation Significant Flora*, Unpublished report prepared by Biota Environmental Sciences Pty Ltd for Rio Tinto, August 2014

Biota 2014b *Yandi Billiards – Interim Report on Conservation Significant Terrestrial Fauna*, Unpublished report prepared by Biota Environmental Sciences Pty Ltd for Rio Tinto, August 2014

DMP/EPA (2011) Guidelines for Preparing Mine Closure Plans. Department of Mines and Petroleum Western Australia, Environmental Protection Authority Western Australia. Retrieved from http://www.dmp.wa.gov.au/documents/Mine_Closure(2).pdf

Environment Australia (2000). Revision of the Interim Biogeographic Regionalisation for Australia (IBRA) and development of Version 6.1. Summary Report, Perth.

EPBC Decision Notice 2011/5815 (2012) Yandicoogina Junction South West and Oxbow Iron Ore Project, WA, November 2012

RTIO (2013) Yandicoogina Iron Ore Operations Environmental Management Program March 2013 (EMP)

8. Figures

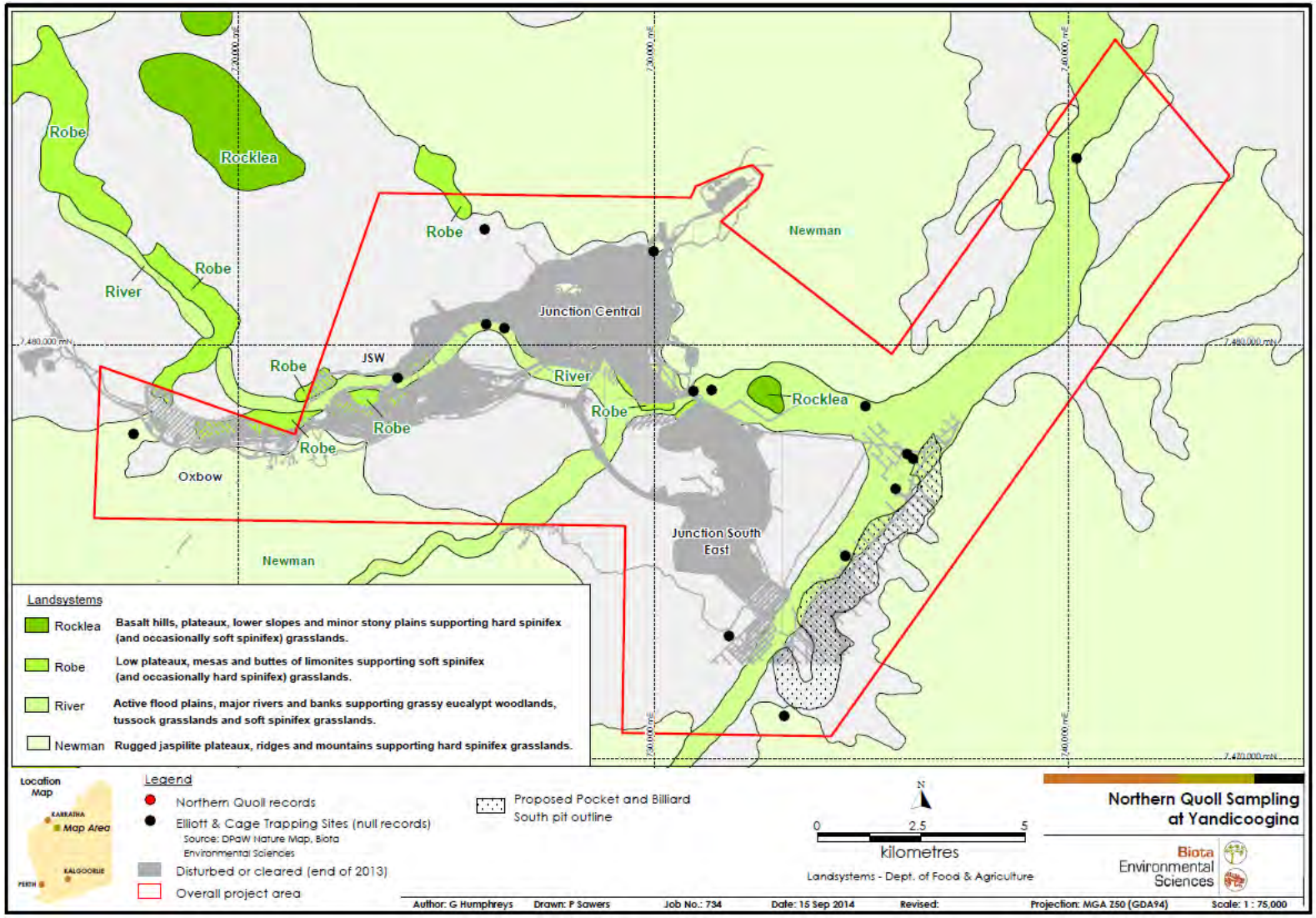


Figure 8-1 Distribution of Northern Quoll (*Dasyurus hallucatus*) records in the Yandicoogina Area.

Yandicoogina

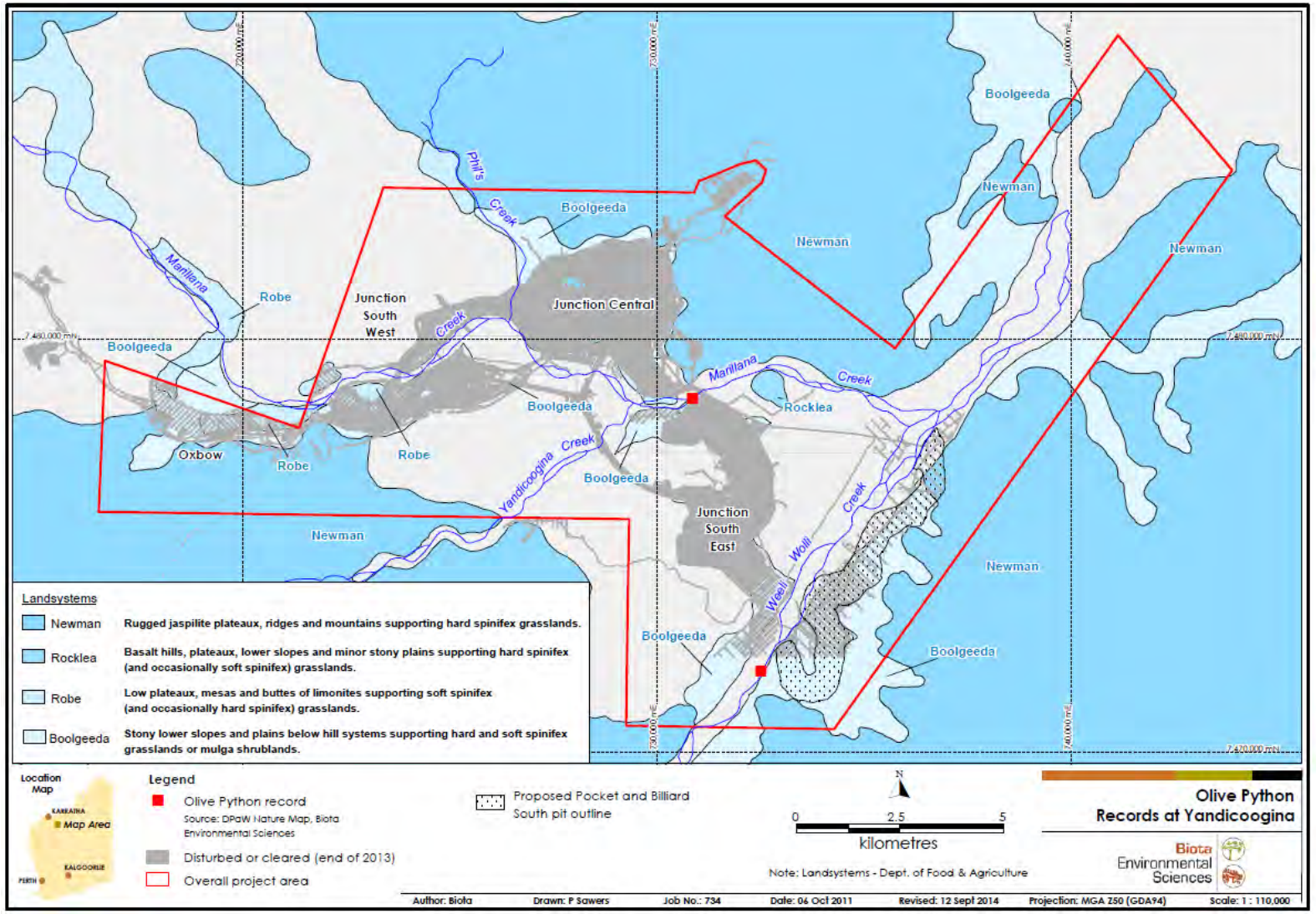


Figure 8-2 Distribution of Pilbara Olive Python (*Liasis olivaceus barroni*) in the Yandicoogina Area.

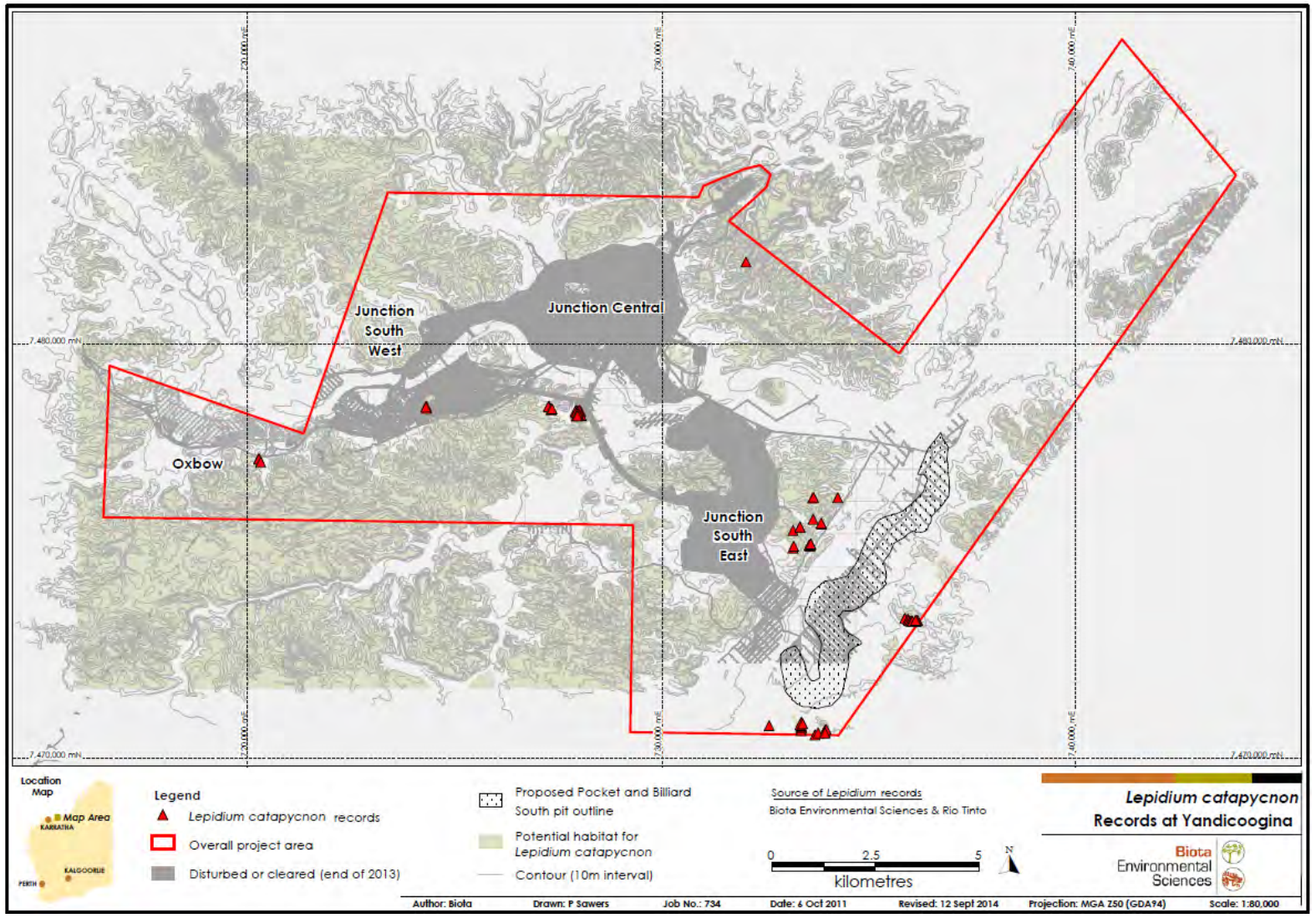


Figure 8-3 Distribution of Hamersley Lepidium (*Lepidium catapycnon*) in the Yandicoogina Area.

Yandicoogina

9. EPBC Decision Notice 2011/5815 for Yandicoogina Junction South West and Oxbow Iron Ore Mine

Australian Government

Department of Sustainability, Environment, Water, Population and Communities

Approval

Yandicoogina Junction South West and Oxbow Iron Ore Project, WA (EPBC 2011/5815)

This decision is made under sections 130(1) and 133 of the *Environment Protection and Biodiversity Conservation Act 1999*.

Proposed action

person to whom the approval is granted	Hamersley Iron Pty Ltd
proponent's ACN (if applicable)	ACN 004558276
proposed action	To develop new mine pits and supporting infrastructure, at Yandicoogina, central Pilbara region of WA, as described in the referral received by the department on 20 January 2011. [See EPBC Act referral 2011/5815].

Approval decision

Controlling Provision	Decision
Listed threatened species and communities (sections 18 & 18A)	Approve

conditions of approval

This approval is subject to the conditions specified below.

expiry date of approval

This approval has effect until 30 September 2025

Decision-maker

name and position	James Tregurtha Assistant Secretary South-Eastern Australia Environment Assessment Branch
signature	
date of decision	20 NOVEMBER 2012

Conditions attached to the approval

1) To protect habitat for the **Northern Quoll** and **Pilbara Olive Python disturbance** of vegetation must:

   a) not exceed a total of 2,200 hectares and must only occur within the **development footprint**; and

   b) not exceed 40 hectares within the floodplain and riparian vegetation zone associated with **Marillana Creek** located within the **development footprint**.

2) The person taking the action must establish and maintain an **EPBC Act listed threatened species** Register on a publicly available website. The Register must record any sightings of **EPBC Act listed threatened species**, alive or dead, in the **project area** no less than every three months during **construction**, and no less than every 12 months during **operation**. The web address of the register must be provided to the **department** within 30 days of establishment.

3) The person taking the action must develop a staff environmental induction to be undertaken by all staff, including contractors, prior to the **commencement** of their duties and annually thereafter. The induction material must include, but not necessarily be limited to:

   a) clear colour images and simple descriptions of the ecology and diagnostic features of **EPBC Act listed threatened species** and their habitat;

   b) protocols for reporting sightings, including vehicle strike (including GPS coordinates), of **EPBC Act listed threatened species** within seven days to the officer in charge of implementing the **EPBC Act listed threatened species** Register described in condition 2);

   c) reference to the penalties imposed for causing intentional harm to **EPBC Act listed threatened species**; and

   d) legal and on site environmental responsibilities.

4) The person taking the action must display the information required in condition 3) a) on signs or posters around staff amenities, construction camps and material/equipment depots, and on laminated cards for all staff vehicles. The signs, posters and laminated cards must also state that the **Pilbara Olive Python** is slow moving and highly susceptible to road strike.

5) In the event one or more **Northern Quoll** and/or **Pilbara Olive Python** individuals are detected within the **development footprint**, the person taking the action must limit vehicle speeds outside the **active pit areas**, excluding automated haulage machines, to 40 km per hour on all roads within the **development footprint** between dusk and dawn until no **Northern Quolls** and/or **Pilbara Olive Python** individuals are sighted for a continuous period of four weeks;

6) The person taking the action must ensure that all vehicles, machinery, and equipment remain within the **development footprint**, and must prevent off road driving, unless in case of an emergency;

7) The person taking the action must ensure that all vehicles, machinery and equipment are prevented from accessing known locations of the **Hamersley Lepidium**, as seen in Annexure 1 during **construction** and **operation**.

8) The person taking the action must implement measures to prevent the spread or establishment of feral animal species populations within the **project area** in a manner that is sympathetic with the conservation of **EPBC Act listed threatened species**. Measures must include, but not necessarily be limited to:

a) appropriate waste management associated with staff amenities, **construction** camps and material/equipment depots;

b) a control program which is consistent with current national guidelines for pest control; and

c) annual monitoring, reporting and evaluation of the measures.

9) The person taking the action must implement measures to prevent the spread or establishment of invasive weeds within the **project area** in a manner that is sympathetic with the conservation of **EPBC Act listed threatened species**. Measures must include, but not necessarily be limited to:

a) baseline surveys and Geographical Information System mapping of target weed species, as determined by a **suitably qualified expert**;

b) a targeted control program;

c) weed hygiene measures for vehicles and mining equipment and machinery; and

d) annual monitoring, reporting and evaluation of the measures identified in conditions 9) a) to c).

10) The person taking the action must implement measures to prevent and/or control the spread of fires caused by any component of **construction** and **operation**.

11) In the event the person taking the action becomes aware of new information regarding the presence of any **EPBC Act listed threatened species** within the **development footprint**, that information must be reported to the **Minister** within seven business days of becoming aware of the new information.

12) The person taking the action must implement measures to minimise potential impacts from **dewatering** and discharge of surplus water on habitat for the **Northern Quoll** and **Pilbara Olive Python** along **Marillana Creek** and **Weeli Wolli Creek**, both in the dewatering and surplus water discharge impact areas. Measures must include, but not necessarily be limited to:

a) baseline data surveys to be undertaken prior to **dewatering** and the discharge of surplus water, for **Northern Quoll** and **Pilbara Olive Python** habitat, including vegetation abundance, health, foliage cover and diversity;

b) appropriate monitoring (including annual surveys) to detect changes, occurring as a result of the action, to **Northern Quoll** and **Pilbara Olive Python** habitat, including vegetation abundance, health, foliage cover and diversity;

c) thresholds appropriate for the changes determined for condition 12) b) that establish when the action is resulting in degradation of habitat taking into consideration climatic variability, seasonal variation and discharge volumes from other relevant mines;

d) contingency measures to be implemented, should the thresholds indentified in condition 12) c) be exceeded as a result of the action, for addressing current and future exceedances and remediation of habitat degraded by dewatering and discharge activities;

e) protocols for reporting to the **Minister** within seven days if the thresholds developed for condition 12) c) are exceeded, within 30 days for contingency measures implemented and within 6 months on the success the contingency measures.

13) The person taking the action must rehabilitate all potentially suitable habitat for **EPBC Act listed threatened species** that is **disturbed** during **construction** and **operation**. The rehabilitation must be developed in consultation with a **suitably qualified expert** and must include, but not necessarily be limited to:

a) baseline data of the characteristics of the pre-mining ecosystems within the **development footprint**;

b) use of plant species of local provenance that are compatible with land system units that provide suitable habitat for **EPBC Act listed threatened species**; and

c) monitoring and evaluation annually for three years or until establishment.

14) To compensate for the residual impacts of the action and for the better protection and long-term conservation of the **Northern Quoll** and **Pilbara Olive Python**, a Threatened Species Offset Plan (TSOP) must be submitted to the **Minister** for approval. The TSOP must include, but not necessarily be limited to:

a) a contribution of no less than $3,000,000 (GST exclusive) to fund, extend or expand a land management program within the Pilbara bioregion for a period of no less than five years;

b) details of measures to control and/or manage, for the benefit of the **Northern Quoll** and **Pilbara Olive Python**:

i) introduced predators;

ii) feral herbivores;

iii) wild fires; and

iv) invasive weeds.

c) for each threat identified in condition 14) b), the TSOP must define:

i) how the control/management measures are expected to benefit the **Northern Quoll** and **Pilbara Olive Python**;

ii) details of the location and area of land to be managed which must be mapped and provided to the **department** in a **shapefile(s)**;

iii) details of methodology, timing, frequency and intensity (effort) of management measures;

iv) responsibility for management measures;

v) details of how the management actions identified for condition 14) b) will be undertaken in a manner that is sympathetic with the conservation of other relevant threatened species listed under the **EPBC Act** known to occur in the area identified under 14) c) ii);

d) details of a monitoring program, including but not necessarily limited to:

i) methodology, timing, frequency, scope and survey effort for/of monitoring;

ii) baseline surveys of the area to be managed;

iii) monitoring during and post land management actions to determine the effectiveness of land management actions;

iv) performance indicators, which will determine the effectiveness of the land management program; and

v) measures to make the results of the monitoring made publically available.

The TSOP must be submitted to the **Minister** for approval by 31 December 2013. Should the TSOP be approved then the approved TSOP must be implemented.

15) Documentary evidence must be submitted to the **department** showing that payments of the total amount required in condition 14) a) have been made to the person(s) responsible for implementation of the land management program within 18 months of the date of approval of the TSOP.

16) Annually on 30 April, after **commencement** of the action, a report must be submitted to the **Minister** detailing how condition 14) is, or has been, met including:

    a) whether the timeframes for undertaking the management actions identified in condition 14) c) and d) have been met; and

    b) whether the performance indicators required for condition 14) c) have been met.

17) Within 10 days after the **commencement** of the action, the person taking the action must advise the **Department** in writing of the actual date of **commencement**.

18) The person taking the action must maintain accurate records substantiating all activities associated with or relevant to the conditions of approval, including measures taken to implement the plans required by this approval, and make them available upon request to the **department**. Such records may be subject to audit by the **department** or an independent auditor in accordance with section 458 of the **EPBC Act**, or used to verify compliance with the conditions of approval. Summaries of audits will be posted on the **department's** website. The results of audits may also be publicised through the general media.

19) Annually on 30 April, after **commencement** of the action, the person taking the action must publish a report on their website addressing compliance with each of the conditions of this approval, including implementation of any management plans as specified in the conditions. Documentary evidence providing proof of the date of publication and non-compliance with any of the conditions of this approval must be provided to the **department** at the same time as the compliance report is published.

20) Upon the direction of the **Minister**, the person taking the action must ensure that an independent audit of compliance with the conditions of approval is conducted and a report submitted to the **Minister**. The independent auditor must be approved by the **Minister** prior to the commencement of the audit. Audit criteria must be agreed to by the **Minister** and the audit report must address the criteria to the satisfaction of the **Minister**.

21) If the person taking the action wishes to carry out any activity otherwise than in accordance with the plan(s) as specified in the conditions, the person taking the action must submit to the **department** for the **Minister's** written approval a revised version of that plan(s). The varied activity shall not commence until the **Minister** has approved the varied plan(s) in writing. The **Minister** will not approve a varied plan(s) unless the revised plan(s) would result in an equivalent or improved environmental outcome over time. If the **Minister** approves the revised plan(s), that plan(s) must be implemented in place of the plan(s) originally approved.

22) If the **Minister** believes that it is necessary or convenient for the better protection of listed threatened species and communities to do so, the **Minister** may request that the person taking the action make specified revisions to the plan(s) specified in the conditions and submit the revised plan(s) for the **Minister's** written approval. The person taking the action must comply with any such request. The revised approved plan(s) must be implemented. Unless the **Minister** has approved the revised plan(s), then the person taking the action must continue to implement the plan(s) originally approved, as specified in the conditions.

23) If, at any time after five (5) years from the date of this approval, the person taking the action has not **substantially commenced** the action, then the person taking the action must not **substantially commence** the action without the written agreement of the **Minister**.

24) Unless otherwise agreed to in writing by the **Minister**, the person taking the action must publish all plan(s) referred to in these conditions of approval on their website. Each plan must be published on the website within 1 month of being approved.

Definitions

Active pit areas means the area identified as 'JSW & Oxbow Conceptual Mine Pits' in Annexure 3.

Commencement of the action (except in the sense of **substantial commencement**) means the **commencement** of **construction**.

Construction means clearance of vegetation, the erection of any onsite temporary structures and the use of heavy duty equipment for the purpose of breaking the ground for buildings or infrastructure within the **development footprint** excluding works associated with the **existing mining operation**.

Department means the Australian Government Department administering the *Environment Protection and Biodiversity Conservation Act 1999.*

Development footprint means the area identified as "JSW & Oxbow proposed mining and infrastructure" in Annexure 1 excluding the areas associated with the **existing mining operation**.

De-watering means the removal of water by pumping, drainage, or evaporation.

Diagnostic features mean physical features or distinguishing characteristics which may aid in species identification

Disturb or **disturbance** of vegetation means the cutting down, felling, thinning, logging, removing, killing, destroying, poisoning, ringbarking, uprooting or burning of native vegetation, this also includes any activities associated with earth moving.

EPBC Act Listed threatened species means the **Northern Quoll**, the **Pilbara Olive Python** and the **Hamersley Lepidium**.

Existing mining operation means the area identified as "disturbed or cleared – associated with MS417, 523 & 695" in Annexure 1.

Hamersley Lepidium means *Lepidium catapycnon.*

Marillana Creek means the creek line identified as "Marillana Creek" in Annexure 2.

Minister means the Minister administering the *Environment Protection and Biodiversity Conservation Act 1999* and includes a delegate of the Minister.

Northern Quoll means *Dasyurus hallucatus.*

Operation includes any activities associated with the extraction and transportation of iron ore.

Pilbara Olive Python means *Liasis olivaceus barroni*

Population means 'population of a species' as per the Significant Impact Guidelines 1.1 – Matters of National Environmental Significance.

Project area means the area identified as "Overall project area" in Annexure 1.

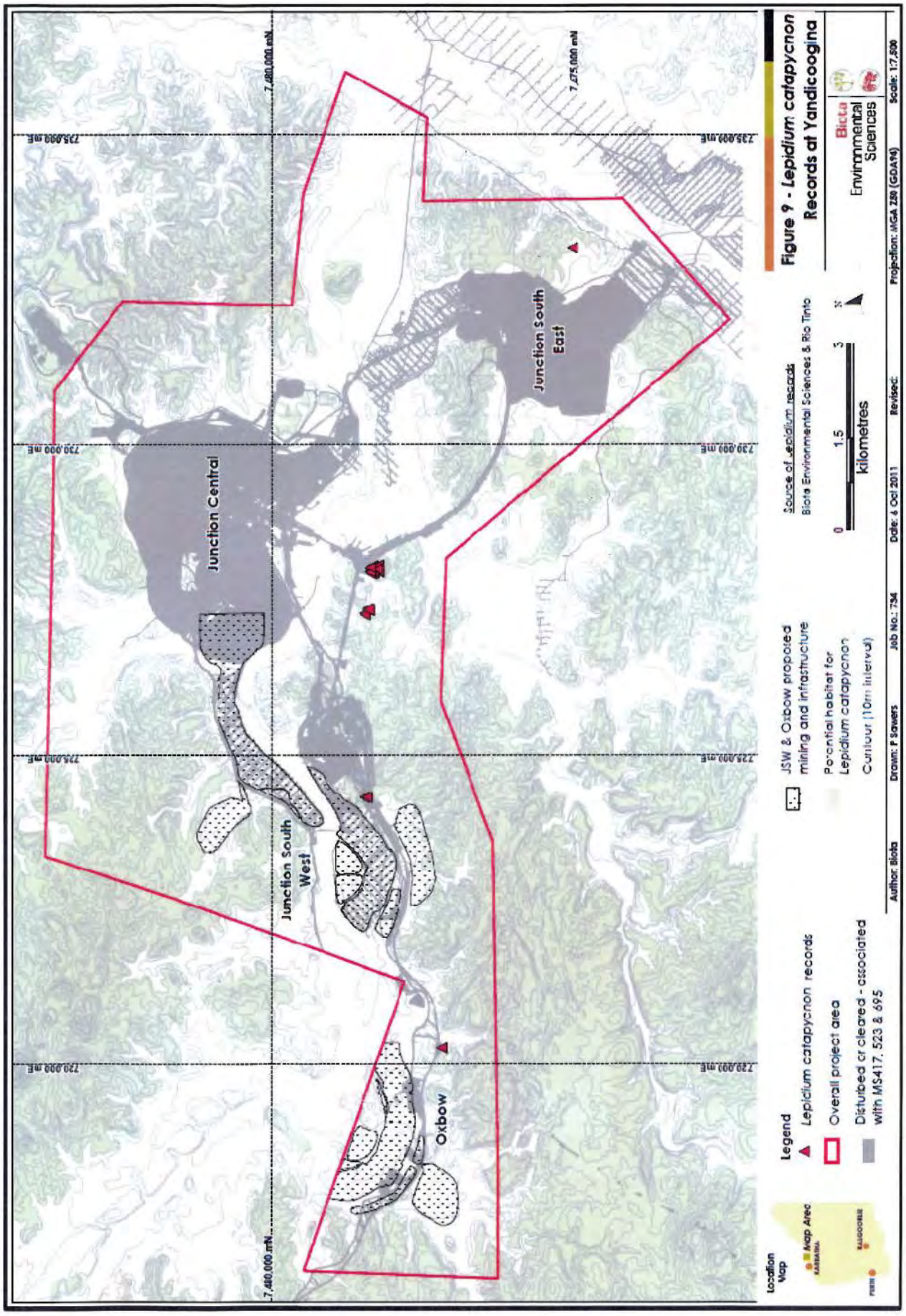
Shapefiles means an ESRI ArcGIS Shapefile, containing '.shp', '.shx.' and '.dbf' files and other files. Shapefiles must include appropriate metadata capturing attributes including but not limited to the EPBC reference number of the approved action and details of the EPBC protected matters present within the offset, covenant or legal protection details, including type and identification. The **department** prefers **shapefiles** using the Geocentric Datum of Australia (GDA) 94.

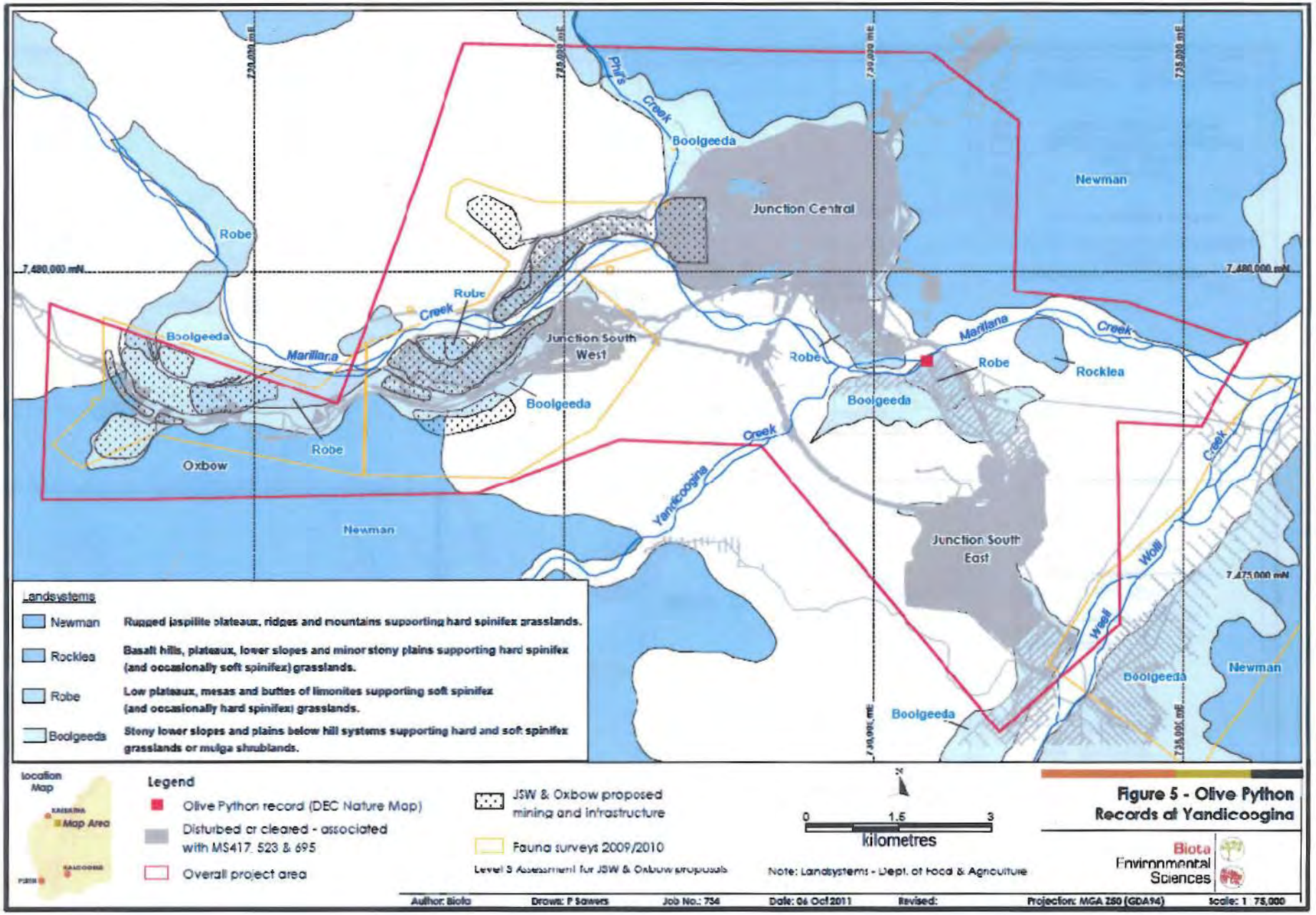
Substantially commence means the erection of any permanent infrastructure, excluding signage and fences, associated with the action.

Suitably qualified expert means a suitably qualified botanist, ecologist, or environmental scientist with demonstrated expertise in the survey, management and, if need be, translocation in the relevant **EPBC Act Listed threatened species**.

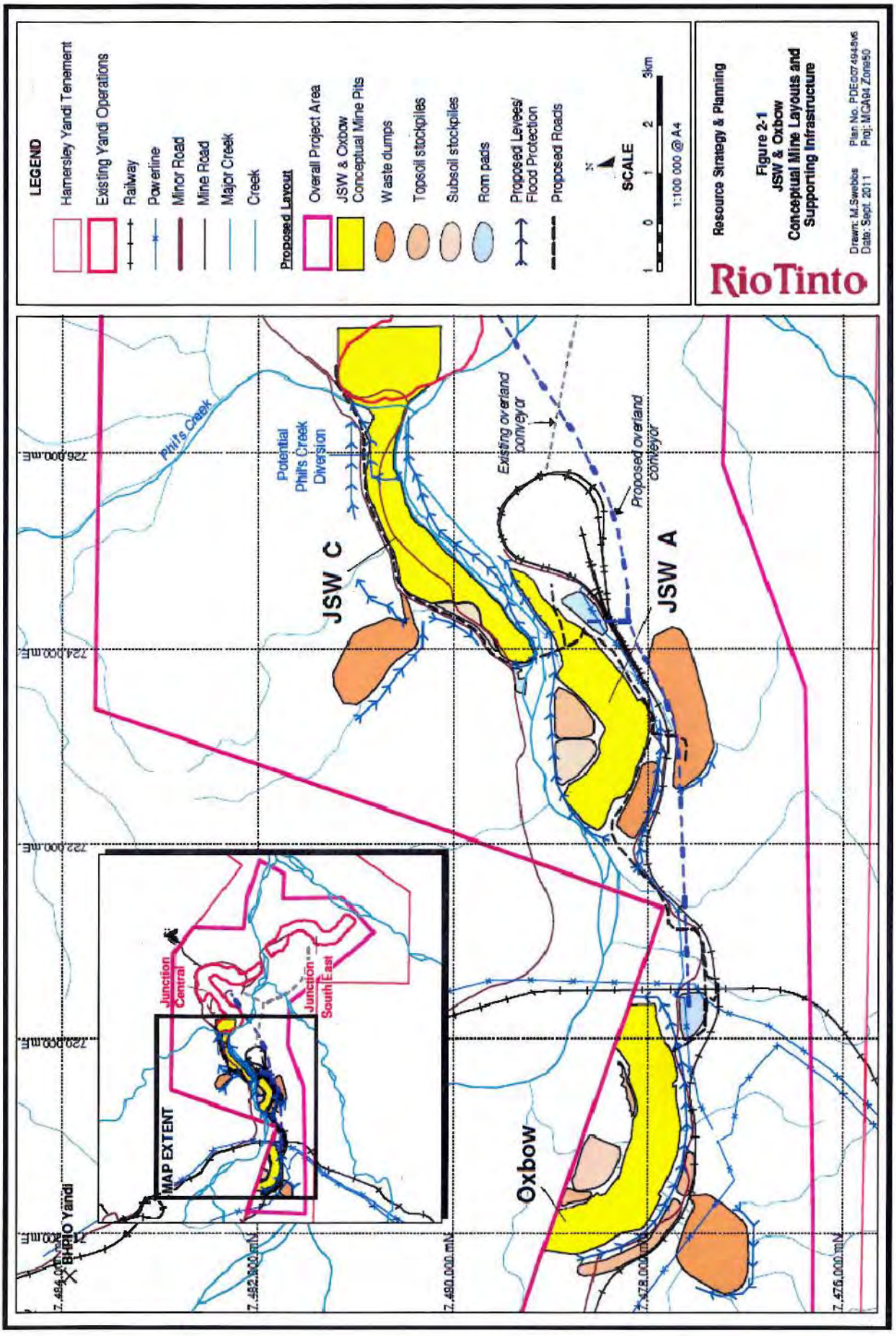
Weeli Wolli Creek means the creek line identified as "Weeli Wolli Creek" in Annexure 2.

Annexure 1.


Junction Central
Junction South West
Junction South East
Oxbow
7,400,000 mN
7,395,000 mN
730,000 mE
735,000 mE
725,000 mE
720,000 mE
Legend
Lepidium catapycnon records
Overall project area
Disturbed or cleared - associated with MS417, 523 & 695
JSW & Oxbow proposed mining and infrastructure
Potential habitat for Lepidium catapycnon
Contour (10m interval)
Source of Lepidium records
Biota Environmental Sciences & Rio Tinto
0
1.5
3
kilometres
N
Figure 9 - Lepidium catapycnon Records at Yandicoogina
Biota Environmental Sciences
Location Map
Author: Biota
Drawn: P Sawers
Job No.: 734
Date: 6 Oct 2011
Revised:
Projection: MGA Z50 (GDA94)
Scale: 1:7,500


Phil's Creek
Boolgeeda
Junction Central
Newman
Robe
Robe Creek
Junction South West
Marillana
Marillana Creek
Rocklea
Oxbow
Yandicoogina Creek
Junction South East
Wolli Creek
7,480,000 mN
7,475,000 mN
735,000 mE
730,000 mE
Landsystems
Newman
Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands.
Rocklea
Basalt hills, plateaux, lower slopes and minor stony plains supporting hard spinifex (and occasionally soft spinifex) grasslands.
Robe
Low plateaux, mesas and buttes of limonites supporting soft spinifex (and occasionally hard spinifex) grasslands.
Boolgeeda
Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands or mulga shrublands.
location Map
Map Area
Legend
Olive Python record (DEC Nature Map)
Disturbed or cleared - associated with MS417, 523 & 695
Overall project area
JSW & Oxbow proposed mining and infrastructure
Fauna surveys 2009/2010
Level 3 Assessment for JSW & Oxbow proposals
N
0
1.5
3
kilometres
Note: Landsystems - Dept. of Food & Agriculture
Figure 5 - Olive Python Records at Yandicoogina
Biota Environmental Sciences
Author: Biota
Drawn: P Sawers
Job No.: 754
Date: 06 Oct 2011
Revised:
Projection: MGA 250 (GDA94)
Scale: 1 75,000

Annexure 3.


LEGEND
Hamersley Yandi Tenement
Existing Yandi Operations
Railway
Powerline
Minor Road
Mine Road
Major Creek
Creek
Proposed Layout
Overall Project Area
JSW & Oxbow Conceptual Mine Pits
Waste dumps
Topsoil stockpiles
Subsoil stockpiles
Rom pads
Proposed Levees/ Flood Protection
Proposed Roads
SCALE
1:100 000 @ A4
Resource Strategy & Planning
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RioTinto
Phil's Creek
Potential Phil's Creek Diversion
Existing overland conveyor
Proposed overland conveyor
JSW C
JSW A
Oxbow
MAP EXTENT
Junction Central
Junction South East
BHPBIO Yandi

YANDICOOGINA BILLIARD SOUTH WATER BALANCE

YANDICOOGINA BILLIARD SOUTH WATER BALANCE

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	Name	Position	Signature	Date
Author	Mark Nicholls	Senior Water Resources Engineer		24/04/15
Reviewer	Daragh Monaghan	Principal Water Resources Engineer		24/04/15

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EXECUTIVE SUMMARY

Rio Tinto is seeking environmental approval for mining of Pocket and Billiards South (PBS) Pit at the Yandicoogina mine site. For closure of the pit, backfilling above the water table with waste from the Billiards North is proposed to prevent any groundwater closure issues. However, in the event that Billiards North pit development does not proceed, RTIO has asked RPS to complete water balance modeling of PBS water levels under a scenario where no pit backfill occurs.

A GoldSim model simulating water conditions post mine closure has been created for PBS pit. The purpose of the model is to estimate the following:

- Variations in pit pond water levels with time.
- Range of likely salt concentrations within the pit pond.
- Frequency of pit pond overtopping the pit void.

The hydrogeological parameters within the GoldSim model were the same as those adopted in a previous study, when they were calibrated such that GoldSim replicated groundwater conditions at PBS predicted by Rio Tinto's regional groundwater model.

The GoldSim model was used to perform a Monte Carlo analysis to estimate potential ranges of pit water levels and pit water salinities, using 1,000 iterations of the model. RTIO wishes to use the statistics to report likely pit water conditions to environmental assessors.

The GoldSim Monte Carlo analysis of the water balance predicts the following:

- Pit water levels varies in response to the magnitude and frequency of creek overflow events.
- The mean pit water level is typically RL467m.
- The pit is likely to overtop on average 1.5 times every 100 years.
- Salinity is highly variable with time, and responds to pit water levels and creek overflow events.
- The mean pit water salinity is 3,000mg/L at the end of the 1,000 year model run.
- Models with more frequent pit overtopping events generally have much lower pit salinities (salinity as low as 200mg/L).
- Models with few pit overtopping events show a trend of increasing pit salinity (salinity up to 13,000mg/L).
- The high pit salinity model runs only require a large creek overtopping event to reduce the overall pit salinity.

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1. BACKGROUND

1.1 General

The Yandicoogina Mine Site (Yandi) is an iron ore mine operated by Rio Tinto Iron Ore (RTIO) and located 90km north of Newman. RTIO are mining a Channel Iron Deposit (CID), which has formed in the Tertiary sediment infilling a historic river valley. The mine currently consists of several separate pits that follow the meandering path of this historic river.

Pocket and Billiards South (PBS) Pit is one of the deposits that is being developed by RTIO at Yandi (refer Figure 1). As part of the pit closure and rehabilitation studies, RTIO has asked RPS to prepare a GoldSim water balance and salt balance model of the PBS pit to predict the outcomes of a potential pit closure scenario.

GoldSim is a Monte Carlo simulation software, that allows for users to create customised models based on built-in functions within the software. The software is well suited for water balance projects, and because the calculations are only set once, and then run through every time-step, it is computationally more efficient than MS Excel, in this instance, where the formulas are defined every time step.

1.2 Context

Rio Tinto is seeking environmental approval for mining of Pocket and Billiards South (PBS) Pit at the Yandicoogina mine site. For closure of the pit, backfilling above the water table with waste from the Billiards North is proposed to reduce environmental closure issues related to groundwater. However, in the event that Billiards North pit development does not proceed, RTIO has asked RPS to complete water and salt balance modeling of PBS water levels under a scenario where the pit is not backfilled. The pit does contain a “pillar” of waste in the central part of the pit to an elevation of RL465m. A plan of the PBS pit, showing the footprint of the open-pit closure landform is shown in Figure 2.

A GoldSim model simulating groundwater conditions post mine closure has been created for PBS pit. The purpose of this model is to estimate the following:

- Long-term (recovered) pit water levels.
- Frequency and volume of water overtopping pit.
- Pit pond water salinity concentration with time.

The purpose of this report is to:

- Document the assumptions that have been made in the model, including using the GoldSim model to generate synthetic rainfall patterns and approximate groundwater conditions.
- Summarise the formulas and logic within the model.
- Present the results from the model.
- Discuss the results from the model.

2. CONCEPTUAL MODEL OVERVIEW AND HIGH LEVEL ASSUMPTIONS

2.1 Conceptual Model

Groundwater flows through the PBS pit have been modelled using GoldSim. An overview of the conceptual model is shown in Figure 3. Conceptually, the PBS pit is modelled as a single "bucket" for which the groundwater and surface water flows in and out of the bucket are balanced with changes in storage volume of the bucket at each time step. The GoldSim model predicts the water level in the bucket at each time step using the defined stage/storage relationship for the pit, and the sum of all groundwater and surface water inflows and outflows.

The water balance for the pit can be summarised by the following list of inflows and losses:

- Water inflows:
  - Direct rainfall
  - External catchment runoff
  - Weeli Wolli Creek overflow into pit
  - Creek seepage
  - Groundwater inflow
- Water losses:
  - Evaporation
  - Pit overflow
  - Groundwater outflow.

A constant estimated salinity was assigned to each of the water inputs to the pit, and a salt mass balance model was used for the pit to estimate the mass of salt within the pit, and therefore the salinity concentration of ponded water within the pit at each time step (assuming full water mixing). The pond water salinity concentration at each time step was applied to each water loss component from the pit to complete the salt balance model.

Note that in the conceptual model there is no groundwater flow in/out of the pit to the surrounding low permeability basement rocks (i.e. all groundwater flow through CID aquifer only).

Previously, RPS completed a GoldSim water balance exercise for all six pits at Yandi, and used groundwater level recovery predictions from a short-term RTIO developed regional Modflow groundwater flow model for the Yandicoogina Mine Site as the boundary conditions for the model. For the current project, constant groundwater levels immediately upstream and downstream of the pit were assumed for the full duration of the model, and hydrogeological parameters adopted for the PBS pit in the Six Pit Model were again adopted.

Weeli Wolli Creek crosses the CID formation to the south west of PBS pit and flows adjacent to the north west side of the pit. When the GoldSim model dictates that the creek is flowing, a hydraulic gradient is formed between the creek bed and the pit water level which causes seepage into the pit. The hydraulic gradient is used in Darcy's Law to estimate the rate of seepage from the creek. The conditions which dictate that Weeli Wolli Creek is flowing are discussed later in Section 3 of this document.

The model approximates water levels over a 1,000 year period on a daily timestep, such that all calculations are updated every day. The model is run for a number of iterations (100) to allow a Monte Carlo analysis of results from the model.

2.2 High Level Assumptions

2.2.1 Horizontal Groundwater Flow

The groundwater flow calculations within the model are based on Darcy's Law for flow caused by differential groundwater levels. Darcy's Law is as follows:

$$= \frac{K * A * H}{L}$$

Where:

- Q = groundwater flow (m^3/d).
- K = hydraulic conductivity (m/d).
- A = cross sectional area for flow (m^2).
- H = pressure differential, in this case elevation difference (m).
- L = length over which the change in head is occurring (m).

In the GoldSim model, the hydraulic conductivity has been assumed to have a value of 10m/d in the CID, and 5m/d in the alluvial aquifer.

A multiplier is applied to the hydraulic conductivity values used within the model to vary the value about the mean, with the multiplier selected from a normal distribution (discussed further below in Section 3, with baseline distribution factor values listed in Section 4). The purpose of the multiplier is to account for potential sensitivities in the model due to variations in the conductivity values being used. This multiplier is calculated separately for each hydraulic linkage to the pit, and is only changed after each iteration of the model is complete (i.e. it is constant throughout each iteration for each hydraulic linkage).

The water level differential for the calculations is the elevation difference between water levels on either side of the hydraulic link (i.e. the pit water level and the external groundwater level, or creek bed level for seepage calculations).

For the connection between the external groundwater in the CID either side of PBS pit, the assumed area of flow is a semi-circle circumference where the diameter is the average width of the pit (assumed to be half the top width of the pit) multiplied by the depth of water in the pit.

Where creek seepage into the pit is calculated, the effective flow area is assumed to be the difference between the height of the pre-mining water table at the pit edge and the base pit water level, multiplied by a semi-circle circumference where the diameter is the average (half) width of the pit (although the driving head is assumed to be the difference between the creek level and the pit water level).

2.2.2 General

Logic has been programmed into the GoldSim PBS pit model to produce a stochastic rainfall record for use in model predictions. The generation of this rainfall record has been based on statistics derived by RTIO from historic climate records at the Flat Rocks gauging station. The climate events have been applied to the whole site.

The GoldSim model assumes that the rainfall distribution fits a Gumbel (Extreme Value Distribution) probability distribution. However, the magnitude of large rainfall events produced by the Gumbel distribution (as defined by statistics derived from historic rainfall data) are too small compared with the assumed IFD data for Yandi (provided by RTIO). A random multiplier (between 0 and 4) was introduced into the model to ensure that large rainfall events (and therefore hydrological responses caused by large rainfall events) would occur at a reasonable frequency. The random multiplier fit a probability distribution that ensured that the annual average rainfall was not altered by modifying the magnitude of large rainfall events.

The calculation of stream flow durations for Weeli Wolli Creek was completed by RTIO through the use of a RORB model to provide tables of the stream flow duration that would occur for rainfall events of standard duration and recurrence interval. Similarly, RTIO also completed 2-D flood modeling of Weeli Wolli Creek and the proposed pit closure landform to estimate the volume of water that may overtop from Weeli Wolli Creek into the pit following different rainfall events of standard duration and frequency. These tables are “looked up” within the GoldSim water balance whenever a rainfall event occurs. This calculation is a limitation to the model approach, which is discussed in further detail in Section 2.3.

The model uses a constant groundwater elevation outside either end of the pit as the groundwater boundary conditions for the model calculations.

2.3 Model Limitations

The largest limitation in the model approach is that all rainfall events occur over a 1-day period in the model, regardless of rainfall duration. In addition to this, modeled hydrological responses from the rainfall event are modeled as occurring over the same 1-day period as the rainfall event. These hydrological responses include catchment runoff to the cells, seepage input from the creeks and overflow from Weeli Wolli Creek. The impact of this limitation is that modeled ponding levels will generally be higher due to the rainfall response occurring immediately, rather than being spread out over a longer time period. Given that the same volume of water reports to the pit (but in a shorter period of time), the impact of this limitation on long-term results is likely to be negligible.

A further limitation is that all lookup tables only extend to a maximum return period of 100 years. If a rainfall event occurs within the model which is greater than the 100-year event, the model assigns the event with a 100-year return period for the purpose of using the hydrological response look-up tables, whereas larger hydraulic responses may actually occur.

3. MODEL STRUCTURE

The GoldSim model is run on a daily time step, to ensure the synthetic rainfall generation can be based on the statistics derived from daily rainfall records.

When the model simulates rainfall events, these are calculated at the start of each day, with the rainfall event held constant until the following day. This means that only one rainfall event can occur on any single day within the model, and that the entire rainfall event occurs over a single day (i.e. even though the rainfall simulation model may produce a storm with a duration of 72 hours for ARI definition purposes, the model assumes that the impact of that rainfall event occurs over the day that the event occurs at three times the rate and not spread out over three days). Consequently, if the model is run with a time step length longer than 1 day, the results will under-estimate rainfall.

Some data inputs that are used globally throughout the model are defined within the model run settings rather than as a data input element with the model. These include:

- Mean hydraulic conductivity of the CID aquifer (10m/d).
- Mean hydraulic conductivity of the alluvial aquifer (5m/d).
- Salinity of rainwater (0.005kg/m^3).
- Salinity of river seepage (0.05kg/m^3).
- Salinity of groundwater (0.5kg/m^3).

The majority of the GoldSim model logic has remained unchanged from previous model reports, but is documented below for completeness.

3.1 Climate

The following sub-containers (in Goldsim) have been setup within the Climate container and are discussed below. The climate data and logic is largely unchanged from the previous modelling by RPS (apart from the extreme rainfall probability distribution), but repeated below for completeness:

- Rainfall Probability
- Rainfall Volume
- Rainfall Duration
- ARI
- Evaporation.

3.1.1 Rainfall Probability

The Rainfall Probability sub-container calculates what the probability of rainfall is for each day in the model. The logic behind this calculation is based on the formulas that were contained in the original Rio Tinto Excel based water balance, but transposed into GoldSim.

Each month, the number of rain-days per month is randomly chosen within a truncated normal probability distribution defined by the mean, standard deviation and minimum (always set to zero) and maximum number of rain days as defined in Table 4.3.

The probability of rainfall is used to determine if the rainfall event is classed as a “Storm” (probability greater than 0.6) or “Rain” (probability less than 0.6) event when determining the rainfall volume.

3.1.2 Rainfall Volume

The Rainfall Volume sub-container is used to determine the depth of rainfall that will fall on each day of the model run. The calculations performed in this container are based on the outcome of the Rainfall Probability outcome discussed above. Where the probability of rainfall is equal to zero, the depth of rainfall on that day will be equal to zero.

A rainfall event is classified as either a “Storm” (Rainfall Probability > 0.6) or as “Rain” (Rainfall Probability < 0.6). Based on this outcome, relevant Storm or Rain lookup tables for each month are used to determine the rainfall depth that would occur for the given rainfall probability.

The lookup table that relates probability to rainfall depth was generated in Excel assuming a normal distribution for Rain events, and a Gumbel distribution for Storm events. Monthly values for rainfall median and standard deviation were provided by RTIO to define the Rain normal probability distribution and Storm Gumbel probability distribution. For Storm events, the rainfall depth that is returned by the model is multiplied by a random number generated by GoldSim to increase the rainfall depth in extreme events. The random number was sampled from the a cumulative probability distribution defined as follows:

- Probability = 0, Value = 0
- Probability = 0.1, Value = 0.8
- Probability = 0.95, Value = 1.2
- Probability =1, Value = 4.

The daily evaporation rate is subtracted from the calculated rainfall depth prior to use in the model. The calculation of Daily Evaporation is described below.

3.1.3 Rainfall Duration

The duration of an individual rainfall event was generated by RTIO based on observed data extracted from the Flat Rocks rainfall gauge (~22 km west of the Yandi mine). A linear function was fitted to simplify the relationship between rainfall and duration of the Flat Rocks data and this relationship was applied in the rainfall duration simulator to randomly generate the duration of each rainfall event. The rainfall duration (regardless of classification as a “Storm” or “Rain” event) is calculated based on the formula:

$$Storm\ Duration = ABS(A * Daily\ Rainfall + C)$$

The formula is applied only if the Daily Rainfall is greater than 0, the coefficient A is set at 0.1294 and the coefficient C is a randomly selected number from a uniform probability distribution bounded by values of -7.5069 and 15.4931 (as provided by RTIO).

3.1.4 ARI

The annual recurrence interval (ARI) for the stochastically generated rainfall event is calculated within the model. The ARI is calculated based on a lookup table of event duration vs. rainfall volume (as discussed above). The model uses the resultant ARI value within lookup table calculations for runoff coefficients and creek flow durations based on each rainfall’s event duration and ARI.

3.1.5 Evaporation

The evaporation rate is sampled each day from a truncated normal distribution that is defined by distribution parameters which are set for each month of the year (standard deviation, mean, minimum value and maximum value). The values of the factors used to define the evaporation are displayed in Table 4.4.

3.2 Creek Flows

The model calculates the creek discharge volume and duration of creek flow for each of the creeks that impact the model (Weeli Wolli Creek). The logic behind the calculation of discharges through the creeks is similar for each of the creeks, with lookup tables used to determine the flow volume and duration for a given rainfall event (defined by duration and ARI).

3.3 PBS Pit Data

The PBS pit is represented by a sub-container that calculates the water balance and groundwater and surface water inputs and losses to the pit based on the results of the Climate and Creek Flow containers (discussed above).

Within the PBS pit sub-container, the following main components are found.

3.3.1 Pit Water Reservoir Element

The pit water reservoir element calculates the stored volume of water within the pit at each time-step by determining the change in volume over the time step through subtracting the sum of water losses out of the pit from the sum of water additions to the pit. The water losses and gains are quantified in the other sub-containers within the PBS pit container. The pit dimensions and starting conditions are defined.

3.3.2 Pit Characteristics

The following list of pit characteristics which are defined are as follows:

- Stage versus Surface Area relationship.
- Stage versus Volume relationship.
- Initial volume of water held in the pit.
- Ex-pit groundwater elevation time series.
- Distance to creek.
- Creek elevation.
- Creek contact length.
- Distance to external groundwater boundary condition.
- Pit backfill elevation.
- Pit surface water catchment area.
- Pit evapotranspiration (ET) rate.
- Pit overflow elevation.

3.3.3 Runoff Generation

The volume of surface water run-off to the pit is calculated from the surface water catchment area around the pit, and the direct rainfall on the pit area. The runoff coefficient used for the pit runoff is dependent on the ARI of the rainfall event. Typically for larger catchments in the Yandi area, on average less than 5% of the annual rainfall runs off to creeks/rivers as measurable flow (Upper Fortescue River near Newman 4.8%, Marillana Creek at Flat Rocks 2.2%). Given that the pit catchments are smaller and relatively steep compared to a major creek or river system, the annual runoff coefficient would be expected to be greater than 5%. The runoff coefficients adopted in this model result in an average annual volume of runoff from the pit catchments to the pit of around 10% to 15% of the annual rainfall in the model, which RPS feels is a reasonable estimation.

3.3.4 Groundwater

The groundwater calculations in the GoldSim water balance model provide an analytical estimate of groundwater flow conditions in the PBS pit area. This simplification means that the model can be run assuming a range of input conditions in a time frame consistent with the overall project requirements.

As discussed, RTIO developed a regional groundwater model and the results of the regional model were used to check that the GoldSim model replicates expected groundwater flow conditions in previous modeling excercises. This process was not repeated for this project, as a regional groundwater model was not completed for this closure option.

As mentioned in Section 2, to account for potential sensitivities in the GoldSim model due to variations in the permeability of aquifers, a multiplier factor is used to vary the hydraulic

conductivity around the mean value. The mean, standard deviation (sigma), minimum and maximum values for the normal distribution of the multiplier factor are defined, and used to determine the multiplier factor (refer Section 4 for baseline values). Note that the GoldSim model chooses the multiplier factor at the beginning of each model iteration, and this remains constant for the full iteration.

Creek seepage into the pit is predicted within the pit sub-container (in GoldSim). The predictions are dependent on the location of the surrounding creeks, the contact lengths between the creek channel and the pit, and if the contact is with an alluvial aquifer or directly with the CID aquifer.

The data that was used for this calculation was based on measurements from mapping and input from RTIO Hydrogeology to the original regional groundwater flow model. One of the key parameters that was introduced to the GoldSim model to ensure consistency with the Modflow regional model predictions was a Seepage Reduction Factor. This factor was previously adjusted to achieve GoldSim prediction results similar to the Modflow predictions, with the same factor adopted for this project.

3.3.5 Pit Evaporation

The evaporative losses from any ponded water within the pit are calculated within the model. The calculation applies the evaporation rate to the pit pond's surface area.

3.3.6 Pit Pond Overflow

Logic was incorporated within the model to allow ponded water above a set depth (i.e. pit overflow point of 487.5mRL) to overflow out of the pit. The model does not simulate water levels in Weeli Wolli Creek, and therefore assumes that water from PBS pit above RL487.5 can discharge to Weeli Wolli Creek.

4. INPUT DATA

The model parameters that define the model are listed in the tables below for completeness. The model parameters listed generated the solution discussed in the results section of this report (Section 5).

4.1 Pit Data Inputs

The pit characteristics data is summarised in Table 4.1.

The Stage/Surface Area/Volume relationship was determined based on the PBS pit closure geometry profile provided to RPS by RTIO. The PBS pit closure geometry file contained a "pillar" of backfill within the pit, which reduced the relative pit volume at each stage level used within the GoldSim model. These relationships are an input to the model in the form of a lookup table, and aren't reproduced in this report. The volume/area data was determined for every 0.1m elevation increment within each cell.

Table 4.1: Summary of Inputs Defining PBS Pit

Pit	PBS
Pit base level (mRL)	419.9
Initial water level (mRL)	645
Backfill elevation (mRL)	N/A
Top of pit (mRL)	487.5
Pit width (m)	500
Upstream groundwater elevation (mRL)	500
Downstream groundwater elevation (mRL)	465
Distance to groundwater boundary conditions (m)	3000
Distance to Weeli Wolli Creek (m)	500
Weeli Wolli Creek elevation (mRL)	525
Alluvium contact length (m)	2750
Pit Catchment Area (km^2)	47

4.2 Climate Inputs

The following inputs are contained within the Climate sub-container in GoldSim to define the Rainfall Probability.

Table 4.2: Summary of Inputs Defining Rainfall Probability

	Max Month Rain Days	Std Dev Rain Days	Mean Rain Days
January	21	5.2	10.2
February	18	4.6	11.8
March	22	5.1	8.6
April	11	3.4	4.8
May	4	1.6	1.7
June	8	2.4	2.5
July	8	2.8	2.6
August	4	1.3	1.2

	Max Month Rain Days	Std Dev Rain Days	Mean Rain Days
September	3	1.2	0.8
October	10	3.1	2.3
November	9	3.1	4.4
December	14	4.3	6.7

The Rainfall Volume is calculated based on using the probability calculated from the Rainfall Probability container within a probability distribution. The probability distribution for the Rainfall Volume calculation is based on the parameters shown in Table 4.3. For events classed as "Rain", a normal probability distribution is used. For events classed as "Storm", a Gumbel distribution is used.

Table 4.3: Summary of Inputs Defining Rainfall Volume

	Rainfall Median	Storm Rain Vol Std Dev	Rain Vol Std Dev
January	2.3mm	22.2mm	2.5mm
February	3.6mm	14.1mm	2.8mm
March	2.8mm	16.1mm	2.9mm
April	2.2mm	8.2mm	2.5mm
May	1.4mm	7.5mm	2.5mm
June	1.8mm	5.5mm	2.6mm
July	1.2mm	14.7mm	2.0mm
August	1.8mm	4.1mm	2.4mm
September	2mm	15.1mm	3.2mm
October	0.8mm	6.4mm	2.1mm
November	1.4mm	7.0mm	2.4mm
December	2.2mm	32.0mm	2.6mm

For Storm events, the rainfall depth that is returned by the model is multiplied by a random number generated by GoldSim to increase the rainfall depth in extreme events. The random number was sampled from a cumulative probability distribution defined as follows:

- Probability = 0, Value = 0
- Probability = 0.1, Value = 0.8
- Probability = 0.95, Value = 1.2
- Probability =1, Value = 4.

The evaporation rates are calculated using the coefficients in Table 4.4. These parameters are used to define the truncated normal distribution from which the evaporation rates are selected for each of the daily time steps.

Table 4.4: Summary of Inputs Defining Evaporation Probability Distribution

	Evaporation Mean	Evaporation Std Dev	Evaporation Minimum	Evaporation Maximum
January	5.1mm	3.1mm	0.6mm	14.9mm
February	5.8mm	3.6mm	0.5mm	17.3mm
March	5.0mm	3.2mm	0.3mm	17.7mm
April	4.8mm	2.7mm	0.5mm	17.1mm

	Evaporation Mean	Evaporation Std Dev	Evaporation Minimum	Evaporation Maximum
May	3.6mm	1.5mm	0.3mm	6.7mm
June	3.0mm	1.3mm	0.2mm	5.3mm
July	3.0mm	1.1mm	0.1mm	5.0mm
August	4.7mm	1.4mm	1.7mm	7.9mm
September	6.0mm	1.8mm	0.2mm	9.2mm
October	5.6mm	2.6mm	0.3mm	16.3mm
November	5.8mm	3.1mm	0.3mm	14.6mm
December	5.5mm	3.4mm	1.0mm	16.3mm

The ARI calculations use look-up tables of rainfall volumes for different duration and return interval events for the Yandi and Hope Downs mine sites. The data used in the look up tables is summarised in Table 4.5 and 4.6.

Table 4.5: Yandi ARI Lookup Table Summary

	<1yr ARI	1yr ARI	2yr ARI	5yr ARI	10yr ARI	20yr ARI	50yr ARI	100yr ARI
0hr	0mm	0mm	0mm	0mm	0mm	0mm	0mm	0mm
0.17hr	0mm	8.9mm	11.6mm	15.6mm	18.0mm	21.1mm	25.3mm	28.5mm
0.25hr	0mm	11.2mm	14.6mm	19.7mm	22.9mm	26.8mm	32.2mm	36.3mm
0.33hr	0mm	13.0mm	17.1mm	23.1mm	26.8mm	31.5mm	37.8mm	42.7mm
0.42hr	0mm	14.6mm	19.2mm	26.0mm	30.2mm	35.6mm	42.7mm	48.3mm
0.50hr	0mm	16.0mm	21.0mm	28.5mm	33.2mm	39.1mm	47.0mm	53.2mm
0.75hr	0mm	19.3mm	25.5mm	34.8mm	40.5mm	47.8mm	57.7mm	65.3mm
1hr	0mm	22.0mm	29.0mm	39.7mm	46.4mm	54.9mm	66.3mm	75.1mm
1.5hr	0mm	24.7mm	32.7mm	45.8mm	54.0mm	64.4mm	78.5mm	89.6mm
2hr	0mm	26.6mm	35.5mm	50.4mm	59.9mm	71.8mm	88.2mm	101.1mm
3hr	0mm	29.6mm	39.8mm	57.5mm	69.1mm	83.6mm	103.7mm	119.7mm
4hr	0mm	32.8mm	44.4mm	65.6mm	79.6mm	97.2mm	121.8mm	141.5mm
6hr	0mm	35.3mm	48.0mm	72.0mm	88.0mm	108.2mm	136.5mm	159.3mm
9hr	0mm	39.2mm	53.7mm	82.2mm	101.6mm	125.9mm	160.4mm	188.5mm
12hr	0mm	42.2mm	58.2mm	90.3mm	112.5mm	140.3mm	180.0mm	212.5mm
18hr	0mm	46.5mm	64.4mm	101.4mm	127.3mm	159.8mm	206.5mm	245.0mm
24hr	0mm	49.6mm	69.0mm	109.8mm	138.6mm	174.8mm	227.1mm	270.3mm
30hr	0mm	52.1mm	72.6mm	116.5mm	147.6mm	186.9mm	243.8mm	291.0mm
36hr	0mm	53.9mm	75.4mm	121.9mm	155.0mm	196.9mm	257.6mm	308.2mm
48 hr	0mm	56.6mm	79.5mm	129.9mm	166.2mm	212.1mm	279.1mm	335.1mm
72hr	0mm	59.2mm	83.5mm	138.9mm	179.4mm	230.6mm	306.0mm	369.5mm

Table 4.6: Hope Downs ARI Lookup Table Summary

	<1yr ARI	1yr ARI	2yr ARI	5yr ARI	10yr ARI	20yr ARI	50yr ARI	100yr ARI
0hr	0mm	0mm	0mm	0mm	0mm	0mm	0mm	0mm
0.17hr	0mm	8.59mm	11.27mm	15.26mm	17.69mm	20.8mm	24.97 mm	28.21 mm
0.25hr	0mm	10.80mm	14.19mm	19.28mm	22.4 m	26.39mm	31.73 mm	35.89 mm
0.33hr	0mm	12.58mm	16.55mm	22.55mm	26.23mm	30.94mm	37.27 mm	42.18 mm
0.42hr	0mm	14.11mm	18.57mm	25.36mm	29.54mm	34.89mm	42.06 mm	47.65 mm
0.50hr	0mm	15.42mm	20.32mm	27.80mm	32.42mm	38.31mm	46.24mm	52.41mm
0.75hr	0mm	18.64mm	24.60mm	33.82mm	39.53mm	46.82mm	56.63mm	64.29mm
1hr	0mm	21.19mm	28.00mm	38.63mm	45.23mm	53.64mm	65.00mm	73.87mm
1.5hr	0mm	23.37mm	31.18mm	44.24mm	52.57mm	63.11mm	77.51mm	88.90mm
2hr	0mm	24.93mm	33.51mm	48.52mm	58.27mm	70.57mm	87.53mm	101.06mm
3hr	0mm	27.22mm	36.97mm	55.10mm	67.17mm	82.37mm	103.62mm	120.75mm
4hr	0mm	29.67mm	40.72mm	62.48mm	77.34mm	96.03mm	122.52mm	144.14mm
6hr	0mm	31.56mm	43.62mm	68.32mm	85.49mm	107.10mm	138.02mm	163.45mm
9hr	0mm	34.45mm	48.11mm	77.57mm	98.54mm	125.00mm	163.37mm	195.29mm
12hr	0mm	36.68mm	51.60mm	84.91mm	109.03mm	139.54mm	184.19mm	221.65mm
18hr	0mm	41.28mm	57.93mm	94.65mm	121.09mm	154.50mm	203.23mm	244.01mm
24hr	0mm	44.77mm	62.71mm	101.95mm	130.08mm	165.60mm	217.30mm	260.47mm
30hr	0mm	47.53mm	66.49mm	107.66mm	137.08mm	174.21mm	228.15mm	273.12mm
36hr	0mm	49.77mm	69.55mm	112.23mm	142.64mm	181.02mm	236.68mm	283.02mm
48 hr	0mm	53.12mm	74.09mm	118.91mm	150.70mm	190.79mm	248.80mm	296.98mm
72hr	0mm	56.95mm	79.20mm	126.06mm	159.07mm	200.67mm	260.62mm	310.26mm

4.3 Runoff Coefficients

The data in Table 4.7 has been used to define the run-off to the PBS Pit.

4.4 Groundwater Parameters

The baseline hydraulic conductivity for the CID is set as 10m/d and the hydraulic conductivity for the alluvium is set as 5m/d.

For each iteration of the model, the hydraulic conductivity is modified around the mean values provided above by a multiplier factor that is based on a truncated normal distribution defined by the following base parameters:

- Multiplier Mean = 0
- Multiplier Sigma = 0.067
- Multiplier Min = -0.2
- Multiplier Max = 0.2.

Table 4.7: Summary of Inputs Defining Runoff to Each Pit

	JSE
Runoff Coef. (<1yr ARI)	0.42
Runoff Coef. (1yr ARI)	0.47
Runoff Coef. (2yr ARI)	0.51

	JSE
Runoff Coef. (5yr ARI)	0.56
Runoff Coef. (10yr ARI)	0.60
Runoff Coef. (20yr ARI)	0.64
Runoff Coef. (50yr ARI)	0.70
Runoff Coef. (100yr ARI)	0.74
Runoff Coef. Reduction Factor	0.25

4.5 Creek Flow Data

RTIO provided creek flow durations for each standard rainfall event (defined by rainfall duration and annual recurrence interval) for Weeli Wolli Creek. The data provided is summarised in Table 4.8.

Table 4.8: Weeli Wolli Creek Flow Duration Lookup Table (Hours)

	<1yr ARI	1yr ARI	2yr ARI	5yr ARI	10yr ARI	20yr ARI	50yr ARI	100yr ARI
0hr	-	-	-	-	-	-	-	-
0.17hr	-	-	-	-	-	-	-	1580
0.25hr	-	-	-	-	-	-	-	1630
0.33hr	-	-	-	-	-	-	-	1646
0.42hr	-	-	-	-	-	-	-	1657
0.50hr	-	-	-	-	-	-	-	1663
0.75hr	-	-	-	-	-	-	-	1671
1hr	-	-	-	-	-	-	1640	1683
1.5hr	-	-	-	-	-	-	1662	1689
2hr	-	-	1326	-	-	1589	1676	1693
3hr	-	-	1518	1385	-	1656	1686	1698
4hr	-	-	1434	1498	1553	1669	1691	1701
6hr	-	-	1531	1586	1609	1673	1694	1703
9hr	-	-	1598	1640	1658	1683	1699	1707
12hr	-	808	1608	1662	1677	1686	1702	1709
18hr	-	-	1469	1632	1663	1685	1700	1708
24hr	-	-	1348	1619	1660	1687	1703	1711
30hr	-	-	1490	1644	1666	1680	1698	1708
36hr	-	-	1468	1642	1664	1680	1694	1706
48 hr	-	-	-	1576	1606	1676	1688	1704
72hr	-	-	-	-	-	1668	1684	1704

4.6 Weeli Wolli Creek Overflow Data

RTIO provided overflow volumes from Weeli Wolli Creek flow durations for each standard rainfall event (defined by rainfall duration and annual recurrence interval) for Weeli Wolli Creek. The data provided is summarised in Table 4.9.

Table 4.9: Weeli Wolli Creek Overflow Volume Lookup Table (m^3)

	<1yr ARI	1yr ARI	2yr ARI	5yr ARI	10yr ARI	20yr ARI	50yr ARI	100yr ARI
0hr	0	0	0	0	0	0	0	0
0.17hr	0	0	0	0	0	0	705,236	802,368
0.25hr	0	0	0	0	0	0	905,049	1,047,874
0.33hr	0	0	0	0	0	0	1,156,860	1,489,059
0.42hr	0	0	0	0	0	0	1,334,722	2,183,571
0.50hr	0	0	0	0	0	0	1,488,091	2,977,110
0.75hr	0	0	0	0	0	0	2,553,043	11,557,080
1hr	0	0	0	0	0	0	3,884,157	23,542,236
1.5hr	0	0	0	0	0	0	6,952,230	35,153,874
2hr	0	0	0	0	0	347,004	14,035,833	47,702,898
3hr	0	0	0	0	90,882	885,663	24,136,884	64,058,553
4hr	0	0	0	0	386,199	1,364,958	27,539,208	72,370,980
6hr	0	0	216	28,575	635,157	5,823,279	35,935,614	82,215,252
9hr	0	0	37,314	255,204	1,416,924	11,237,436	41,595,336	89,568,846
12hr	0	0	43,344	682,488	4,975,362	11,343,276	52,739,307	106,124,454
18hr	0	0	0	239,589	1,583,100	15,179,031	61,680,006	109,562,985
24hr	0	0	0	258,714	1,854,765	17,795,817	67,503,051	119,454,993
30hr	0	0	0	463,356	2,637,144	7,295,958	47,561,112	107,418,348
36hr	0	0	0	457,524	2,400,714	8,827,326	50,612,454	111,832,758
48 hr	0	0	0	0	1,215,342	3,845,124	38,807,316	96,014,808
72hr	0	0	0	0	1,024,632	2,741,148	36,910,188	94,284,666

5. RESULTS

The GoldSim model was run for 100 model iterations over a 1,000 year period to produce the results that are discussed below.

5.1 Pit Water Levels

The GoldSim model has been started with an initial pit water level of RL465m, to match the elevation of the assumed downstream recovered groundwater elevation. Following an initial drop in the median pit water level across the model runs, the median pit water level varies between RL471m and RL466m. Within any individual model run, the pit pond water level could range between RL453m and RL487.5m (pit overflow level). A probability time series plot of the pit pond water level is shown in Figure 4.

On any individual model run, the pit pond water levels appear to respond to events that cause Weeli Wolli Creek to overtop into the pit. In between these periodic large water input pulses, pit pond water levels decline due to the evaporation from the pit pond surface area and groundwater discharge to the downstream end of the pit. An example of a typical time series of the pit pond water level for an individual model run is shown in Figure 5.

As an indicator of the processes that are driving the pit water levels, the main median inflow and outflow volumes from the pit over the 1,000 year model run were determined, as shown in Table 5.1. The table indicates that evaporation is the dominant process on the water balance, followed by local runoff and Weeli Wolli Creek overflow into the pit.

Table 5.1: Median Pit Water Balance - Summary

Pit Inputs		Pit Outputs	
Net groundwater from U/S	1.2GL/yr	Net groundwater from D/S	0.1GL/yr
Local runoff	2.9GL/yr	Evaporation	6.0GL/yr
Weeli Wolli Creek overflow	2.1GL/yr	Pit Overflow	0.4GL/yr
Weeli Wolli Creek seepage	0.3GL/yr		

A median across the 100 model iterations of 820 total creek overtop events per 1,000 year model run were recorded (above 1,000m^3 overtop volume). Given overflow events occur from some 2-year ARI rainfall events, this number appears reasonable. A statistical time series of the total cumulative Weeli Wolli Creek overflow events predicted by the model is shown in Figure 6.

Typically, between 4 and 14 overflow events of greater than 70GL (nominal definition of 100 year creek overflow event) occur within a single model iteration, which appears reasonable. A time series plot of Weeli Wolli Creek overflow volumes is shown in Figure 7.

5.2 Pit Overtopping Frequency

Pit overtopping frequency is largely driven by the frequency of large magnitude Weeli Wolli Creek overtopping events into the pit. The storage volume within the pit between the starting water level (RL465m) and the pit overflow level (RL487.5m) is approximately 80GL, which is a similar magnitude to a single 100-year creek overflow event (refer above). Hence, the pit would be expected to overtop more frequently than once every 100 years.

The GoldSim model predicts pit overtopping to occur at a frequency of approximately 1.5 events per 100 years, with model iterations ranging between 5 and 20 overtopping events across the 1,000 year model duration.

5.3 Pit Salinity

The salinity of pit pond water in PBS started with an assumed initial concentration of 500mg/L (equivalent to that assumed from groundwater seepage into the pit). With time, the median salinity

in the pit increases at a relatively steady rate to approximately 3,000mg/L by around year 900, but remains steady thereafter. A time series probability plot of pit salinity is shown in Figure 8.

The peak salinity concentration across the iterations at the end of the model is about 11,000mg/L, while other model iterations have salinity concentrations as low as 200mg/L. Inspection of individual model iterations indicates that the salinity concentration is dependent on the timing of overflow events from the pit, with the model run that returns the high salinity concentration only having 1 overflow event in the 1,000 year model run.

The salinity concentration in the ponded pit water with time from a typical model run is shown in Figure 9.

6. SUMMARY

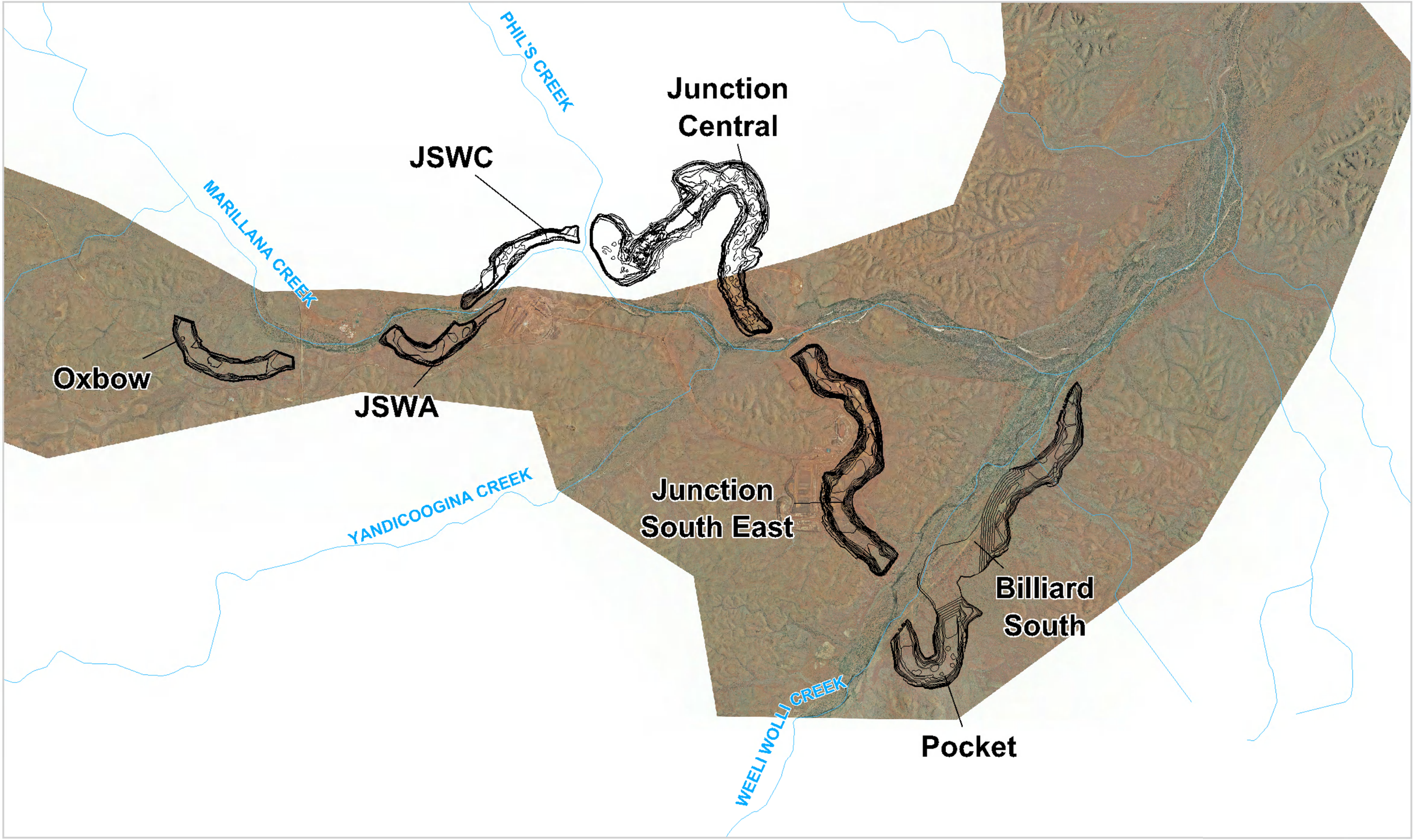
A GoldSim model has been created to simulate pit water volumes within the PBS pit for a pit closure strategy that allows some stream flow events from the adjacent Weeli Wolli Creek to overtop the mine closure structures and discharge to the pit. The GoldSim model that was created simulated groundwater levels and salinity concentrations in the PBS pit over a 1,000 year period. The model was used to perform a Monte Carlo analysis of the pit water levels, with 100 iterations of the model run to produce statistical results for the water level and salinity concentration predictions within the pit.

The key results from the modelling exercise were as follows:

- Pit water levels vary in response to the magnitude and frequency of creek overflow events.
- The mean pit water level is typically RL467m.
- The pit is likely to overtop on average 1.5 times every 100 years.
- Salinity is highly variable with time, and responds to pit water levels and creek overflow events.
- The mean pit water salinity is 3,000mg/L at the end of the 1,000 year model run.
- Models with more frequent pit overtopping events generally have much lower pit salinities (salinity as low as 200mg/L).
- Models with few pit overtopping events show a trend of increasing pit salinity (salinity up to 13,000mg/L).
- The high pit salinity model runs only require a large creek overtopping event to reduce the overall pit salinity.

FIGURES

Figure 1: Yandi Mine Site Layout Plan
Figure 2: PBS Pit Layout Plan
Figure 3: PBS Pit Conceptual Water Balance Model
Figure 4: PBS Pit Water Level Predictions (Statistics)
Figure 5: PBS Pit Water Level Predictions (Typical Iteration)
Figure 6: Weeli Wolli Creek Overtopping Counter (Statistics)
Figure 7: Weeli Wolli Creek Overtopping Counter (Typical Iteration)
Figure 8: PBS Pit Salinity Predictions (Statistics)
Figure 9: PBS Pit Salinity Predictions (Typical Iteration)



LOCATION MAP

N

0 750 1500 2250 3000

Metres

Scale: 1:75,000 @A3

GDA 1994 Zone 50

AUTHOR:	MN	REPORT NO:	007
DRAWN:	MN	REVISION:	A
DATE:	04/07/2012	JOB NO:	1167F

Creek Lines

Pit Footprint

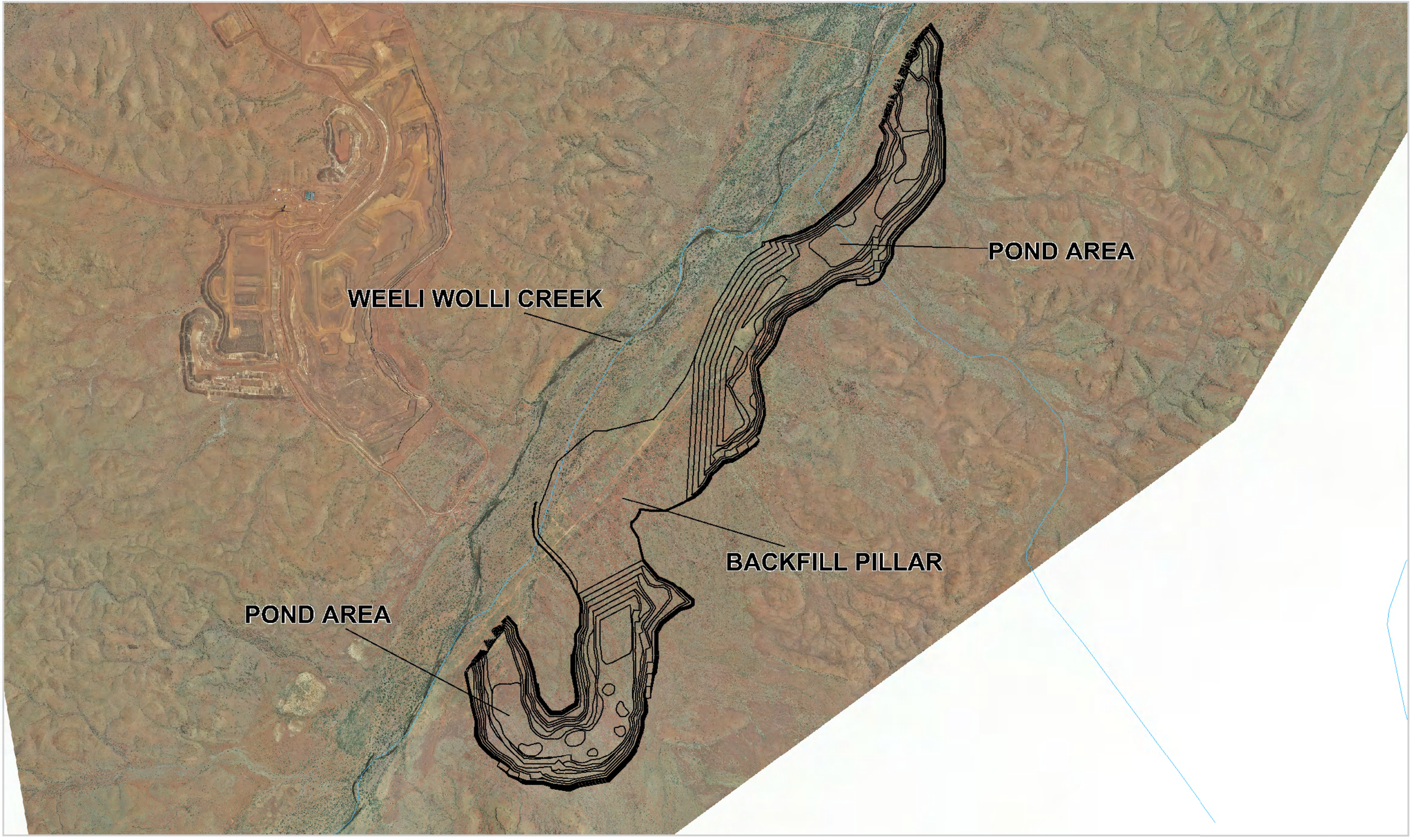
DATA SOURCES:

Location: F:\1167F\Spatial Data\Work Spaces\007a Figure 1.wor

RPS

FIGURE 1

YANDICOOGINA GOLDSIM MODEL
PIT LAYOUT PLAN



LOCATION MAP

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0 0.25 0.5 0.75 1

Kilometres

Scale: 1:30,000 @A3

GDA 1994 Zone 50

AUTHOR:	MN	REPORT NO:	007
DRAWN:	MN	REVISION:	A
DATE:	04/07/2012	JOB NO:	1167F

Creek Lines

Pit Footprint

DATA SOURCES:

RPS

FIGURE 2

PBS WATER BALANCE MODEL
PBS PIT LAYOUT PLAN

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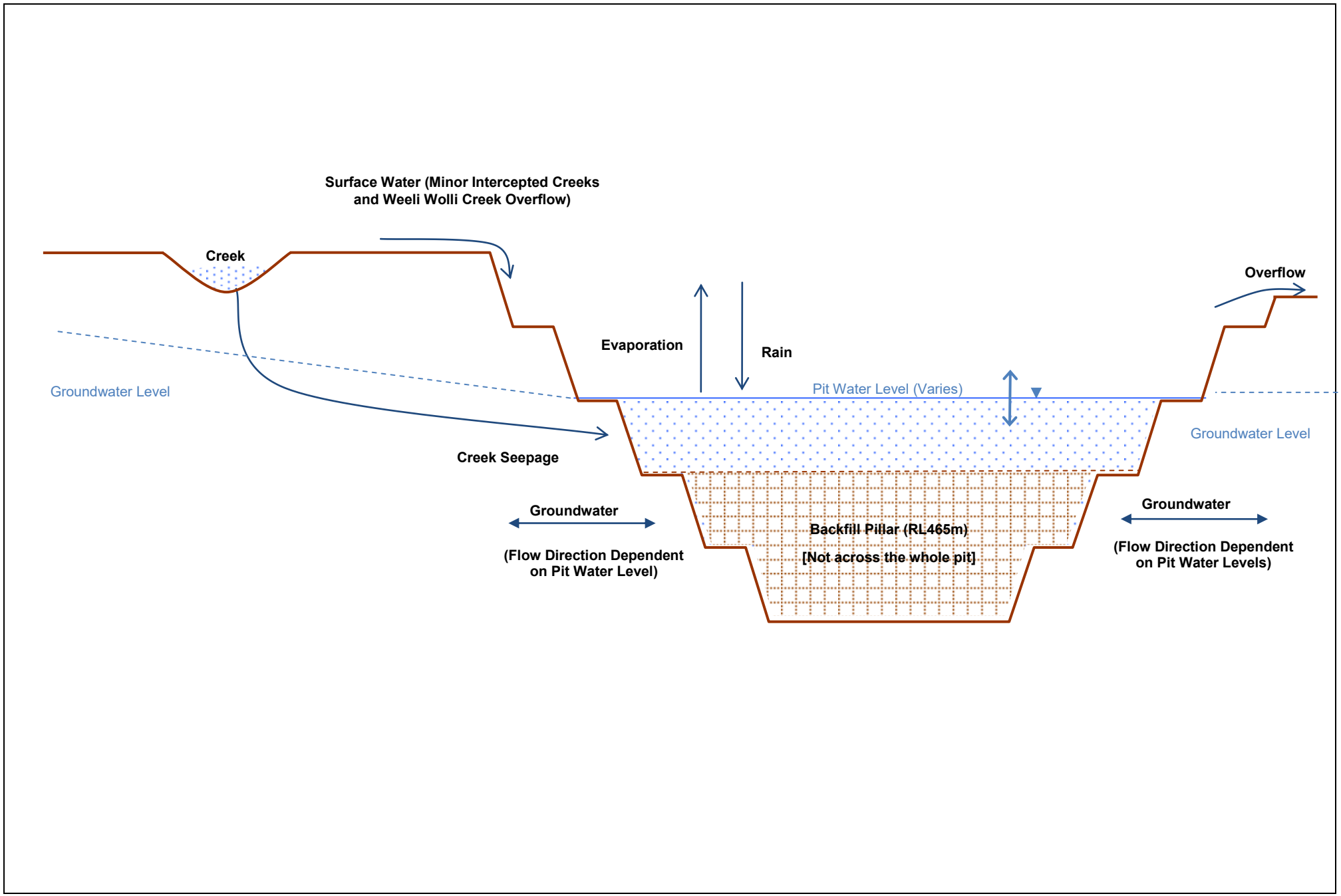

RPS Aquaterra

CONCEPTUAL WATER BALANCE FIGURE 3

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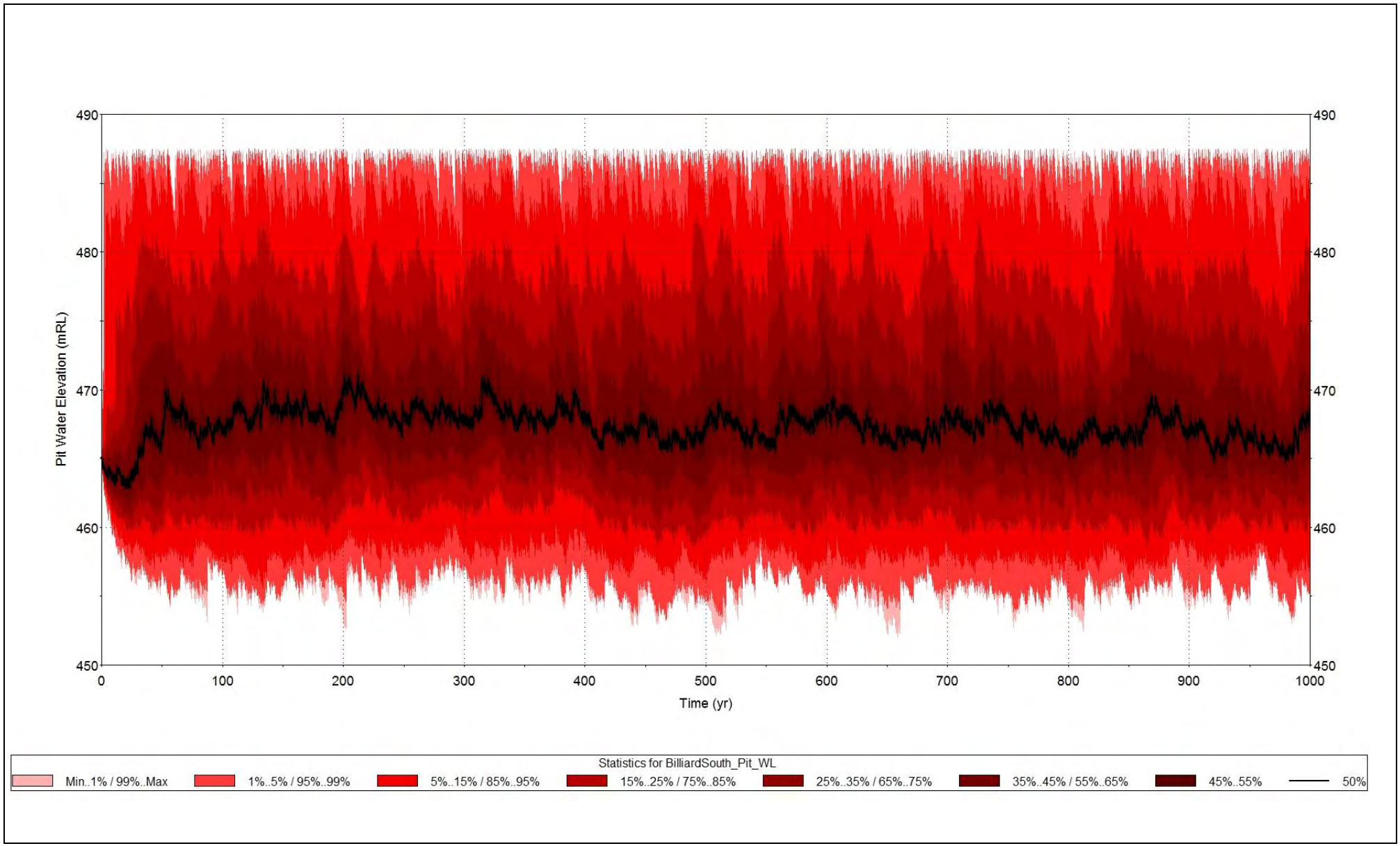

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PBS PIT WATER BALANCE MODEL

PIT WATER LEVEL STATISTICAL TIME SERIES

FIGURE 4

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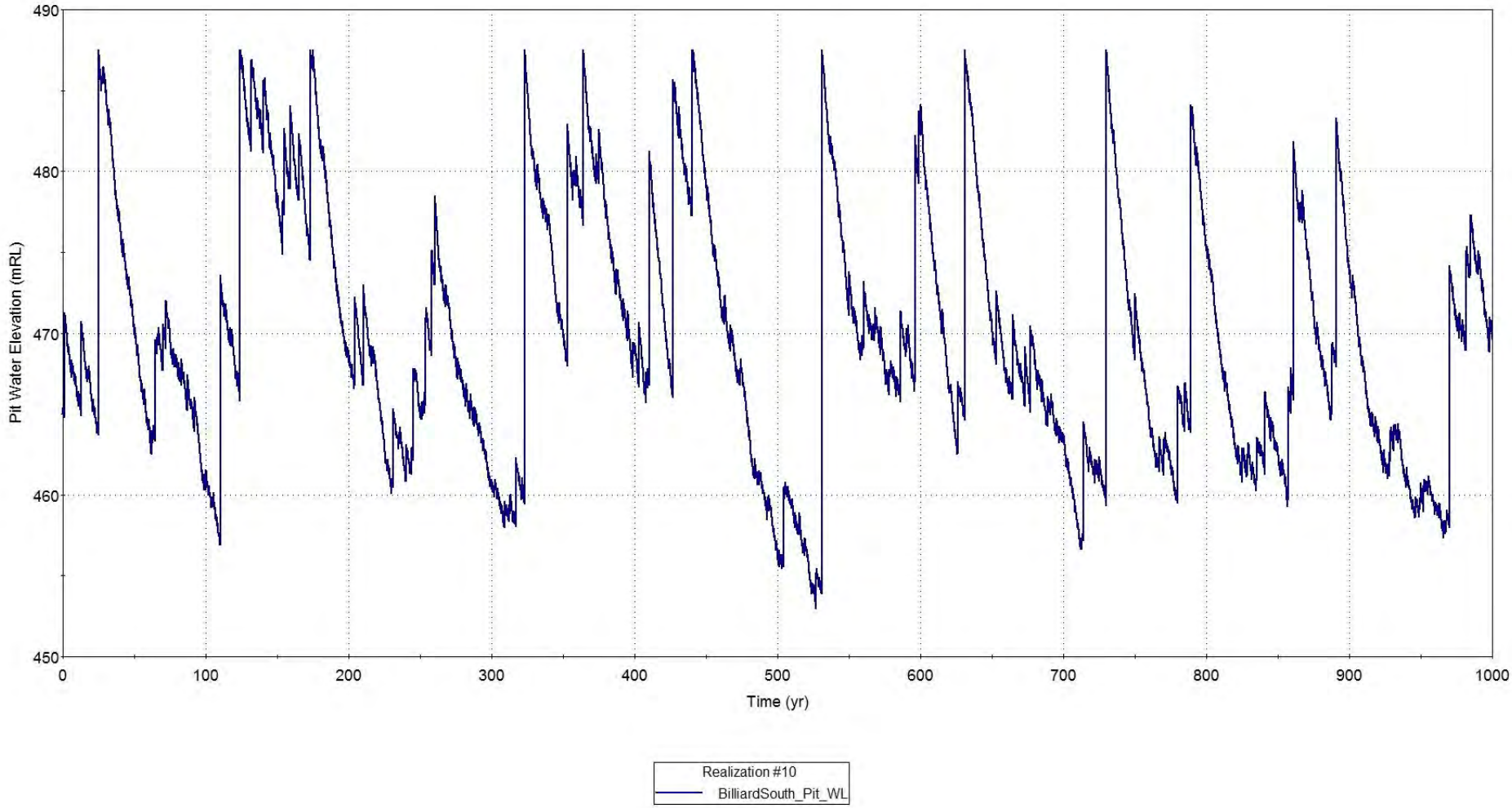

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PBS PIT WATER BALANCE MODEL

TYPICAL ITERATION – PBS PIT WATER LEVEL

FIGURE 5

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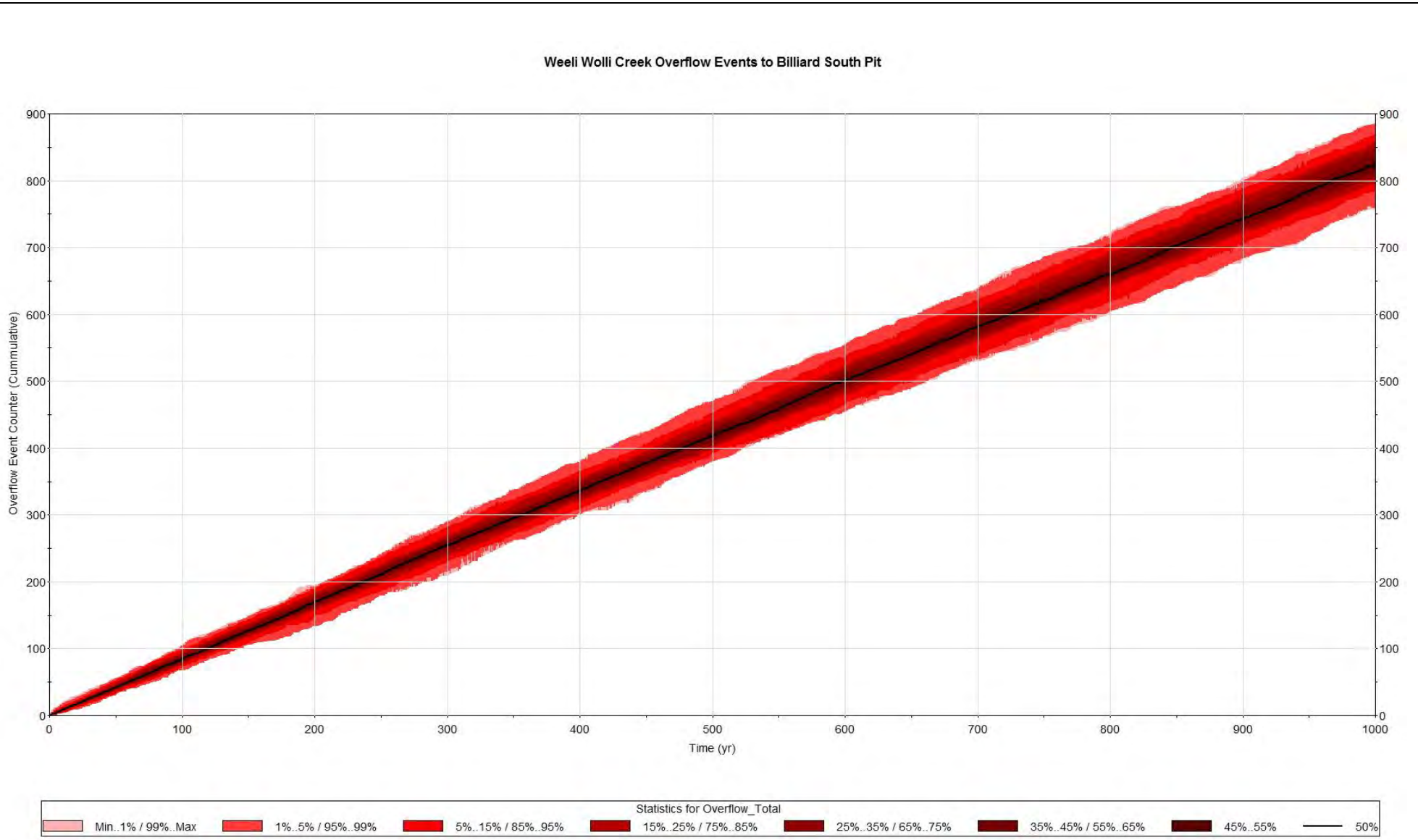

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PBS PIT WATER BALANCE MODEL

WEELI WOLLI CREEK OVERFLOW COUNTER

FIGURE 6

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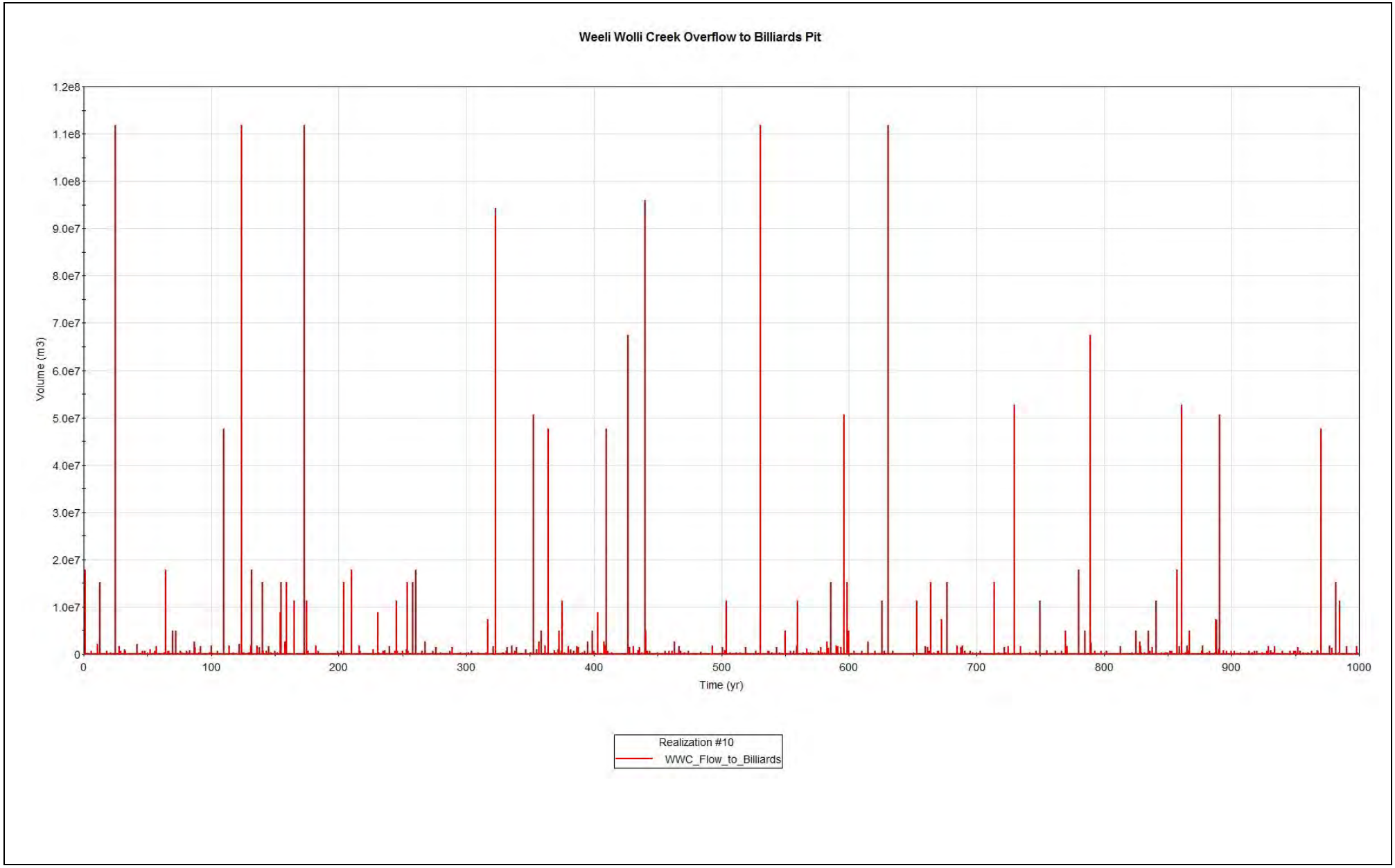

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PBS PIT WATER BALANCE MODEL

TYPICAL ITERATION – WEELI WOLLI CREEK OVERFLOW TO PBS PIT

FIGURE 7

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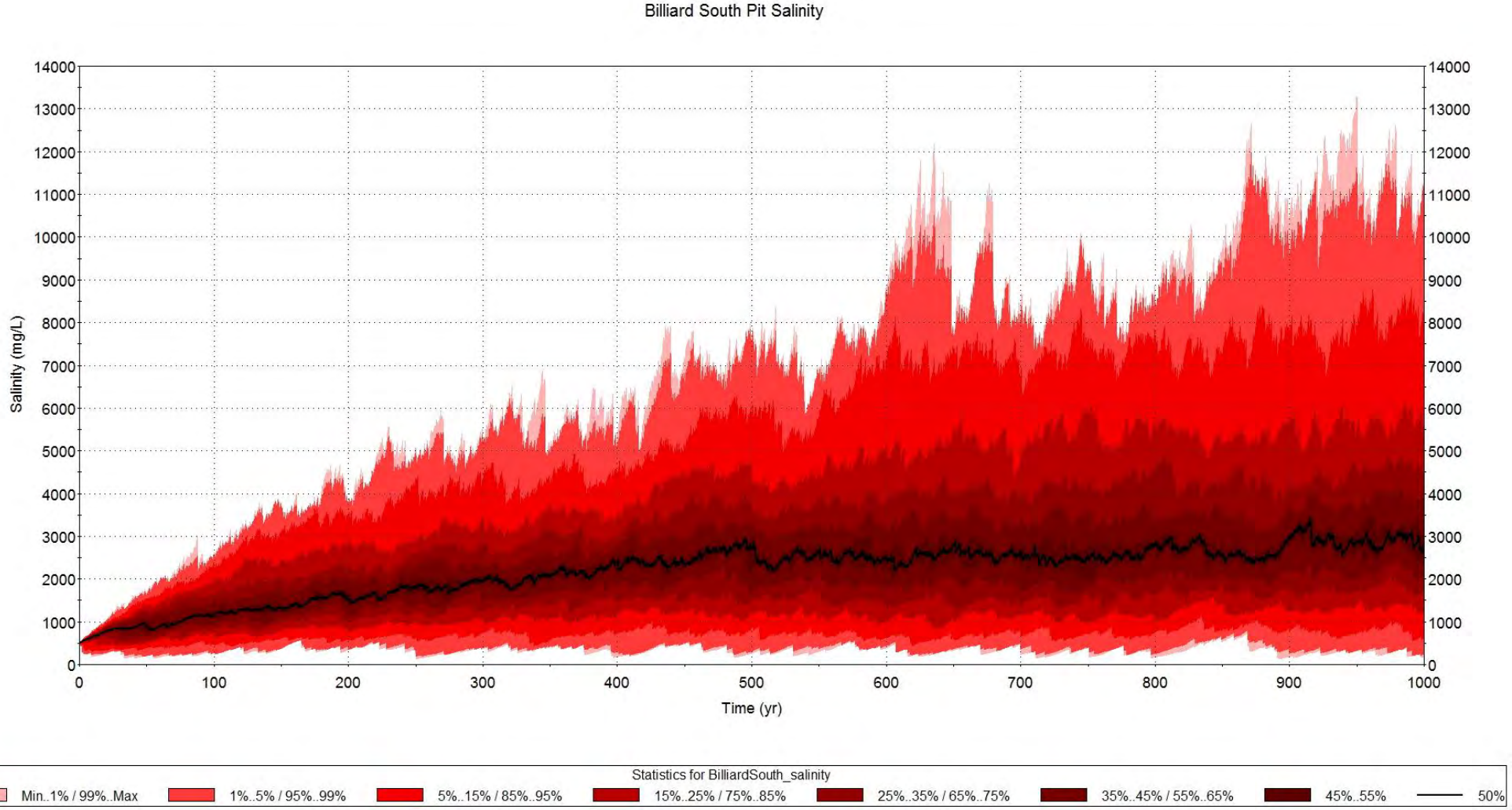

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PBS PIT WATER BALANCE MODEL

PIT WATER SALINITY

FIGURE 8

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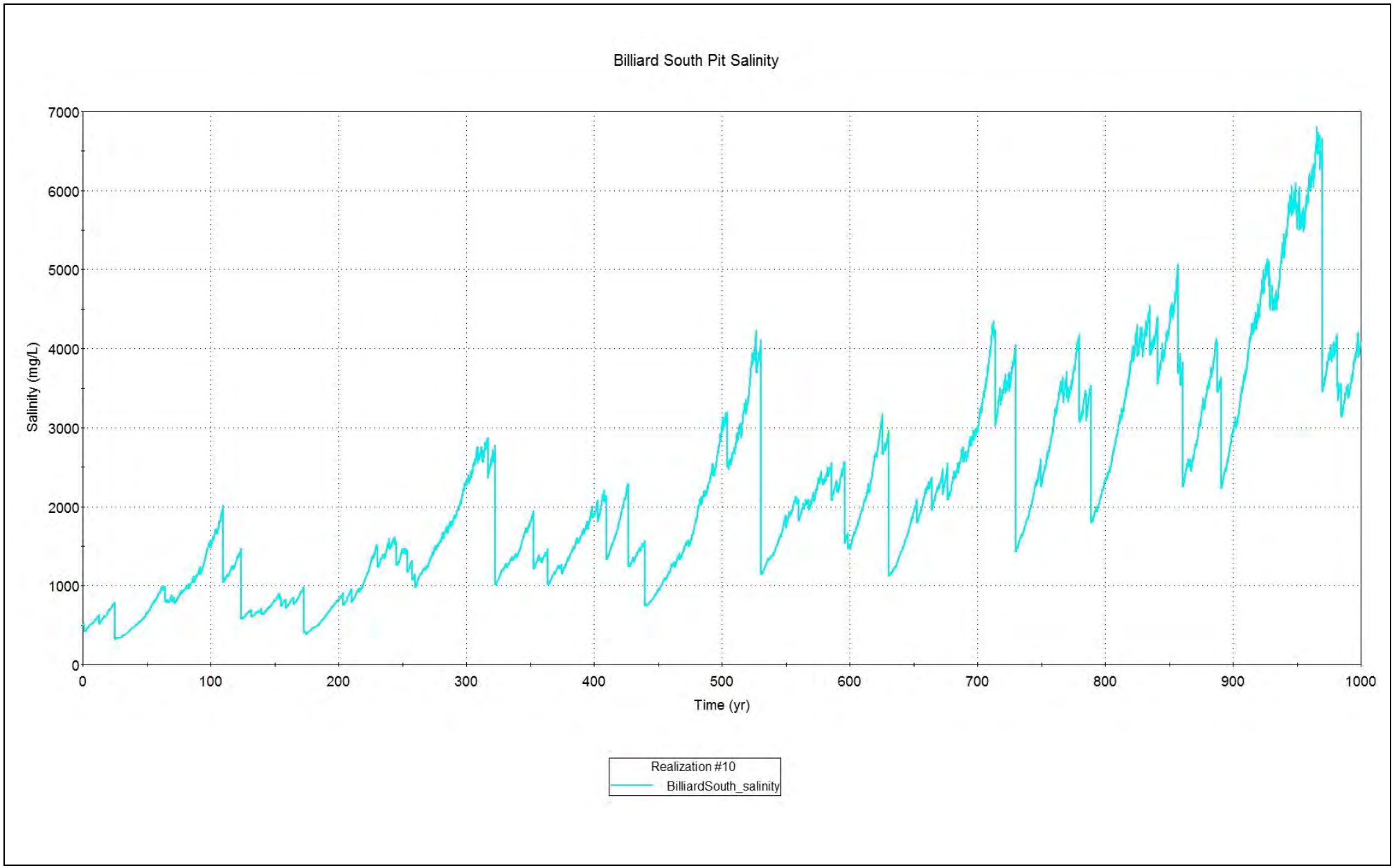

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PBS PIT WATER BALANCE MODEL

TYPICAL ITERATION - PIT WATER SALINITY

FIGURE 9

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Yandicoogina Monitoring and Management Plan

Water Discharge Monitoring and Management

Vegetation and Groundwater Dependent Ecosystems Monitoring and Management

October 2015

Hamersley Iron - Yandi Pty Limited

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Disclaimer and Limitation

This plan has been prepared by Rio Tinto, on behalf of Hamersley Iron – Yandi Pty Limited (the Proponent), specifically for the Yandicoogina Project. Neither the report nor its contents may be referred to without the express approval of the Proponent, unless the report has been released for referral and assessment of proposals.

Document Status					
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				To Whom	**Date**
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1 Context and Scope

1.1 Yandicoogina Project

Hamersley Iron – Yandi Pty Limited (the **Proponent**) manages and operates the Yandicoogina Iron Ore Project (**Yandicoogina project**). The Yandicoogina project is approved under the *Environmental Protection Act 1986* (**EP Act**) by the Minister for the Environment via Ministerial Statement (**MS**) 914.

The Yandicoogina project is located in the central Pilbara region of Western Australia, approximately 90 km east of Newman and is approximately 40 km South of Fortescue Marsh. Mineralisation occurs in an extensive Channel Iron Deposit (**CID**) located along a palaeochannel adjacent to, and in some areas intersecting, the downstream reaches of Marillana and Weeli Wolli Creek. The ore resource is predominantly below water table (**BWT**) and deposits, currently approved by MS 914, include:

- Junction Central (JC);
- Junction South East (JSE);
- Junction South West (JSW); and
- Oxbow.

In addition to the deposits currently approved, the Pocket and Billiard South (**PBS**) deposit is a proposed future deposit and is currently undergoing assessment under Part IV of the EP Act. The PBS deposit was referred under the EP Act in July 2014.

The spatial configuration of the PBS deposits within the context of the current approved mining operation is shown in Figure 1-1. The PBS deposits are contained within ML274SA established under the *Iron Ore (Yandicoogina) Agreement Act 1996*. The Yandicoogina camp is located in L021123.

1.2 Key Regulatory Requirements

The Proponent has obtained the following key regulatory environmental approvals for the Yandicoogina deposits:

- MS 417 on 25 May 1996 with subsequent modifications approved via MS 523 on 1 October 1999 (JC deposit).
- MS 695 on 22 October 2005 (JSE deposit).
- MS 914 (as revised proposal) on 18 October 2012 (JSW and Oxbow deposits).
- *Environmental Protection and Biodiversity Conservation Act* 1999 (**EPBC Act**) Decision Notice 2011/5815 on 20 November 2012 (JSW and Oxbow deposits).

The implementation conditions of MS 914 supersede those of MS 417, 523 and 695 in accordance with section 45B of the EP Act. As a consequence, MS 914 provides the current regulatory framework under the EP Act for environmental management across the entire Yandicoogina project (available at www.epa.gov.org).

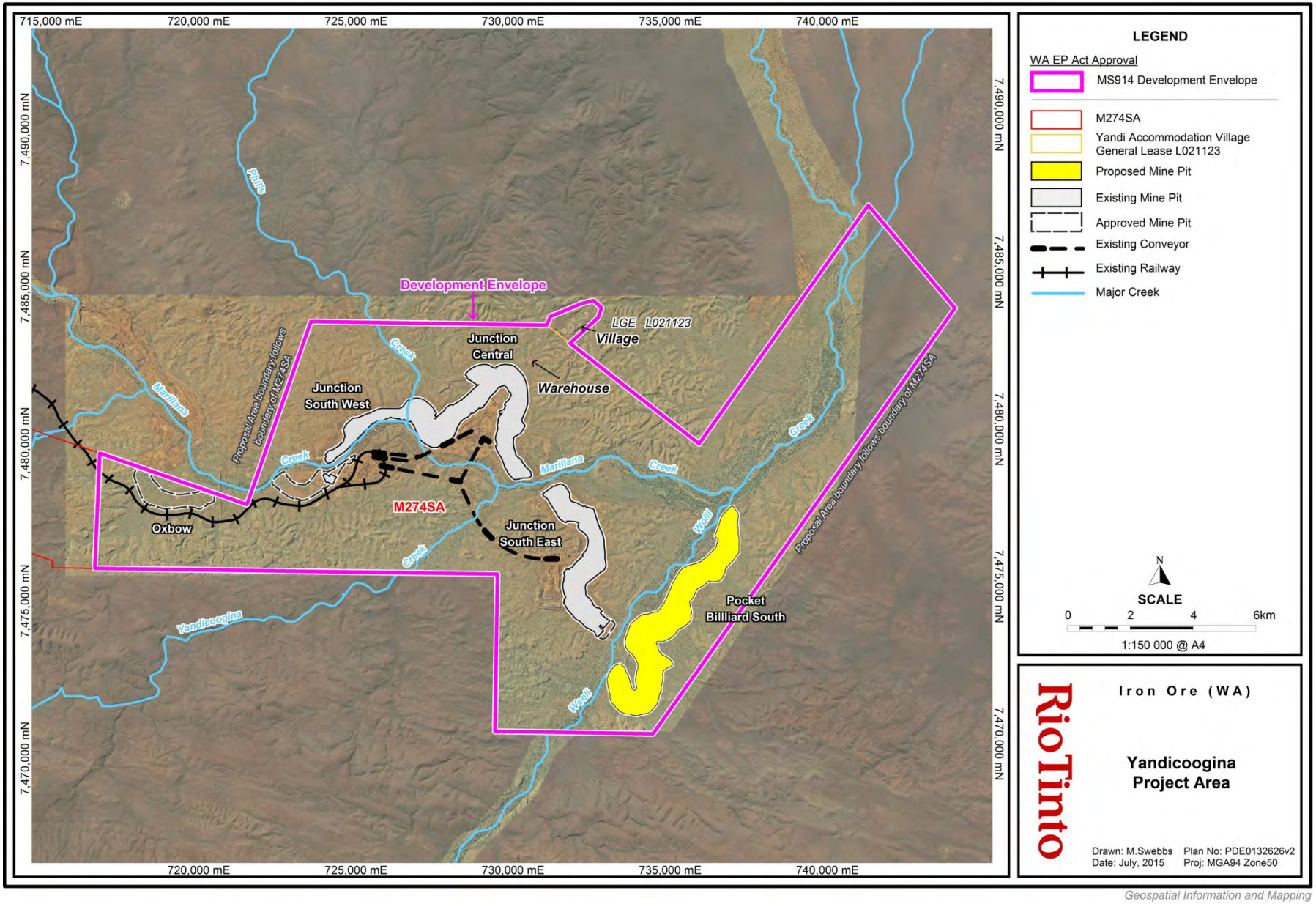

Figure 1-1: Yandicoogina Project Area

1.3 Environmental Factors

During assessment of the Yandicoogina Project, the Environmental Protection Authority (**EPA**) (EPA Bulletin 1148, August 2012) identified the following as key environmental factors which required conditioning in MS 914 via conditions 6 and 7:

(a) Vegetation, flora and fauna

(b) Groundwater and surface water.

This Monitoring and Management Plan (**MMP**) specifically addresses the requirements of Conditions 6 and 7 of MS 914, including the development of an Environmental Values Statement (**EVS**) and a comprehensive monitoring program for surface water and groundwater dependent ecosystems with associated management strategies.

In accordance with conditions 6-7 and 7-6, the MMP was implemented prior to commencing groundwater abstraction from or excavation below the water table at JSW and Oxbow and will continue to be implemented until advised otherwise by the CEO of EPA. In accordance with condition 7-7, the MMP has been reviewed and revised within the required 5 year interval, and to include the Pocket and Billiard South deposit. The MMP will continue to be reviewed and updated in future years as part of an ongoing adaptive management approach.

1.4 Environmental Objectives

The Proponent will ensure that dewatering required to implement the Yandicoogina project, and any contingency measures implemented, will not result in long term impacts to the environmental values identified in the Environmental Values Statement (**EVS**).

This approach is aligned with the EPA's broader environmental objectives for environmental factors vegetation, flora, groundwater and surface water, which are to:

- Maintain the quantity and quality of water so that existing and potential environmental values, including ecosystem maintenance, are protected.
- Maintain the abundance, diversity, geographic distribution and productivity of flora at species and ecosystem levels through the avoidance or management of adverse impacts and improvement in knowledge.
- Protect Declared Rare and Priority Flora, consistent with provisions of the *Wildlife Conservation Act 1950*

1.4.1 Environmental Values Statement

Condition 6-2 of MS 914 mandates the development of an EVS for the Weeli Wolli Creek System that defines the key environmental values of the Weeli Wolli Creek System, to the satisfaction of the CEO of the OEPA in consultation with the Department of Parks and Wildlife.

The key values of the Weeli Wolli Creek system are presented in Appendix 1 and are summarised as follows:

- **Value 1 – Fortescue Marsh:** The Yandicoogina Development Envelope is intersected by major ephemeral creek systems that ultimately drain into the Fortescue Marsh Priority Ecological Community and form part of its catchment.

- **Value 2 – Vegetation and Flora:** The vegetation communities and fauna habitats of the Yandicoogina Development Envelope are relatively widespread and well represented regionally. This includes local riparian vegetation communities and groundwater dependant ecosystems commonly associated with large ephemeral creek systems of the Pilbara region.

  One community, identified locally as the C1A riparian community, broadly comprises a Eucalypt woodland containing a co-dominant *Melaleuca argentea* component and is considered to have local conservation significance due to its groundwater dependency, associated mesic habitat values, somewhat restricted distribution, and association with a major creekline in the area. This community is similar but of different structure and reduced significance in relation to the vegetation community of Weeli Wolli Spring (significant *Melaleuca argentea* woodlands).

  The Yandicoogina Development Envelope also includes individuals of Declared Rare Flora (**DRF**) *Lepidium catapycnon*.

- **Value 3 – Stygofauna:** The Yandicoogina Development Envelope contains a number of stygofauna species known only from the Marillana-Weeli Wolli Catchment.

Note: Riparian habitat provides a corridor for the movement of microbats and other fauna. In the wider catchment, the Weeli Wolli Spring Priority Ecological Community (upstream from the Yandicoogina project area) is known to support microbat species.

The Yandicoogina Development Envelope contains potential habitat for the Pilbara olive python and northern quoll.

Heritage and social values are recognised and are addressed by the *Heritage of Western Australia Act 1990.*

1.4.2 Site Specific Trigger Values

Condition 6-4 of MS 914 requires the Proponent to ensure that the water quality of any surplus water discharged into the environment does not impact on the environmental values of the Weeli Wolli Creek System.

Local conditions vary naturally between river systems as influenced by geology, hydrology, ecosystem process and historical land uses. For this reason site specific trigger values (**SSTVs**) are preferable to the default guideline values contained in the ANZECC/ARMCANZ (2000) *Australian Water Quality Guidelines*, as depicted in the preferred hierarchy for deriving trigger values shown in Figure 2-1, and in line with the requirements of Condition 6-4 (3).

Rio Tinto has collected baseline (or reference) water quality data from the Yandicoogina groundwater and creek systems which have been used to develop SSTVs for the analytes shown in Appendix 2 and are based on an ecosystem hazard analysis (WRM 2015a), consistent with the ANZECC/ARMCANZ (2000) *Australian Water Quality Guidelines*.

2 Implementation of the Monitoring and Management Plan

This MMP addresses related environmental factors (and relevant environmental objectives), which were determined by the EPA as being relevant to the appropriate management of surface water and groundwater dependent ecosystems. In addition, it identifies the environmental criteria that the Proponent will use to monitor performance of the measures proposed to address the requirements of Conditions 6 and 7 of MS 914. Finally, it defines the management actions that the Proponent will take in response to monitoring results.

2.1 Environmental Criteria

Three levels of environmental criteria have been developed for this MMP. Level 1 and 2 criteria trigger investigative works and early management actions, whilst level 3 defines threshold criteria to measure compliance and ensure the environmental objectives are not compromised. In circumstances where three criteria levels are not appropriate only one or two levels of criteria are used.

Triggers

- **Level 1:** Conservative, early warning criteria to provide early feedback on potential impacts.
- **Level 2:** Causal investigations to be undertaken to ensure the event or issue is understood. Increased monitoring focus. Determine whether the event is the effect of mining activities or caused by changes in the natural environment. Remedial actions to be identified and may be taken where necessary. No significant or irreversible impacts are foreseen.

Threshold

- **Level 3:** Criteria framed to measure achievement of the environmental objective. Highest level of investigation with advisory notification of event or issue to regulatory agencies and other appropriate stakeholders including the relevant Traditional Owners. Activate appropriate intervention / contingency measures.

2.2 Monitoring and Management Actions

The purpose of monitoring is to inform, through the environmental criteria, if the environmental objective is being achieved and to identify when appropriate management actions need to be implemented.

Table 2-1 and Table 2-2 address the monitoring and management actions required for surface water and groundwater dependent ecosystems respectively. Figure 2-2 and Figure 2-4 depict the monitoring locations.

Monitoring results and management actions will be included in the annual Compliance Assessment Report, in accordance with the approved compliance assessment plan (MS 914, condition 4).

Table 2-1: Monitoring to Evaluate Environmental Performance against Trigger and Threshold Criteria and associated Management Actions for Surface Water

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
To maintain the quantity and quality of water so that existing and potential environmental values, including ecosystem maintenance are protected.										
Preserve the environmental values of the Weeli Wolli creek system as identified in the EVS: Stygofauna & Ensure water discharged to the environment meets specified water quality requirements	6-1 6-6(1) 6-6(2) 6-6(3) 6-6(4) 6-4	Establish baseline surface water quality which supports subterranean habitat for Stygofauna. **Action Complete** Assess time series changes in surface water quality	**Surface water quality parameters (based on hazard analysis – Section 7; Appendix 2):** Alkalinity (as $CaCO_3$) Ba B Ca CO_3 EC Hardness Fe $N\text{-}NO_3$ pH P-total SO_4 TDS TSS U V **Surface water quality monitoring locations:** Compliance sites ▪ MAR 2-6 (Lower Marillana Creek below DO9) ▪ DPW0012 (Weeli Wolli Creek below DO6) **Upstream reference sites:** ▪ BHP discharge outlet ▪ MAR 1-1 (entering from BHP discharge outlet Yandi upstream) ▪ DPW0011 (entering from RTIO HD1 upstream) ▪ Operating discharge outlets (will vary over time – refer to DER licence) Extent of surface water discharge ▪ WW4-8 (Lower Weeli Wolli Creek)	Quarterly (subject to flow during monitoring schedule)	**Toxicant:** Rolling median concentration of any analyte recorded at MAR 2-6 or DPW0012 is above the hardness modified SSTV OR a single value is above the 95%ile of baseline or ANZECC/ ARMCANZ (2000) default 80% species protection level. **Stressor:** Rolling median concentration of any analyte recorded at MAR 2-6 or DPW0012 is above the hardness modified SSTV (refer to Appendix 2)	Investigate potential cause of water quality change Review water quality at the discharge points, compare to baseline and reference sites, review discharge volumes Determine environmental conditions in lead up to monitoring event; review rainfall and flood events Re-sample to validate results.	**Toxicant:** Rolling median concentration is statistically higher (refer figure 2-1) than the SSTV and resampling confirms the value still exceeds the SSTV local baseline and reference sites. **Stressor:** Rolling median concentration is statistically higher (figure 2-1) than the SSTV and resampling confirms the value still exceeds the SSTV local baseline and reference sites.	Investigate potential contamination sources other than dewatering discharge. If other sources are identified as a result of the Proponent's Yandicoogina operations then remove / eliminate source from the most likely pathway and resample. Review groundwater monitoring data from production borefield and investigate potential source from geology of orebody being dewatered. If investigations warrant, increase frequency of monitoring at selected downstream and reference sites to determine geographic extent of SSTV exceedance. Increase suite of parameters to include: Al, Cu, Mn, Se and SiO_2 until level 2 criteria are no longer met Seek expert advice on potential risk to the environment, and assess bioavailability of toxicants if warranted. Investigate possible remedial actions, for example, modification of discharge regime. Investigate field ecological monitoring at potential impact sites in comparison to baseline and reference sites	**Toxicant & Stressor:** Investigation indicates there is potential for detrimental long term impacts to the values identified in the EVS as a result of operations:	Implement the management options identified in the investigations stage to remediate the impacts If warranted, instigate additional field surveys and/or ecotoxicity studies to determine level of impact, if any, on aquatic biota. Consult with relevant stakeholders. Instigate external reporting. If field ecological monitoring or ecotoxicity studies indicate exceedance has no acute or chronic effect on biota, revise SSTVs in consultation with stakeholders and experts.

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
Preserve the environmental values of the Weeli Wolli creek system as identified in the EVS: Stygofauna	6-1	Assess time series changes in subterranean habitat quantity.	Water availability in alluvium ▪ Dewatering discharge outlets volume (kL) ▪ Site based weather station rainfall (mm) ▪ Groundwater levels from selected groundwater monitoring bores within alluvium (when accessible)	Quarterly	Groundwater levels outside predicted range for all sites	Determine if linked to specific events (e.g. rains, flood or change in discharge regimes from the Proponent's Yandicoogina operations or other mines in the catchment	Groundwater levels outside predicted range at all sites for successive quarterly monitoring events	Investigate and establish the potential cause of water level deviation from predicted natural range. If the Proponent's operations are identified as a potential cause of detrimental water level change then operations will identify options for modifying water levels to maintain sufficient groundwater habitat. Context results with critical correlative environmental parameters including: ▪ monthly rainfall ▪ proximal groundwater levels ▪ flood events; ▪ monthly discharge volumes ▪ Additional groundwater quality parameters as per GWOS ▪ Stygofauna assemblages (opportunistic)	Groundwater levels outside predicted range at all sites for successive monitoring events with no reversible trend, and investigation indicates there is potential for detrimental long term impacts to Stygofauna as a result of operations	Implement the management options identified in the investigations stage to remediate groundwater habitat impacts Consult with relevant stakeholders
Prevent discharge from water flow or pooling further than 17km downstream from the Marillana and Weeli Wolli Creek System Confluence Discharge extent to prevent permanent connection to Fortescue Marsh (EVS 3)	6-3 6-6(2) 6-6(4) 7(2)	Monitor the extent of the discharge footprint in the Weeli Wolli Creek. "Discharge footprint" is defined as the saturated creek bed once steady state conditions are established. Respond to the extent of the wetting front in Weeli Wolli Creek if a trigger exceedance or potential for trigger exceedance is identified	Distance of persistent water flow (the discharge footprint) extends from the Marillana Creek and Weeli Wolli Creek, into Weeli Wolli Creek (Zone 3) System confluence where discharge footprint is defined as saturated creek bed once steady state conditions are established.	Monthly	Water flow occurs >15km from the Marillana Creek and Weeli Wolli Creek System confluence.	Investigate and establish the potential cause of persistent water flow or pooling. Compare against critical correlative environmental parameters: ▪ Monthly rainfall ▪ Groundwater levels ▪ Flood events ▪ Monthly discharge from the Proponent's operations. ▪ Change in discharge regime of other mines in the catchment) Identify potential actions to reduce the extent of the discharge footprint within Weeli Wolli	N/A	N/A	Water flow occurs ≥17km from the Marillana Creek and Weeli Wolli Creek System confluence, and investigation indicates it is attributable to the Proponent's operations:	Consult with relevant stakeholders (OEPA, DoW and DER) Evaluate extent of impact to the values (as per the EVS). If appropriate, modify discharge regime to meet management objective.

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
						Creek.				
Maintain major creekline flood flows and minimise erosion in the creeklines.	6-6(2) 6-6(5) 7-5(5)	Erosion and sedimentation assessment	Visual assessment of erosion and photographic record at operational discharge outlets 2, 3, 5, 6, 8 and 9	Biannually (post wet season and dry season)	Erosion visually identified at discharge outlets (severity rating ≥ medium) Erosion and/or sedimentation visually identified in major creek channels (severity rating ≥ medium)	Review results of total suspended solids monitoring from discharge outlets and surface water sites Mar 1-1, Mar 2-6, DPWW0011, DPWW0012 and WW4-8 (refer to Figure 2-2) Compare against critical correlative environmental parameters: ▪ Monthly rainfall ▪ Flood events ▪ Monthly discharge volumes	Erosion assessed to be a result of surplus water discharge	Assess whether erosion is continuing or accelerating through comparison over multiple inspections Assess extent of erosion downstream of discharge outlet/s Investigate possible remediation actions, for example modification of discharge regime. If warranted, seek expert advice on probable causes and environmental risk of changes observed.	Erosion is confirmed to be a result of discharge, extends beyond the immediate proximity of the discharge outlet and is assessed to be continuing/ worsening	Consult with relevant stakeholders. Instigate external reporting. Implement any dewatering discharge improvements which were identified in the investigation. Undertake rehabilitation works as required and as permitted.

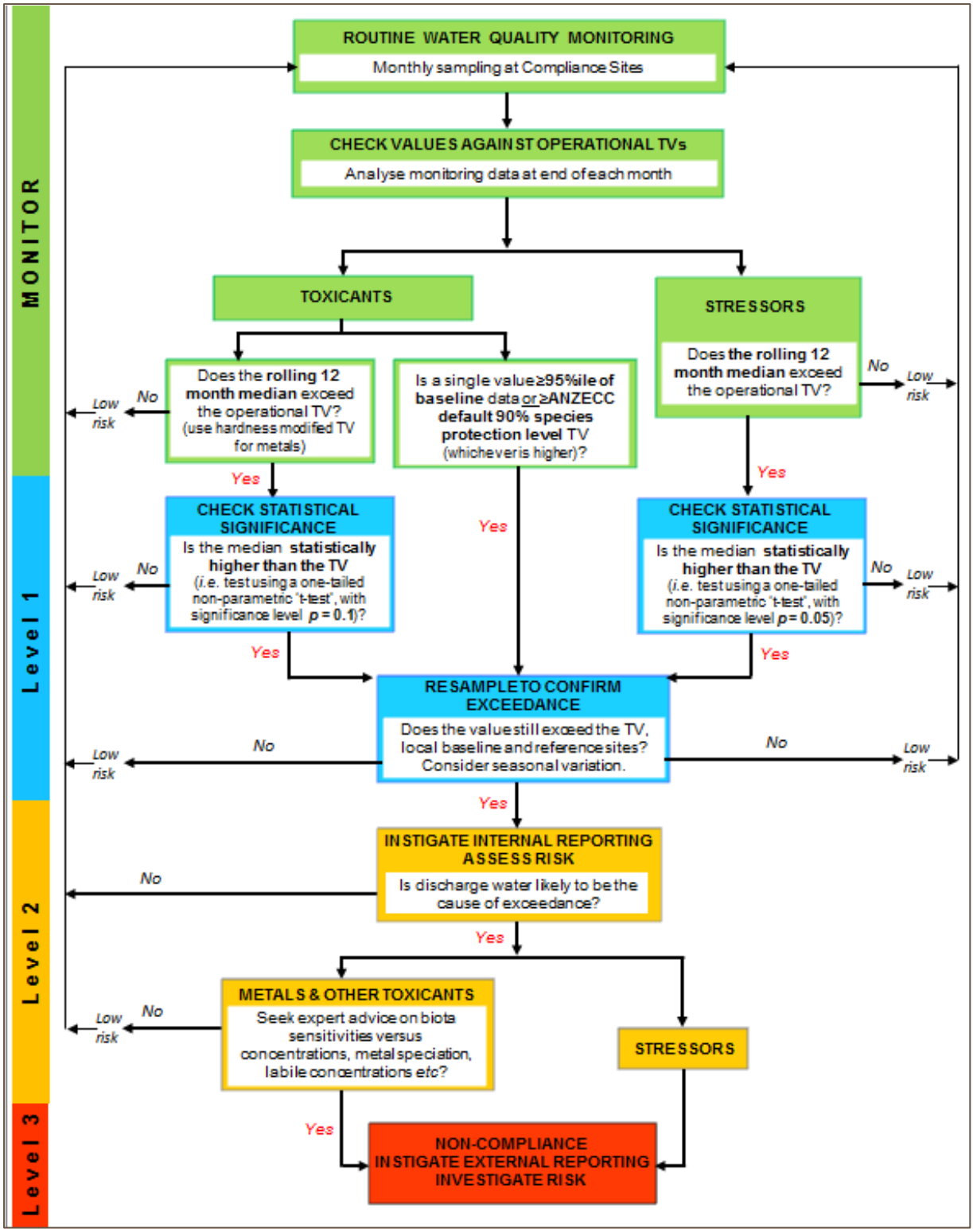

Figure 2-1: Decision support framework for applying water quality guideline trigger (adapted from WRM2014)

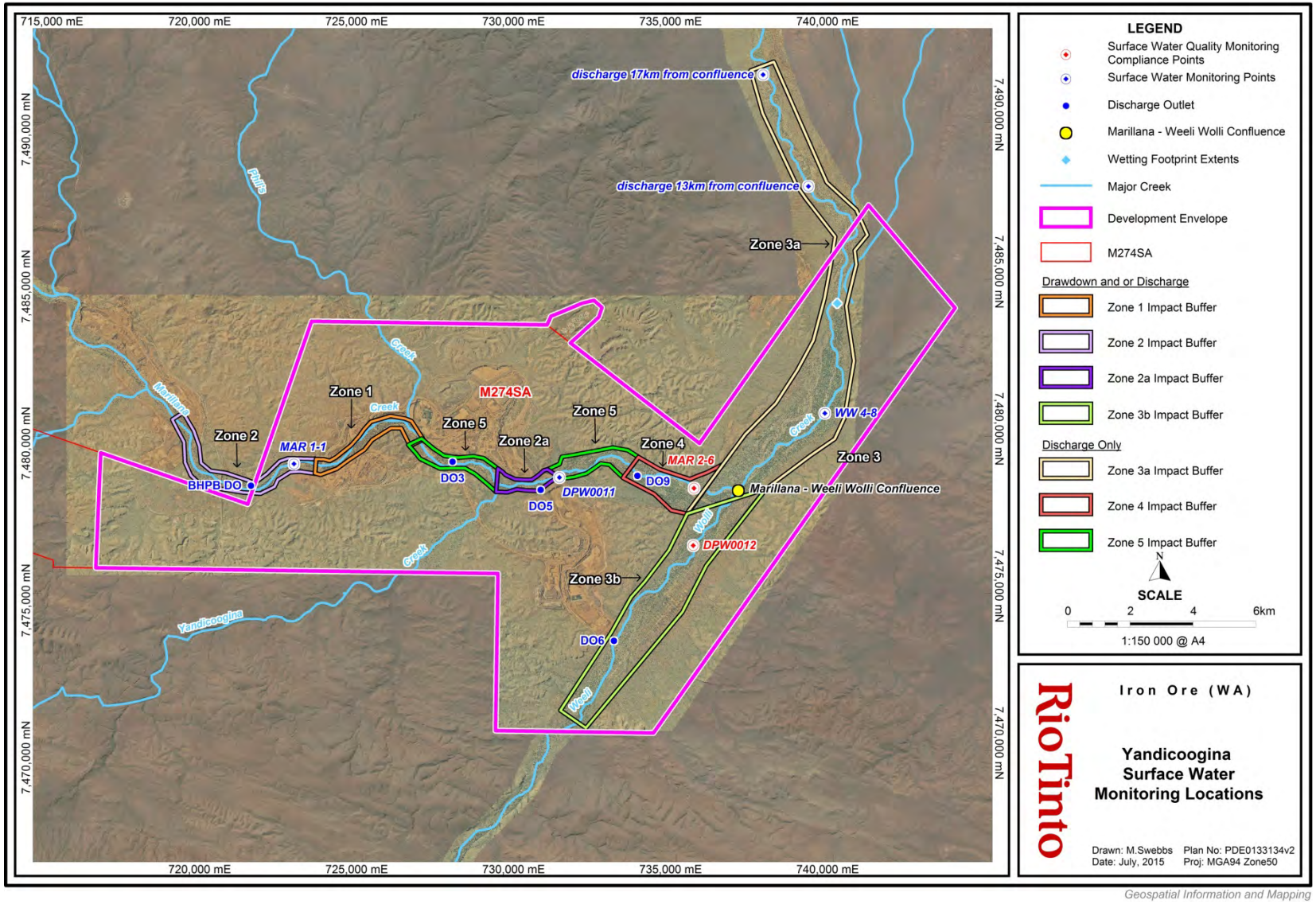

Figure 2-2: Yandicoogina Surface Water Monitoring Locations

Table 2-2: Monitoring to Evaluate Environmental Performance against Trigger and Threshold Criteria and associated Management Actions for Vegetation and Groundwater Dependent Ecosystems

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
Maintain the abundance, diversity, geographic distribution and productivity of flora at species and ecosystem levels through the avoidance or management of adverse impacts and improvement in knowledge										
Prevent clearing or loss of vegetation or GDEs outside Zones 1, 2, 2a, 3*, 3a*, 4 and 5 resulting from dewatering discharge	7-2 7-5 (1-3;7)	Establish baseline riparian vegetation condition outside Zones 1, 2, 2a, 3: (3a & 3b), 4 and 5. **Action complete** Monitor riparian vegetation condition downstream of the zone 3 northern boundary	Canopy foliage cover as an indicator of tree health Site: Pug's Bore	Quarterly On detection of any clearing or loss	Water flow occurs ≥17km from the Marillana Creek and Weeli Wolli Creek System confluence	Quantify extent of discharge beyond 17km Confirm the cause of water flow ≥17km from the confluence, comparing the following correlative factors with assumptions used in predictive modelling: ▪ Monthly rainfall ▪ Groundwater levels ▪ Flood events ▪ Discharge from the Proponent's operations ▪ Discharge from other mining operations, including BHP Yandi and Hope Downs 1. Review the results of canopy foliage cover monitoring	Canopy foliage cover declines by ≥25% from baseline AND Investigation indicates persistent water flow occurring ≥17km from the Marillana Creek and Weeli Wolli Creek System confluence is attributable to the Proponent's operations	Review remotely sensed vegetation spectral data and vegetation monitoring (transect survey) data Review regional and reference sites to context decline with seasonal trends If investigations indicate it is warranted, initiate more frequent qualitative assessment of local riparian vegetation in impacted areas. Investigate possible remedial actions, for example, modification of discharge regime	Investigation confirms ≥25% foliage cover decline from baseline, in excess of declines in reference areas, is representative of riparian vegetation condition trends downstream from the zone 3 northern boundary, and is attributable to the proponent's dewatering discharge extending beyond the zone 3 boundary	Consult with relevant stakeholders Modify discharge regime to correct the exceedance in consultation with relevant stakeholders Evaluate if clearing or loss has occurred in the effected zone for a period of 12 months following corrective actions
			Riparian vegetation monitoring transects to determine species present (includes introduced taxa) Sites: WW25, WW30 and WW31	Biannually (post wet season and dry season)	Persistent water flow occurs ≥17km from the Marillana Creek and Weeli Wolli Creek System confluence	Confirm the cause of water flow ≥17km from the confluence, comparing the following correlative factors with assumptions used in predictive modelling: ▪ Monthly rainfall ▪ Groundwater levels ▪ Flood events ▪ Discharge from the Proponent's operations ▪ Discharge from other mining operations, including BHP Yandi and Hope Downs 1 Review the results of vegetation transects monitoring	Species richness of common native perennial riparian understorey and groundcover species at potential impact sites declines ≥ 20% from baseline, in excess of declines in reference areas AND Investigation indicates persistent water flow occurring ≥17km from the Marillana Creek and Weeli Wolli Creek System confluence is attributable to the Proponent's operations	Quantify extent of discharge beyond 17km. Review remotely sensed vegetation spectral data and vegetation monitoring (transect survey) data If investigations indicate it is warranted, initiate more frequent qualitative assessment of local riparian vegetation in impacted areas Investigate possible remedial actions, for example, modification of discharge regime	Investigation confirms ≥ 20% decline from baseline of species richness of common native perennial riparian understory and groundcover species at potential impact sites, in excess of declines in reference areas, is representative of riparian vegetation condition trends downstream from the zone 3 northern boundary, and is attributable to the proponent's dewatering discharge extending beyond the zone 3 boundary	Consult with relevant stakeholders. Modify discharge regime to correct the exceedance in consultation with relevant stakeholders Evaluate if clearing or loss has occurred in the effected zone for a period of 12 months following corrective actions

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
Prevent clearing or loss of vegetation or GDEs outside Zones 1, 2, 2a, 3*, 3a*, 4 and 5 resulting from groundwater abstraction	7-1 7-5(1-3; 7)	Establish baseline riparian vegetation condition outside Zones 1, 2, 2a, 3: (3a & 3b), 4 and 5. **Action complete** Monitor riparian vegetation condition in Weeli Wolli Creek upstream from the southern boundary of zone 3a	Canopy foliage cover as an indicator of tree health Weeli Wolli Creek: Y10, Y11, Y12	Quarterly On detection of any clearing or loss	N/A	N/A	Canopy foliage cover declines by ≥25% from baseline, in excess of declines in reference areas	Review water availability, including surface water flows and groundwater levels to assess the likelihood of drawdown impacting riparian vegetation Review remotely sensed vegetation spectral data and vegetation monitoring transect data Identify potential remedial actions	Investigation indicates canopy foliage cover which has declined ≥25% from baseline, in excess of declines in reference areas is attributable to drawdown	Confirm cause of drawdown and implement remedial actions as required. Evaluate if clearing of loss has occurred in the effected zone for a period of 12 months following corrective actions. Notify relevant stakeholders
Maintain the abundance, diversity, geographical distribution and productivity of vegetation communities in the project area by avoiding or managing adverse impacts	7-5(4) 6-6(5)	Define limits of acceptable disturbance within the riparian zone. **Action complete** Respond to any disturbance (irreversible loss) exceeding defined limits of acceptable disturbance	Clearing requests Clearing permits Survey of cleared area & reconciliation with permit	Q1 2013 Ongoing If trigger values exceeded	Clearing request made for riparian vegetation community	Check area request against defined limits of acceptable disturbance for riparian vegetation	Clearing approved and works completed	Validate that approved disturbance is contained within approved boundaries Report total land clearing figures within the riparian zone in the annual Compliance Assessment Report	Disturbance occurs outside approved Approval Request permit area	Notify relevant stakeholders. If warranted, rehabilitate disturbed area outside approved clearing area.

Environmental Objective	Ministerial Statement Condition	Monitoring Aspect	Monitoring Parameter	Monitoring Frequency	Trigger				Threshold	
					Level 1 Criteria	Level 1 Management Actions	Level 2 Criteria	Level 2 Management Actions	Level 3 Criteria	Level 3 Management Actions
Prevent irreversible impact to riparian vegetation or GDEs within zones 1, 2, 2a, 3*, 3a*, 4 and 5 resulting from groundwater abstraction or discharge AND Maintain the abundance, diversity, geographical distribution and productivity of vegetation communities in the project area by avoiding or managing adverse impacts	7-3 7-5(1-3; 7) 7-5(4) 6-6(5)	Establish baseline riparian vegetation condition within zones 1, 2, 2a, 3: (3a & 3b), 4 and 5. **Action complete** Monitor riparian vegetation condition within all zones along Marillana and Weeli Wolli Creek	Canopy foliage cover as an indicator of tree health All Zones (Refer to Figure 2-3 and Figure 2-4)	Quarterly	±25% decrease in mean foliage cover relative to baseline at any individual DCP site within the riparian management zones	Identify the riparian community present at the DCP monitoring site. Context decline in foliage cover with reference and regional tree health results, taking into account the distribution of different riparian vegetation communities Review other environmental factors (such as climate, storm damage, fire and insect activity) Review groundwater abstraction and discharge operations/ volumes, and identify potential remedial actions Review remotely sensed vegetation spectral data If investigations indicate it is warranted, initiate more frequent qualitative assessment of local riparian vegetation in impacted areas	Within 2 or more zones, monitoring results exceed all of the following: 40% decrease in mean foliage cover from baseline at all DCP sites in excess of declines in reference areas 25% decline from baseline in species richness of common, native perennial riparian understory groundcover species at all vegetation transects, in excess of declines in reference areas 80% groundcover of weed species not recorded within the project area during baseline monitoring	Initiate additional monitoring as required to assess riparian vegetation condition in all appropriate zones against irreversible impact threshold criteria. Review regional and reference sites to context decline with seasonal trends If necessary, implement feasible remedial actions	Within 4 or more zones all of the following are exceeded: 30% death of mature trees (Diameter Breast Height >20 cm) in excess of mature tree deaths recorded at non-impact or reference sites 25% decline from baseline in species richness of common, native perennial riparian understory groundcover species, in excess of declines in reference areas Absence of recruitment of key local riparian tree species when compared to reference and non-impact sites 80% groundcover of weed species not recorded within the project area during baseline monitoring	Notify and consult with relevant stakeholders. Review operation and efficiency of dewatering and surplus water management system. Implement additional remedial actions on advice from relevant stakeholders. Instigate external reporting.
			Riparian vegetation monitoring transects to determine species present (includes introduced taxa) All Zones (Refer to Figure 2-3 and Figure 2-4)	Biannually (post wet season and dry season)	20% decline (from baseline) of species richness of common native perennial riparian understory and groundcover species at any potential impact site/s, in excess of declines in reference areas	Conduct visual qualitative inspection of local riparian vegetation, including the C1A community Review other environmental factors such as climate, fire, insect activity Review exposure of impacted sites to i) changed creek flow conditions; or ii) extent and duration of inundation with dewatering discharge Context change with reference and regional site results to ascertain if existing weed populations or populations of other native species are expanding where the number of common native species has declined. If investigations indicate it is necessary, manage weeds at the level appropriate to the weed risk and priority identified for each species (in accordance with the Invasive Plant Prioritisation Process, DEC 2011) Investigate other possible remedial actions, for example, modification of discharge regime				

Whilst establishing trigger and threshold* criteria, it was noted that due to the complexity of riparian woodland communities, there is insufficient scientific knowledge to use a singular pre-existing criterion, or establish a new criterion to define an irreversible impact, based on a singular monitoring technique. Individual monitoring techniques provide insight into how individual aspects of riparian vegetation respond to environmental conditions, and should be used collectively to assess the overall condition of the community. As such, the above criteria have been adopted as a threshold for irreversible impact to riparian vegetation

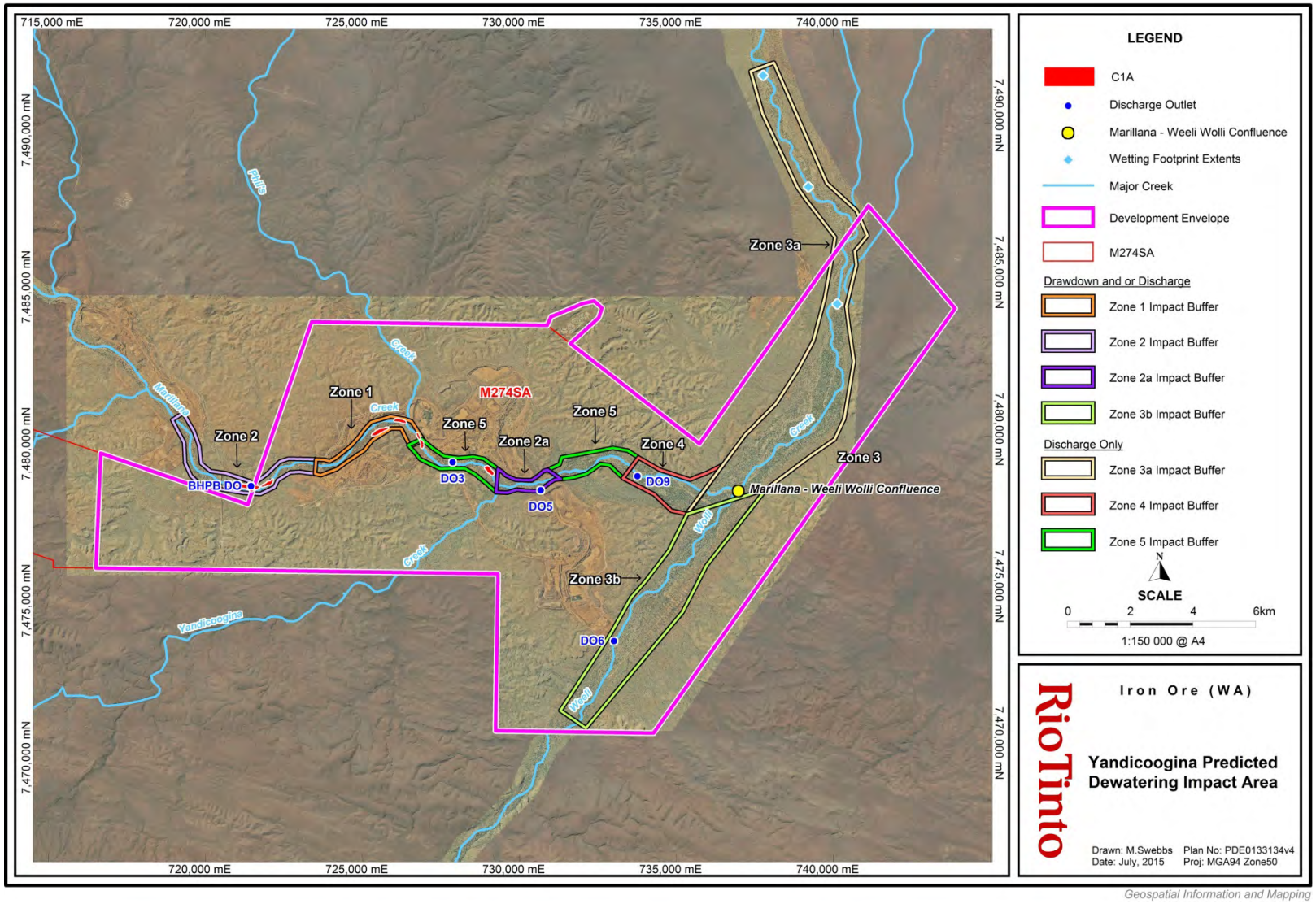

Figure 2-3: Yandicoogina Predicted Dewatering Impact Area

Note: the Proponent identified five riparian management zones where indirect impacts on environmental values may occur as a result of dewatering and discharge activities. Further details on the zones are available in the Report and Recommendations of the Environmental Protection Authority Report for Yandicoogina Iron Ore Project (EPA 2012). Zone 3 & 3a from (EPA2012) has been updated to Zone 3a and 3b to reflect predicted impact areas for the inclusion of the Pocket and Billiard South Project.

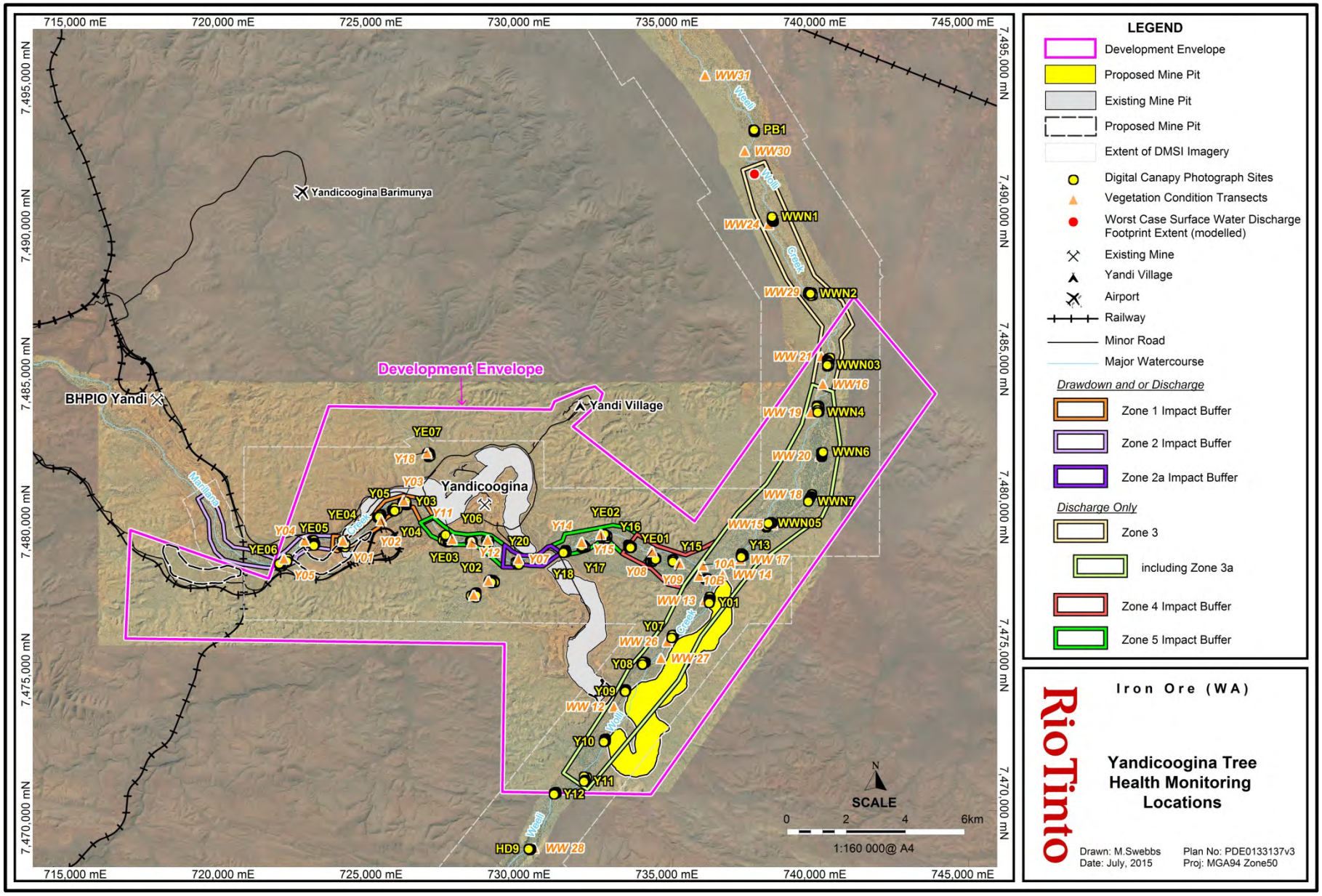

Figure 2-4: Yandicoogina Tree Health Monitoring Locations

3 Monitoring and Management Plan Review

This MMP will be reviewed as required throughout the duration of the Yandicoogina project at intervals not exceeding 5 years to the approval of the CEO of the EPA. In addition, review and revision of the plan will occur as appropriate in response to environmental incident resolutions, audit findings, monitoring results, continuous improvement and changes in regulatory and corporate requirements.

4 Stakeholder Consultation

The MMP and EVS was originally developed in consultation with the Department of Parks and Wildlife (**Parks and Wildlife**), Department of Water (**DoW**) and the Office of the EPA (**OEPA**) during 2012, post assessment of the Yandicoogina project and based on the conditions set out in MS914.

This update will be finalised in consultation with Parks and Wildlife, the Department of Environmental Regulation (**DER**) and the OEPA and will be ongoing as part of an adaptive management process and to support the development of the Pocket and Billiard South deposits.

The Proponent will continue consultation with relevant stakeholders during environmental assessment processes and through the implementation of the Yandicoogina project. These stakeholder groups include the Traditional Owner group represented by the Gumala Aboriginal Corporation and Marillana pastoral station operators.

5 Definitions

Baseline water quality levels: Water quality as defined by the inputs from upstream Mining operations which discharge surplus water into the Marillana and Weeli Wolli Creek systems (including at the western margin of the tenement: BHPBIO Yandi, and including the southern margin of the project area within Weeli Wolli creek: BHPBIO Jinidi operations and HMS Hope Downs 1 operation), and measured at locations depicted in Figure 2-2.

Irreversible impacts: an impact resulting in a permanent loss of environmental value(s); or where intensive, and/or un-proven management intervention, potentially over a long timeframe, would be required to restore the environmental value(s).

Life-of-Mine: Includes the time period from the start of construction until the end of active operations for the Yandicoogina JC, JSE, JSW deposits, Oxbow deposits and PBS deposit.

Long Term Impacts: an impact to an environmental value(s) over several decades which is not irreversible.

Major creekline flood flows: is defined as the 50yr ARI.

Project Area (Development Envelope): Encompasses the Yandicoogina project footprint within ML248SA as delineated in Figure 1-1.

17 km discharge: The discharge footprint is defined as the saturated creek bed once steady state conditions are established. The 17 km limit is defined based on the modelled discharge extent from the Yandicoogina project during *dry conditions*; at a dewatering rate of 53 GL/a; and as of October 2012 approved licence limits of other operations within the catchment (BHPBIO Yandi, Hope Downs 1) (Refer to Figure 2-2 and Figure 2-3).

6 References

ANZECC/ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Agriculture and Resource management Council of Australia and New Zealand and Australian and New Zealand Environment and Conservation Council, Canberra

EPA 2007, *Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia*, Guidance Statement No. 54a, Environmental Protection Authority, Perth

EPA 2012, *Yandicoogina Iron Ore Project - Expansion to include Junction South West and Oxbow Deposits*, Report 1448, Environmental Protection Authority, Perth

EPA 2012 *Yandicoogina Iron Ore Project - Expansion to include Junction South West and Oxbow Deposits,* Ministerial Statement 914

Rio Tinto 2008 Marillana Creek Catchment Hydrology and Local Catchment impacts: Yandicoogina +52 Mtpa Expansion Prefeasibility, Junction South West (Stage 1) and Oxbow Deposits, January 2008, Rio Tinto Iron Ore, Perth.

Rio Tinto 2010 Marillana Creek Regional Flow Balance – pre and Post-mining comparison, May 2010, Rio Tinto Iron Ore, Perth

Rio Tinto 2011, *Yandicoogina Junction South West and Oxbow Iron Ore Project - Public Environmental Review*, September 2011, Rio Tinto, Perth

WRM 2011, Preliminary Water Quality guidelines for dewatering discharge into Marillana Creek (Draft report). Wetland Research and Management, Perth.

WRM 2015a Yandicoogina Hazard Analysis Report, Wetland Research and Management, Perth.

WRM 2015b Yandicoogina Site Specific Trigger Values, Wetland Research and Management, Perth.

7 Appendices

Appendix 1: Yandicoogina - High Level Values Statement

Weeli Wolli Creek Catchment - October 2015

High Level Values	Description
Fortescue Marsh	The Fortescue Marsh is the largest ephemeral wetland in the Pilbara region and is listed on the Directory of Important Wetlands of Australia as a wetland of national significance. The diverse ecosystem includes endemic flora, fauna and supports a rich diversity of restricted aquatic and terrestrial invertebrates. The Fortescue Marsh is classified as a Priority Ecological Community (PEC). Marillana and Weeli Wolli Creeks are ephemeral watercourses supported by a combination of groundwater flows and surface run off. This system ultimately drains into Fortescue Marsh, approximately 40 km downstream of Yandicoogina.
Flora and vegetation	A number of populations of the DRF (Declared Rare Flora) *Lepidium catapycnon* occur within the Yandicoogina Development Envelope. The species is listed as a DRF under the Wildlife Conservation Act and as Vulnerable under the EPBC Act. Five broad riparian woodland vegetation communities exist along the Weeli Wolli and Marillana creekline areas within the Yandicoogina Development Envelope. One community (C1A - open riparian Eucalypt woodland containing a mature and co-dominant *Melaleuca argentea* component) is considered to have local conservation significance due to its groundwater dependency, associated values, somewhat restricted distribution, and association with a major creekline in the area. This community is similar but of different structure and reduced significance to the vegetation community of Weeli Wolli Spring (significant *Melaleuca argentea* woodlands).
Stygofauna	A number of subterranean fauna species are known only from the Marillana-Weeli Wolli Catchment. The riparian woodland and ephemeral nature of the Weeli Wolli and Marillana Creeks, together with the underlying CID aquifer provide habitat for a range of fauna, including terrestrial, avian, aquatic and subterranean. Assemblages include aquatic fauna (micro and macroinvertebrates and fish), stygofauna, and animals of the hyporheic zone. The Development Envelope does not contain any permanent pools as refuge for aquatic fauna, and as a result there is no elevated conservation significance for aquatic fauna in the Development Envelope.
Other Recognised Values	
Fauna	In the wider catchment, the Weeli Wolli Spring (upstream from the Development Envelope) is known to support a significant microbat species assemblage, which includes the most northerly population of the Chocolate Wattle Bat (*Chalinobolus morio*). This bat species has been recorded in the south-west corner of the Development Envelope. The Pilbara Olive Python (*Liasis olivaceus barroni*) has been recorded within Weeli Wolli Creek within the southern area of the Development Envelope, and the Development Envelope may contain habitat for the Northern Quoll (*Dasyurus hallucatus*). The Weeli Wolli Creek catchment also contains records of listed migratory birds and Priority species.
Heritage and social	Aboriginal culture is spiritually and physically connected to the landscape through Jukurppa (Dreaming) stories, ceremony, and physical places such as ethnographic and archaeological heritage sites. Weeli Wolli Creek is an important ephemeral water source, food source, camping and meeting place and has been visited by the Traditional Owners of the area for many thousands of years. Significant ethnographic and archaeological heritage sites are also associated with the Marillana and Weeli Wolli water courses. Heritage and social values are recognised and are addressed by the *Heritage of Western Australia Act 1990.* Weeli Wolli Creek is also a significant tourism destination in the region.

Appendix 2: SSTVs for Yandicoogina operations (WRM2015a)

Analyte	SSTV MAR2-6	SSTV WW3-5	Comment	Frequency
Aluminium (Al)	0.055	0.055	Not elevated in surface water, but elevated in groundwater.	Only if potential source for significant enrichment identified (*e.g*. from regular monitoring of dewatering bores)
Alkalinity-total (as $CaCO_3$)	300	310	Elevated downstream of discharge outlet(s). Important to monitor hardness as it ameliorates toxicity of many metals. Alkalinity buffers waters against large fluctuations in pH. Increasing levels are also often associated with NMD. Readily analysed with water hardness.	**Quarterly**
Barium (Ba)	0.054	0.02	Elevated in surface water downstream of discharge outlet(s). Naturally elevated in surface water at some reference sites.	**Quarterly**
Boron (B)	0.37	0.37	Elevated in surface water downstream of discharge outlet(s). Naturally elevated in surface water at some reference sites.	**Quarterly**
Calcium (Ca)	53	57	Elevated in surface water downstream of discharge outlet(s). No ANZECC TV, but is important as it can have an ameliorating effect on metal toxicity. May be indicative of carbonate precipitate and bed armouring.	**Quarterly**
Carbonate (CO_3)	1	1	Elevated in surface water downstream of discharge outlet. No ANZECC TV, but is important as it can have an ameliorating effect on metal toxicity. May be indicative of carbonate precipitate and bed armouring.	**Quarterly**
Copper (Cu)	0.0014	0.0014	Not elevated in surface water. Occasional exceedances in groundwater may be sampling artefact. Requires further investigation.	Only if potential source for significant enrichment identified (*e.g*. from regular monitoring of dewatering bores)
Electrical Conductivity µS/cm (EC)	1010	880	Elevated in surface water downstream of discharge outlet(s). EC can be used as a surrogate for monitoring some major ions (*i.e*. K, Na, Cl, HCO_3). Important indicator of potential osmotic stress in aquatic fauna.	**Quarterly**
Hardness (as mg/L $CaCO_3$)	344	370	Elevated in surface water downstream of discharge outlet(s). Is important to monitor hardness as it ameliorates toxicity of many metals and can be used to adjust SSTVs. Also an indicator of NMD. Readily analysed with alkalinity.	**Quarterly**
Iron (Fe)	0.3	0.3	ANZECC state the default TV for iron is interim only as there is insufficient data on its toxicity. Occasionally elevated in surface water and enriched in ground-water.	**Quarterly**
Manganese (Mn)	1.9	1.9	Not elevated in surface water but elevated in groundwater.	Only if potential source for significant enrichment identified (*e.g*. from regular monitoring of dewatering bores)

Nitrate (NO_3)	11	11	Elevated in surface water downstream of discharge outlet(s). SSTV is to protect against direct toxicity effects. The concentration of NO_3 can be calculated from N-NO_3 and *vice versa* (see N-NO_3 below). Will also be captured in monitoring N-NO_3.	**Quarterly**
Nitrate-nitrogen (N-NO_3)	2.5	2.5	Elevated in surface water downstream of discharge outlet(s). To compare against the TV for nitrate (NO_3) as a toxicant (see above), multiply nitrate-nitrogen (N-NO_3) by 4.43.	**Quarterly**
N_NOx (eutrophication TV)	1.16	0.16	ANZECC only provide a TV for N-NOx (0.03 mg/L), which is the sum of N-NO_3 and N-NO_2 and is designed to protect against eutrophication. In Yandi surface and groundwaters, N-NO_3 constitutes most of the nitrogen present.	**Quarterly**
pH	6 - 8.5	6 - 8.5	Current levels in surface and groundwater well within SSTVs. Must be measured in the field using regularly calibrated field meters. Will be captured as part of aquatic fauna monitoring, but should be regularly monitored if AMD or NMD is potentially an issue.	**Quarterly**
Phosphorus-total (P-total)	0.02	0.02	Occasionally elevated downstream of discharge outlet(s). SSTV designed to protect against eutrophication.	**Quarterly**
Selenium (Se-total)	0.011	0.011	Not currently elevated downstream of discharge outlet(s). No ANZECC TV, but is important to monitor as increasing levels are often associated with NMD (neutral mine drainage). Se can also bioaccumulate through aquatic food chains.	Only if potential source for significant enrichment identified (*e.g*. from regular monitoring of dewatering bores)
Silicon (SiO_2)	50	30	Not currently elevated in surface water or ground-water. No ANZECC TV. Can have ameliorating effect on toxicity of Al. Often enriched in groundwaters due to weathering of minerals.	Only if potential source for significant enrichment identified (*e.g*. from regular monitoring of dewatering bores)
Sulphate (SO_4)	60	56	Elevated in surface water downstream of discharge outlet(s). No ANZECC TV, but is important to monitor (as either SO_4 or S-SO_4), as increasing levels are often associated with AMD or NMD.	**Quarterly**
Temperature	28	28	Biannual aquatic ecosystem monitoring indicated significant increase in temperature over time in lower Marillana Creek. May become elevated above SSTV as mining progresses further below water table. Must be measured in the field with regularly calibrated meters.	**Quarterly**
Total Dissolved Solids (TDS)	560	500	Elevated in surface water downstream of discharge outlet(s). Important to monitor as provides an indication of change in total concentration of major ions (*e.g*. Ca, K, Mg, Na, Cl, HCO_3, SO_4).	**Quarterly**
Total Suspended Solids (TSS)	5	5	Elevated in surface water downstream of discharge outlet(s). Provides an indication of turbidity and sediment loads; constant very high levels can smother / bury aquatic biota. Natural TSS in creeklines can be highly	**Quarterly**

			variable depending on seasonal rainfall runoff.	
Uranium (U)	0.002	0.002	Elevated in surface water downstream of discharge outlet(s). No ANZECC default TV as there is insufficient data on its toxicity. Important to monitor if only to demonstrate no effect on aquatic biota.	**Quarterly**
Vanadium (V)	0.005	0.005	Elevated in surface water downstream of discharge outlet(s). No ANZECC default TV as there is insufficient data on its toxicity. Important to monitor if only to demonstrate no effect on aquatic biota.	**Quarterly**