Section 16

Water Resources

16 Water Resources

16.1 Surface Water

The Project is located on a gently undulating bauxite plateau landform cut by a network of rivers and smaller creeks. The elevated bauxite plateau is fringed for most of the coastal margin by low cliffs and lateritic outcrop. A number of semi-perennial watercourses plus numerous smaller ephemeral creeks traverse the Project area and flow in a westerly direction eventually discharging into the Gulf of Carpentaria. The Project area is bound by the Hey and Embley Rivers to the north, the Ward River to the south, and the Gulf of Carpentaria to the west. There are large estuaries associated with the Hey, Embley and Ward Rivers.

The Watson River is located south of the southern boundary of ML7024 and, while part of the river's catchment is within ML7024, the proposed footprint of the Project is outside the catchment boundary of the Watson River. The Archer River, a declared Wild River, is located south of the Watson River catchment and is not affected by the Project. The Wenlock River is a declared Wild River with a large catchment well north of, and outside, the Project area. That catchment extends west–north-west across the Cape and the river discharges into the Gulf of Carpentaria north of Mapoon. The catchment boundaries of the main rivers surrounding the Project area are shown on **Figure 16-1**.

16.1.1 Surface Water Hydrology

Numerous catchments are located within the Project area. The northern part of the Project area contains Triluck Creek, Winda Winda Creek and a small part of the Hey River catchment. The Norman Creek catchment and the Ina Creek catchment are within the western-central portion of the Project area. The Ward River catchment encompasses the eastern and southern Project area and includes the following sub-catchments: Coconut Creek, Tappelbang Creek, Sandy Creek and Possum Creek.

The principal catchment boundaries in the Project area are shown in **Figure 16-2** and the associated catchment areas are presented in **Table 16-1**.

Table 16-1 Catchment Areas

Project Area Catchments	**Area (km^2)**
Embley River	1,000
Hey River	756
Triluck Creek	108
Winda Winda Creek	94
Norman Creek (all tributaries)	259
Ina Creek	65
Ward River (all tributaries)	668
• *Ward River sub-catchment*	187
• *Coconut Creek*	119
• *Tappelbang Creek*	127
• *Sandy Creek*	105
• *Possum Creek*	130
Adjacent Catchments	
Watson River	2,872
Archer River	13,820

Plans\SoE\2013\EIS Figure 16\Fig 16-01 Weipa Region Catchment Boundaries.wor

Rio Tinto Alcan

- Lease boundary
- Township
- River / Creek
- Road / track
- River catchment boundary
- DNRM stream gauging station

South of Embley Project

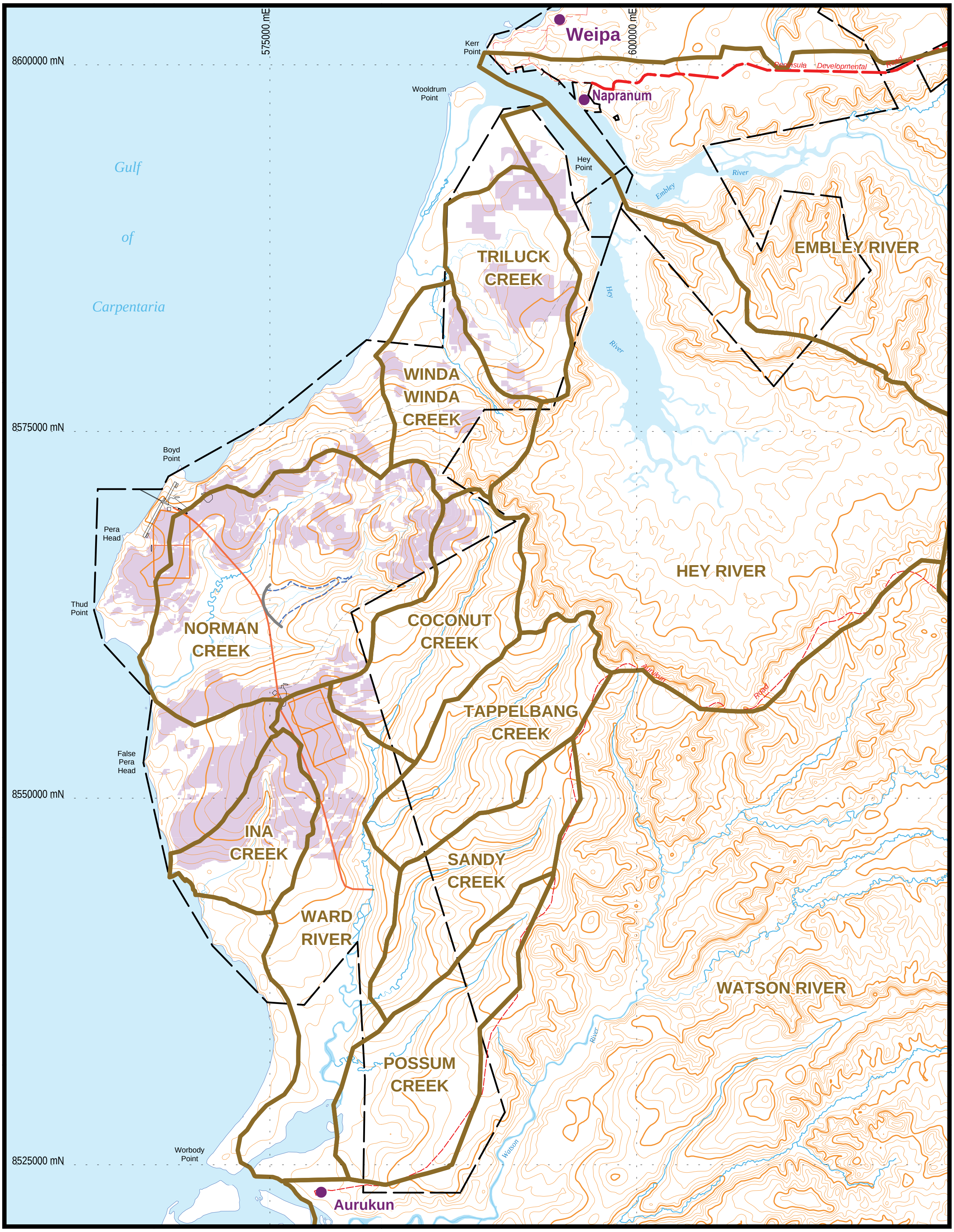
Fig. 16-1: Weipa Region Catchment Boundaries

N

0 50km

Datum/Projection: GDA94/MGA Zone 54

Date: 26/02/2013



Lease boundary
Township
Road/track
5m topographic contour
Drainage
Catchment boundaries
40 Year Mine Plan

South of Embley Project

Fig. 16-2: Project Area Catchment Boundaries

N

0 10km

Datum/Projection: GDA94/MGA Zone 54 Date: 26/07/2012

The Watson River drains a relatively small area in the southern extremity of ML7024. The Embley River catchment is located north of the Project area and is partially within ML7024 (see **Figure 16-1**).

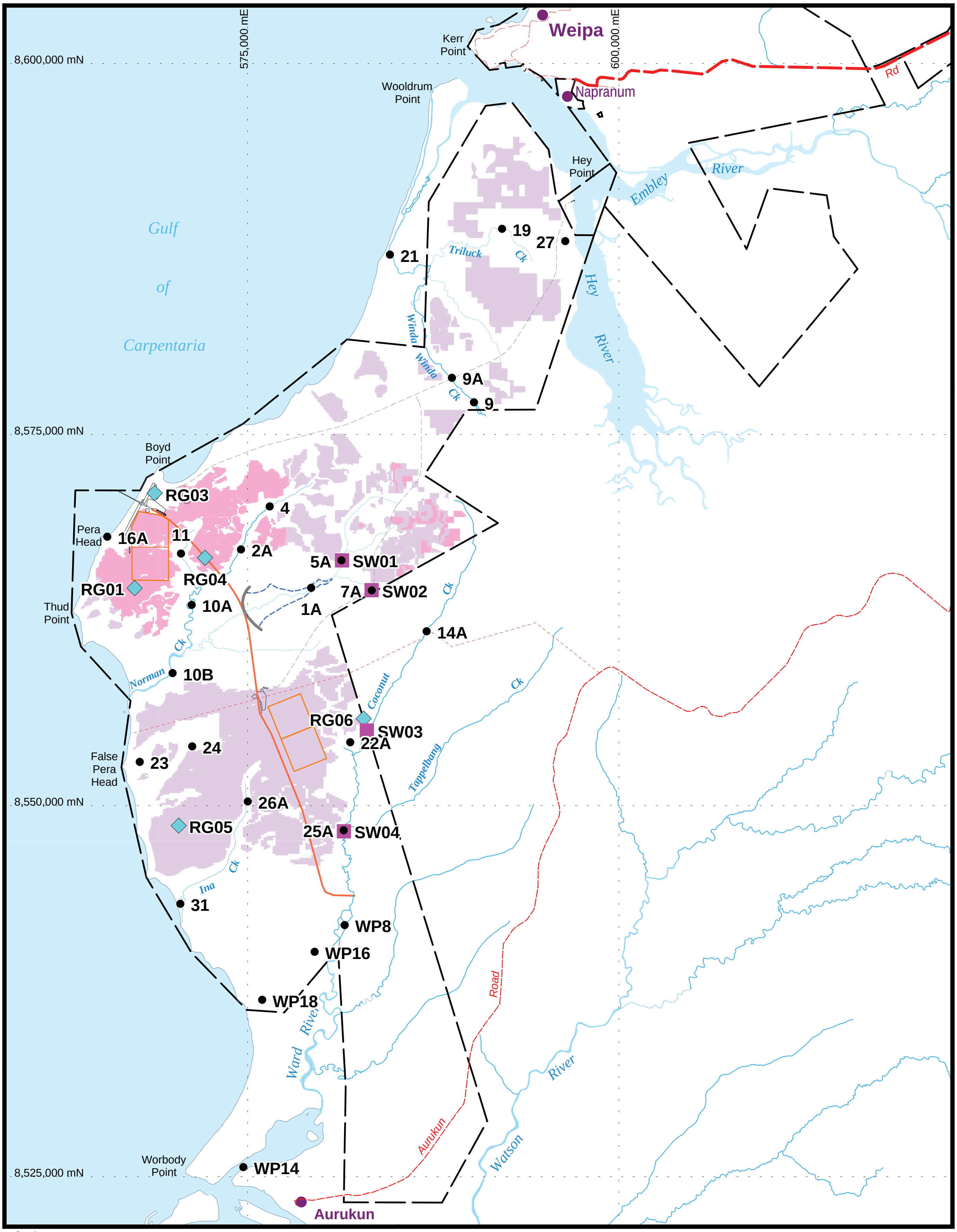
The drainage patterns of the catchments in the Project area are dendritic (tree-like). These catchments are typified by confluences with one or more tributaries that join larger reaches at acute angles, which give way to broader flood plains downstream.

The characteristics of the creeks (including length, source and habitat) with catchments predominantly within the Project area are summarised in **Table 16-2**. Details of the stream geomorphology of Norman, Winda Winda, Triluck, Ina and Coconut Creeks and the Ward River, are presented in RTA (2011).

Table 16-2 Project Area Creek Characteristics

Creek	Approx. length (km)	Sampling Locations	Source	Habitat	Part of larger system?
Winda Winda Creek	13.8	9, 9A	Seasonal groundwater fed reaches with some isolated perennial pools (9)	Supports perennial pools /lagoons	Winda Winda Creek flows into Triluck Creek which discharges into the mouth of the Embley River estuary.
Triluck Creek	14.0	19, 21	Seasonal groundwater fed reaches with some isolated perennial pools (19)	Supports perennial pools /lagoons lower reaches (21) are tidal	Winda Winda Creek joins two branches of Triluck Creek which discharges into the mouth of the Embley River estuary.
Norman Creek	27.1	1A, 2A, 4, 5A, 7A, 10A, 10B, 11	Perennial stream with some seasonal/semi-perennial stream channels (4, 2A) and perennial groundwater fed reaches (7A)	Supports pools, lagoons and tree swamps (11) and lower reaches (10A and 10B) are tidal	Norman Creek has three main branches which join and discharge into the Gulf of Carpentaria.
Ina Creek	12.9	26, 31	Seasonal stream channel with isolated perennial pools	Supports perennial pools (26) and is tidally influenced at lower reaches (31)	Isolated. Discharges into the Gulf of Carpentaria.
Ward River	42.1	25A, WP8, WP16	Combination of seasonal surface flow and perennial groundwater fed reaches	Supports pools and tree swamp (WP16) and is tidally influenced at lower reaches (WP8, WP14)	Coconut Creek joins with Tappelbang Creek and becomes Ward River. Sandy Creek and Possum Creek enter downstream. Ward River estuary links to larger Watson and Archer estuary system.
Coconut Creek	21.2	14A, 22A	Seasonal stream channel	Supports tree swamp (22A), not tidally influenced	Coconut Creek is a tributary of Ward River which discharges into the Gulf of Carpentaria.

A network of stream gauging stations and rain gauges were installed in the Project area (refer **Figure 16-3**). The stream gauging stations were installed in October 2007. Stations SW02 and SW03 use Level Troll 500 pressure transducer sensors and Stations SW01 and SW03 use Argonaut SW Acoustic Doppler sensors. The five rain gauges were installed for various periods throughout the Project area, starting in 2006. The response of streamflow to rainfall at four gauging stations (SW01, SW02, SW03, and SW04) is shown in **Figure 16-4**.



RTA Mining Lease boundary

Road/track

Town

Surface water quality sampling sites

Stream Gauge (with data logger)

Rain Gauge

Mining Years 1 -13

Mining Years 14 - 40

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South of Embley Project

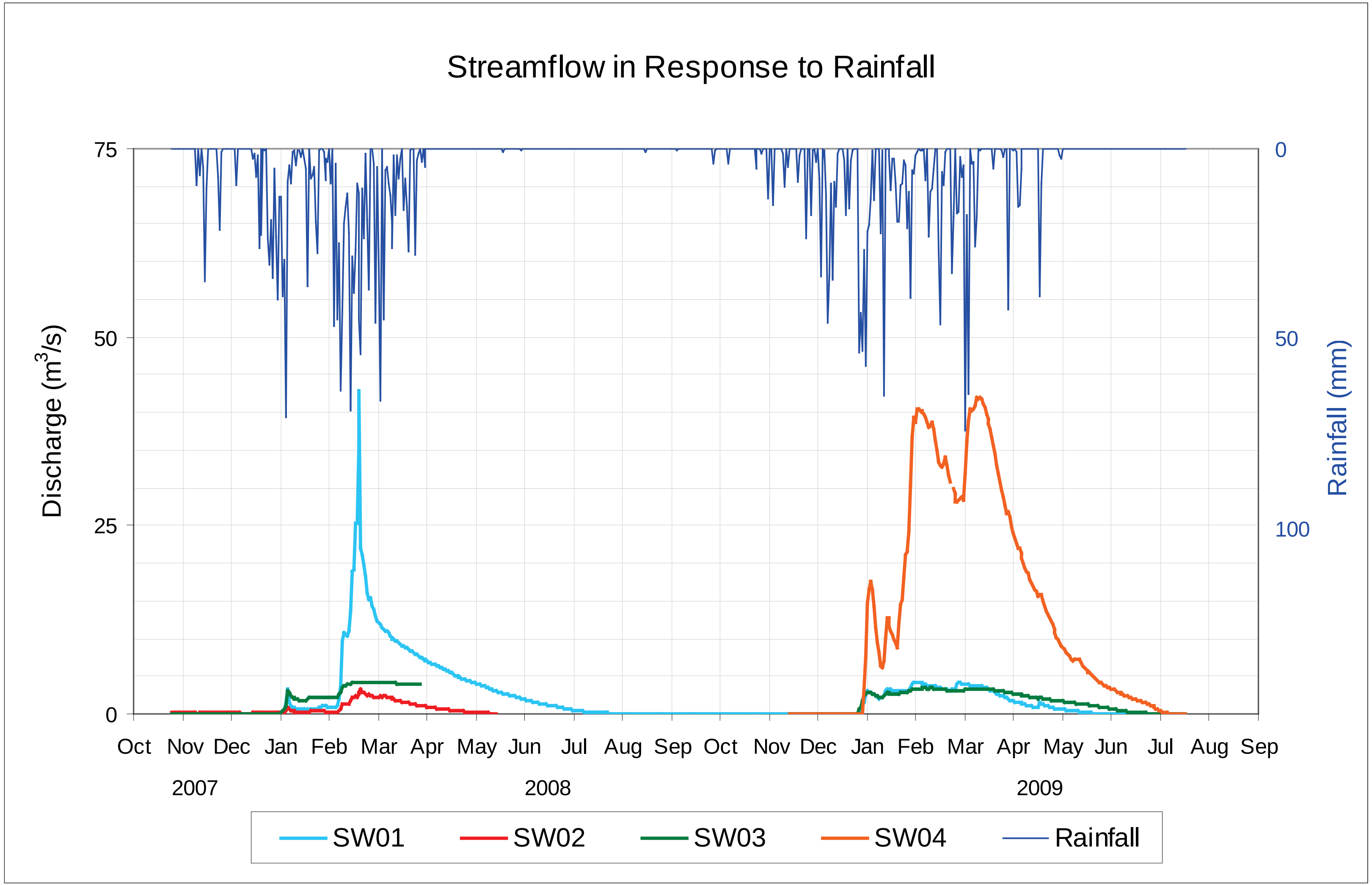
Fig. 16-3: Surface Water Monitoring Locations

N

0 10km

Datum/Projection: GDA94/MGA Zone 54 Date: 26/07/2012

Figure 16-4 Streamflow in response to rainfall



Rainfall–runoff relationships were derived using Boughton's Australian Water Balance Model (AWBM) (CRC for Catchment Hydrology undated). AWBM is a catchment water balance model that relates runoff to rainfall, based on a conceptualised representation of a catchment's temporary surface and baseflow stores, rainfall loss to evaporation and gradual release of water from both stores to streamflow at the catchment outlet. The sum of water released from surface and baseflow stores provides an estimate of daily runoff (Boughton 1993).

The model was calibrated to establish representative model parameters to use for predictive model simulations of streamflow. The model parameters are catchment specific and it is therefore necessary to calibrate to gauged streams in close proximity to the Project area where possible.

The AWBM has been calibrated at two streamflow gauging stations:

- SW01 (upstream of proposed Dam C on a Norman Creek tributary); and,
- SW04 (on the Ward River).

The input data for calibration included:

- catchment area;
- rainfall;
- runoff (streamflow); and,
- evapotranspiration.

The catchment area reporting to SW01 is 33.02km^2 and to SW04 is 281.73km^2. Local rainfall data recorded at RG04 was used for the calibration of AWBM at SW01 and at RG06 for the calibration at SW04. Data gaps in rain gauge records were filled at RG04 with data from RG06 and at RG06 from RG05.

Streamflow data was recorded by Argonaut SW Acoustic Dopplers (Dopplers) located at SW01 and SW04. Evapotranspiration data was obtained from SILO data drill (BoM 2009). Data drill is gridded interpolated data from point observations provided by the Bureau of Meteorology (BoM).

The calibration procedure is undertaken to determine the model parameters that provide the best fit of "modelled" to "measured" streamflow in terms of runoff from the surface and recession curve (baseflow) components, and the overall total flow volume.

The following calibration parameters are identified by the model:

- C1, C2 and C3 (surface storage capacities);
- A1, A2 and A3 (partial areas of surface stores);
- Ks (surface recession constant) – the rate of discharge of water from the surface store;
- BFI (baseflow index) – the amount of runoff that becomes baseflow; and,
- Kb (baseflow recession constant) – the rate of discharge of water from the baseflow store.

An initial visual assessment of the runoff hydrograph showed the falling limb (representative of baseflow) meets the zero flow axis at a greater angle than is typically the case. The falling limb typically asymptotes to a point of lowest flow (or zero flow). It was concluded that a proportion of baseflow continues below the invert of the stream channel and the actual asymptote of the falling limb occurs at a point approximately 0.5mm/day (d) below the axis of the hydrograph. This value of up to 0.5mm/day has been concluded to be representative of "deep baseflow" (baseflow that does not enter the stream at the flow measurement point) and is included as part of the calibration. The AWBM calibration parameters are shown in **Table 16-3**.

Table 16-3 AWBM Calibration Parameters

Calibration Parameter	Value
A1	0.134
A2	0.433
C1	0
C2	0
C3	260
Ks	0.1
BFI	0.99
Kb	0.979

The AWBM was used to estimate the annual partitioning of incident rainfall into the following components:

- evapotranspiration (evaporation and water vapour from vegetation);
- surface runoff (water that does not infiltrate);
- baseflow (water that infiltrates and moves as saturated flow to the stream); and,
- deep baseflow (water that infiltrates and moves as saturated flow below the stream bed).

Deep baseflow may emerge as streamflow at a lower point in the catchment, or may emerge as a freshwater upwelling in estuaries or off the coast in the Gulf of Carpentaria. A small proportion may become recharge to a deeper aquifer.

The partitioning of the annual incident rainfall from the 5 rain gauges in the Project area (1,741mm) is shown in **Table 16-4**. Annual average rainfall is similar (1,769mm at Eastern Avenue station) and Aurukun (1,647mm). The Western Cape region has a moderate inter-annual variability in rainfall and hence runoff and recharge. Coefficients of variation are relatively low compared to the other regions across northern Australia. The CSIRO (2009) estimates that, under a median future climate change scenario, future flows are expected to be similar to historical levels; hence little change is expected in the high and low flows. The annual average potential evaporation rate for the Project area is 2,289mm (BoM 2009).

Table 16-4 Partitioning of Annual Rainfall

Component	Annual Incident Rainfall	
	mm	%
Evapotranspiration	735	42.6
Surface runoff	10	0.6
Baseflow	843	48.0
Deep baseflow/recharge	153	8.8
Total	1741	100.0

The annual evapotranspiration rate is 32.1% of annual potential evaporation, which is comparable to the rate found by Hutley *et al.* (2000) and Vardavas (1988) for other tropical savannah woodlands in northern Australia.

The proportion of surface runoff (<1%) is unusually small and reflects the flat topography and the very high infiltration rates of the soils and lateritic strata. The consequence of this is that streamflow does not respond quickly to incident runoff until after the catchment is "wetted up" and there is no "first flush" response to rainfall at the start of the wet season. Wet season rainfall typically commences in November but it is usually not until January, after soil moisture stores are filled, that streams show appreciable flow. Thereafter, flows rise until March or April in response to wet season rainfall and then decline once rainfall ceases (refer **Figure 16-4**). In lower catchment locations within the Project area, flow may persist until late in the dry season.

In typical "hard" ephemeral catchments there are short-term spikes in stream-flow volume following rainfall events. The response of streams on the bauxite plateau to rainfall is much more modulated given that the baseflow component is so dominant and the direct surface runoff component is usually very small. The low surface runoff component also means streams carry a low concentration of suspended solids, even during high flows (refer **Section 16.1.3** for further discussion on turbidity).

The stream gauge data from Norman Creek (SW01) and the Ward River (SW04) was analysed to determine the Average Recurrence Interval (ARI) of "bank full" flow. Once bank full flow is exceeded, over bank flow occurs and any adjacent floodplains and wetlands are inundated. The timing and frequency of bank full flows may have significant ecological implications. The AWBM was used to generate synthetic streamflow records from SILO rainfall records. The bank full flow at the Norman Creek site (4.5 cubic metres per second (m^3/s)) was found to have an average recurrence interval (ARI) of 1:2.5 and the bank full flow at the Ward River site ($30.5m^3/s$) had an ARI of 1:1.5. The 1:100 ARI flood event flows for these respective sites are $7.4m^3/s$ and $65m^3/s$. The relatively small increment in flow rate between bank full flow and a 1:100 year flood reflects the relatively minor contribution of direct surface to flow. The streamflow data indicates that adjacent floodplains and wetlands are inundated almost every year and the ecology of these areas is not dependent on extreme flood events. The streamflow information has been used to evaluate the potential impact of a water storage dam on the hydrological regime (refer **Section 16.2.3**).

16.1.2 Existing Surface Water Users

There are no existing surface water dams or weirs in the Project area. The surface waters of the Project area are used by Traditional Owners and visitors for fishing, camping and recreation. RTA uses very small amounts of surface water during mineral exploration activities. There are no cattle farms in the Project area.

16.1.3 Surface Water Quality

This section describes existing surface water quality conditions both upstream, downstream and within the Project area. Where applicable, results are compared with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

A total of 25 locations within different catchments and habitat types were sampled over multiple seasons. The spatial and seasonal variation in sampling was designed to account for the variation in wet and dry season climatic conditions that influence surface water in the Project area. The locations of the sampling sites are shown in **Figure 16-3**.

Four rounds of sampling were initially undertaken for the EIS:

- mid dry season between 30 August and 1 September 2007 (10 locations);
- late dry season between 26 and 30 November 2007 (12 locations);
- wet season between 26 February and 3 March 2008 (19 locations); and,
- early dry season between 22 and 25 May 2008 (19 locations).

After these sampling rounds, a second water supply dam in the Ward River catchment was proposed (this option has not been pursued however). Three additional rounds of sampling were then undertaken in the Ward River and elsewhere:

- late dry season between 4 and 11 December 2008 (12 locations);
- wet season between 24 February and 3 March 2009 including the additional Ward catchment sites (22 locations); and,
- early dry season on 18 and 19 May 2009 (five locations; Ward only).

The category and catchment of each sampling location are summarised in **Table 16-5**.

Table 16-5 Sampling Location by Category and Catchment

Category	Catchment	Locations
Freshwater	Norman Creek	1A, 2A, 4, 5A, 7A
	Triluck Creek	9, 9A, 19
	Ward River	14A, 25A
	Ina Creek	26, 31
	Norman Creek	11, 24
Tree swamps	Ward River	WP16, WP18, 22
	Hey River	27
	Norman Creek	23
Estuarine	Ward River	WP8
	Norman Creek	10A, 10B, 21
Lagoon (back dune)	Norman Creek	16A
Marine	Ward River	WP05

Representative habitat types were sampled at multiple locations in the main catchments. The characteristics of sampling locations are summarised in **Table 16-6**.

At each site, physicochemical conditions were measured using a multi-parameter water quality meter and water samples were collected for laboratory analysis. Sampling was conducted in accordance with the Queensland EPA Water Quality Sampling Manual (EPA 1999), except where noted below. Samples were analysed for physiochemical parameters, cations, anions, nutrients and a suite of total and dissolved metals. Select samples were also analysed for hydrocarbons.

Table 16-6 Sampling Location, Habitat and Catchment

Sampling Location	Habitat type	Catchment
1A	Perennial channel hosted pools/lagoons	Norman Creek (eastern tributary)
2A	Semi-perennial stream (flowing)	Norman Creek (northern tributary)
4	Seasonal stream channel (flowing)	Norman Creek (northern tributary)
5A	Perennial stream (flowing)	Norman Creek (eastern tributary)
7A	Perennial stream (flowing)	Norman Creek (eastern tributary)
9	Seasonal stream channel (flowing)	Winda Winda Creek
9A	Perennial channel hosted pools/lagoons	Winda Winda Creek
10A	Estuary (tidal)	Norman Creek
10B	Estuary (tidal)	Norman Creek
11	Seasonal tree swamp with perennial stream (flowing)	Norman Creek (northern tributary)
14A	Seasonal stream channel (flowing)	Coconut Creek
16A	Semi-perennial coastal lakes/lagoons (pool)	Pera Head Backdune lagoon
19	Seasonal stream channel (flowing)	Triluck Creek
21	Estuary (tidal)	Winda Winda Triluck Creek
22	Seasonal tree swamp (pool with seasonal flowing spring)	Coconut Creek / Ward River
23	Seasonal tree swamp (pool)	East of False Pera Head
24	Seasonal stream channel (flowing)	Un-named drainage False Pera Head
25A	Seasonal stream with perennial channel hosted pools (tidally influenced in dry season)	Ward River downstream of Coconut and Tapplebang Creek confluence
26	Seasonal stream with semi-perennial channel hosted pools	Ina Creek
27	Seasonal tree swamp (pool)	Hey River
WP8	Estuary (tidal)	Ward River
WP14	Estuary (tidal)	Ward River
WP16	Seasonal tree swamp (pool)	Ward River
WP18	Seasonal tree swamp (pool)	Ward River

For the analysis of metals, other than calcium, magnesium, potassium and sodium, field and laboratory procedures were modified to achieve ultra trace levels (below 1µg/L). Ultra trace levels were sought because the default low reliability trigger value of ANZECC/ARMCANZ (2000) for aluminium in freshwaters with pH below 6.5 is less than commercial laboratory detection limits. The CSIRO Centre for Environmental Contaminants Research (CECR) laboratory at Lucas Heights, NSW, was contracted to undertake the trace metals analyses, with other parameters subcontracted to the National Measurement Institute (NMI) in Sydney. CECR prepared all sampling and sample filtration equipment for the Project, and shipped them to Weipa.

It was recognised that the EIS field and laboratory procedures are not feasible for long-term data collection and thus duplicate samples were collected in May 2009 for analyses by a commercial laboratory (ALS Environmental, a NATA-accredited laboratory) and commercial low-level detection limits were requested.

Results

Field and laboratory results are summarised in **Table 16-7** to **Table 16-9** by surface water category: freshwater streams, freshwater tree swamps and estuarine/marine, respectively. In general, freshwater stream locations (refer **Table 16-7**) were flowing at the time of sampling but this group contains some samples from pools (26A, 9A, 1A, 11 and 25A) whereas tree swamps (refer **Table 16-8**) represent stagnant water.

The 20th and 80th percentiles of measured parameters were calculated for categories with more than five data points and these are presented along with the median (50th percentile) value.

The *Environmental Protection (Water) Policy 2009* (Qld) (EPP (Water)) consists of a framework that identifies environmental values (EVs) and water quality objectives (WQOs) to enhance or protect EVs. However, WQO's have not yet been established for the Cape York region. Therefore, in conformity with the Queensland Water Quality Guidelines (DERM 2009a), the national guidelines (ANZECC) described below have been used for comparison purposes.

The results are discussed below and are compared with:

- Local data – other habitat categories in the Project area;
- Regional data – northern Australian tropical waters; and,
- National guidelines – Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

The following data from northern Australian tropical waters has been summarised in **Table 16-10**.

- metal concentration data from a reference stream in the Gove bauxite deposit area and general parameter data from the wider Gove area (RTA data and Zaar *et al.* 1999);
- streams from baseline sampling in the Ely bauxite deposit area, north of Weipa (RTA data);
- post- first flush wet season flows in Magela Creek in the Alligator Rivers Region in the Northern Territory (data from Hart *et al.* 1987);
- rivers in the southern Gulf of Carpentaria and the Mitchell River, southern Cape York Peninsula (Hydrobiology 2004); and,
- Mary River catchment, Northern Territory (Shultz *et al.* 2002).

ANZECC/ARMCANZ (2000) proposes water quality guidelines designed to protect the EVs of aquatic ecosystems. The guidelines are not mandatory standards; rather, they provide a risk-based decision framework, wherever possible, to enable the development of guideline trigger values for application at local and/or regional scales. The guidelines provide default water quality trigger values and a process to derive guideline trigger values tailored to the local environment, where required.

In cases where baseline water quality parameters exceed default trigger values, it is recommended that local or regional trigger values are derived based on a statistical analysis of the baseline dataset. In some instances, default guidelines have not been developed due to data deficiencies and low reliability or interim working levels have been proposed for comparative purposes.

Table 16-7 Freshwater Stream Water Quality

	Parameter	units	Min	Max	Mean	Median	20th percent	80th percent	n	ANZECC Freshwater 95%	Commercial laboratory LOR*
Field	pH-fld	pH	4.0	6.9	5.3	5.4	4.6	5.8	44	6-8	
	EC	uS/cm	12	91	26	21	18	30	56	20-250	
	ORP	mV	-21.5	252	128	148	41.6	211	45		
	Turb	NTU	0.1	930	19	1.4	0.4	4.2	58	2-15	
	Temperature	°C	23.2	41.0	28.2	28.1	26.6	29.6	58		
	DOpc	% saturation	31.5	105	78.2	79.1	74.3	87.0	17	85-120	
	DO	mg/L	0.6	7.8	5.1	5.6	4.2	6.4	48		
Cations / Anions / Nutrients	Ca-F	mg/L	0.005	1.6	0.1	0.06	0.03	0.15	56		
	Mg-F	mg/L	0.09	1.6	0.4	0.3	0.2	0.4	56		
	Hard	mg CaCO3/L	0.4	9	1.9	1.3	0.82	2.0	56		
	Si-F	ug/L	1.1	3200	592	135	9.0	892	18		
	K-F	mg/L	0.003	1.2	0.09	0.03	0.03	0.03	56		
	Na-F	mg/L	0.6	8.8	3	2.4	1.5	3.2	56		
	Cl	mg/L	2.8	33	6	4.2	3.3	6.4	56		
	Alkalinity	pH	3	10	3.3	2.5	2.5	2.5	57		
	Total phosphorus	mg/L	0.01	0.06	0.03	0.03	0.03	0.03	27	0.01[a]	
	NH4-N	mg/L	0.003	0.45	0.02	0.003	0.003	0.01	48	0.01[a]	
	Total nitrogen as N	mg/L	0.03	1.1	0.10	0.03	0.03	0.09	49	0.2-0.3[a]	
	NOx	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	49	0.01[a]	
	TDS	mg/L	9	280	21	13	10	20	56		
	TOC	mg/L	2	11	3.8	3	2	8.8	7		
	DOC	mg/L	0.5	10	1.8	1	0.5	2.4	19		
	SO4	mg/L	0.05	6.5	1	0.1	0.05	3.7	56		
Metals	Al-F	ug/L	0.1	668	40	18	6.2	40	57	55[b]	5
	Al-T	ug/L	19	1820	169	68	29	140	57	55[b]	5
	Fe-F	ug/L	2	553	46	11	5	65	57	300[c]	50
	Fe-T	ug/L	5	4940	276	36	10	179	57	300[c]	50
	Cr-F	ug/L	0.005	0.56	0.06	0.03	0.02	0.08	57	1[d]	1
	Cr-T	ug/L	0.005	0.47	0.09	0.05	0.02	0.13	57	1[d]	1
	Mn-F	ug/L	0.02	80	3.9	0.94	0.33	2.55	57	1900	1
	Mn-T	ug/L	0.1	213	7.6	1.03	0.49	2.80	57	1900	1
	Ni-F	ug/L	0.005	0.28	0.04	0.02	0.01	0.06	57	11[e]	1
	Ni-T	ug/L	0.001	0.48	0.06	0.02	0.01	0.08	57	11	1
	Cu-F	ug/L	0.003	0.39	0.03	0.01	0.01	0.03	57	1.4[f]	1
	Cu-T	ug/L	0.003	1.92	0.09	0.02	0.01	0.13	57	1.4	1
	Zn-F	ug/L	0.004	7.1	0.61	0.08	0.03	0.38	57	8[g]	5
	Zn-T	ug/L	0.005	3.1	0.22	0.04	0.01	0.21	57	8	5
	As-F	ug/L	0.005	0.44	0.06	0.03	0.02	0.05	57	13[h]	1
	As-T	ug/L	0.003	0.43	0.06	0.03	0.02	0.06	57	13[h]	1
	Cd-F	ug/L	0.0002	0.02	0.003	0.002	0.001	0.003	56	0.2[i]	0.1
	Cd-T	ug/L	0.0002	0.09	0.005	0.002	0.001	0.003	56	0.2	0.1
	Pb-F	ug/L	0.001	0.65	0.05	0.02	0.01	0.05	56	3.4[j]	1
	Pb-T	ug/L	0.005	1.03	0.10	0.05	0.03	0.13	56	3.4	1

Notes:

*: LOR maybe elevated if matrix interference (e.g. salts) in sample
[a]: ANZECC Default trigger values for Tropical Australian Lowland Rivers
[b]: Note: 0.8 for low reliability working level , pH<6.5,
[c]: interim working level
[d]: assumes all as Cr(VI), hardness modified value 0.078
[e]: hardness modified value 0.783
[f]: hardness modified value 0.10
[g]: hardness modified value 0.57
[h]: assumes all As(V)
[i]: hardness modified value 0.013
[j]: hardness modified value 0.066

Table 16-8 Freshwater Tree Swamp Water Quality

	Parameter	units	Min	Max	Mean	Median	20th percent	80th percent	n	ANZECC Freshwater 95%	Commercial laboratory LOR*
Field	pH-fld	pH	4.2	6.6	5.1	4.9	4.6	5.5	11	6-8	
	EC	uS/cm	15	136	43	26	22	29	12	20-250	
	ORP	mV	52	331	147	84	61	248	9		
	Turb	NTU	0.1	3.7	1.6	1.1	0.3	3.4	11	2-15	
	Temperature	°C	23.9	34.5	28.7	28.4	26.8	30.1	13		
	DOpc	% saturation	52	78	52	25	16	61	14	85-120	
	DO	mg/L	1.3	6.0	3.4	3.1	2.3	4.6	10		
Cations/ Anions/N utrients	Ca-F	mg/L	0.008	0.60	0.15	0.07	0.02	0.17	12		
	Mg-F	mg/L	0.08	2.0	0.55	0.30	0.27	0.46	12		
	Hard	mg CaCO3/L	0.36	9.7	2.6	1.4	1.2	2.3	12		
	Si-F	ug/L	46	3700	835	350	106	838	7		
	K-F	mg/L	0.03	0.36	0.09	0.03	0.03	0.13	12		
	Na-F	mg/L	0.55	16	4.6	3.4	1.9	3.8	12		
	Cl	mg/L	2.8	29	8.3	4.9	3.4	5.4	12		
	Alkalinity	pH	2.5	8.0	3.0	2.5	2.5	3	12		
	Total phosphorus	mg/L	0.03	0.025	0.03	0.03	0.03	0.03	7	0.01[a]	
	NH4-N	mg/L	0.003	0.02	0.01	0.003	0.003	0.01	12	0.01[a]	
	Total nitrogen as N	mg/L	0.03	0.41	0.1	0.03	0.03	0.23	12	0.2-0.3[a]	
	NOx	mg/L	0.01	0.005	0.01	0.01	0.01	0.01	12	0.01[a]	
	TDS	mg/L	10	3640	322	16	13	23	12		
	TOC	mg/L	NA	NA	NA	NA	NA	NA	NA		
	DOC	mg/L	0.5	10	3.7	2.5	1	6.2	8		
	SO4	mg/L	0.05	11	1.5	0.2	0.05	0.4	11		
Metals	Al-F	ug/L	3.0	108	44.7	40.5	19.7	73.1	12	55[b]	5
	Al-T	ug/L	13.0	189	84.5	72.6	37.7	135	12	55[b]	5
	Fe-F	ug/L	0.05	1920	251	11.5	2.4	32.2	12	300[c]	50
	Fe-T	ug/L	2.0	2450	334	12.5	7.8	32.7	12	300[c]	50
	Cr-F	ug/L	0.01	0.24	0.06	0.02	0.01	0.10	12	1[d]	1
	Cr-T	ug/L	0.01	0.29	0.1	0.03	0.015	0.12	12	1[d]	1
	Mn-F	ug/L	0.01	7.3	1.4	0.36	0.16	1.9	12	1900	1
	Mn-T	ug/L	0.01	7.1	1.4	0.47	0.18	2.0	12	1900	1
	Ni-F	ug/L	0.01	0.26	0.1	0.03	0.02	0.06	12	11[e]	1
	Ni-T	ug/L	0.01	0.27	0.1	0.04	0.02	0.05	12	11	1
	Cu-F	ug/L	0.005	0.11	0.02	0.01	0.01	0.02	10	1.4[f]	1
	Cu-T	ug/L	0.005	0.14	0.03	0.01	0.01	0.03	11	1.4	1
	Zn-F	ug/L	0.01	2.4	0.36	0.10	0.03	0.42	12	8[g]	5
	Zn-T	ug/L	0.01	2.3	0.4	0.14	0.03	0.57	12	8	5
	As-F	ug/L	0.01	0.44	0.08	0.03	0.02	0.06	12	13[h]	1
	As-T	ug/L	0.01	0.49	0.09	0.03	0.02	0.06	12	13[h]	1
	Cd-F	ug/L	0.0002	0.006	0.002	0.002	0.001	0.003	12	0.2[i]	0.1
	Cd-T	ug/L	0.0002	0.009	0.003	0.003	0.001	0.003	12	0.2	0.1
	Pb-F	ug/L	0.005	0.082	0.025	0.017	0.010	0.034	12	3.4[j]	1
	Pb-T	ug/L	0.013	0.059	0.034	0.038	0.015	0.049	12	3.4	1

Notes:

*: LOR may be elevated if matrix interference (e.g. salts) in sample

a: ANZECC Default trigger values for Tropical Australian Lowland Rivers

b: Note: 0.8 for low reliability working level , pH<6.5,

c: interim working level

d: assumes all as Cr(VI), hardness modified value 0.078

e: hardness modified value 0.783

NA: not analyzed

f: hardness modified value 0.10

g: hardness modified value 0.57

h: assumes all As(V)

i: hardness modified value 0.013

j: hardness modified value 0.066

Table 16-9 Estuarine and Marine Water Quality

	Parameter	units	Estuary (WP8, 10A, 10B, 21)							WP14 Ward River Marine							16A Pera Head Back dune Lagoon							ANZECC Marine 95%
			Min	Max	Mean	Median	20th percent	80th percent	n	Min	Max	Mean	Median	20th percent	80th percent	n	Min	Max	Mean	Median	20th percent	80th percent	n	
Field	pH-fd	pH	5.1	7.7	6.3	6.3	5.7	6.7	11	7.0	7.7	7.3	7.3	NA	NA	3	4.5	8.2	6.2	6.2	5.1	7.1	6	7-8.5
	EC	uS/cm	50	51592	16600	2100	430	45300	11	19000	53233	35478	34200	NA	NA	3	13	14412	2889	287	69	2266	6	
	ORP	mV	-104.1	366	79	69	-19	135	9	-32	322	110	41	NA	NA	3	-51.9	133	76.9	108	57.2	115	5	
	Turb	NTU	1.2	5	2.7	2.6	1.54	3.3	12	5.9	16.5	10.6	9.5	NA	NA	3	0.8	14	4.7	3.0	1.1	6.2	6	1-20
	Temperature	°C	25.1	32.2	28.6	28.6	26.4	31	11	29.4	30.2	29.8	29.9	NA	NA	3	22.4	42.9	30.5	29.6	26.6	31.6	6	
	DOpc	% saturation	46	83	65	60	56	79	5	64	109	85	82	NA	NA	3	64	118	91	91	NA	NA	2	80-120
	DO	mg/L	2.3	6.0	4.3	4.6	3.2	5.0	9	4.0	5.9	4.9	4.9	NA	NA	2	4.3	8.7	5.9	4.8	4.7	7.2	5	
	Ca-F	mg/L	0.19	450	119	14.6	2.08	328	12	96	410	239	210	NA	NA	3	0.2	160	45	6.3	0.39	98	6	
	Mg-F	mg/L	0.72	1390	376	49	6.4	1050	12	300	1310	750	640	NA	NA	3	0.78	340	117	18.4	1.5	320	6	
	Hard	mg CaCO3/L	3.4	6848	2156	238	24	6049	10	1475	6418	3684	3160	NA	NA	3	3.7	1800	676	9.0	6.5	1610	5	
	Si-F	ug/L	0.79	3500	1300	1150	2	2000	6	0.9	2600	1150	850	NA	NA	3	7.5	2600	1304	1304	NA	NA	2	
	K-F	mg/L	0.16	430	112	14.6	2.2	299	12	110	420	237	180	NA	NA	3	0.17	97	33	6.9	0.41	87	6	
	Na-F	mg/L	5.6	12700	3379	420	64.6	9502	12	2570	12100	6827	5810	NA	NA	3	7.7	2510	875	173	16	2370	6	
	Cl	mg/L	12	18000	5151	1100	142	12940	12	5100	20000	13367	15000	NA	NA	3	15	4200	1403	385	31	3400	6	
	Alkalinity	pH	2.5	96	26	15	3.2	33	12	3	110	51	40	NA	NA	3	10	24	15	12	10.6	17	4	
	Total phosphorus	mg/L	0.02	0.14	0.05	0.03	0.03	0.06	7	0.03	0.14	0.06	0.03	NA	NA	3	0.03	0.18	0.08	0.03	NA	NA	3	0.015[a]
	NH4-N	mg/L	0.003	0.04	0.008	0.003	0.003	0.013	11	0.003	0.03	0.02	0.03	NA	NA	3	0.003	1.8	0.36	0.003	0.003	0.37	5	0.001 -0.01[a]
	Total nitrogen as N	mg/L	0.06	0.72	0.22	0.17	0.14	0.22	9	0.12	0.26	0.18	0.15	NA	NA	3	0.025	4.8	1.2	0.18	0.025	1.6	5	0.1[a]
	NOx	mg/L	0.01	0.03	0.01	0.005	0.005	0.005	11	<0.01	<0.01	<0.01	<0.01	NA	NA	3	0.005	0.01	0.006	0.005	0.005	0.006	5	0.002-008[a]
	TOC	mg/L	3	5	4	4.00	NA	NA	2	4	4	4	4	NA	NA	1	52	52	52	52	NA	NA	1	
	DOC	mg/L	0.5	5	2.2	2.00	1.4	2.6	8	2	4	2.7	2	NA	NA	3	1	52	19	3	1.8	32.4	3	
	TDS	mg/L	33	32000	9495	2250	332	23000	12	9910	34000	21303	20000	NA	NA	3	44	8800	2940	860	77	7000	6	
	Al-F	ug/L	0.1	15	4.8	4	1.8	7.4	13	0.5	3	1.8	2	NA	NA	3	1.7	850	268	50.5	3.6	650	6	0.5[b]
	Al-T	ug/L	0.5	559	110	56	27	147	13	475	1980	1205	1160	NA	NA	3	12	68	29	21	12	40	6	0.5[b]
	Fe-F	ug/L	0.5	85	24	13	3.8	31	13	1	4	2	1	NA	NA	3	25	718	219	104	33	327	6	300[b]
	Fe-T	ug/L	0.5	742	267	218	174	409	13	279	1410	710	440	NA	NA	3	8.4	414	123	52.7	11.6	198	6	300[b]
	Cr-F	ug/L	0.005	0.1	0.05	0.02	0.02	0.09	11	0.04	0.25	0.18	0.25	NA	NA	3	0.015	0.28	0.13	0.12	0.03	0.21	6	4.4[c]
	Cr-T	ug/L	0.005	0.7	0.18	0.11	0.05	0.21	12	0.4	1	0.7	0.7	NA	NA	2	0.015	0.61	0.28	0.23	0.08	0.50	6	4.4[c]
	Mn-F	ug/L	0.005	8.7	3.3	2.5	1.5	4.1	11	2.2	2.2	2.2	2.2	NA	NA	1	0.29	42.6	11.1	2.3	0.33	19.1	6	80[b]
	Mn-T	ug/L	0.005	9.8	3.4	2.8	1.0	4.4	11	13	13	13	13	NA	NA	1	0.37	44.5	11.4	2.1	0.64	18.9	6	80[b]
	Ni-F	ug/L	0.005	0.47	0.11	0.05	0.02	0.16	11	0.22	0.24	0.23	0.23	NA	NA	2	0.01	1.06	0.27	0.03	0.01	0.48	6	70
	Ni-T	ug/L	0.01	0.43	0.14	0.09	0.03	0.23	12	0.34	0.69	0.52	0.52	NA	NA	2	0.01	0.98	0.32	0.06	0.02	0.81	6	70
	Cu-F	ug/L	0.005	0.19	0.06	0.01	0.005	0.11	11	0.12	0.19	0.16	0.16	NA	NA	2	0.01	0.43	0.13	0.06	0.03	0.23	6	1.3
	Cu-T	ug/L	0.005	0.2	0.09	0.08	0.01	0.15	12	0.19	0.36	0.28	0.28	NA	NA	2	0.01	0.99	0.25	0.12	0.02	0.26	6	1.3
	Zn-F	ug/L	0.015	3.4	0.72	0.5	0.04	0.65	11	0.09	0.23	0.16	0.16	NA	NA	2	0.04	6.49	1.36	0.25	0.15	0.96	6	15
	Zn-T	ug/L	0.015	1.2	0.40	0.33	0.06	0.66	12	0.33	0.93	0.63	0.63	NA	NA	2	0.04	6.33	1.65	0.27	0.04	2.98	6	15
	As-F	ug/L	0.01	0.49	0.17	0.12	0.03	0.26	11	NA	NA	NA	NA	NA	NA	0	0.02	4.86	1.02	0.19	0.04	0.83	6	4.5[bd]
	As-T	ug/L	0.01	0.52	0.25	0.19	0.06	0.42	11	NA	NA	NA	NA	NA	NA	0	0.03	5.3	1.13	0.21	0.07	0.95	6	4.5[bd]
	Cd-F	ug/L	0.002	0.03	0.01	0.004	0.003	0.01	10	0.007	0.008	0.008	0.008	NA	NA	2	0.002	0.09	0.02	0.003	0.002	0.02	6	5.5
	Cd-T	ug/L	0.003	0.04	0.01	0.004	0.003	0.01	11	0.01	0.02	0.02	0.02	NA	NA	2	0.002	0.06	0.01	0.002	0.002	0.005	6	5.5
	Pb-F	ug/L	0.002	0.08	0.02	0.009	0.003	0.03	9	0.004	0.11	0.06	0.06	NA	NA	2	0.01	0.14	0.05	0.03	0.02	0.07	6	4.4
	Pb-T	ug/L	0.002	0.15	0.06	0.05	0.04	0.09	11	0.14	0.39	0.26	0.26	NA	NA	2	0.01	0.50	0.18	0.12	0.04	0.28	6	4.4

Notes:

[a]: ANZECC Default trigger values for tropical Australian marine waters

[b]: low reliability level

[c]: as Cr(VI)

[d]: as As(V)

NA: not analyzed/applicable

Table 16-10 Comparison of Fresh Water Quality in Tropical Streams

Location	South of Embley	Gove, NT	Ely, Qld.	Magela Creek, NT	Mitchell River, Qld.	Gregory River, Qld.	Nicholson River, Qld.	Mary River, NT
Reference	This project - all freshwater	RTA data and Zaar et al. 1999	RTA data	Hart et al. (1987)	Hydrobiology (2004)	Hydrobiology (2004)	Hydrobiology (2004)	Shultz et al. (2002)
Field Physico-Chemistry								
pH Field	4.0-6.9	5.4-7	4.5-6.6	4.8-6	6-9.6	6-9	6-9	6-8
EC (µS/cm)	12-136	9-390	3-11.8	5.4-50	36-400	55-700	33-700	12-342
Turbidity (NTU)	0.1-930		<0.1-4.7					0.7-40
Dissolved Oxygen (% saturation)	31.5-105		28-97					25-102
Dissolved Oxygen (mg/L)	0.55-7.8		3-7.9					2.2-8.8
Major Anions/Cations & Solids								
Ca filtered (mg/L)	0.005-1.6	1-144	<0.1-3.2	<0.1-1.8	0.7-53	5-104	1-34	
Mg filtered (mg/L)	0.08-2	0.5-1	0.2-10	0.2-2.7	0.1-12.3	2-58	1-54	
K filtered (mg/L)	0.003-1.2	0.7-2		0.2-1.1	0.5-5.4	0.3-6	1-9	
Na filtered (mg/L)	0.55-16	7-12		0.6-3.7	2-34	1-124	1-92	
Cl filtered (mg/L)	2.8-33			<1-9	0.78-34	1-165	2-165	
Hardness (mgCaCO3/L)	0.36-9.7	4-12	<1-3.6	~1.1-15.6	2-157	31-406	7-290	3.2-153
Alkalinity (mgCaCO3/L)	2.5-10	4-4.5			4.1-174	20-435	8-301	4-200
Silica (mg/L)	1.1-3700	3-29						
Sulphate (mg/L)	0.05-11	1-410		2-9	0.32-12.5	1-12	2-12	
Total Organic Carbon (mg/L)	2-4	1-5						
Nutrients								
Total Phosphorous (mg/L)	0.02-0.063	<2-3	<0.02	<0.01-0.03				0.001-0.036
Ammonium-N (mg/L)	0.003-0.45			<0.01				<0.01-0.04
Total Nitrogen (mg/L)	0.025-1.1	0.05-0.25	<0.05-0.18					<0.03-0.32
Oxides of Nitrogen (mg/L)	<0.01-0.01	0.2-2		<0.01-0.42	0.0005-141	0.2-11	0.4-2	
Metals								
Al filtered (µg/L)	3-668	<5-23						
Al total (µg/L)	13-1820							5-260
As filtered (µg/L)	0.005-0.44	<5-5						
As total (µg/L)	0.003-0.49		<1					
Cd total (µg/L)	0.0002-0.02		<0.1					
Cr total (µg/L)	0.005-0.47		<1-2	0.1-6				<1
Cu filtered (µg/L)	0.003-0.39			<0.2-1.2				
Cu total (µg/L)	0.0025-0.73		1-2					<1-12
Fe filtered (µg/L)	0.05-1920	50-420		34-2600				
Fe total (µg/L)	2-4940			110-3900				44-1200
Mn filtered (µg/L)	0.01-79.5			2-8				
Mn total (µg/L)	0.01-213		<1-94	11749				3.8-390
Ni total (µg/L)	0.001-0.48			0.1-0.4				<1-16
Pb filtered (µg/L)	0.0005-0.65	<1-1		<0.2-0.4				
Pb total (µg/L)	0.005-1.03		<1-1					<1
Zn filtered (µg/L)	0.004-7.1	<5		<0.5-1.8				
Zn total (µg/L)	0.005-3.1		<5-13					<1-200

pH

The streams and tree swamps were generally acidic. The 20th percentile field pH of both streams and tree swamps was 4.6 and the 80th percentile pH was 5.8 and 5.5 respectively. The pH of Project area freshwaters is typically at the lower end of the range of other freshwater tropical streams and typically below the ANZECC/ARMCANZ (2000) default trigger value of 6.

The pH of marine waters ranged from 7.0 to 7.7 and was within the ANZECC/ARMCANZ (2000) range of 7 to 8.5. Estuarine waters exhibited a wider pH range of 5.1 to 7.7 owing to the seasonal inflow of freshwater.

Electrical conductivity

The electrical conductivity of freshwaters ranged from 12 to 136 microSiemens per centimetre (µS/cm). The median conductivity for freshwater tree swamps was 27µS/cm, similar to the median for freshwater streams (21µS/cm). The fresh surface waters of the Project area were typically at the lower end of the conductivity range found in other tropical streams, although higher than Ely stream water. The ANZECC/ARMCANZ default conductivity trigger values for freshwater ranges from 20 to 250µS/cm for upland and lowland rivers. The single backdune lagoon (site 16A at Pera Head), was intermediate in its characteristics, but became brackish in December 2008, when king tides breached the dune system at its mouth, and it remained brackish in March 2009 with a conductivity of 2,266µS/cm.

During the late dry season, conductivity in pools within streams that became isolated from other surface or ground waters (e.g. isolated deep clay lined pools in Winda Winda Creek (site 9A)) increased moderately from 26µS/cm (September 2007) to 80µS/cm (November 2007).

The water quality characteristics of the Project area reflect the nature of water flowing through and within bauxite terraces, with the ferro-alluminosilicate matrix of the laterite layers acting as a physical and chemical filter for particulates resulting in very clear, almost salt-free surface waters. The low conductivity of the Project area surface waters presents challenges both to the accurate measurement of its chemical characteristics and comparison with appropriate guidelines. The low conductivity is consistent with naturally low macro invertebrate diversity and abundance found in the Project area (see Section 8.8 of Queensland EIS (RTA 2011)).

Conductivity in estuaries ranged from 50 to 51,590µS/cm, reflecting the tidal influence. Conductivity was less variable in marine waters, ranging from 19,000 to 53,200µS/cm.

Turbidity

Freshwater turbidity was very low, with a median of 1.1NTU in tree swamps and 1.4NTU in streams. This is lower than most tropical streams, but comparable to that found in the Ely bauxite deposit area. The ANZECC/ARMCANZ range for turbidity is 2 to 15NTU in freshwater. The surface waters of the Project area are characterised by high clarity.

Turbidity in estuarine waters ranged from 1.2 to 5NTU, with a median value of 2.6NTU. Turbidity increased in marine waters, with a range of 5.9 to 16.5NTU and a median value of 9.5NTU. The ANZECC/ARMCANZ range for turbidity is 1 to 20NTU in marine waters and the Project estuarine and marine waters are within this range.

Nutrients

The ANZECC/ARMCANZ (2000) default guideline criteria for ammonium, total nitrogen and total phosphorus were exceeded by select freshwater and estuarine/marine samples and are discussed below.

A maximum concentration of 0.06mg/L total phosphorus, 1.1mg/L total nitrogen and 0.45mg/L ammonium was recorded for freshwater, which exceeded the ANZECC/ARMCANZ (2000) guideline for tropical lowland rivers of 0.01mg/L total phosphorus, 0.2-0.3mg/L total nitrogen, and 0.01mg/L ammonium.

Estuarine and marine waters had higher concentrations of total phosphorus, total nitrogen and ammonium when compared with Project freshwater. The maximum concentration of total phosphorus estuarine/marine waters was 0.18mg/L. The maximum concentration of total nitrogen in estuarine/marine waters was 4.8mg/L and ammonium was 1.8mg/L.

The nutrient levels were generally at or near the level of resolution of the analyses for all other analytes in freshwater samples. Despite the generally low concentrations of solutes, surface waters contribute nutrient inputs into the drainage networks, thereby affecting downstream productivity. Nutrient levels in the Project area freshwaters were generally as low as or lower than that of Ely, Magela Creek, Gove, and/or Mary River.

Dissolved Organic Carbon

The concentration of dissolved organic carbon ranged from 0.5 to 10mg/L in freshwater samples with a median of 1mg/L in stream samples and 2.5mg/L in tree swamp samples. The concentration of dissolved organic carbon in estuarine samples ranged from 0.5 to 5mg/L with a median of 2mg/L. Organic carbon can complex some trace metals, such as aluminium, copper, zinc and cadmium into non-biologically available forms (ANZECC/ARMCANZ 2000). Based on these results in the fresh surface waters of the Project area dissolved organic carbon is not considered an appreciable contributor to metal complexation.

Hardness

Freshwater hardness ranged from 0.4 - 9mg/L $CaCO_3$. Freshwater hardness was predominantly very low with a median of 1.4mg/L $CaCO_3$ in freshwater tree swamps and 1.3mg/L $CaCO_3$ in freshwater streams.

Hardness in estuarine waters ranged from 3.4 to 6,800mg/L $CaCO_3$, reflecting seasonal freshwater inflows, with a median value of 238mg/L $CaCO_3$. The range in marine waters was from 1,475 to 6,418mg/L $CaCO_3$, with a median value of 3,160mg/L $CaCO_3$.

The hardness for the Project area fresh surface waters was generally lower than for other tropical streams, but comparable to that for the Ely area, Gove and Magela Creek.

Hardness may affect metal toxicity in two ways: first, in terms of the competition for uptake sites between calcium and other metals; and second, as an indicator for the potential for inorganic complexation of metals in solution into forms of low bioavailability. Therefore, some metals have hardness dependent trigger values and the ANZECC/ARMCANZ (2000) guidelines provide a mechanism for adjustment of the trigger values for hardness. Weiner (2008) classifies soft waters as being waters with hardness below 75mg/L $CaCO_3$. The hardness of fresh surface waters in the Project area is less than 10mg/L $CaCO_3$. When the ANZECC/ARMCANZ (2000) hardness correction algorithms are applied to determine trigger values for relevant metals (cadmium, chromium (III), lead, nickel, zinc) in such soft waters the hardness modified trigger value is commonly below commercial laboratory detection limits.

Metals in freshwater

The maximum dissolved concentration of arsenic cadmium, chromium, copper, lead, manganese, nickel and zinc was less than the default ANZECC/ARMCANZ guideline trigger value in freshwater streams and tree swamps.

An ANZECC/ARMCANZ guideline for iron in freshwaters has not yet been developed and the Canadian criterion of 300µg/L has been adopted in the interim. Freshwater dissolved iron concentrations were usually below 300µg/L with the 80th percentile of stream samples being 65µg/L and tree swamps 32µg/L. The maximum concentration of dissolved iron in some freshwater stream and tree swamp samples exceeded 300µg/L. Iron is a parameter that may be affected by natural or anthropogenic geochemical changes in water and is discussed below in relation to seasonality.

The dissolved concentration of manganese in freshwaters did not exceed the ANZECC/ARMCANZ guideline of 1,900µg/L. The median concentration of dissolved manganese in surface waters ranged from 0.94µg/L in streams to 0.36µg/L in tree swamps.

Aluminium concentrations for freshwater sites exceeded the ANZECC/ARMCANZ low reliability trigger value of 0.8µg/L (applicable to waters with pH below 6.5) but generally not the 55µg/L trigger value (applicable to waters with pH above 6.5). The median concentration of dissolved aluminium ranged from 18µg/L in freshwater streams to 41µg/L in tree swamps.

Generally, the dominant metals in surface waters of the Project area are aluminium and iron. The concentration of dissolved aluminium, iron and manganese in surface water is seasonal. While for many sites concentrations of aluminium were above the default trigger values in all months, much higher values and greater variability was found for samples from the late dry season in November 2007 and December 2008. The median concentration of aluminium in freshwater streams ranged from 55µg/L in December (before onset of wet season flows) to 12µg/L in January, after the onset of stream flows. Similarly, the median concentration of iron and manganese in freshwater streams ranged from 162µg/L and 5.1µg/L in December to 10µg/L and 0.98µg/L in January, respectively.

Iron is much more soluble in anoxic water, and rapidly oxidises and flocculates out of solution when exposed to air. The presence of elevated dissolved iron concentrations late in the dry season indicates that they were influenced by surface expression of groundwater close to the point of sampling. Where there is sufficient groundwater contribution to result in aerated stream flow, iron is removed from solution with distance (and time) from the point(s) of surface expression of groundwater. In the late dry season, few streams receive sufficient inflows to form a continuous flow of water in any reach, resulting in a greater dominance of recently expressed groundwater in the existing surface waters, with higher dissolved iron. Therefore, the relatively higher dissolved iron concentrations in the late dry season reflect the higher proportion of recently expressed groundwater in the remaining surface waters.

For the perennially flowing sites 7A, 5A and 1A in the eastern branch of Norman Creek, the seasonality of dissolved aluminium and iron was much less marked, because longitudinal surface waters flows and aeration were maintained.

When iron flocculates out of solution the floc tends to adsorb other metals and remove them from solution. Although defined as dissolved, the water sample fraction that can be filtered through 0.45µm filters can contain ultra-fine colloidal particles, particularly in the early stages of formation of iron and aluminium flocs. Much of the reported higher metal concentrations in the late dry season sampling may be associated with such colloidal material, and may be of limited bioavailability for most metals. Over time, these colloids would form flocs that settle, removing the metals from the water column.

The concentration of dissolved nickel, copper and zinc increases late in the dry season. The median concentration of dissolved nickel in freshwater streams ranged from 0.013µg/L in January to 0.06µg/L in August–September. The median concentration of dissolved copper in freshwater streams ranged from 0.005µg/L in January to 0.07µg/L in November. The median concentration of dissolved zinc in freshwater streams ranged from 0.078µg/L in January to 0.72µg/L in November.

Metals in Estuarine and Marine Waters

The concentration of dissolved aluminium in most estuarine and marine samples exceeded the low reliability default ANZECC/ARMCANZ trigger value for marine water of 0.5µg/L. The median concentration ranged from 2.5µg/L in marine waters (three samples only site WP14) to a median of 4.0µg/L in estuarine samples.

The median concentration of dissolved iron in marine and estuarine waters was 1µg/L and 13µg/L, respectively. There is no ANZECC/ARMCANZ marine guideline for iron.

The total and dissolved concentration of other metals analysed did not exceed applicable ANZECC/ARMCANZ guidelines in estuarine or marine samples.

Hydrocarbons

As the Project area is relatively undisturbed, hydrocarbons were not anticipated to be present in fresh, estuarine or marine waters but sampling was carried out to assess baseline conditions. During August–September 2007, ten freshwater and estuarine locations (16A, 10A, 25A, 11, 1A, 2A, 5A, 7A, 26A, 9A) were sampled for total petroleum hydrocarbons, benzene, toluene, ethylbenzene and xylenes. All results were below the corresponding laboratory detection limits.

Summary

These results suggest the Project area freshwater streams are not unusual in terms of conductivity and hardness compared with streams in other bauxite areas (e.g. Ely and Gove). However, they have lower solute concentrations and lower hardness compared to other waters in northern Australia. The Project area streams and tree swamps have naturally elevated dissolved aluminium concentrations.

16.2 Surface Water – Potential Impacts and Mitigation Measures

16.2.1 Water Supply

The Project's principal water requirements are for process water, haul road watering, vehicle wash-down, dust suppression and potable supplies. The Project's sources of supply are recycled water from tailings storage facilities, surface water (water storage dam and direct pumping from stream), deep artesian groundwater and water recovered from slots adjacent to the tailings storage facilities. The average annual water balance for the Project over a range of production scenarios is summarised in **Table 16-11.** The EIS prepared under Queensland legislation (RTA 2011) assessed the impact the Project on water resources at minimum, intermediate and maximum production rates of 15, 30 and 50Mdptpa. The decision has since been taken that the initial production rate shall be at 22.5Mdptpa. For the purposes of consistency, this current EIS presents certain modelling results from RTA (2011) for impacts on hydrology at production rates of 15, 30 and 50Mdptpa. The impact of the 22.5Mdptpa rate is intermediate between 15 and 30Mdptpa.

Table 16-11 Average Annual Water Balance

Production Rate	Average Annual Demand* (GL)	Average Annual Supply (GL)					
		Recycle from tailings	Artesian	Dam C	Slots**	River	Total Supply*
15Mdptpa	16.4	4.7	3.1 (5.2 Peak)	7.8 (Stage 1)	0.8	0	16.4
22.5Mdptpa	24.8	7.1	4.9 (7.8 peak)	12.0 (Stage 1)	0.8	0	24.8
30Mdptpa	33.0	9.4	6.0 (10.6 peak)	13.8 (Stage 2)	1.6	2.2	33.1
50Mdptpa	63.7**	22.1	11.9 (15 peak)	25.4 (Stage 2)	1.6	2.5	63.5**

* Demand and supply values may differ due to rounding errors.

**Trenches dug adjacent to tailings storage facilities to recover water.

Typically, water would be drawn in order of preference from tailings recycle, recovery slots, and then a combination of the surface water dam (Dam C) and artesian bores. After the construction of the Norman Creek plant, some supplementary surface water would be drawn directly from the Ward River to minimise the risk of inadequate supply from Dam C. The artesian demand would therefore fluctuate depending on whether there is above or below average rainfall runoff into the dam. The average annual artesian demand at 50Mdptpa would be 11.9GL per annum, with fluctuations up to 15GL per annum. RTA has an existing artesian Water Licence for 9GL per annum which allows abstraction from bores located on ML7024. RTA has applied to increase the artesian allocation to cover the fluctuations in artesian demand. The overall demand averages 12GL per annum, with a peak abstraction of 15GL in any one year. The impact of abstraction on the artesian aquifer has been modelled and is discussed in **Section 16.4.2.**

The impacts on streamflow of the proposed water storage dam and of direct pumping from the Ward River are discussed in **Section 16.2.3.** The water supply infrastructure for the Project would not be connected to the water supply infrastructure for the existing Weipa operations.

16.2.2 Site Water Management

Water management system

Schematic diagrams of the proposed water management systems are shown in **Figure 16-5** and **Figure 16-6**. The locations of water management infrastructure are shown in **Figure 3-2** and **Figure 3-3**.

The process water ponds have been designed to contain an operational buffer supply of water for the beneficiation plants, dust suppression and other industrial uses. Water would be recycled from the tailings storage facilities and the mine industrial area drainage slots and used preferentially as process water. A third of the water used in the beneficiation plants would be recycled from these sources.

Water would be recycled from the tailings storage facilities, via the decant sump, to the process water pond. Further engineering studies shall assess the option of pumping water directly to the process water pond, eliminating the need for the decant sump. Water from the heavy and light vehicle wash bays would be treated in oil water separators prior to recycling.

Stormwater runoff from product stockpiles and the wharf would be directed through sediment ponds. Provision would be made to recycle some of this water.

Treated effluent from the Boyd and Norman Creek sewage treatment plants (STPs) would also be recycled. Treated effluent from the construction camp STP would be used for irrigation of landscaping near the camp during the construction period.

A reverse osmosis potable water treatment plant would be used to treat raw water from Dam C to a standard that meets the *Australian Drinking Water Guidelines* (NHMRC 2004).

The process water ponds and tailings storage facilities would be constructed as "turkeys' nests", meaning they would only capture the rainfall that falls directly on the dam impoundment. Neither of these dams would contain contaminants in concentrations that are hazardous (refer **Section 3.5.4**).

Tailings solids and liquids are not hazardous wastes as defined in Information Sheet *Determining dams containing hazardous waste* (EHP 2012b) (refer **Section 3.5.4**). Nevertheless, the hazard category of the tailings storage facilities has been rated as "significant" for a dam break scenario in accordance with EHP's *Manual for Assessing Hazard Categories and Hydraulic Performance of Dams* (EHP 2012d). The relevant design criteria for tailing storage facilities are shown in **Table 16-12**.

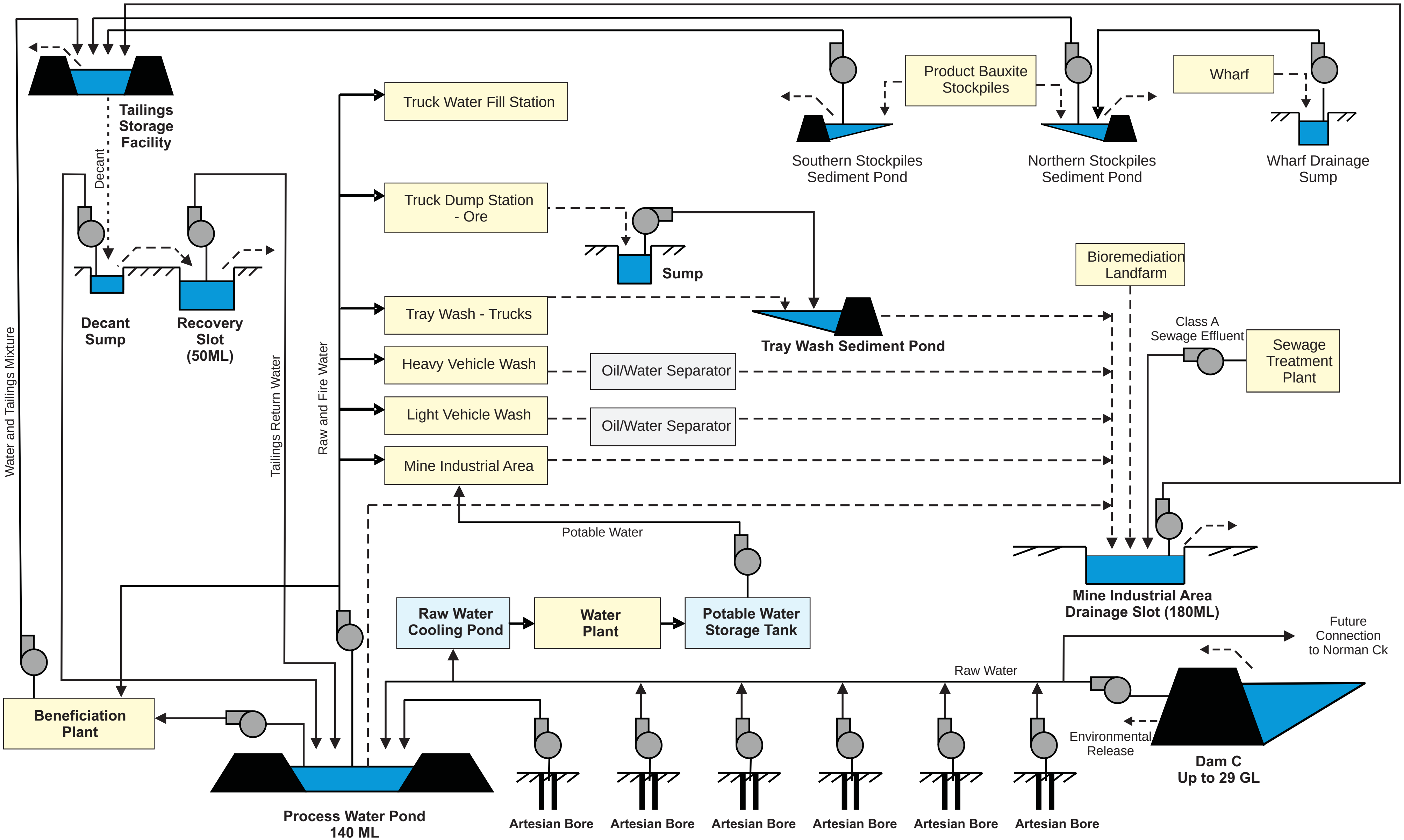
Table 16-12 Tailings Storage Facility Design Criteria

Location	Design Storage Allowance*	Spillway Critical Design Storm	Mandatory Reporting Level
Boyd tailings storage facility	0.02 AEP, 2 month wet season plus other net inputs for the 2 month wet season, to be available on 1st November each year	0.001 AEP	72-hour 0.1 AEP
Norman Creek tailings storage facility	0.02 AEP, 2 month wet season plus other net inputs for the 2 month wet season, to be available on 1st November each year	0.001 AEP	72-hour 0.1 AEP

AEP = Annual Exceedance Probability

The process water ponds are "low" hazard category and therefore will be designed for a spillway critical design storm of 1:100 year ARI. The process water ponds will be designed to operate a freeboard equivalent to a 24-hour 1:100 year ARI rainfall event.

Design details for the water supply dam (Dam C) are presented in **Section 16.2.3**.



- - - - Gravity flow
—— Pipeline

South of Embley Project

Fig. 16-5: Boyd Water Management System

Date: 15/08/2012

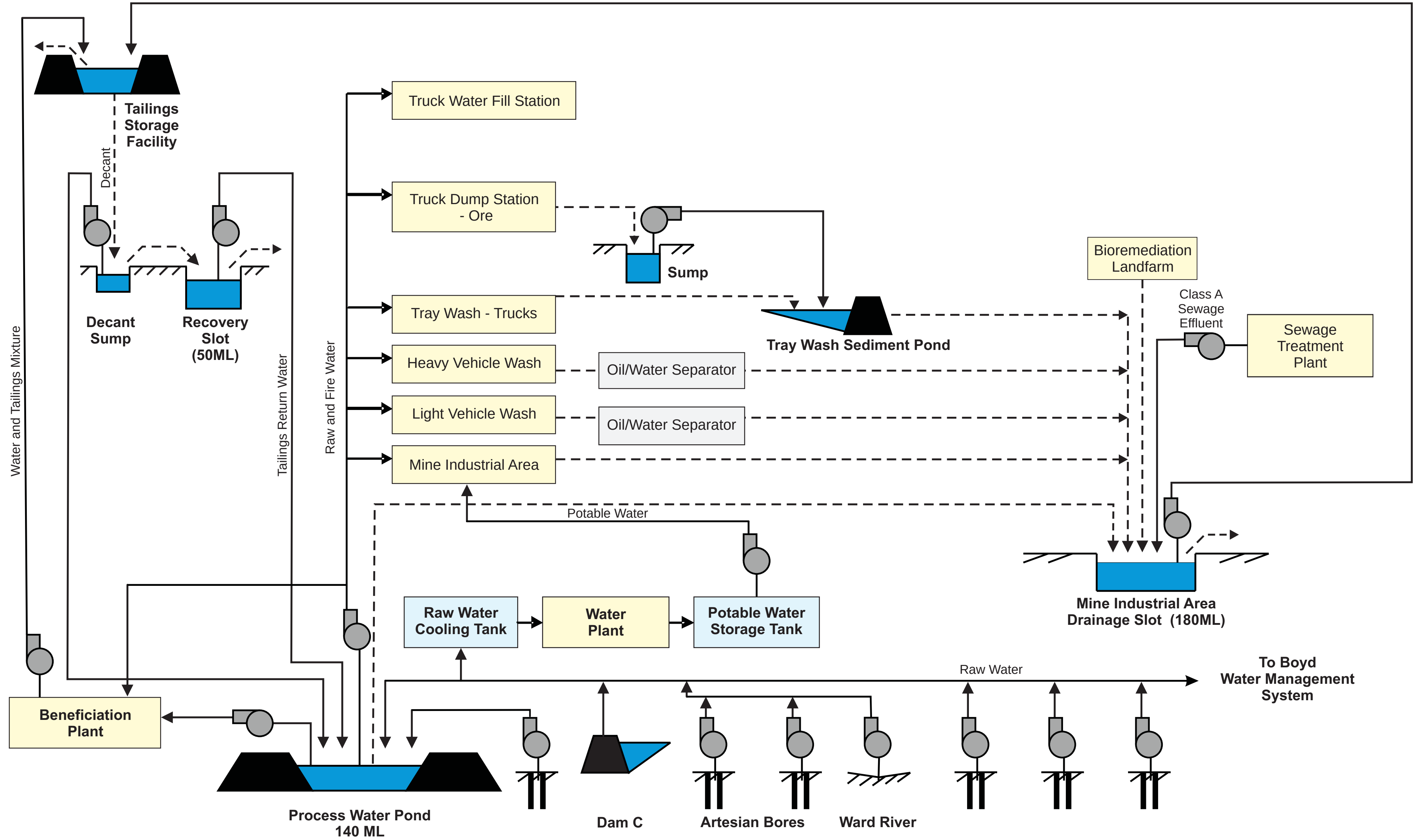


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Fig. 16-6: Norman Creek Water Management System

Date: 16/08/2012

Stormwater management

The Mine Industrial Area drainage slots and the stockpile sediment ponds would receive stormwater runoff. These ponds would be sized to a volume equivalent to the runoff volume from a 1:10 ARI 24-hour rainfall event, and would be maintained above plus maximum sediment deposition level. The truck dump station and beneficiation plant are in the catchment of the Mine Industrial Area drainage slot. The water from these ponds would be either recycled for use in the beneficiation plants, dust suppression, and other industrial uses or may be released from these ponds in accordance with the water quality conditions of the EA. Bauxite is a benign, non-hazardous, material (refer **Section 3.5.4**).

Stormwater runoff generated within active mine areas is predominantly contained within the internally draining mine pits. The post-mining landscape effectively provides internally draining sumps that are lower than the surrounding land and which contain stormwater runoff, which then infiltrates through the pit floor and walls. An average of 3.4m thickness of bauxite shall be removed, providing a very large stormwater retention capacity within mine pits. Even on sloping land, capacity to retain in excess of a 1:100 ARI 24-hour rainfall event would be available. In the event that the active pit or post-mining topography is not a fully internally draining pit, stormwater runoff would be directed via a sediment pond.

The mine access road alignment follows elevated portions of the landscape wherever possible to enable all weather access; however, culvert causeways would be required at certain drainage lines where low level crossings are not appropriate. The Norman Creek access road and certain internal mine haul roads will also require culvert causeways for a number of drainage line crossings. Sediment traps would be included as part of the drainage designs at points where haul roads cross watercourses.

Erosion and sediment control

Erosion rates from active mining areas are higher than from unmined areas. In the wet season, increased erosion is expected to occur during mining operations from activities such as soil stripping, mining, and haul road construction. However, due to pit layout and topography, rainfall runoff would be predominantly retained within the mined areas.

Some elevated sediment concentrations are expected to occur in stormwater runoff from ore processing and stockpile areas, and such runoff would be directed to sediment control structures.

An Erosion and Sediment Control Management Plan would be prepared prior to construction.

Areas disturbed by mining activities and infrastructure would be rehabilitated to a stable landform with a self-sustaining vegetation cover. After overburden and soil are returned to mined-out pits the overall slope of the landform would be similar. Where mining leaves batters on the edges of the pit, these would be recontoured to a maximum slope of 20% (1 in 5). The final landform would not have any out-of-pit dumps of excavated wastes or soil.

Sediment laden runoff from ship loading activities has the potential to cause turbidity in the vicinity of the proposed Port. Runoff and sediment collected from catch trays, belt scrapings, and the sealed maintenance area on the wharf would be pumped back to the wharf drainage sump on shore. Spillage prevention measures at the ship-loader are described in **Section 3.7.3**.

The water quality of natural surface drainage systems would be maintained by preserving riparian vegetation corridors. The proposed SoE environmental buffer system would exceed the minimum requirements of the Queensland Government’s Regional Vegetation Management Codes as they relate to clearing set-back distances from watercourses and wetlands (DERM 2009b) (refer **Section 3.13.2**). The discharge from sediment control structures (and internally draining mine pits, if any) would need to pass through the proposed SoE environmental buffers around and adjoining surface drainage lines and wetland features before entering watercourses. Slow flow velocities through these vegetated buffers (due to the very flat topography of the bauxite plateau) and the retention effect provided by ground layer vegetation and leaf litter provides additional protection against elevated sediment load risks that would otherwise impact aquatic ecosystems. Areas that are disturbed by mining activities and infrastructure would be rehabilitated to a stable landform with a self-sustaining vegetation cover.

16.2.3 Surface Water Supply

Water supply dam

A water supply dam (Dam C) would be constructed on a freshwater tributary of Norman Creek (refer **Figure 3-2**). In determining that Dam C was the best option for water supply for the Project, alternate water sources were considered and a wide range of supply combinations utilising various proportions of these sources were investigated. Originally, two dams were considered, with the second dam being located on the Ward River. Following consultation with Traditional Owners and further feasibility studies, this was amended to only one larger dam (Dam C) on a freshwater tributary of Norman Creek.

Dam C would have a maximum storage capacity of 29GL and could be constructed in either two stages or a single stage. If constructed in two stages, the first stage would provide 10.9GL storage capacity and, later, the wall would be raised to provide 29GL storage capacity. The dam would be constructed in a single stage (29GL capacity) should expansion of production above 22.5Mdptpa be anticipated to occur quickly. This is the subject of ongoing feasibility studies. Details of both Dam C stages are summarised in **Table 16-13**. Dam C would be a conventional earth-fill dam.

Table 16-13 Water Supply Dam Summary

	Dam C	
	At 10.9GL capacity	**At 29.9GL capacity**
Total catchment area (km^2)	259.0	
Dam catchment area (km^2)	77.3	
Dam catchment as % of total catchment	29.8%	
Maximum dam volume (GL)	10.9	29.0
Dam surface area (km^2) (at spillway)	3.6	6.5
Dam wall height (m) (at spillway)	8.0	12.0
Freeboard above spillway (m)	2.75	3.0

The Australian National Committee on Large Dams (ANCOLD 2000) provides hydrologic design criteria for spillways based on downstream flood hazard. Dam C represents a low to significant incremental flood hazard category and, as such, the spillway should be designed to pass a 1:1,000 ARI storm event as a minimum. A 1:1,000 ARI storm event is considered a rare event (IE Aust 2001). The dam spillway would be designed to pass the peak flow from a 1:2,000 ARI flood event. The spillway would be at a low gradient (overall gradient of <3% from top to bottom) and be designed to facilitate fish passage during spillway flow events.

The conceptual design for the Dam C spillway and fish passage is shown in **Figure 16-7**. RTA is engaging with DAFF regarding the final design, which will require DAFF approval. The dam would have a low level outlet pipe equipped with a valve to allow environmental flow releases when required.

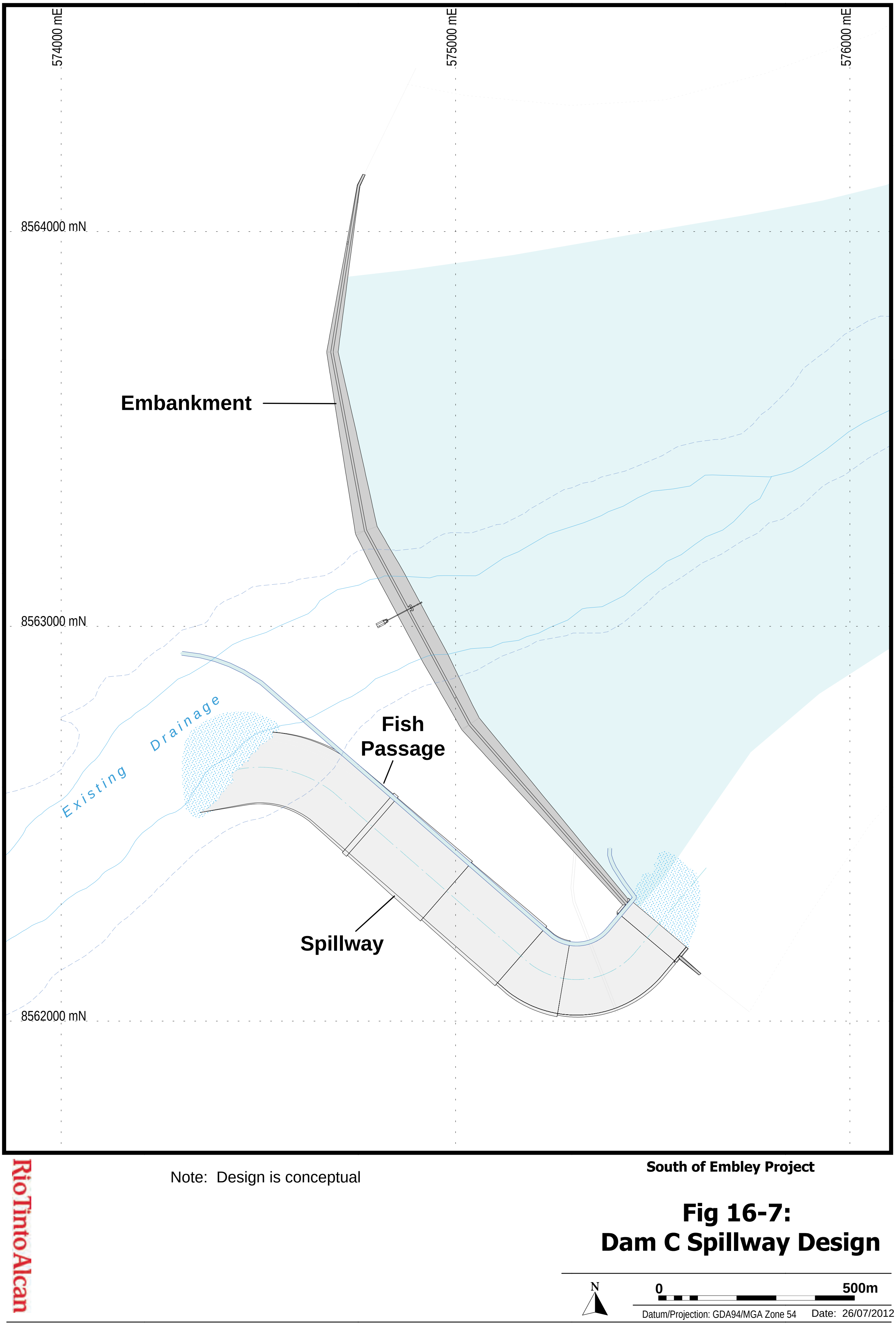
Dam C would supply both the Boyd beneficiation plant and the Norman Creek beneficiation plant. The artesian borefield can supply water to both plants.

The impact of Dam C on downstream flow was modelled using a daily rainfall–runoff model (Boughton's AWBM) embedded in a GoldSim model that takes into account inputs (catchment runoff, direct rainfall) and outputs (pumped withdrawals, actual evaporation, seepage, spillway overflow and environmental releases).

The GoldSim model applies stochastic (Monte Carlo) trials to assess flows in streams and yield in dams of various sizes. For each trial or model realisation, rainfall was generated stochastically from the SILO rainfall recorded for the region using the Transition Probability Matrix (TPM) model. The record generated in the Monte Carlo approach has the same statistical character as the actual record (i.e. the parameters attaching to each record such as variance and standard deviation remain unchanged), but it would include instances of extreme behaviour such as long periods of low rainfall which are not captured using methods based on an average rainfall value method.

The TPM model allows a supply system to be tested over an extremely long period, which includes a wide spectrum of potential extreme conditions. It has been refined to incorporate climate change. Instances of extreme behaviour, as well as long periods of either higher or lower than average rainfall, have been incorporated into the model through use of recorded Southern Oscillation Index (SOI) data. The use of the data allows the generation of rainfall to be influenced by different consequences of the SOI that produce El Nino conditions, La Nina conditions or neither.

The GoldSim model was used to estimate dam inflow, spillway overflow and environmental releases. The downstream flow (spillway overflow plus environmental releases) was compared to the inflows into the dam to evaluate the effect of the dam on the hydrological regime. For the purposes of modelling, environmental releases were assumed to be 5% of daily dam inflows. The effect of rainfall variation was assessed by estimating the 10th and 90th percentile flows. The modelled effect of Dam C on flow immediately downstream of the dam and on annual flow from the whole Norman Creek catchment under production rates of 15Mdptpa, 30Mdptpa and 50Mdptpa is summarised in **Table 16-14**, **Table 16-15** and **Table 16-16** respectively.



Date: 26/07/2012

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Note: Design is conceptual

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Fig 16-7:
Dam C Spillway Design

Table 16-14 Effect of Dam C on Monthly Downstream Flow at 15Mdptpa

Month	Mean Monthly Inflow (GL)	Mean Downstream Flow (GL)	Downstream Flow at 15Mdptpa Production (as % of inflow)			
			Mean	10th percentile	Median	90th percentile
Flow Downstream of Dam C Wall						
January	6.15	2.31	37.5%	4.7%	13.2%	60.7%
February	14.63	13.01	88.9%	52.2%	91.8%	94.9%
March	18.11	17.00	93.9%	90.1%	93.7%	94.0%
April	13.55	12.10	89.3%	86.7%	88.4%	91.9%
May	7.32	5.31	72.6%	53.7%	70.9%	81.5%
June	3.31	1.54	46.4%	9.0%	38.5%	63.8%
July	1.19	0.18	15.0%	5.2%	4.8%	22.2%
August	0.22	0.06	25.4%	0%	25.0%	25.0%
September	0.01	0.002	25.0%	0%	0%	25.0%
October	0.01	0.002	25.0%	0%	0%	25.0%
November	0.12	0.01	4.7%	3.4%	4.6%	4.7%
December	1.20	0.06	5.1%	4.4%	4.6%	4.6%
Annual	65.84	51.58	78.3%	66.7%	77.3%	83.3%
Flow to Norman Estuary						
January	20.63	16.78	81.3%	71.6%	74.1%	88.3%
February	49.05	47.43	96.7%	85.7%	97.5%	98.5%
March	60.72	59.61	98.2%	97.0%	98.1%	98.2%
April	45.43	43.98	96.8%	96.0%	96.5%	97.6%
May	24.54	22.53	91.8%	86.2%	91.3%	94.5%
June	11.11	9.33	84.0%	72.9%	81.6%	89.2%
July	3.99	2.98	74.6%	71.7%	71.6%	76.8%
August	0.73	0.57	77.7%	0%	77.6%	77.6%
September	0.02	0.02	77.6%	0%	0%	77.6%
October	0.03	0.02	77.6%	0%	0%	77.6%
November	0.42	0.30	71.6%	71.2%	71.5%	71.6%
December	4.01	2.88	71.7%	71.5%	71.5%	71.5%
Annual	220.68	206.42	93.55%	90.15%	93.2%	95.0%

Table 16-15 Effect of Dam C on Monthly Downstream Flow at 30Mdptpa

Month	Mean Monthly Inflow (GL)	Mean Downstream Flow (GL)	Downstream Flow at 30Mdptpa Production (as % of inflow)			
			Mean	10th percentile	Median	90th percentile
Flow Downstream of Dam C Wall						
January	6.15	1.50	24.5%	4.6%	4.7%	48.1%
February	14.63	10.81	73.9%	6.1%	69.2%	97.1%
March	18.11	16.02	88.4%	68.6%	90.2%	95.1%
April	13.55	11.06	81.6%	70.1%	80.2%	88.1%
May	7.32	3.79	51.7%	19.4%	47.7%	66.5%
June	3.31	0.65	19.7%	4.9%	8.9%	33.9%
July	1.19	0.29	24.7%	5.1%	4.6%	45.9%
August	0.22	0.06	26.3%	0%	25.0%	25.0%
September	0.01	0.002	25.0%	0%	0%	25.0%
October	0.01	0.002	25.0%	0%	0%	25.0%
November	0.12	0.01	4.7%	3.6%	4.8%	4.9%
December	1.20	0.06	4.7%	6.5%	4.7%	4.6%
Annual	65.84	44.25	67.2%	43.3%	63.7%	80.4%
Flow to Norman Estuary						
January	20.63	15.98	77.5%	71.5%	71.6%	84.5%
February	49.05	45.23	92.2%	72.0%	90.8%	99.1%
March	60.72	58.62	96.5%	90.6%	97.1%	98.5%
April	45.43	42.94	94.5%	91.1%	94.1%	96.4%
May	24.54	21.00	85.6%	75.9%	84.4%	90.0%
June	11.11	8.45	76.0%	71.6%	72.8%	80.3%
July	3.99	3.10	77.5%	71.7%	71.5%	83.9%
August	0.73	0.57	78.0%	0%	77.6%	77.6%
September	0.02	0.02	77.6%	0%	0%	77.6%
October	0.03	0.02	77.6%	0%	0%	77.6%
November	0.42	0.30	71.6%	71.3%	71.6%	71.6%
December	4.01	2.87	71.6%	72.1%	71.6%	71.5%
Annual	220.68	199.09	90.2%	83.1%	89.2%	94.2%

Table 16-16 Effect of Dam C on Monthly Downstream Flow at 50Mdptpa

Month	Mean Monthly Inflow (GL)	Mean Downstream Flow (GL)	Downstream Flow at 50Mdptpa Production (as % of inflow)			
			Mean	10th percentile	Median	90th percentile
Flow Downstream of Dam C Wall						
January	6.15	0.58	9.4%	4.9%	4.8%	6.6%
February	14.63	6.24	42.6%	4.7%	22.8%	78.4%
March	18.11	12.87	71.0%	11.3%	74.0%	86.3%
April	13.55	9.99	73.7%	50.1%	74.0%	82.0%
May	7.32	2.42	33.0%	5.0%	26.0%	48.1%
June	3.31	0.26	7.9%	4.5%	4.6%	10.2%
July	1.19	0.13	10.9%	4.4%	4.6%	10.8%
August	0.22	0.05	25.0%	0%	25.0%	25.0%
September	0.01	0.002	25.0%	0%	0%	25.0%
October	0.01	0.002	25.0%	0%	0%	25.0%
November	0.12	0.01	4.1%	3.0%	4.2%	4.2%
December	1.20	0.06	4.7%	3.5%	4.6%	4.6%
Annual	65.84	32.61	49.5%	19.2%	46.9%	63.6%
Flow to Norman Estuary						
January	20.63	15.06	73.0%	71.6%	71.6%	72.1%
February	49.05	40.66	82.9%	71.6%	77.0%	93.6%
March	60.72	55.47	91.4%	73.5%	92.2%	95.9%
April	45.43	41.87	92.2%	85.1%	92.2%	94.6%
May	24.54	19.63	80.0%	71.6%	77.9%	84.5%
June	11.11	8.06	72.5%	71.5%	71.6%	73.2%
July	3.99	2.93	73.4%	71.5%	71.5%	73.4%
August	0.73	0.57	77.6%	0%	77.6%	77.6%
September	0.02	0.02	77.6%	0%	0%	77.6%
October	0.03	0.02	77.6%	0%	0%	77.6%
November	0.42	0.30	71.4%	71.1%	71.4%	71.4%
December	4.01	2.87	71.6%	71.2%	71.5%	71.5%
Annual	220.68	187.45	84.9%	75.9%	84.1%	89.1%

The key findings are:

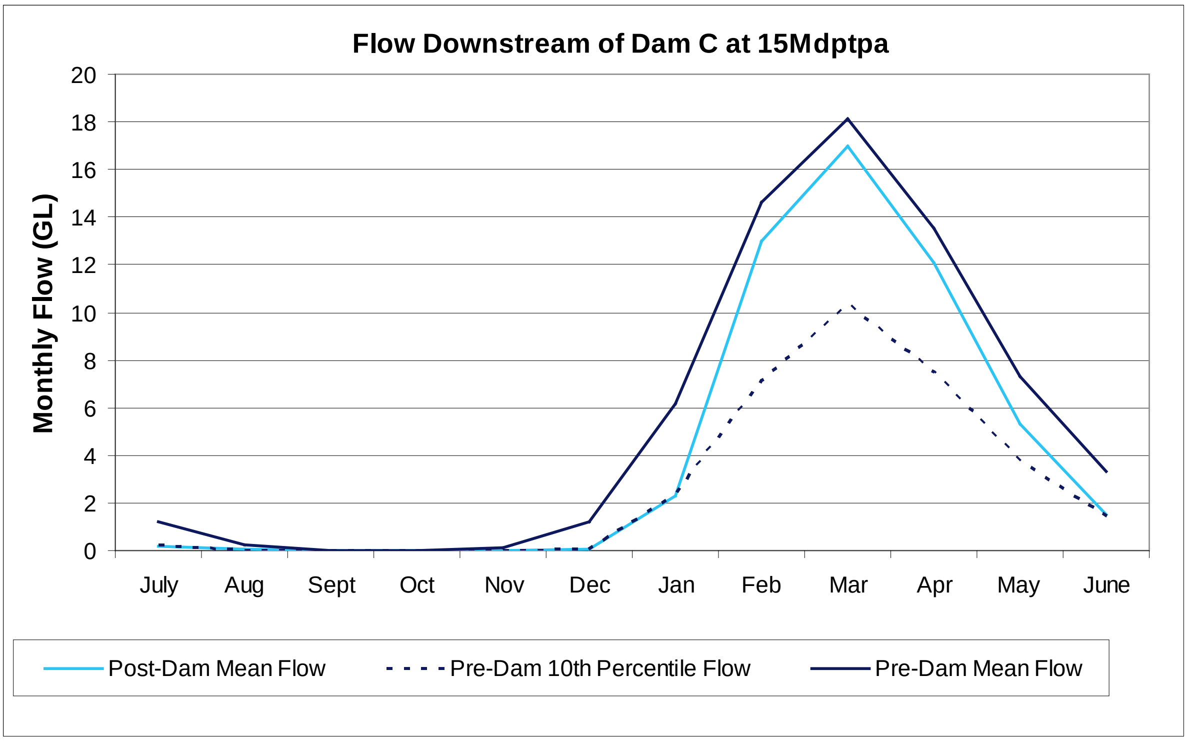
- the effect of Dam C at 15Mdptpa, 30Mdptpa and 50Mdptpa production rates is to reduce mean annual flow immediately downstream in the Norman Creek tributary to 78.3%, 67.2% and 49.5% of original flow respectively; and,
- considering the whole Norman Creek system catchment discharge (i.e. discharge into the estuary), the mean annual input into the estuary would be 93.5%, 90.2% and 84.9% of original flow respectively.

In summary, at 50Mdptpa production rate, Dam C leads to an appreciable annual decline (>20%) in flows immediately downstream on that particular branch of the Norman Creek. However, when the catchment is considered as a whole, the overall maximum decline is 15% and well within the range of normal year-to-year variation.

The change in monthly flow in the Norman Creek tributary immediately downstream is shown at production rates of 15Mdptpa, 30Mdptpa and 50Mdptpa in **Figures 16-8** to **16-10**. The change in monthly flow into the Norman Creek estuary is shown in **Figure 16-11**.

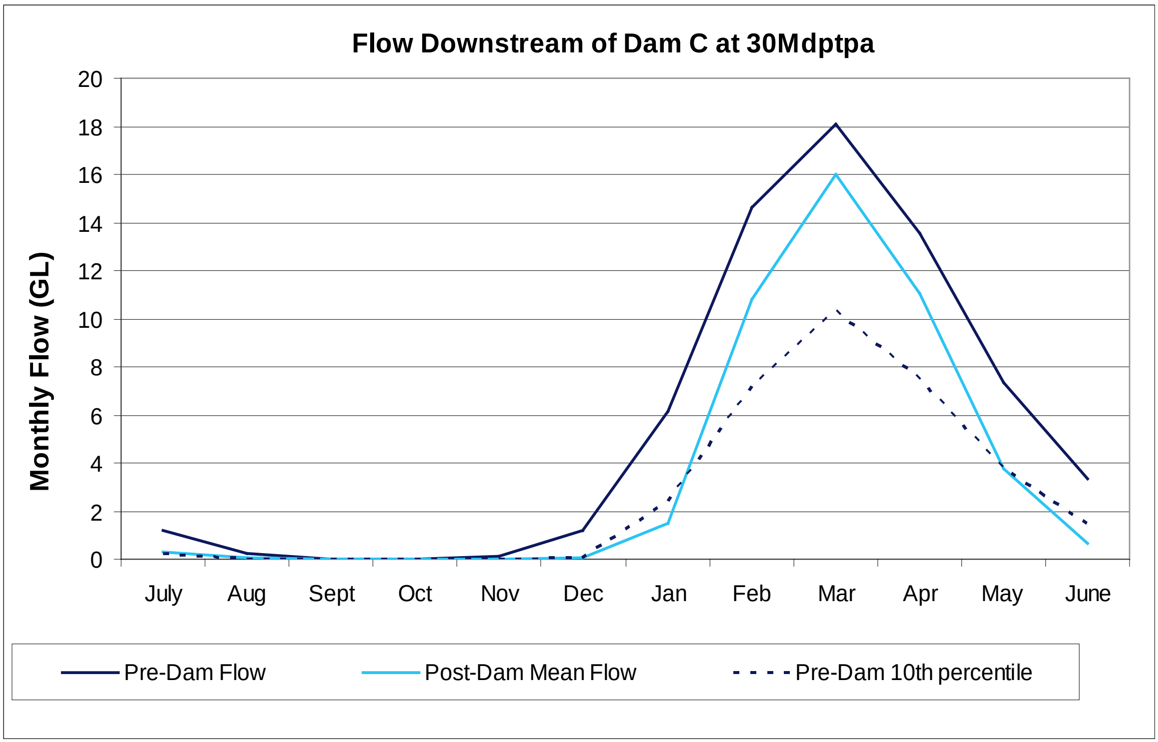
The modelling shows that the onset of wet season flow immediately downstream of the dam is delayed by about a month as it fills following the dry season. However, there is little delay effect on the estuaries downstream due to contributing flows from other sub-catchments.

Figure 16-8 Flow Downstream of Dam C at 15Mdptpa



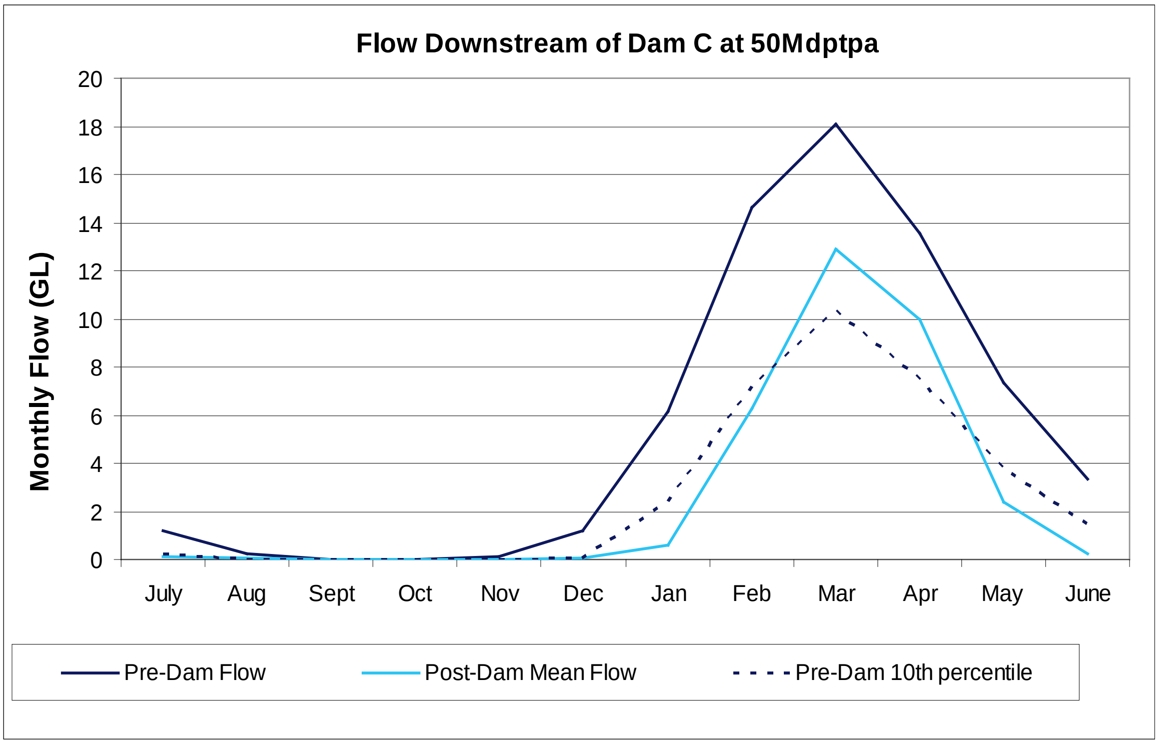
Note: Dam modelled at Stage 1 storage capacity of 10.9GL.

Figure 16-9 Flow Downstream of Dam C at 30Mdptpa



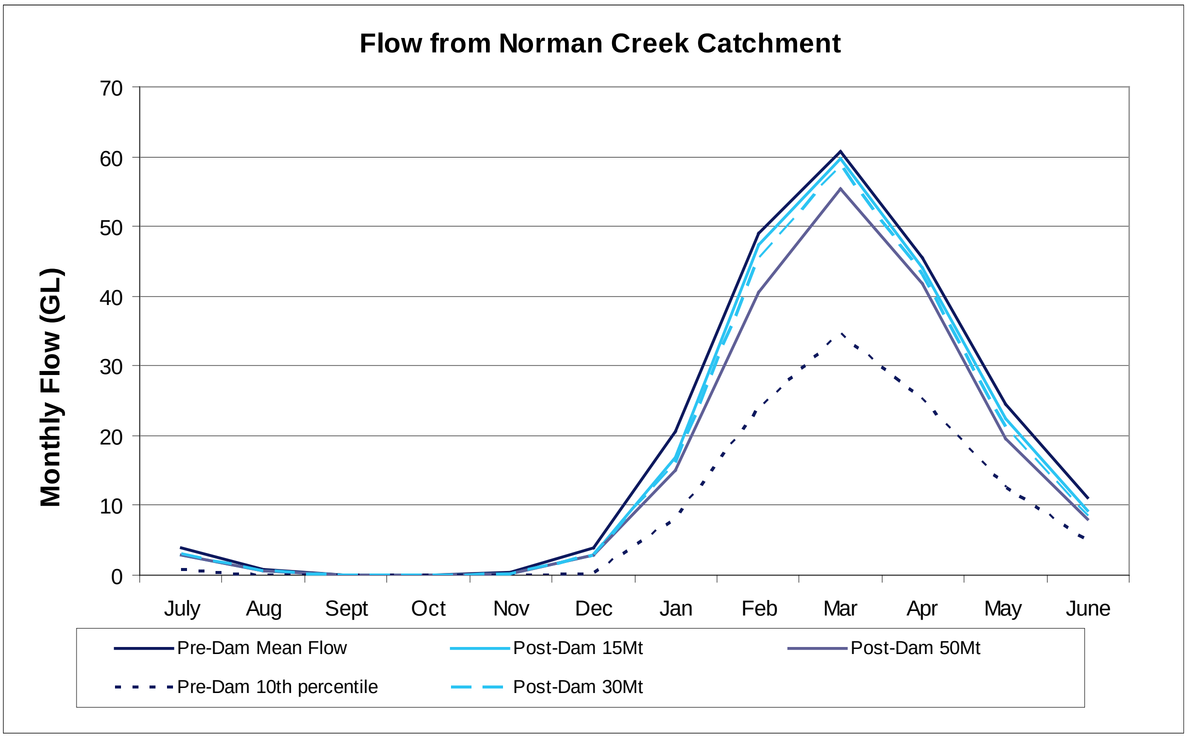
Note: Dam modelled at Stage 2 storage capacity of 29GL.

Figure 16-10 Flow Downstream of Dam C at 50Mdptpa



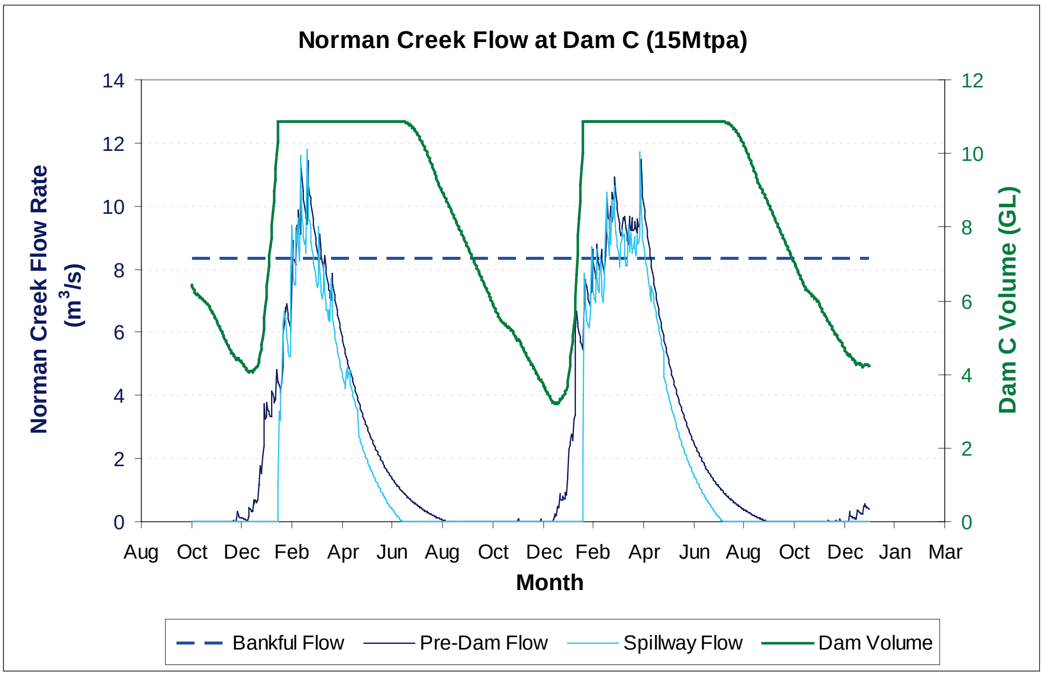
Note: Dam modelled at Stage 2 storage capacity of 29GL.

Figure 16-11 Flow from Norman Creek Catchment



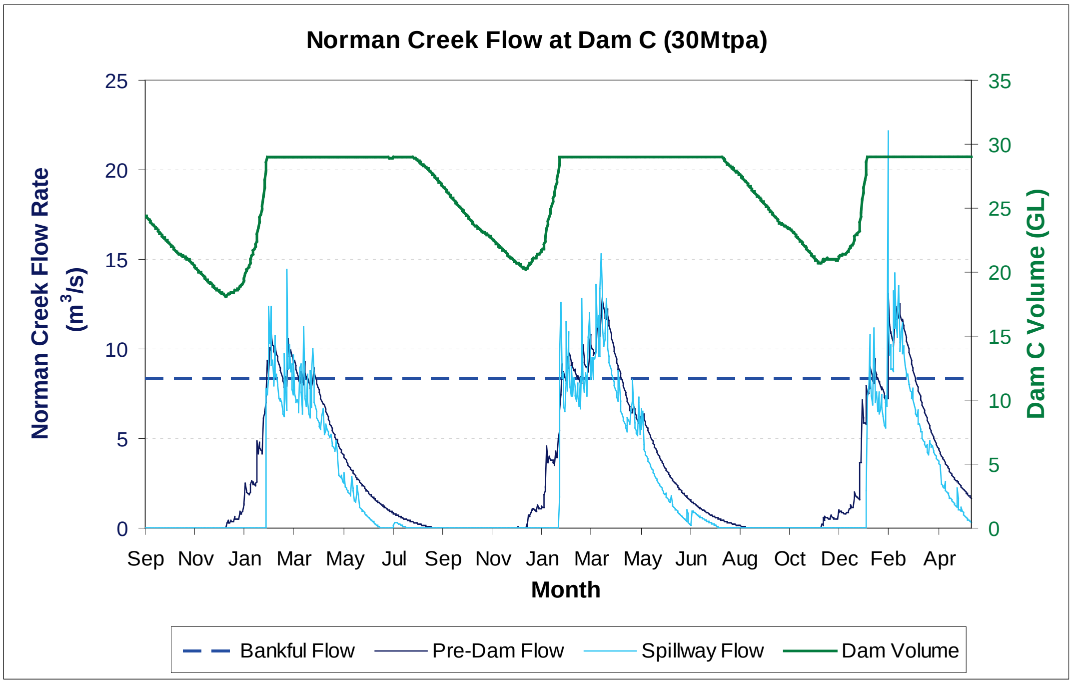
The effect of Dam C on the timing of downstream flow during the onset of the wet season was examined in relation to the timing of bank full flow. Once bank full flow is exceeded, adjacent floodplains and wetlands (if present) begin to flood. The bank full flow on Norman Creek was estimated to have an ARI of 1:2.5 years (refer **Section 16.1.1**), which is equivalent to 8,300L/s at the dam site. GoldSim model output for typical flows with and without Dam C at 15Mdptpa, 30Mdptpa and 50Mdptpa are shown in **Figures 16-12** to **16-14**.

Figure 16-12 Norman Creek Flow at Dam C (15Mdptpa)



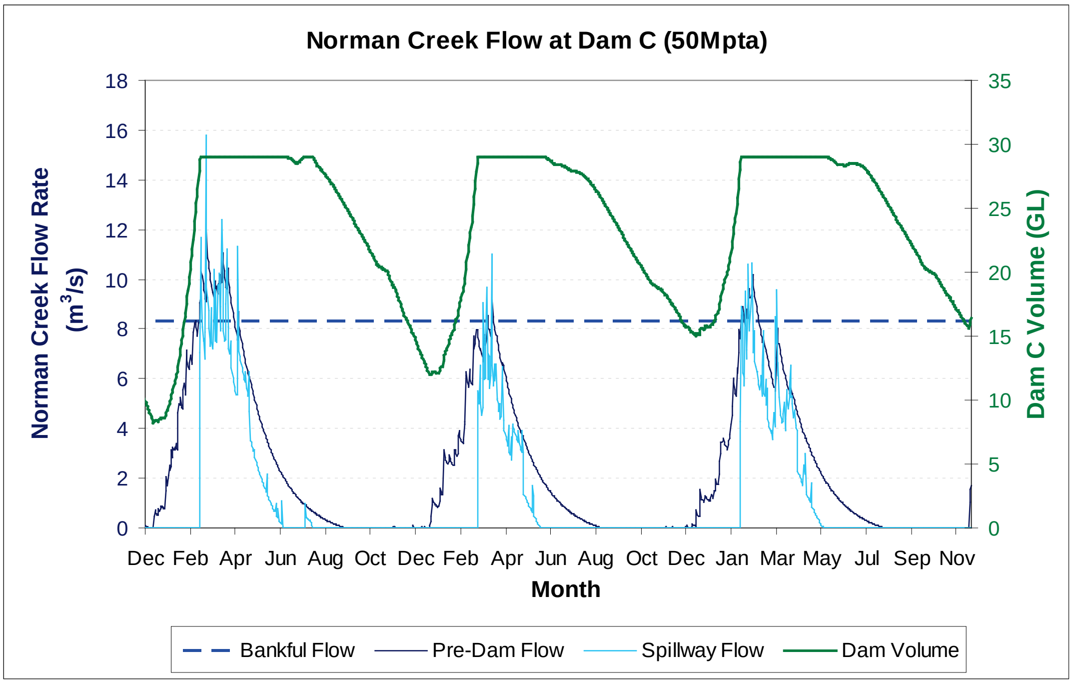
Note: Dam modelled at Stage 1 storage capacity of 10.9GL.

Figure 16-13 Norman Creek Flow at Dam C (30Mdptpa)



Note: Dam modelled at Stage 2 storage capacity of 29GL.

Figure 16-14 Norman Creek Flow at Dam C (50Mdptpa)



Note: Dam modelled at Stage 2 storage capacity of 29GL.

A statistical analysis shows that the onset of bank full flow downstream of Dam C is delayed on average only one day at 15Mdptpa, six days at 30Mdptpa and nine days at 50Mdptpa. The small time delay that the dam causes in downstream bank full flow is due to the nature of the rainfall–runoff relationship for the bauxite plateau:

- the annual surface runoff component of incident rainfall is very small (<1%) and therefore flows are unresponsive to incident rainfall unless the catchment is saturated already;
- the catchments must wet-up before there is any substantial baseflow into streams;
- the baseflow rises quite smoothly over time as the wet season progresses and is not highly variable like surface runoff in a “hard” catchment. Unlike a “hard” catchment, there is no conventional early wet season “first flush” or “pulses”, rather a fairly sustained increase in flow over January, February and March to an April peak, followed by a decline, with cessation of flow around September (on average);
- the key factor is that the dam is typically already full by the time bankfull flow rates would normally be reached (mid-February on average), hence such inflows just pass over the spillway; and,
- to the extent that timing of overbank flow may have an environmental influence, the installation of the dam would, on average, have negligible impact.

There is typically little dry season flow at Dam C after July (see **Figure 16-11** and **Table 16-16**). When flow ceases, pools within the channel are no longer connected and some without groundwater inflow eventually dry up. The effect of Dam C would be to stop flow between pools earlier than would be the case under natural conditions. This is not expected to have an impact on matters of NES. Dam C would be fitted with a low level outlet pipe which would permit the controlled release of environmental flows when required. Sufficient water would be reserved for environmental flows to enable continued releases in the driest months (August to October) of a volume equivalent to 25% of dam inflows. The pipe would be sized to enable peak discharge of up to 1,000L/s, if required. When dam inflows cease, environmental flow releases would cease. Once the dam is full following the onset of the wet season, the spillway would typically overflow on a regular basis. If environmental flow releases are required during the wet season, they would commence after the dam is full.

Impact of Dam C on Flood Events

Wet season inundation of floodplains resulting in overtopping of the main channel banks is a seasonal characteristic of the area. Dam C would not increase the risk of flooding as it would reduce the peak flow during rain events.

Dam C has had a dam failure impact assessment in accordance with the *Guidelines for Failure Impact Assessment for Water Dams* (DNRW 2002). There are no residences, buildings or public roads downstream of Dam C that would be at risk of flooding.

“Impact benchmarking” methods that assess levels of change from modelled or measured predevelopment annual flow statistics have been used to consider risk to flow-dependent ecological assets including estuaries in subtropical Queensland (Brizga 2000, Hydrobiology 2008). These methods considered changes of >20% in mean annual flow and other annual flow statistics as having the potential for “class 2” impacts on flow-dependent ecological assets, i.e. they represent “values above which assessed sites are more likely to have major/very major impacts of water resource development on geomorphological and/or ecological conditions” (Brizga 2000). The relevance of this benchmarking method to tropical aquatic ecosystems in the Project area has not been demonstrated but, in the absence of more specific science, it may be considered indicative.

The indicative threshold for “class 1” (no/minor) impacts to downstream ecological and geomorphological conditions used by Brizga (2000) is a reduction up to 16% of mean annual flow. The overall maximum decline in mean annual flow to the Norman Creek estuary is 15% at 50 Mdptpa.

Modelling indicates the timing and relative magnitude of the March peak flow event is maintained despite the presence of Dam C. Mean monthly flows to the receiving estuary are generally maintained above 80% of pre-impact flows for the core wet season period, impacts on wet season primary productivity and fisheries recruitment in the estuary, if they occur, are predicted to be small (RTA 2011).

Direct Pumping

To maintain the reliability of the overall surface water supply at production rates between 30Mdptpa and 50Mdptpa and supplement the Dam C supply, some water would be pumped directly from the lower reaches of the Ward River (refer **Figure 2-5** for location of pump). Water could be pumped via a pipeline corridor to either the Norman Creek or Boyd beneficiation plants.

The annual volume of water pumped from the Ward River would be capped at 1% of mean annual river flow at the pump station (2.67GL). In addition, no pumping would occur when Ward River flow was less than 1,000L/s and the rate of pumping at all times would be less than 20% of the river flow rate.

The GoldSim daily water balance model was used to estimate Ward River flow at the pump station and the pumped volumes. The downstream flow (river flow minus pumped volumes) was compared to the upstream flow to evaluate the effect of the pumping on the hydrological regime. The effect of the pumping on downstream monthly flow is summarised in **Table 16-17**.

Table 16-17 Effect of Pumping from Ward River on Monthly Downstream Flow

Month	Upstream Mean Monthly Flow (GL)	Mean Volume Pumped (GL)	Decrease in Downstream Flow (at 50Mdptpa Production)			
			Mean	10th percentile	Median	90th percentile
January	25.01	0.49	–2.0%	–4.3%	–2.4%	–1.2%
February	59.46	0.36	–0.6%	–0.2%	–0.8%	–0.6%
March	73.60	0.11	–0.1%	0%	0%	–0.4%
April	55.07	0.02	0%	0%	0%	0%
May	29.75	0.08	–0.3%	0%	0%	–0.7%
June	13.47	0.35	–2.6%	–1.8%	–3.0%	–2.4%
July	4.84	0.80	–16.6%	–3.1%	–17.1%	–17.6%
August	0.88	0.03	–3.2%	0%	0%	–4.6%
September	0.03	0	0%	0%	0%	0%
October	0.04	0.001	–3.2%	0%	0%	0%
November	0.51	0.03	–5.3%	0%	0%	–3.1%
December	4.87	0.23	–4.8%	0%	–2.3%	–6.4%
Annual (at pump station)	267.5	2.50	–0.9%	–1.4%	–1.0%	–0.7%
Annual flow to estuary	567.3	2.50	–0.4%	–0.6%	–0.5%	–0.3%

July is the only month when pumped volumes exceed 10% of monthly river flow and this reduction is well within the normal seasonal monthly flow variation. The natural 10th percentile flow for July (0.96GL) is 80% less than mean flow (4.84GL). The effect of pumping at the 30Mdptpa and 50Mdptpa production rates is to reduce mean annual flow immediately downstream of the pump station by a very small amount (0.8% and 0.9% of original flow respectively). The overall impact of pumping on the Ward River hydrological regime is minor.

In the past, a separate 6.5Mdptpa bauxite mining project (the discontinued Aurukun Bauxite Project) was proposed by Chalco within the catchment of the Ward River estuary (GHD 2007a). In June 2010 the Queensland Government announced that the development agreement which would have facilitated the mine had come to an end. However, in February 2013 the State of Queensland sought expressions of interest from companies interested in developing the Aurukun Bauxite Resource.

Assuming the surface operational water demands for the potential future development of the Aurukun Bauxite Resource (based the discontinued Aurukun Bauxite Project) would be proportional to the 25Mdptpa Norman Creek beneficiation plant surface water demands, the demand would be 4.2GL per annum. If this demand was met from a dam on a tributary of the Ward River, the cumulative overall decline in mean annual discharge to the Ward River estuary would be very minor (about 1.2%) and well within natural seasonal variation.

16.2.4 Mining and Catchment Hydrology

To assess the effect of mining on the discharge from catchments subject to mining, rainfall–runoff characteristics of undisturbed, active mine and rehabilitated areas need to be estimated. The AWBM rainfall–runoff model was used to determine the water balance characteristics of the undisturbed catchment and of open mining areas. A study of recharge characteristics of undisturbed, mined and rehabilitated land at Weipa by Volker and Crees (1993) found there were no long-term major changes to the recharge of the shallow aquifer once vegetation was fully re-established. Hence, for the purposes of estimating impacts on catchment discharge, water balance characteristics for immature rehabilitation (<15 years old) and mature rehabilitation (≥15 years old) were interpolated between the undisturbed and fully disturbed AWBM cases. These characteristics are summarised in **Table 16-18**.

Table 16-18 SoE Project AWBM Water Balance Characteristics

Water Balance Component		Undisturbed	Open Mining Area	Immature Rehabilitation	Mature Rehabilitation
Evapotranspiration	mm	735	615	724	747
	%	42.6%	35.3%	41.6%	42.9%
Surface Runoff	mm	10	23	5	3
	%	0.6%	1.3%	0.3%	0.2%
Baseflow	mm	843	905	820	801
	%	48.0%	52.0%	47.1%	46.0%
Deep baseflow / recharge	mm	153	198	192	190
	%	8.8%	11.4%	11.0%	10.9%

The active mining area exhibits the largest change from the “undisturbed” situation. Internal in-pit surface runoff increases due to compaction from mining equipment traffic. However, although such runoff ponds in low spots, not much spills to the external catchment as the geometry of the pit provides a large sump. Rather, the extra in-pit runoff infiltrates and leads to increased baseflow. Without vegetation, annualised evapotranspiration declines.

In the “immature” rehabilitation situation, the rainfall partitioning pattern shifts partway back toward the “undisturbed” situation and this trend continues with the “mature” rehabilitation. However, the mature rehabilitation situation does not quite return completely to the “undisturbed” state because the residual post-mine topography still “traps” a little extra rainfall.

For each main catchment within which mining is planned, the annual discharge of the catchment was estimated for the following situations:

- undisturbed;
- maximum footprint of mining (i.e. largest footprint of open mining area and previously rehabilitated area); and,
- post-mine closure (i.e. when all rehabilitated disturbed areas are mature).

The catchment discharge is the sum of the surface runoff and baseflow and is dominated by the baseflow component.

A summary of the annual catchment discharges is presented in **Table 16-19**.

The Ina Creek catchment has the largest proportion of area mined but the overall change to average annual discharge is very small (–1.2% at maximum mining impact; –2.9% post-closure). There are only very small changes to the discharge from the overall Norman Creek system (–1.1% at maximum mining impact; –1.9% post-closure) and overall Ward River system (–0.1% at maximum mining impact; –0.4% post-closure).

The discontinued Aurukun Bauxite Project proposal (GHD 2007a) was located in the catchment of the Ward River estuary. While the Queensland Government announced in June 2010 that the development agreement which would have facilitated the mine had come to an end, the Queensland Government has sought expressions of interest from companies interested in developing the Aurukun Bauxite Resource. An estimate of cumulative impact has been undertaken assuming a similar project to the discontinued Aurukun Bauxite Project was undertaken simultaneously with the SoE Project.

In the absence of publicly stated areas of disturbance, estimations of mining disturbance associated with the potential development of the Aurukun Bauxite Resource were calculated using publicly available information on bauxite reserves. It is predicted this mining disturbance would total approximately 9,300ha. This would increase the potential aggregate mining disturbance in the Ward River estuary catchment to 13,950ha but would have a very minor change on the annual discharge from the overall Ward system (–0.5% at maximum mining impact; –1.1% post-closure).

The Ward River catchment makes up a minor part (3.8%) of the catchment of the Archer Bay Aggregation along with the Watson and Archer Rivers. The Project would not have any impact on the Watson River or Archer River and therefore the impact on discharge to the Archer Bay Aggregation would also be very minor, if any.

The modelling indicates the overall impact of mining on catchment discharge is very much less than the normal year-to-year variation driven by rainfall variation. This is consistent with the calibrated rainfall–runoff model which shows that surface runoff is extremely low and hence changes to surface drainage patterns have little impact on overall discharge into streams.

Table 16-19 Impact of Mining on Catchment Discharge

Sub-catchment	Total Area (ha)	Undisturbed (ha)	Open Pit (ha)	Immature Rehabilitation (ha)	Mature Rehabilitation (ha)	Mean Flow From Catchment (GL)	Flow as % of Pre-Mine
Undisturbed Catchment (pre-mining)							
Triluck Creek	10,840	10,840	0	0	0	92	100%
Winda Winda Creek	9,385	9,385	0	0	0	80	100%
Whole Norman System	25,902	25,902	0	0	0	221	100%
Ina Creek	6,542	6,542	0	0	0	56	100%
Ward River Sub-catchment	18,687	1,8687	0	0	0	159	100%
Coconut Creek	11,918	11,918	0	0	0	102	100%
Whole Ward System	66,581	66,581	0	0	0	568	100%
Total	119,250	119,250	0	0	0	1,017	100%
Maximum Footprint within Sub-catchment							
Triluck Creek	10,840	7,458	540	1,421	1,421	92	99.3%
Winda Winda Creek	9,385	8,234	270	441	441	80	99.8%
Whole Norman System	25,902	17,394	810	3,849	3,894	219	98.9%
Ina Creek	6,542	3,243	540	1,380	1,380	55	98.8%
Ward River	18,687	15,391	540	1,378	1,378	158	99.6%
Coconut Creek	11,918	10,567	405	473	473	102	99.9%
Whole Ward System	66,581	61,934	945	1,851	1,851	567	99.9%
Total	119,250	98,263	3,105	8,941	8,941	1,013	99.3%
Post Mine Closure							
Triluck Creek	10,840	7,458	0	0	3,382	91	98.2%
Winda Winda Creek	9,385	8,234	0	0	1,151	80	99.3%

Sub-catchment	Total Area (ha)	Undisturbed (ha)	Open Pit (ha)	Immature Rehabilitation (ha)	Mature Rehabilitation (ha)	Mean Flow From Catchment (GL)	Flow as % of Pre-Mine
Whole Norman System	25902	17,394	0	0	8,508	217	98.1%
Ina Creek	6,542	3.243	0	0	3,299	54	97.1%
Ward River	18,687	15,391	0	0	3,296	157	99.0%
Coconut Creek	11,918	10,567	0	0	1,351	101	99.4%
Whole Ward System	66,581	61,934	0	0	4,647	561	99.6%
Total	119,250	98,263	0	0	20,987	1,007	99.0%

Impact of Mining on Flood Events

Wet season inundation of floodplains resulting of overtopping of the main channel banks is a seasonal characteristic of the area. There are no buildings or public roads downstream of the mining areas that would be at risk of flooding. The main impact of seasonal flooding is restricted access for vehicles rather than flood damage.

Mining would not increase the risk of flooding as the geometry of pits provides a large sump, resulting in infiltration rather than runoff to the external catchment.

16.2.5 Surface Water Quality Impacts

The environmental values of waters to be protected (Queensland EPP (Water)) are:

- biological integrity of a slightly modified aquatic ecosystem;
- suitability for recreational use;
- suitability for minimal treatment before supply as drinking water;
- suitability for agricultural use; and,
- suitability for industrial use.

Proposed mining activities may result in impacts on surface water quality. The two potential impacts are sedimentation and contamination, which are discussed below.

Clearing of vegetation would be scheduled to follow the wet season when the soil profile at depth has sufficient moisture to facilitate the pushing over of trees by a bulldozer. Soil stripping would not occur during wet periods in order to minimise soil compaction and the potential for erosion. Due to the flat topography, stormwater runoff generated within active mine areas would be predominantly contained within the internally draining mine pits (see **Section 16.2.2**). Some elevated sediment concentrations are expected to occur in stormwater runoff from ore processing and stockpile areas, and such runoff would be directed to sediment control structures (see **Figures 16-5** and **16-6**). In addition, turbidity would be regularly monitored in surface waters (refer **Section 16.5.1**) to provide an early indicator of any potential impacts.

Mining activities may potentially introduce contaminants to surface waters via the following:

- hydrocarbon spills;
- sewage;
- mining, processing and handling – release of contaminants from crude ore, process water, or runoff from ore stockpiles; or,
- ore spills from shiploading.

Hydrocarbons (fuel and lubricants) would be transported from Weipa in road tankers, via barge and the mine access road, to the mine infrastructure areas. Small volumes would be stored in bunded on-site tanks in accordance with Australian Standard AS1940.

The construction camp and Boyd and Norman Creek infrastructure areas would be serviced by separate gravity-fed package STPs. The treated sewerage effluent from the construction camp would be treated to Class A standard (as defined in Schedule 3D of the Public Health Regulation 2005). During construction treated effluent from the construction camp STP would be recycled for use in irrigation of landscaped areas in the construction camp as well for dust suppression and earthwork compaction during construction in the Boyd infrastructure area, the mine access road, infrastructure corridor, Dam C and the TSFs. Treated sewage effluent released to land would be monitored to ensure it meets the contaminant release limits described in the environmental authority. During operations, treated effluent from the Boyd and Norman Creek STPs would be transferred to the process water ponds Mine Industrial Area Drainage slots and recycled. Any water released from the Mine Industrial Area Drainage slots shall be monitored and must meet the conditions of the EA under the EP Act.

Bauxite is formed in an environment of extreme weathering and does not have any potential to release acid mine drainage or saline leachate. A range of analyses were carried out on crude ore, product ore and tailings (refer **Section 3.5.4**). The results show:

- metals are not significantly enriched compared to average crustal abundance;
- tailings are not hazardous waste according to EHP (2012b) guidelines;
- arsenic, boron, chromium, cobalt, copper, lead, nickel, selenium, zinc and mercury concentrations are very low and are not considered potential constituents of concern; and,
- the concentration of aluminium in tailings leachate (10µg/L) and ore leachate (<10µg/L) was lower than the median of freshwater streams from the Project area (18µg/L).

Based on these results, leaching from ore or tailings is not anticipated to have an adverse effect on surface or groundwater quality.

A range of measures are proposed to reduce the likelihood of spills while ship loading (refer **Section 3.7.3**). Bauxite is non-hazardous does not leach metals in seawater (refer **Section 3.5.4**). There is negligible risk of spilled material adversely affecting marine water quality.

A range of metals would be regularly monitored in surface waters (refer **Section 16.5.1**) to provide an early indicator of any potential impacts.

16.2.6 Regulatory Requirements

The *Water Act 2000* (Qld) regulates the use of surface waters and the interference with watercourses, lakes or springs. Pre-existing rights for taking and interfering with water are held under section 1037A of the *Water Act 2000* due to the *Commonwealth Aluminium Corporation Limited Agreement Act 1957* (Qld) (Comalco Agreement Act). Taking and interfering with water for the Project would be undertaken pursuant to pre-existing rights or further approvals, where required.

The Cape York Peninsula Moratorium Area has been declared under the *Water Act 2000*. It covers most of northern Cape York, including the Project area south of Boyd Point. The Moratorium restricts the type and volume of new Water Licences that can be issued under the *Water Act 2000* while the Moratorium is in force. The Moratorium recognises RTA's pre-existing rights under the Comalco Agreement Act.

Dam C has had a dam failure impact assessment in accordance the Guidelines for Failure Impact Assessment for Water Dams (DNRW 2002). The dam does not have a population at risk located downstream of the dam wall and would not be a referrable dam under the *Water Supply (Safety & Reliability) Act 2008* (Qld).

16.3 Groundwater

16.3.1 Regional Hydrogeology

Environmental Values

The environmental values of waters to be protected (Queensland EPP (Water)) are:

- biological integrity of an aquatic ecosystem;
- suitability for agricultural use; and,
- suitability for industrial use.

Hydrogeology

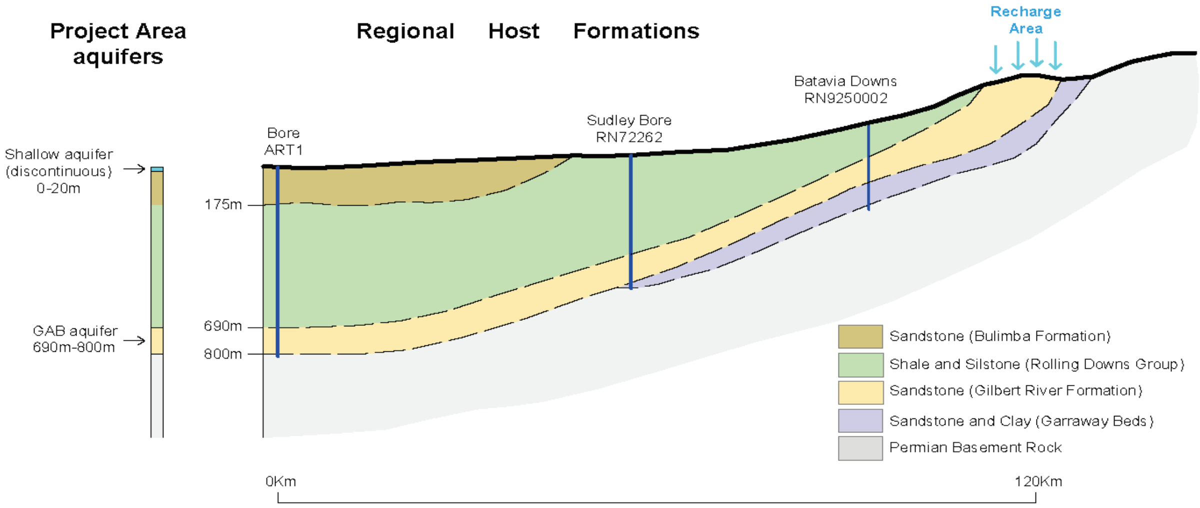
This section describes the key sources of groundwater in the Western Cape region. The geology of the Project area is represented by the following geological units, which are listed in descending stratigraphic order:

- coastal dunes;
- estuarine and delta deposits;
- Ferruginous duricrust, including bauxite (the Aurukun Surface which is derived from laterised Bulimba Formation). This formation is part of the Wyaaba beds;
- Bulimba Formation;
- Rolling Downs Group;
- Gilbert River Formation;
- Garraway Beds; and,
- Permian Basement Rock.

The contact between the bauxite and sandstone Bulimba Formation is a transitional zone consisting of kaolinite clay.

The groundwater bodies in the area have been differentiated as shallow aquifer and artesian aquifer resources. The artesian resources are hosted within the Gilbert River formation and Garraway Beds, and the shallow aquifer resources are those occurring within the formations above the Rolling Downs Group. A conceptual hydrogeological cross section for the superficial formations from east to west across the Project area is shown in **Figure 16-15**.

Figure 16-15 Cross Section through Artesian Host Formations



Shallow aquifers

The coastal dunes and estuarine and delta deposits do not provide a viable groundwater resource, as extraction is difficult due to the fine-grained nature of the sediments. Furthermore, the saline conditions and risk of saltwater intrusion are key factors against development of the coastal aquifers (CSIRO 2009).

The Ferruginous duricrust (bauxite) consists of medium to coarse ferruginous gravel in clayey matrix. This formation is highly permeable and is usually unsaturated, with the water table residing in the underlying Bulimba Formation (CSIRO 2009).

The bauxite overlies a kaolinite clay layer, which is part of the Bulimba Formation and contains kaolinite clay, to layers of fine clayey sand, to fine sands. This unit is generally of low permeability and is characterised as an aquitard, with some poor aquifer units of moderate permeability present. The kaolinite clays typically contain macropores which allow preferential flow.

The Bulimba Formation hosts a high yielding shallow aquifer which is an important resource over the Weipa Peninsula. It contains groundwater suitable for industrial and domestic use. Aquifers are typically constrained to old stream channels which trend easterly and meander through a matrix of clayey, less transmissive sediments and hence are not continuous and not always in hydraulic connection with one another. Recharge occurs where the Bulimba Formation outcrops. Discharge occurs as baseflow to creeks, which helps maintain flow into the dry season (CSIRO 2009).

The shallow aquifers in the Project area are not as uniform as those used to supply existing RTA mining operations north of the Embley River and tend to be poorly developed and discontinuous.

The shallow aquifers are separated from the artesian aquifers by mudstones of the Rolling Downs Group (refer **Figure 16-15**). The Rolling Downs Group is a predominantly argillaceous confining unit which ranges in thickness from approximately 500m to 900m in the area of the Gilbert and Staaten Rivers (AGNWC 2009). The Geoscience Australia Geological Provinces Interactive Mapping System “Rolling Downs Group” shows the confining unit is 500m thick in the vicinity of the Project area.

Artesian aquifers

The Gilbert River Formation is part of the GAB aquifers and is the main artesian groundwater resource in the region. The Gilbert River Formation aquifer is present across the entire Western Cape region, west of the Great Dividing Range. It comprises fine to coarse-grained quartzose sandstone with pebble conglomerate and siltstone. Within the Project area this formation is artesian and is confined by the mudstones of the overlying Rolling Downs Group. The confining layer has low hydraulic conductivity and holds groundwater within the artesian aquifers under pressure. It is capable of supporting a large rate of abstraction. Habermehl (1980 in GABCC (2010)) cites the average vertical conductivities of the Rolling Downs confining Beds as being in the range of 10-6 to 10-9m/s. The transient groundwater model of the GAB developed by Welsh (2006) gave a vertical leakage rate of 2.58 x10-6m/day (0.942mm/year) out of the artesian aquifer. The Garraway Beds underlie the Gilbert River Formation in the Project area. The Garraway Beds are similar to the Gilbert River Formation in lithology and artesian groundwater is also present in this unit. In relation to water resources management, the Gilbert River Formation and Garraway Beds are considered equivalents and are managed as one unit.

16.3.2 Shallow Aquifer

The shallow aquifer in the Project area has been investigated through groundwater level monitoring and aquifer parameter tests. Investigative boreholes were installed in 2006 (25 bores) and 2007 (19 bores) in the Project area. A sub-set of bores has been selected for ongoing monitoring. The location of bores is shown in **Figure 16-16.** Four monitoring bores were equipped with dataloggers to monitor water level continuously (MB01, MB02, MB03, MB04) and the rest were manually measured.

The bauxite layer is present typically as a laminate overlying the kaolinite layer within which poorly developed and discrete aquifers are present. As a consequence, the shallow aquifers are not as uniform as those used to supply operations on the Weipa Peninsula. Aquifer parameter testing was carried out using airlift pump out tests and falling head tests. Low yields were recorded at all of the bores tested with the exception of MB04 and SOE10 where discharges of 0.5L/s and 1.0L/s respectively were measured over 30-minute trials. The low yields mean the shallow aquifer is not proposed to be used as a water supply source for the Project.

The hydraulic conductivities measured in falling head trials vary between 0.007 and 1.9m/d across the range of monitoring bores tested. Given the shallow aquifer depths, these conductivities indicate minimal transmissivities, which result in low groundwater flows and poor yields in the vicinity of the bores tested.

Localised semi-permanent baseflow into streams and tree swamps was observed, even at the end of the dry season. This indicates that although the extent of the shallow aquifers might be limited in places, the aquifer parameters such as storativity and transmissivity are highly variable, and are capable of supporting high baseflows at specific locations, including tree swamps.

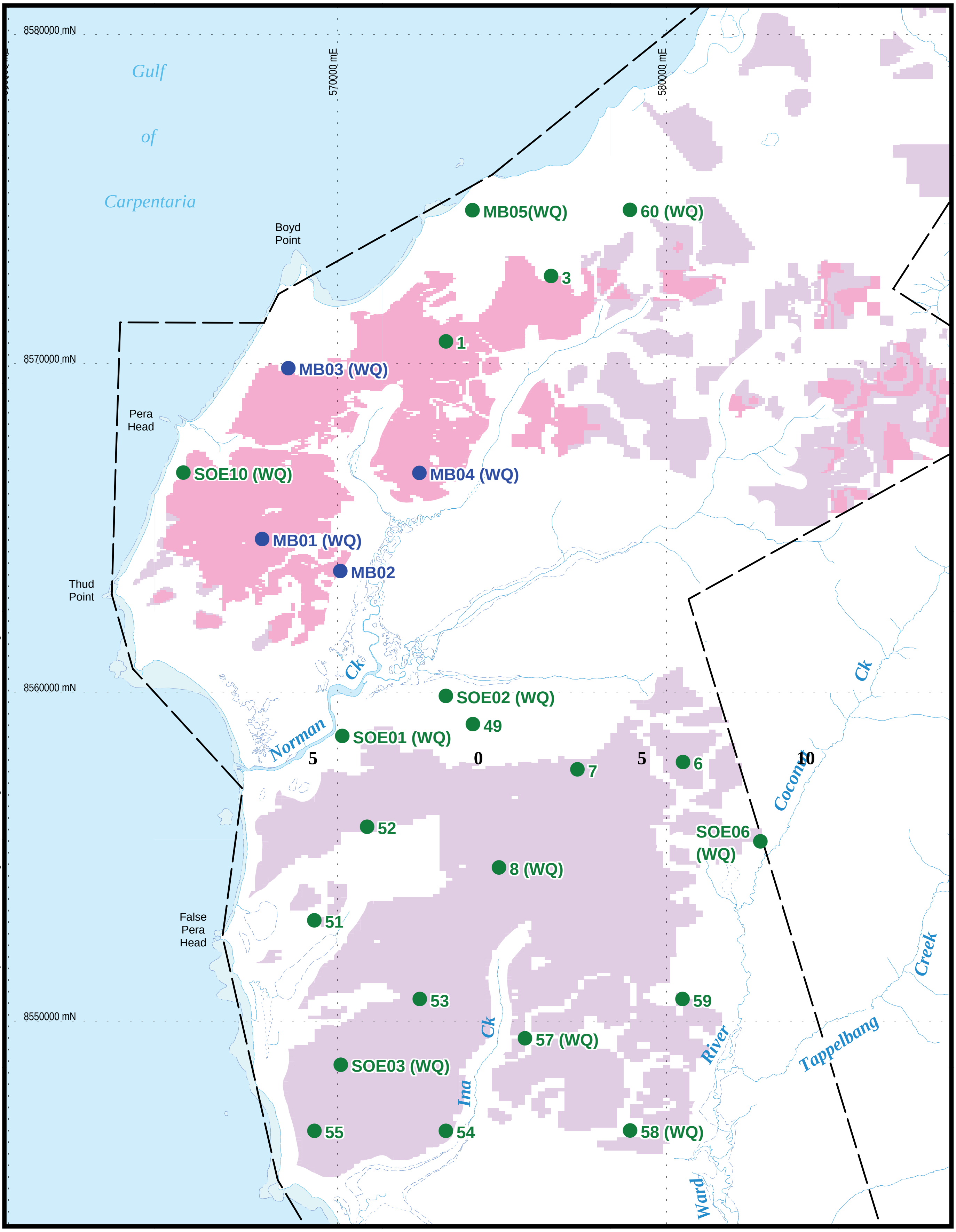
This is consistent with the explanatory notes for the Weipa 1:250 000 scale geological map sheet SD/54-3 from the Bureau of Mineral Resources, Geology and Geophysics, which suggests permeabilities across the area may be influenced by the original depositional conditions. Buried stream channels running east–west can be expected to provide zones of higher permeability. Piezometric contour maps of the shallow aquifer indicate a general groundwater flow direction from east to west (RTA 2011).

There is a large seasonal influence on the level of the water table. The maximum and minimum water table levels recorded in each groundwater monitoring bore are shown in relation to the bauxite layer in **Table 16-20**. This data shows that the water table rises above the base of the bauxite infrequently.

The seasonal response of groundwater level to rain in the continuously monitored bores (MB01, MB02, MB03 and MB04) is shown in **Figure 16-17** to **Figure 16-20**.

The 2007–2008 year was one of average rainfall (1,758mm) and the water table rose above the base of the bauxite temporarily, at the height of the wet season, in two of the four monitoring bores. The 2006–2007 and 2008–2009 years had below average rainfall and 2009-2010 was above average. The response of the water table to rainfall is very similar to the response of streamflow to rainfall (refer **Figure 16-4**) and shows:

- the “soil” water store has to “wet up” before there is a rise in the water table;
- once that happens, there is a rapid response to incident rainfall; and,
- peak wet season water table levels vary with incident rainfall, but the end of dry season water table levels are less variable and tend to return to a similar level each year.



P:\RTA\Plans\SoE\2012\MNES Assesment Report\Final Numbering\Section 16\Fig 16-16 Groundwater Monitoring Locations.wor

RioTintoAlcan

RTA Mining Lease boundary
Road/track
Groundwater level monitoring bore
Groundwater level monitoring bore (with data logger)
(WQ) Water quality sampling location
Mining Years 1 -13
Mining Years 14 - 40

South of Embley Project

Fig. 16-16: Groundwater Monitoring Locations

N
0 5
Datum/Projection: GDA94/MGA Zone 54
Date: 26/07/2012

Table 16-20 Monitoring Bore Network

Bore ID	Easting (m MGA94)	Northing (m MGA94)	Date Completed	Bore Depth (mbRP)	Collar Ground Level (mRL)	Top of Bauxite (mRL)	Base of Bauxite (mRL)	Max Groundwater Level		Min Groundwater Level	
								mRL	Month*	mRL	Month*
1	573297	8570666	3 July 06	24.5	63.66	62.4	56.2	43.6	June 08	39.2	Sept 07
3	576494	8572656	4 July 06	25.1	42.15	41.9	40.7	22.3	June 08	20.4	Oct 07
6	580501	8557870	6 July 06	24.8	46.43	45.7	42.2	35.7	Mar 09	27.8	Sept 07
7	577290	8557654	6 July 06	24.3	42.96	41.5	39.5	31.0	June 08	18.2	June 06
8	574907	8554670	6 July 06	24.3	43.45	42.9	39.5	36.0	Mar 09	30.8	Nov 07
49	574116	8559026	8 July 06	24.6	20.44	20.2	14.7	6.2	June 08	4.6	Sept 07
51	569296	8553060	9 July 06	25.4	11.95	11.5	7.3	6.5	June 08	0.4	Sept 07
52	570901	8555906	9 July 06	25.2	20.85	20.6	17.4	14.9	June 08	8.9	Sept 07
53	572500	8550672	9 July 06	25.2	28.20	27.9	23.5	19.0	Mar 08	14.8	Oct 07
54	573294	8546664	10 July 06	24.3	12.86	No bauxite		3.4	June 08	1.2	Oct 07
55	568492	8546664	10 July 06	22.4	9.94	9.4	5.7	1.7	June 08	-1.1	Nov 07
57	575698	8549480	11 July 06	24.7	30.03	29.7	26.3	22.4	June 08	17.4	Nov 07
58	578893	8546668	11 July 06	25.1	27.80	27.3	21.1	15.1	June 08	11.5	Nov 07
59	580486	8550668	11 July 06	24.9	31.99	31.7	27.4	16.7	June 08	15.2	Oct 07
60	578889	8574664	13 July 06	25.1	45.00	No bauxite		30.3	Aug 09	28.7	Oct 07
MB01	567707	8564656	20 July 06	17.8	24.00	23.7	20.0	18.1	Mar 08	8.8	Feb 08
MB02	570084	8563676	20 July 06	25.5	7.20	6.9	3.9	4.3	Feb 08	–0.7	Nov 07
MB03	568505	8569852	04 Jul 06	21.2	27.02	25.8	25.3	20.0	Apr 08	8.3	Nov 07
MB04	572490	8566660	04 July 06	23.4	17.81	17.3	11.3	12.5	Mar 08	5.8	Feb 08
MB05	574102	8574656	04 July 06	~25	9.52	9.3	4.5	1.9	Aug 09	0	Mar 09
SOE01	570143	8558682	5 Oct 07	38.0	7.31	6.3	1.3	1.0	June 08	0	Nov 07
SOE02	573293	8559886	6 Oct 07	28.0	8.07	7.1	3.1	3.3	June 08	–0.1	Nov 07
SOE03	570101	8548670	21 Oct 07	26.0	16.74	16.2	10.7	8.0	Mar 09	0.1	Nov 07
SOE06	582855	8555462	8 Oct 07	23.0	23.28	22.5	17.3	23.0	Mar 09	9.0	Nov 07
SOE10	565313	8566680	26 Oct 07	31.0	18.81	18.6	13.6	8.4	June 08	4.5	Mar 09

Figure 16-17 Groundwater Level in Response to Rainfall – MB01

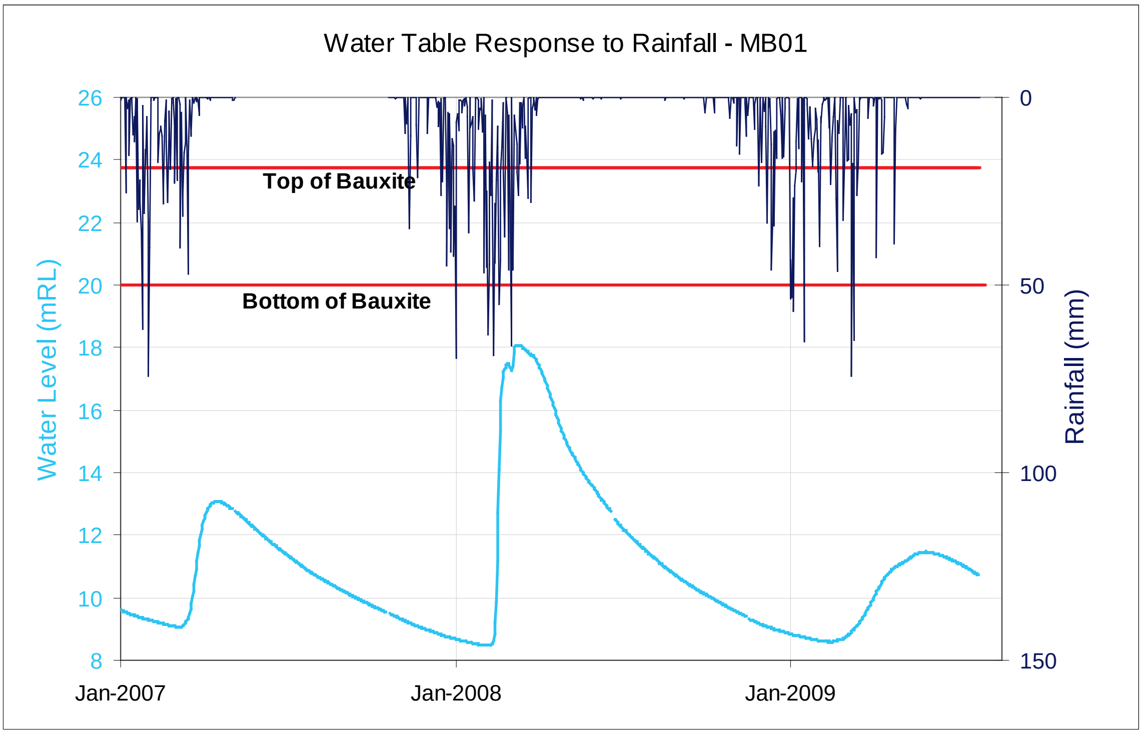


Figure 16-18 Groundwater Level in Response to Rainfall – MB02

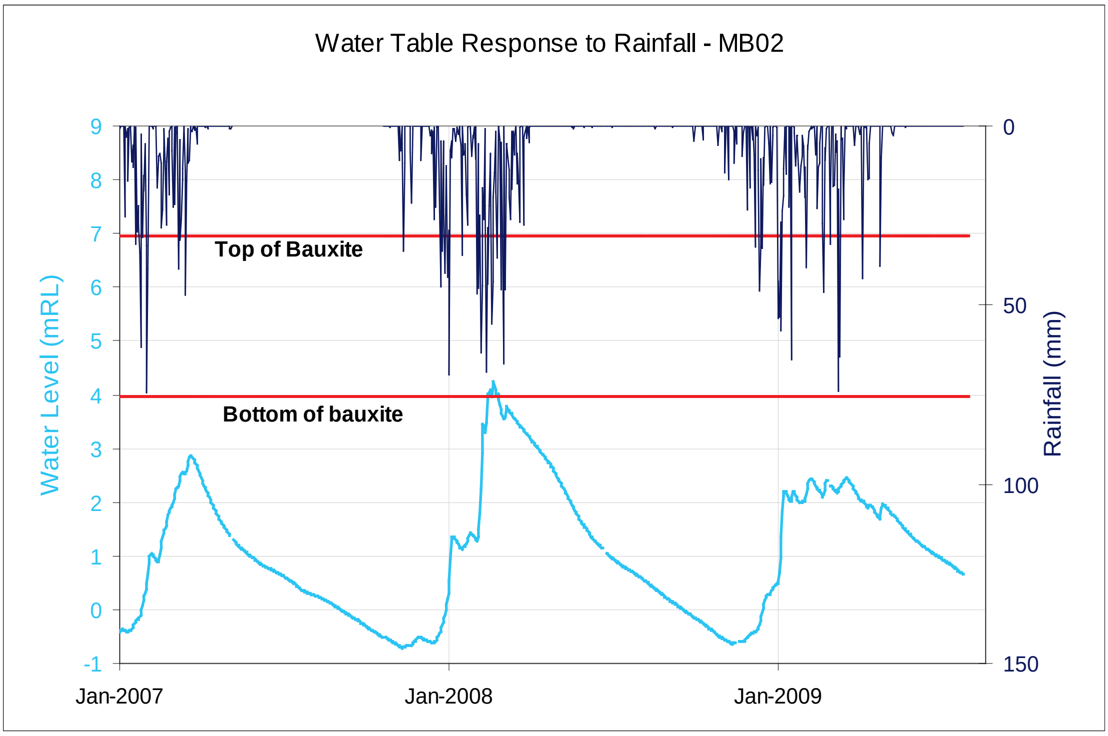


Figure 16-19 Groundwater Level in Response to Rainfall – MB03

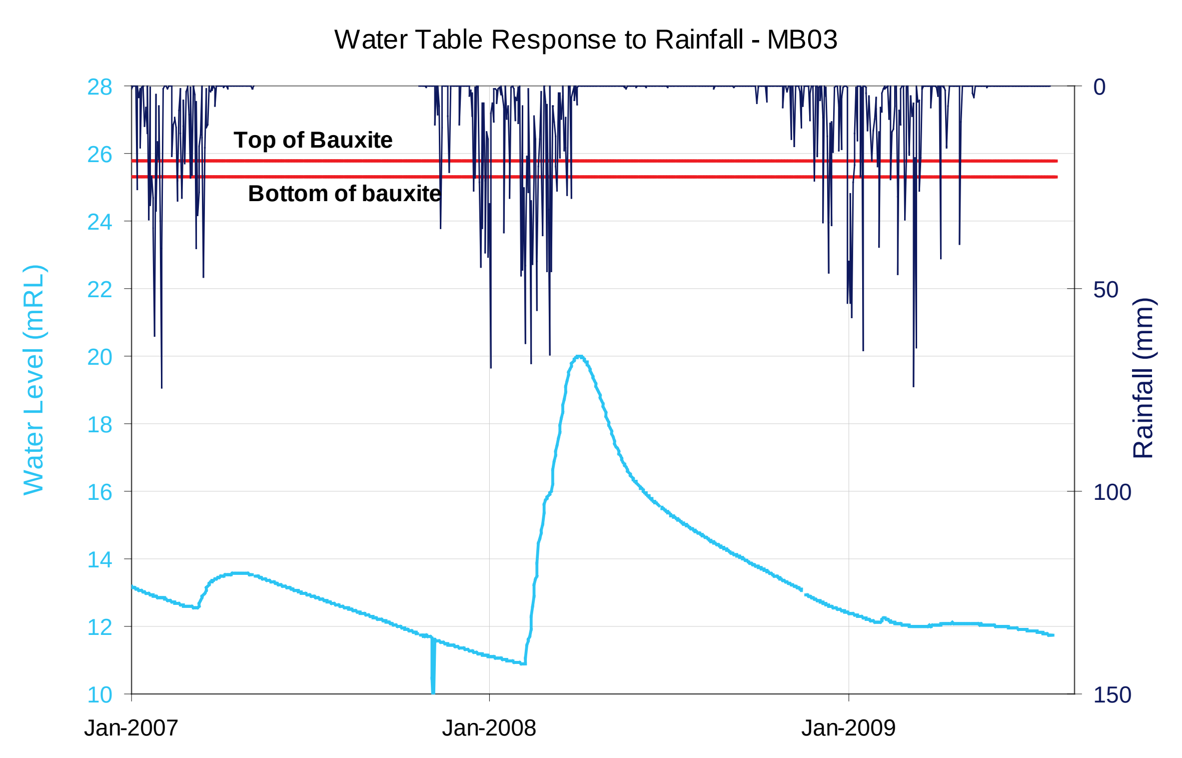
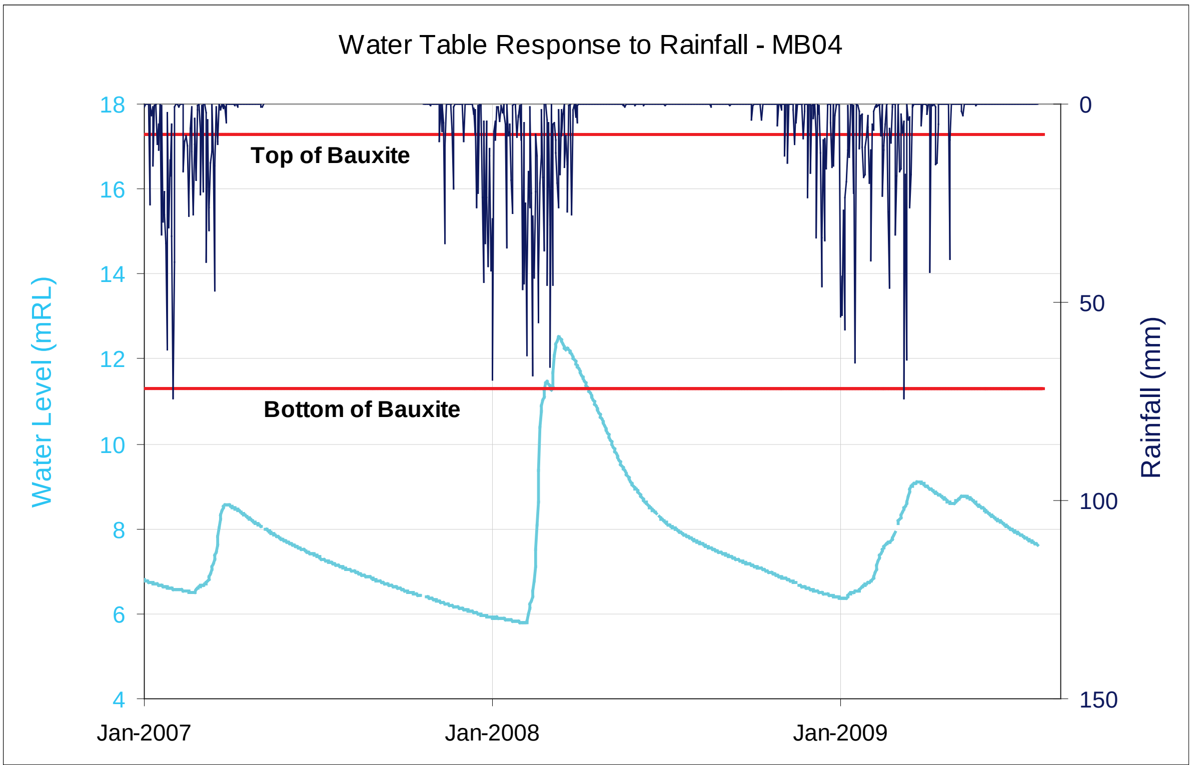


Figure 16-20 Groundwater Level in Response to Rainfall – MB04



The available data on groundwater levels indicates the kaolinitic layer below the bauxite is generally hosting the shallow aquifer during the dry season. Hence, in situations where streamflow extends well into the dry season, it is unlikely this is due to baseflow originating from the bauxite.

The potentiometric surface of the shallow aquifer generally follows the surface topography.

16.3.3 Shallow Groundwater Quality

This section describes existing shallow groundwater quality conditions in the Project area. To provide a spatial representation of groundwater quality across the Project area, 13 monitoring bores were selected for sampling. Locations are shown in **Figure 16-16**. All bores were sampled at the end of the dry season in November 2007. Two bores were sampled again in June 2008. Laboratory results are summarised in **Table 16-21**.

Generally, the pH of water in all bores was acidic to slightly acidic, with a range of 3.9 to 6.5. Such acidic groundwater is typical of leached, tropical environments that have a relatively rapid recharge through rainfall and a low residence time, such as the Project area.

Generally, all bores contained freshwater, with exceptions noted below. Bore SOE01 was saline with a field EC measurement of 21,600µS/cm. This bore is located about 3.5km from the coast upstream along Norman Creek, a section that is still tidally influenced. Bores MB05, SoE02, SoE06, SoE03 and 57 were brackish with a measured EC of 635 to 1,330µS/cm.

In freshwater bores sampled, hardness ranged from <1.0 to 6mg/L $CaCO_3$. The soft water is consistent with Project area fresh surface waters where hardness ranged from 0.4 to 9mg/L $CaCO_3$. Hardness ranged from 14 to 168mg/L $CaCO_3$ in brackish groundwaters with a maximum of 54,530mg/L $CaCO_3$ in the saline groundwater of bore SoE01. These ranges are comparable to Project area surface waters with corresponding salinities.

Mercury was not detected at concentrations greater than the laboratory reporting limit in any samples. The concentration of dissolved arsenic, chromium and lead was less than the laboratory reporting limit or very low. The following maximum concentrations in groundwater samples were recorded: arsenic 3µg/L, chromium 0.5µg/L and lead 1.0µg/L.

The concentration of dissolved cadmium in groundwater was less than the laboratory reporting limit in samples from eight locations and reported at low levels in samples from four locations, with a maximum of 0.27µg/L. A concentration of 13.4µg/L dissolved cadmium was reported in the sample from location 57. This was one of two samples that were not filtered until the sample arrived at the laboratory and the result is suspected to be anomalous.

The concentration of dissolved iron in brackish samples was generally greater than that of fresh groundwaters. The concentration of dissolved iron in brackish groundwater ranged from <2 to 1,030µg/L, which is also greater than the range for Project estuarine surface waters (0.5 to 86µg/L). The concentration of dissolved iron in fresh groundwater ranged from <2 to 107µg/L, which is less than the range of Project area fresh surface water streams (2 to 553µg/L).

The concentration of dissolved manganese in fresh groundwater ranged from <0.5 to 11.7µg/L, comparable to the range of Project area fresh surface waters (0.02 to 80µg/L). The concentration of dissolved manganese in brackish groundwater ranged from 8.7 to 867µg/L, greater than the maximum estuarine surface water value of 8.7µg/L.

Table 16-21 SoE Project Groundwater Quality Results

Analyte	Lab/ Units	SOE10	MB01	MB03			MB04			MB05	SOE02	SOE01	8	SOE06	58	57	60	SOE03
		Nov 07	Nov 07	Nov 07	Jun 08		Nov 07	Jun 08		Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07
		ALS	ALS	ALS	ALS	CSIRO	ALS	ALS	CSIRO	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS
ph field	pH Unit	5.15	5.12	4.75			5.08			4.87	4.58	6.48	4.59	5.55	4.55	2.58	5.11	3.54
pH Value	pH Unit	6.19	6.16	5.84	4.95		6.08	5.53		6.01	5.76	6.96	5.96	6.52	5.79	5.76	6.18	3.89
Field EC	µS/cm	89	58	66			47			920	960	21600	31	1330	53.	890	68	635
Lab EC	µS/cm	65	44	49	53		29	28		729	682	11000	23	1050	21	18	54	499
TDS	mg/L	34	2.0	20	35		12	20		422	348	15800	4	1220	68	34	174	268
Suspended Solids (SS)	mg/L	27	432	3020	59		581	75		287	174	110	80	564	738	78	1540	10
Turbidity	NTU	1.1	200	700	2.5		120	3.5		60	17	33	26	28	800	31	1000	2.9
Field Temp.	°C	28.5	29.1	29.2			28.8			28.6	28.6	29.3	30.8	30.1	29.2	28.9	31.1	29.1
Total Hardness	as mg/L CaCO3	<1	6	4	<1		5	<1		94	14	5430	<1	168	<1	<1	<1	45
Hydroxide Alkalinity	as mg/L CaCO3	<1	<1	<1	<1		<1	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity	as mg/L CaCO3	<1	<1	<1	<1		<1	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1
Total Alkalinity	as mg/L CaCO3	8.0	13.0	6.0	2.0		9.0	3.0		9.0	5.0	123.0	6.0	144	4.0	4.0	20.0	<1
Major Anions																		
Sulphate as SO4 2-	mg/L	<1	<1	1.0	<1		<1	<1		27.0	8.0	800	<1	128	<1	<1	1.0	42.0
Chloride	mg/L		14.0	14.0	9.0		8.0	6.0		196	182	6460	8	201	8.0	8.0	8.0	108
Major Cations																		
Ca	mg/L	<1	2.0	2.0	<1		2.0	<1		8	2.0	1280	<1	31	<1	<1	<1	12.0
Mg	mg/L	<1	<1	<1	<1		<1	<1		18	2.0	545	<1	22	<1	<1	<1	4.0
Na	mg/L	1.0	8.0	9.0	6.0		4.0	2.0		106	26.0	2440	5	203	4.0	4.0	13.0	71.0
K	mg/L	<1	<1	<1	<1		<1	<1		<1	<1	44.0	<1	2.0	<1	<1	1.0	1.0

Analyte	Lab/ Units	SOE10	MB01	MB03			MB04			MB05	SOE02	SOE01	8	SOE06	58	57	60	SOE03
		Nov 07	Nov 07	Nov 07	Jun 08		Nov 07	Jun 08		Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07	Nov 07
		ALS	ALS	ALS	ALS	CSIRO	ALS	ALS	CSIRO	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS
Metals*																		
Al – F	µg/L	34.0	27.0	<5	50	7.0	<5	50	5.0	10.0	90.0	5.0	88.0	62.0	<5	72.0	287.0	186.0
Al – T	µg/L	291.0	1370	3100	50	247.0	485	240	13	980.0	252.0	8120	414	236.0	1550	688.0	2010.	353.0
As – F	µg/L	<0.2	<0.2	<0.2	<1	<0.02	<0.2	<1	<0.02	0.50	<0.2	<0.2	<0.2	3.00	<0.2	<0.2	0.40	0.20
As – T	µg/L	<0.2	0.20	0.30	<1	<0.02	<0.2	<1	<0.02	0.20	0.20	1.70	<0.2	3.10	0.30	<0.2	1.70	0.30
Cd – F	µg/L	<0.05	<0.05	0.27	0.10	0.003	<0.05	0.20	0.003	<0.05	<0.05	0.12	<0.05	<0.05	<0.05	13.40	<0.05	0.80
Cd – T	µg/L	<0.05	<0.05	<0.05	<0.1	0.005	0.05	<0.1	0.003	<0.05	<0.05	1.15	<0.05	<0.05	<0.05	<0.05	0.16	0.67
Cr – F	µg/L	<0.2	<0.2	<0.2	<1	0.020	<0.2	<1	<0.02	<0.2	<0.2	<0.2	<0.2	0.50	<0.2	<0.2	<0.2	0.20
Cr – T	µg/L	0.60	2.50	5.70	<1	0.170	1.30	<1	0.020	2.00	0.50	4.60	0.40	0.60	2.80	0.60	2.80	0.50
Cu – F	µg/L	<0.5	2.50	6.90	9.00	8.740	<0.5	16.00	12.40	<0.5	<0.5	<0.5	<0.5	2.60	1.00	<0.5	0.60	0.60
Cu – T	µg/L	<0.5	24.10	38.20	11	15.5	14.40	18.00	15.60	<0.5	<0.5	1.00	<0.5	3.50	1.40	<0.5	11.70	<0.5
Iron – F	µg/L	38.00	6.00	<2	<50	1.00	<2	<50	2.000	78.00	28.00	3.00	9.00	746	5.00	25.00	107.00	1030
Iron – T	µg/L	160	490	833	200	55.00	149	60.0	2.000	584	128	2030	85.00	496	610.00	162	1190	960.00
Lead – F	µg/L	<0.1	<0.1	<0.1	<1	0.043	<0.1	<1	0.026	<0.1	<0.1	<0.1	0.10	1.00	<0.1	0.30	<0.1	0.30
Lead – T	µg/L	0.20	2.80	7.30	<1	1.280	1.50	<1	0.035	0.70	<0.1	2.20	0.40	1.30	2.10	0.30	3.10	0.50
Mn – F	µg/L	5.20	11.70	5.80	6.00	3.210	0.60	1.00	0.520	867	23.50	7.80	<0.5	56.80	5.40	8.70	4.30	24.70
Mn – T	µg/L	9.00	23.80	10.50	<1	7.620	2.70	18.00	0.720	11.70	16.70	954.00	2.10	42.60	15.20	13.40	44.80	23.30
Nickel – F	µg/L	<0.5	1.50	0.80	<1	0.260	<0.5	<1	0.270	39.20	1.80	0.60	<0.5	7.90	<0.5	<0.5	<0.5	<0.5
Nickel – T	µg/L	<0.5	1.90	1.20	<1	0.510	<0.5	<1	0.034	0.60	1.10	38.40	<0.5	7.50	<0.5	<0.5	4.20	<0.5
Zinc – F	µg/L	15.00	49.00	35.00	73	46.2	28.0	59.0	33.2	70.0	27.0	58.0	6.0	132	14.0	260. 0	18.00	183.0
Zinc –T	µg/L	26.00	410.00	253.00	87.0	1000	153	56	59.8	56.0	10.00	79.00	35.00	30.00	72.00	89.00	78.00	70.00

* T = Total F = Filtered

Note: Location MB05 is not shown on **Figure 5-22**, located west of 60.

The concentration of dissolved aluminium ranged from <5 to 287µg/L in samples from fresh shallow groundwater bores and 10 to 186µg/L in samples from brackish groundwater bores, both consistent with the range recorded for Project area fresh surface waters.

The maximum concentration of dissolved copper, nickel and zinc in all groundwater samples was greater than that of surface waters. The concentration of dissolved copper in all groundwater samples ranged from <0.5 to 16µg/L, compared with a maximum surface water value of 0.43µg/L. The concentration of dissolved nickel in fresh groundwater ranged from <0.5 to 1.5µg/L, slightly greater than the maximum surface water value of 0.28µg/L. The concentration of dissolved nickel in brackish groundwater ranged from 1.8 to 39µg/L, greater than the maximum estuarine surface water value of 0.47µg/L. The concentration of dissolved zinc in fresh groundwater ranged from 6 to 73µg/L, greater than the maximum surface water value of 7.1µg/L. The concentration of dissolved zinc in brackish groundwater ranged from 27 to 260µg/L, greater than the maximum estuarine surface water value of 3.4µg/L.

The values of parameters measured in the groundwater generally tend to reflect those recorded for the surface waters, with the exception of higher concentrations of copper, nickel and zinc. However, it should be noted that the most groundwater samples were collected during one event at the end of the dry season (November 2007) when the residence time of groundwater would be at its longest. These late dry season results have been compared with medians and ranges from the surface water program which generally covered multiple sampling events over wet and dry seasons.

16.3.4 Artesian Aquifer

The hydrology and current uses of the artesian aquifer in the vicinity of the Project area are described in the sections below.

Hydrogeology

Typically, water-bearing formations in the Project area are located at depths of between 750 and 1,000m below ground level. Groundwater moves in a westerly direction from what are known as “recharge beds” or “intake beds” to the Gulf of Carpentaria (CSIRO 2009). Artesian conditions occur from the coastal margin inland to areas where topography lies below 30 to 40m above sea level. Experience of similar aquifer conditions in the Weipa area, and test pumping in the Aurukun area, indicates the aquifer transmissivities tend to lie in the range 180 to 300m^2/d, and storativities in the range ~10^{-4} (dimensionless).

Large supplies (>60L/s) of medium quality groundwater can be obtained from the Gilbert River Formation aquifer from bores that intersect the entire sandstone sequence (CSIRO 2009). Shallow bores that intersect the unconfined Gilbert River Formation typically provide yields of 1 to 5L/s of groundwater (DNRM 2005).

The GAB aquifers are recharged primarily by direct infiltration of rainfall where the GAB sandstone outcrops along the eastern margin of the region (the recharge area) – along the flanks of the Great Dividing Range, particularly along watercourses. During the wet season stream leakage recharges the unconfined aquifers through which the streams are incised. Diffuse subsurface outflow is the likely discharge mechanism from the western margin of the GAB beneath the Gulf of Carpentaria.

Springs

The Great Artesian Basin Resource Operations Plan (GAB-ROP) (DNRW 2007) defines three spring types being recharge, watercourse and discharge springs. The GAB-ROP specifies criteria to protect the flow of water to springs and creates the Springs Register which lists recharge, watercourse and discharge springs.

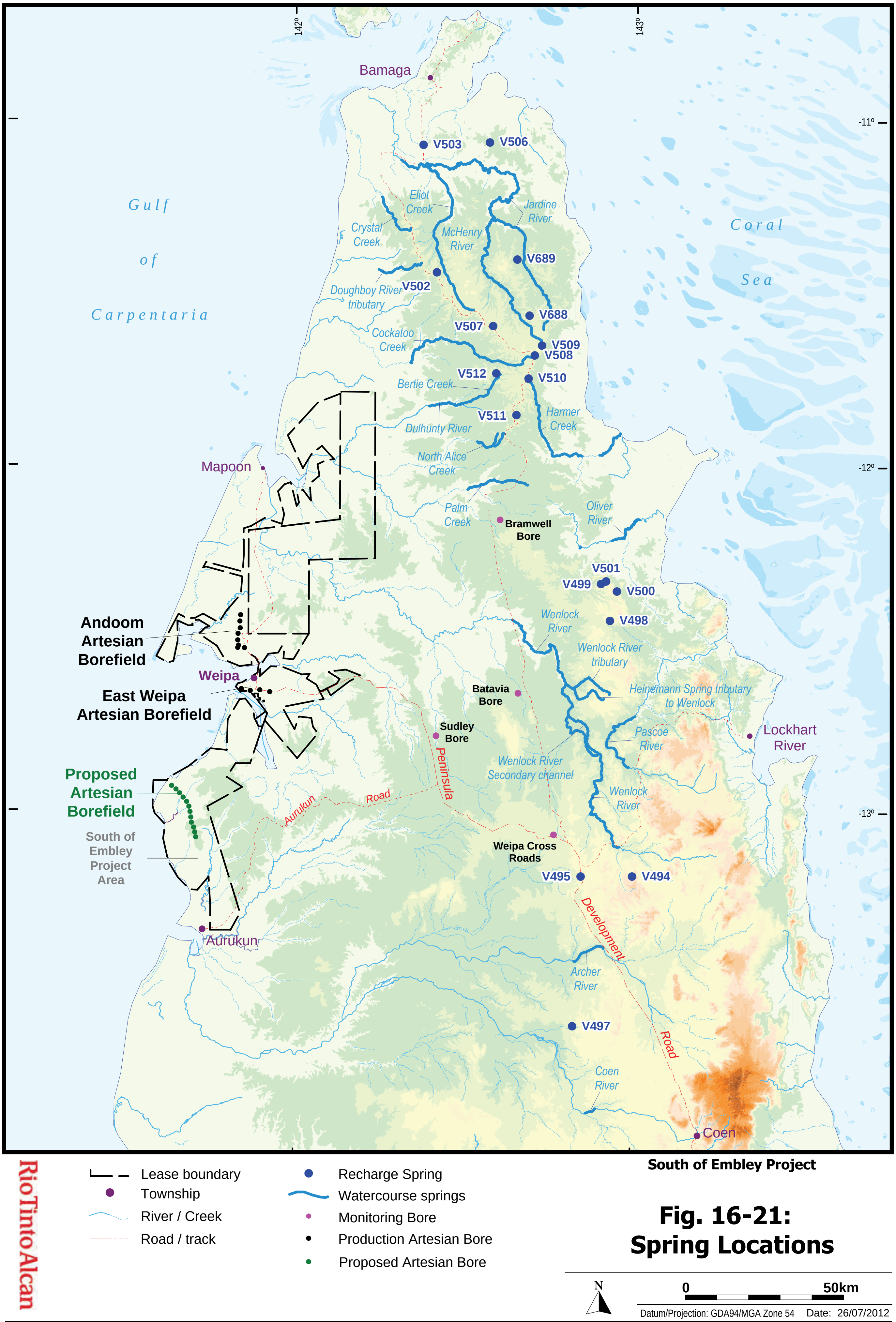
The majority of the Western Cape region, including the Project area, is represented in the GAB-ROP by the Cape Management Area. The Project area is located within the Cape 1 Management Unit. The Cape Management Area serves to protect the groundwater resources of the GAB sediments in the Carpentaria Basin north of the Holroyd River. Recharge and watercourse spring locations derived from the DNRM Spring Register for the Cape Management Area are shown on **Figure 16-21**. There are no registered springs within the Project area.

Recharge and watercourse springs are quite common in the Great Dividing Range recharge areas on Eastern Cape York Peninsula. Recharge springs result from overflow or the rejection of recharge from the overfilling of aquifers and most occur where the sandstone aquifer is at the surface, allowing water to be absorbed and then discharged within a relatively short period (EPA 2005). Watercourse springs are defined in the GAB-ROP as a part of a watercourse where water from a GAB aquifer enters the watercourse through its bed or banks to become baseflow in the watercourse. Outflow from recharge and watercourse springs are related to changes in topography and/or geology (for example, watercourse springs may occur at the transition from permeable sands and gravels to low-permeability silts and clays in alluvial deposits associated with rivers and creeks). The Jardine, Wenlock, Archer, Coen, Holroyd and Dulhunty rivers all receive groundwater baseflow through watercourse springs from the Gilbert River Formation aquifer (CSIRO 2009), and also partially from shallow alluvial aquifers. These springs are all registered watercourse springs in the GAB-ROP Springs Register.

There are no discharge springs listed on the Springs Register within the Cape Management Area. These are defined as spring's supplied by underground water from a confined aquifer.

It should be noted that an EPBC Act Protected Matters search was conducted of the pre-defined Cape York NRM region (accessed on 25/03/2011). The search identified the potential occurrence of discharge springs within the Cape York Management Area. The discharge springs are identified through association with the threatened ecological community *'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'*. The listing advice for the community identifies that these springs are only associated with discharge springs.t is likely that the Protected Matters database includes information from the Communities of National Environmental Significance database mapping (Environment Australia 2003) which identifies one spring group in the Cape York Peninsula.

However, although the Protected Matters search identifies this community as potentially occurring in the Cape York NRM region, the GAB-ROP does not identify any discharge springs within the Cape Management Area. All other available evidence, detailed below, also supports the conclusion that GAB discharge springs do not occur within the Cape Management Area.



South of Embley Project

Fig. 16-21: Spring Locations

Datum/Projection: GDA94/MGA Zone 54 Date: 26/07/2012

The *Great Artesian Basin Resource Study* (Cox and Barron 1998) separates this mapped Cape York spring group from the remainder of the known discharge spring groups at the time of publication, and associates these springs with recharge areas on the Cape York Peninsula. An update to this study (GABCC 2010) provides a quantification of spring complexes within Queensland. Sixteen spring complexes are identified within the Cape Management Area, and all 16 are classified as active recharge springs. In addition, the *Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin* (Fensham *et al*. 2010), also state that the "GAB discharge springs occur from the southern end of Cape York Peninsula to Lake Eyre in South Australia, spanning tropical semi-arid and temperate arid climates". Fensham *et al* 2010 also state "GAB discharge spring wetlands occur within all supergroups except the Cape York supergroup". In reference to Cape York springs, the SPRAT database states all such springs "are now considered to be recharge springs". The SPRAT distribution map does not show any of the relevant threatened ecological community in the Cape Management Area. Graham Herbert (Manager, Water Information Water Services, Natural Resource Operations Group - North Region, Department of Natural Resources and Mines has advised (pers. comm.) "The DNRM are not aware of any GAB discharge springs west of the Great Dividing Range on northern Cape York, which is more than 120km from the Project area".

Discharge springs are therefore not associated with the Cape Management Area or the Project area. It is therefore unlikely that the threatened ecological community *'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'* would occur in the Project area.

Existing Groundwater Use

The major water use from the Gilbert River Formation in the Project area and surrounds is for industrial and mining purposes associated with the RTA's existing operation north of the Embley River. Artesian groundwater is used to supplement process water supplies but would require significant treatment to make it suitable for sustained potable use.

RTA extracts artesian groundwater from borefields at both the East Weipa and Andoom operations. Three production bores are currently installed at East Weipa and seven production bores installed at Andoom. The locations of existing production bores are shown on **Figure 16-21**. RTA takes water from these bores under an existing Water Licence, under the *Water Act 2000,* which allows abstraction of up to 9GL per annum. There are no other large users of artesian groundwater on Cape York.

RTA has installed monitoring bores within the artesian aquifer both on-site and off-site at various locations throughout the Cape York region. The Bramwell and Batavia Downs monitoring bores which are located off-site are both used for stock watering. The small number of stock and domestic bores that access GAB aquifers in the Western Cape region are restricted to areas of outcrop to the east, where only shallow bores are required (DNRM 2005).

Existing Groundwater Monitoring Network

A condition of the Water Licence is that taking of water by RTA must not lower piezometric levels in monitoring bores located at Bramwell, Batavia Downs Homestead or Weipa Crossroads by more than five metres. To meet Water Licence conditions, and internal RTA objectives, a borefield monitoring network has been installed at various locations throughout the Cape York region (refer **Figure 16-21**). The monitoring bores and their status are listed in **Table 16-22**.

Table 16-22 Artesian Aquifer Monitoring Bores

Bore ID	Status
ART 4 Bore	Former production bore at East Weipa, now monitoring bore
ART 5 Bore	Former production bore at Andoom, now monitoring bore
Sudley Station Bore	Artesian, east of Project area
Batavia Downs Bore	Sub-artesian, east of Project area
Weipa Crossroads Bore	Sub-artesian, east of Project area
Bramwell Station Bore	Sub-artesian, east of Project area

16.3.5 Artesian Groundwater Quality

Water quality results from five artesian bores are shown in **Table 16-23**, including one from the existing Andoom borefield (Art 7). Artesian water quality is variable:

- pH ranged from 4.7 to 8.3;
- artesian water is generally brackish with EC ranging from 1,800µS/cm (Art 7) to 16,000µS/cm (however, 330µS/cm was recorded at Batavia Downs);
- the concentration of dissolved iron ranged from <100 to 2,000µg/L; and,
- the concentration of dissolved manganese ranged from 40 to 1,500µg/L.

Table 16-23 Artesian Water Quality

Parameter	Units	Sudley Station	Weipa Crossroads	Bramwell Station	Batavia Downs	Art 7 – Andoom
pH	pH	8.2	4.7	6.9	7.1	8.3
Electrical Conductance	µS/cm	2,800	8,000	16,000	330	1,800
Calcium	mg/L	16	460	1,060	8.6	7.2
Magnesium	mg/L	0.8	1.3	300	1.8	0.2
Carbonate Alkalinity	mg/L as CaCO3	<0.1	<0.1	<0.1	<0.1	<0.1
Hardness – Total	mg/L	43	1,000	4,000	29	19
Chloride	mg/L	620	2,200	5,100	36	310
Alkalinity – Total	mg/L CaCO3	490	<0.1	160	94	320
Fluoride	mg/L	1.4	NA	NA	0.2	2.3
Hydroxide Alkalinity	mg/L OH	<0.1	<0.1	<0.1	<0.1	<0.1
Potassium	mg/L	3.7	17	27	15	6.5
Sodium	mg/L	640	1,340	2,130	43	390
Solids – Total Dissolved	mg/L	1,500	5,100	11,000	190	980
Sulphate	mg/L	2.9	851	768	10	66
Iron – F (dissolved)	µg/L	400	2,000	<100	400	200
Manganese – F (dissolved)	µg/L	60	100	1,500	60	40

High chloride levels in product bauxite have an undesirable impact on the alumina refining process and hence the proportion of artesian water used in the beneficiation of bauxite is restricted to 50%. Artesian water is added to a closed process circuit and not released to the environment.

16.4 Groundwater – Potential Impacts and Mitigation Measures

16.4.1 Shallow Aquifer

Mining may have the potential to affect the shallow aquifer in two ways:

- alterations to the surface drainage regime by the creation of internally draining post-mining landform may lead to changes in the shallow aquifer response; and,
- removal of a portion of the lateritic bauxite strata that may host the aquifer.

The AWBM modelling of mining impacts has shown (refer **Section 16.2.4**) that mining has a temporary impact on the partitioning of surface runoff and baseflow and that, as rehabilitation matures, the overall hydrological regime at a catchment scale returns toward an “undisturbed” situation. The main reason the change due to mining has a small impact is that direct surface runoff from the bauxite plateau is a very small proportion of average incident rainfall (<1%); hence, redirection of surface flow does not greatly alter aquifer recharge characteristics.

The potentiometric surface of the shallow aquifer generally follows the surface topography and the direction of flow would not alter due to mining. The removal of bauxite would only have the potential to change discharge from the shallow aquifer in situations where the bauxite is an appreciable source of baseflow. Typically in the Project area, the water table is within the bauxite only at the height of the wet season, if at all. In the dry season the water table generally falls to 4 to 8m below the base of the bauxite. Streamflow during the dry season tends to be maintained by baseflow originating predominantly from kaolinitic strata. The overall effect of mining on the baseflow and deep baseflow component of the water balance is very small (refer **Section 16.2.4**).

16.4.2 Artesian Aquifer

RTA proposes to install an artesian borefield that accesses the Gilbert River Formation artesian aquifer as part of the Project. The artesian water would form one component of the water supply for the Project (refer **Section 16.2.1**). RTA has an existing artesian Water Licence for 9GL per annum which allows abstraction from bores located on ML7024. RTA has applied to increase the artesian allocation to cover the fluctuations in artesian demand. The overall demand averages 12GL per annum, with a peak abstraction of 15GL in any one year.

The general location of the proposed artesian borefield is shown in **Figure 16-21**. It is expected that approximately 12 artesian bores would be required to achieve the planned abstraction rates.

From experience of discharge rates at East Weipa and Andoom, it is expected the individual bores would be capable of delivering 80 to 100L/s with built-in standby redundancy. The exact locations of the bores would be determined at design stage to ensure the bores are sufficiently well spaced to prevent interference.

The potential drawdown impacts in the artesian aquifer at various stages over the life of the Project were assessed using a groundwater modelling package. The proposed abstraction scenarios, the model code, development and calibration and the potential drawdown impacts at existing production and monitoring bores are discussed below.

Groundwater Modelling

Assessment of two proposed abstraction scenarios was carried out using the FEFLOW modelling package, an industry standard software package for simulation of groundwater behaviour. All modelling was undertaken by Golder Associates Pty Ltd. The model was developed on behalf of RTA, and is in active use as part of the operational planning of Andoom and East Weipa. It is regularly updated in response to new field information from ongoing pumping tests and with data extension from updated monitoring records.

Abstraction Scenarios

The potential impacts of artesian groundwater abstraction were modelled under two different scenarios:

- a constant 12GL per annum over the 40-year mine life (the “12 GL/year scenario”); and,
- 12GL per annum for the first 13 years and then 18GL per annum for the remainder of the 40-year mine life (the “18GL/year scenario”).

The 12GL per annum scenario was used to determine the maximum potential impact for the proposed Project. This scenario overestimates the actual abstraction rate as it assumes a constant annual average abstraction rate of 12GL per annum for the mine life of 40 years. The total volume of water abstracted over 40 years would be less than the amount modelled as the mining production rate would increase in stages to 50Mdptpa. The 18GL per annum scenario was modelled to obtain an indication of the upper bounds of aquifer sustainability.

The abstraction scenarios tested in the FEFLOW model are listed in **Table 16-24**.

Table 16-24 Abstraction Scenarios

Scenario	Year 1 – Year 13		Year 14 – Year 40	
	Andoom / Weipa Borefield Abstraction (GL / year)	SoE Borefield Abstraction (GL / year)	SoE Borefield Abstraction (GL / year)	Andoom / Weipa Borefield Abstraction (GL / year)
12 GL/year	6	6	12	0
18 GL/year	6	6	18	0

For each scenario, the same initial conditions apply. The start of abstraction was nominally set at 2013 for the purposes of modelling and it was assumed that simulation Year One coincides with 2013. The initial conditions were simulated for 2012 based on historical data and from simulation of predicted usage between 2009 and 2012. That is, the model predicted the most likely and representative conditions expected to prevail in 2012 and these were then applied as the initial conditions for the tested scenarios. Mean recharge conditions were applied throughout each scenario simulation. The model was run in each trial for a further 70 years beyond the abstraction period to estimate the progress of the aquifer recovery following mine closure.

Model Code

FEFLOW (version 5.3) is a finite element groundwater modelling package developed by WASY Institute for Water Resources Planning and Systems Research in Berlin, Germany. It has the following attributes:

- capability to simulate seepage flow in conditions dominated by irregular geological structure;
- ability to represent complex boundary conditions;
- capability to present distributions output in a range of different formats;
- ability to incorporate transient physical changes to the host aquifer, including excavation or the placing of tailings, for example;
- an enhanced capability to represent 3D geometry accurately provides the following as primary computed results;
- hydraulic head distributions;
- pressure distributions; and,
- flow distribution.

These can be reproduced for steady-state or transient conditions at any point within the simulated extent of the aquifers.

Model Mesh

The model mesh is shown in **Appendix 16-A**, **Figure 1**. It is bounded by the Great Dividing Range in the east. The north and south boundaries are set along groundwater flow lines and the western boundary out beneath the Gulf of Carpentaria. The distance to these boundaries is intended to be sufficient such that they do not have a significant effect on drawdown. In circumstances where drawdown reaches a no flow boundary, the spatial drawdown is overestimated in the region of the boundary.

Recharge

It is believed the majority of the recharge occurs in the Great Dividing Range area via fractured sandstone in the Gilbert River Formation during rainfall events. Higher recharge to the aquifer may occur in the Wenlock River area, and this is reflected in the model boundary conditions.

Recharge was based on data for the nearest rainfall gauge to the recharge area, which is located at Moreton Telegraph station. The average annual rainfall for this station is 1,390mm.

This record is conservative when compared to the continuous daily rainfall record derived from the BoM SILO website’s Data Drill database (BoM 2009) corresponding to a location in the Dividing Range recharge area. The Data Drill record at this location indicates an average annual rainfall value of 1,560mm. Data Drill accesses grids of data derived by interpolating the BoM's station records calculated by splining and kriging techniques.

Aquifer Properties

The initial aquifer hydraulic properties adopted in the model were based on values estimated from all available test pumping program results from production bores at East Weipa and Andoom. These parameters were then refined within acceptable bounds during the subsequent calibration process.

The model parameter distributions are generalised and extend over a wide area. Although they should not necessarily be expected to reflect the detailed conditions at single production bores or monitoring bores exactly, the storativities in the model were found after calibration to lie in the order of 10^{-6} to 10^{-4}, which is consistent with the pumping test results found using the Theis equation. Specific yield values are applied in the model to represent unconfined conditions where they occur during simulation.

The initial model parameter distributions were based on transmissivity values predicted from pumping tests. These distributions were then refined in a calibration exercise, and yielded results in the borefield area for transmissivities that lie in the range 180 to 300m^2/day. The pumping test results, when analysed using the Theis equation, tend to predict higher values (typically in the range 300 to 500m^2/day) for the individual production well sites because they are localised values estimated using analytical approaches to estimation. These analytical approaches are substantially different to the finite element modelling approach, which provides generalised values over a larger area. The outputs from the analysis of the individual tests are shown in **Appendix 16-A**, **Figures 2** to **9**.

Initial Conditions

Simulation starts from aquifer conditions based on the expected state of the aquifer at Year 1 (i.e. approximately 2013). To derive these conditions, the model is run from the time of the earliest aquifer development in the Weipa area, which took place around 1971. A steady-state model was developed in the first instance to simulate the original heads prevailing at 1971. It was then run for the period between 1971 and 2008 using the best estimates and known discharge details for the bores in both the Andoom and East Weipa borefields during this period. Finally, it was run for predicted extraction rates for the period from 2008 to 2012. Hence the resulting simulation of aquifer conditions provides a representative starting point for the transient trials that investigate long-term borefield usage.

Boundary Conditions

The applied boundary conditions included recharge at the Great Dividing Range and a no flow boundary heads to the west. Geophysical information received recently indicates the Gilbert River formation, which is host to the aquifer, pinches out in the Gulf of Carpentaria at a depth in excess of ~1,000m, about 150 to 180km to the west of Andoom.

No flow boundaries are applied at the northern and southern margins of the model domain, coinciding with groundwater flow lines which are assumed to be approximately aligned to an east-west direction. Modelling the aquifer as a single layer applies no flow from either the bedrock or Rolling Downs Group.

Steady-State Calibration

The steady-state calibration carried out to simulate the natural conditions assumed prior to the East Weipa borefield development in 1971 considered recharge entering the aquifer in the Great Dividing Range area, and refinement of the aquifer parameters that have been collated from available pumping test information.

The aquifer parameters and the recharge applied over the exposed extent of the Gilbert River sandstone was varied in parameter estimation software (PEST).

The model boundary conditions include nodes corresponding to locations along the Wenlock riverbed alignment where there is the highest potential for either losses from the river to occur (as recharge to the artesian aquifer) or gains to the river to occur (as groundwater baseflow). These losses or gains are predicted by the model on the basis of the relative groundwater head and river level, and the estimated aquifer conductivity. The net recharge to the aquifer from the Wenlock River under steady-state conditions is 1,640m^3/day.

Model calibration trials indicate the average direct rainfall recharge rates are approximately 1.2mm/year over the area.

Observed heads applied in the calibration were taken from representative estimates for East Weipa bores ART1 to ART4, based on bore construction completion records. The calibrated steady-state head distribution for the natural conditions prevailing prior to development in 1971 is shown in **Appendix 16-A**, **Figure 10**.

Transient Calibration

Transient calibration of the model was carried out using the steady-state initial conditions described previously based on relevant recorded data. Comparisons were made between available observed head data from monitoring and production bores for the wider area representative of transient conditions. Representative output for these calibrations are plotted as time series plots for the period subsequent to 1971, and are shown in **Appendix 16-A**, **Figures 11** to **18**.

As part of the calibration exercise to simulate the pumping test conditions, the model was used to estimate local and regional aquifer parameters being determined by the test.

Long-term time series plots, which show comparisons with field values monitored at different times over the 26-year period, indicate the model shows reasonable agreement with field conditions.

A summary of the parameter extents for hydraulic conductivity and storage used in modelling is provided in **Appendix 16-A**, **Figures 19** and **20** respectively.

The monitoring program, which is now well-established as part of the management of the Andoom borefield, is important for providing information on the resource with representative data on the state of both temporal and spatial conditions. This information is essential for calibration of the model and would provide a valuable check on model performance over time.

Modelling Simulation Results

The existing Water Licence requires that drawdown does not exceed 5m at Bramwell Station, Batavia Downs and Weipa Crossroads monitoring bores. The FEFLOW model was used to predict relative drawdown for each abstraction scenario and determine whether current Water Licence conditions would be met.

The drawdown for each scenario described in **Table 16-25** is defined here as the difference in simulated aquifer head relative to simulated baseline conditions where no abstraction takes place; i.e. a baseline scenario is simulated in which there is no abstraction. The results of each scenario are then compared to this baseline, with the difference between the two data sets being the relative drawdown. The drawdown calculated in this way will then represent the direct influence of the proposed abstraction scenario only.

The predicted relative drawdown for each abstraction scenario at various time steps is shown in **Table 16-25**. Drawdown hydrographs for these locations over the full simulation period are provided in **Appendix 16-A**, **Figures 21** to **26**.

Table 16-25 Predicted Drawdown

12 GL/year Scenario		**Drawdown Relative to Baseline Scenario (m)**					
Year From Start of Simulation	**Year**	**Andoom Borefield**	**SoE Borefield**	**Bramwell Station Bore***	**Batavia Downs Bore***	**Sudley Station Bore**	**Weipa Crossroads***
1	2013	78.6	22.9	0.0	0.0	0.0	0.0
13	2026	26.3	46.1	0.3	1.0	3.4	0.2
40	2053	18.4	71.0	1.0	3.2	9.4	1.5
90	2103	6.1	7.9	1.1	1.9	4.1	1.2
110	2123	4.5	6.0	0.9	1.4	2.9	1.0
18 GL/year Scenario		**Drawdown Relative to Baseline Scenario (m)**					
Year From Start of Simulation	**Year**	**Andoom Borefield**	**SoE Borefield**	**Bramwell Station Bore***	**Batavia Downs Bore***	**Sudley Station Bore**	**Weipa Crossroads***
1	**2013**	78.6	22.9	0.0	0.0	0.0	0.0
13	**2026**	26.3	46.1	0.3	1.0	3.4	0.2
40	**2053**	25.1	120.0	1.1	4.1	12.5	2.0
90	**2103**	8.2	10.4	1.3	2.5	5.5	1.6
110	**2123**	6.0	7.8	1.1	2.9	3.9	1.3

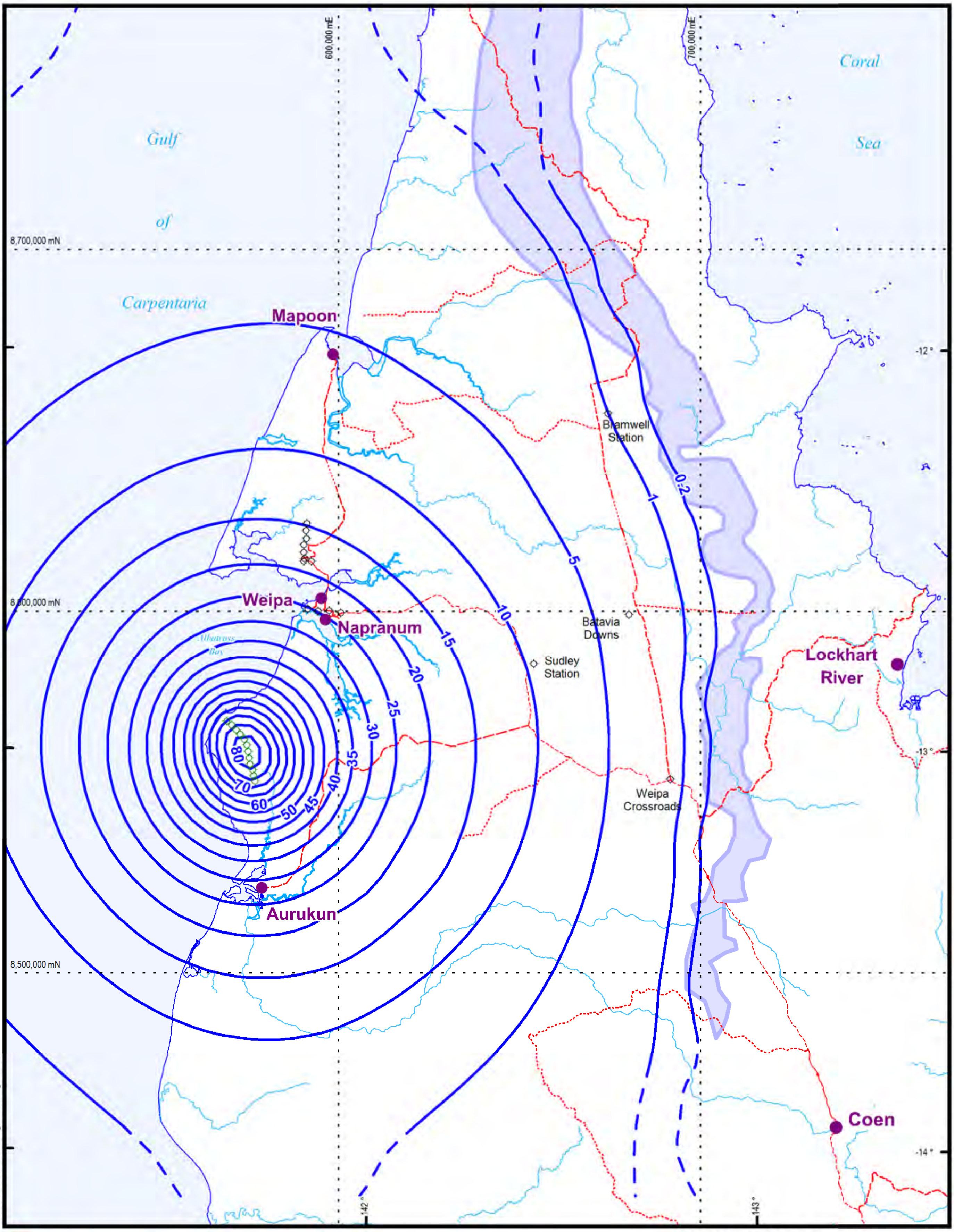
* Water Licence compliance monitoring bore.

The drawdown contours for the 12GL per annum scenario at the end of mine life (Year 40) are shown in **Figure 16-22**. Note that the drawdown shown at the outer regions of the model domain is overestimated due to (a) the models' no-flow boundary conditions assigned to the north and south, and above and below the aquifer (see **Section 16.4.2**), and (b) the constant annual average 12GL/year abstraction rate. Without these conservative aspects of the model, the 1m and 0.2m drawdown lines would move westward by many kilometres. The overestimation of drawdown is evident in cases where the predicted 5m, 1m and 0.2m drawdown contours are distorted to the north and south due to the no-flow boundary condition (see **Figure 16-22**). These contours would be expected to be approximately concentric with the larger predicted drawdown contours not affected by the boundary condition.

Predicted drawdown contour maps related to other years for 12GL per annum scenario are presented in **Appendix 16-A**, **Figures 27** to **31** and **Figures 32** to **36** for the 18GL per annum scenario.

The existing Water Licence requires that drawdown does not exceed 5m at Bramwell Station, Batavia Downs and Weipa Crossroads monitoring bores. The modelling results for those three monitoring bores show that, for the proposed abstraction of 12GL per annum, the maximum drawdown occurs at Batavia Downs bore (3.75m at Year 50, refer **Appendix 16-A**, **Figure 24**). The maximum drawdown was less than 2m at Bramwell bore (Year 60) (refer **Appendix 16-A**, **Figure 23**) and at Weipa Crossroads bore (Year 52) (**Appendix 16-A**, **Figure 26**).

The modelling results indicate that under the proposed abstraction regime the existing Water Licence condition relating to maximum relative drawdown would be met. The modelling also predicted that the existing Water Licence condition relating to maximum relative drawdown would also be met for a 18GL per annum scenario, with the maximum drawdown of 4.95m occurring in 2063 (year 50) at Batavia Downs. The results indicate that the aquifer could sustainably support abstraction rates greater than a rate of 12GL per annum and meet existing licence conditions.



Plans\SoE\2013\EIS Figure 16\Fig 16-22 Predicted DD Contours 12GL Yr40.wor

RioTintoAlcan

- Recharge area
- Township
- River
- Road/track
- Existing Borehole
- Proposed Borehole
- Predicted drawdown
- Predicted drawdown overestimated by model boundary condition

South of Embley Project

Fig. 16-22: Predicted Drawdown Contours - 12GL/year Scenario Year 40

0 50km

N

Datum/Projection: GDA94/MGA Zone 54 Date: 28/02/2013

The model predicts losses or gains from the artesian aquifer at the Wenlock River based on the relative groundwater head and the river level. The model predicts that the net recharge to the artesian aquifer from the Wenlock River would not increase at any time by more than $6m^3$/day above the existing steady-state average of $1,640m^3$/day. The median flow in the Wenlock River in this area in the driest month of the year (November) is $106,000m^3$/day (Moreton gauging station 925001A, see **Figure 16-1**). A loss of $6m^3$/day from the river would represent a 0.006% reduction in flow in the driest month. The modelling results show that there would be negligible impact on flow in the Wenlock River and hence impacts on matters of NES are not expected. It is also unlikely that there would be a significant impact on recharge springs. The net rainfall recharge to the Gilbert River Formation in the recharge area would not change and there would not be an impact on the recharge area.

The Rolling Downs Group separates the shallow and artesian aquifers with a 500m thick confining layer of low hydraulic conductivity. Abstraction of artesian groundwater is not expected to have any impact on the shallow aquifer.

Spring Factors

Section 39 of the GAB-ROP (DNRW 2007) prescribes conditions that must be met for the chief executive to make a decision about a Water Licence, if the decision is associated with a management unit connected to a spring, and the water is for purposes other than domestic and stock watering. A decision associated with abstraction from a management unit connected to a spring is subject to the cumulative spring factor not exceeding 400mm head of water. The GAB-ROP (DNRW 2007) prescribes how the spring factors are to be calculated.

The proposed artesian groundwater abstraction from existing and proposed new bores would take water from the Gilbert River Formation, which is connected to watercourse and recharge springs. The spring factors for the closest recharge and watercourse springs have been calculated to demonstrate that cumulative spring factor limit of 400mm is not exceeded for any of the existing or proposed new bores.

Table D-1 and Table D-2 of the GAB-ROP (DNRW 2007) must be used to determine the spring factor for each spring:

- Table D-1 is used to associate regions to transmissivity groups (TG); and,
- Table D-2 provides multiplying factors according to the TG, distance and spring type to calculate cumulative spring factors.

Table D-2 is reproduced as **Table 16-26**.

Spring factors are calculated by multiplying the annual take of water in megalitres by the relevant spring factor multiplier determined from Table D-2. Where the actual distance between a spring and the bore is not shown in Table D-2, the spring factor multiplier can be determined on a pro-rata basis using the distances in Table D-2 that are the closest to the actual distance (DNRW 2007).

Table 16-26 Spring Factor Multipliers from GAB-ROP

Table D-2. Spring factor multipliers

Column 1	Column 2			Column 3		
Distance (kilometre)	Spring factor multiplier for recharge and watercourse springs			Spring factor multiplier for discharge springs		
	TG- 50	TG-150	TG-250	TG-50	TG-150	TG-250
5	15.28508	6.67424	4.44776	25.25164	10.01124	6.45172
10	9.4634	4.68536	3.24852	19.23328	8.0002	5.24448
20	4.24556	2.76844	2.07556	13.28132	5.99656	4.03992
40	0.81688	1.1108	1.00128	7.5866	4.02228	2.846
60	0.11384	0.43412	0.49552	4.5996	2.9088	2.16276
80	0.0104	0.15416	0.2364	2.80004	2.1608	1.6936
100	0.0006	0.0484	0.1062	1.6776	1.6214	1.34532
120	0	0.01324	0.04436	0.97932	1.21904	1.07588
140	0	0.00312	0.01708	0.5536	0.91412	0.86252
160	0	0.00064	0.00604	0.30184	0.6816	0.69136
180	0	0.00012	0.00196	0.15824	0.50432	0.55304
200	0	0	0.00056	0.0796	0.36976	0.44092
220	0	0	0.00016	0.03832	0.26828	0.34996
240	0	0	0.00004	0.01764	0.19248	0.2764
260	0	0	0	0.00776	0.13644	0.217
280	0	0	0	0.00328	0.09552	0.16932
320	0	0	0	0.00048	0.04496	0.101
360	0	0	0	0	0.02004	0.05852
400	0	0	0	0	0.0084	0.03284
450	0	0	0	0	0.0026	0.01524
480	0	0	0	0	0.00124	0.00936
500	0	0	0	0	0.00072	0.00668
560	0	0	0	0	0.00016	0.00232
580	0	0	0	0	0	0.0016
600	0	0	0	0	0	0.00108
660	0	0	0	0	0	0.00032
700	0	0	0	0	0	0.00012
720	0	0	0	0	0	0.00008
780	0	0	0	0	0	0

Spring Factor Calculation Results

Springs in the Cape 1 management unit are designated as either watercourse or recharge springs (not discharge springs) according to the definitions for spring types given in the GAB-ROP (DNRW 2007). Table D-1 of the GAB-ROP (DNRW 2007) indicates the relevant TG for the Cape 1 management unit is TG-50.

The watercourses and springs on the DNRM Spring Register closest to the existing and proposed borefields are presented in **Table 16-27** with their respective calculated spring factors. The spring factors for the closest watercourse and recharge springs to the north-east, east and south-east were calculated by multiplying the spring factor multiplier by a constant abstraction rate of 12GL/year and 18GL/year respectively.

The calculated spring factors represent the highest possible cumulative spring factor for each spring because the spring factors are calculated on the assumption that all the water is abstracted from the closest bore. The calculated spring factors are all well below the spring factor limit of 400mm head of water, demonstrating the spring factor requirement is met in all cases.

Table 16-27 Spring Factors

Spring Type	Spring ID	Distance from Closest Borefield (km)	Closest Borefield	Spring Factor Multiplier (from Table D-2)	Spring Factor (mm Head of Water) (spring factor x abstraction rate)	
					12 GL/year	18 GL/year
Recharge	V512	110	Andoom	0.0003	3.6	5.4
Recharge	V511	107	Andoom	0.0004	4.8	7.2
Recharge	V499	113	Andoom	0.0002	2.4	3.6
Recharge	V498	112	East Weipa	0.0002	2.4	3.6
Recharge	V495	126	SoE	0	0	0
Recharge	V497	138	SoE	0	0	0
Watercourse	Palm Creek	84	Andoom	0.008	96	144
Watercourse	Oliver River	100	Andoom	0.0006	7.2	10.8
Watercourse	Wenlock River	87	Andoom	0.007	84	126
Watercourse	Wenlock River	94	East Weipa	0.004	48	72
Watercourse	Archer River	129	SoE	0	0	0
Watercourse	Coen River	154	SoE	0	0	0

16.4.3 Regulatory Requirements

Water Licence Requirements

RTA has an existing artesian Water Licence under the *Water Act 2000* (Qld) for 9GL per annum which allows abstraction from artesian bores located on ML7024, which access the Gilbert River Formation and Garraway Beds aquifers. RTA has applied to increase the artesian allocation to cover the fluctuations in artesian demand. The overall demand averages 12GL per annum, with a peak abstraction of 15GL in any one year.

The Queensland Coordinator General (CG) has assessed this issue and recommended that a licence to take artesian water up to 15GL/year be granted, which would replace the existing licence to take artesian water (Queensland Government 2012). The CG also recommended to DNRM, as the State agency administering the Water Act, that work be undertaken to determine the sustainable capacity of the Great Artesian Basin in the Cape York region to inform on any future development in the region.

Water Resource (Great Artesian Basin) Plan 2006

A primary purpose of the *Water Act 2000* is to advance sustainable management and efficient use of water and other resources by establishing a system for the planning, allocation and use of water. One of its main provisions is the development and implementation of Water Resource Plans for river basins in Queensland.

The Project area is located within the plan area of the *Water Resource (Great Artesian Basin) Plan 2006*, which will be referred to here as the GAB WRP. The GAB WRP applies to artesian water in the plan area and a licence application has been made to the State. The stated objectives for the GAB

WRP are that water is to be allocated in a way that seeks to achieve a balance in the following outcomes:

- to protect the flow of water to springs and baseflow to watercourses that support significant cultural and environmental values;
- to provide for the continued use of all water entitlements and other authorizations to take or interfere with water;
- to reserve water in storage in aquifers for future generations;
- to ensure a reliable supply of water from the plan area; and,
- to make water available for new users.

The GAB WRP deals with principles and objectives of the planning and management of water resources in the GAB. Section 12 of the GAB WRP states that Water Licences in the plan area must be consistent with the criteria for the protection of the flow of water to springs and baseflow to watercourses stated in the GAB-ROP (DNRW 2007). Criteria to protect the flow of water to springs are detailed in Section 3 of the GAB-ROP (DNRW 2007), and include:

- for a management unit connected to a spring, the chief executive must not make a decision about a Water Licence that would increase the amount of water that can be taken from within 5km of that spring; and,
- for a decision about a Water Licence associated with a management unit connected to a spring, the chief executive may make a decision about a Water Licence if the decision does not result in the cumulative spring factor for the spring exceeding 400mm of water head.

The distances for the recharge springs and watercourse springs within the Great Dividing Range that have the closest location to the existing and proposed borefields all greatly exceed 5km. The calculated spring factors (refer **Table 16-27**) are all well below the spring factor limit of 400mm head of water, demonstrating that the spring factor criteria are met in all cases.

Under its licence conditions, RTA undertakes periodic validation of the predictive model. Should the predictive model indicate a future drawdown in excess of the 5m drawdown limit, mitigation measures could include changes to artesian bore location or moderation of abstraction rates.

16.5 Monitoring

16.5.1 Surface Water

The Queensland Coordinator General's approval conditions for the SoE Project (Queensland Government 2012) set out the both the monitoring and management measures that will apply to surface waters. These conditions are presented in **Appendix 16-B**.

A network of at least 28 surface water monitoring locations would be maintained as per the Queensland Coordinator General's approval conditions. Monitoring locations shall be at authorised surface water release points, downstream of those release points and at reference sites. The parameters specified to be monitored include pH, EC, turbidity, sulphate, suspended solids, aluminium, copper, lead, iron and zinc. These are the same as those specified in the existing Environmental Authority for current operations north of the Embley River. They include the standard physical parameters (pH, EC, turbidity, suspended solids). Aluminium is included because it is naturally enriched in waters from the bauxite plateau. Iron is included because it is an indicator of anoxic conditions and concentrations tends to be seasonal and rise in the dry season when the proportion of groundwater in streamflow is highest. Copper, lead, zinc and sulphate are not enriched in the bauxite ore, or in surface waters in the Project area, but are included because of the Queensland Coordinator General's requirement to do so. Locations would be monitored regularly to establish a statistical baseline (consistent with ANZECC requirements) and also when any releases to surface water occur.

As per the Queensland Coordinator General's approval conditions (Queensland Government 2012), investigation trigger values for fresh and estuarine waters have been set based on ANZECC (2000) default values for 99% species protection and site-specific contaminant limits for receiving waters are to be set based on the statistical baseline.

Streamflow gauging stations would be installed upstream and downstream of Dam C, as well as in two Norman Creek sub-catchments (one to be mined and one non-mined "control"). When the Ward River pump station is installed, a stream gauging station would be installed on the river in the vicinity of the pump. The streamflow monitoring network (with the exception of the Ward River) locations would be implemented prior to commencement of mining. The streamflow monitoring for Ward River would be implemented prior to pumping from the Ward River.

Macro invertebrate monitoring would also be carried out in accordance with the AusRIVAS methodology (see **Appendix 16-B**).

16.5.2 Shallow Aquifer

The Queensland Coordinator General's approval conditions for the SoE Project (Queensland Government 2012) set out the both the monitoring and management measures that will apply to groundwater. These conditions are presented in **Appendix 16-B**.

A network of at least 25 shallow groundwater bores would be maintained as per the Coordinator General's approval conditions. Some of the existing bores are likely to be discontinued and replaced by new bores more closely aligned with the mine plan and positioned up-gradient and down-gradient of mining pits. Exact locations would be determined once the detailed mine plan is developed. Water levels would be measured manually on a quarterly basis (subject to access), as would pH, EC, aluminium, copper, lead, iron and zinc.

16.5.3 Artesian Aquifer

RTA proposes to continue the current monitoring and reporting requirements under the existing Water Licence:

- quantity of water abstracted from production bores;
- artesian groundwater quality and changes in water quality;
- artesian groundwater levels and changes in groundwater levels; and,
- drawdown levels in monitoring bores at Bramwell Station, Batavia Downs and Weipa Crossroads.