APPENDIX C: INLAND WATERS

C.1: Hydrology and Floodplain Assessment for the West Angelas Beyond 2020 Study

Water Resource Evaluation / Projects & Development

West Angelas: hydrology and floodplain assessment for the West Angelas Beyond 2020 study

April 2021

The West Angelas Beyond 2020 study includes resources at Western Hill, Mount Ella East, Deposit F North, Deposit H, and Deposit J. The resource footprints are spread across a broad area to the east and west of existing operations at West Angelas, overlapping three regional catchments – Turee Creek East, Angelo River and Weeli Wolli Creek as shown in Figure 2-1. This study describes the hydrological setting and floodplain characteristics of each deposit, identifies surface water related sensitive receptors, quantifies changes in the hydrological regime of Turee Creek East, and scopes likely requirements for management of surface water and flood risks.

Flood estimation techniques and hydraulic modelling was used to simulate flood events across the study area and define floodplain extent and design flood flows for locations of interest. The approach followed guidelines for application of direct rainfall, Monte Carlo and ensemble modelling techniques as discussed in Engineers Australia (2012) and ARR2019, and utilised RORB hydrological modelling and TUFLOW hydraulic modelling. Pre- and post-development flooding was evaluated for the five deposits for design storm events of between 1:2 and 1:200 Annual Exceedance Probabilities (AEPs). Closure surface water and land from stability risks were evaluated using regional TUFLOW modelling of rare to extreme flooding, including the 1:1000 and 1:10,000AEP design flood events.

The key flood risks and drainage requirements associated with development of each deposit are summarised below. Surface water related risks were no greater than Class II, but stormwater management will be required for all deposits.

- **Western Hill:** Haul road crossings of Turee Creek East should maintain conveyance to Karijini National Park. Dump and stockpile designs in the vicinity of the park will need to apply appropriate stand-off from the park boundary and floodplain of Turee Creek East and minimise interference with overland flow paths to prevent mobilisation of sediment. No flood protection is required for pits which are located on upper hillslopes and catchment divides.
- **Deposit F north:** No flood protection is required for the current pit design which does not intercept large catchments. Potential expansions of the pit to the east may require small diversion drains to protect the pit from flooding. Access routes should consider local terrain and avoid incised channels.
- **Deposit H:** Flood mitigation is recommended for the western pit at Deposit H and may consist of strategic dumping of the contributing catchment, diversion or management of stormwater in pit.
- **Deposit J:** Both eastern and western pits will require flood protection in the form of diversions and revised dump footprints to avoid drainage lines. Mine infrastructure should avoid the creek at the far western extent of Deposit J to limit exposure to flooding.

- **Mount Ella:** With the current pit and dump footprints there is no risk of flooding to mine infrastructure. Minor drainage works will be required along the haul route.

Surface water level monitoring is in place across 17 sites in Angelo River and Turee Creek East catchments. Sites are located to characterise flood and flow regimes at key locations, and to support model calibration and environmental approvals in future. Several sensitive receptors were identified and will be a focus of ongoing monitoring.

Potential changes in the surface water regime of sensitive receptors are as follows.

- Development of Beyond 2020 deposits will cause a further reduction in the contributing catchment area of Turee Creek East upstream of the Karijini National Park boundary. Currently the catchment has been reduced by 26% as a result of West Angelas mine operations, and this would increase to 29% with the proposed development. This would result in a small reduction in flow delivered downstream in large flood events – e.g. for the selected 1:10AEP design flood a 6% reduction in peak, and 3% reduction in volume.
- A small reduction in surface flow delivered from the eastern catchment flowing to the Guburingu heritage area west of western hill, caused by removal of catchment area upstream at Western Hill. Estimated at 13% reduction in flood peak and 10% reduction in volume for a 1:10AEP event.
- A large reduction in surface flow to the ephemeral pool at Deposit H, with most (~90%) of the contributing catchment removed by mining.
- A small reduction in surface flow delivered to the pGDE downstream of Deposit H, with 13% of the contributing catchment removed by mining.
- No change in the surface flow regime of the West Angelas cracking clays (PEC-P1).
- No change in the surface flow regime of the Mulga community south of Deposit J.

Discharge extent modelling was completed as contingency should surplus water discharge be required at Deposit J, and biological surveys have been targeted based on the anticipated maximum extent of surface flows up to 4km downstream from potential outlet. However, with current site water balances it is not anticipated that there will be surplus water at Deposit J.

This study was completed using the best available information at the time, which included “Order of Magnitude” level pit and waste dump locations, and proposed linear infrastructure routes.

Contents page

Introduction

1. Overview

The West Angelas Beyond 2020 study includes five mineral resources near existing operations at West Angelas, but up to 30km apart. The large spatial domain means that three regional level catchments are included within the study with diverse hydrological setting of each deposit. The regional catchment catchments are Turee Creek East, Angelo River and Weeli Wolli Ceek as shown in Figure 2-1. The investigations include resources at Western Hill, Deposit H, Deposit F North, Deposit J and Mount Ella East.

This report describes the hydrological setting and floodplain characteristics of each deposit using regional and local scale direct rainfall modelling. The main objectives of the study are to:

- Identify key hydrological risks for all study deposits.
- Scope conceptual surface water management strategies to enable safe mining.
- Identify sensitive receptors and develop monitoring plans and mitigation strategies if required.
- Assess site wide closure risks for very rare to extreme rainfall and flood events.
- Identify additional work required to progress deposits to PFS level of ore body knowledge.

A combination of flood estimation techniques and hydraulic modelling were used to characterise catchment flows and define representative design storms for use in floodplain modelling across the broader study area. This study has followed guidelines for application of direct rainfall, Monte Carlo and ensemble modelling techniques as discussed in Engineers Australia (2012) and ARR2019.

2. Terminology

2.1 Flood hydrology

Probability concepts are fundamental to design flood estimation. The terminology used in the communication of these concepts is paramount if it is to be effective for all stakeholders. The term ‘average recurrence interval’ or ‘ARI’ has generally been used within Rio Tinto and by industry professionals to describe the probability of a particular magnitude of flood occurring i.e. ‘100 yr ARI’ or ‘1 in 100 year flood’.

This description of flood events has often been misinterpreted by professionals, community members impacted by floods and other stakeholders, as the probability of the chosen event is not explicitly defined. To ensure effective communication of event probabilities alternative terminology will be adopted by the Bureau of Meteorology and other industry bodies. ARR2019 has outlined the proposed terminology to be adopted as shown in Table 2-1.

Use of the terminology can be summarised as follows:

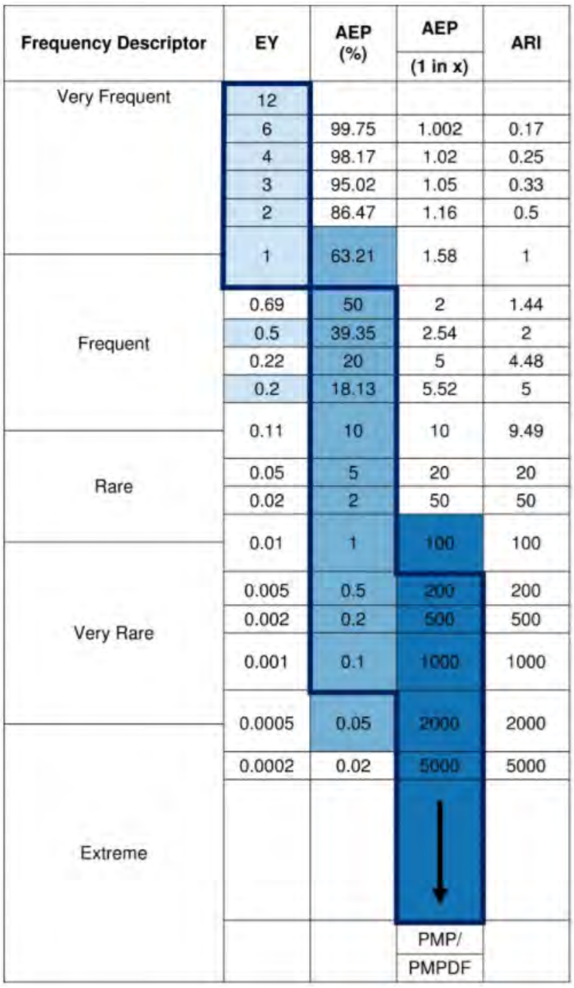
Events per Year (EY) – The number of times an event is exceeded in a given year. Used for “Very Frequent” events that are likely to occur once or more per year.

Annual Exceedance Probability (AEP) – the probability of an event occurring or being exceeded within a year. For example, a 1% AEP event has a 1% probability of being equalled or exceeded in any year. Used to describe “Frequent” to “Very Rare” events. For events up to 1%AEP the probability is described as a percentage, for rarer events a ratio is used, for example 1:200 AEP is used in preference to 0.5%AEP.

Average Recurrence Interval (ARI) - the average period between occurrences equalling or exceeding a given value. This terminology is not preferred.

This report is focused on flood events in the range of “Frequent” to “Very Rare” and as such the AEP terminology is used throughout. The 1 in x or 1:x terminology has been used in preference of %AEP unless referencing previous reports.

Table 2-1: Australian Rainfall and Runoff preferred terminology (ARR2019 Book 1)



Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
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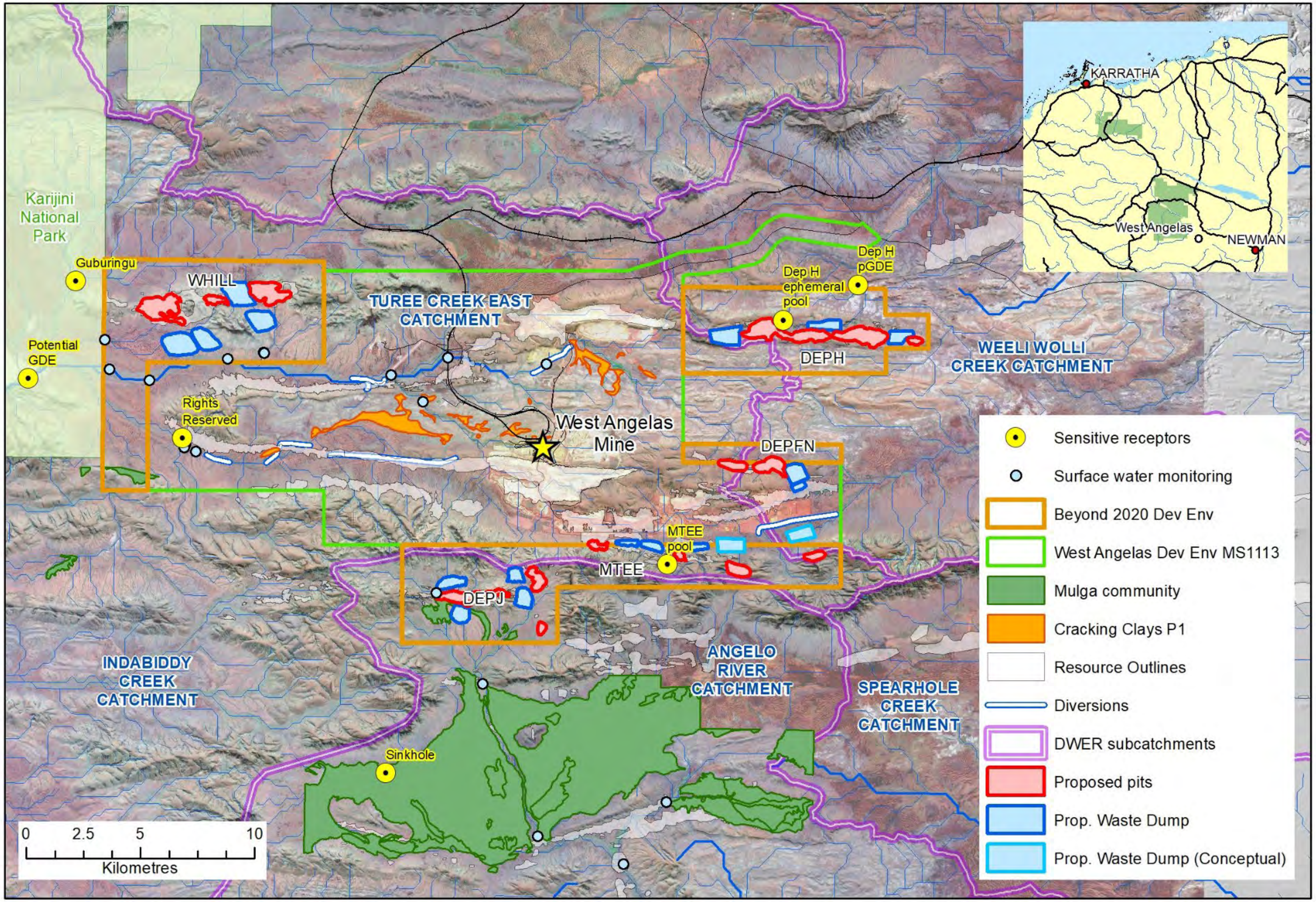


Figure 2-1: West Angelas Beyond 2020 study deposits, regional setting and known sensitive receptors

3. Previous reports

There is a large body of work developed for the greater West Angelas, and the most recent study reports are summarised below.

West Angelas Deposits C & D feasibility study, RTIO, April 2018

This study chapter discusses management of surface and groundwater to enable mining at deposits C & D. These deposits have 18 and 45% of inventory below water table, with the dewatering having implications for management of surplus, and drawdown beneath Karijni National Park and a potential GDE area which was a key focus of the study. Discharge extent modelling indicated that up to 32 ML/d could be discharge from existing licensed discharge outlets without surface water expression at the national park. Significant flood protection is required along Turee Creek East and its southern tributary, including diversion channels and flood protection bunds. The surface water management strategy is to provide flood protection to operations while maintaining natural water course function in Turee Creek, with a focus on flow conveyance to the national park and a Rights Reserved sight adjacent to Deposit D.

West Angelas Deposit C & D DES hydrology and hydraulics study, Jacobs, December 2017

The definitive engineering study for development of deposits C & D at West Angelas describing flood protection from Turee Creek East and its tributaries. This report describes design hydrology and hydraulic simulation of flood events between 50% and 1% AEP. Design hydrology was based on Australian Rainfall and Runoff 2016, and incorporated RORB Monte Carlo analysis, with comparison to regional flood frequency procedures. Existing and post-development scenarios were simulated using TUFLOW hydraulic modelling. A 1% level of protection was designed for deposit C pits, mining plants and conveyors, with 2%AEP protection for Deposit C and D local (tributary) catchments, production hub and workshop. Culverts are designed to convey a 50%AEP event, with higher conveyance of a 10%AEP event at the access road crossing of Turee Creek East.

West Angelas Deposit F feasibility study, RTIO, December 2015

This study chapter provides an overview of the hydrology and hydrogeology investigations undertaken to support development of Deposit F. The pits at Deposit F are 7% BWT, with groundwater between 95 and 115 BGL, with no surplus water expected. Surface water management at Deposit F includes a single 3.5km diversion channel to provide flood protection to the eastern pit from Central Creek up to a 2%AEP event. Passive management was adopted to manage inflow from remaining small catchments surrounding the pits.

West Angelas Deposit B feasibility study, RTIO, October 2013

Only 6% of the high-grade resource at Deposit B is located below water table. The deposit intercepts Padtherung Creek, a large (48km^2) catchment to the south-east and tributary of Turee Creek East. The adopted surface water management strategy for this creek was to construct a diversion berm with constricting culverts to store and slowly release water from the creek via a 2.1km diversion channel. Diverted water discharges to a natural creek, ultimately flowing to its original downstream receptor of Turee Creek East. The diversion was designed to reduce peak flows to meet the pre-existing capacity of rail and road culverts downstream. The diversion berm will overtop at a controlled low-point in events above the 2%AEP.

Catchment characteristics

The full study area covers the catchment divide of Turee Creek East, Angelo River and Weeli Wolli Creeks, with the existing operations at West Angelas mostly within the Turee Creek East catchment.

West Angelas has undergone significant hydrological changes since mining began, with blocking of some tributary catchments via dumps and pits, restriction of flows where linear infrastructure is present, and more recently catchment diversion to allow mining at Deposits B, F, C and D. Despite these changes, catchment connectivity has been retained with a general east-west movement of water across the site to Turee Creek East. The creek flows into Karijini National Park to the west of Deposits C and D, joining Turee Creek main branch, which eventually reaches the Ashburton River, which ultimately discharges to the Indian Ocean.

West Angelas is surrounded by steep ranges with multiple short drainage lines conveying flow to broad, flat valley plains. Because of the flat gradient throughout the lower parts of the catchment, the main channel of Turee Creek East does not exhibit the features of a high-energy creek system. At the far eastern extent of West Angelas is a poorly defined catchment divide, with parts of Deposit F and F north flowing to Weeli Wolli Creek. Deposit H is located completely within the Pebble Mouse Creek catchment, a tributary of Weeli Wolli Creek that drains to the terminal sink of Fortescue Marsh.

To the south of West Angelas across the dividing range is the Angelo River catchment, which hosts Deposit J. Steep ranges surround the northern section of this catchment, with multiple small tributaries discharging to flat terrain occupied by mulga communities through a central basin area. On the slopes the tributaries are incised and high-energy, however as they enter the plains the channel form is lost in detrital deposits and colluvium, with only a single north-south drainage line visible in terrain datasets. Overland flow is the primary mechanism of drainage and it is likely that connectivity across the plain to the south of Deposit J is poor, with significant infiltration losses occurring between the ranges and the outlet of the area in the south.

West Angelas currently discharges surplus mine water at two licensed discharge outlets located at Deposit B and Deposit A. A third licensed discharge point will be commissioned to support dewatering at Deposits C and D and will be located near the Deposit A outlet. All outlets discharge to tributaries of Turee Creek East, with a requirement that continuous surface flows not extend to within 2km of the Karijni National Park Boundary under natural no flow conditions. The discharge has resulted in persistent flows in sections of the creeks receiving discharge.

4. Climate and hydrology

4.1 Rainfall

Under the Köppen climate classification scheme (http://www.bom.gov.au/) based on rainfall and temperature the West Angelas area is described as grassland, hot and persistently dry. Using a seasonal rainfall classification, the broader Pilbara region is considered "arid" with average rainfall generally less than 350mm. However, rainfall is highly seasonal, with most rain falling during the summer wet-season between October and May. In the Pilbara annual rainfall is generally reported for the water year, 1st October to 30th September, and individual years are reported using the starting year (i.e. 1985 refers to the water year 1st Oct 1985 to 30th of September 1986).

Rainfall records are available at Benchmark and Campbell Scientific weather stations within or near the catchment, listed below and locations shown in Figure 4-1, although the periods of record are relatively short, being associated with the commencement of mining in the area. Gridded climate data is also available across the region from the SILO database (Environment and Science, 2020) and rainfall and evaporation data was extracted at the West Angelas and Angelo River catchments to provide a continuous long-term climatic record.

Table 4-1: Weather stations in the Greater West Angelas and Angelo River area

Station	Availability	Source
West Angelas Benchmark	2004 – present	RTIO
Angelo River Campbell Scientific	2011 – present	RTIO
SILO West Angelas 118.75, -23.15	1889 – present	QLD Gov.
SILO Angelo River 118.80, -23.30	1889 – present	QLD Gov.

Annual rainfall totals for Angelo River and West Angelas for the period 1981 to present are shown in Figure 4-2. Angelo River has slightly lower average rainfall consistent with a decline in rainfall with distance from the coast. As has been observed throughout the east Pilbara, the period 1996 to 2006 was associated with several very high annual rainfall totals, and wetter conditions overall, including the wettest year on record over the 1999/2000 wet season. The most recent rainfall years (2017 – 2019) have been below average. These years correlate with when baseline monitoring of surface water began for most creek or pool monitoring locations, and no significant single day rainfall events have been recorded in that period as highlighted by comparing daily rainfall records and design rainfalls for West Angelas (Figure 4-3). As such the streamflow records collected over this period are more representative of typical dry years than wet years.

Cumulative rainfall records from 2011 to present for the Benchmark and Campbell scientific rain gauges, and the SILO rainfall data are displayed in Figure 4-4. Rainfall trends are consistent across the four datasets, with the local rainfall sites recording lower rainfall depths on average. In the 2017/18 wet season the Angelo River station reported twice as much rainfall as the other three sources, and it is very likely that a systematic over recording of rainfall has happened, rendering the data unusable over this period.

Box and whisker plots (Figure 4-5 & Figure 4-6) highlight the seasonal nature of rainfall for both areas. Rainfall is summer dominant with December to January generally the wettest months. Significant rainfall in summer is caused by topical lows and thunderstorms that are associated with the development of the monsoon in northern Australia. Winter is the dry season, with low rainfall recorded between June and September. Rainfall occasionally occurs in these months when very large winter cold fronts track sufficiently far north, and intense rainfall can occur when these systems meet moisture funnelled from the tropics via north-west cloud bands.

The maximum monthly totals were generally recorded in the same years for both the Angelo and West Angelas, implying that the same event/s contribute to the totals. The daily rainfall statistics at Angelo River and West Angelas shown in Table 4-2 and Table 4-3 demonstrate that in summer rainfall occurs more frequently and has larger single day totals in comparison to winter rainfall. In general, less runoff will be generated from winter rainfall due to moisture deficit in the catchment, and the lower intensity of winter rainfall. The largest recorded flood events in the catchment have all been associated with summer rainfall events, and even very heavy dry season rainfall usually fails to produce creek flow.

4.2 Evaporation

Evaporation data was sourced from the SILO database (Environment and Science, 2020). Annual Class A pan evaporation at West Angelas averages 3050 mm per year, with the highest evaporation rates over the summer months as shown in Table 4-4 and Figure 4-7. FAO56 reference evapotranspiration estimates evapotranspiration potential for a reference crop based on temperature, radiation, wind speed and humidity. At West Angelas it totals 2051 mm per year, with maximum potential evapotranspiration (PET) during summer when solar radiation and temperatures are at their peak. It is a useful metric for defining an upper limit on potential vegetation water use within a catchment, assuming no constraint of water supply. There is no meaningful difference in evaporation in the Angelo River region, with pan evaporation averaging 3053 mm annually, and PET averaging 2043mm.

The broader West Angelas area functions with a substantial rainfall deficit, with pan evaporation exceeding rainfall by a factor of ten in average years. The rainfall deficit means that actual catchment evaporation and PET are far lower than the potential rates listed in Table 4-4. Most of the year the catchment will function with a rainfall deficit, with much rainfall infiltrating into dry soils and gravel without producing runoff. The high evaporation rates mean that exposed pools, river flows or surface expressions of groundwater are subject to substantial evaporative losses, particularly in summer.

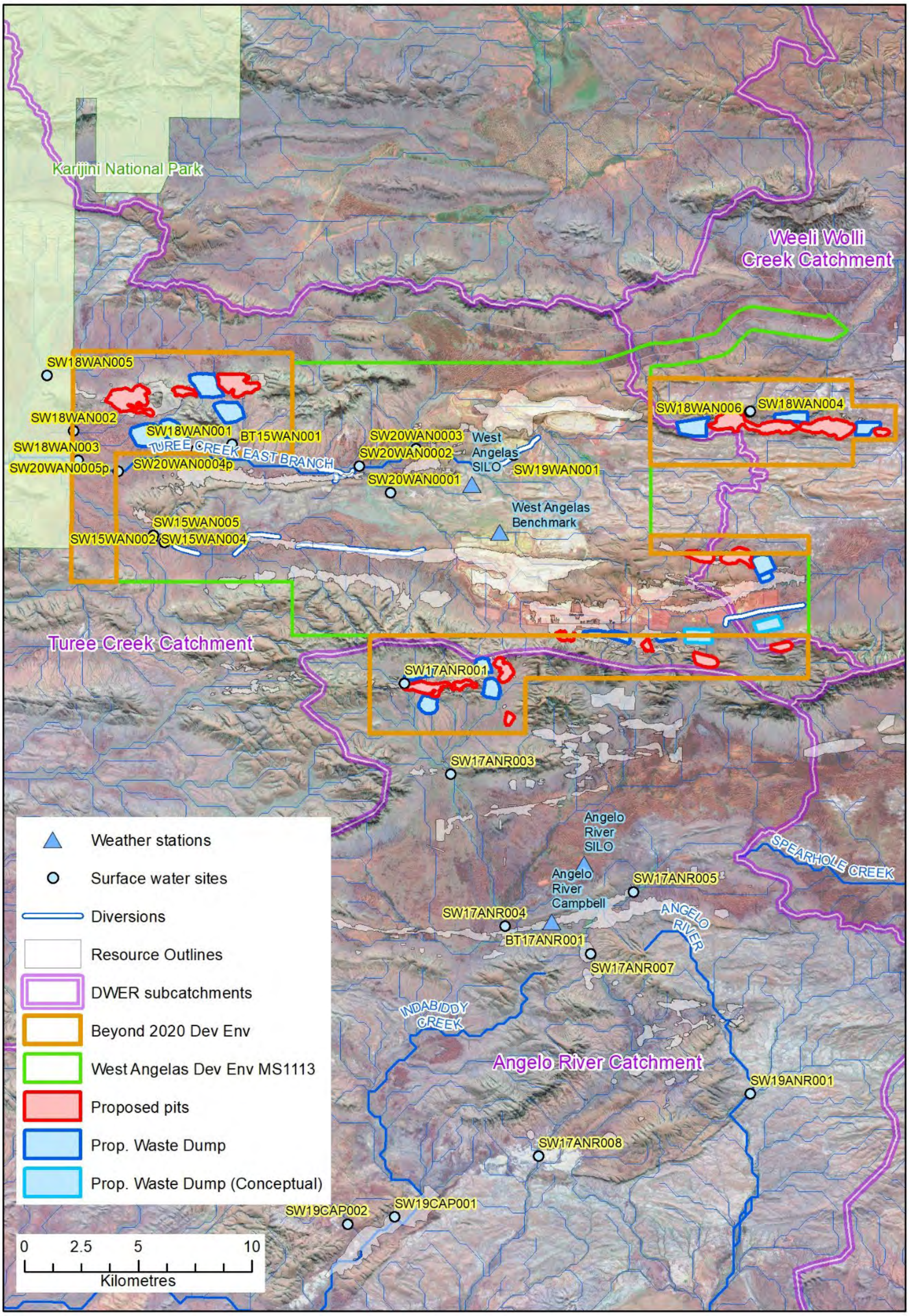


Figure 4-1: Weather stations and surface water monitoring sites in the broader study area

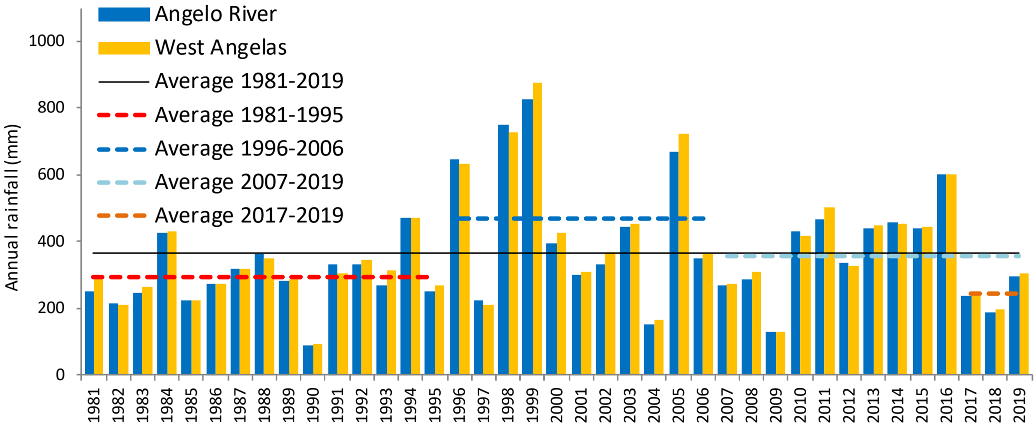


Figure 4-2: Annual rainfall from SILO grid cells at Angelo River and West Angelas (1981 to 2019), showing mean values for various time periods (combine average of West Angelas and Angelo River)

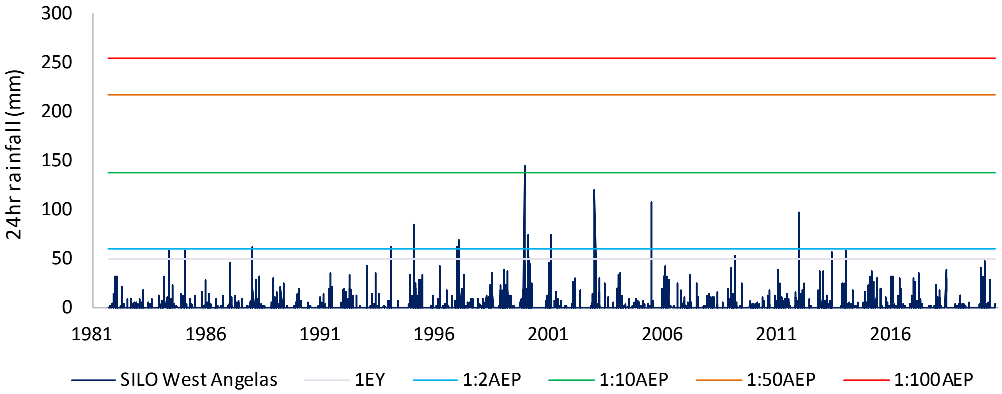


Figure 4-3: Comparison of 24hr rainfall at West Angelas using SILO gridded data (1981 to 2019), and point design rainfalls sourced from Bureau of Meteorology 2016 IFD data portal

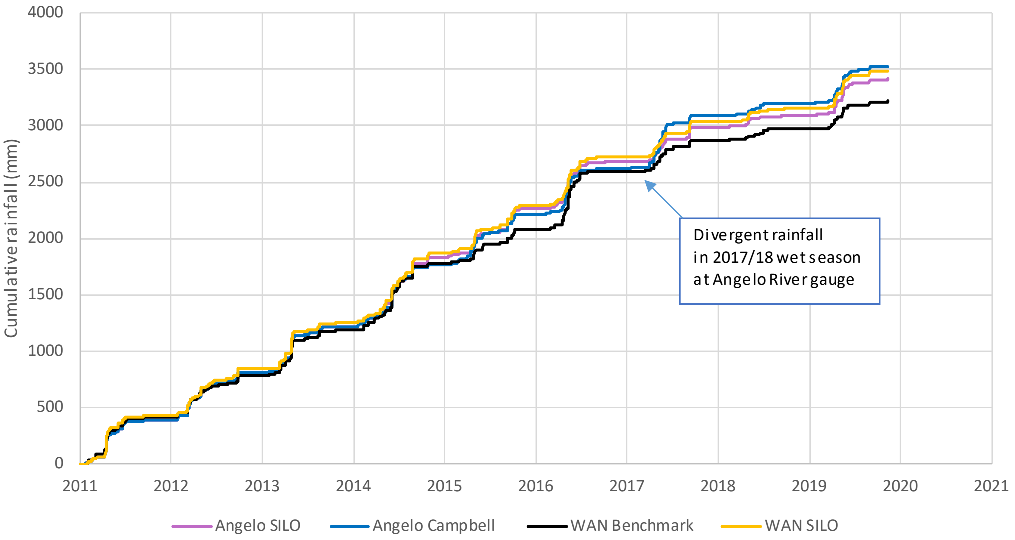


Figure 4-4: Cumulative rainfall series 2014 to 2019 for SILO grid cells and RTIO rainfall stations at Angelo River and West Angelas (missing days of record in-filled with SILO data)

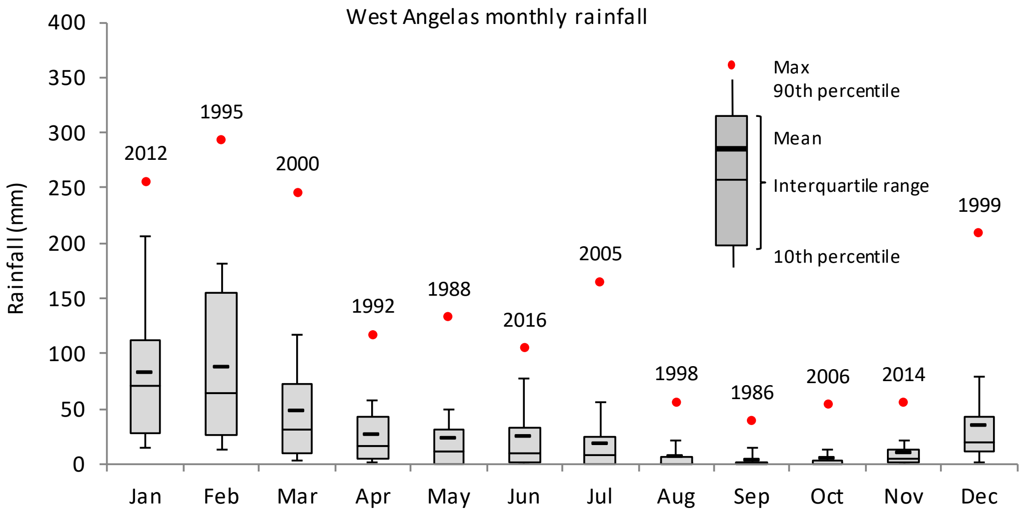


Figure 4-5: Monthly rainfall statistics (1981 to 2019) using SILO gridded data for West Angelas

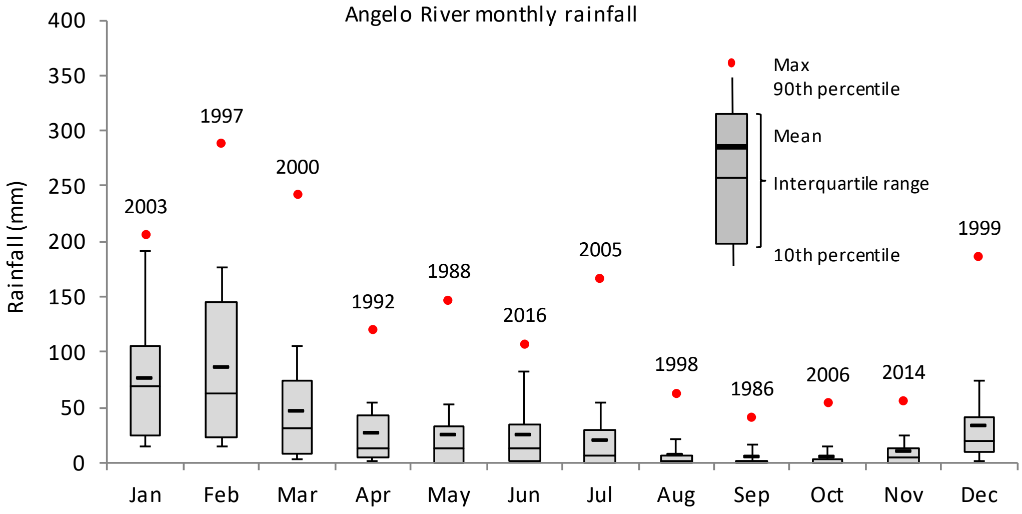


Figure 4-6: Monthly rainfall statistics (1981 to 2019) using SILO gridded data for Angelo River

Table 4-2: Daily rainfall statistics (1981 to 2019) using SILO gridded data for West Angelas

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (mm)	119.7	84.4	54.2	42.9	58.4	57.5	108.7	34.9	24.7	17.9	19.7	146.0
Average daily rain (mm)	5.4	6.5	4.5	3.8	4.9	4.8	5.1	2.7	2.5	1.9	2.0	3.8
Standard deviation (mm)	10.5	11.2	8.3	6.1	7.8	8.1	11.5	5.2	4.6	3.4	3.1	9.0
Maximum days with rain >1mm	22	19	17	14	14	9	8	4	6	10	9	18
Mean days with rain >1mm	9.5	8.7	5.7	3.9	2.8	3.0	2.1	0.9	0.5	1.1	2.1	5.1
Maximum days with rain >5mm	11	13	9	8	7	6	6	2	4	2	4	7
Mean days with rain >5mm	4.3	4.1	2.4	1.6	1.2	1.3	0.9	0.3	0.2	0.3	0.6	1.9

Table 4-3: Daily rainfall statistics (1981 to 2019) using SILO gridded data for Angelo River

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (mm)	104.4	102.9	50.5	35.5	61.2	58.5	111.3	39.6	24.8	20.3	22.2	127.3
Average daily rain (mm)	5.1	6.6	4.6	3.7	5.5	5.0	5.7	2.9	2.9	2.1	2.2	3.8
Standard deviation (mm)	9.6	11.6	8.1	5.8	8.6	8.5	12.2	5.8	4.9	3.7	3.5	8.5
Maximum days with rain >1mm	20	18	17	14	13	9	9	4	7	11	8	17
Mean days with rain >1mm	9.4	8.4	5.5	3.9	2.7	2.9	2.1	0.9	0.5	1.0	2.0	4.7
Maximum days with rain >5mm	11	12	10	8	8	6	6	2	4	3	4	9
Mean days with rain >5mm	4.1	4.1	2.5	1.7	1.3	1.5	0.9	0.3	0.2	0.3	0.6	1.9

Table 4-4: Evaporation rates calculated at West Angelas mine using SILO data drill (1981-2019).

Month	Class A pan evaporation statistics at West Angelas site (mm/day)				Class A Pan evaporation (mm)	FAO56 PET (mm)
	Min	Max	Mean	Std dev.		
Jan	0.2	22.1	11.5	3.1	357	228
Feb	2.0	19.2	10.1	3.1	285	187
Mar	1.3	17.4	9.2	2.4	284	189
Apr	1.2	14.1	7.3	2.1	219	151
May	0.2	13.2	5.3	1.7	164	119
Jun	0.4	9.2	4.1	1.2	122	91
Jul	0.3	10.1	4.3	1.2	134	102
Aug	0.9	10.9	5.7	1.2	178	133
Sep	1.9	14.2	8.1	1.6	244	171
Oct	3.6	16.9	10.7	1.9	333	218
Nov	1.3	18.4	12.1	2.1	364	231
Dec	2.3	21.3	12.5	2.7	387	244
Annual					3070	2064

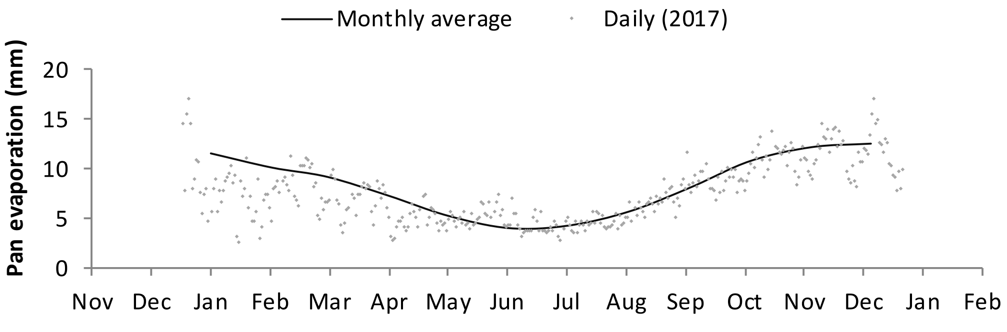


Figure 4-7: Seasonal pan evaporation plot at West Angelas mine using SILO gridded data (2017 shown)

4.3 Hydrology and streamflow monitoring

There are no formal flow gauges located within the local catchments of West Angelas and Angelo River. The nearest DWER gauging stations are well downstream on Weeli Wolli Creek (Tarina) and on the Ashburton River (Capricorn Range). The relative catchment area and position of these gauges make them unsuitable for analysis in the upper catchment where the study deposits are situated.

To address the lack of data, multiple temporary pressure transducers have been installed across West Angelas and Angelo River to record water levels in ephemeral creeks and at one ephemeral pool. These were installed to support calibration of flood modelling in future, characterise baseline conditions and improve catchment conceptualisation. In some instances, equipment was installed at or near the location of potential sensitive receptors (as identified in section 11).

All active surface water sites in the broader West Angelas and Angelo River region are displayed in Figure 4-1, with the local setting described for those relevant to the Beyond 2020 deposits. The earliest site commenced recording in March 2017, with additional locations added over time. Monitoring will continue as appropriate.

Despite the number of locations monitored, no major flood events were recorded between 2017 and 2019. The wet season rainfall totals were below average at West Angelas, and the largest individual daily rainfall depth of 48mm recorded in early February 2020 associated with Tropical Cyclone (TC) Damien. This rainfall depth is roughly a 1EY 24hr duration event, which would not be expected to generate significant runoff in an arid catchment. Although it is likely that this rainfall extended across the whole catchment, low soil moisture after an extended dry period meant that it resulted in little runoff.

In general, isolated flow events were recorded at some monitoring locations, but no significant flooding was measured, and larger creeks including Turee Creek East did not record large flows. As would be expected, monitoring at most locations is consistent with the ephemeral creek systems in the arid east Pilbara. The only location with more persistent surface water is at an ephemeral rock pool near Deposit H. The creek flow events that were recorded were not large enough to be used for flood model calibration. In general, it was observed that rainfall depths must be in the range of ~40mm or more to initiate catchment flows, especially in the major creeks. For example, only two small flow events were recorded in three years on Turee Creek East at the Karijini National Park boundary.

SW15WAN002 – Turee Creek East southern tributary at Deposit D

This site monitors water levels in the creek upstream of Gajiringu heritage site and is located in the low flow chnnel of an ephemeral creek which is a southern tributary of Turee Creek East. Monitoring commenced in 2017 and with several small shallow flows recorded during 2017, but no others for the remaining period of record.

Figure 4-8: Site photos looking downstream (left), and upstream (right) at SW15WAN002, and water levels for period of record (bottom).

SW15WAN004 – Turee Creek East southern tributary – secondary tributary

This site records water levels in a minor tributary flowing to Gajiringu heritage site. Coarse gravel material in the creek bed indicates a higher energy regime relative to the main southern tributary channel, however no flow events have been registered at the site since recording began.

Figure 4-9: Site photo looking downstream at SW15WAN004 (top), water levels for period of record (bottom)

SW15WAN005 – Turee Creek East southern tributary downstream of confluence near Rights Reserved site

This site records water levels downstream from SW15WAN002 & SW15WAN004 and records the combined inflows from the main and tributary branch. Only minor flow events have been recorded over the last three wet seasons, with flow sourced from the main branch as measured at SW15WAN002.

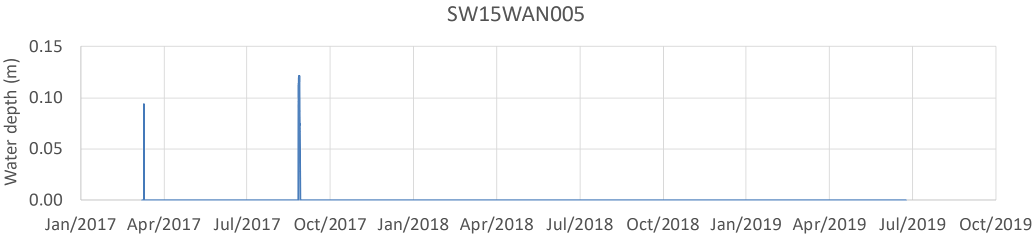


Figure 4-10: Site photos at SW15WAN005 looking downstream (left) and upstream (right), and water levels for period of record (bottom).

SW18WAN001 – Incised tributary to Turee Creek East near Western Hill

This site records water levels in a small incised creek with a 5.8 km^2 catchment which drains a section of Western Hill. The site was installed in early 2017 and recorded one flashy flow event at the end of the wet season, with water levels reaching 50cm following a short bust of rainfall at West Angelas. A second small flow was recorded in February 2020 during TC Damien.

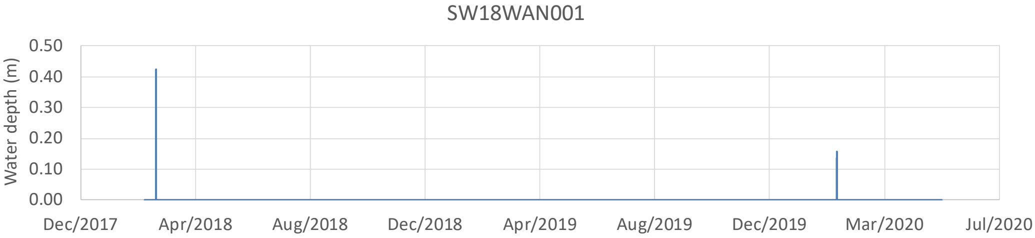


Figure 4-11: Site photo at SW18WAN001 looking upstream (top) and water levels for period of record (bottom)

SW18WAN002 – sheet flow area on border of Karijini National Park

This site is located just outside the national park boundary in a local depression within a broader sheet flow area that drains to Turee Creek East. A signal pulse of flow was recorded in 2020 during TC Damien, but water levels did not exceed the crest level of the local depression and as such no downstream flow occurred.

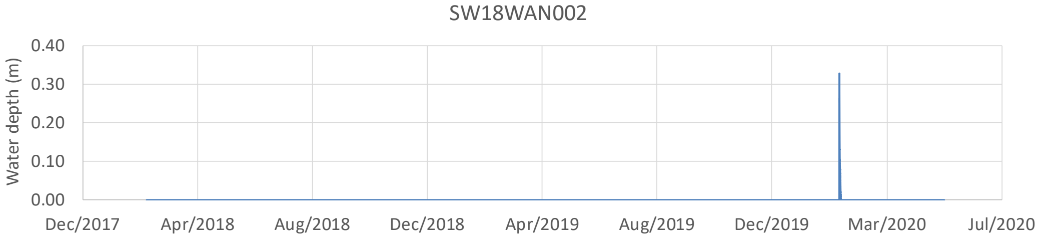


Figure 4-12: Site photo at SW18WAN002 in depression (top) and water levels for period of record (bottom)

SW18WAN003 – Main channel of Turee Creek East on the border with Karijini National Park

This site is located just upstream of the national park boundary within the main channel of Turee Creek East, downstream from Deposit C, but upstream from the confluence with the main southern tributary from Deposit D. Two small flow events were recorded in early 2020, with water depths reaching only 30-40cm. The peak flow rate for these events was estimated at less than 1m^3/s using hydraulic ratings of the channel.

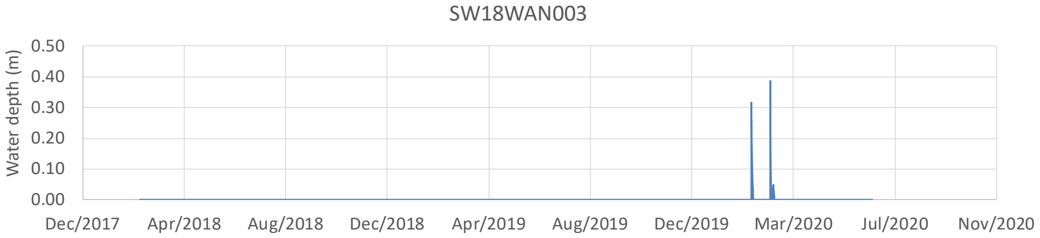


Figure 4-13: Site photo looking upstream on Turee Creek East main branch (top), and water levels for period of record (bottom)

SW18WAN004 & SW18WAN006 – Monitoring of pool and contributing catchment at Deposit H

These two sites were installed during dry season 2018 to record water levels at an ephemeral pool site within Deposit H, and flow in the contributing catchment. Limited flow events were recorded in the catchment, however in early 2020 flow was sufficient to fill the pool to over 2m, with storage remaining into the dry season in July. Photographic records from 2019 also indicate that the catchment inflows recorded early in the wet season sustained storage for a period of several months following the event. The pool was observed to be dry during the low rainfall 2018/19 wet season with no catchment inflow.

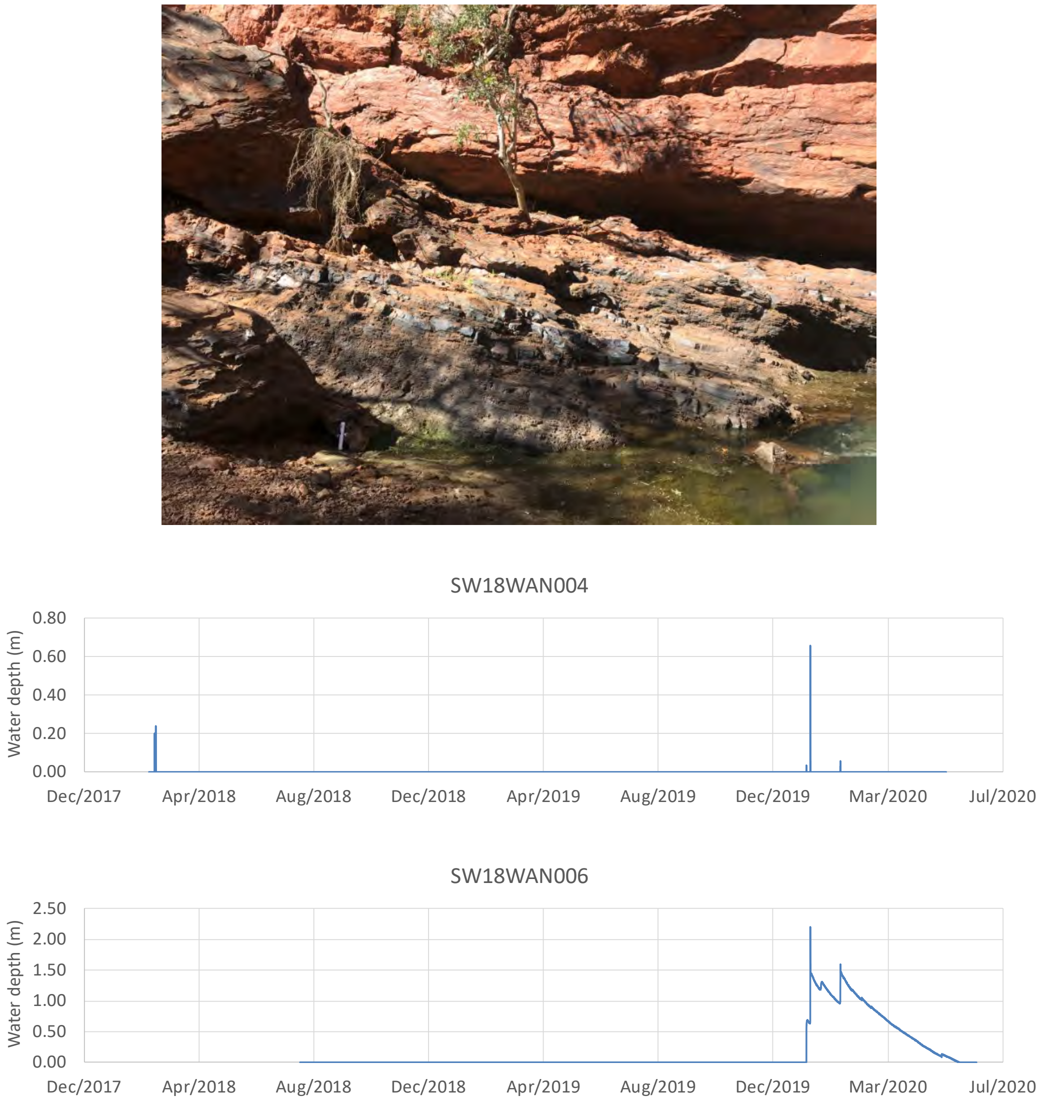


Figure 4-14: Site photo of SW18WAN006 installation at ephemeral pool (top), water levels recorded at catchment inflow SW18WAN004 (middle) and pool water levels recorded at SW18WAN006 (bottom)

SW18WAN005 – Guburingu heritage area at Western Hill

A pressure transducer was installed with permission of Yinhawangka group within the Guburingu heritage area, just inside the national park boundary to the west of Western Hill. Two creeks converge at the site, but the logger was placed in a lateral tributary channel that is associated with enhanced vegetation. Water levels of above 50cm were recorded during TC Damien, but these were short-lived and there was no evidence of persistent pooling at the location.

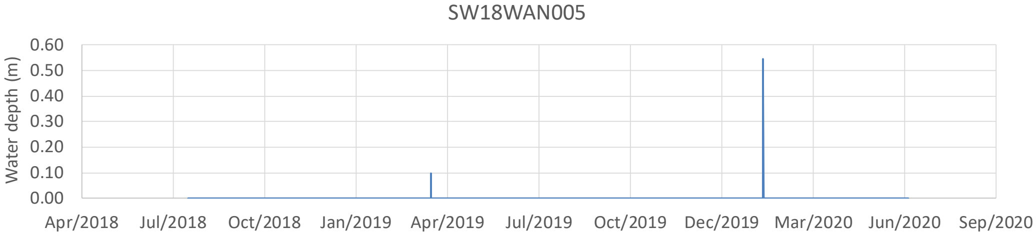


Figure 4-15: Site photo of SW18WAN005 installed in tributary channel of Guburingu heritage area (top) and water levels for period of record (bottom)

SW19WAN001, SW20WAN0002 and SW20WAN0003 – Monitoring of discharge downstream from Deposit B

Monitoring was installed downstream from the licensed discharge outlet at Deposit B during 2019 and 2020, prior to commencement of increased discharge rates. Pressure transducers were installed at the outlet of the Deposit B diversion drain (SW19WAN001), further downstream at the West Angelas rail (SW20WAN0003) and on the Turee Creek East main channel near West Angelas airport (SW20WAN0002). Water levels illustrate the migration of the wetting front downstream as discharge is increased as shown in Figure 4-16.

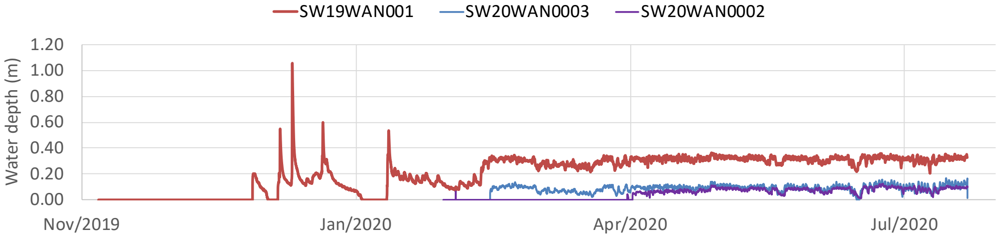


Figure 4-16: Water levels for the period of record for SW19WAN001, SW20WAN0003 and SW20WAN0002

SW17ANR001 – High energy creek at western end of Deposit J

This logger is installed on the 9.1 km^2 catchment which skirts the western end of the resource at Deposit J. This site recorded multiple minor flow events during the 2017/18 wet season and the 2019/20 season. Monitoring suggests it flows more regularly than other creeks monitored at West Angelas with lower rainfall thresholds required to initiate flow.

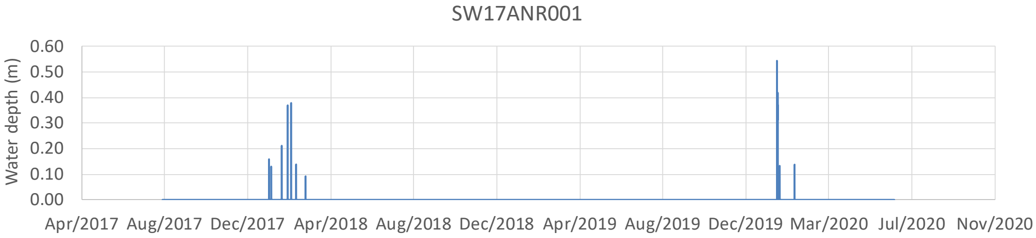


Figure 4-17: Site photo of SW17ANR001 looking downstream towards Deposit J (top) and water levels for period of record

Hydrological and Hydraulic modelling

The Beyond 2020 study deposits are geographically disparate, with highly variable terrain ranging from steep incised creek lines and gorge systems to broad flat plains with overland sheet flow the dominant rainfall-runoff process. There is no long-term flow gauging within the study domain, and the short-term logging deployed by RTIO hydrology is insufficient for use in model calibration and statistical analysis of flows.

For this reason, a direct rainfall ensemble modelling approach was combined with a RORB Monte Carlo assessment to characterise flood behaviour within the study area. A regional TUFLOW direct rainfall model was configured for the full catchment of the West Angelas area including parts of Turee Creek East, Weeli Wolli and Pebble Mouse Creek catchments. A regional RORB model was developed covering the Turee Creek East catchment. Deposit J was incorporated in a separate direct rainfall model domain.

The flood estimates derived from the direct rainfall modelling and RORB Monte Carlo simulations were assessed against regional flood estimation techniques. The final design flood estimates for key catchment interceptions were adopted based on the best available estimate considering the limitations of each technique. Representative design storms were identified for use in higher resolution local-scale hydraulic modelling of each deposit which were used to identify surface water management requirements and assess post-development impacts to hydrology and flooding.

This study follows guidelines for application of direct rainfall and ensemble modelling and Monte Carlo simulation techniques as discussed in Engineers Australia (2012) and ARR2019. Flood estimation and hydraulic flood simulations were completed for each study deposit for floods of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100 and 1:200AEP. A site wide assessment was also completed for rarer flood events to provide a general risk assessment for above design flood events (1:1,000AEP and 1:10,000AEP event).

5. Hydrological modelling and flood estimation

5.1 Rainfall Intensity Frequency Duration

Design rainfall depths for frequent to very rare events (1EY to 1:2000AEP) were sourced from the Bureau of Meteorology 2016 IFD data portal (see Appendix A). Rainfall depths for the probable maximum precipitation (PMP) event were calculated using the Generalised Short Duration Method (GSDM, BoM 2003a) for storm durations between 1 and 6 hours, and the revised Generalised Tropical Storm Method (GTSMR BoM 2003b) for storm durations between 24 and 120 hours. Depths for the 12 hour duration event were calculated using interpolation between the 6 hour and 24 hour event. Table 5-1 lists the catchment adjustment factors used to estimate the PMP. Appendix A lists the final PMP rainfall depth estimates for the range of durations considered. The AEP of the PMPF was estimated from catchment area based on the methods of Laurenson and Kuczera (1999). Logarithmic interpolation was used to estimate design rainfall depths for AEPs between 1:2000 and the PMP. Figure 5-1 illustrates the rainfall IFD curves adopted for the West Angelas Beyond 2020 study.

Table 5-1: Catchment adjustment factors used with GTSMR and GSDM procedures

	GSDM parameters			GTSMR parameters		
Zone	Roughness	Elevation adjustment factor	Moisture adjustment factor	Decay amplitude factor	Topographic adjustment factor	Annual moisture adjustment factor
Coastal	Smooth	1.00	0.95	0.90	1.00	99.00

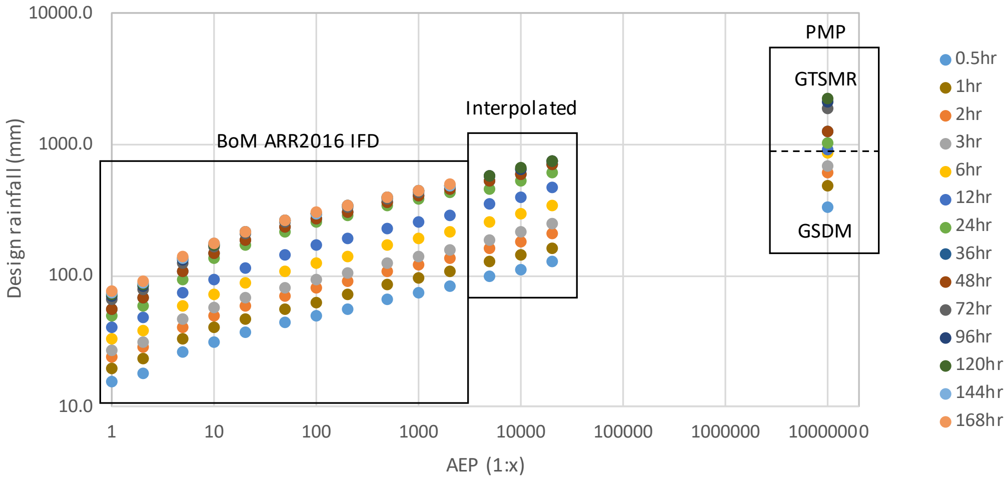


Figure 5-1: Point rainfall IFD curves for AEPs of 1EY and the PMP

Design rainfalls are typically calculated from point readings of rainfall IFD data at meteorological stations, and as such they represent the probability of rainfall depths at a point in space, and are not representative of large catchment areas. To correct for this discrepancy Areal Reduction Factors (ARFs) can be used to adjust a point rainfall depth to a catchment rainfall depth. This is important in large catchments where the ARF can be significant. Because most catchment interceptions for the study are generally less than 10km^2 ARFs are not applicable. However, at some locations such as on the floodplain of Turee Creek East the ARF may be larger and have a larger influence on the final design rainfall. For the purposes of the direct rainfall assessment the ARFs were ignored (no reduction), simplifying the direct rainfall ensemble modelling across large domains with variable catchment areas. The RORB Monte Carlo assessment has incorporated sensitivity testing with and without ARFs applied.

5.2 Temporal patterns

Rangelands West point temporal patterns were sourced from the ARR2019 data hub. The point temporal patterns are appropriate for use for catchments of less than 75 km^2 which is appropriate across most of the model domain. However, as with the ARFs, for larger catchment intercepts such as the floodplain of TCE areal temporal patterns should be selected in future assessments.

5.3 Rainfall design losses

The loss model adopted for the hydrological analysis was initial loss (IL) and continuing loss (CL), with the continuing loss parameter applied as a rainfall loss. West Angelas is situated outside of the region for which the Australian Rainfall and Runoff data hub provides regional loss estimates. As such several sources of information were considered for IL and CL parameters including soil properties defined in the Atlas of Australian soils, regional surface geological mapping, and ARR2019 prediction equations and nearby regional estimates.

Soils across the greater West Angelas area fall under three main map units based on the Atlas of Australian Soils FA13, FA14 and FB3 (Northcote et al. 1960-1968). The spatial resolution of the soil units is insufficient for use as distributed soil properties, and reported saturated conductivities associated with map units range from 1 mm/hr to over 1000 mm/hr (McKenzie et al. 2000). Using the percentage clay content in the limiting soil horizon, saturated hydraulic conductivity was estimated based on soil texture classification (adapted from Clapp & Hornberger (1978), Cosby et al (1983) and van Gool et al (2005). The soils FA13, FA14 and FB3 all fall within a clay loam classification, with an estimated Ksat of 6.1mm/hr.

Surface geological mapping (Newman 250K geology) provides an improved resolution of mapping demarcating outcropping Brockman and Marra Mamba Iron formation in the ranges, with extensive alluvium, colluvium and detritals associated with the valley floors. Generally lower losses would be expected on the steep rocky outcrops, with increased losses throughout the valley floors.

There is significant uncertainty associated with soil losses in the Pilbara with a wide range in possibilities as listed in Table 5-2. In catchment simulation, the selection of a large initial loss tends to remove all of the design rainfall for shorter duration events, and smaller design rainfalls. This limits the applicability of Monte Carlo and ensemble methods and tends to artificially bias the critical duration event upwards, since longer events have greater depths overall. As such, a lower initial loss was adopted, at 30mm, with a slightly higher continuing loss of 8mm/hr. These rainfall design losses were adopted for both RORB and direct rainfall simulations.

Table 5-2: Loss parameters considered and adopted for direct rainfall ensemble and RORB Monte Carlo simulations

Catchment area (km^2)	**IL (mm)**	**CL (mm/hr)**
Gridded losses at Karijini (118.9, -22.5) ARR2019 data hub	80	7.3
Harding catchment (Hill et al. 2014)	60	8.3
Flavell and Belstead (1986) lower limit of expected	50	5
Region 2 prediction equations ARR2019 (Min)	20	1.4
Region 2 prediction equations ARR2019 (Median)	37.5	2.7
Region 2 prediction equations ARR2019 (Max)	60	8.3
Atlas of Australian Soils – soil texture derived saturated conductivity	-	6.1
Adopted parameters		
Greater West Angelas	30	8

5.4 West Angelas regional RORB modelling

A hydrologic model of the Greater West Angelas region were developed using the RORB Runoff Routing Program (Laurenson *et al.*, 2010) in order to estimate peak flows. RORB is a rainfall runoff and streamflow routing model that calculates flood hydrographs from rainfall and other catchment and channel inputs. Rainfall excess, calculated by subtracting losses from rainfall, is routed through catchment storages to produce runoff hydrographs at any location; losses in RORB are processes that occur on the catchment surface before the water enters the channel network.

In addition to catchment storage, RORB allows for storage reservoirs and channel inflow and outflow processes, such as baseflow or catchment breakouts, to be modelled. Channel inflows and outflows can be modelled using a hydrograph, constant value or discharge relationship. Using available topographic information catchments encompassing the areas of interest are divided into sub-areas bounded by drainage divides. A rainfall excess for each sub-area is assumed to enter the channel network at a point near the centroid of the sub-area, added to any existing flow in the channel and routed through storages by a routing procedure based on continuity and a storage-discharge relationship:

$$S = 3600kQ^m$$

where S is the storage (m^3), Q is the outflow discharge (m^3/s), m is a dimensionless exponent that is a measure of the catchment's non-linearity and k is a dimensionless empirical coefficient. The coefficient k is calculated as:

$$k = k_c k_r$$

where k_c is an empirical coefficient applicable to the catchment and stream network and k_r is a dimensionless ratio called the relative delay time applicable to an individual reach storage. Channel storages are proportional to the reach length and hydrographs are combined at channel junctions (Laurenson *et al.*, 2007).

5.4.1 RORB model domain and structure

The RORB model incorporates the full extent of the Turee Creek East catchment to within Karijini National Park, which includes most of the West Angelas mine (Figure 5-2). The extent of the model was defined to capture all contributing catchments to Turee Creek East to support design flood estimation adjacent to Western Hill with the latest information including development at Deposit C and D. The intent of the RORB model is to act as a cross reference for flood estimates derived from the direct rainfall ensemble modelling for Turee Creek East at Western Hill.

The model consists of 56 sub-catchments ranging in area from 1.5 to 35 km^2 with an average of 8.8 km^2.and a total area of 492 km^2. A total of 124 reaches are included, with 10 of these defined as excavated channels, corresponding to constructed channels and diversions at Deposit B and Deposit D.

The rail alignment acts as a hydraulic control on flow received by Turee Creek East downstream, with rail culverts and the rail embankment acting to store and release floodwater for rarer events. The Deposit B diversion berm and drain system acts as a similar control, storing water upstream and releasing it through restricting culverts to the drain downstream. These structures were included in the RORB model as storage nodes, defined with culvert and weir outlets, and stage-storage relationships for the area upstream from the rail embankment and diversion berm (Table 5-3). This allows the hydraulic controls to be represented dynamically within the routing network. Note that smaller culverts, and those which do not connect a major upstream contributing area were not included in the RORB model.

Table 5-3: Configuration of hydraulic controls

Parameter	Dep B diversion berm	Rail culverts north (x2)		Rail culvert south
Weir coefficient	2	2	2	2
Weir crest mAHD	738.1	714.5	714.5	708
Crest width* m	300	500	500	500
Culvert diameter m	1.5	1.8	1.2	3
Culvert count #	2	4	5	1
Culvert length m	70	25	25	25
Entrance loss	0.5	0.5	0.5	0.5
Invert level mAHD	730.3	710.5	711.5	702.5

** Notional crest width as embankment varies in height*

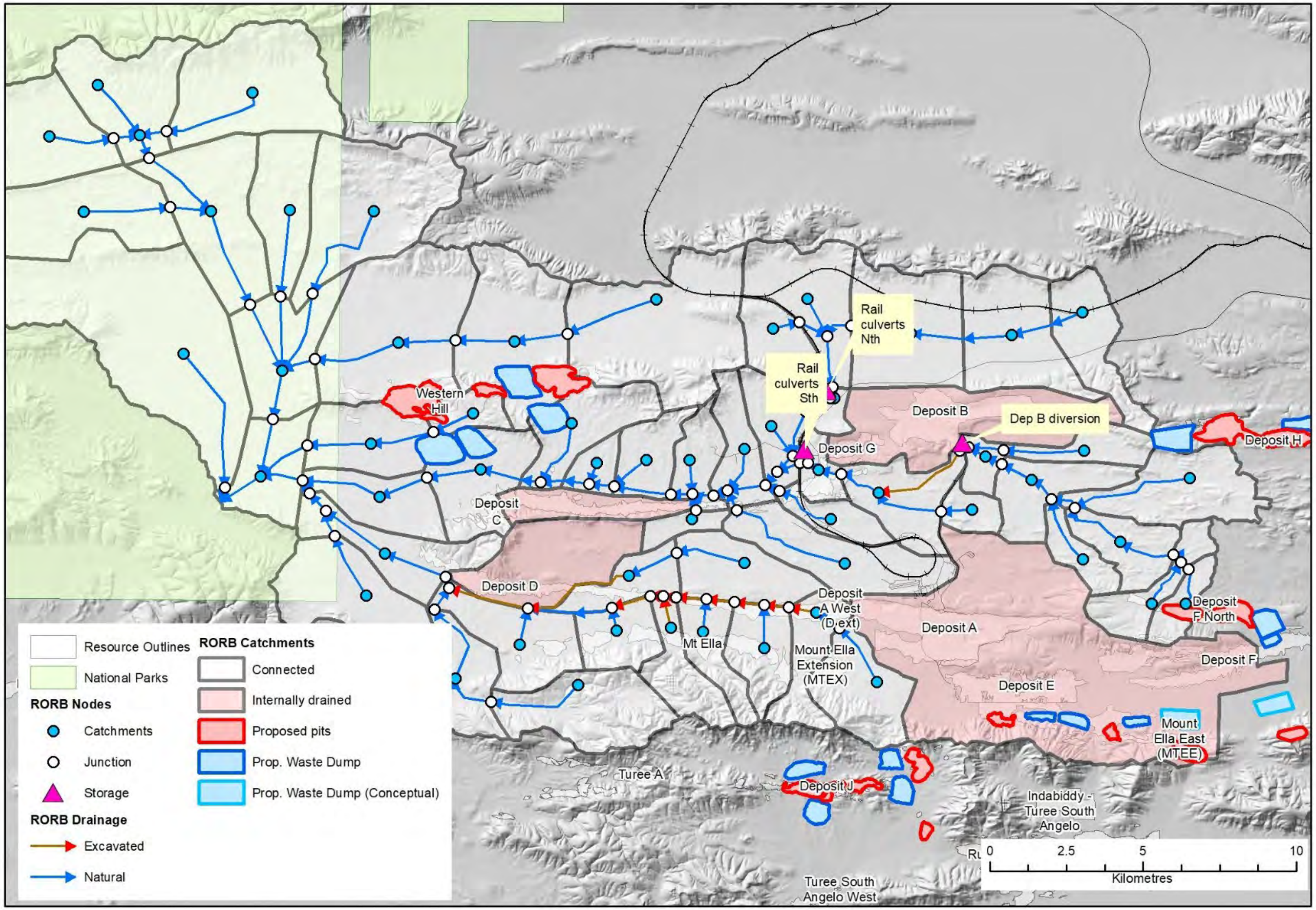


Figure 5-2: West Angelas regional RORB model

5.4.2 Model routing and loss parameters

Ideally, the routing parameter values would be selected based on calibration to recorded historic flood events. However, as discussed in Section 4, there is insufficient gauged water level or streamflow data to support such a calibration process in the catchments covered by this investigation. Consequently, reliance was placed on regional estimates to determine these model parameter values.

The methods described in Pearcey *et. al.* (2014) for estimating the k_c parameter were adopted for this study, whereby k_c is directly proportional to d_{av} by the relationship:

$$C_{0.8} = \frac{k_c}{d_{av}}$$

Where:

d_{av} = the average flow distance in the channel network of sub area inflows; and

$C_{0.8}$ = area-standardised lag parameter (with m = 0.8) that can be expected to be essentially independent of catchment size

Pearcey *et. al.* (2014) developed an expected area-standardised lag parameter estimated for the Pilbara region, with $C_{0.8}$ = 0.59. By applying this method to the RORB model developed for West Angelas, the parameter k_c was estimated to be 9.86.

In line with Flavell *et al.* (1983), Pearcey *et al.* (2014) and the recommendations of ARR (Ball *et al.*, 2019) an m value of 0.8 was adopted.

Rainfall losses were selected as described in Section 5.3, with initial loss set to 30mm, and continuing loss set to 8 mm/hr.

5.4.3 Monte Carlo simulation

The estimation of design floods using RORB was based on a joint probability Monte Carlo approach, consistent with the recommendations in ARR 2019. The RORB Monte Carlo functionality enables estimation of design floods by simulating catchment response to rainfall stochastically. Both rainfall temporal patterns and initial loss (surrogate for catchment antecedent conditions) can be included stochastically in analysis. The functionality was introduced with recognition that previous approaches suffered from subjectivity when attempting to achieve AEP neutrality (where a particular design flood has the same AEP as its causative rainfall). By incorporating the joint probability of rainfall temporal patterns and losses, it is possible to more realistically estimate flood generation processes of the catchment and the range of probable flood events for given rainfall depths. RORB Monte Carlo simulations generate a flood frequency curve which can be used to determine flood quantiles as required, and as such provides an alternative to flood frequency analysis.

Flood estimates were derived for Turee Creek East to the east of Deposit C near Western Hill. Monte Carlo simulations were run for the catchment, with three separate iterations, one without catchment ARFs applied – equivalent to the direct rainfall ensemble which did not apply ARFs. One with the ARFs applied. And one using the loss values applied in the most recent study of the catchment (Jacobs 2017) using the current RORB model structure. ARFs are based on a catchment area of 132 km^2 which is the upstream area from the TCE reporting location, excluding internally draining areas. Results are displayed in Table 5-4 below.

Table 5-4: Design flood estimates derived from RORB Monte Carlo joint probability simulations

TCE at Deposit C & Western Hill Design flood estimate m^3/s						
AEP (1 in x)	RORB Monte Carlo IL 30mm, CL 8mm/hr	Critical duration	RORB Monte Carlo & ARF IL 30mm, CL 8mm/hr	Critical duration	RORB Monte Carlo & ARF and Jacobs (2017) losses IL 65mm, CL 6.8mm/hr	Critical duration
2	0	9	0	24	0	12
5	39	6	28	6	6	168
10	81	6	63	6	37	48
20	133	6	103	6	86	48
50	202	6	155	6	130	24
100	263	6	191	9	167	12
200	367	6	254	9	215	24
500	538	6	360	6	349	24
1000	677	6	457	6	447	24

**Cells in grey are unreliable as IL significantly impacts on flood estimates*

The 1:100AEP estimate for TCE upstream from Deposit C were 263 m^3/s (with no ARF, IL=30mm, CL=8mm/hr), 191 m^3/s with ARFs applied, and 167 m^3/s assuming the previously adopted losses (Jacobs, 2017). For AEPs less than 1:10 the large initial loss reduces the rainfall excess available for routing in the model, and artificially reduces the design flood estimate. These are not appropriate for use in hydraulic modelling and alternative methods of flood estimation are required. Model runs with the lower IL produce a critical duration that was consistently 6 hrs across AEPs. It is notable that much longer critical durations of between 12 and 48 hours were estimated when using the higher 65mm loss.

Given the absence of long-term gauging in the area, there is no “best choice” of loss parameters. In this instance it is considered that the design flows estimated using the 30mm IL, 8mm/hr CL, and incorporating the ARF best represented catchment processes.

5.5 West Angelas regional direct rainfall modelling

Direct rainfall modelling is a technique in which a rainfall time-series or design storm is applied to individual grid cells or model elements, with runoff between cells controlled by cell size, depth of rainfall/water, roughness, hydraulic slope and losses (infiltration/evaporation) (Engineers Australia 2012).

In the case of the Beyond 2020 study where terrain is highly variable with multiple hydraulic controls upstream of the areas of interest, direct rainfall modelling has the advantage that storage, flood routing and cross-catchment flows are captured by the model terrain in more detail than a RORB hydrologic routing model. Direct rainfall modelling enables rapid characterisation of catchment-wide flood behaviour and allows a single model to be used to simulate hydrology and hydraulics within each model domain. The application of GPU-based solvers has reduced model run-times and enabled an ensemble modelling approach. This makes possible both critical duration analysis, and accounts for the uncertainty associated with storm temporal patterns.

The intent of using direct rainfall modelling in this study is to:

- confirm catchment routing behaviour applied in the RORB model and the importance of hydraulic controls and linear infrastructure;
- identify representative storm events for local model domains; and
- generate broad-scale floodplain mapping for high level risk-assessment and calculation of site-wide cumulative impacts on catchment hydrology.

5.5.1 Model domain

One regional and five local model domains were developed for the study. The regional model was used in catchment hydrological and floodplain analysis, and the local area models used for deposit-specific analysis of surface water management options. The extent of each model domain is shown in Figure 5-3.

5.5.2 Model selection

The 2D hydraulic modelling software TUFLOW (build 2016-03-AE-w64) was used for all model domains and simulations. The GPU solver was used to minimise run-times, avoid mass balance errors, and provide fundamentally stable model runs.

5.5.3 Roughness

A fixed global Manning's roughness coefficient of n=0.04 was applied across all model domains representing a typical value for rocky floodplains with grass and scrub. The global value simplified the model build process where multiple scenarios and locations being considered.

5.5.4 Terrain data and model resolution

Digital elevation models were developed for each model domain from a range of sources. LiDAR is available across almost all of the study area at 1m resolution. Selected locations were infilled using a regional 20m resolution digital elevation model, drone survey, or end of month survey where available for operational mine areas. In some instances, Life of Mine pit shells and dumps were included to better represent future terrain when study deposits would be operational.

For sub-grid-cell features including roads, rail alignments, levees, drains and culverts, break-lines were configured to allow the elevation associated with the feature to be better defined in the model at a coarse resolution. Note that hydraulic structures were not modelled explicitly, but were included with DEM break-lines with a width proportional to the structure width. It is anticipated that hydraulic structures will be modelled explicitly and at higher resolution during the preliminary engineering design phase.

Post-development scenarios incorporated available design information including pit and dump arrangements, and access. Table 5-5 lists the sources of elevation data used for each model domain, and Figure 5-4 illustrates high resolution LiDAR and break-lines applied across the Greater West Angelas regional model domain.

Table 5-5: Model domains and terrain data sources

Model domain	Terrain data source/s	Date	Model resolution (m)
West Angelas regional	2011-12_Fugro_10cm LiDAR WAN_2018-03 LiDAR WAN end of month survey Deposit C & D landforms and flood protection Pilbara regional 20m DEM Zsh Breaklines	2011-12 2018-03 2020-01 2018-03 - -	10
Western Hill	2011-12_Fugro_10cm LiDAR WAN_2018-03 LiDAR Deposit C & D landforms and flood protection Pilbara regional 20m DEM Zsh Breaklines	2011-12 2018-03 2018-03 - -	5
Deposit F north	2011-12_Fugro_10cm LiDAR Pilbara regional 20m DEM	2011-12 -	5
Deposit H	2011-12_Fugro_10cm LiDAR Pilbara regional 20m DEM	2011-12 -	5
Deposit J	2011-12_Fugro_10cm	2011-12	5
Mount Ella East	2011-12_Fugro_10cm LiDAR Dep F LoM dumps Pilbara regional 20m DEM	2011-12 - -	5

5.5.5 Boundary conditions

Rainfall was applied uniformly as a global rainfall boundary condition. TUFLOW event files were configured to allow multiple rainfall events in the ensemble to be efficiently simulated.

Outflow boundaries were configured at the model outlet using a stage discharge (HQ) rating. A 1% slope was applied at the outlet boundaries. The outflow boundaries are located a sufficient distance downstream to limit sensitivity of model results in the area of interest.

For the Western Hill local model, inflow boundaries to Turee Creek East were applied as a source area boundary condition. For all other models including the West Angelas regional model, no external catchment inflows were used as the full catchment extent was included in the model domain.

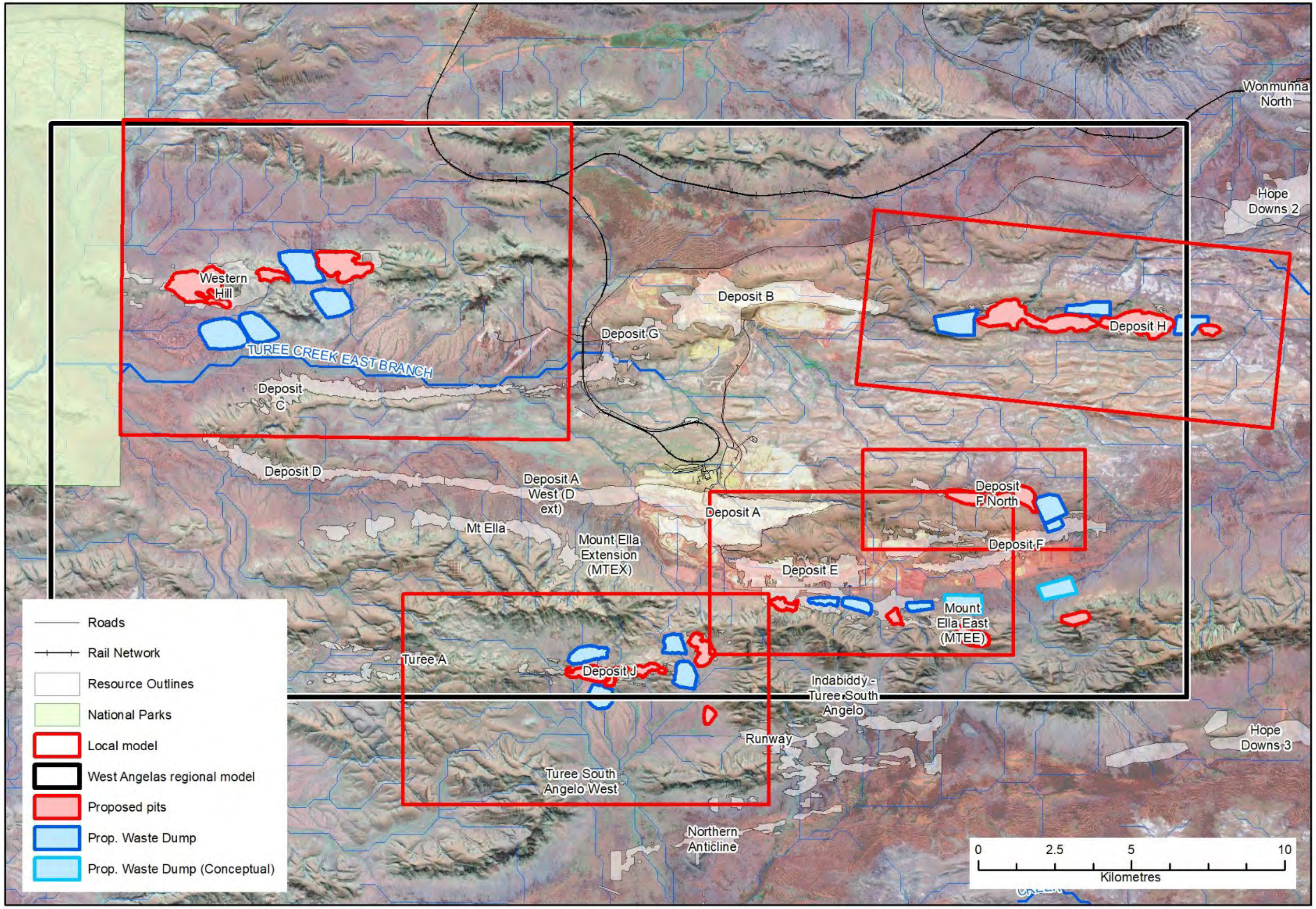


Figure 5-3: Model domains

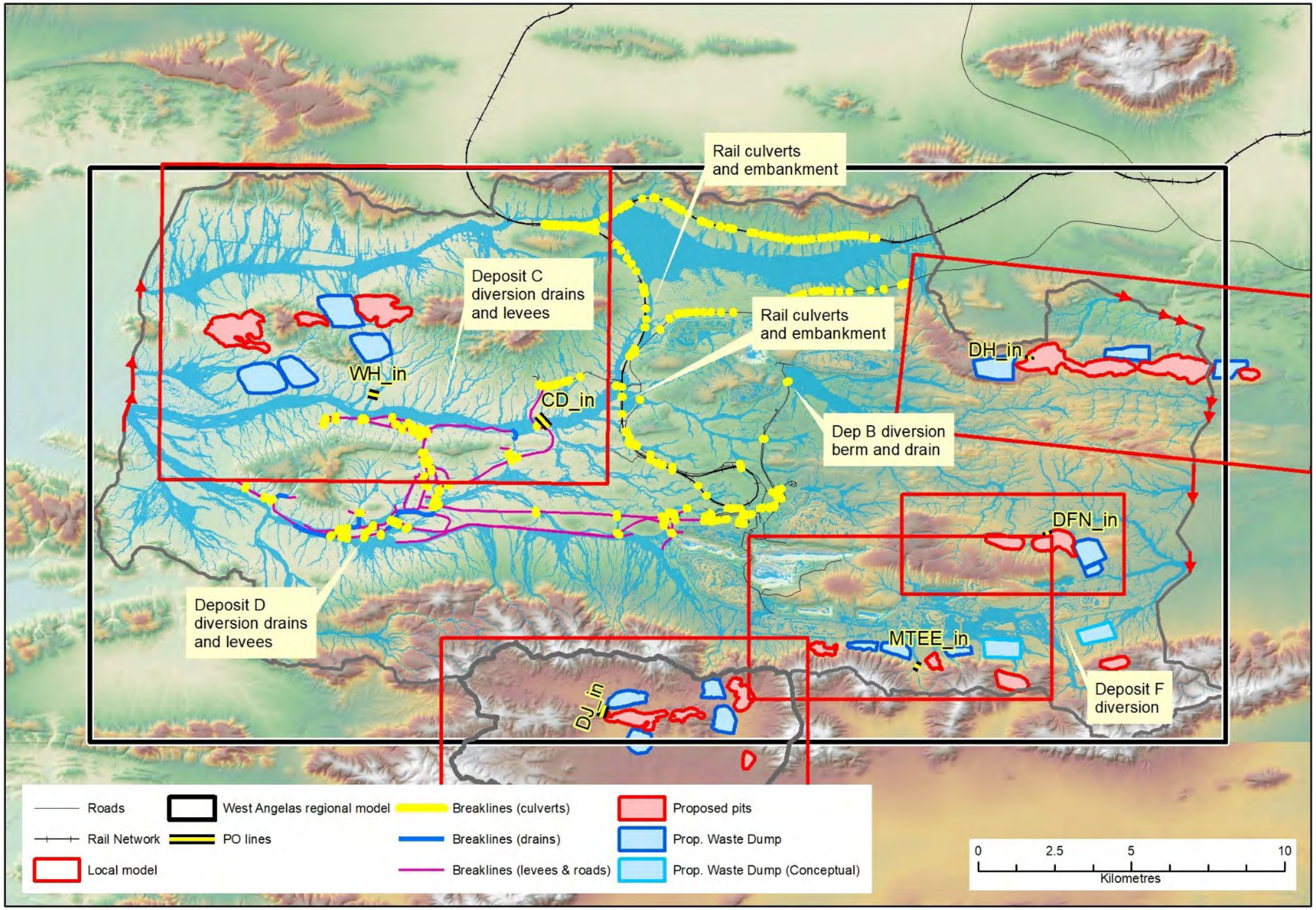


Figure 5-4: West Angelas regional TUFLOW model illustrating key features and PO lines used to define representative storms for local model domains (regional 1:100AEP floodplain shown)

5.5.6 Ensemble events for direct rainfall modelling

An ensemble event approach incorporates variability of model inputs to account for differences in catchment and hydrograph response. This study incorporates variability in temporal pattern (TP) as part of the ensemble modelling approach. Each ensemble consists of 10 TPs, and 9 standard durations of between 1 and 24hrs. Event magnitudes of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100 and 1:200AEP were assessed.

Model hydrographs were recorded at key cross-section locations (PO lines) where mine infrastructure is likely to intercept catchment inflows for each of the development areas (see Figure 5-3). Peak flow and event volume was calculated at each location for comparison with regional flood estimates and RORB simulations.

5.5.7 Identifying critical storm duration

For each duration the results from an ensemble of 10 TPs were ranked by peak discharge, and by total event volume. Events representing the closest-to-average peak can then be selected for each duration. For volume critical flooding closest-to-average volume can be calculated, although not used for this study. Representative events are then compared for all durations to identify the critical duration event for any location. The procedure allows a single representative storm event to be selected for each AEP rainfall event.

5.5.8 Selecting the representative design storm from the direct rainfall ensemble

For the AEPs assessed, a representative storm event was selected based on event peak at the main catchment interception for each deposit. These events were used in the higher resolution local area model for assessment of surface water management strategies. The selected events for each deposit are summarised below. An example of the hydrograph ranking and identification of the representative storm event is shown in Figure 5-5 below.

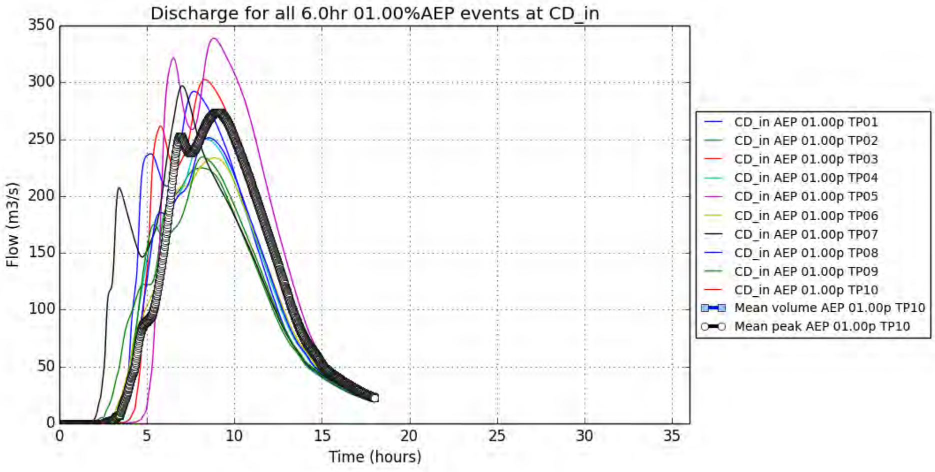


Figure 5-5: Example of hydrograph ranking for the 1:100AEP critical duration event (6hrs) as simulated with the direct rainfall modelling ensemble of ten temporal patterns on Turee Creek East adjacent to Deposit C

5.5.9 Regional flood frequency

In addition to the direct rainfall ensemble modelling and RORB Monte Carlo simulations, two regional flood frequency methods were applied.

The first method was Regional Flood Frequency Estimation (RFFE), developed with the revision of ARR (Ball *et al.*, 2019). This is based on the concept of regionalisation, with a data driven approach where data from gauged catchments are utilised to make flood quantile estimates at ungauged locations (Rahman *et al.*, 2015). The method has limits in applicability, with flood estimates for small catchments considered less reliable, and the method is inappropriate for developed catchments and those with hydraulic controls.

The second method was the Pilbara region Regional Flood Frequency Procedure (RFFP) (Flavell, 2012) which used multiple regression analysis to relate catchment and climate factors to regional flood quantiles. The catchment and climate factors used in this approach include catchment area, mainstream length, equivalent uniform slope, latitude and longitude. The RFFP has similar limitations as the RFFE. The list of input parameters used for flood estimation for the locations of interest are shown in Table 5-6 below. Both the RFFE and RFFP methods provide flood estimates from 1:2 to 1:100AEP.

The results of the regional flood estimation are included in 5.6 below.

Table 5-6: Input parameters for RFFE model and RFFP method

				Catchment Centroid		Catchment outlet	
	Slope (Se) (m/km)	Mainstream Length (km)	Area (km²)	X	Y	X	Y
CD_in*	3.6	21.2	132.00	118.7810	-23.1440	118.7030	-23.1410
DFN_in	35.0	1.3	0.31	118.8583	-23.1798	118.8615	-23.1747
DH_in	42.5	2.0	1.46	118.8460	-23.1241	118.8551	-23.1231
MTEE_in	67.4	2.2	1.79	118.8203	-23.2188	118.8205	-23.2144
WH_in	24.9	4.1	5.83	118.6567	-23.1217	118.6462	-23.1363
DJ_in	17.0	4.9	9.13	118.7014	-23.2209	118.7206	-23.2288

**Catchment contains hydraulic controls, RFFE/RFFP inputs unreliable*

5.6 Selection of design flood estimates and storms for hydraulic modelling

The adopted design flood quantiles were determined by comparing estimates derived from the different methods and selecting the most appropriate method for the given AEP with consideration of method limitations. This generally meant that the regional methods were used to determine flood peaks for frequent events (1:2 to 1:10AEP), and the direct rainfall ensemble method was used to define peaks for the rarer events (1:20 to 1:200AEP). The design storms and losses were selected and adjusted such that peak flows simulated in the local model domain were consistent with the adopted values. Further adjustment of losses was required in some cases with the higher model resolution of 5m used for the local model domains. Selected flood quantiles, design storms and parameterisation are discussed for each deposit below.

5.6.1 Western Hill

Flood estimates for the *local* catchments of Western Hill were defined for the largest catchment running from the development area, which is a tributary of TCE. This catchment is 4.1km^2 and is representative of the hillslope areas over which the eastern part of the development is planned. Table 5-7 lists the flood estimates developed using the different methods for this location, with the final adopted flood peak flows, design storms and parameters highlighted. The direct rainfall ensemble identified critical durations of between 3 and 1 hours, with shorter durations critical for the rarer events. Flavell RFFP estimates were adopted for the more frequent evens (1:2 and 1:5AEP) as the losses used in the direct rainfall ensemble were too large to generate runoff.

The southern extent of development at Western Hill includes two heavy vehicle crossings of TCE and a possible a conveyor crossing. As such TCE must be considered in the local model domain with design flows calculated separately for that location.

Table 5-8 lists the peak flow estimates for all methods, including results from the regional RORB Monte Carlo modelling. In general, there was good agreement between methods and the estimates form the Jacobs (2017) study. Lower peak flows were estimated for the 1:50 and 1:100AEP events which was likely caused by specific inclusion of structures and storages in the new RORB model. The RORB Monte Carlo (no ARF) results were consistent with the regional direct rainfall modelling (no ARF) which gives confidence in the simpler implementation of structures in the RORB model and adopted *Kc* parameter. Both RORB and the direct rainfall ensemble (no ARF) methods identified a 6hr critical duration for the creek at this location. Given the 132km^2 upstream catchment, it was considered more appropriate to use the RORB Monte Carlo estimates that incorporate ARFs for AEPs of between 1:10 and 1:200. For the frequent events (1:2 and 1:5AEP) the RFFE estimates were adopted and RORB design storm parameters were adjusted to meet the adopted peaks. Figure 5-6 illustrates the flood frequency curves for all methods, with the adopted design flows highlighted.

The Western Hill local model incorporated the adopted design storm as a direct rainfall boundary in the local model domain, with an external catchment boundary condition sourced from RORB.

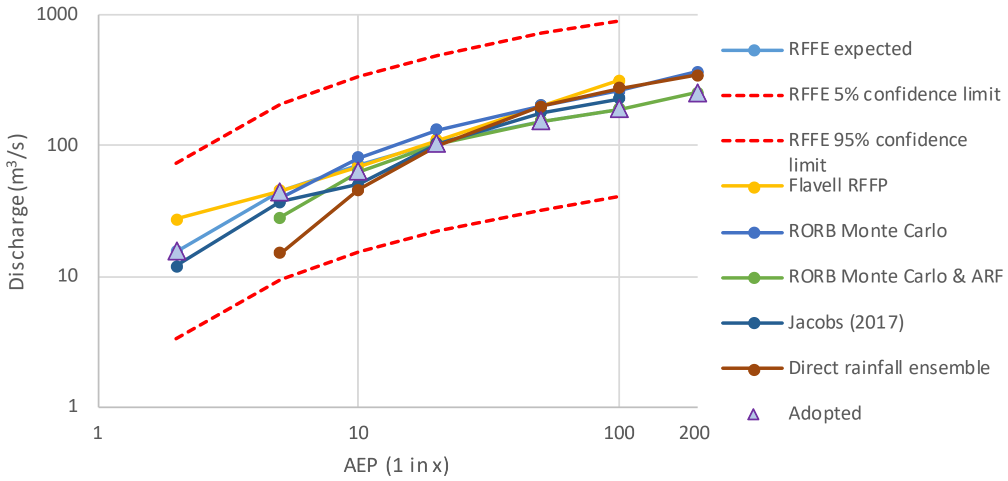


Figure 5-6: Flood frequency curves for Turee Creek East, east of Deposit C and Western Hill

5.6.2 Deposit F north

The largest catchment interception at Deposit F north is only 0.3km^2 and as such does not present a significant flood risk. Table 5-9 lists flood estimates for this location with the largest estimate for the 1:100AEP peak flow only 6.7m^3/s. The lower estimates adopted design storms and parameters were based on the direct rainfall ensemble for AEPs of between 1:10 and 1:200, with RFFP estimates used for more frequent events. Critical durations were identified as between 1 and 3 hours.

5.6.3 Deposit H

The western pit at Deposit H intercepts a small creek with a catchment of 1.5km^2. Flood estimates for this location are shown in Table 5-10. The adopted design storms and parameters were based on the Flavell RFFP peak flows for AEPs between 1:2 and 1:10, and direct rainfall modelling for the rarer events.

5.6.4 Deposit J

At the western extent of Deposit J, the development area intercepts a 9km^2 catchment which has the potential to cause significant flooding depending on the final footprint adjacent to the creek. Flood estimates derived from the direct rainfall model were consistently higher than those of the RFFE and RFFP for rarer events (Table 5-11) and this is attributed to the steep and linear basin shape upstream which tends to cause "flashier" flood events. Critical durations of between 3 and 6 hrs were identified for the AEPs considered. The adopted design storms for Deposit J were based on Flavell RFFP peak flows for the 1:2AEP event, with direct rainfall modelling estimates used for all others.

5.6.5 Mount Ella East

The largest catchment adjacent to the deposits at Mount Ella East is 1.8km^2, and flood estimates were derived at that location as shown in Table 5-12. Critical storm durations of between 1 and 3hrs were identified using the direct rainfall ensemble technique which is appropriate given the small catchment area. As with the other catchments, the direct rainfall approach failed to produce plausible peak flows for the frequent events (1:2 to 1:10AEP) and as such the RFFP flows were adopted for these events. For the rarer events the direct rainfall estimates were adopted.

Table 5-7: Comparison of flood estimates for Western Hill at location "WH_in"

Western Hill (WH_in) peak flow (m3/s)							Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	2.7	0.5	14.2	5.6	0.0	na	5.6	2	3.0	15.0	8.0
5	7.9	1.5	40.8	8.7	5.5	6.0	8.7	2	3.0	25.0	8.0
10	12.8	2.5	66.4	12.8	16.8	3.0	16.8	7	3.0	40.0	8.0
20	18.7	3.6	96.7	19.7	36.3	3.0	36.3	5	3.0	40.0	8.0
50	27.1	5.3	141.0	34.7	45.7	2.0	45.7	8	2.0	35.0	8.0
100	33.8	6.6	175.0	53.4	60.1	2.0	60.1	3	2.0	40.0	8.0
200					81.4	1.0	81.4	4	1.0	40.0	8.0

Table 5-8: Comparison of flood estimates for Western Hill at location "CD_in"

Turee Creek East at Deposit C inflow (CD_in) peak flow (m3/s)										Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	RORB Monte Carlo	RORB Monte Carlo & ARF	Jacobs (2017)	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	15.4	3.3	72.5	27.5	0.0	0.0	12.0	0.0	na	15.4	4	6	10.0	8.0
5	44.2	9.4	208.0	45.0	39.1	28.2	37.0	15.0	6.0	44.2	4	6	15.0	8.0
10	72.0	15.3	339.0	69.0	81.4	63.0	50.0	45.9	6.0	63.0	5	6	25.0	8.0
20	105.0	22.4	493.0	109.5	132.8	102.7	104.0	100.3	6.0	102.7	5	6	25.0	8.0
50	152.0	32.5	717.0	201.0	202.3	154.7	179.0	199.1	6.0	154.7	1	6	25.0	8.0
100	190.0	40.5	894.0	316.2	262.9	191.0	228.0	274.1	6.0	191.0	1	6	30.0	8.0
200					366.8	254.2		347.4	6.0	254.2	4	6	20.0	8.0

Table 5-9: Comparison of flood estimates for Deposit F north at location "DFN_in"

Deposit F north (DFN_in) peak flow (m3/s)							Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	0.5	0.1	3.3	0.6	0.0	na	0.6	3	3.0	7.0	5.0
5	1.6	0.3	9.4	0.8	0.3	12.0	0.8	3	3.0	20.0	5.0
10	2.6	0.4	15.4	1.1	0.7	3.0	1.1	3	3.0	30.0	8.0
20	3.7	0.6	22.4	2.0	2.1	3.0	2.1	3	3.0	30.0	8.0
50	5.4	0.9	32.6	3.4	2.6	2.0	2.6	5	2.0	30.0	8.0
100	6.7	1.1	40.6	5.0	3.4	1.0	3.4	4	1.0	30.0	8.0
200					4.7	1.0	4.7	4	1.0	30.0	8.0

Table 5-10: Comparison of flood estimates for Deposit H at location "DH_in"

Deposit H (DH_in) peak flow (m3/s)							Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	1.4	0.3	7.9	2.6	0.0	na	2.6	7	3.0	15.0	5.0
5	4.0	0.7	22.6	3.8	0.5	12.0	3.8	7	3.0	20.0	5.0
10	6.6	1.2	36.8	5.5	2.1	6.0	5.5	8	3.0	40.0	8.0
20	9.5	1.7	53.5	8.3	8.3	3.0	8.3	8	3.0	45.0	8.0
50	13.9	2.5	77.8	14.3	12.1	3.0	12.1	2	3.0	35.0	8.0
100	17.3	3.2	97.0	21.7	15.8	2.0	15.8	8	2.0	30.0	8.0
200					21.3	1.0	21.3	4	1.0	45.0	8.0

Table 5-11: Comparison of flood estimates for Deposit J at location "DJ_in"

Deposit J (DJ_in) peak flow (m3/s)							Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	3.4	0.7	16.9	7.3	0.0	na	7.3	4.0	6	30.0	8.0
5	9.6	1.9	48.5	10.9	10.7	6.0	10.7	4.0	6	50.0	8.0
10	15.7	3.1	79.0	15.4	29.2	3.0	29.2	7.0	3	45.0	8.0
20	22.8	4.5	115.0	23.8	59.5	3.0	59.5	5.0	3	50.0	8.0
50	33.1	6.6	167.0	42.2	69.0	6.0	69.0	1.0	6	45.0	8.0
100	41.3	8.2	208.0	65.2	91.2	6.0	91.2	1.0	6	45.0	8.0
200					120.9	1.0	120.9	4.0	1	42.0	8.0

Table 5-12: Comparison of flood estimates for Mount Ella East at location "MEE_in"

Mount Ella East (MTEE_in) peak flow (m3/s)							Adopted design storm and parameters				
AEP (1 in x)	RFFE expected	RFFE 5% confidence limit	RFFE 95% confidence limit	Flavell RFFP	Direct rainfall ensemble	Critical duration (hrs)	Adopted design flow	Temporal pattern	Duration	IL	CL
2	1.4	0.3	7.6	3.5	0.0	na	3.5	3	3.0	5.0	5.0
5	4.0	0.8	21.7	5.1	1.8	6.0	5.1	3	3.0	10.0	5.0
10	6.5	1.2	35.3	7.3	5.1	3.0	7.3	3	3.0	35.0	8.0
20	9.4	1.8	51.4	11.1	13.7	3.0	13.7	3	3.0	40.0	8.0
50	13.7	2.6	74.6	19.2	14.9	2.0	14.9	8	2.0	30.0	8.0
100	17.1	3.2	93.1	29.2	22.4	1.0	22.4	4	1.0	40.0	8.0
200					30.1	1.0	30.1	4	1.0	40.0	8.0

Design standards

As with most Pilbara creeks, Turee Creek East and the tributaries of Angelo River are ephemeral, often dry for long periods with occasional very large flood events. It can be difficult to identify the edge of the floodplain when vegetation growth may obscure high-flow channels. Therefore, hydraulic modelling is required to delineate the extent of the floodplain and identify risks to mine operations.

It is important to determine whether planned construction will occur within a floodplain and to assess the level of flood protection required. Guidance for selecting the design criteria for construction within a floodplain is provided by ARR2019 and AUSTROADS and is described in detail in the Pilbara Surface Water Management Strategy (RTIO, 2011).

The deposits identified in this study generally have minimal interaction with the floodplains of major creeks, with surface water management limited to smaller tributary catchments of less than 10km^2 for most deposits. The exception is for planned crossings of Turee Creek East at Western Hill.

6. Design criteria for construction

The Pilbara Surface Water Management Strategy (RTIO, 2011) provides guidance on the management of surface water. The objective is to prevent adverse impacts on the natural function and environmental value of water courses, water quality and overland flow downstream from the mine area. The strategy also aims to minimise the impact of uncontrolled surface water movement on mine safety and mine production.

As part of the Rio Tinto Way We Work, the management and impact of proposed mine activities on sensitive areas in or adjacent to Pilbara creeks are considered as part of the options analysis. Furthermore, the Rio Tinto Standard E11 states that we should mitigate water related impacts to human health, environment, biodiversity and ecosystem services within the operational footprint by preferentially avoiding or minimising disturbance or degradation of high value water resources.

Table 6-1 details the current operational life estimates for the study deposits and the recommended flood protection level (if required) for each deposit based on the Beyond 2020 mine schedule. If surface water management infrastructure is required beyond the operational life of the deposit, or is connected with a critical infrastructure system, then the level of protection required for the infrastructure may exceed those recommended in Table 6-1.

Haul road crossings of TCE should incorporate culvert capacity to meet the 1:10AEP design flow consistent with upstream crossings planned as part of Deposit C development and the principle of minimising changes in the flow regime of Turee Creek East. Conveyor crossings should be designed to pass a 1:100AEP event without damaging infrastructure.

Table 6-1: Operational Life estimates and recommended protection levels based on the Pilbara surface water management strategy

Deposit	Current Operational Life Estimate (years)	Recommended Flood Protection Level (AEP)	Flood protection recommended for pits?
Western Hill	14	1:50 AEP	No
Mount Ella East	11	1:50 AEP	No
Deposit F north	4	1:10 AEP	No
Deposit H	6	1:20 to 1:50 AEP	Yes
Deposit J	12	1:50 AEP	Yes
TCE haul road crossings	-	1:10AEP	-
TCE conveyor crossing	-	1:100AEP	-
Culverts and piped drainage	-	1:5AEP	-

Key floodplain interactions with proposed mine infrastructure are highlighted for each deposit in the following section.

7. Local hydraulic modelling

7.1 Floodplain mapping and surface water management

This chapter describes floodplain and drainage interactions with proposed mine infrastructure and highlights any site-specific risks.

TUFLOW 2D hydraulic modelling results are presented using 1:100AEP floodplain mapping for the design storm event selected for each location. Results are presented for the existing case and development case with mine infrastructure in place, based on the available “Order of Magnitude” development footprint and conceptual surface water management strategies. It is anticipated that there will be some changes in the development footprint as engineering studies progress.

Additional maximum flood depth and velocity mapping for events of 1:5, 1:10, 1:50 and 1:100 AEP are provided in Appendix B and Appendix C.

7.1.1 Western Hill

7.1.1.1 Hydrological setting

Western Hill sits in the upper reaches of the Turee Creek East (TCE) catchment – a tributary of Turee Creek. The deposit sits in an elevated position (Figure 7-1) and intercepts small catchments associated with steep drainage. These convey runoff to two main creeks located to the north and south of the deposit. All catchments reporting to pits are <0.5km^2 in area and are low risk with regard to flooding potential. Pre-development floodplain mapping of the areas is shown in Figure 7-2, noting that this does not include the flood protection currently under construction at Deposit C.

Several sensitive receptors are present downstream from Western Hill, including KNP, the Guburingu heritage site and a potential GDE within the park boundary (Figure 7-2).

Haul roads are proposed between Deposit C and Western Hill, and will cross Turee Creek East in one or more places (HV crossing X1 & X2, Figure 7-2). Several conveyor options were considered, all of which would require crossing of TCE. Flood protection infrastructure is under construction at Deposit C including a diversion and levee along the northern edge of Deposit C. Any new crossings of TCE will need to maintain the serviceability of the existing levees at Deposit C. Dumps and linear infrastructure will be configured to maintain the existing hydrological regime of the creek and maintain flows to KNP to reduce approvals risk. Culverts, stormwater drainage and minor creek crossings will be required to manage runoff from the smaller catchments to the south and south east of the Western Hill pits.

Figure 7-1: View south-west from Western Hill

7.1.1.2 Development case with surface water management

Minimal surface water management is required for flood protection of the pits at Western Hill. However, the proximity of the development to KNP, Guburingu heritage area, and proposed crossings of TCE requires surface water management in the area. Development of Western Hill will require:

- Two new crossings of TCE that provide adequate conveyance of flow to the national park and maintain serviceability of Deposit C flood protection. Recommended culvert capacity to convey 1:10AEP flood flow on TCE.

- A conveyor crossing to be elevated above the 1:100AEP flood level, or provide culvert capacity for the 1:100AEP flood event.
- Dump placement to minimise hydrological impact to the tributary creek flowing to the Guburingu heritage area.
- Dump placement to minimise impact to overland flow paths adjacent to KNP.
- Additional infrastructure associated with road drainage, culverts and minor creek crossings.
- Placement of sedimentation basins at the outlet of stormwater drainage to prevent migration of sediment off site.

Revised dump footprints were considered has part of a preliminary assessment and based on this work the western dumps were re-aligned to minimise interference with flow paths near KNP and avoid scour and mobilisation of sediment.

Figure 7-4 illustrates conceptual post-development 1:100AEP floodplain mapping based on TUFLOW hydraulic modelling in the local model domain. This scenario shows development at Western Hill including transport corridors and developed infrastructure at Deposit C. Minor drainage alignments and culverts have been included as breaklines to allow free drainage and should be further evaluated and sized during the PFS.

Conceptual crossings of TCE were included in the post-development assessment using break-lines with approximate capacity to convey a 1:10AEP event, with a floodway activated for larger events. These will be subject to further modelling and detailed design during the preliminary engineering study. It is assumed that road crossings would consist of a combined culvert and floodway arrangement allowing for effective conveyance of flood events. The conveyor alignment was not included in the post-development modelling but it is assumed to effectively convey events up to 1:100AEP with limited restriction of flow in TCE up to this event.

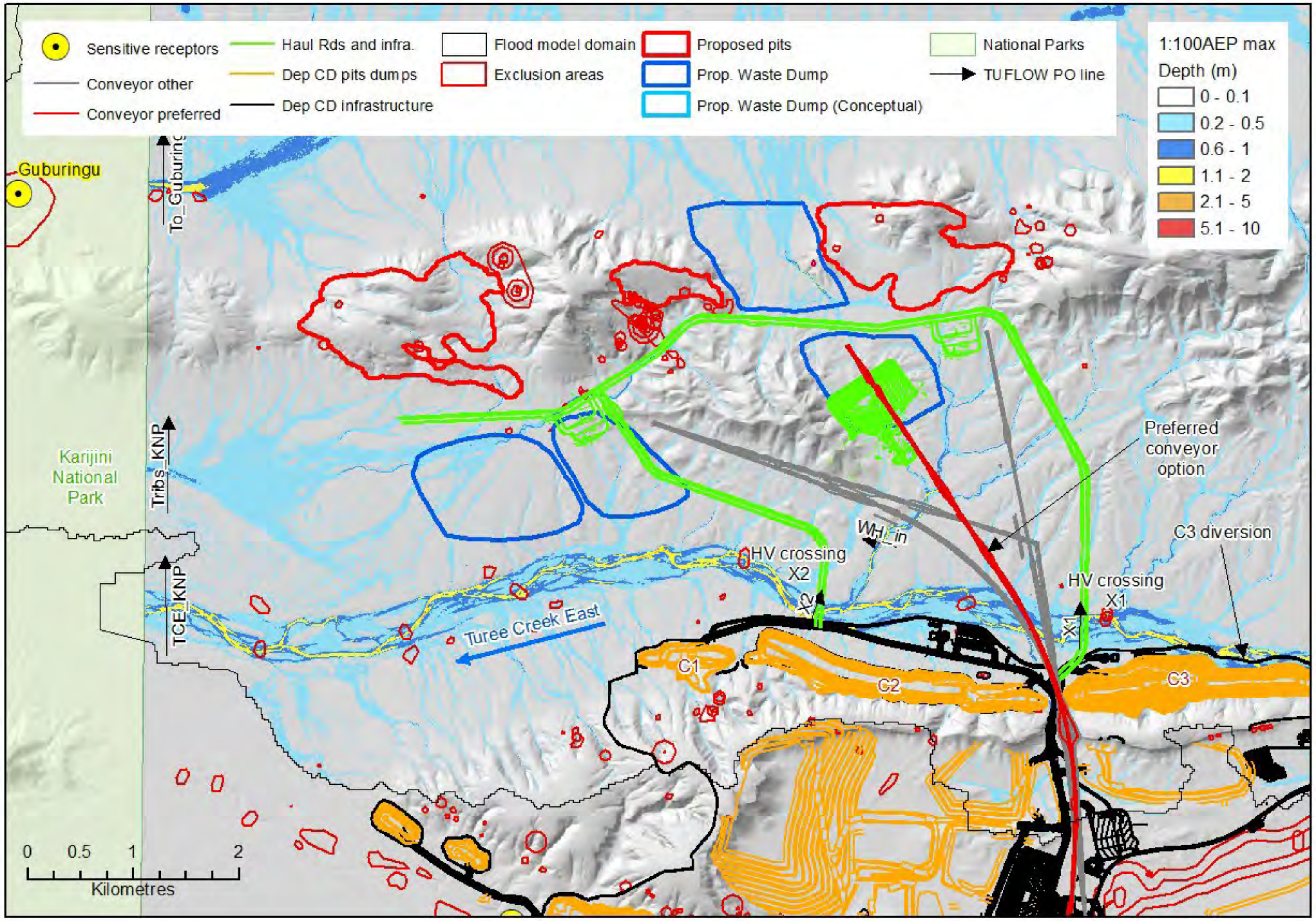


Figure 7-2: WHILL pre-development 1:100AEP floodplain mapping with no development at Deposit C

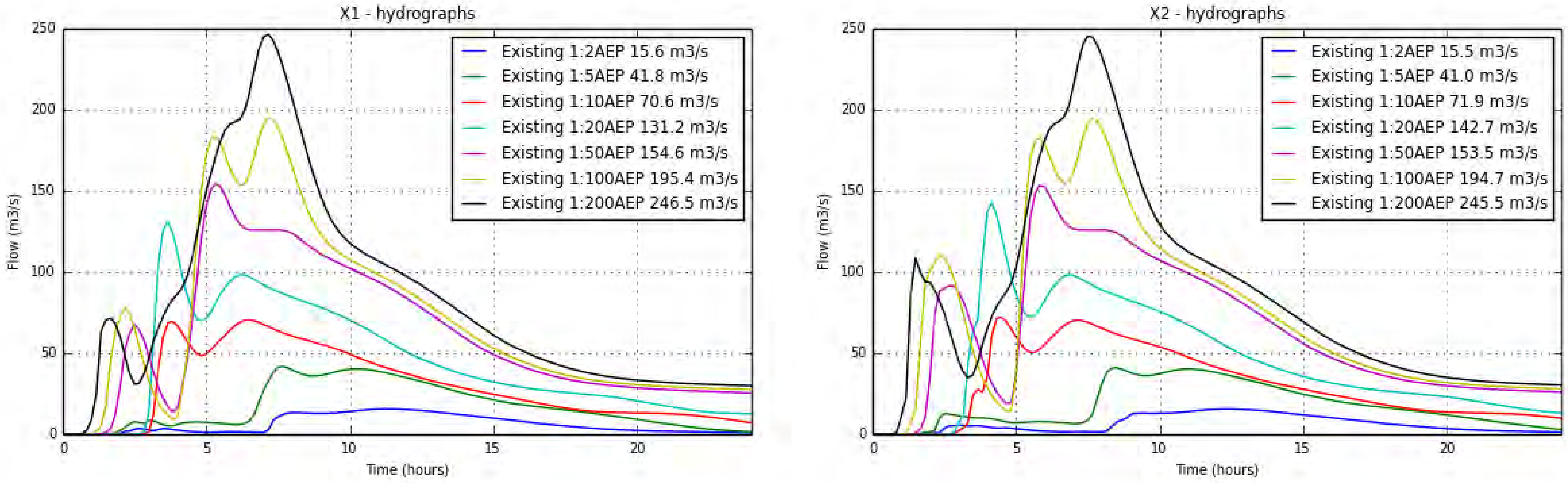


Figure 7-3: Western Hill design hydrographs for critical duration events on Turee Creek East at proposed crossing locations

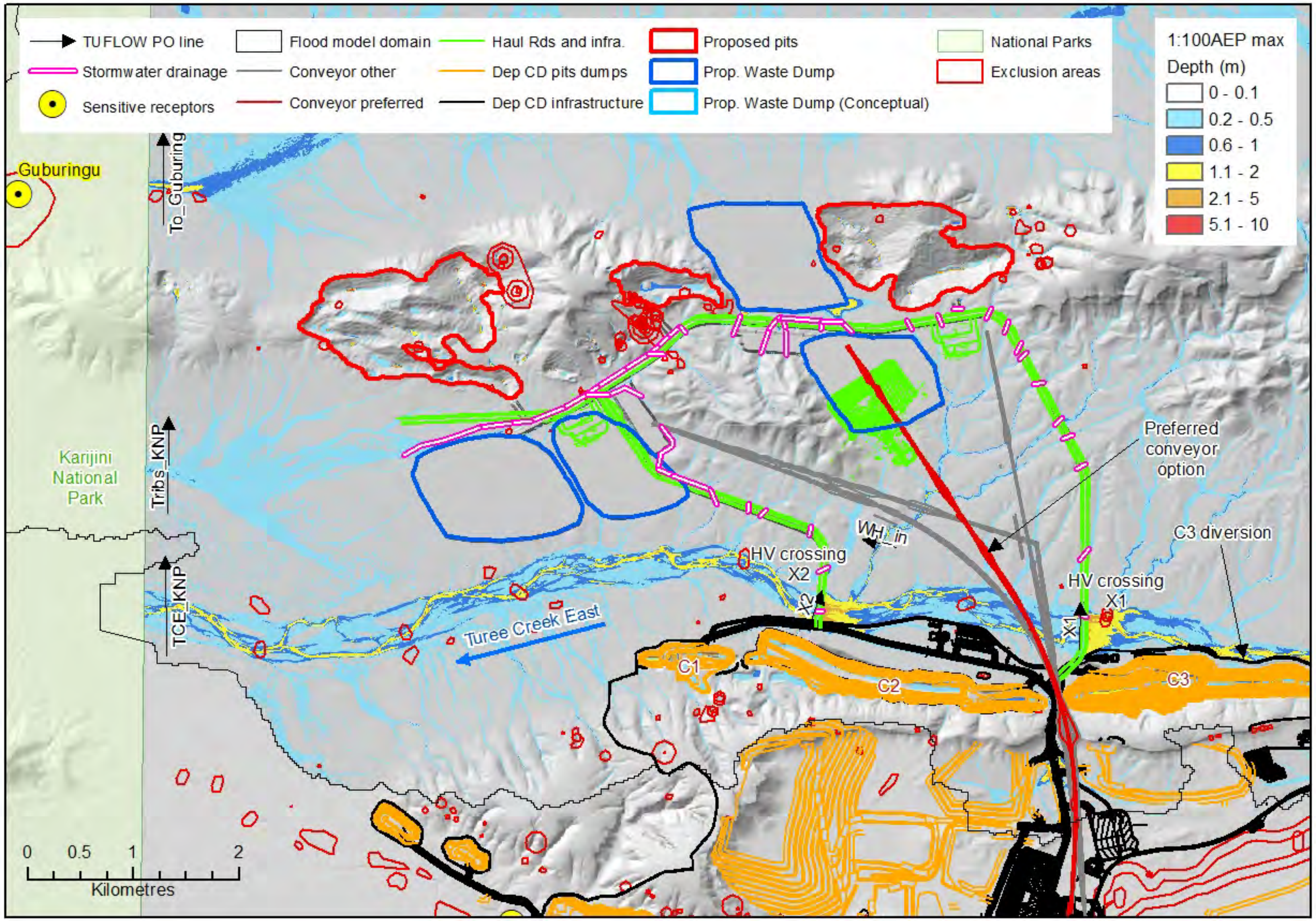


Figure 7-4: WHILL post-development 1:100AEP floodplain mapping with pits, dumps and conceptual surface water management in place, including development at Deposit C

7.1.2 Deposit F north

7.1.2.1 Hydrological setting

Deposit F north sits on a catchment divide, draining eastward to Weeli Wolli Creek, and the west to Turee Creek East catchment. The pit sits in an elevated position and intercepts small catchments associated with steep drainage lines along the southern perimeter. These catchments are <0.5km^2 in total area and not considered a significant flood risk. The small catchments near the pit show the greatest peak flow in response to short duration high intensity rainfall events (<3hrs) and creeks in the area will typically only flow for a short time following rainfall. Access is via a short extension of existing haul routes to Deposit F in the south. Larger more incised creeks are present to the west of the pit (Figure 7-5) and should be avoided where possible. Hydraulic modelling of the 1:100AEP flood event is illustrated in Figure 7-6.

Figure 7-5: Incised creek and gorge system west of Deposit F north

7.1.2.2 Development case with surface water management

The main pit will be located in the eastern portion of the deposit within the Weeli Wolli Creek catchment, which is low-risk with regard to flooding. It will not require active management of floodwater with the current design. There may be an extension of this pit to the west which is not in the current pit design and it is recommended that a small diversion is installed to limit inflows from additional drainage lines should this extension occur. A second conceptual pit is possible further west within the Turee Creek East catchment, but no pit design is available for this assessment. This pit would intercept additional small drainage lines to the south, and a small diversion drain may be constructed to reduce exposure to flooding and maintain flows northward. Figure 7-7 illustrates the maximum 1:100AEP flood depth for the developed case. The southern haul road alignment will continue through to the Deposit F Marlu pit and does not cross major drainage lines.

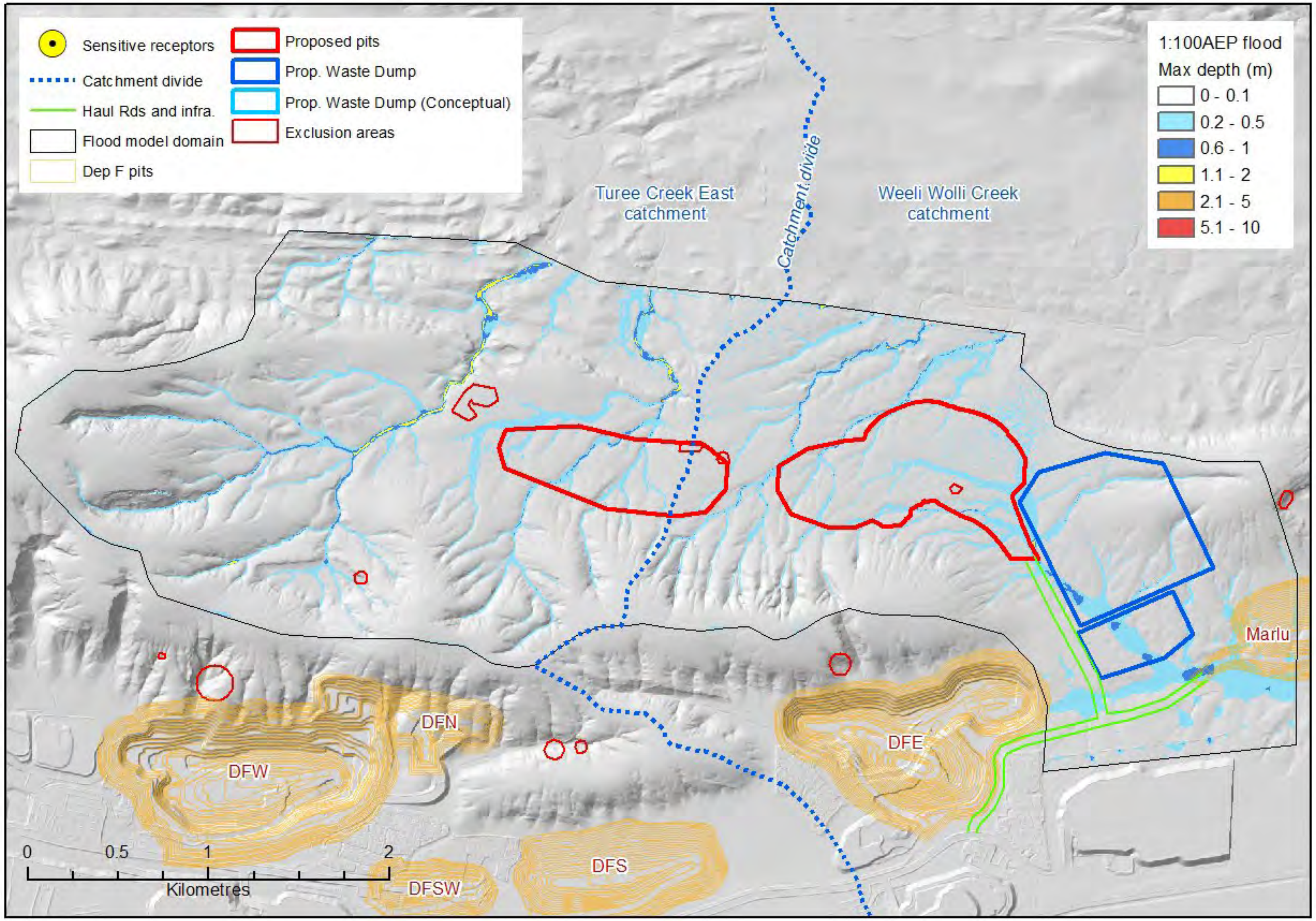


Figure 7-6: Deposit F pre-development 1:100AEP floodplain mapping

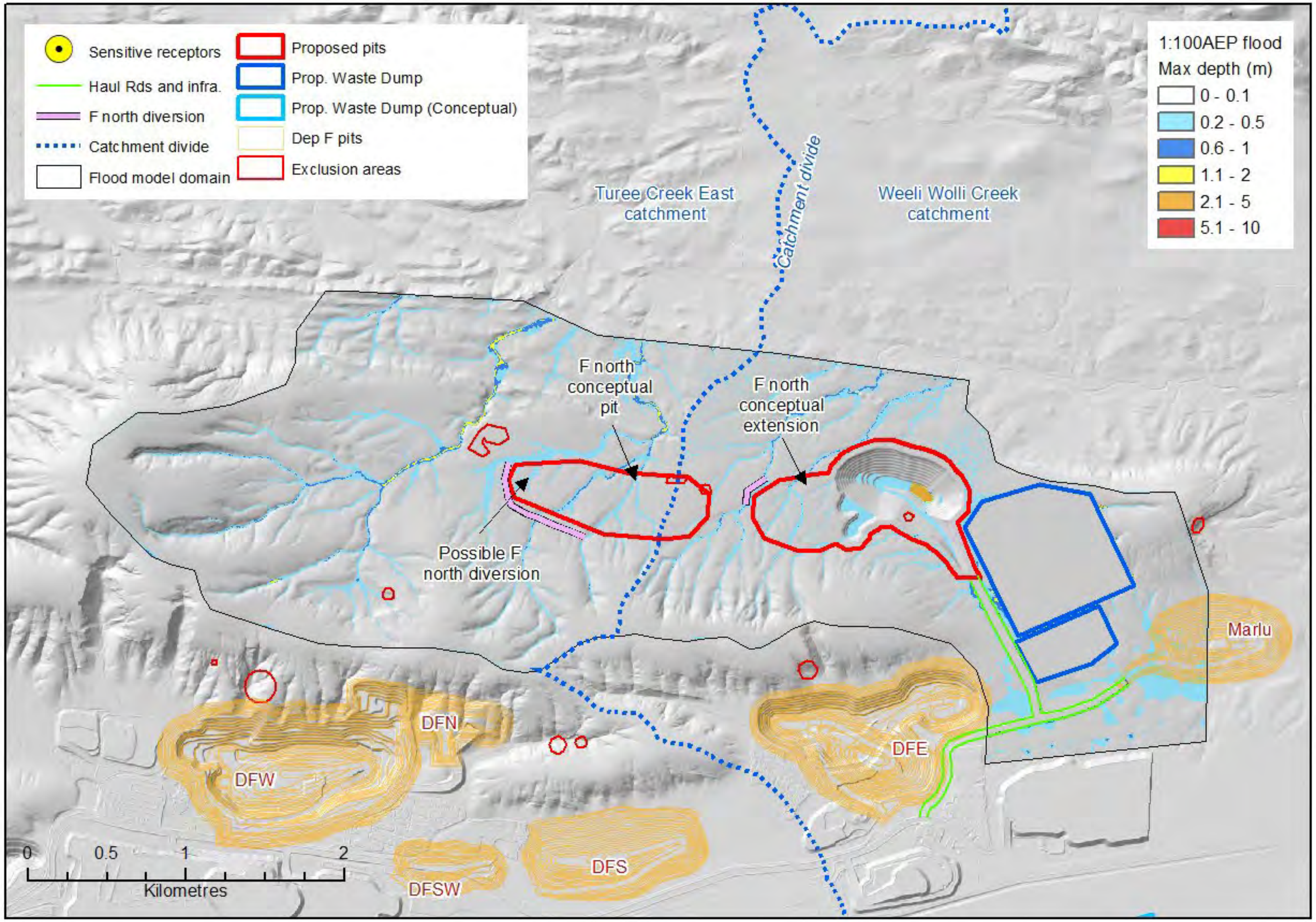


Figure 7-7: Deposit F north post-development 1:100 AEP floodplain mapping with pits and dumps in place

7.1.3 Deposit H

7.1.3.1 Hydrological setting

Deposit H is located east of existing operations at Deposit B in the upper reaches of the Pebble Mouse Creek – a tributary of Weeli Wolli Creek. The deposit sits in an elevated position and intercepts a series of small catchments associated with steep drainage which convey runoff to the north east. The majority of these catchments are <0.5km^2 in area and present low risk with regard to surface water management.

One catchment to the west of the deposit is 1.5km^2 at a point where it intercepts the western pit and will require active management. If feasible, a back-of-bench drain would be suitable to divert runoff from this catchment to the north around the pit, but the steep terrain may eliminate this as an option depending on the final pit geometry. Strategic dumping of the catchment may also be used to limit stormwater reporting to the pit.

TUFLOW 2D hydraulic modelling of the 1:100AEP flood event is illustrated in Figure 7-8 for the pre-development case. Catchments draining to Deposit H area will show the greatest flow response to short duration high intensity rainfall events generally less than 3hrs in duration, and flow events are likely to be similarly short in duration.

A surface water logger (SW18WAN004) was installed in February 2018 at the main outlet of the western catchment, with a second logger installed in July 2018 in an ephemeral rock pool located immediately downstream (SW18WAN006). A small potential GDE was also identified north of the deposit where a creek runs through a pinch point flowing northward. Both locations are discussed further in Section 11.

7.1.3.2 Development case with surface water management

The western pit intercepts the 1.5km^2 catchment and flood protection is recommended. Options include strategic dump placement to intercept the drainage line, back-of-bench drainage or in-pit management of stormwater. These will be revised during the PFS but given the steep terrain the central case for development assumes strategic dumping. The eastern pit intercepts only small catchments and does not require flood protection, however there is a central west to east running drainage line which should be avoided where possible and any crossings will require culverts to allow free drainage. Flood modelling results for the 1:100AEP event developed case is shown below.

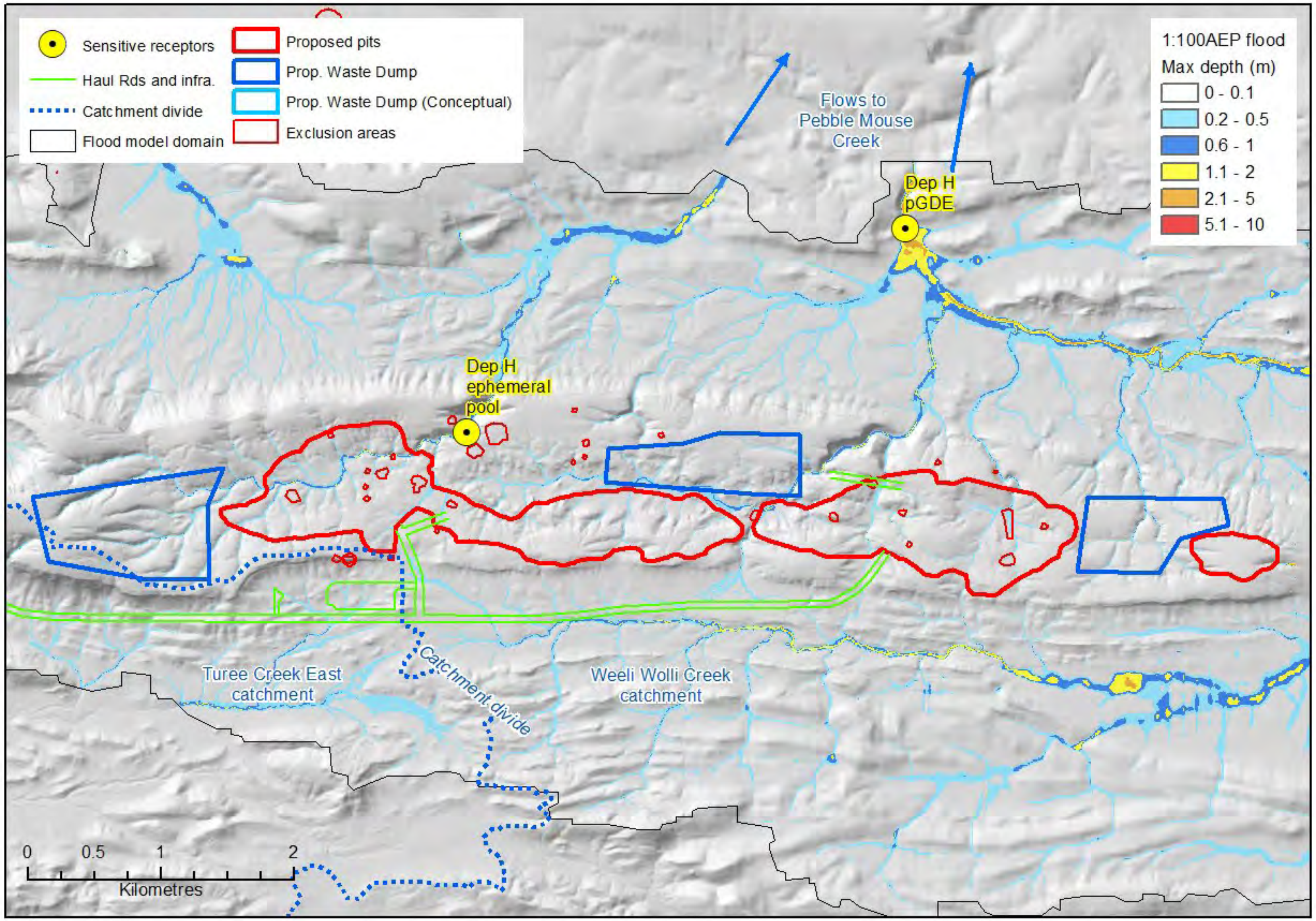


Figure 7-8: Deposit H pre-development 1:100AEP floodplain mapping

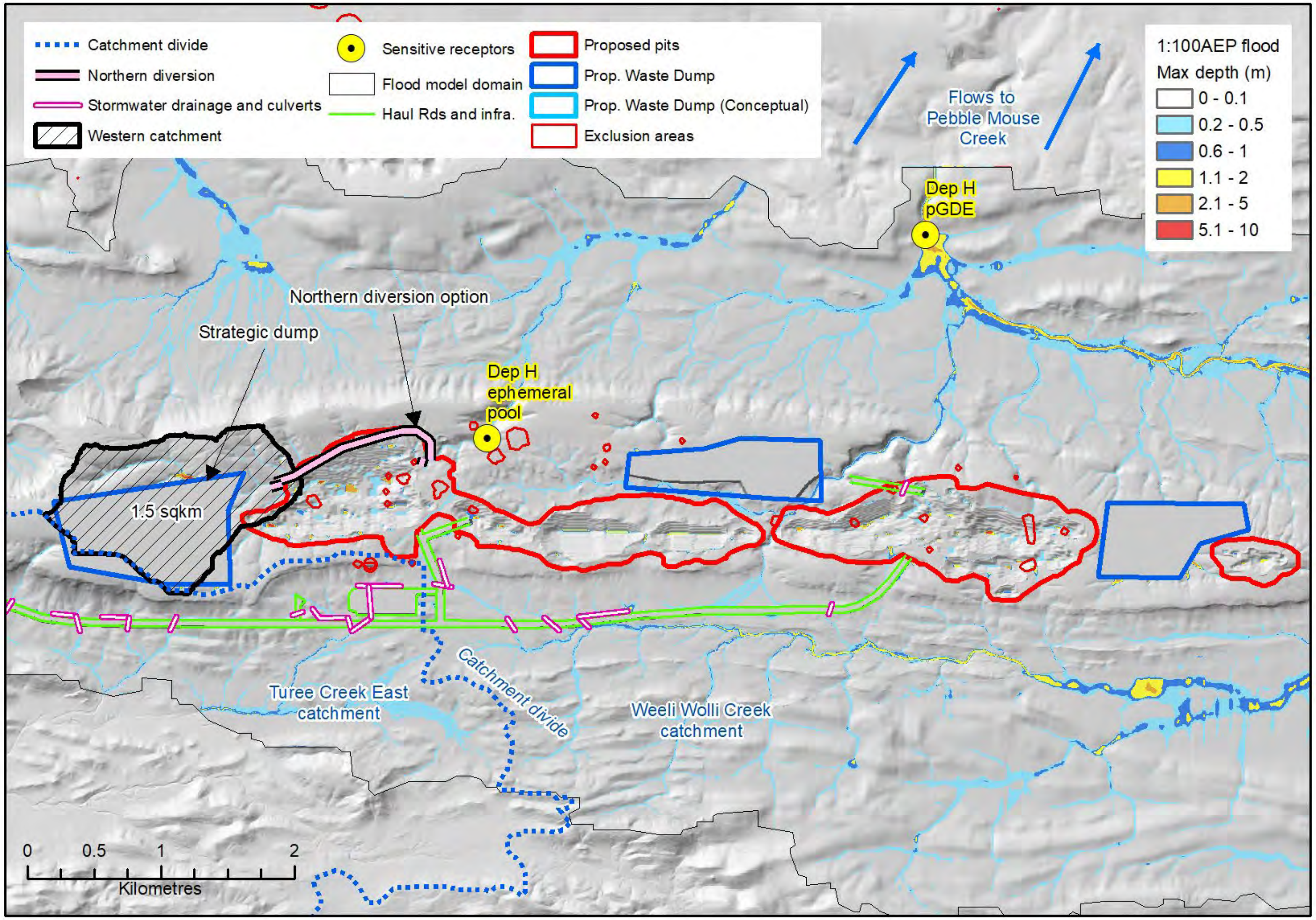


Figure 7-9: DEPH post-development 1:100AEP floodplain mapping with pits and dumps in place, assuming strategic dumping of western catchment and avoidance of central west-east creek

7.1.4 Deposit J

7.1.4.1 Hydrological setting

Deposit J is located to the south of Mt Ella within the Angelo River catchment. The resource outline intercepts four catchments that drain the hills to the north and northeast. The largest of these is 9.1 km^2 and is associated with the main drainage line running from north to south through the catchment area (“DJ_in”, Figure 7-10), with several smaller catchments of 1 to 2 km^2 also intercepting the eastern pit. Drainage lines in this area are small but produce high flow velocities because of the steep terrain and pose a risk for in pit flooding if not controlled.

There are no identified environmental or heritage exclusions, nor any tenure issues associated with the main resource outline, but there is an extensive rights reserved area surrounding Mt Ella to the north that should be avoided.

A small conceptual satellite resource is located to the south-east of the main deposit and may be pursued as a pit if grade allows. The resource is located in a flat sheet-flow area and will not likely require active surface water management.

7.1.4.2 Developed case with surface water management

Development of Deposit J will require a combination of catchment diversion for pit flood protection, stormwater management adjacent to access roads and appropriate revision of dump placement to minimise interference with drainage lines.

Figure 7-10 illustrates post-development flood modelling including revised dump placement and diversion drains, with conceptual culverts and road drainage included to retain flow paths for larger catchments and divert water away from both pits. Cut pit shells have been adopted over generalised footprints, as these do not intercept the creek associated with the western catchment. If the mining footprint extends further west, then this creek will require a diversion. Final requirements for stormwater drainage and diversions for the eastern and western pits will be updated during the PFS once the haul routes and mining footprint are refined. The current surface water management strategy is to divert flow east and the west around the operational areas, then southwards on the two main drainage lines, thus minimising operational impacts and retaining the natural hydrology of the area where possible.

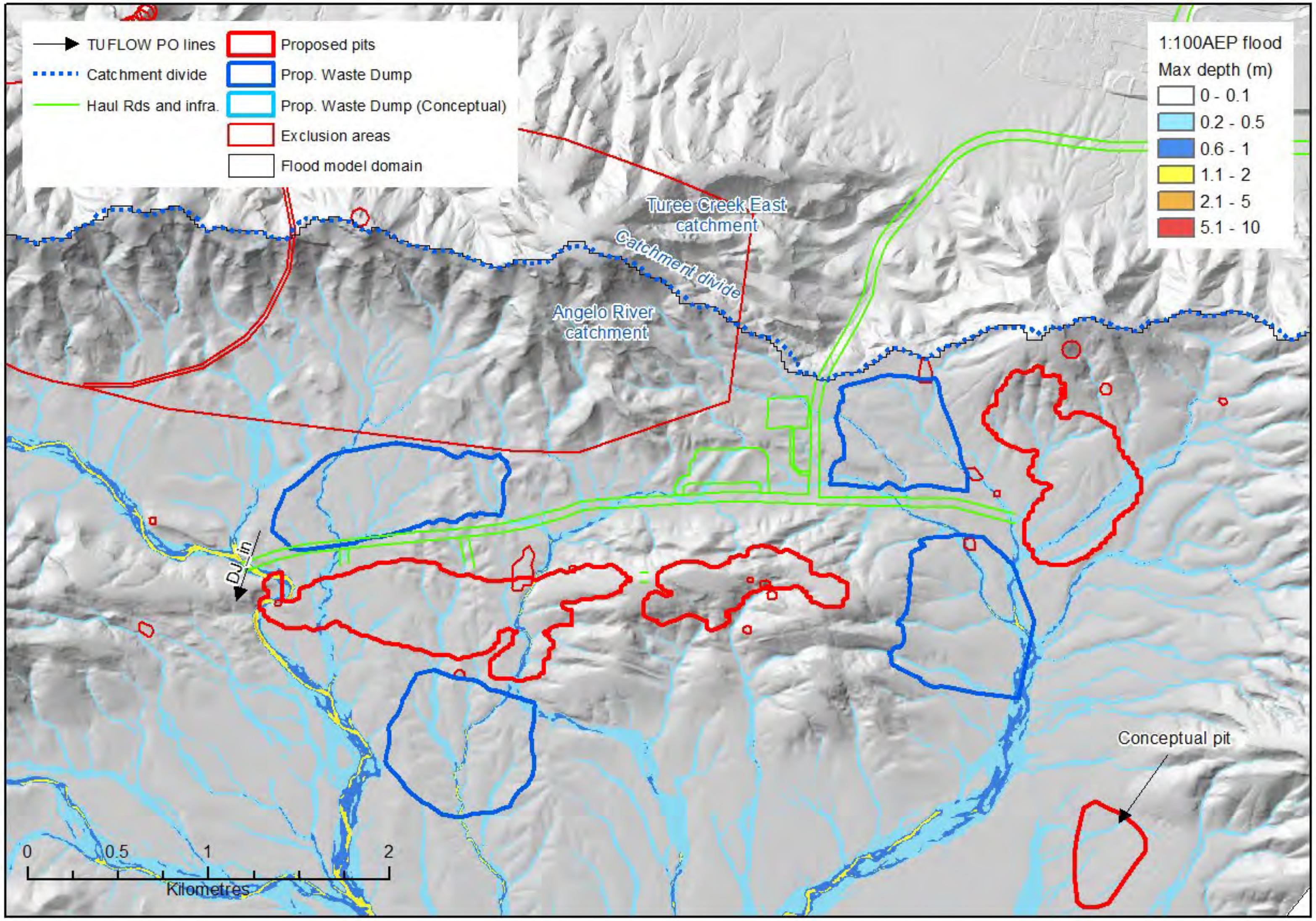


Figure 7-10: Deposit J pre-development 1:100AEP floodplain mapping

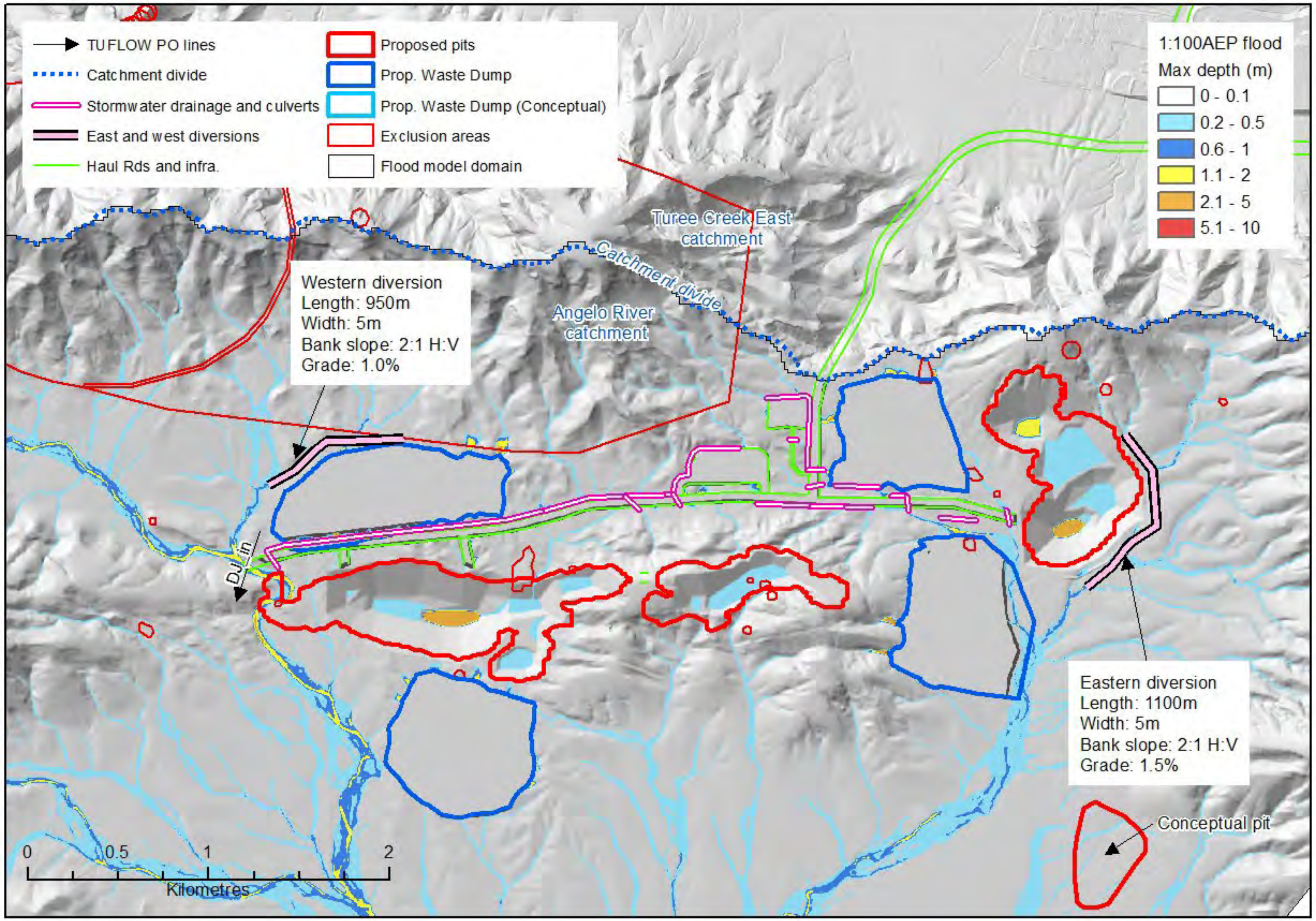


Figure 7-11: Deposit J post-development 1:100AEP floodplain mapping with pits and dumps in place and conceptual diversions and stormwater drainage

7.1.5 Mount Ella East

7.1.5.1 Existing risk

The Mount Ella East deposits are located within the Turee Creek East catchment, to the south of Deposits E and F. The pits sit at the base of steep hills dividing the Turee Creek and Angelo River catchments (Figure 7-12). A series of small, steep and incised drainage lines run from south to north through the resource area, with a significant heritage area and surface water pool located to the south-west of Pit 3. The western pit intercepts several small catchments totalling less than 0.6km^2 and the eastern pit has a negligible contributing catchment. The scenario shown includes the life of mine deposit E/F dump which has the potential to pond water adjacent to the easternmost pit. Two resource areas of interest have been identified further east and may be developed as pits in future depending on grade. These are both located in the upper hillslopes of the ranges and do not intercept larger external catchments, however access to the easternmost pit would require a creek crossing of “central creek” which currently flows to the Deposit F diversion drain. Two conceptual waste dumps have been placed on flat terrain to the north of the conceptual pits away from significant drainage lines.

7.1.5.2 Surface water management

No active management is required for runoff entering pits given the small contributing catchment areas. Ponded water can be expected where dumps intercept small drainage lines. Stormwater drains adjacent to the haul road and several culverts are required to allow free drainage to the north and west and prevent water ponding against the road and park up area. An increase in sump capacity is recommended to the north of the haul road to collect stormwater and allow passive infiltration. Given that post-development flood modelling shows low potential for flooding of the Mount Ella East pits, no flood protection is recommended (Figure 7-13).

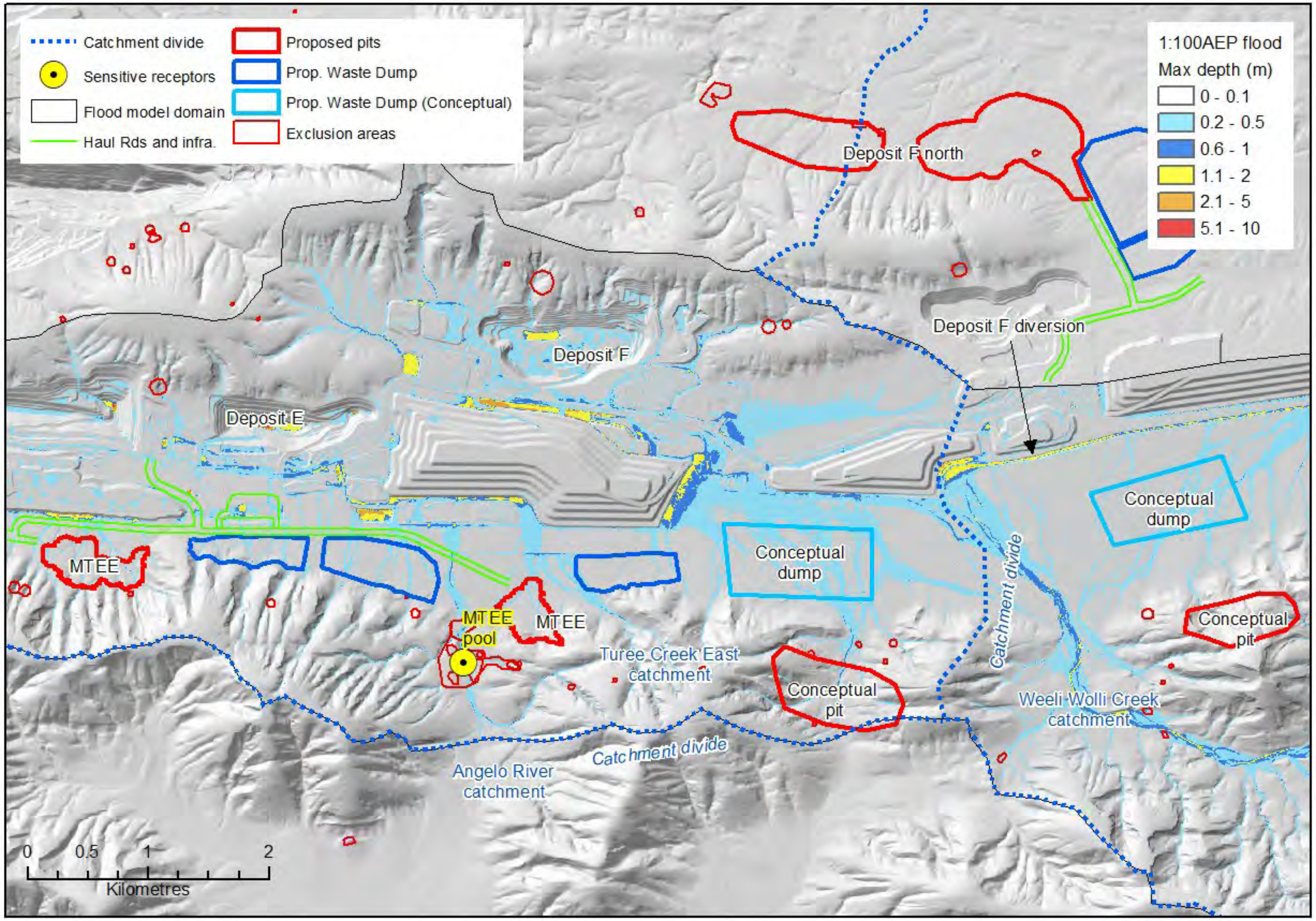


Figure 7-12: Mount Ella East pre-development 1:100AEP floodplain mapping

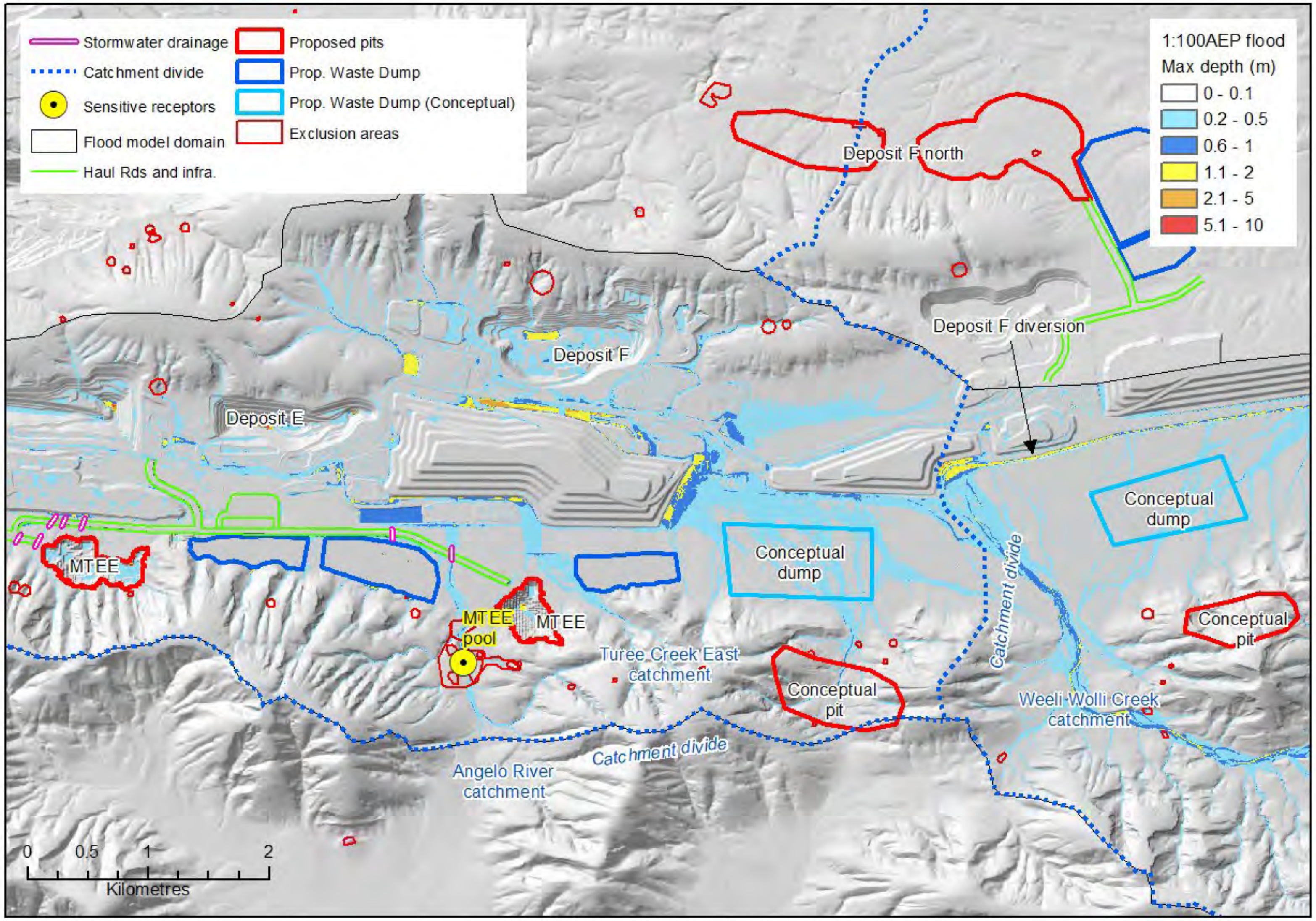


Figure 7-13: Mount Ella East post-development 1:100AEP floodplain mapping with pits and dumps in place

8. Rare to extreme direct rainfall modelling and side-wide closure risk assessment

In order to assess the level of exposure of operations at West Angelas flood events with a very rare probability of occurrence, flood estimation and hydraulic modelling of the 1:1000AEP, 1:10,000AEP and Probable Maximum Flood events was undertaken for all existing and approved operations and the Beyond 2020 development area. The West Angelas regional direct rainfall model described in Section 5.5 was used for the assessment of all deposits located in the Turee Creek East and Weeli Wolli Creek catchments, which includes all existing operations at West Angelas and all Beyond 2020 deposits – excluding Deposit J, which was assessed separately. The modelling work is an extension of the floodplain assessment completed to support closure planning at West Angelas in 2020 (RTIO-PDE-0178993).

The design rainfall and critical duration flood event will vary with location, given the differences in catchment area and routing. However, it is impractical to produce site-wide flood modelling specific to individual locations, considering the many different locations and catchment interceptions. So, selection of representative flood events has focused on the largest, and most critical catchment interceptions when adopting a representative storm event. This evaluation was focused on Turee Creek East at Deposit C, and the western catchment of Deposit J. This is considered a fit-for-purpose evaluation to identify key risk areas, and potential interactions between landforms and the floodplain of larger creeks under extreme rainfall conditions. For detailed design of closure landforms or flood protection a focused flood study is required for each area of interest.

Design rainfall depths for the 1:1000AEP event were sourced from the Bureau of Meteorology 2016 IFD data portal. Rainfall depths for the probable maximum precipitation (PMP) event were calculated using the Generalised Short Duration Method (GSDM, BoM 2003a) for storm durations between 1 and 6 hours, and the revised Generalised Tropical Storm Method (GTSMR BoM 2003b) for storm durations between 24 and 120 hours. For intermediate AEP events between the 1:2000 AEP and PMP, the interpolation methods described in ARR 2019, Book 8 were applied to generate design rainfall estimates

For the West Angelas regional model domain a catchment area of 132km^2 was used when calculating design rainfall, equal to the contributing catchment of Turee Creek East at Deposit C. For Deposit J a 9.1 km^2 area was used, accounting for the largest potential catchment interception at the west of the deposit.

Table 8-1: Rare to extreme rainfall depths for durations of 0.5 to 120 hours, West Angelas at Turee Creek East and Deposit J

	Duration (hrs) and PMP rainfall depth											
Location	**0.5**	**1**	**2**	**3**	**6**	**12**	**24**	**36**	**48**	**72**	**96**	**120**
West Angelas regional model	234	361	462	523	673	780	995	1216	1423	1788	2009	2101
Deposit J	297	442	564	632	793	870	1024	1255	1469	1849	2070	2176

8.1 West Angelas regional model rare to extreme flood estimation

RORB Monte Carlo analysis was used to estimate AEP neutral peak flows for the 1:1000 and 1:10,000AEP flood, as described previously in 5.4. Estimates of the probable maximum flood (PMF) were determined by running an ensemble of temporal patterns for the critical duration rainfall event, using an initial loss of 0 mm and a continuing loss of 1 mm/hr following the guidance of ARR2019 Book 8. The temporal pattern producing the highest peak flow from the ensemble was adopted as the storm event for simulation of the PMF in the hydraulic model. Table 8-2 lists the adopted design flows and storm design parameters.

Table 8-2: Adopted design flows and representative storm events for rare and extreme flood events on Turee Creek East at West Angelas

AEP (1 in x)	RORB Monte Carlo Design flow (m3/s)	Critical duration (hrs)	Temporal pattern	Initial loss (mm)	Continuing loss (mm)
100	191.0	6.0	4	30	8
1000	457.0	6.0	4	30	8
10,000	1229.0	6.0	4	30	8
PMF	6098.0	6.0	5	0	1

8.2 Deposit J rare to extreme flood estimation

The direct rainfall ensemble modelling described in section 5.5 was applied for the Deposit J model domain to identify the representative 1:1000 and 1:10,000AEP storm event, and the PMF event. An ensemble of 10 temporal patterns was simulated in the model domain for the 1hr critical duration event. The event producing the peak flow closest to the ensemble mean was adopted as the representative storm. For the PMF event the flood producing the maximum peak flow from the ensemble was adopted. Table 8-3 lists the adopted design storm parameters.

Table 8-3: Adopted design flows and representative storm events for rare and extreme flood events at Deposit J

AEP (1 in x)	Adopted design flow (m^3/s)	Critical duration (hrs)	Temporal pattern	Initial loss (mm)	Continuing loss (mm)
100	91.2	6.0	1	45	8
1000	208.2	1.0	10	30	8
10,000	349.0	1.0	10	30	8
PMF	1770.0	1.0	1	0	1

8.3 Hydraulic modelling

The selected design storm events were applied to each model domain. Two terrain surfaces were developed for the simulation as described below.

Approved life of mine deposits. Current terrain, with all approved life of mine pit designs and waste dumps, including operational flood protection, and conceptual flood protection for A west and G deposits – noting that these are not yet developed and surface water management is subject to change.

West Angelas Beyond 2020 deposits, cumulative with existing approved deposits. As above with West Angelas Order of Magnitude pit and dump designs, including conceptual operational flood protection.

8.4 Results

Floodplain extent mapping associated with the selected design flood events for 1:1000AEP and 1:10:000AEP events are illustrated below. Locations where there are known hydrology risks associated with rare and extreme events which require management at closure are annotated in the figures below for each of the terrain surfaces (scenarios) considered.

8.4.1 Existing and approved deposits

Risks identified for the existing and approved deposits at West Angelas are as follows:

- Potential for creek capture and landform instability associated with mining adjacent to Turee Creek East at Deposit C.
- Potential for creek capture and landform instability associated with mining adjacent to major tributary of Turee Creek East at Deposit D.
- Raise final height of Deposit B diversion berm above level of PMF (existing closure commitment).
- Requirement to upgrade existing diversion drain at Deposit F to a stable closure diversion.
- Refinement of diversion strategy or landform at closure for Deposit A west (deposit not currently developed)
- Refinement of diversion strategy or landform at closure for Deposit G (under development)

Mitigation options for these risks are currently being investigated as part of routine closure plan revisions.

8.4.2 Beyond 2020 deposits

The Beyond 2020 deposits are located away from the floodplains of the major creek systems in the area, being Turee Creek East and its larger tributaries and as such do not introduce any new large-scale closure risks in relation to surface water management. A brief discussion of each deposit is included below.

8.4.2.1 Western Hill

The pit voids of Western Hill are in an elevated position within the ridgeline between Turee Creek East and a valley to the north. There is no potential for interaction between the floodplain of any major creek and the pit voids. Waste dumps and stockpiles have also been placed in an elevated position away from the floodplain. The dump at the south-western corner of the deposit is outside of the 1:10,000AEP floodplain of Turee Creek East. Small hillslope catchments are likely to be captured by the pit void at closure and it is assumed that waste dumps will be rehabilitated to manage incident rainfall.

8.4.2.2 Deposit F north

Both proposed pits and waste dumps are located away from major watercourses and are unlikely to introduce significant surface water risks at closure. Small catchments to the south of the pit voids will likely be captured at closure, and the proposed waste dump location is located on a hillslope and will not intercept drainage lines.

8.4.2.3 Deposit H

Deposit H is located in an elevated position away from large creek systems. The pit voids will lead to capture of smaller local drainage lines, and waste dumps will also act to remove parts of the catchment area. This is likely to permanently reduce flow through the ephemeral pool at Deposit H, and to the potential GDE area located further downstream (see Section 11). No landform stability risks have been identified for the deposit, and standard waste dump rehabilitation is expected to be adequate.

8.4.2.4 Deposit J

The pits at Deposit J are generally located away from major watercourses, however the western extent of the western pit may interact with the 9km^2 creek in extreme flooding conditions and the requirement for any diversion and upgrade at closure will be further evaluated as orebody knowledge improves during the PFS. The proposed diversions around the waste dump may require upgrading at closure to improve long-term durability, and this will be evaluated as the project progresses. The diversions proposed for the eastern pit are unlikely to be upgraded at closure given the steep terrain and relatively small catchment areas, so it is assumed that these will eventually fail and flow towards the eastern pit. The stormwater drainage required along access roads and between the eastern and western pits is not likely to be suitable long term, so it should be assumed that the drainage lines flowing southward from Mount Ella will eventually be captured by the eastern or western pit voids. In generally the steep terrain around Deposit J means that higher flow velocities should be expected where dump toes meet natural terrain and a drainage gradient is present, so additional armouring and reduced batter slopes may be required along the toe of rehabilitated designs to improve stability.

8.4.2.5 Mount Ella East

The pits at Mount Ella East are located in upper hillslopes and only intercept smaller drainage lines from the ranges, and as such do not present a significant risk with regard to landform stability adjacent to watercourses. The waste dumps at the western end of the deposit will intercept minor creeks and pond water but do not interact with larger drainage lines. The eastern conceptual waste dumps are located within sheet flow areas which have larger catchment areas associated with them which may require modification or small amounts of stream training to divert flows around the waste dump toe. However, since these are only conceptual locations it is not possible to provide detail.

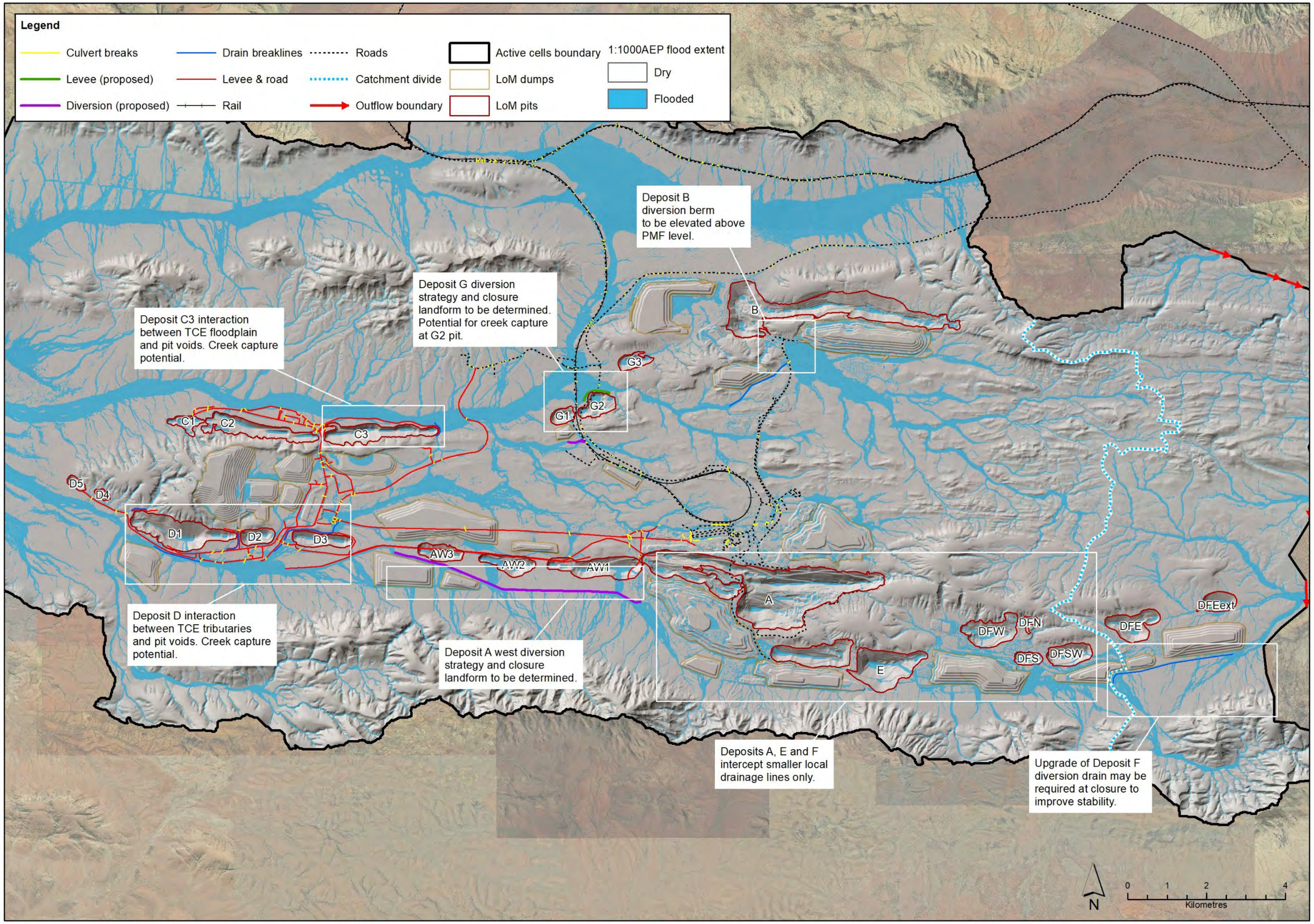
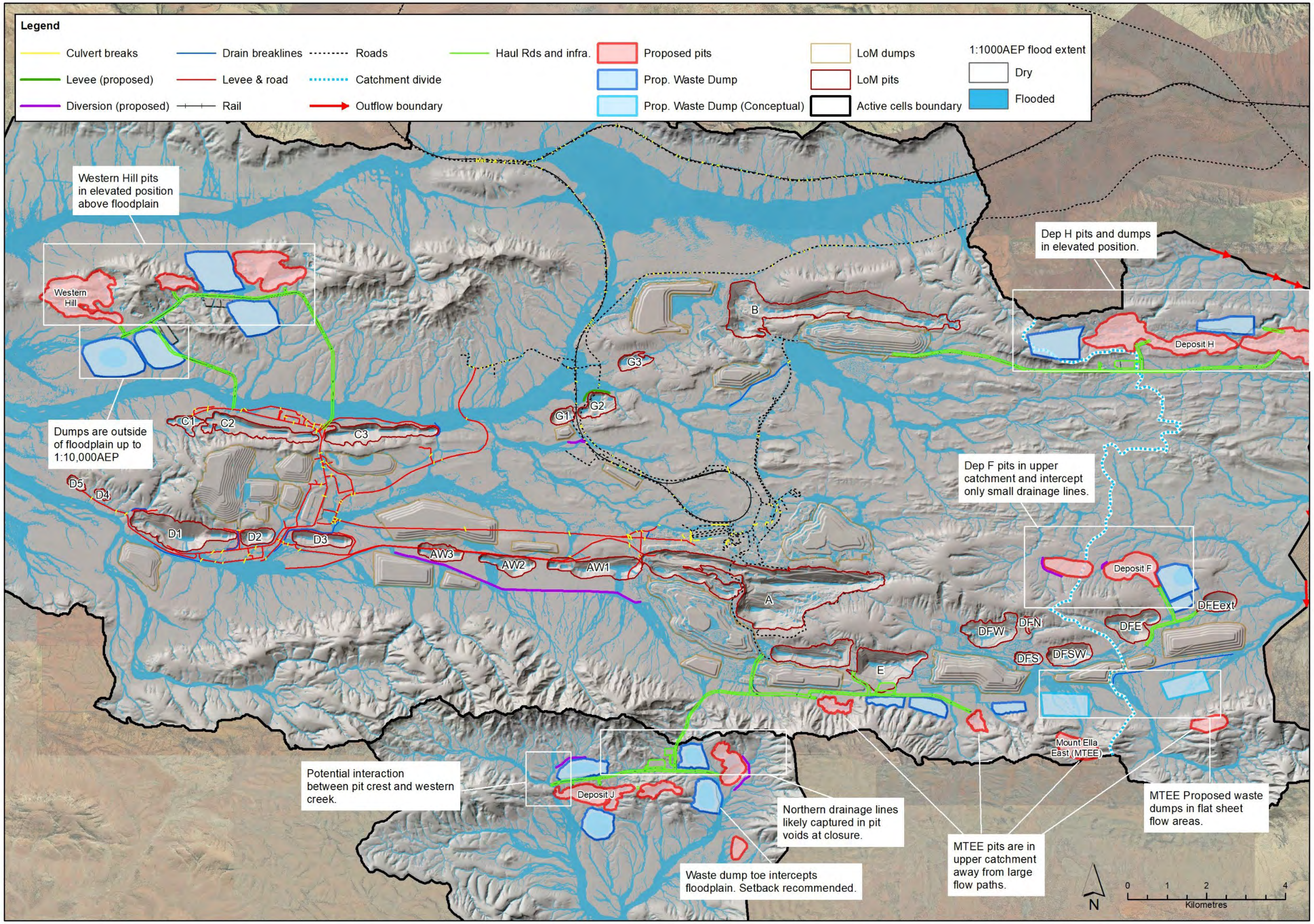


Figure 8-1: Regional 1:1000AEP floodplain mapping for currently approved Life of Mine pits and dumps with operational flood protection.



Western Hill pits in elevated position above floodplain

Dumps are outside of floodplain up to 1:10,000AEP

Dep H pits and dumps in elevated position.

Dep F pits in upper catchment and intercept only small drainage lines.

Potential interaction between pit crest and western creek.

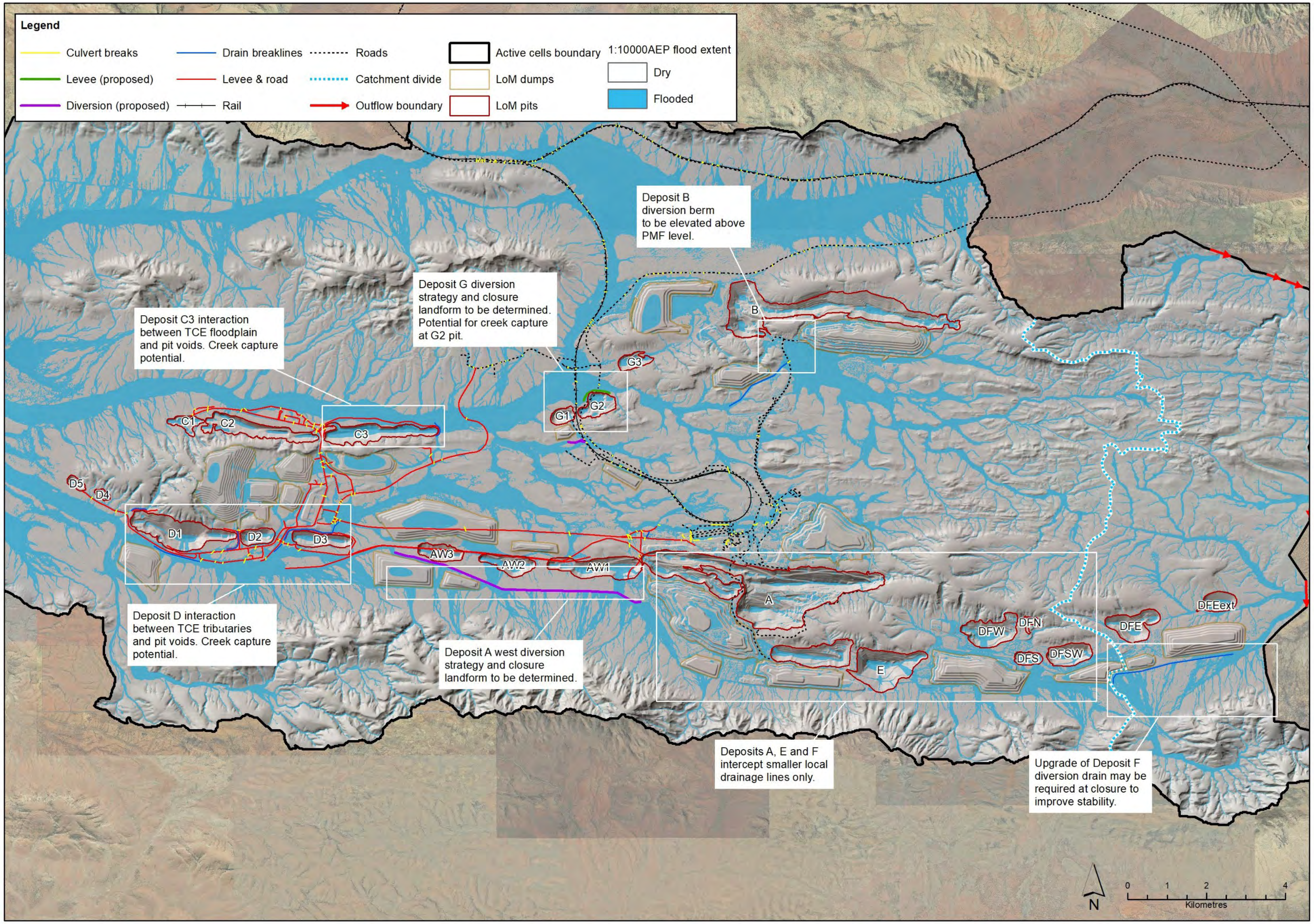
Northern drainage lines likely captured in pit voids at closure.

Waste dump toe intercepts floodplain. Setback recommended.

MTEE pits are in upper catchment away from large flow paths.

MTEE Proposed waste dumps in flat sheet flow areas.

Figure 8-2: Regional 1:1000AEP floodplain mapping including development of Beyond 2020 deposits



Deposit B diversion berm to be elevated above PMF level.

Deposit G diversion strategy and closure landform to be determined. Potential for creek capture at G2 pit.

Deposit C3 interaction between TCE floodplain and pit voids. Creek capture potential.

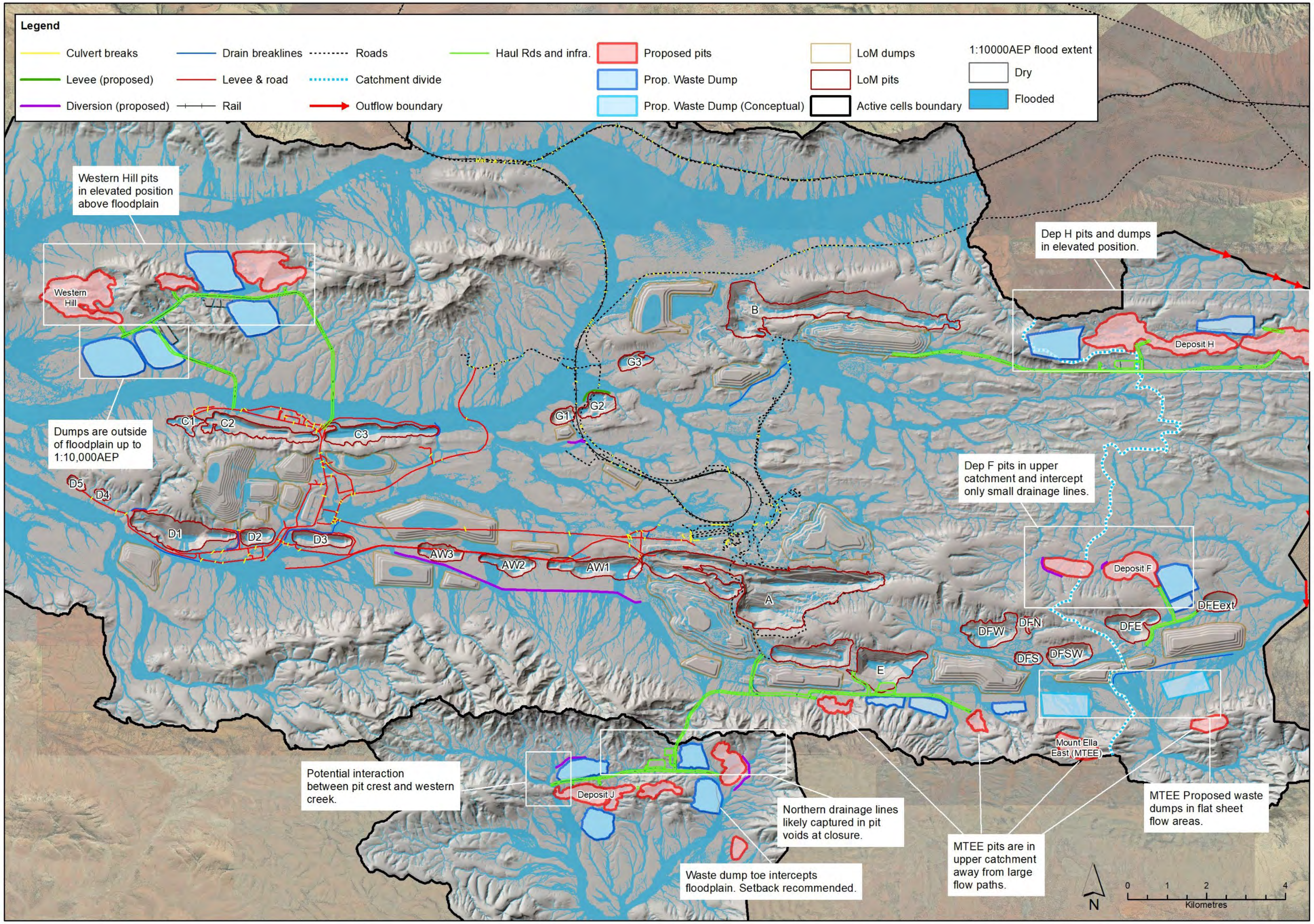
Deposit D interaction between TCE tributaries and pit voids. Creek capture potential.

Deposit A west diversion strategy and closure landform to be determined.

Deposits A, E and F intercept smaller local drainage lines only.

Upgrade of Deposit F diversion drain may be required at closure to improve stability.

Figure 8-3: Regional 1:10,000AEP floodplain mapping for currently approved Life of Mine pits and dumps with operational flood protection.



Western Hill pits in elevated position above floodplain

Dumps are outside of floodplain up to 1:10,000AEP

Dep H pits and dumps in elevated position.

Dep F pits in upper catchment and intercept only small drainage lines.

Potential interaction between pit crest and western creek.

Northern drainage lines likely captured in pit voids at closure.

Waste dump toe intercepts floodplain. Setback recommended.

MTEE pits are in upper catchment away from large flow paths.

MTEE Proposed waste dumps in flat sheet flow areas.

Figure 8-4: Regional 1:10,000AEP floodplain mapping including development of Beyond 2020 deposits

9. Surplus water management

West Angelas currently discharges surplus mine water at two licensed discharge outlets located at Deposit B and Deposit A. A third licensed discharge point will be commissioned to support dewatering at Deposits C and D and will be located near the Deposit A outlet. All outlets discharge to tributaries of Turee Creek East, with a requirement that continuous surface flows not extend to within 2km of the Karijni National Park Boundary under natural no flow conditions.

Deposits at H, F north, Western Hill and Mount Ella East will either be water neutral or will have demand met by supply from existing operations. As such they will not substantially change the mine water balance and will not require new or modified discharge outlets and associated licenses.

Dewatering surplus at Deposit J is unlikely, but given the significant costs associated with transfer of water from Deposit J to the North (West Angelas Deposit A Hub) it is recommended that approval for an additional discharge point in the vicinity of Deposit J be investigated as a contingency option. To support approvals, discharge extent modelling was completed (RTIO-PDE-0175749) for three potential outlets to the south of Deposit J, to identify the maximum extent of surface water which would extend from the outlet assuming a conservative discharge rate. Figure 9-2 illustrates the extent of surface water predicted for a 1.8 and 3.6 ML/d discharge rate for the three locations assessed. Table 9-1 lists the predicted distance that discharge would extend from each outlet. Botanical surveys have been commissioned covering the extent of the creeks which may be impacted by continuous discharge of surplus water.

Table 9-1: Modelled discharge rates and resulting distances from outlets

Reach	Flow Rate (ML/d)	Distance from outlet (m)*
A	1.8	2800
A	3.6	4800
B	1.8	2700
B	3.6	4400
C	1.8	1400
C	3.6	3000

**rounded to nearest 100m*

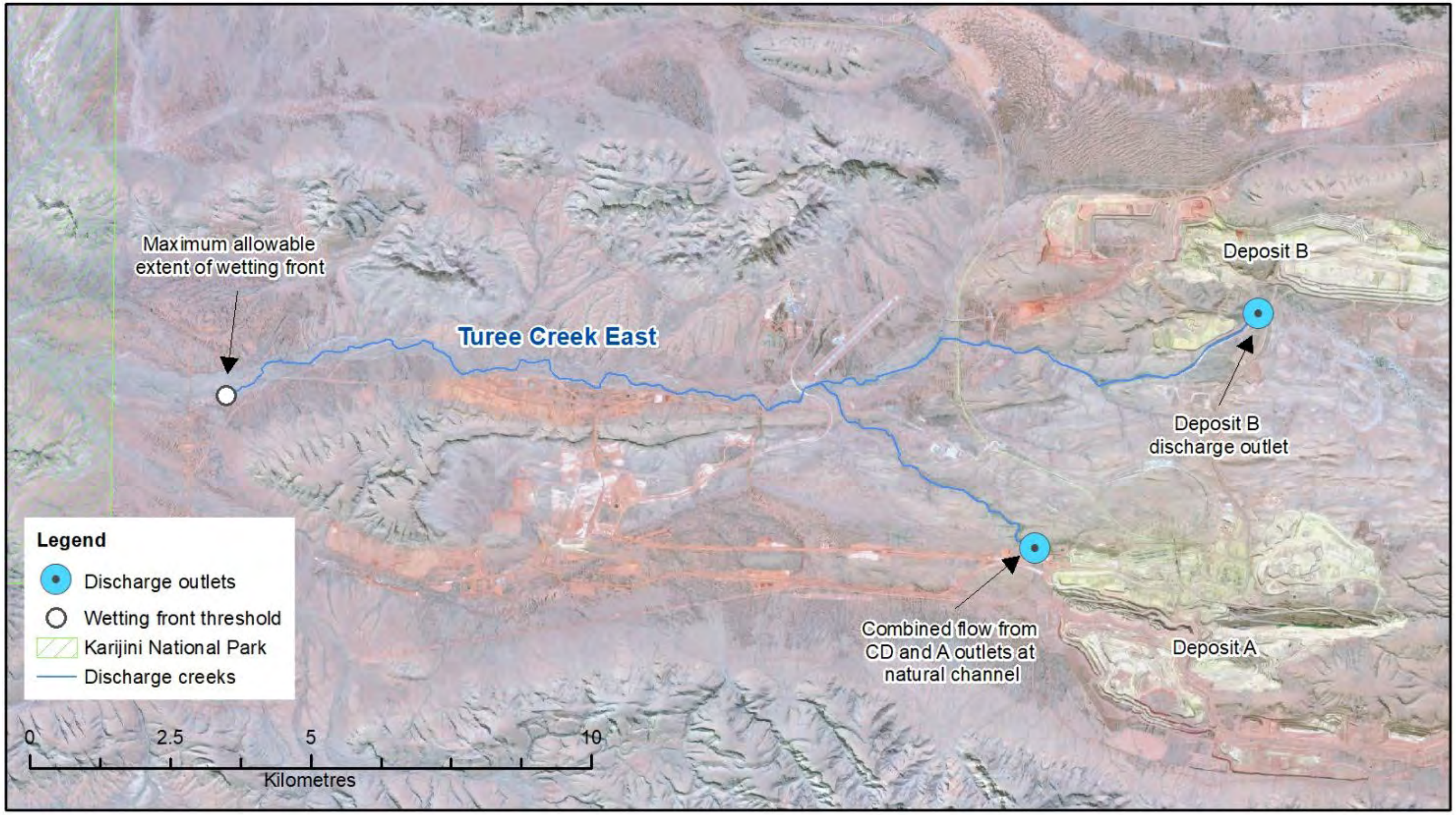


Figure 9-1: Operational and planned licensed discharge outlets at West Angelas, receiving creek, and maximum allowable extent of surface flows

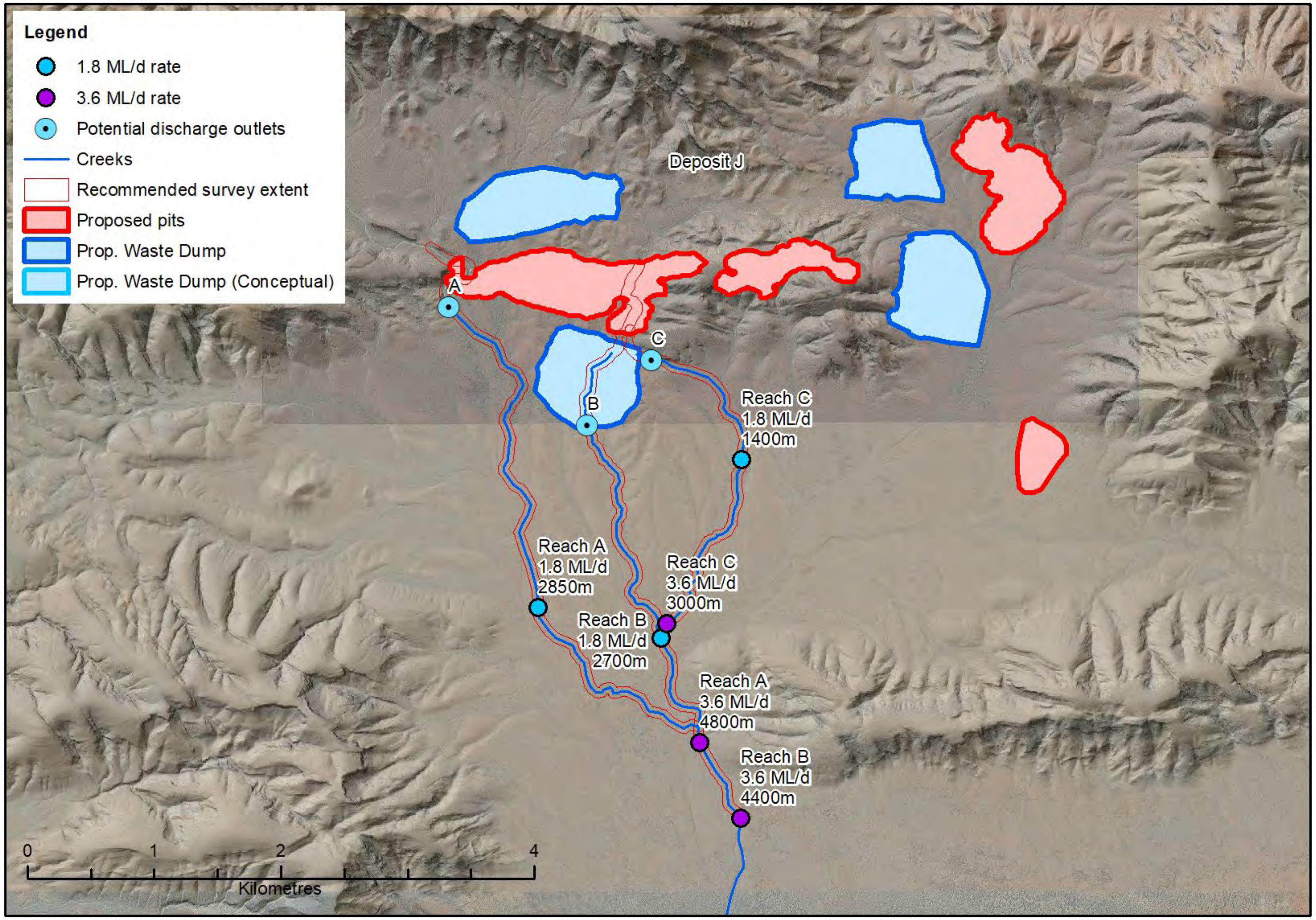


Figure 9-2: Extent of wetting front from potential outlets at Deposit J

10. Potential impacts to hydrological regime of Turee Creek East

West Angelas has undergone incremental hydrological changes since mine development, with blocking of some tributary catchments, restriction of flows by linear infrastructure, and catchment diversion to allow mining at Deposits B and F. However, catchment connectivity has been retained with a general east-west movement of water across the site to Turee Creek East, which delivers flow to KNP west of Deposits C & D. Turee Creek East is a significant tributary of Turee Creek and enters the Karijini National Park boundary to the west of Deposits C and D.

Within the KNP boundary a section of TCE is associated with enhanced vegetation growth and has been identified as a potential groundwater dependent ecosystem (RTIO-PDE-0146318). Shallow groundwater was present at ~1-6 mBGL with evidence that the area is supported by both groundwater and surface water. Outcropping chert rock bars in the main channel likely extend the period of water availability following flow events.

Some impacts to the surface water flow regime to Turee Creek East are anticipated due to the Beyond 2020 development, caused by removal of catchment area due to mining, and restriction of peak flows at creek crossings. The impacts have been assessed cumulatively with existing operations at West Angelas, by calculating the reduction in catchment area, and using TUFLOW modelling of the pre- and post-development flood events for Western Hill.

10.1 Cumulative reduction in catchment area

Figure 10-1 shows reduced catchment area of Turee Creek East resulting from mining at existing deposits, and new developments at Deposits C & D, Western Hill and Mount Ella East (noting other deposits are not in the TCE catchment). The cumulative reduction in catchment area is shown in Table 10-1 relative to the total catchment area of TCE (2,059km^2), and the local catchment area of TCE to the KNP boundary (430km^2).

Development at Mount Ella East is within a portion of the TCE catchment which has become disconnected from the outlet at KNP by mining at Deposits A, E and F, and as such does not result in any further reduction in the total catchment area.

Development of Western Hill will result in removal of hillslope catchments adjacent to Turee Creek east and immediately to the east of KNP. This represents a further reduction in catchment area of 15 km^2. In total with all approved mining and development at West Angelas, 116 km^2 of the TCE catchment has been removed or disconnected, equal to 29% of the catchment at the KNP boundary, and 6% of the total TCE catchment.

Table 10-1: Cumulative Turee Creek East catchment area reduction

		Full TCE catchment (km^2)	TCE catchment to KNP (km^2)
		2,059	430
Deposits	Associated catchment area reduction (km^2)	Reduction of area (%)	Reduction of area (%)
Deposits A, B, E, F, G, Awest	92	4%	21%
With Deposits C & D	110	5%	26%
With Beyond 2020 development	125	6%	29%

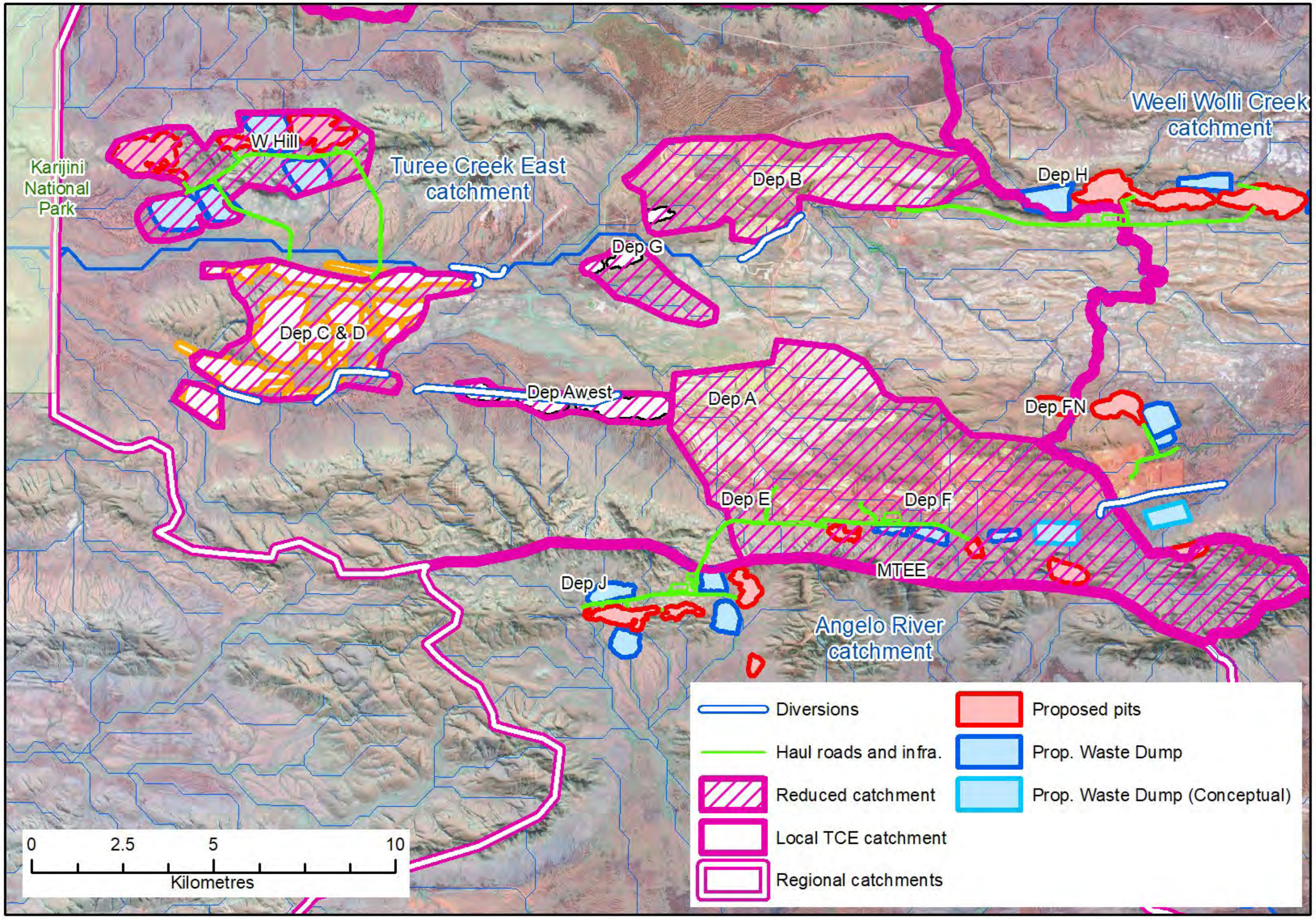


Figure 10-1: Turee Creek East catchment area reduction in the West Angelas area

10.2 Changes in flow regime

Removal of catchment area and restriction of flows at creek crossings will impact on the flow regime of TCE. To quantify the likely impact, pre- and post-development hydrographs were recorded at the western boundary of the development for flow paths leading to Karijini National Park using the Western Hill TUFLOW modelling. Three locations were assessed as shown in Figure 10-2. These were at the main channel of Turee Creek East (TCE_KNP), a sheet flow area flowing from Western Hill to the park (Tribs_KNP), and the northern tributary flowing towards Guburingu heritage area (To_Guburingu) within the park boundary.

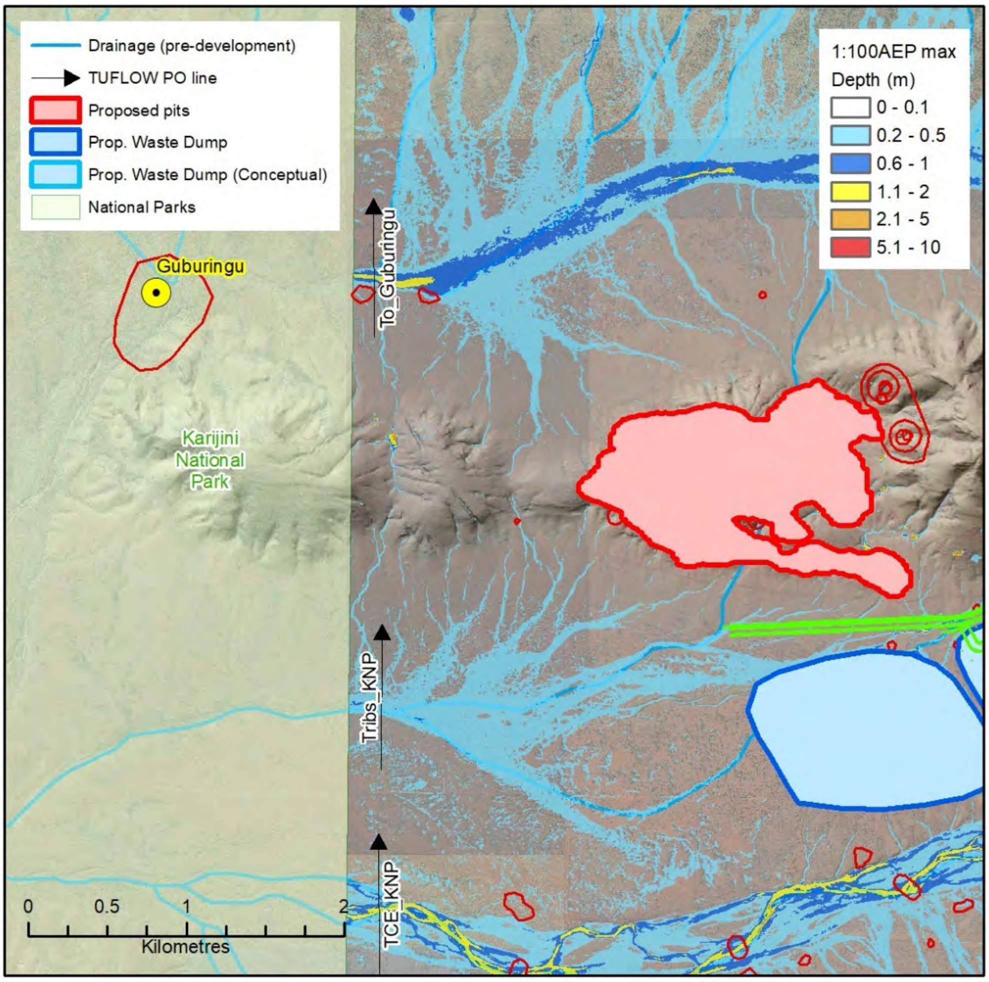


Figure 10-2: Hydrograph Impact assessment locations at the KNP boundary near Western Hill

Figure 10-3 compares the 1:2, 1:10 and 1:100AEP design flow hydrographs covering a range of flow events from more frequent to rare for pre- and post-development cases. Table 10-2 quantifies the change in event peak and volume associated with development. Note that this impact assessment is based on *representative* design events, and as such it gives only an indication of the magnitude of change caused by the development. Pilbara rainfall is highly spatially and temporally variable, and as such there will be significant variations in the actual impact on flows for individual flow events depending on the timing and distribution of rainfalls. The results presented here assume spatially uniform rainfall across the catchment with all connected parts of the catchment contributing flow.

Table 10-2: Post-development change in peak flow and volume for flow delivered to KNP boundary, selected design events based on Western Hill TUFLOW modelling

	Peak flow (m3/s)								
	Pre-development			Post-development			Change		
Location	1:2AEP	1:10 AEP	1:100AEP	1:2AEP	1:10AEP	1:100AEP	1:2AEP	1:10AEP	1:100AEP
To_Guburingu	7.2	30	152	6.4	26	122	11%	13%	19%
Tribs_KNP	1.5	9.0	46	1.1	5.5	31	24%	39%	33%
TCE_KNP	15	70	193	15	66	190	0%	6%	1%
	Event volume over 24hrs (ML)								
	Pre-development			Post-development			Change		
Location	1:2AEP	1:10 AEP	1:100AEP	1:2AEP	1:10AEP	1:100AEP	1:2AEP	1:10AEP	1:100AEP
To_Guburingu	185	526	1726	166	475	1567	10%	10%	9%
Tribs_KNP	24	76	264	17	57	208	31%	26%	21%
TCE_KNP	560	2647	6594	514	2541	6303	8%	4%	4%

The main channel of Turee Creek East (TCE_KNP) will experience a reduction in overall flow volume associated with the removal of catchment area at Western Hill. This is evident in the reduced initial peak flow, and associated volume shown in the first, smaller peak of the hydrograph. This is caused by a reduction in flow from the smaller tributaries close to the KNP boundary and the effect is present for all design events. Impacts to flow are less pronounced in the second larger peak of the hydrograph, which is associated with flow sourced from higher in the catchment constituting the main body of the flood and the largest proportion of water delivered downstream. A small attenuating effect is evident for the rarer flood events (1:10AEP and 1:100AEP) with a reduced peak flow and extended hydrograph tail, caused by the storage and release of water behind the new creek crossings. For the 1:2AEP event water will be delivered downstream uninhibited.

Flow from the small tributaries and sheet flow area immediately east of the KNP boundary (Tribs_KNP) will be reduced by pit and dump development. This reduction in flow is unavoidable, given the limited flat terrain over which dumping can occur. Nonetheless the dump footprint in this location will be placed so as to minimise disruption of flow where possible.

A reduction in peak flow and volume from the eastern tributary of the Guburingu heritage area is expected as a result of pit and dump development. This is evident across all design events assessed.

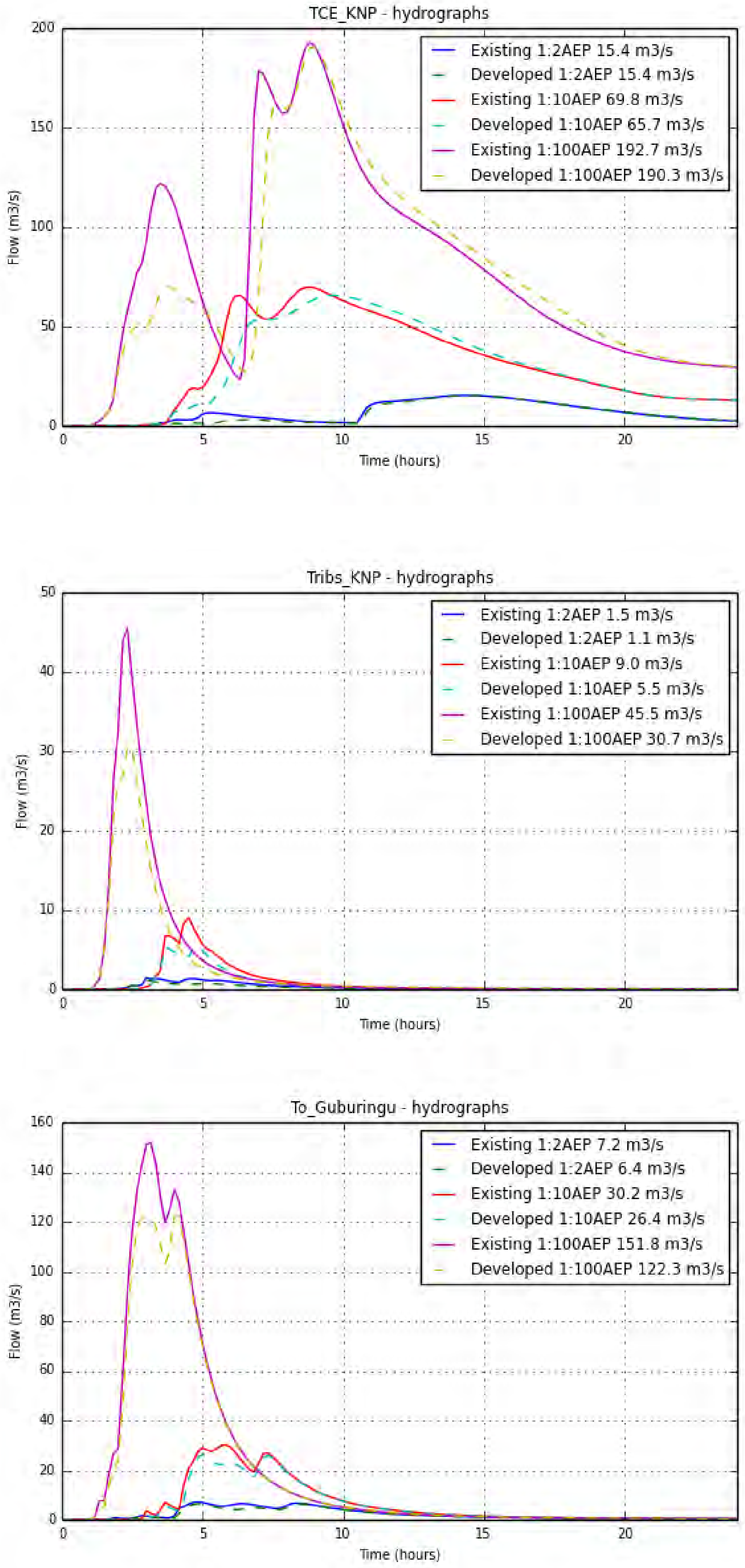


Figure 10-3: Pre- and post-development flow hydrographs at the Karijini National Park boundary

11. Potential surface water impacts to sensitive receptors

A desktop analysis was used in conjunction with site visits of all deposits to identify potential sensitive receptors within the study area. These are shown collectively in Figure 2-1 and are described briefly below. Where appropriate, pressure transducers were installed to monitor water levels at surface water features or in contributing catchments.

11.1 Guburingu heritage site

This site is located within KNP at the western extent of Western Hill at the confluence of two creeks (Figure 11-1). The mining footprint of Western Hill is located within the catchment of the heritage area. Monitoring is in place in the confluence zone within the heritage site with permission from Yinhawangka group. See technical memo RTIO-PDE-0162191 for further information on surface water monitoring, site visits and local hydrological setting. Based on investigations to date there is no evidence of persistently available surface or groundwater at the site. As such this location is representative of a typical ephemeral creek confluence zone.

Development of Western Hill is within the eastern contributing catchment of this site and will result in ~4km^2 reduction in catchment area. This constitutes 6% of the eastern catchment (60km^2), and 2% of the total contributing catchment (151km^2). The closest development is the western pit, which is still over 4km along flow path from Guburingu area, across very flat slow draining terrain. As such there is a very low risk of sediment transport towards the site.

11.2 Deposit H ephemeral pool

There is an ephemeral pool at the base of a gorge and waterfall system located downstream from Deposit H (Figure 11-2). Water levels and flows to the pool have been monitored since 2018 and provide evidence of an intermittent pool which has persistent surface water following rainfall and flow events in the catchment. See technical memo RTIO-PDE-0162189 for details on site visits, monitoring and assessment.

Mining of Deposit H will remove most (~90%) of the contributing catchment for the pool (Figure 11-3) and depending on the final footprint of pits and dumps at Deposit H, more or less of the catchment could be removed. This will result in a reduction in flow volumes delivered to the pool. Given the small storage volume of the pool relative to the catchment area, the pool is expected to still intermittently store surface water following large rainfall events, but the period of inundation and volume of throughflow will be reduced.

11.3 Deposit H potential groundwater dependent ecosystem

Biological surveys completed in 2020 (Biologic, 2020) identified a small stand of *E. camaldulensis* (River Red Gum) near the outlet of a 43km^2 catchment which includes part of the development area at Deposit H. The trees are located immediately upstream of a natural surface flow constriction between two ridge lines. Historical aerial photography does not indicate persistent pools or persistently active vegetation in the dry season (Figure 11-4) and further investigation is required to determine if persistent shallow groundwater is present at the site. Mining of Deposit H will remove 5.4 km^2 (13%) of this catchment as shown in Figure 11-5. As such a small reduction in flow volume through the site is likely following development of Deposit H.

11.4 Mount Ella East ephemeral pool and heritage area

A rock pool and heritage area are located to the south of the proposed Mount Ella East development (WA-18-ETH-01). The pool, heritage exclusion areas and all contributing catchments are located outside of the development footprint at Mount Ella East (Figure 11-6) and as such there will be no impacts to the surface water regime of this site caused by the Beyond 2020 development.

11.5 Gajiringu heritage site (Rights Reserved)

The Gajiringu heritage site is located on a tributary of Turee Creek East, adjacent to Deposit D. The site is currently managed under the West Angelas Deposit C and D YINHARR-20 (Gajaringu) Management Plan. Deposit D is within the upstream catchment of this site, and it is recognised that retention of surface water flows to the area is required to maintain cultural value. To achieve this, diversion drains and earth embankments have been constructed at Deposit D to convey water around pits and waste dumps and retain flow to the site. A small reduction to the volume of water passing through the development will occur as a result of the capture of small creeks into pits where diversion structures are not possible, but most of the upstream catchment has been retained.

The proposed development of the Beyond 2020 deposits will not result in any incremental increase in impact to the site, as there is no development planned within the contributing catchment.

11.6 Mulga community south from Deposit J

An extensive mulga woodland community is present south of Deposit J in the flat terrain below surrounding ranges. Mulga communities in the Pilbara region are recognised as an ecosystem at risk and are of elevated conservation significance. The community is downstream from the Deposit J development but mostly covers terrain producing sheet flow from direct rainfall and is not dependent on channel flow from the north. As such it is unlikely that the development of Deposit J (including the diversion drains) would result in any hydrological impacts on the larger community, noting that some smaller patches of Mulga adjacent to Deposit J may experience some interaction of surface flows from the western pit and dumps. Similarly, the potential surplus discharge outlet at Deposit J would be to one of three defined drainage lines, not associated with the Mulga community. Figure 11-7 illustrates the hydrological setting of the Mulga community relative to Deposit J.

11.7 West Angelas Cracking Clays PEC-P1

A Priority Ecological Community (PEC-P1) known as a Cracking Clay community exists at several locations at West Angelas, between Deposit C and D, and to the south of Deposit B (Figure 2-1). The areas require special consideration due to its sensitive nature and environmental value, and appropriate management is required to minimise the impacts of mining on these vegetation communities.

The footprint of the Beyond 2020 development does not intercept any of the PEC communities and does not interfere with upstream contributing catchments or flow paths. As such it is deemed unlikely that there will be any change in the flow regime to these sites caused by the development.

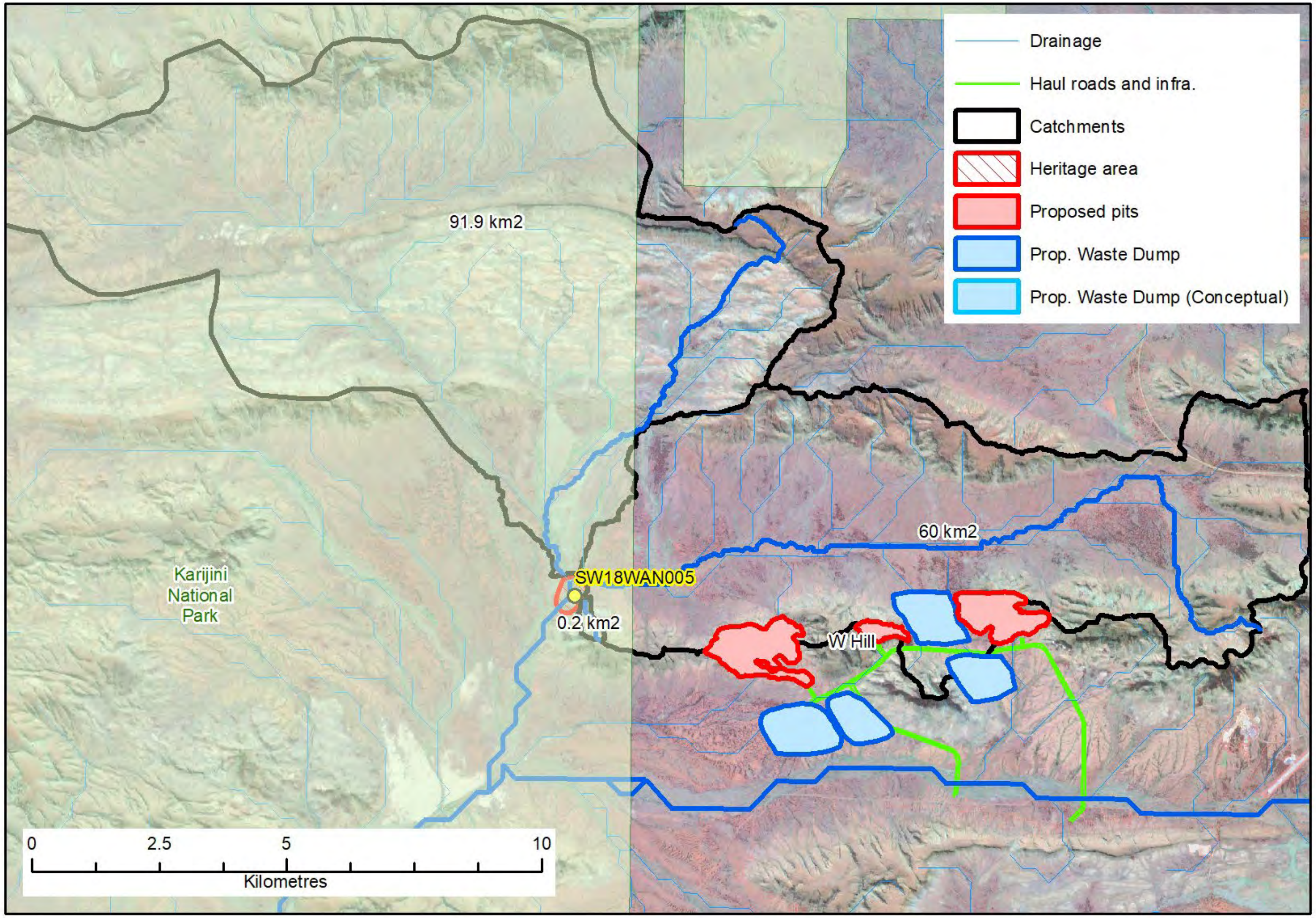


Figure 11-1: Guburingu heritage area hydrological setting

Figure 11-2: Deposit H ephemeral pool (August 2020, May 2019, February 2018)

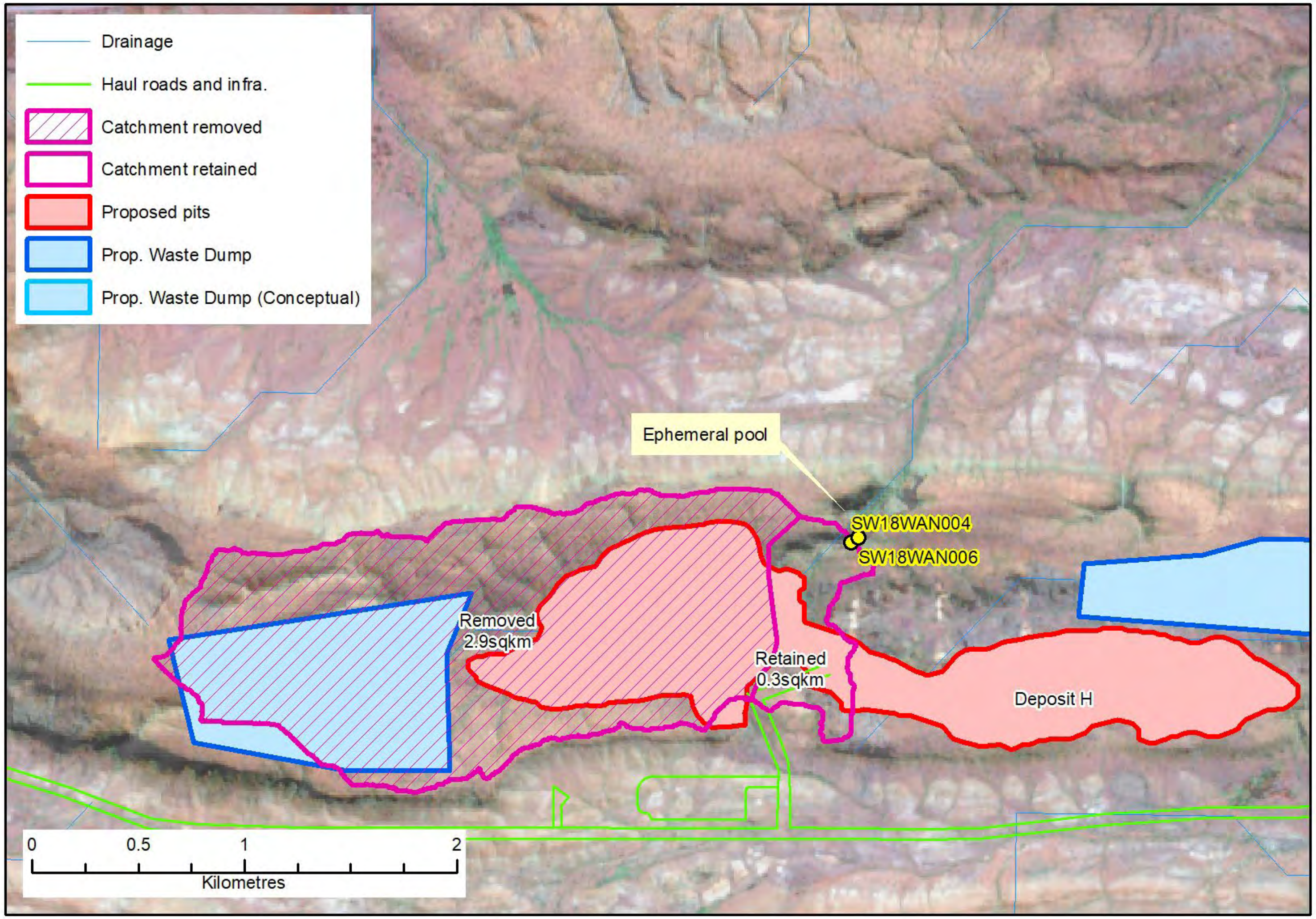


Figure 11-3: Deposit H catchment reduction at ephemeral pool

Figure 11-4: River Redgums at potential GDE (Biologic, 2020) (left), pGDE area post wet 2020 (middle) and pGDE dry season (Dec 2004)

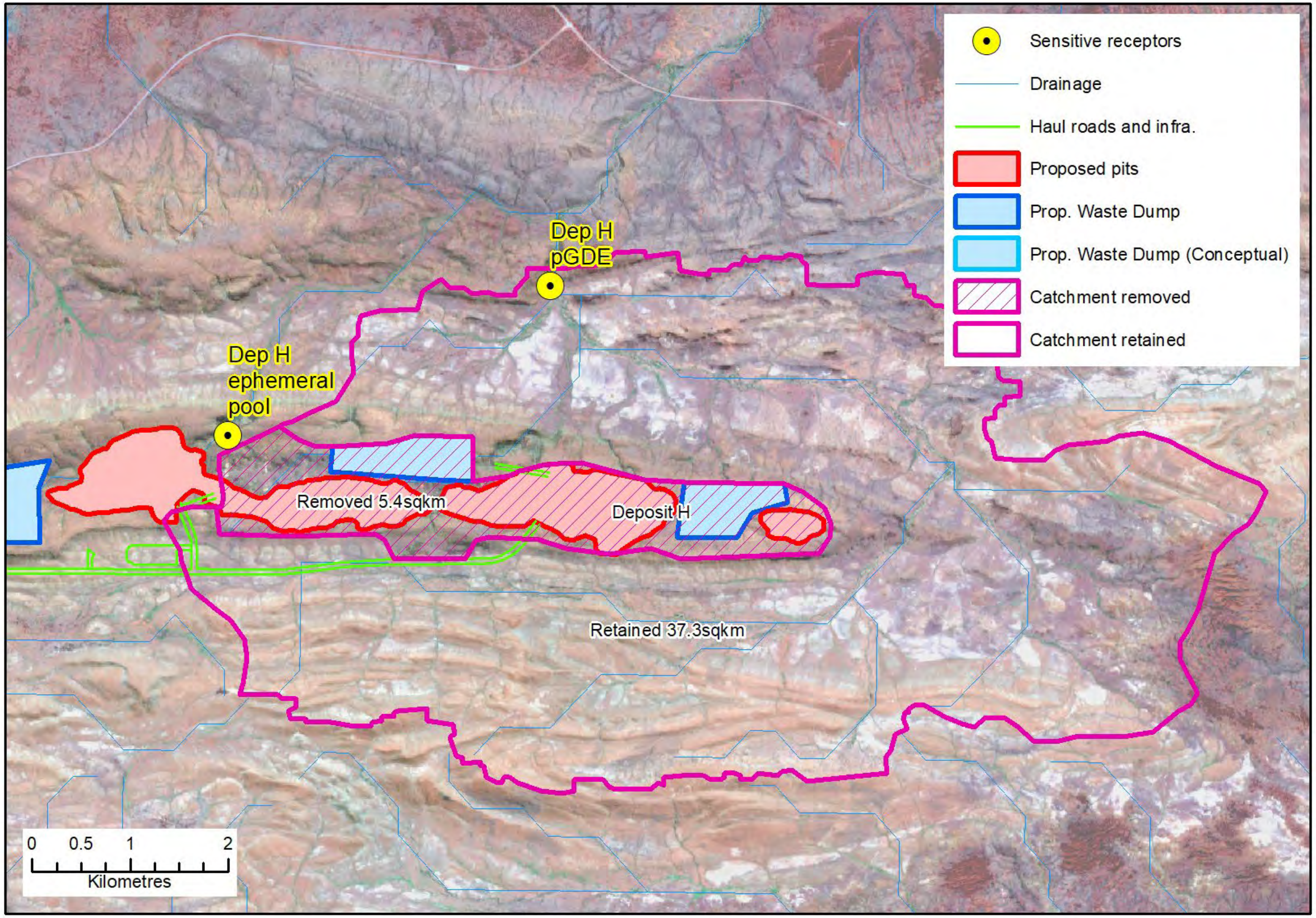


Figure 11-5: Deposit H catchment reduction at potential GDE

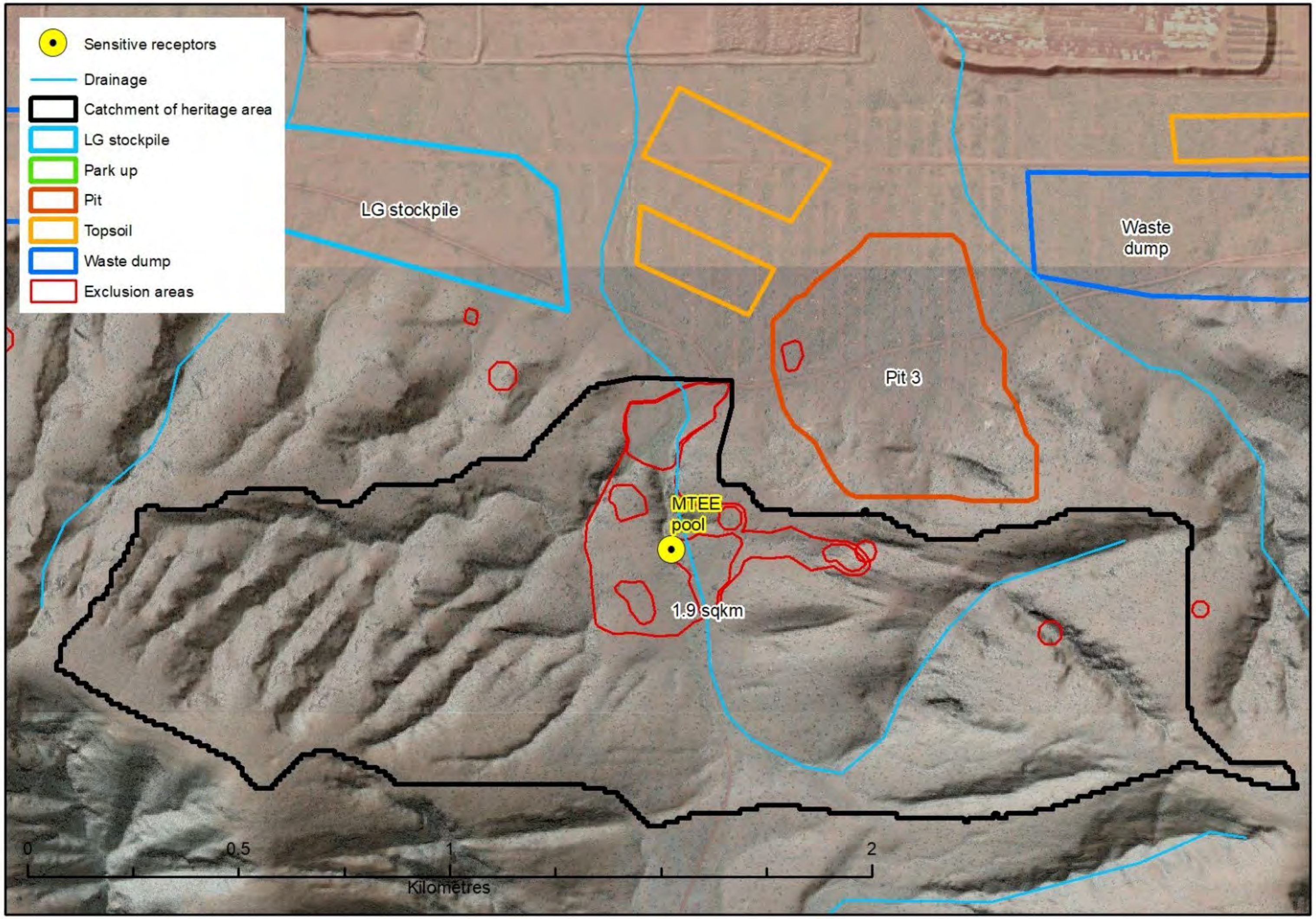


Figure 11-6: Mount Ella East ephemeral pool and heritage site

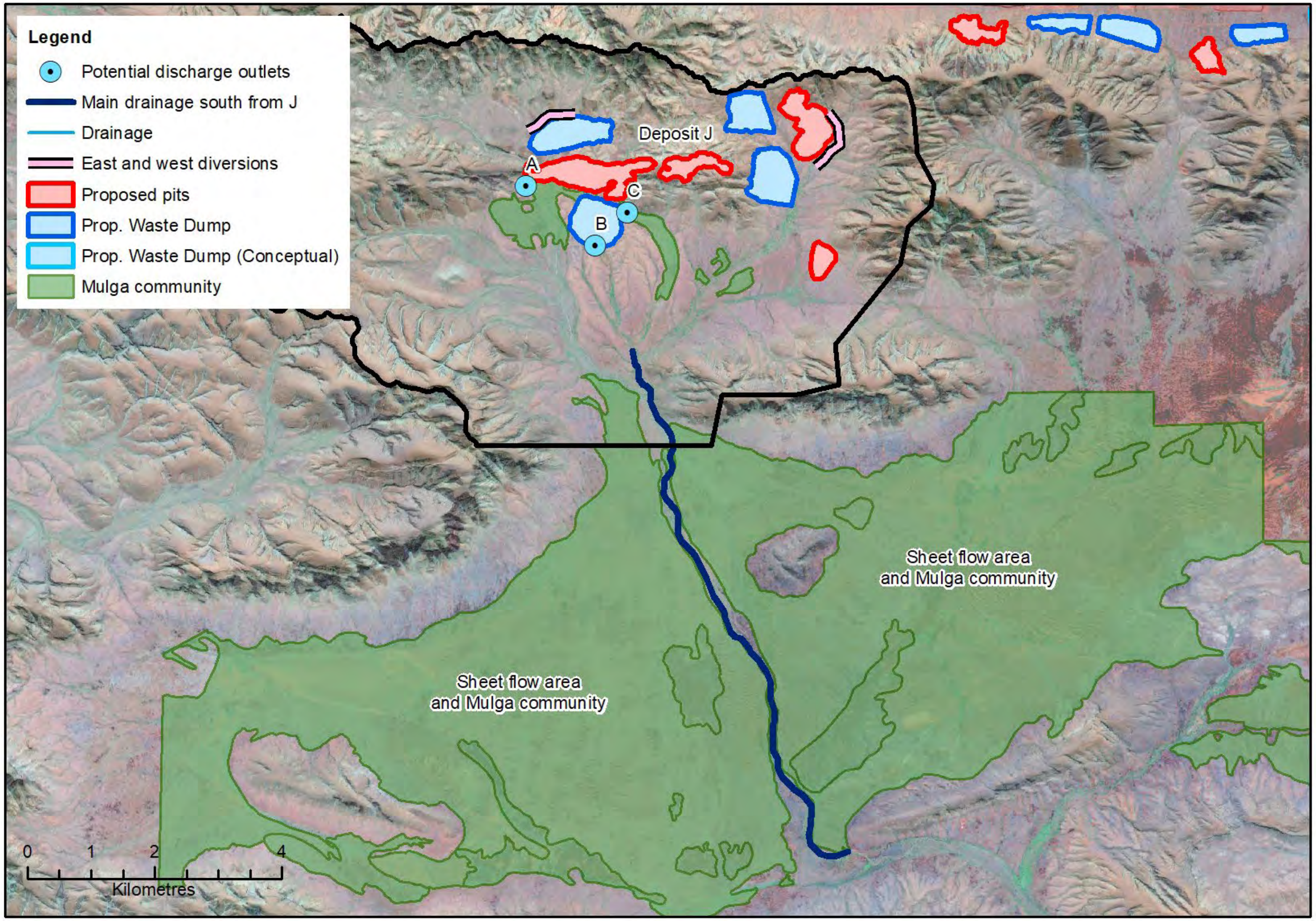


Figure 11-7: Mulga community south from Deposit J

12. Potential Impacts to Surface Water Quality

If not appropriately managed, the proposed development has the potential to impact surface water quality through contamination, erosion and sedimentation. These risks and proposed mitigations are discussed in the following subsections.

12.1 Surface Water Contamination

During construction and operation of the proposed development there is the potential for contamination of surface water due to suspended solids, hydrocarbon spills and acid mine drainage within mining areas. Examples of potential contamination sources include processing areas, workshops, ANFO facilities, ROM pads, roads, re-fuelling facilities, wash-down facilities and exposed PAF material in pit.

The risk of potential hydrocarbon spills and resultant contamination will be minimised through implementation of management, monitoring and contingency measures, which will be detailed in a Hydrocarbon Management Plan contained in the site Environmental Management Plan (EMP). Management measures to be implemented include bunding hydrocarbon storage facilities, provision of re-fuelling locations, and stationary hydrocarbon usage areas in compliance with the relevant standards. Hydrocarbon treatment facilities will be constructed and maintained at workshop and wash-down facilities.

The risk of surface water contamination from discharge of AMD will be minimised through implementation of management, monitoring and contingency measures, which will be detailed in a Mineral Waste Management Plan contained in the site EMP. Management measures to be implemented include constructing bunding to reduce surface runoff flowing over exposed PAF material and material with enriched elements in the pit face; and storing waste material in appropriately designed waste dumps.

Water discharged from operational areas will meet site specific requirements, developed in accordance with the ANZECC & ARMCANZ (2000) guidelines for determining water quality trigger levels. Contamination of surface water as a result of the proposed development is unlikely to present a significant environmental risk given the management measures to be implemented.

12.2 Erosion and Sedimentation

Given that runoff in the Pilbara is typically in response to intense storms or cyclonic activity, runoff in the region naturally has a high sediment load. While sediment transfer is a natural geomorphic process, disturbed material resulting from construction and/or mining activities and areas where vegetation cover has been removed may increase the supply of sediment and hence the sediment load in runoff. The risk of erosion and sedimentation will be minimised through implementation of management, monitoring and contingency measures.

Where practical, natural runoff should be diverted around operating areas, thereby limiting the volume of water required to be treated before being released to the natural environment. Where diversion of larger drainage channels is required, the design will aim to incorporate geomorphic design principles such at a) the natural sediment transport through the channel is maintained and b) the structure itself doesn’t become a sediment source.

Runoff from disturbed areas and overburden dumps created during operations is likely to have a higher sediment load than background. Bunds, sediment basins and other drainage control structures will be used across the mine areas to control surface water runoff and thereby sediment movement. All stormwater emanating from or flowing through a disturbed area will be diverted to sediment basins prior to discharge.

Erosion and sedimentation as a result of the proposed development is unlikely to present a significant environmental risk given the management measures to be implemented.

Conclusions

This hydrology and hydraulics study has identified key surface water risks for all study deposits based on hydraulic flood modelling, field observations and monitoring of creek flow. Flood risks are described below for each of the deposits and are no greater than Class II, although surface water management will be required at all deposits for effective management of stormwater.

Western Hill: Haul road crossings of Turee Creek East should be designed to prevent loss of production during flow events and maintain conveyance of surface water to Karijini National Park. Dump designs may need to incorporate a stand-off from the park boundary and minimise interference with overland flow paths. No flood protection is required for minor catchments reporting to the pits.

Deposit F north: No flood protection is required for the current pit design, but haul alignments should consider local terrain and avoid incised channels where possible. If Deposit F extends further to the west, then small diversion drains should be considered to direct flow around the pits.

Deposit H: Flood mitigation is recommended for the western pit at Deposit H, with strategic dumping or diversion potential management options for the catchment to the west.

Deposit J: Both eastern and western pits will require flood protection in the form of stormwater diversions and revised dump footprints. The proposed haul route alignments cross steep terrain and intercept multiple incised gullies. These are at risk of regular wash out without appropriate drainage and culverts. Mine infrastructure should avoid the creek at the far western extent of Deposit J if possible.

Mount Ella: With the current pit and dump footprints there is no risk of flooding to mine infrastructure. Minor drainage works will be required along the haul route adjacent to the new pits to prevent ponding of water.

Modelling of rare to extreme flood events was used to assess **closure risks** related to surface water and landform stability. The Beyond 2020 deposits are away from the floodplain of major creeks in the study catchment and do not introduce additional significant (Class III or IV) closure risks into the West Angelas mine development.

Sensitive receptors have been identified across the study area and potential impacts to the surface water regime of the sites have been evaluated. Surface flows towards Karijini national park will be reduced as a result of development within the Turee Creek East catchment, mostly at Western Hill. This results from the reduction in catchment area caused by pits and dumps. The current reduction in the Turee Creek East catchment upstream of the KNP boundary area is 26%, and this will increase to 29%. Surface flows to the ephemeral pool and the separate potential GDE area will be reduced as a result of development at Deposit H. Known significant heritage sites west of Western Hill (Guburingu) and at Deposit D (Gajiringu) should not experience appreciable changes in the surface flow regime. The mulga community south of Deposit J is unlikely to be impacted by changes in flow regime caused by development of the deposit as the community is located on flat sheet flow areas away from the footprint and proposed diversions. No changes in the surface flow regime of the West Angelas Cracking Clay PEC-P1 community is expected from the Beyond 2020 development.

The assessment presented here is based on the best available information at the time of completion, but it should be recognised that only Order of Magnitude or Conceptual level information was available in relation to pit and dump designs and locations, and haul routes. As such engineering designs were not available for diversions, roads, creek crossings, culverts and stormwater drainage, and other project infrastructure. Where possible these features have been represented in hydraulic modelling based on likely requirements for management of surface water in the project development, and a Preliminary Engineering Study will be completed as part of the Beyond 2020 PFS.

References

ANZECC & ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia.

Bureau of Meteorology, 2003a, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method, Bureau of Meteorology*, Melbourne, Australia, (http://www.bom.gov.au/water/designRainfalls/pmp/gsdm_document.shtml).

Bureau of Meteorology, 2003b, *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method,* Hydrometeorological Advisory Service, Bureau of Meteorology, November 2003.

Clapp, R and Hornberger, G, 1978 'Empirical Equations for Some Soil Hydraulic Properties', *Water Resources Research*, 14(4): 601 – 604.

Cosby, B, Hornberger, Clapp, R, Ginn, T, 1984, 'Statistical Exploration of the Relationships of Soil Moisture Characteristics to the Physical Properties of Soils', *Water Resources Research*, 20(6): 682 – 690.

Engineers Australia, 2012, *ARR Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains, Stage 1 & 2 Report, P15/S1/009*, November, Barton, ACT, pp. 11- 184 – 11-202.

Environment and Science, 2020, *SILO climate database*, accessed July 2020, Queensland Government, licensed under creative commons attribution 3.0.

Flavell, D. 2012, Design flood estimation in Western Australia, *Australian Journal of Water Resources*, Vol.16, No. 1, pp.1-20, http://dx.doi.org/10.7158/W11-865.2012.16.1.

Flavell, D.J. and Belstead, B.S. 1986, *Losses for design flood estimation in Western Australia*, Hydrology and Water Resources Symposium.

Flavell, D.J., Belstead, B.S., Chivers, B. and Walker, M.C. (1983), *Runoff routing model parameters for catchments in Western Australia*, Hydrology and Water Resources Symposium, Institute of Engineers, Hobart.

Hill, P.I., Graszkiewicz, Z., Taylor, M., Nathan, R.J. 2014, *ARR Revision Project 6 Loss models for catchment simulation. Stage 4 Analysis of rural catchments*, May 2014.

Jacobs 2017, *West Angelas Deposit C & D DES hydrology and hydraulics study*, Jacobs prepared for RTIO, December 2017.

Laurenson E.M., Mein R. G. and Nathan R. J., 2007, *RORB Version 6: Runoff Routing Program User Manual*, Monash University Department of Civil Engineering, Melbourne

Laurenson, E.M. and Kuczera, G. A. 1999, Annual exceedance probability of probable maximum precipitation, *Australian Journal of Water Resources*, 3(2), 167-176.

McKenzie, N, Jacquier, L, Ashton, L and Cresswell, H, 2000, *Estimation of Soil Properties Using the Atlas of Australian Soils*, Technical Report 1 1/00, CSIRO Land and Water, Canberra.

Northcote, K, Beckmann, G, Bettenay, E, Churchward, H, Van Dijk, D, Dimmock, G, Hubble, G, Isbell, R, McArthur, W, Murtha, G, Nicolls, K, Paton, T, Thompson, C, Webb, A, and Wright M, 1960-1968*. Atlas of Australian Soils, Sheets 1 to 10.* With explanatory data (CSIRO Aust. and Melbourne University Press: Melbourne).

Pearcey, M, Pettett, S, Cheng, S, Knoesen, D, 2014 *Estimation of RORB Kc Parameter for Ungauged Catchments in the Pilbara Region of Western Australia*, conference paper presented at Hydrology and Water Resources Symposium 2014, Perth, Western Australia.

Rahman A, Haddad K, Kuczera G. 2015a, *Features of regional flood frequency estimation (RFFE) model in Australian rainfall and runoff*, Partnering with industry and the community for innovation and impact through modelling: proceedings of the 21st international congress on modelling and simulation (MODSIM2015), 2207–2213.

RTIO 2011, *Pilbara Surface Water Management Strategy*, Report RTIO-PDE-005914, RTIO March 2011

RTIO 2013, *West Angelas Deposit B feasibility study*, RTIO, October 2013.

RTIO 2015, *West Angelas Deposit F feasibility study*, RTIO, December 2015.

RTIO 2018, *West Angelas Deposits C & D feasibility study*, RTIO, April 2018.

RTIO-PDE-0146318, *KNP Site Walkover Findings Memo*, RTIO, October 2016.

RTIO-PDE-0162191, *Site Inspection and surface water monitoring at Guburingu heritage area Western Hill*, RTIO, August 2018.

RTIO-PDE-0175749, *Discharge extent modelling of minor creeks*, RTIO, March 2019.

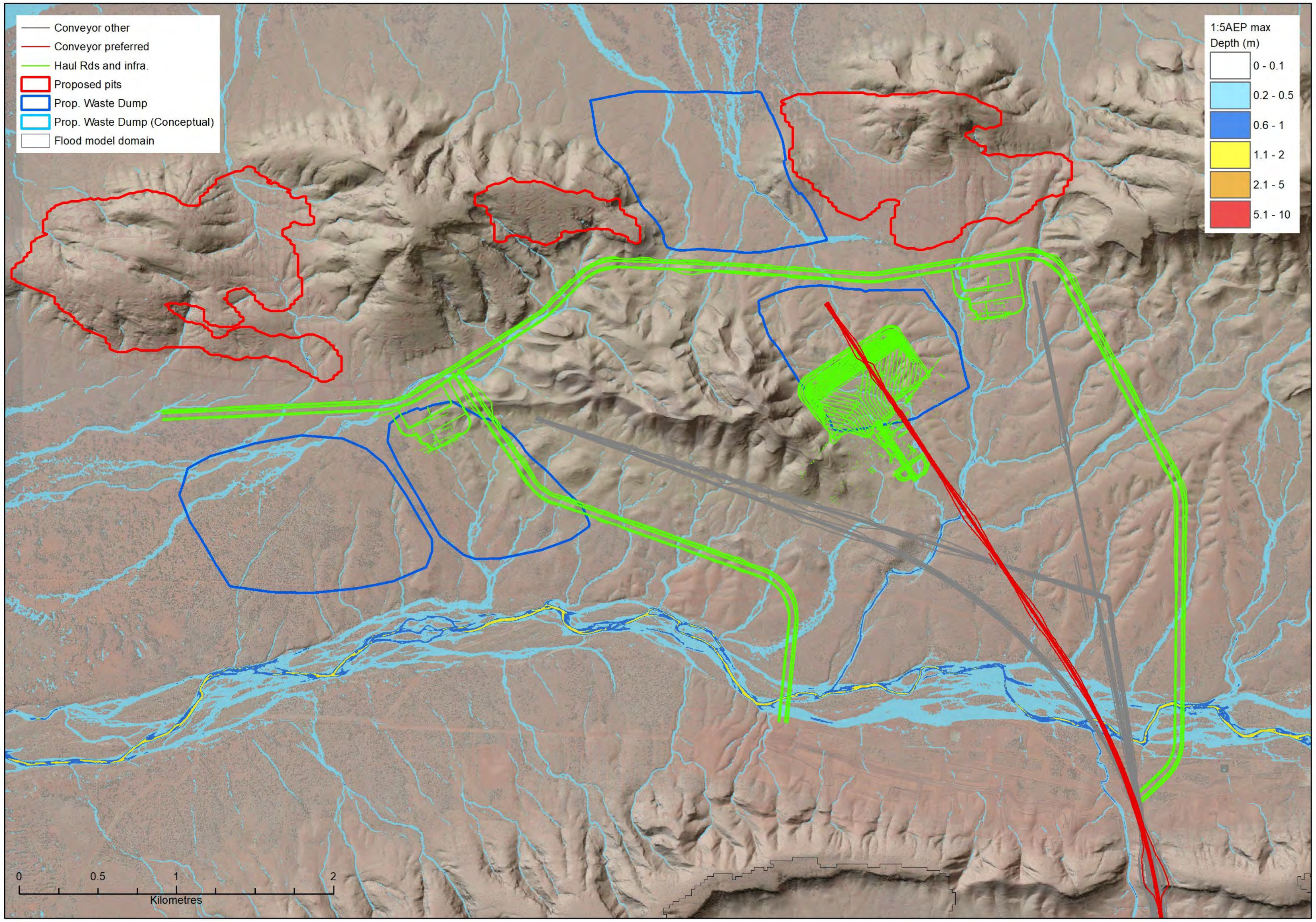
van Gool, D, Tille, P, Moore, G, 2005, *Land evaluation standards for land resource mapping*, Resource Management Technical Report 298, Department of Agriculture Western Australia.

Appendices

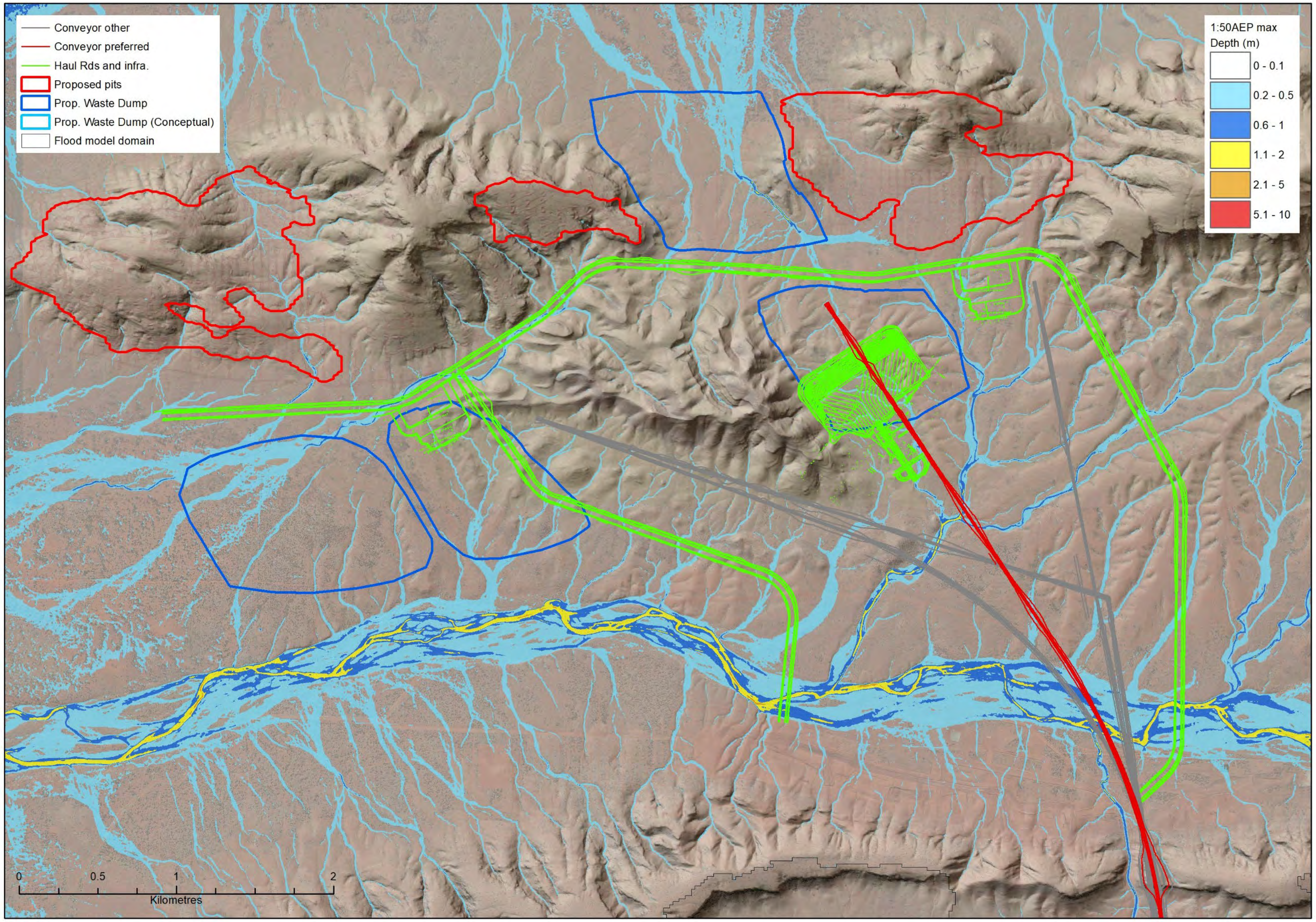
Appendix A – Point rainfall IFD table for West Angelas

	Duration (hrs)													
AEP	**0.5**	**1**	**2**	**3**	**6**	**12**	**24**	**36**	**48**	**72**	**96**	**120**	**144**	**168**
63.20%	16	20	24	27	33	40	50	56	60	66	70	72	74	76
50%	18	23	28	32	39	48	60	67	72	79	83	86	89	90
20%	26	33	41	46	58	74	94	107	115	125	131	135	138	140
10%	32	40	50	57	72	94	138	149	161	168	172	172	175	178
5%	37	47	59	67	87	116	173	186	201	208	213	213	215	218
2%	44	56	71	82	109	146	218	233	250	257	261	261	264	266
1%	49	63	80	94	126	171	255	272	288	295	298	298	301	304
1 in 200	56	72	91	106	142	193	291	310	328	335	339	339	341	343
1 in 500	66	85	108	126	169	230	346	367	384	390	393	393	394	396
1 in 1000	75	96	121	142	191	260	390	412	429	435	439	439	443	448
1 in 2000	84	107	136	159	214	292	436	459	476	481	485	485	489	495
1 in 5000	99	127	162	190	257	352	462	527	554	572	576	579		
1 in 10000	112	144	184	216	294	402	526	601	632	653	657	661		
1 in 20000	127	164	210	247	338	466	611	699	732	752	754	757		
PMP	333	485	618	691	855	915	1034	1272	1492	1883	2106	2218		

Appendix B – TUFLOW flood modelling results maximum depth 1:5 AEP, 1:50AEP, 1:100AEP for pre- and post-development scenarios



Western Hill pre-development maximum flood depth mapping 1:5AEP



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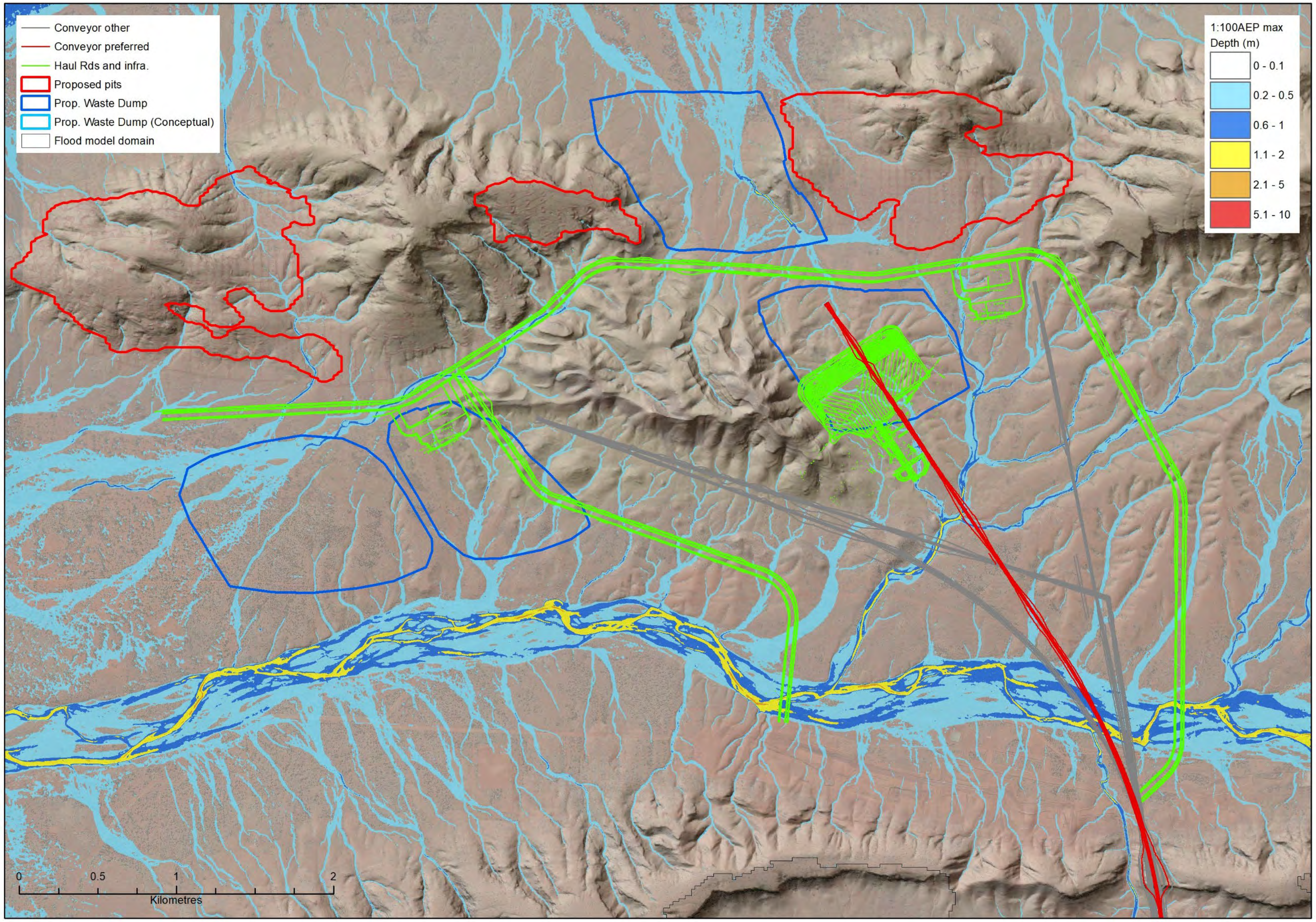
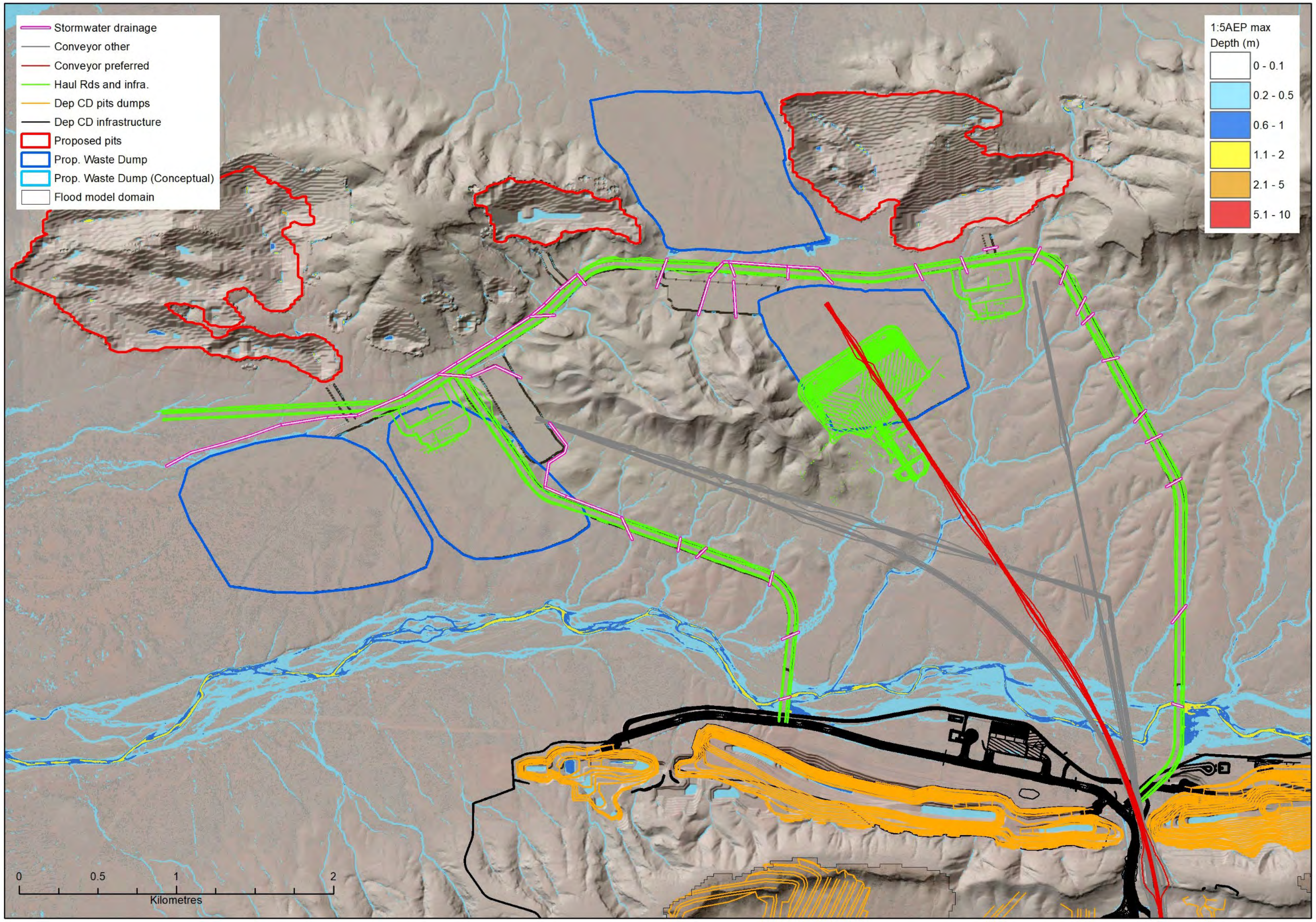
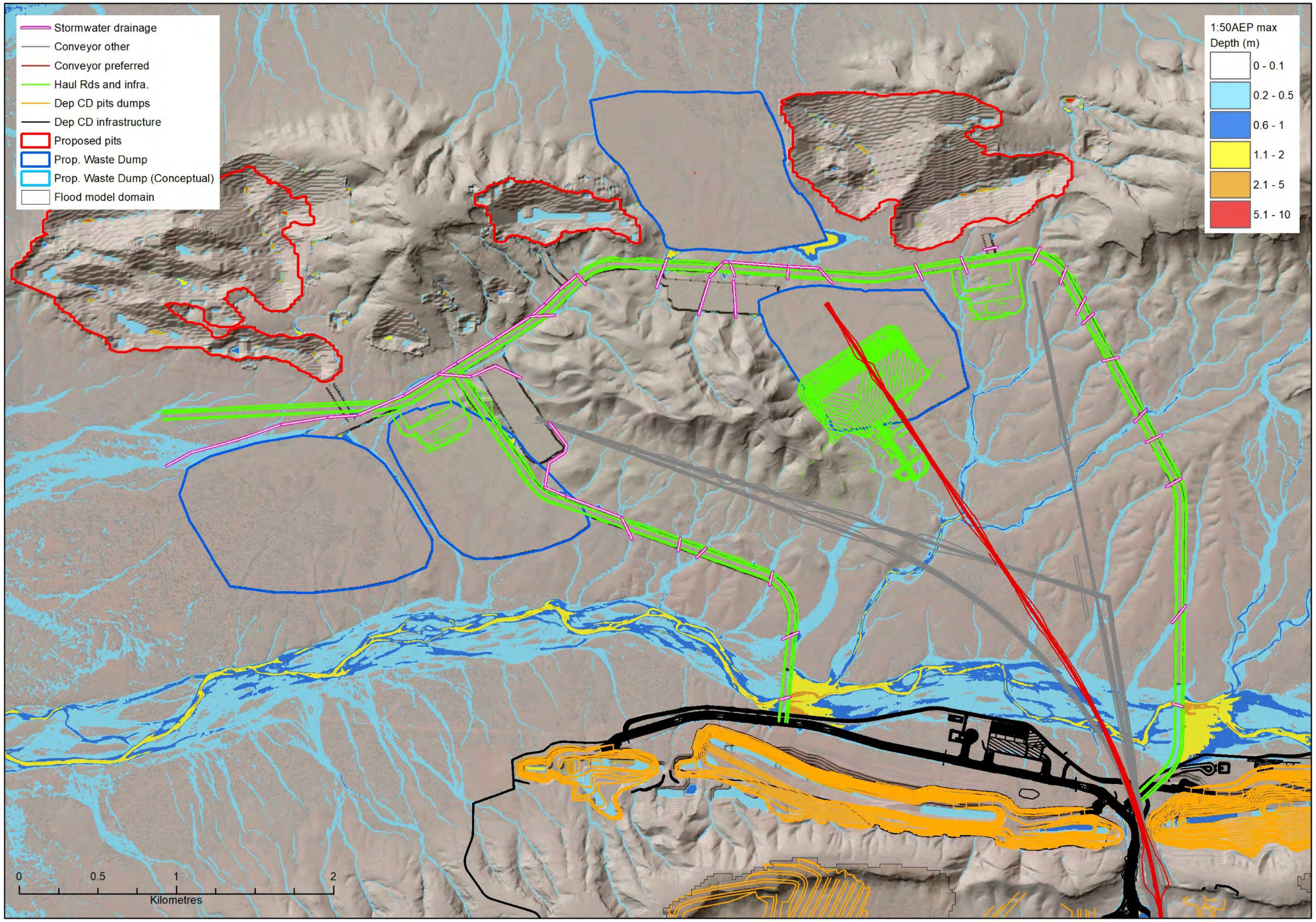


Western Hill pre-development maximum flood depth mapping 1:100AEP



Western Hill post-development maximum flood depth mapping 1:5AEP



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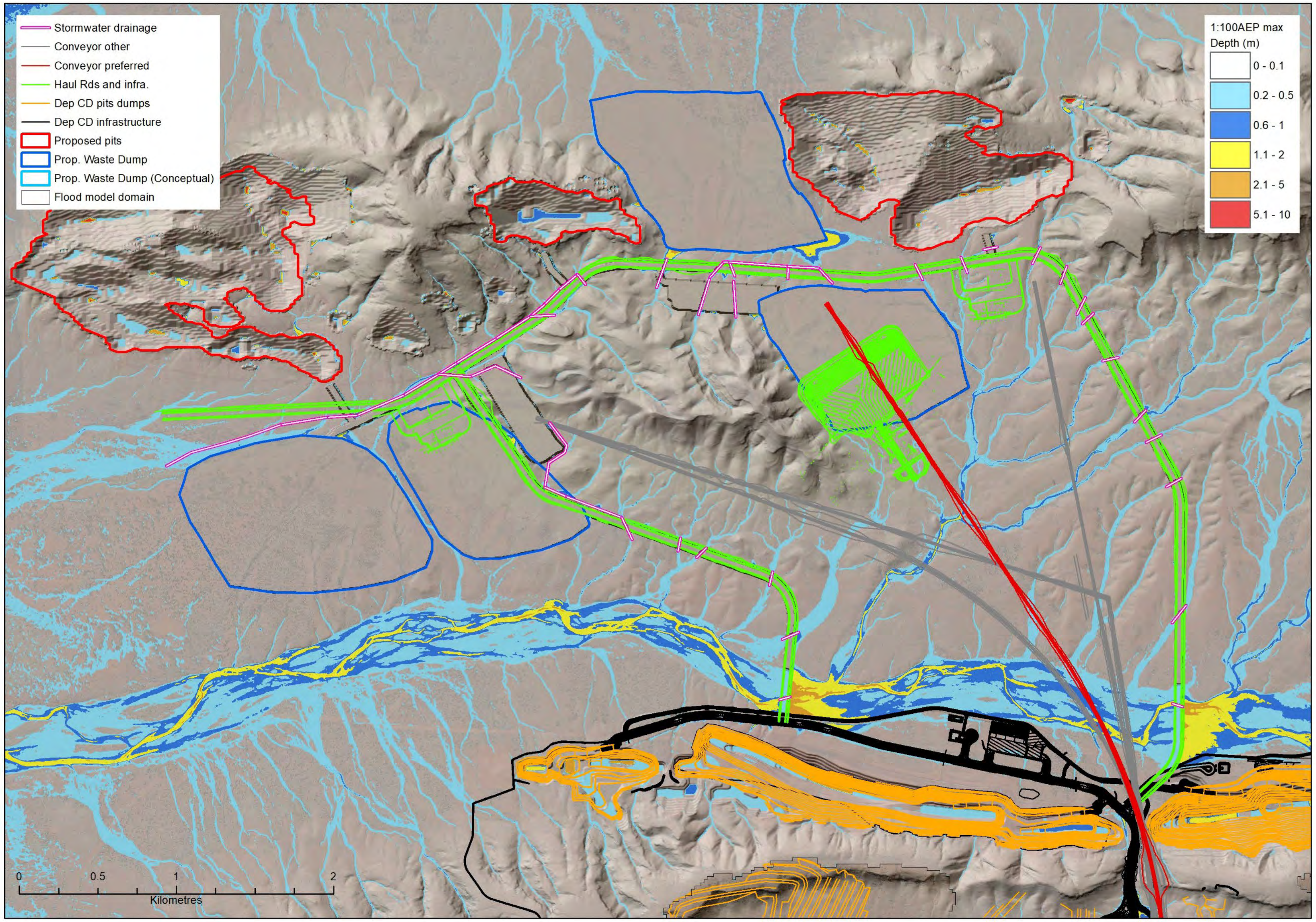

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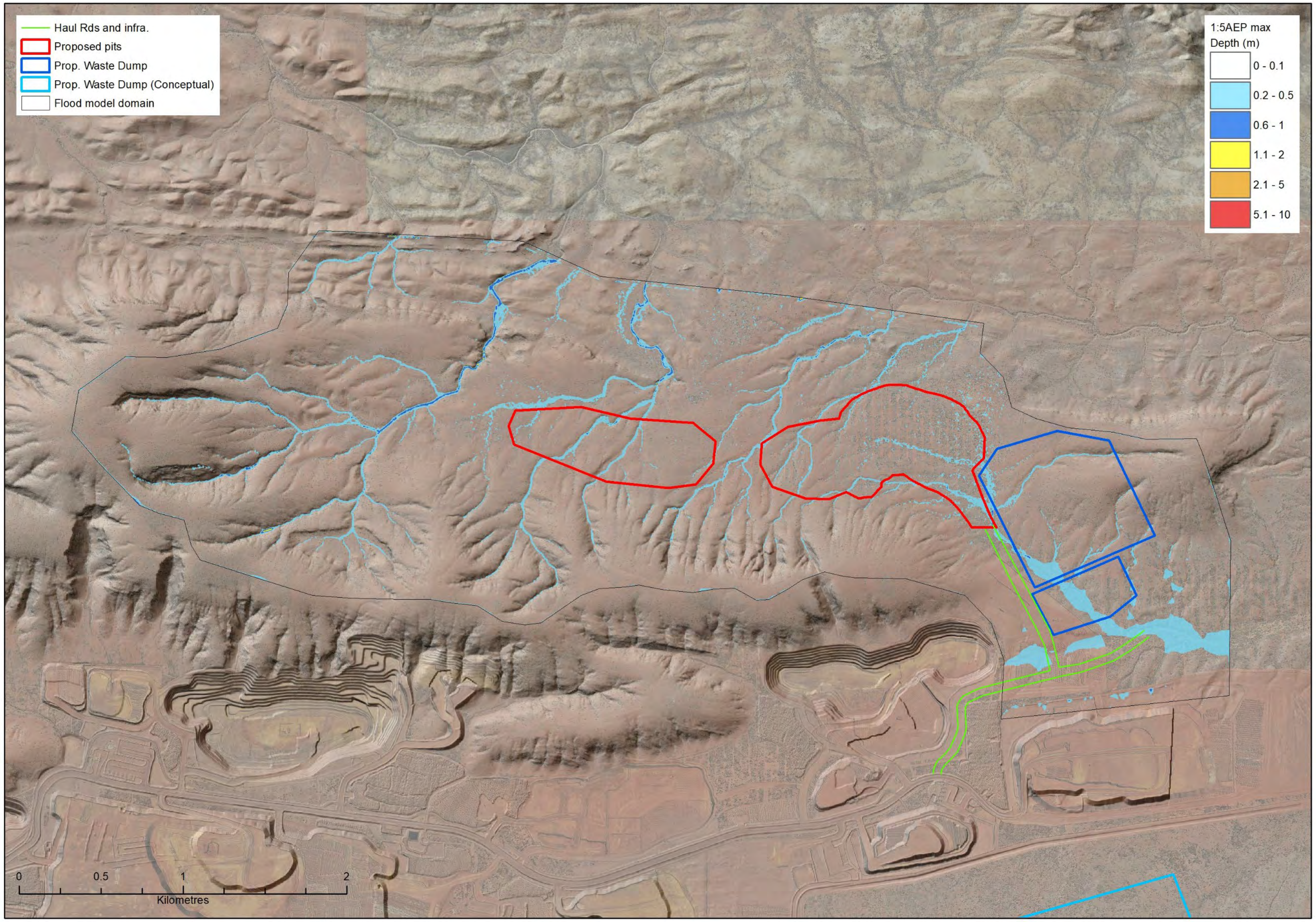
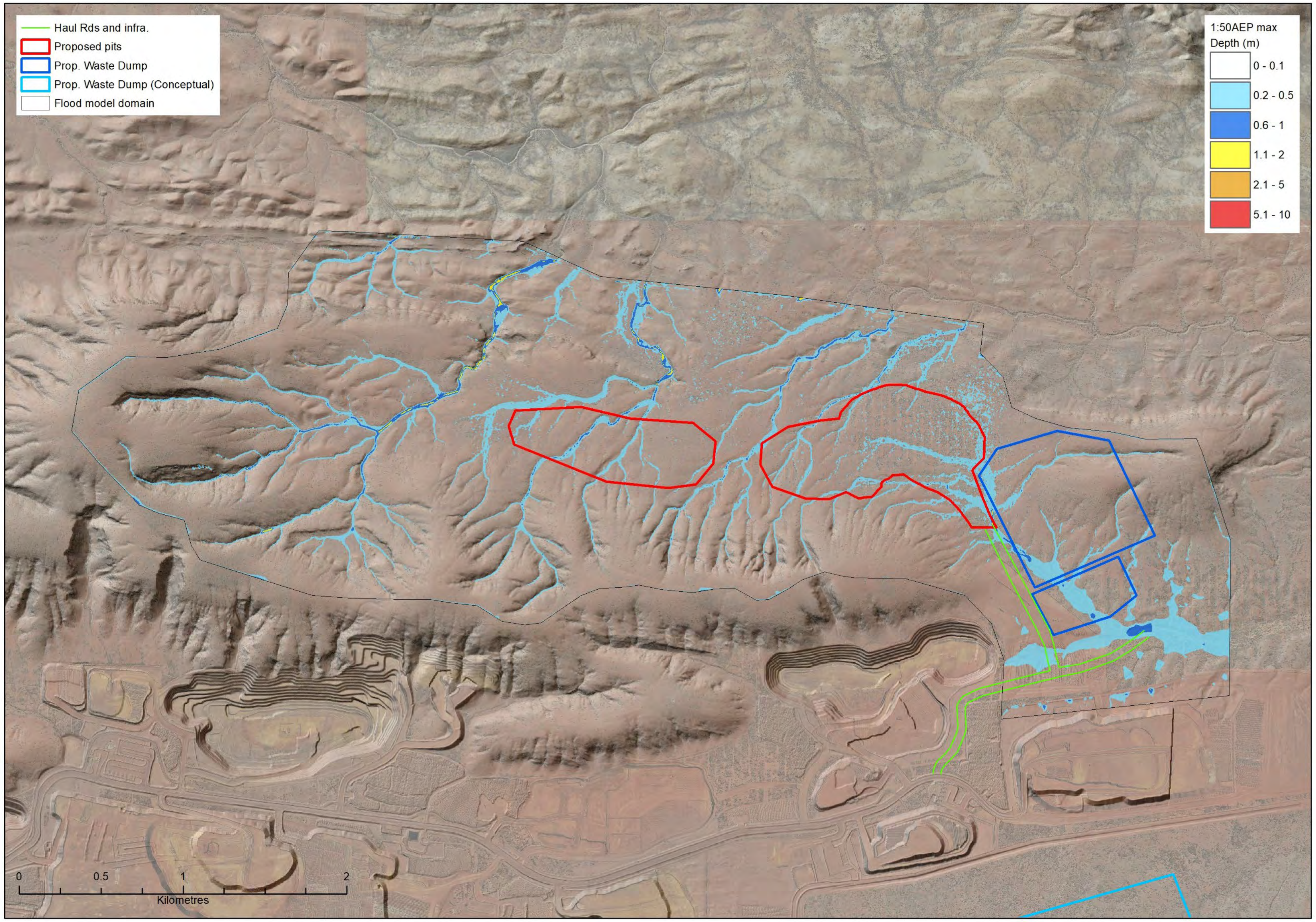


Deposit F north pre-development maximum flood depth mapping 1:5AEP



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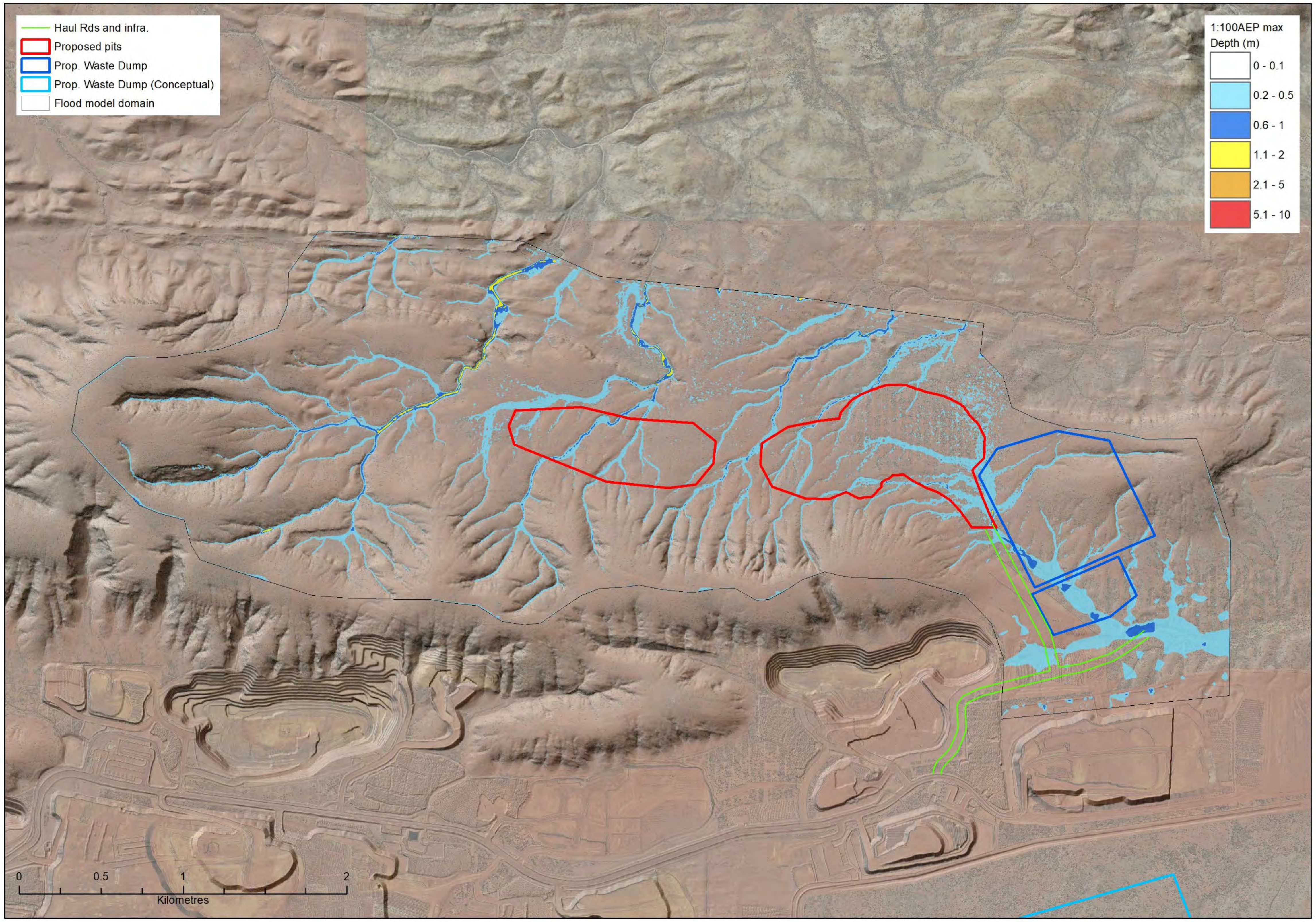

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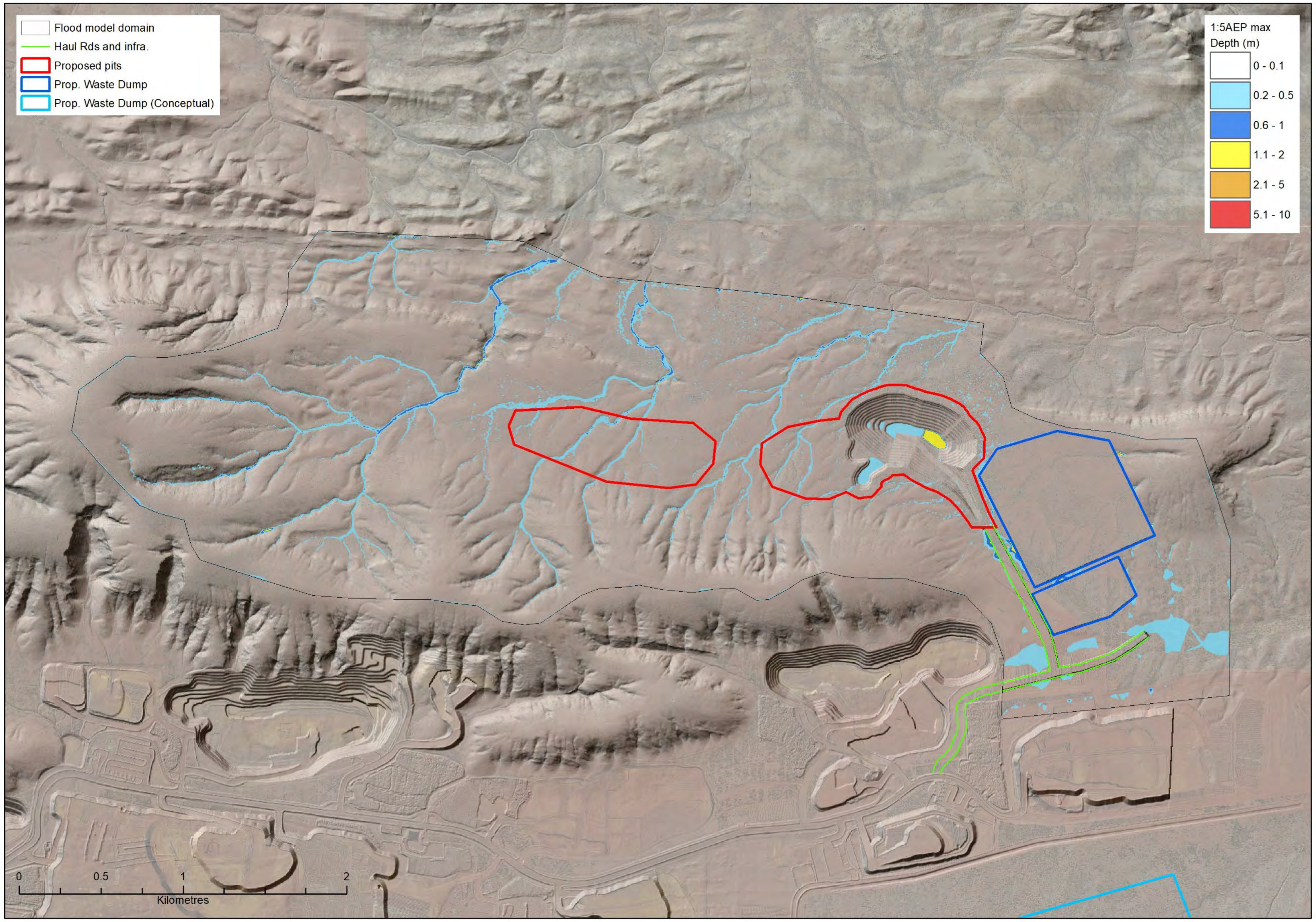

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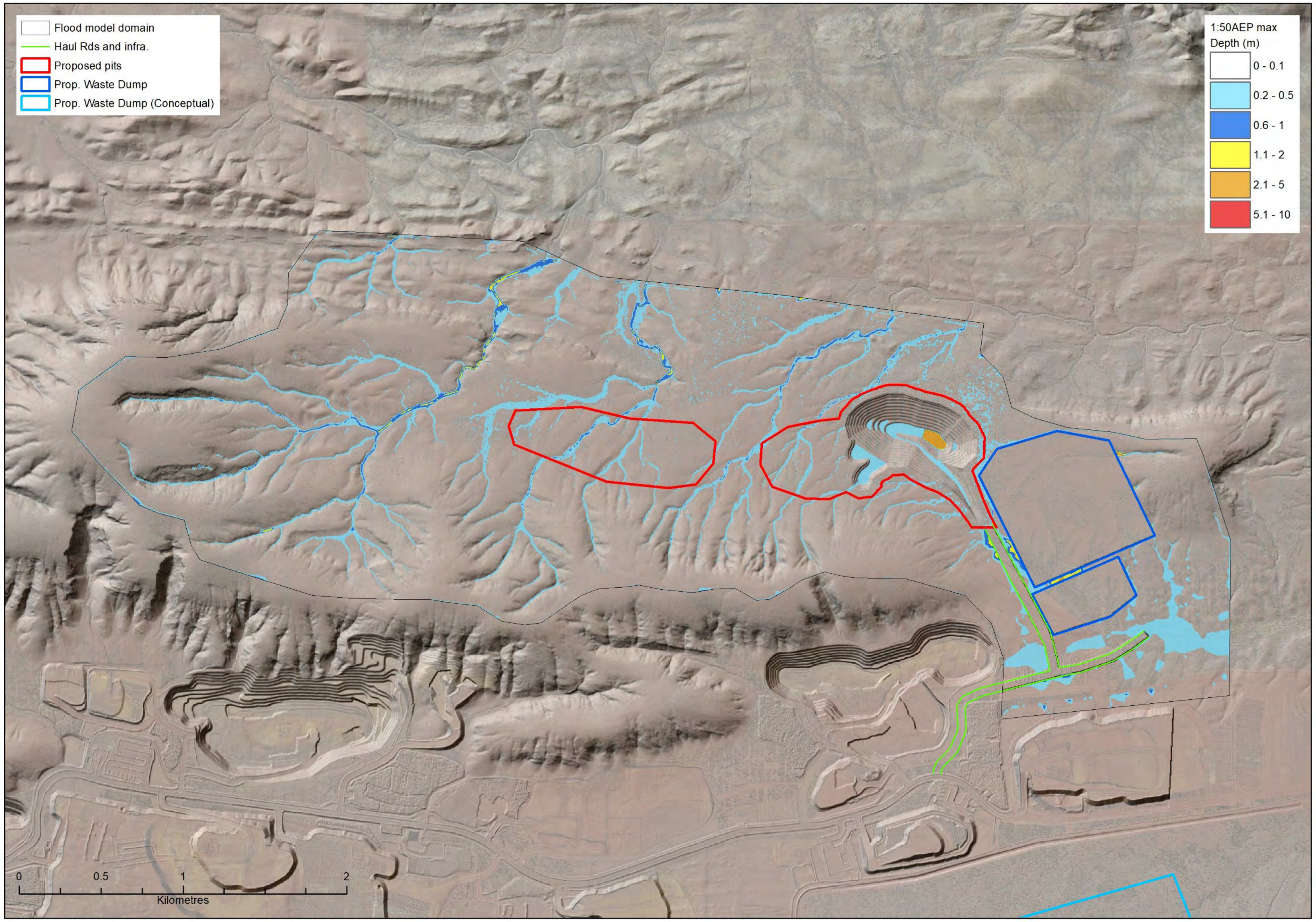

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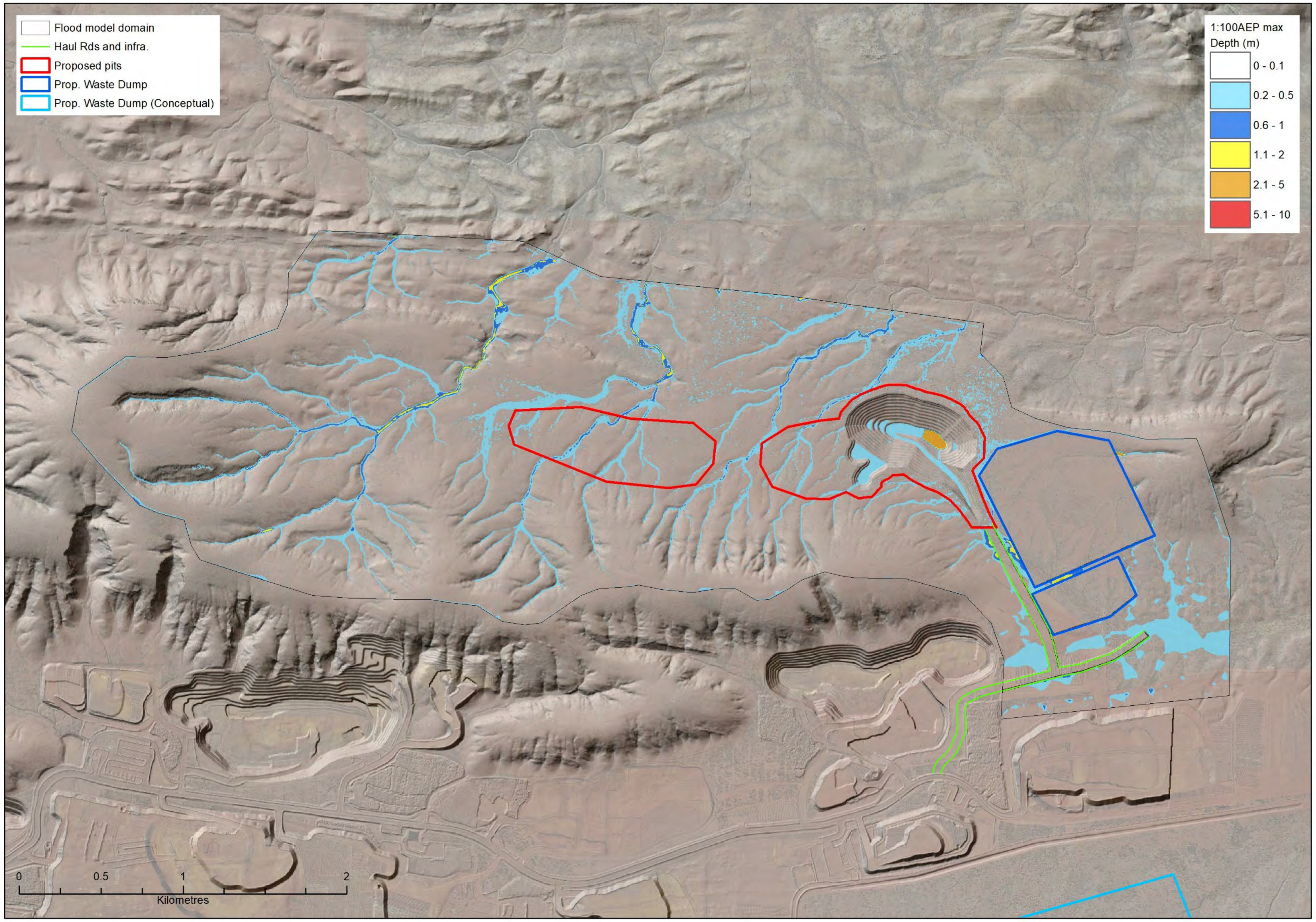

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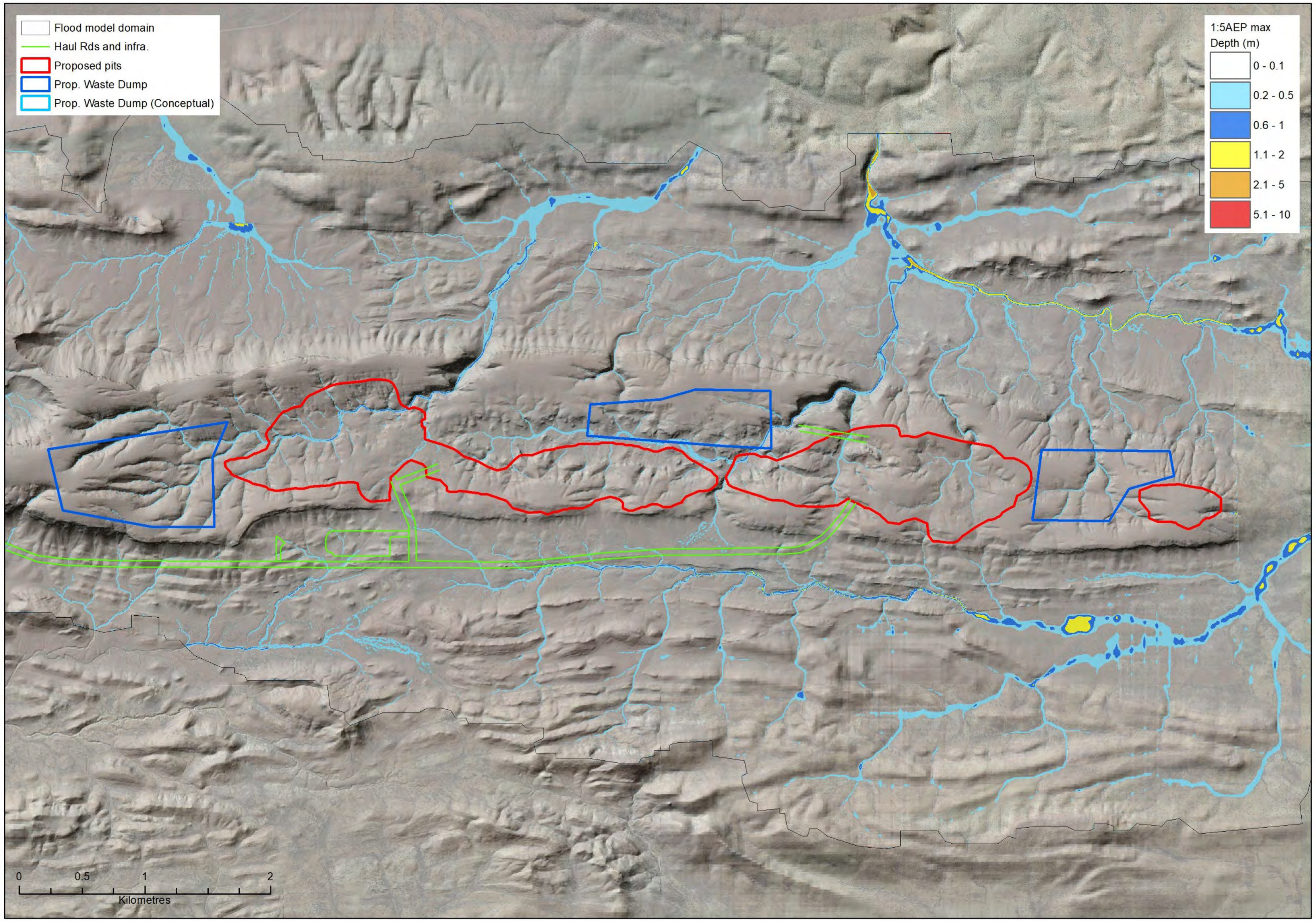

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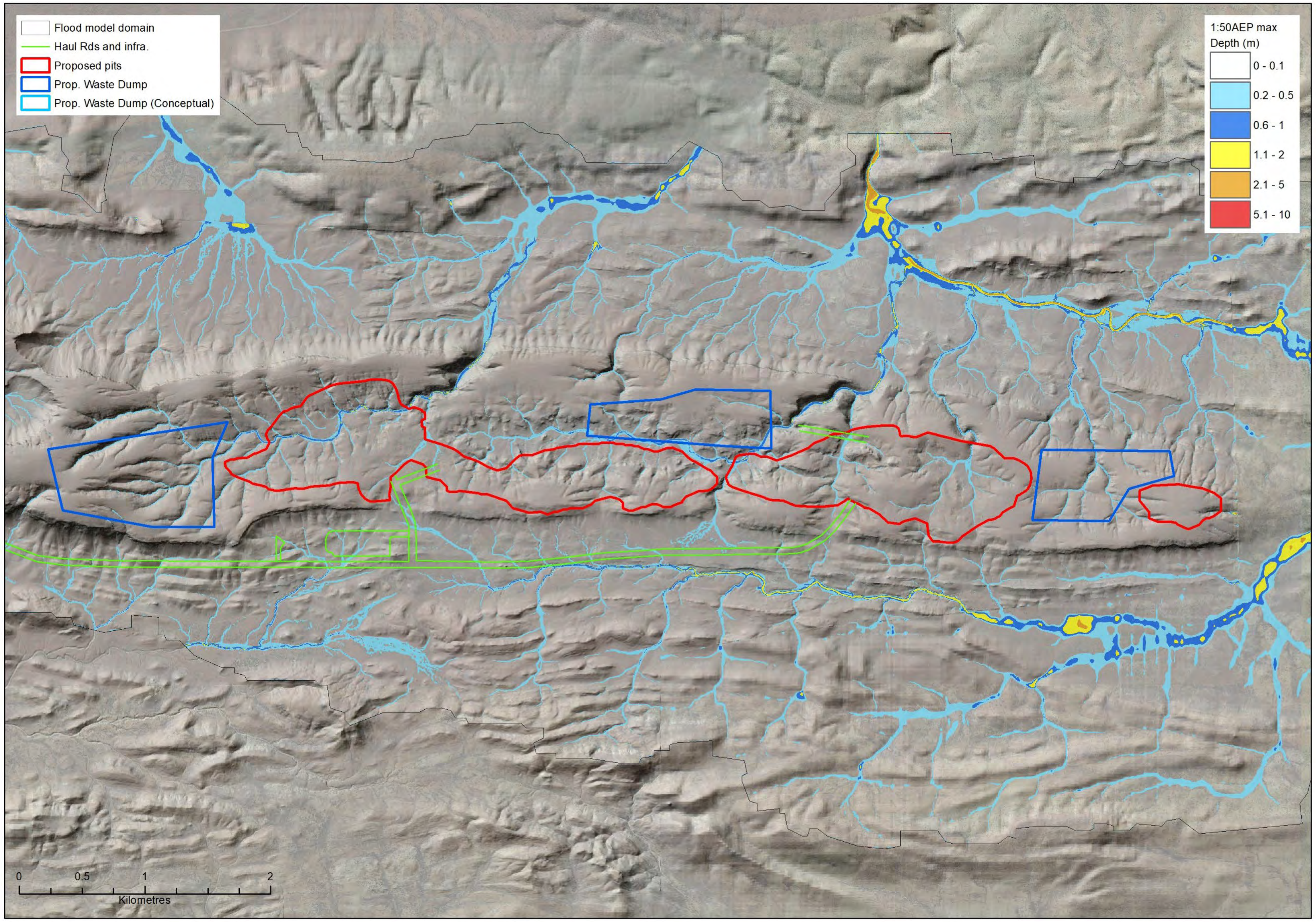

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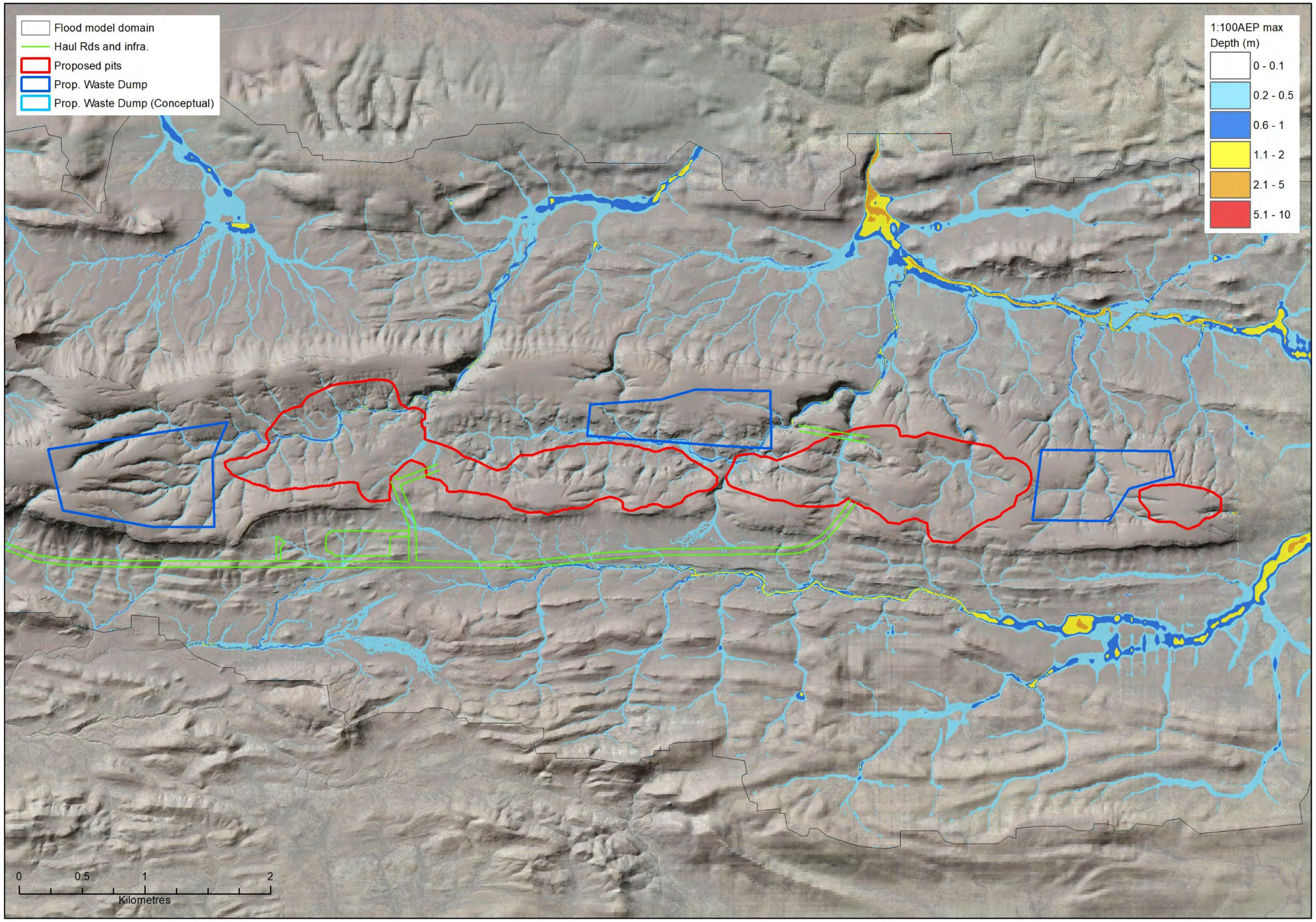

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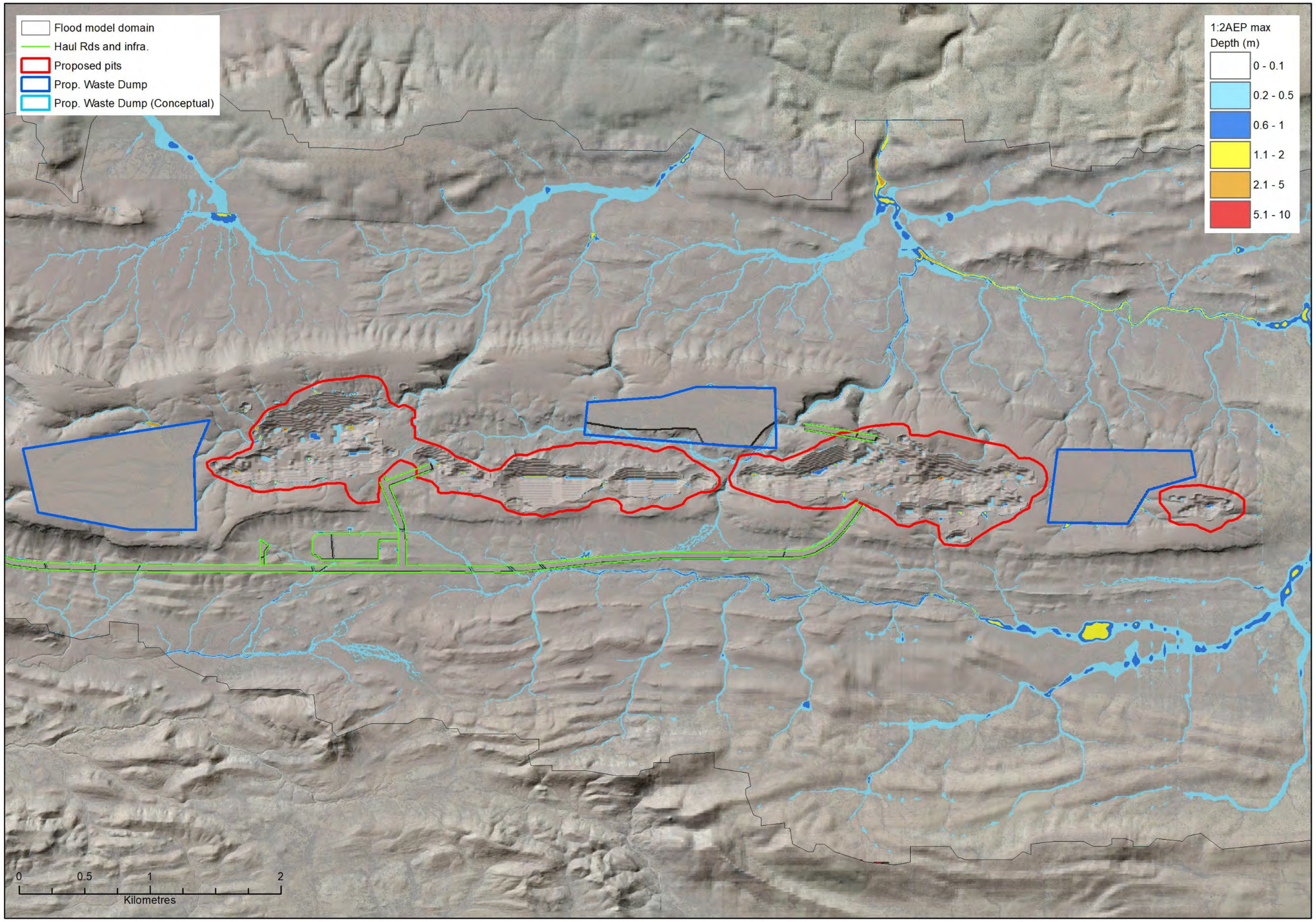

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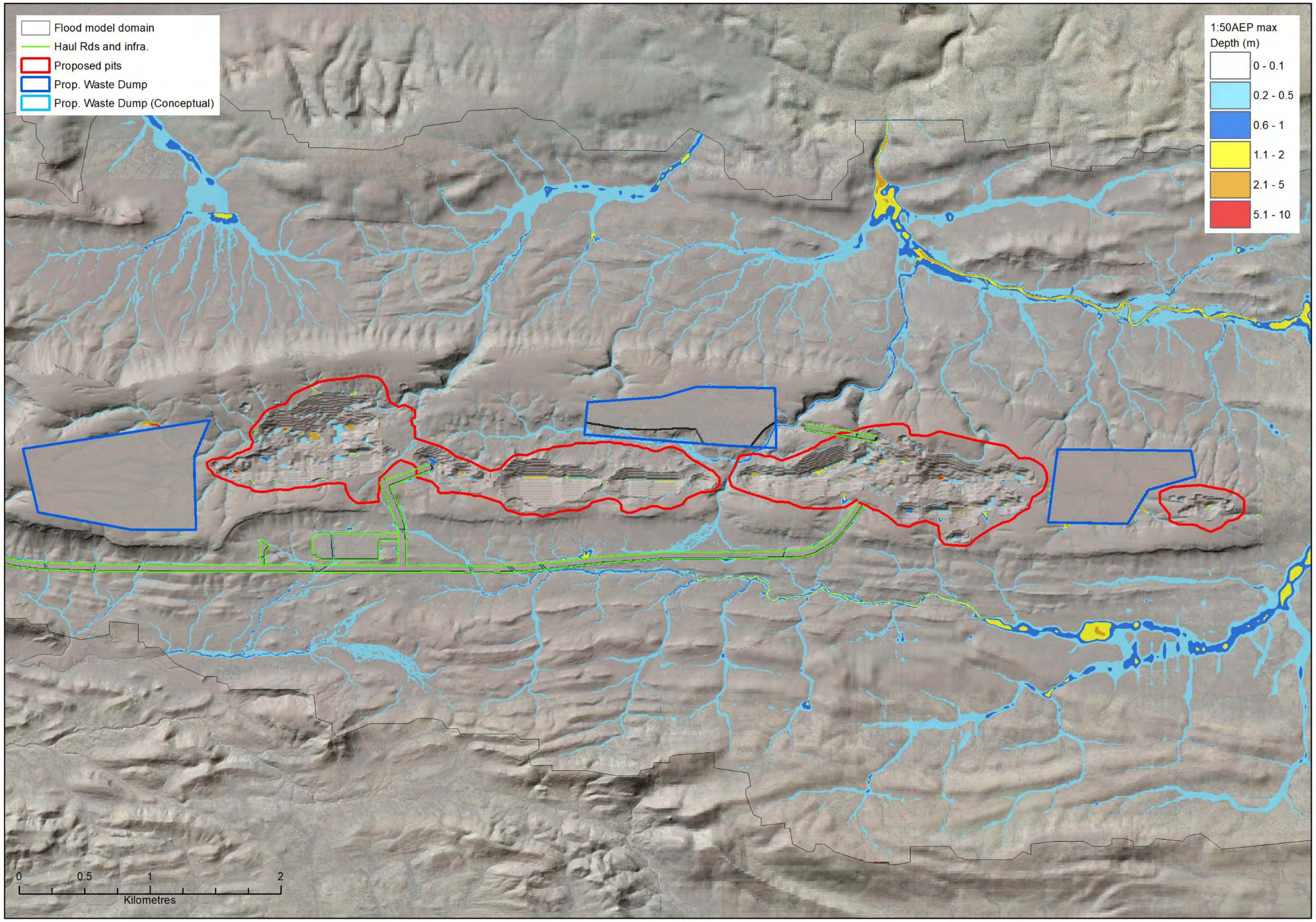

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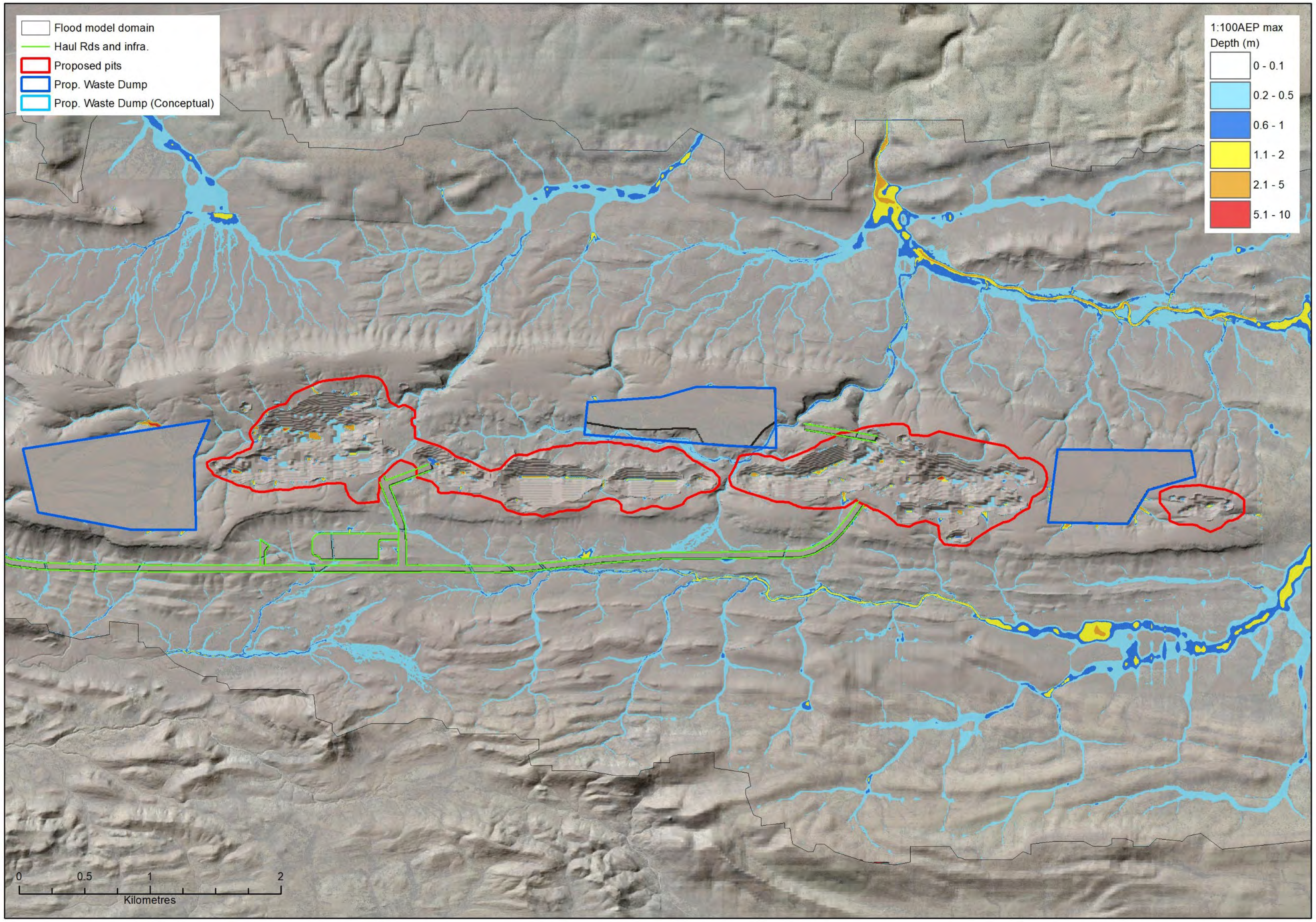

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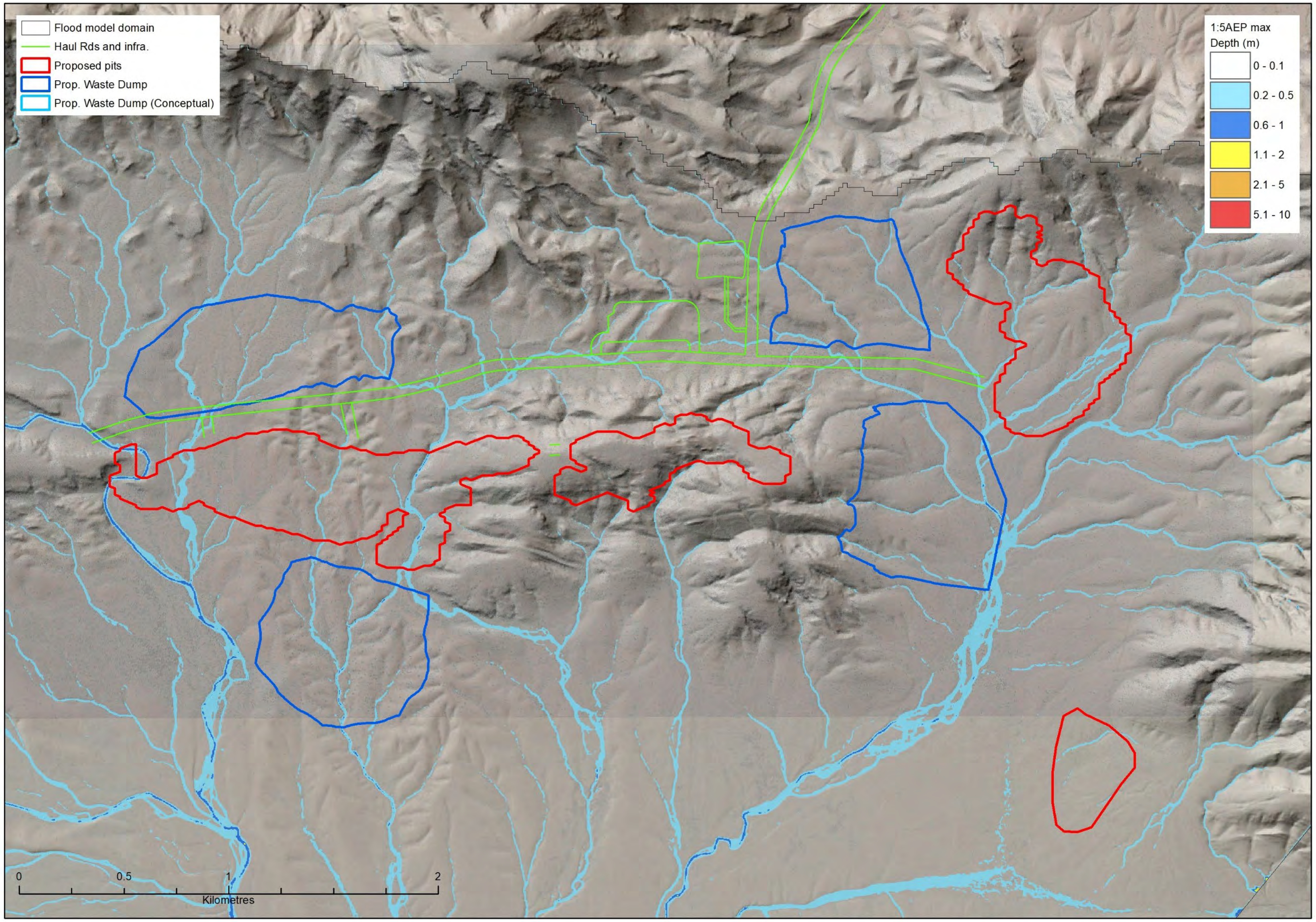

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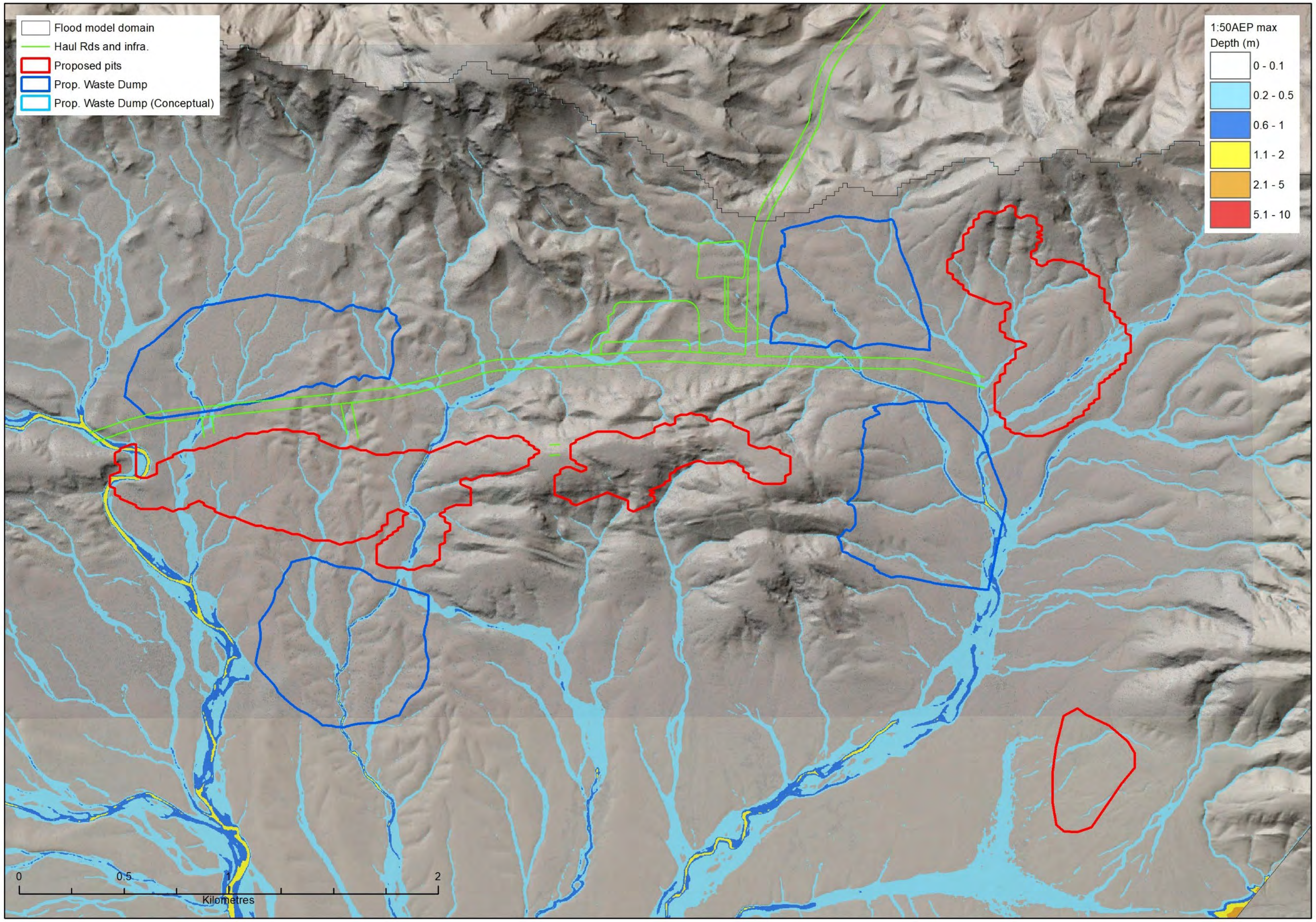

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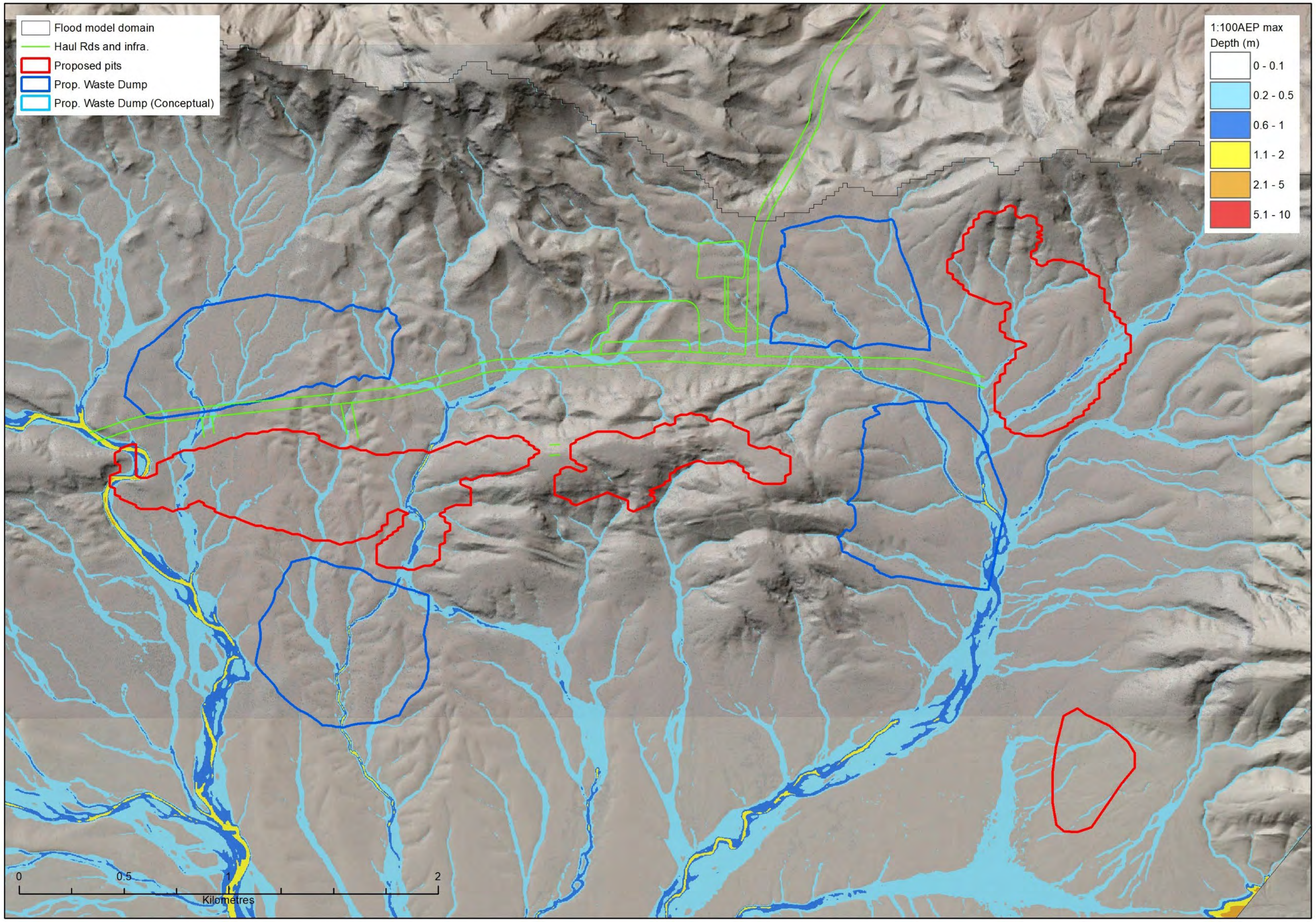

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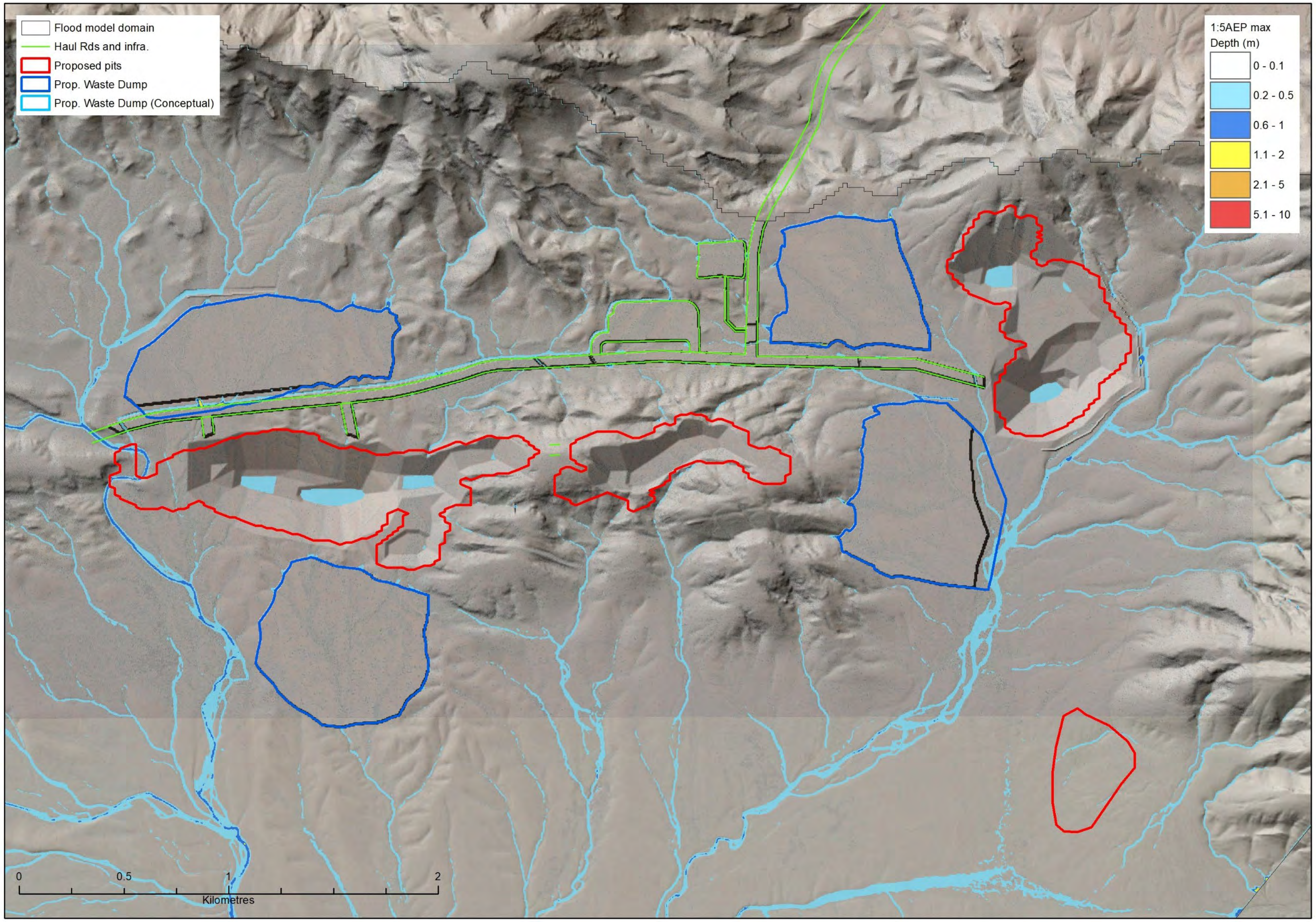
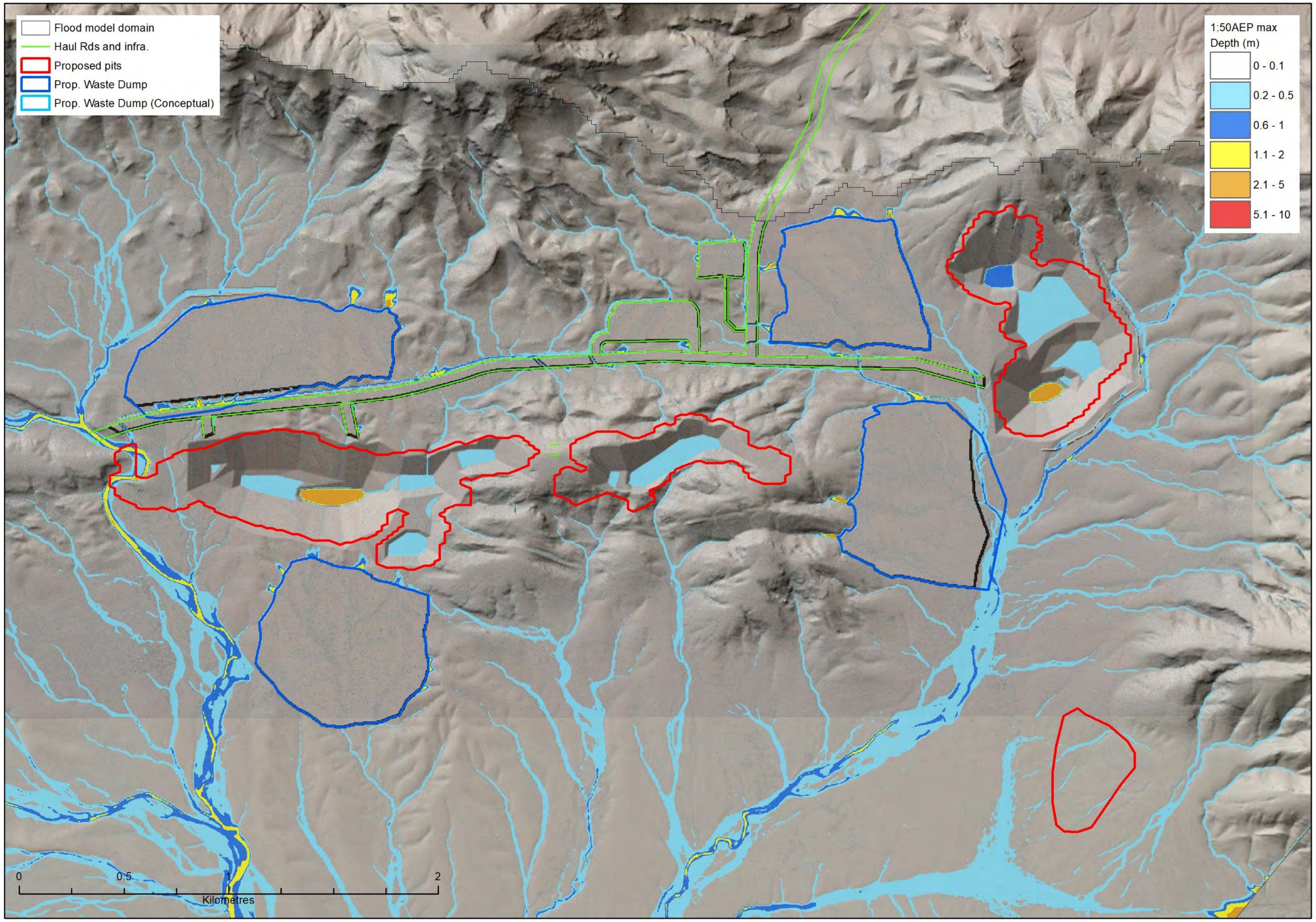


Deposit J north post-development maximum flood depth mapping 1:5AEP



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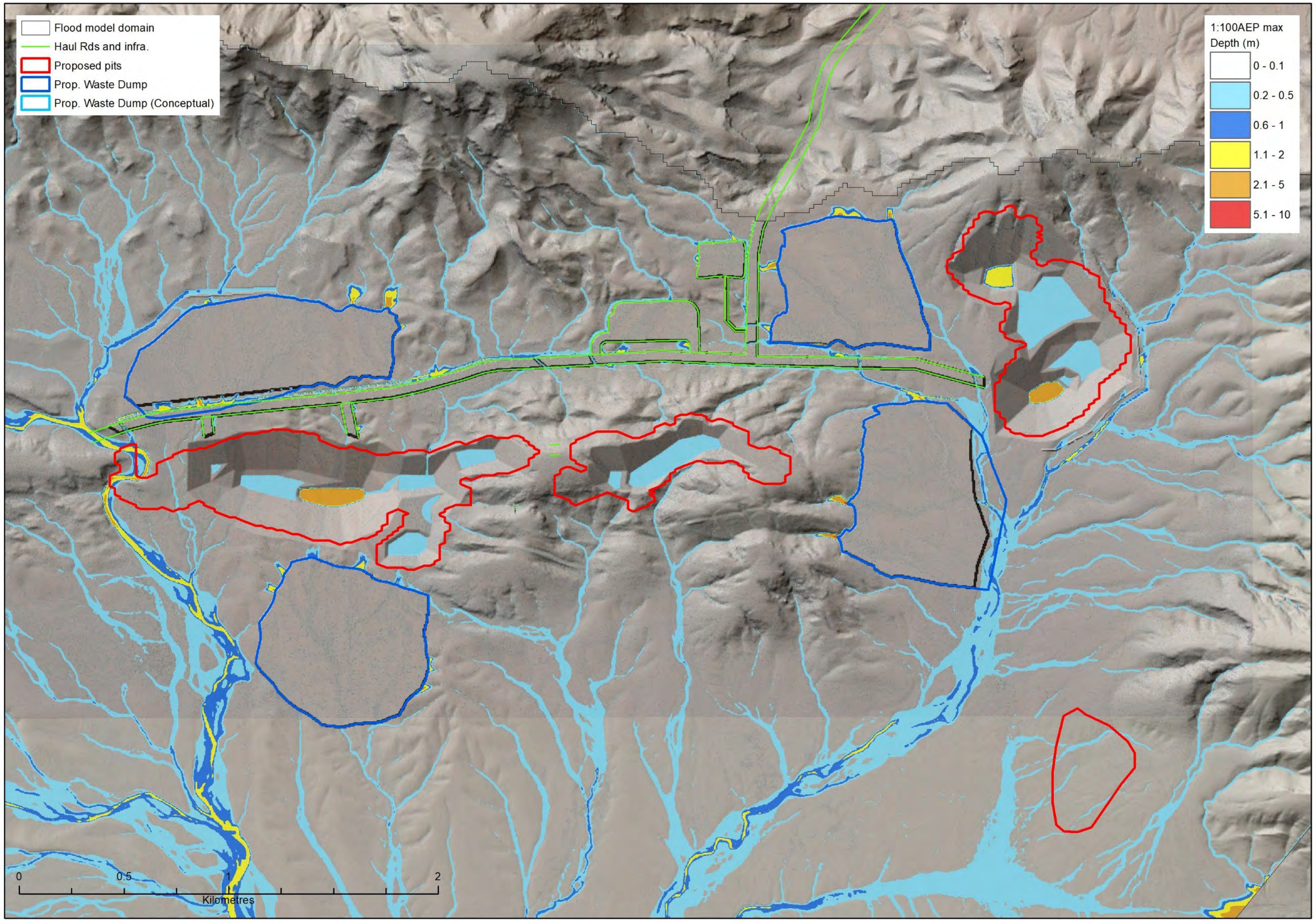

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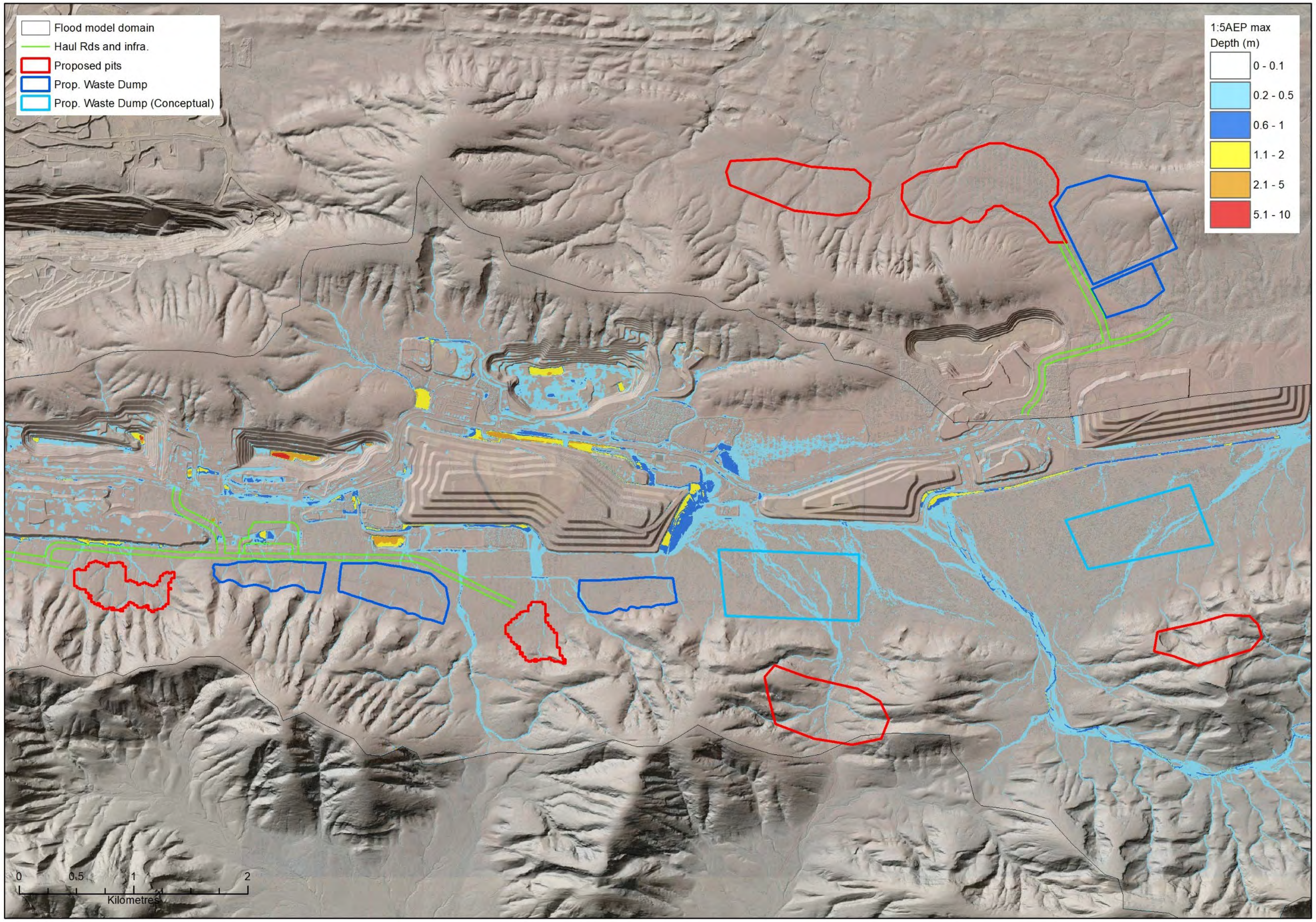
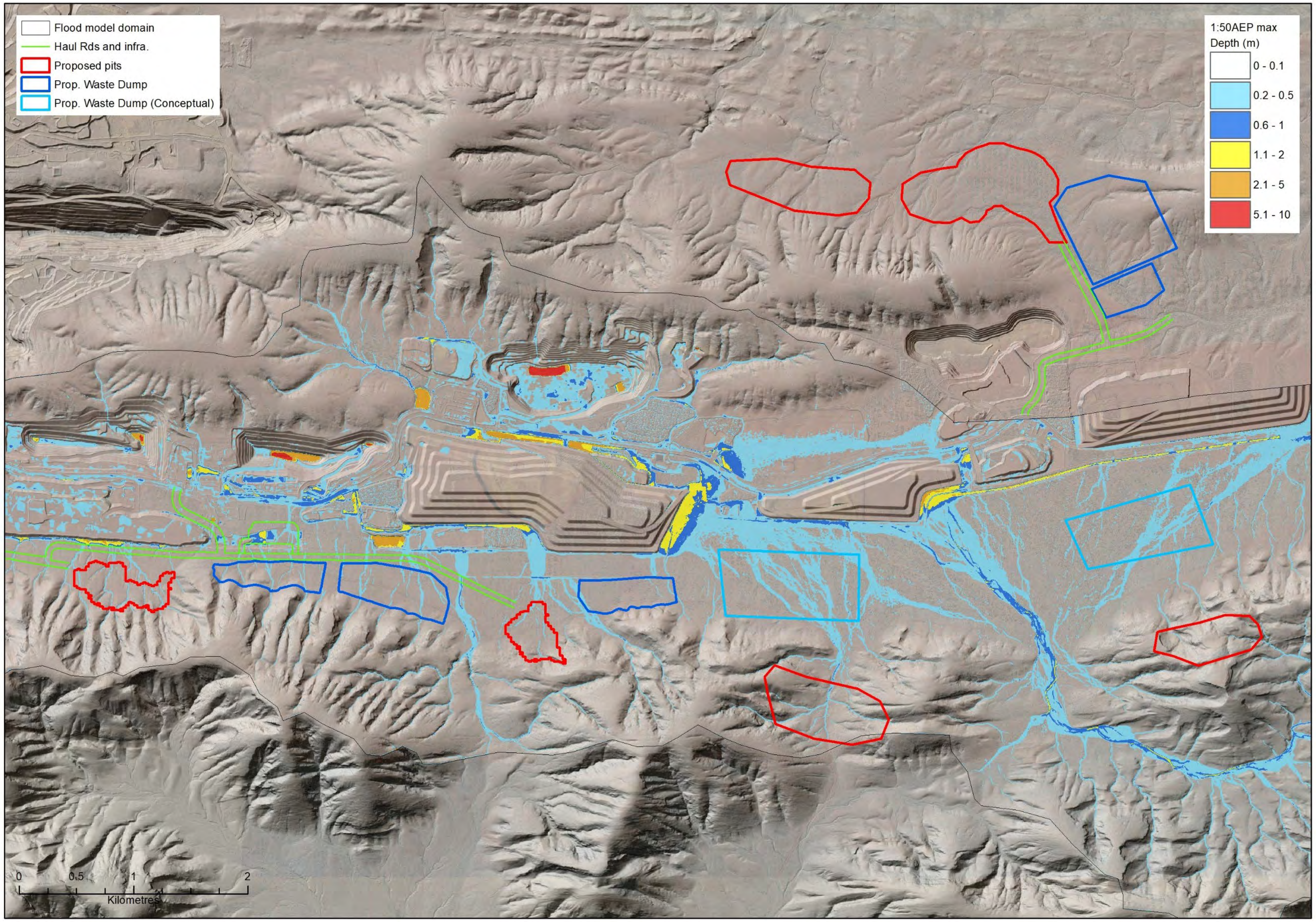


Mount Ella East pre-development maximum flood depth mapping 1:5AEP



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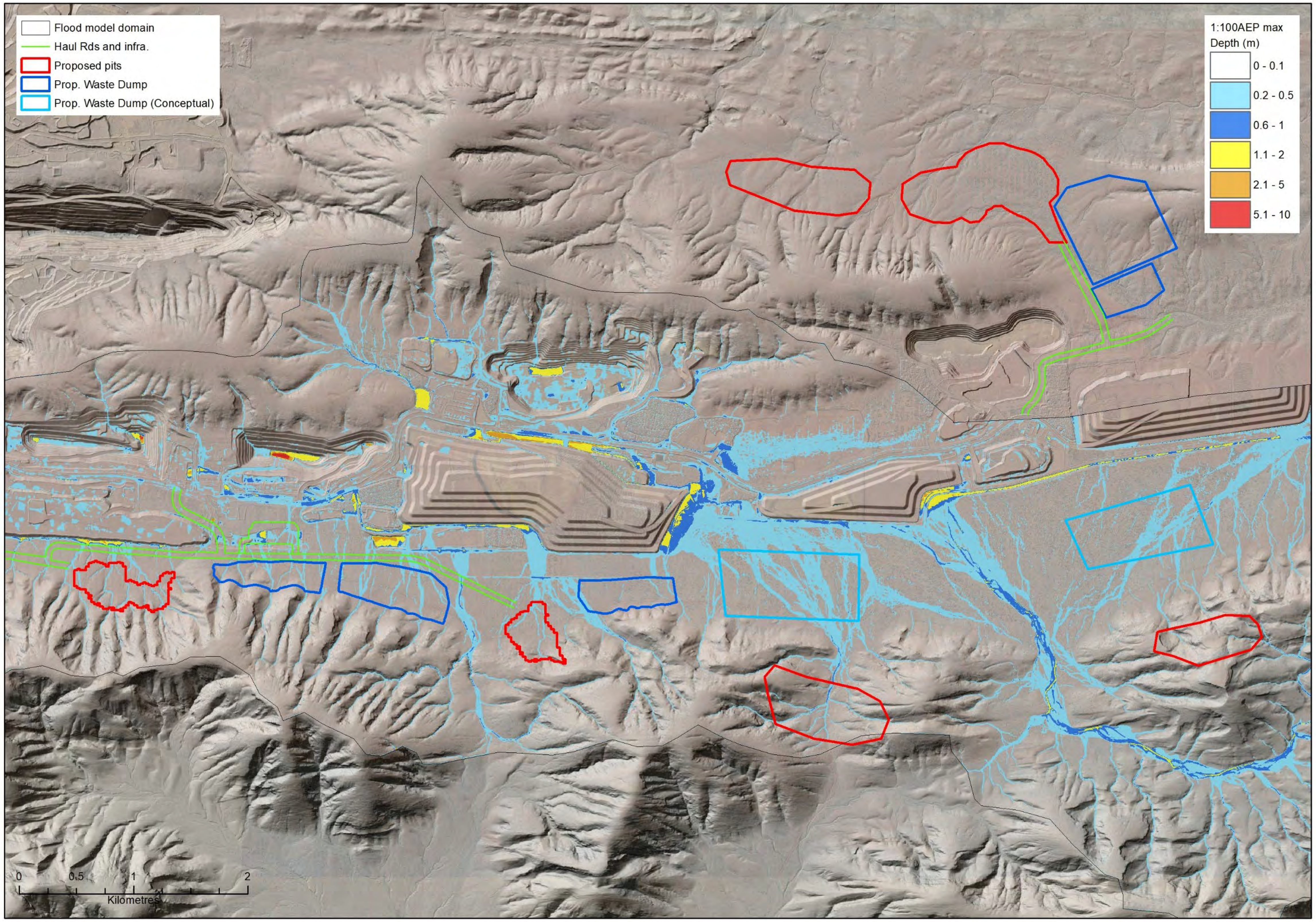

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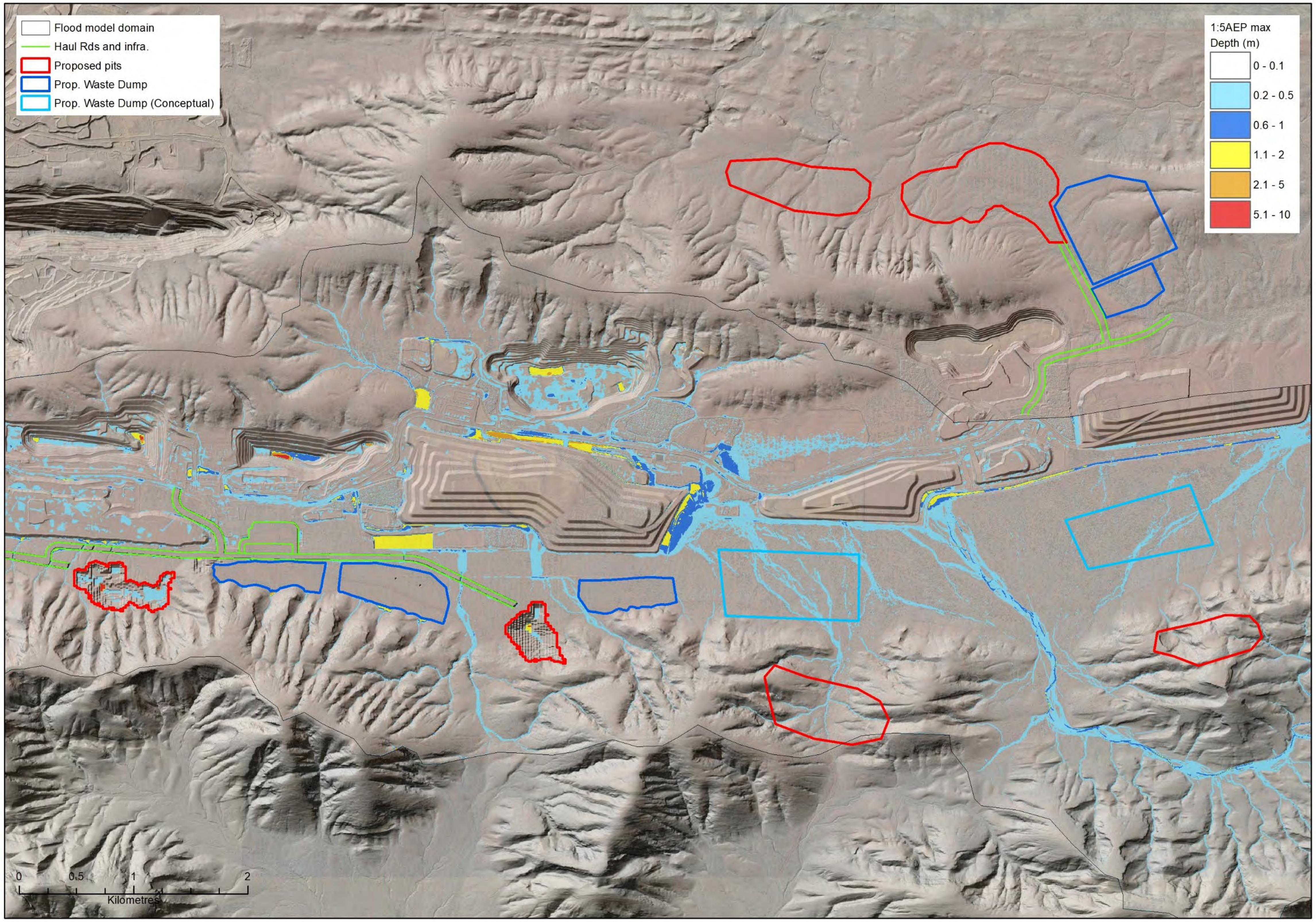

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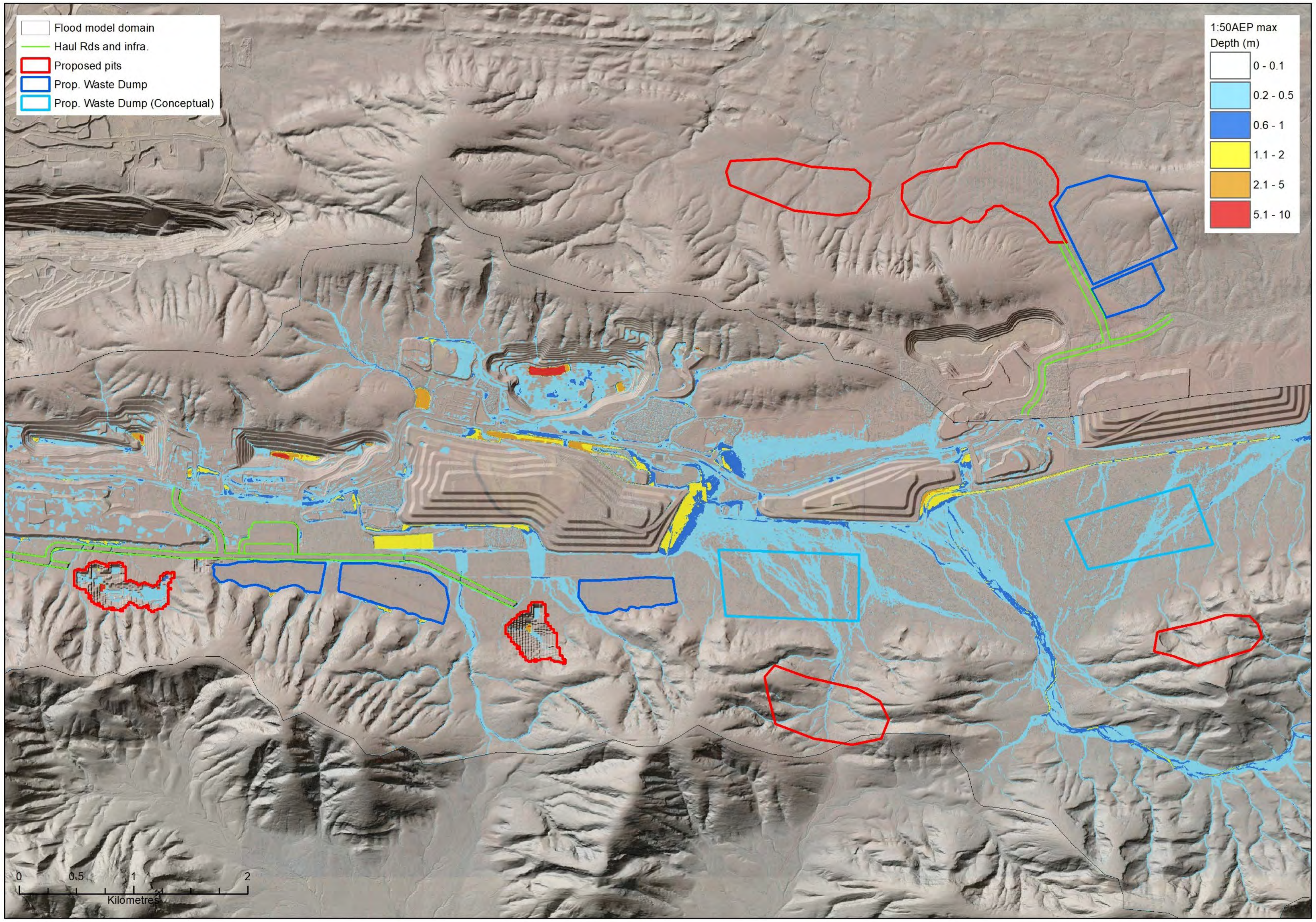

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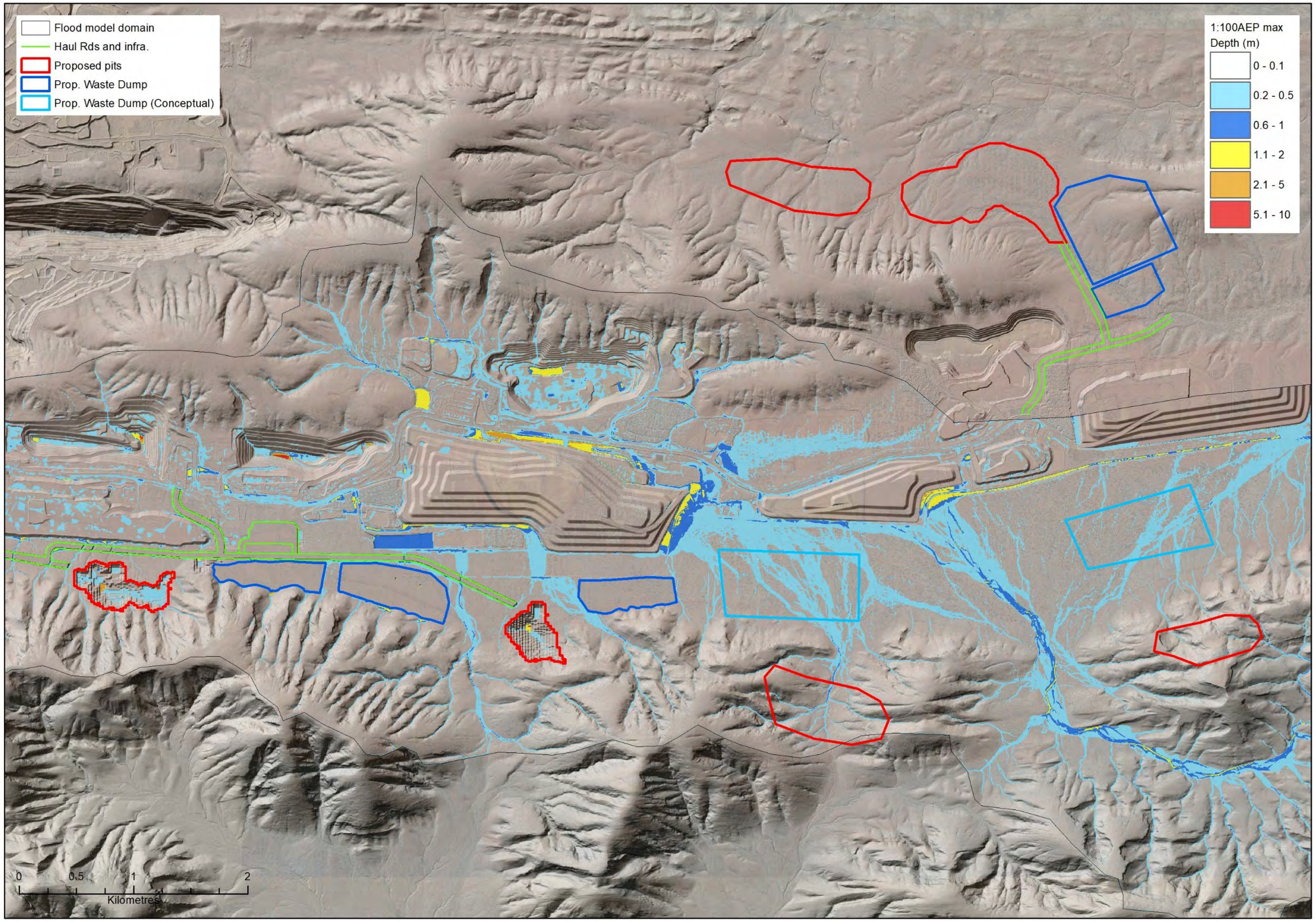
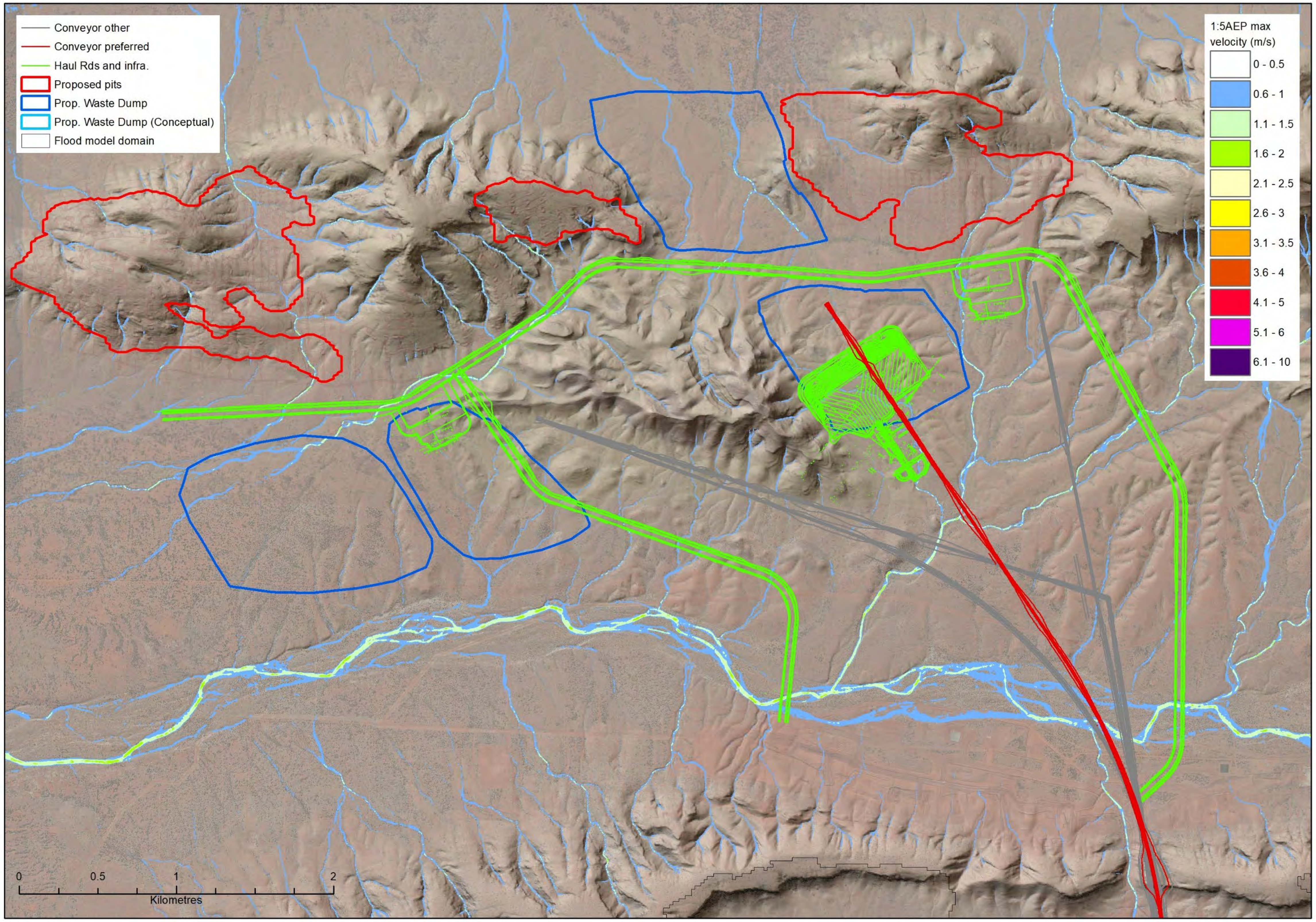
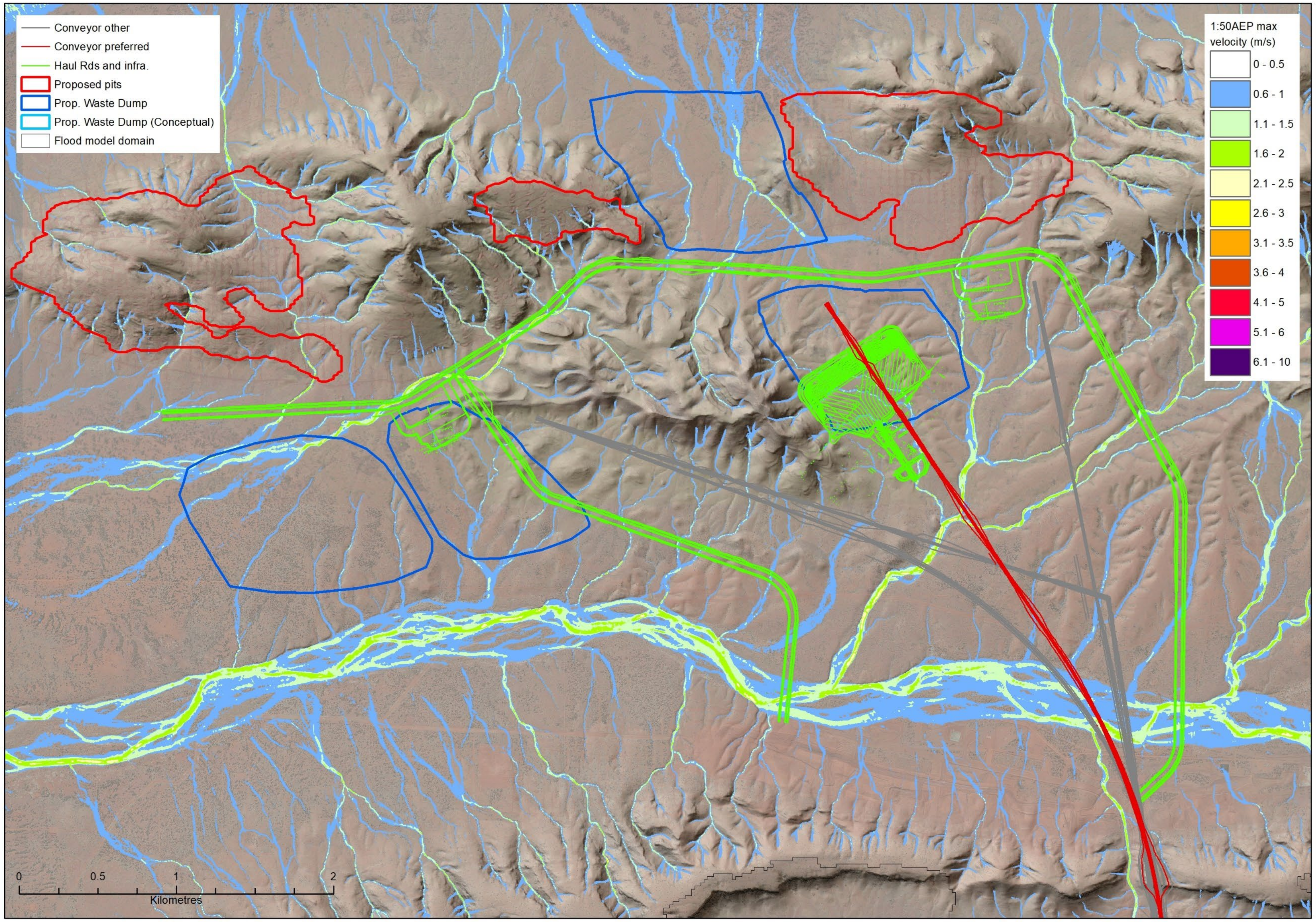


Mount Ella East post-development maximum flood depth mapping 1:100AEP

Appendix C – TUFLOW flood modelling results maximum velocity 1:5AEP, 1:50AEP, 1:100AEP for pre- and post-development scenarios



Western Hill pre-development maximum velocity mapping 1:5AEP



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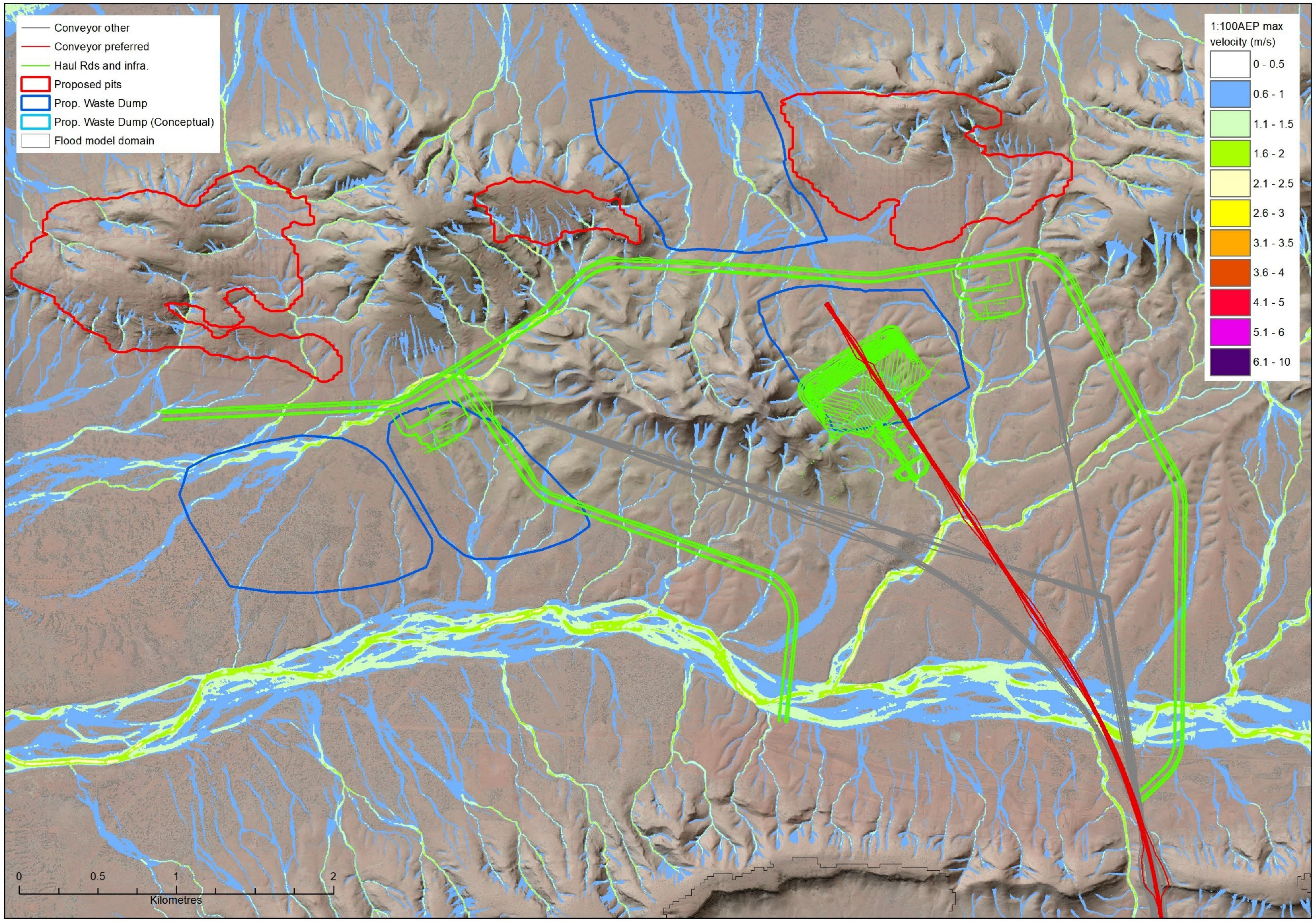

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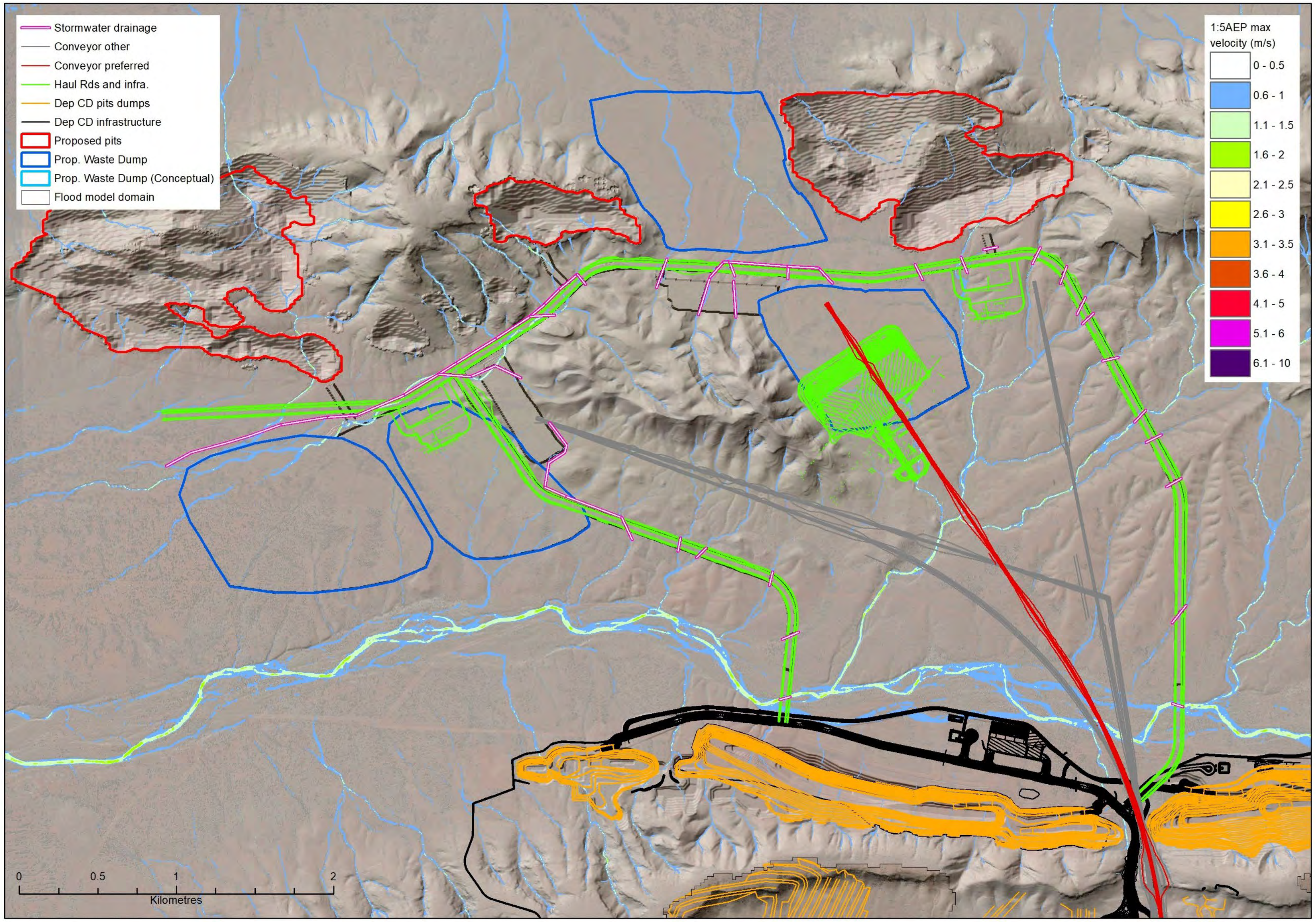

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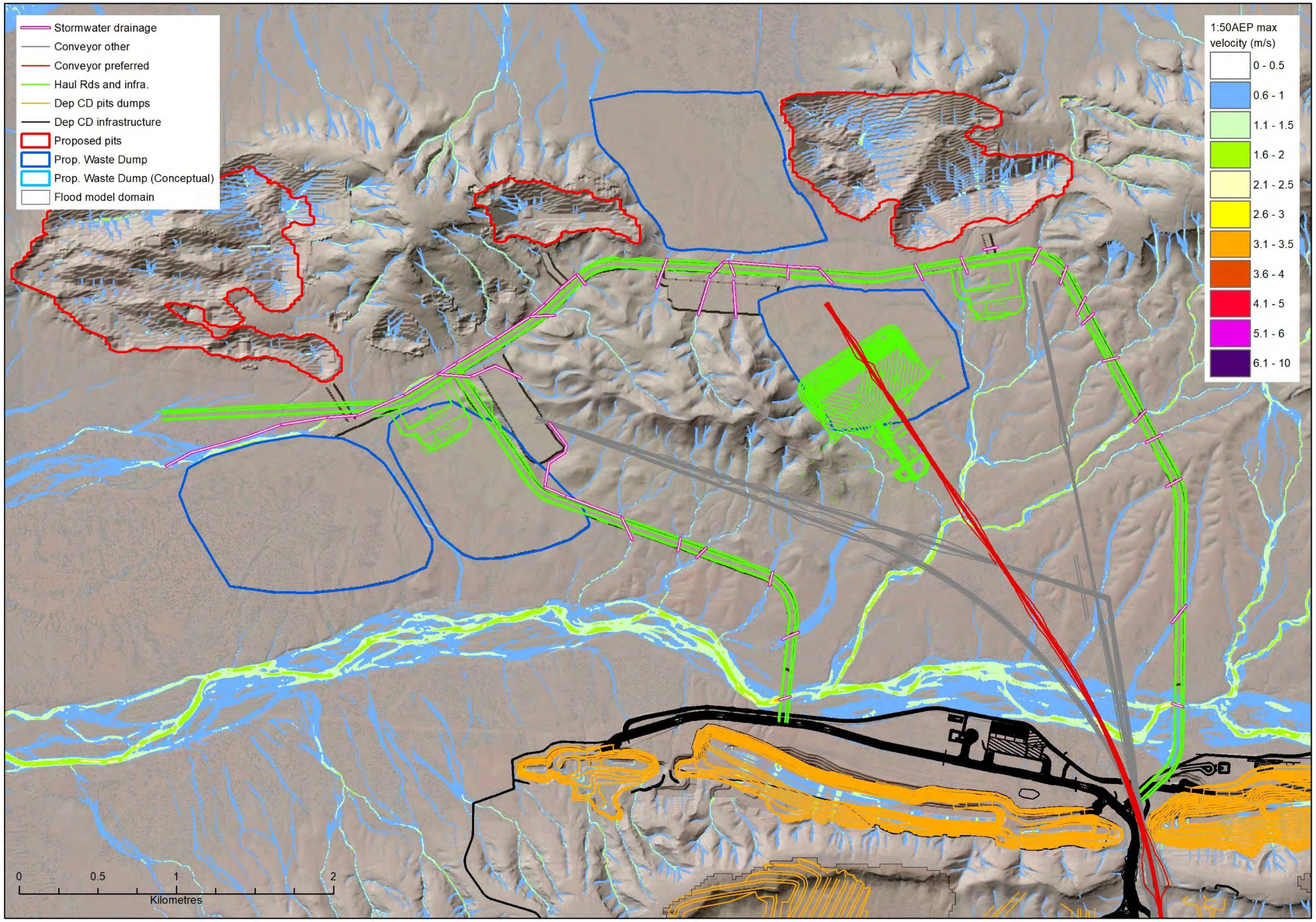

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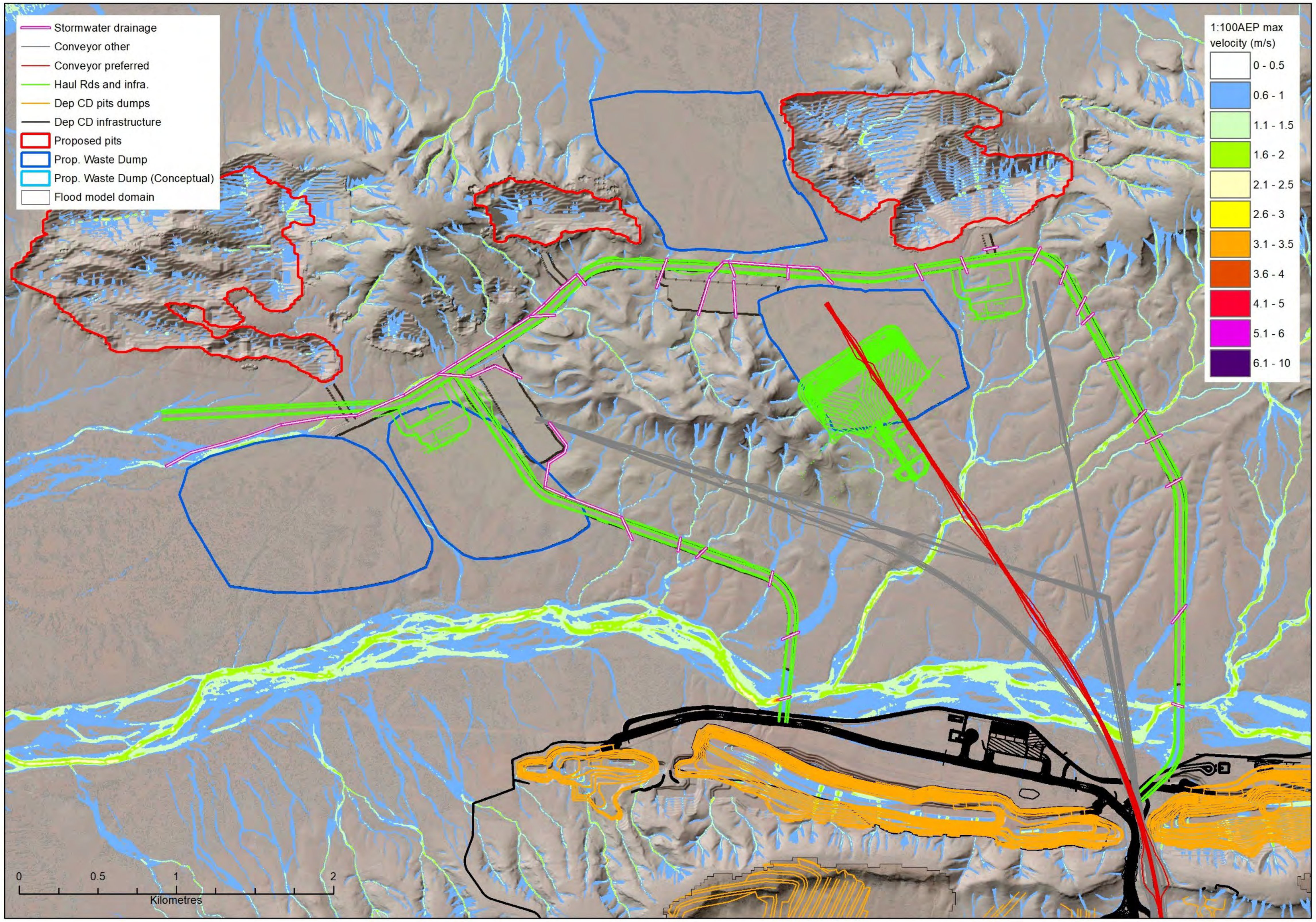

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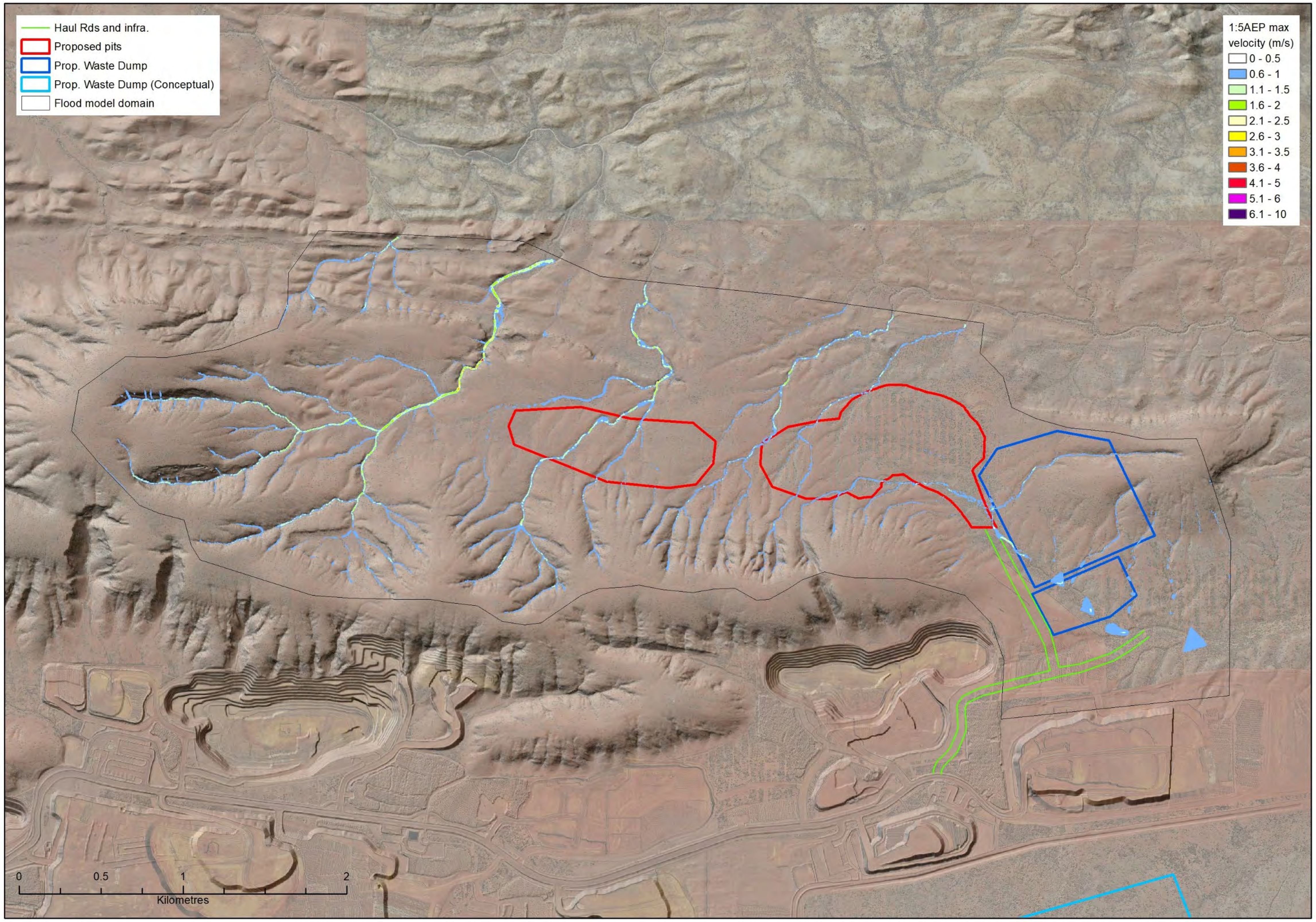
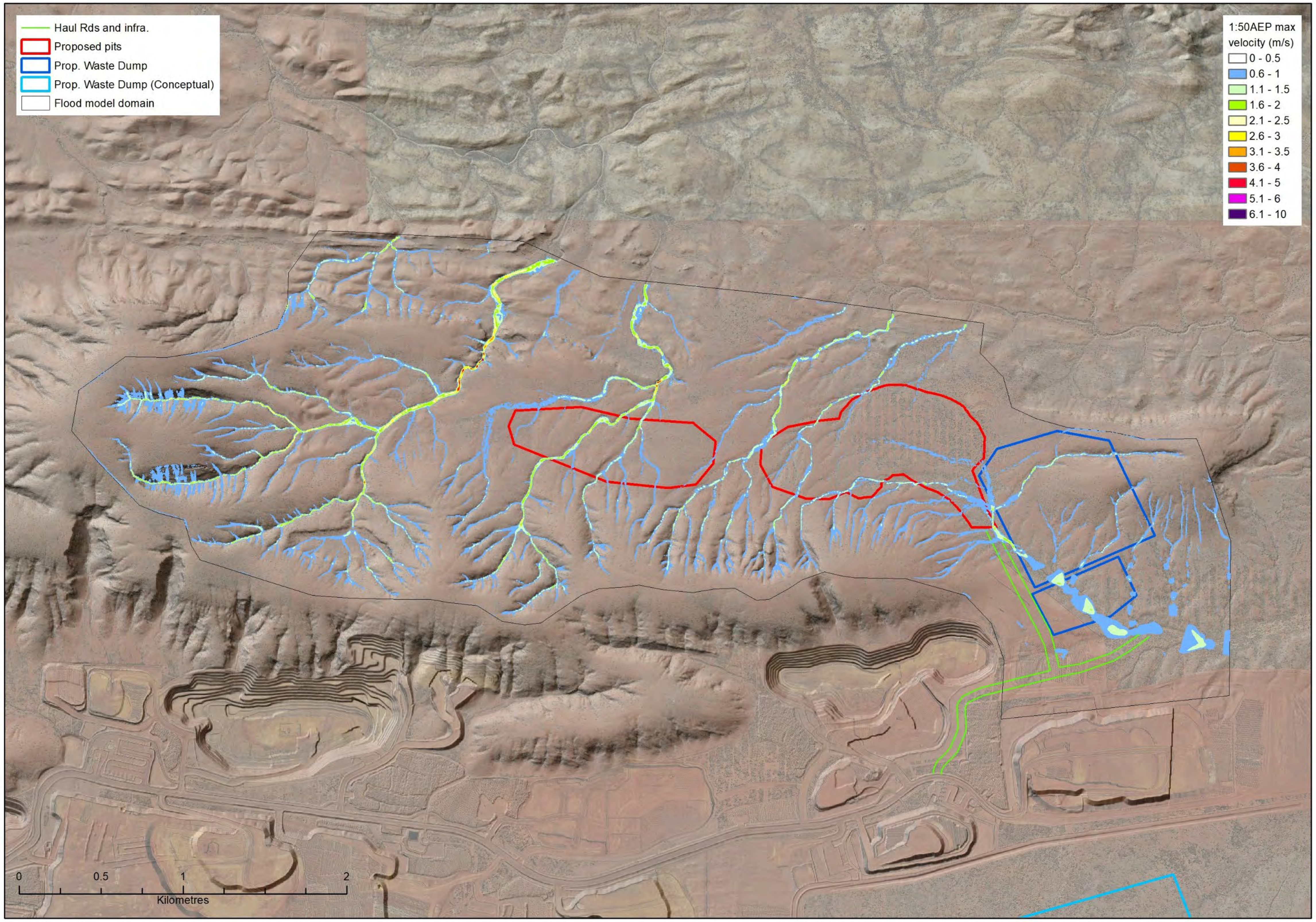


Deposit F north pre-development maximum velocity mapping 1:5AEP



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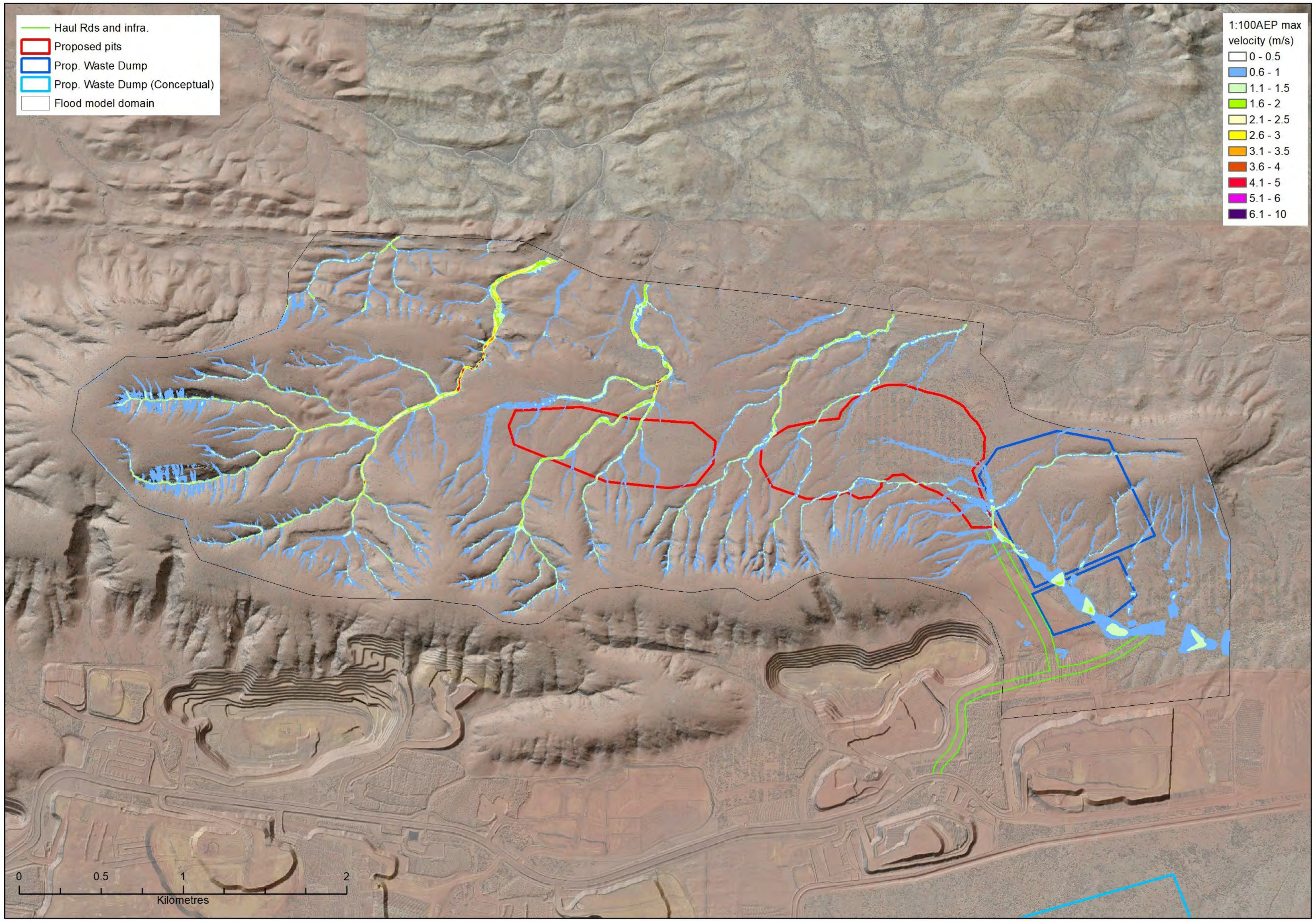

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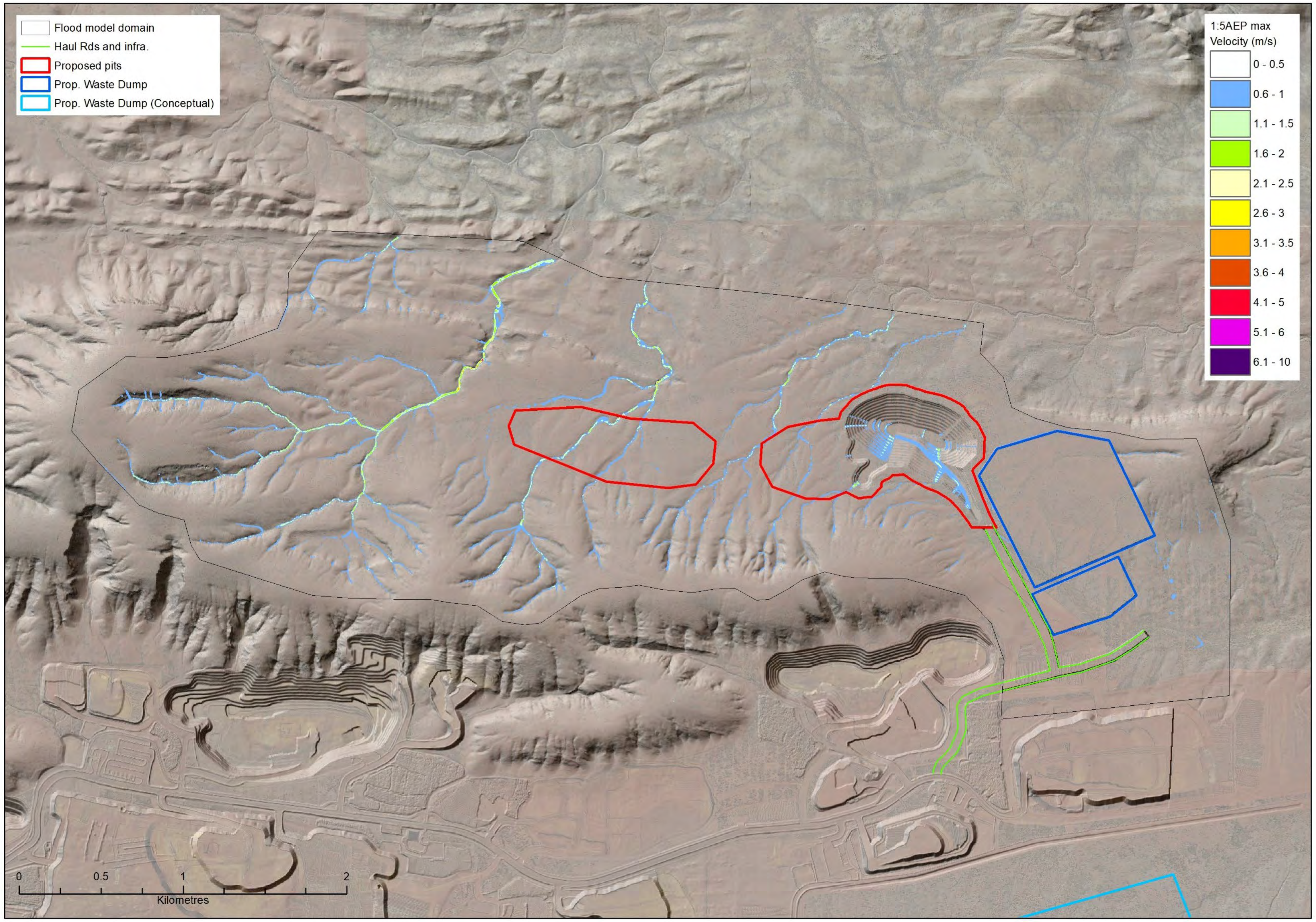

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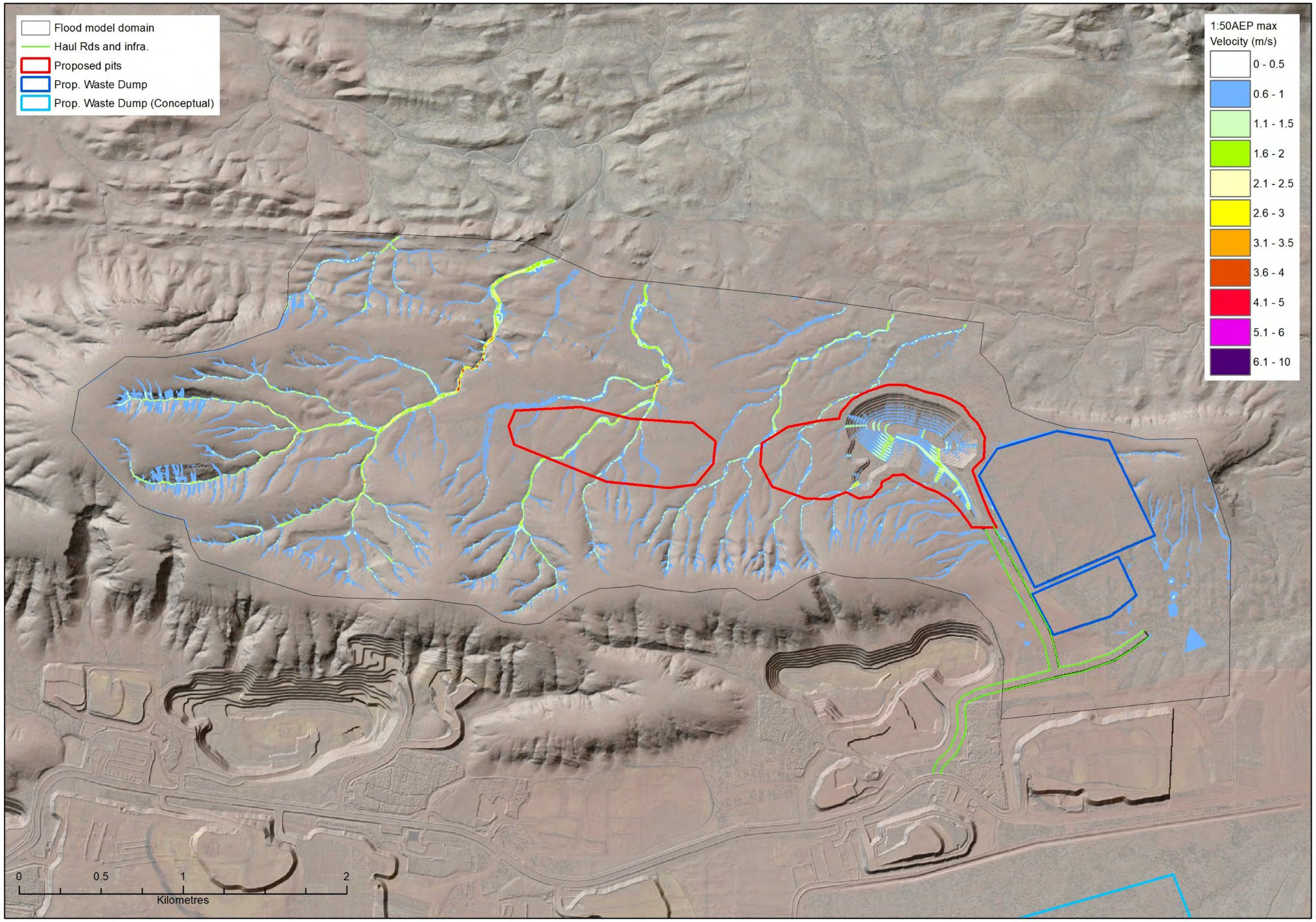

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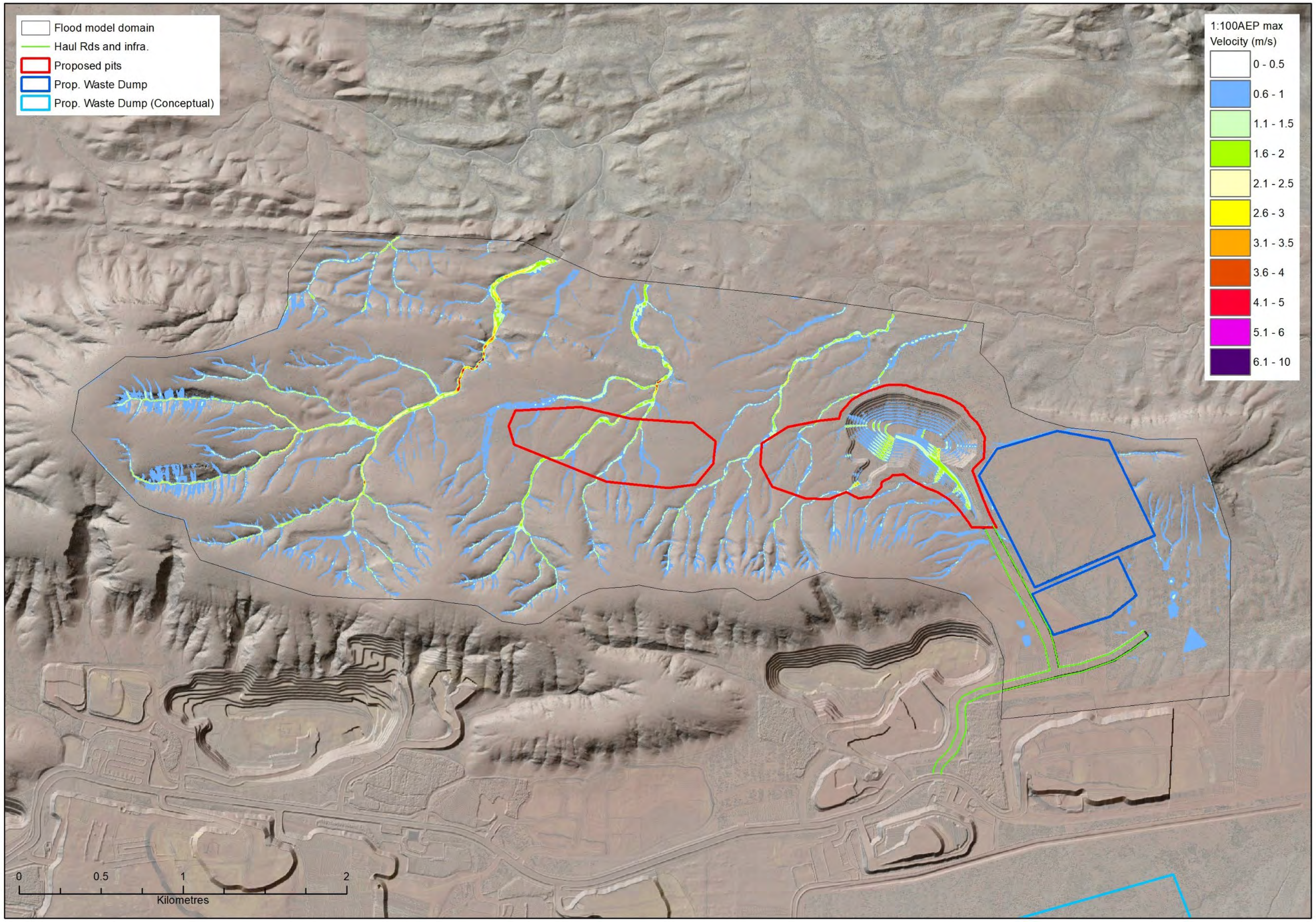

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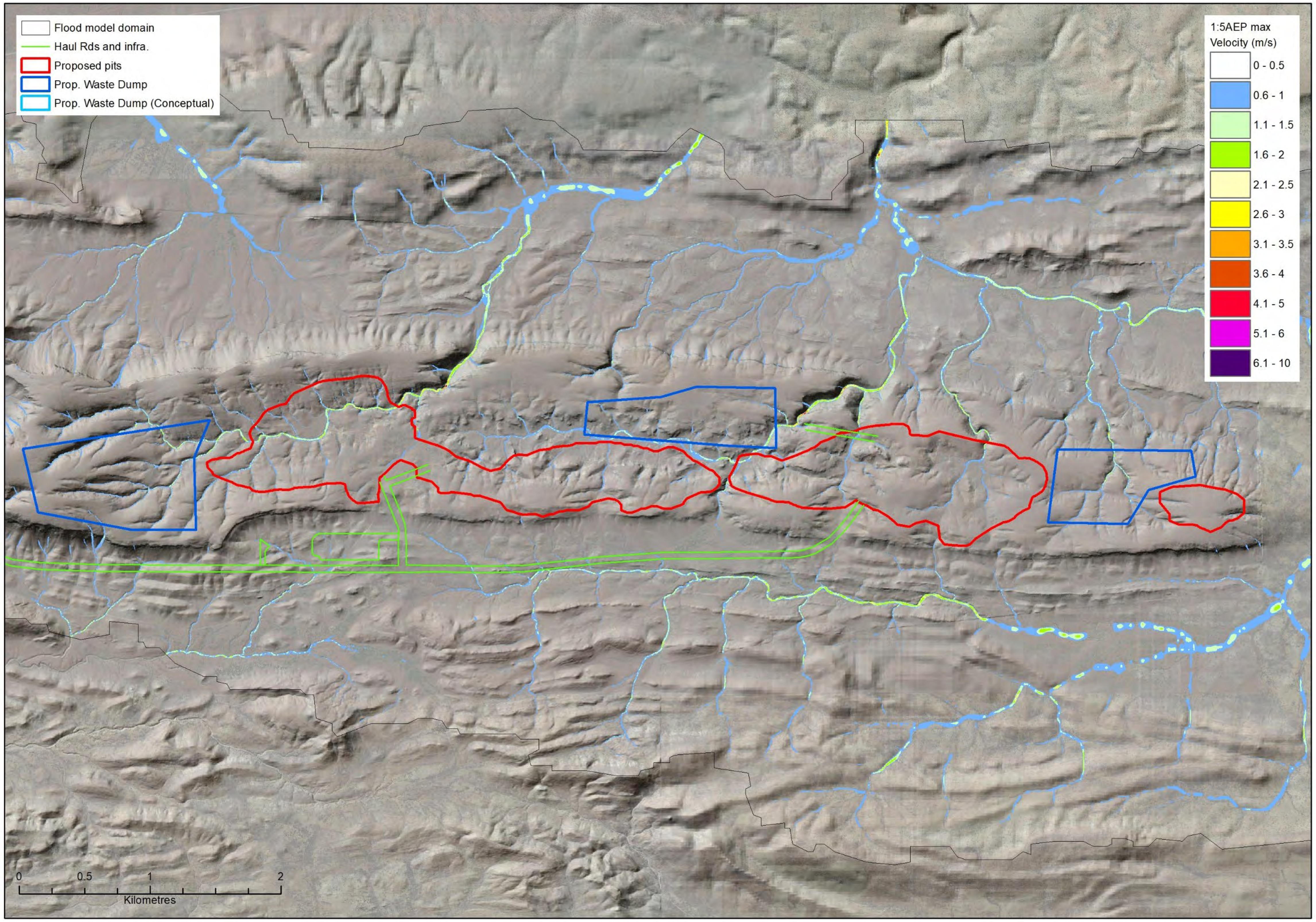

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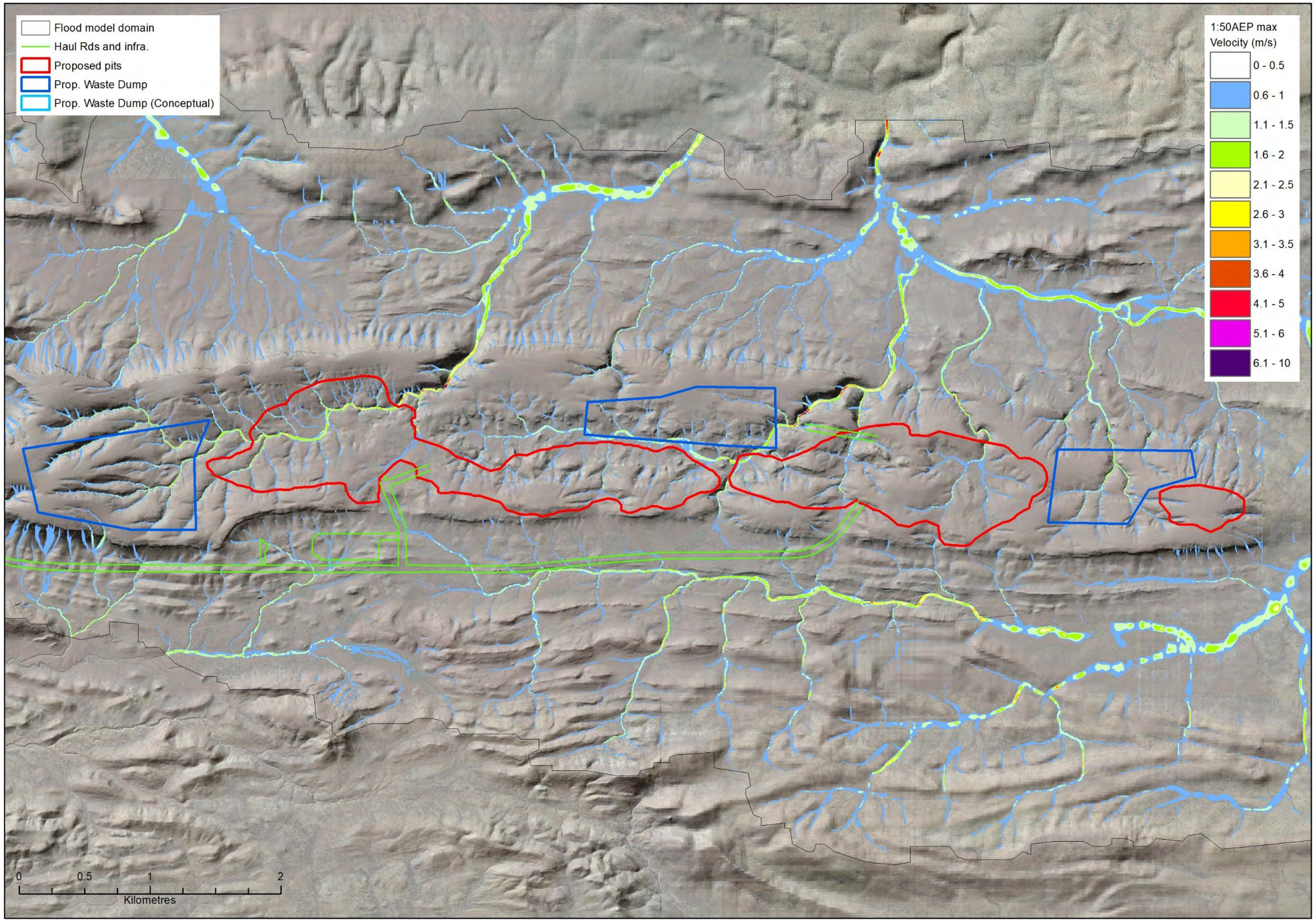

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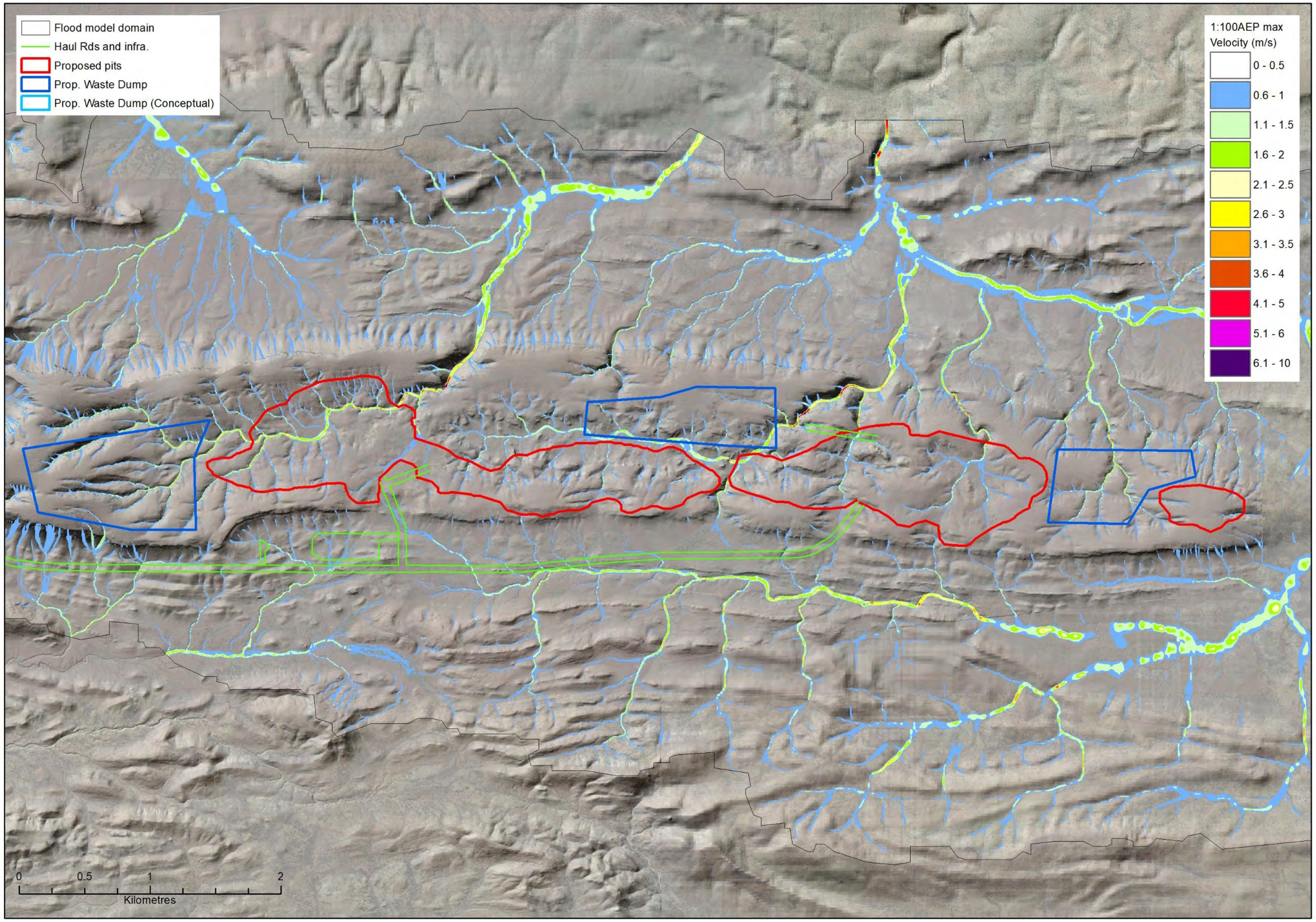

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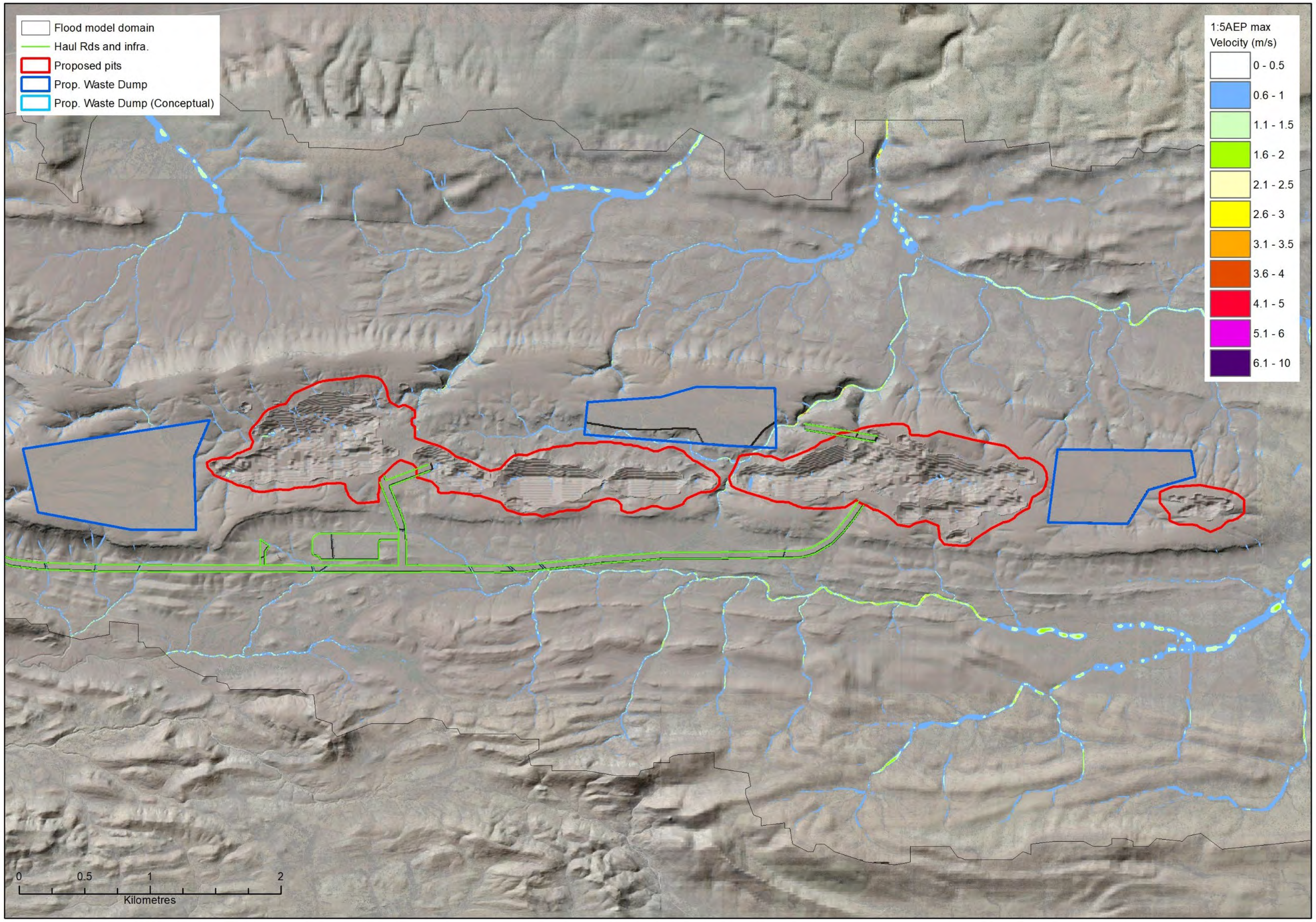

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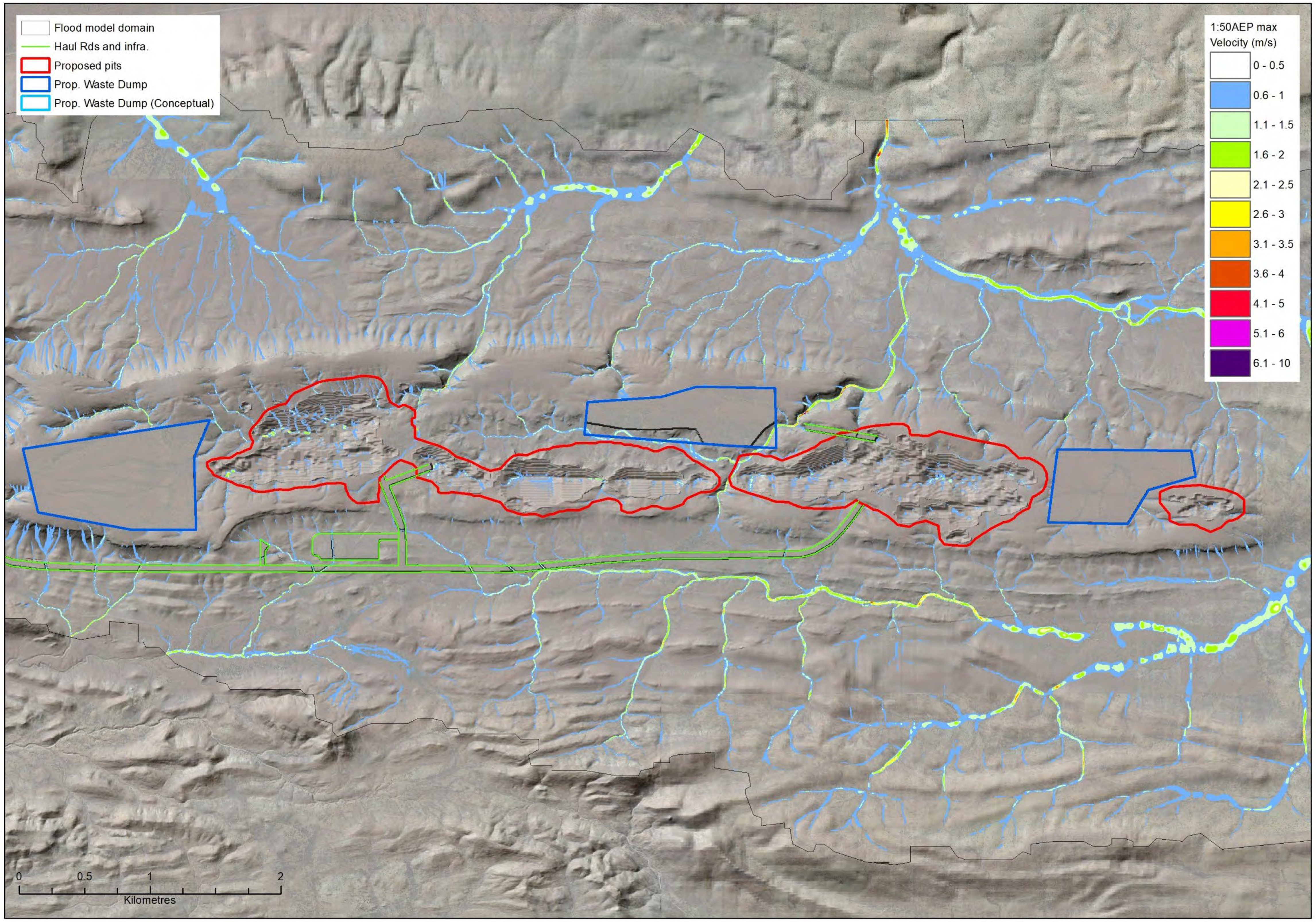

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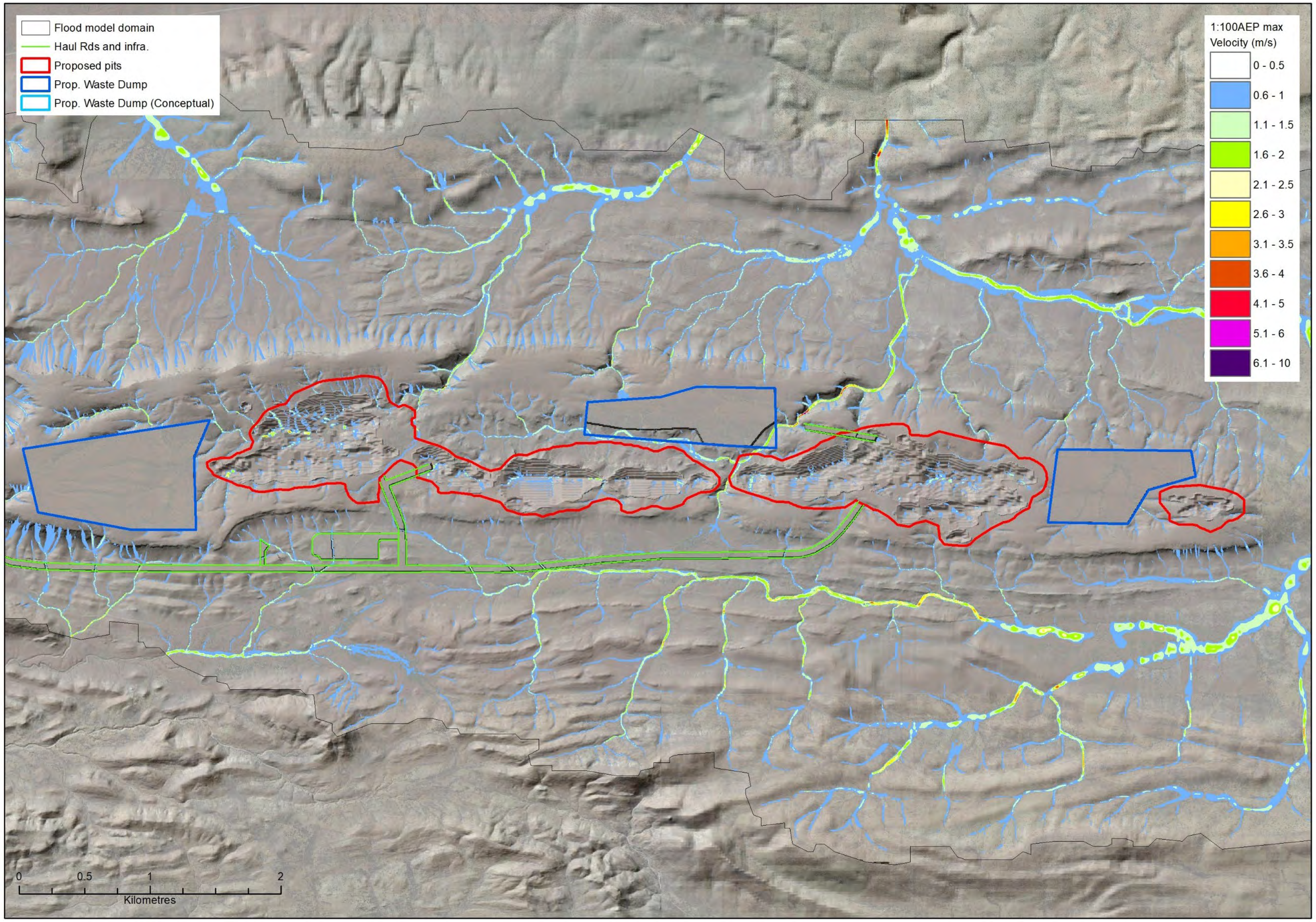

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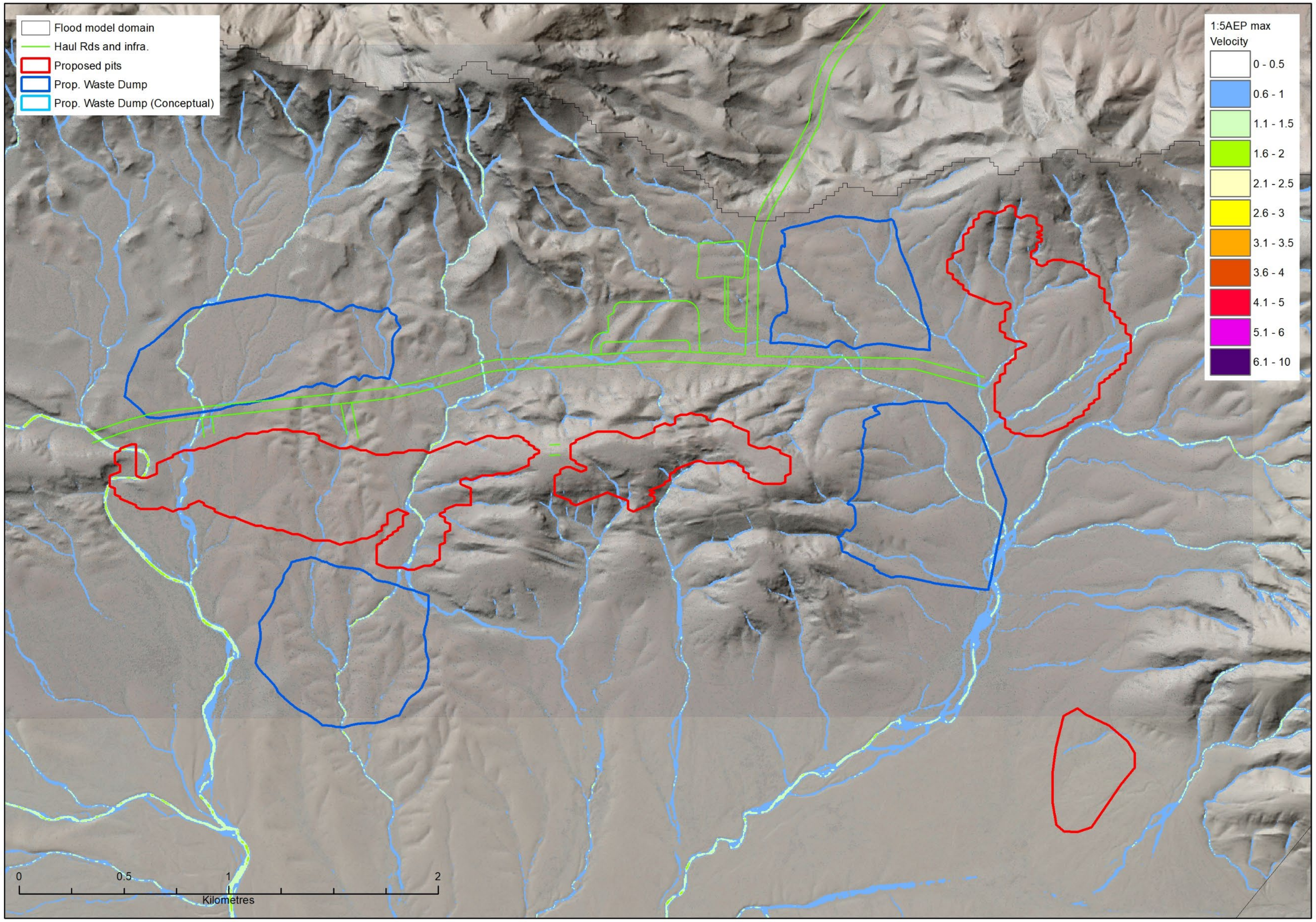

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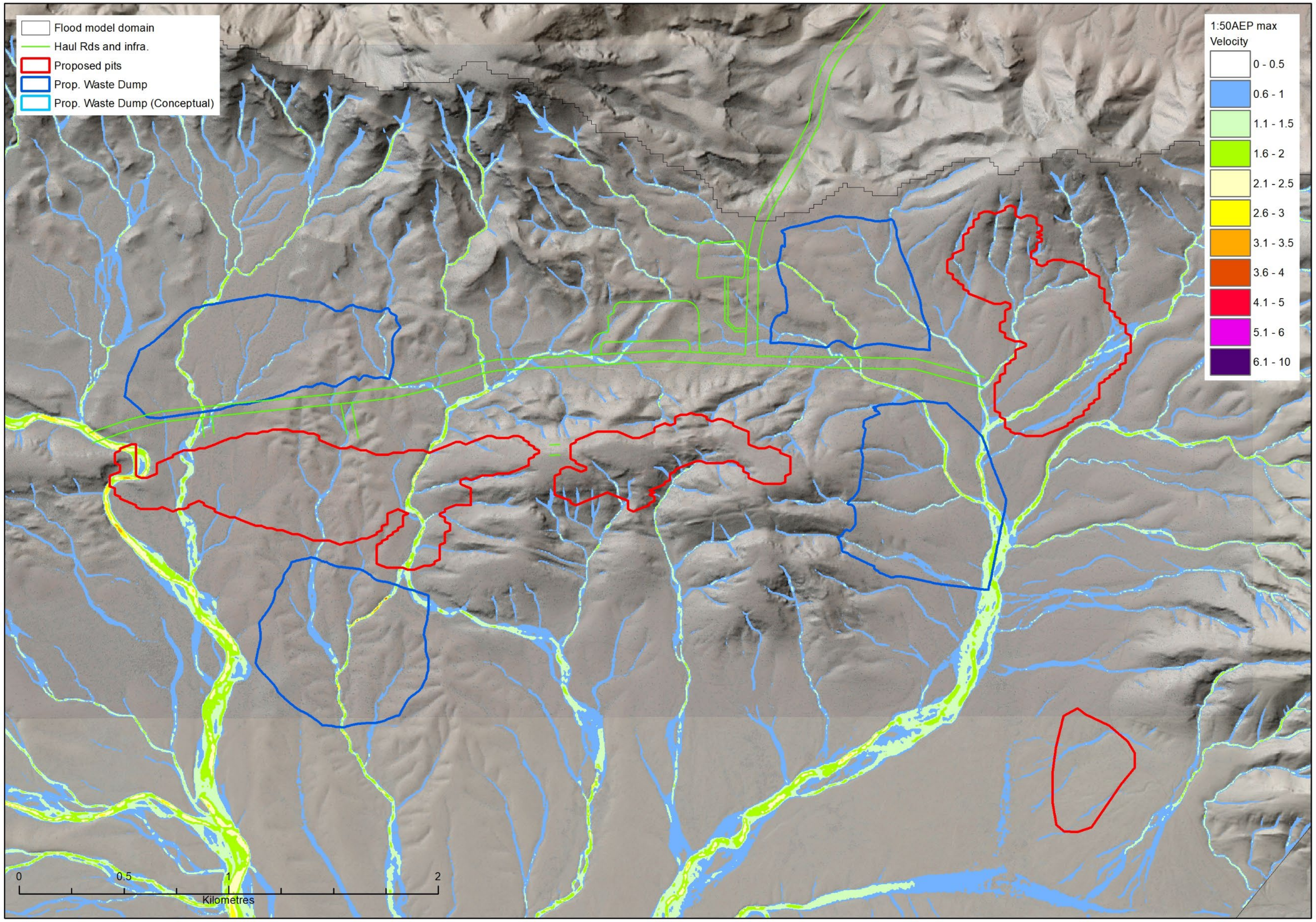

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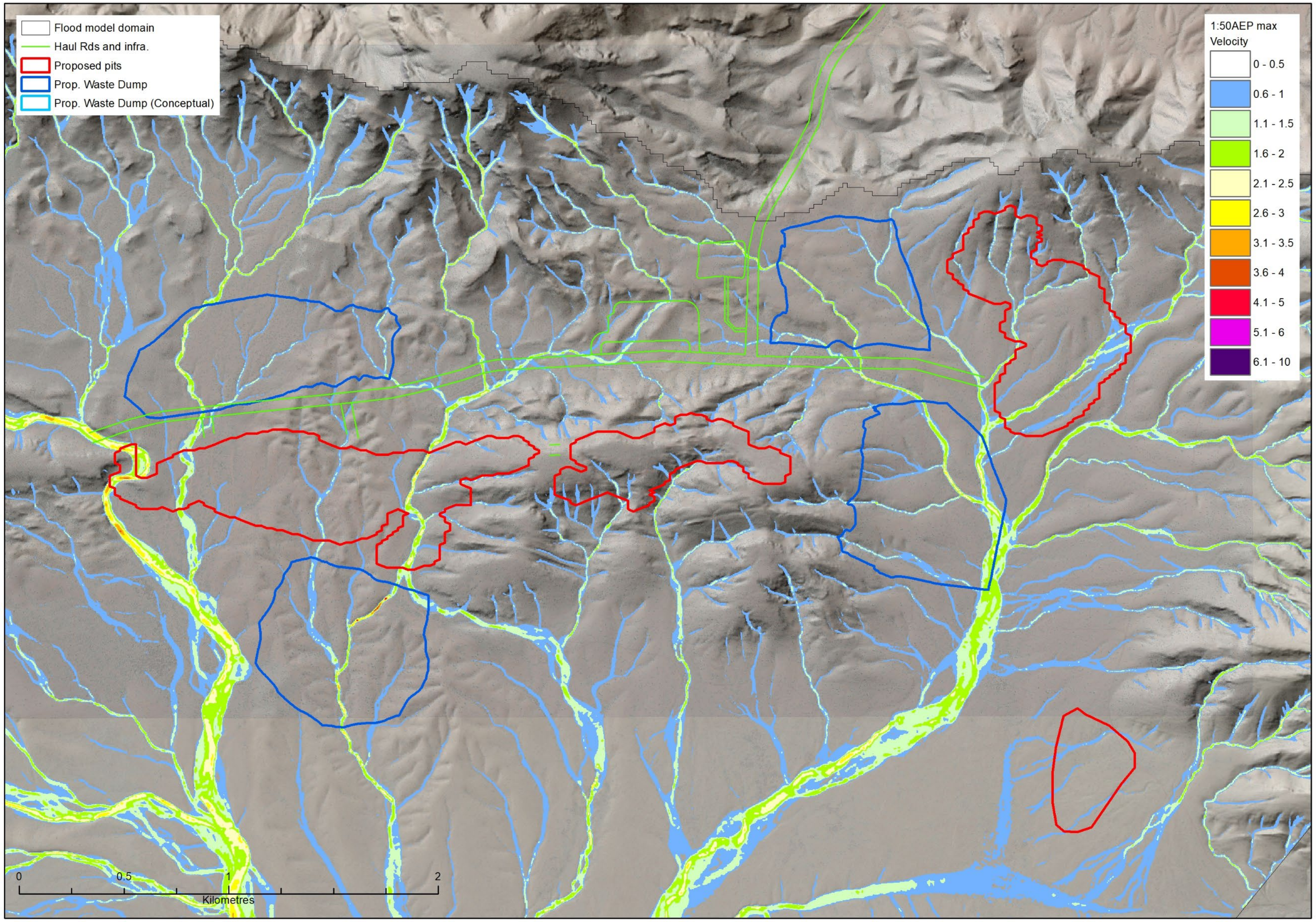

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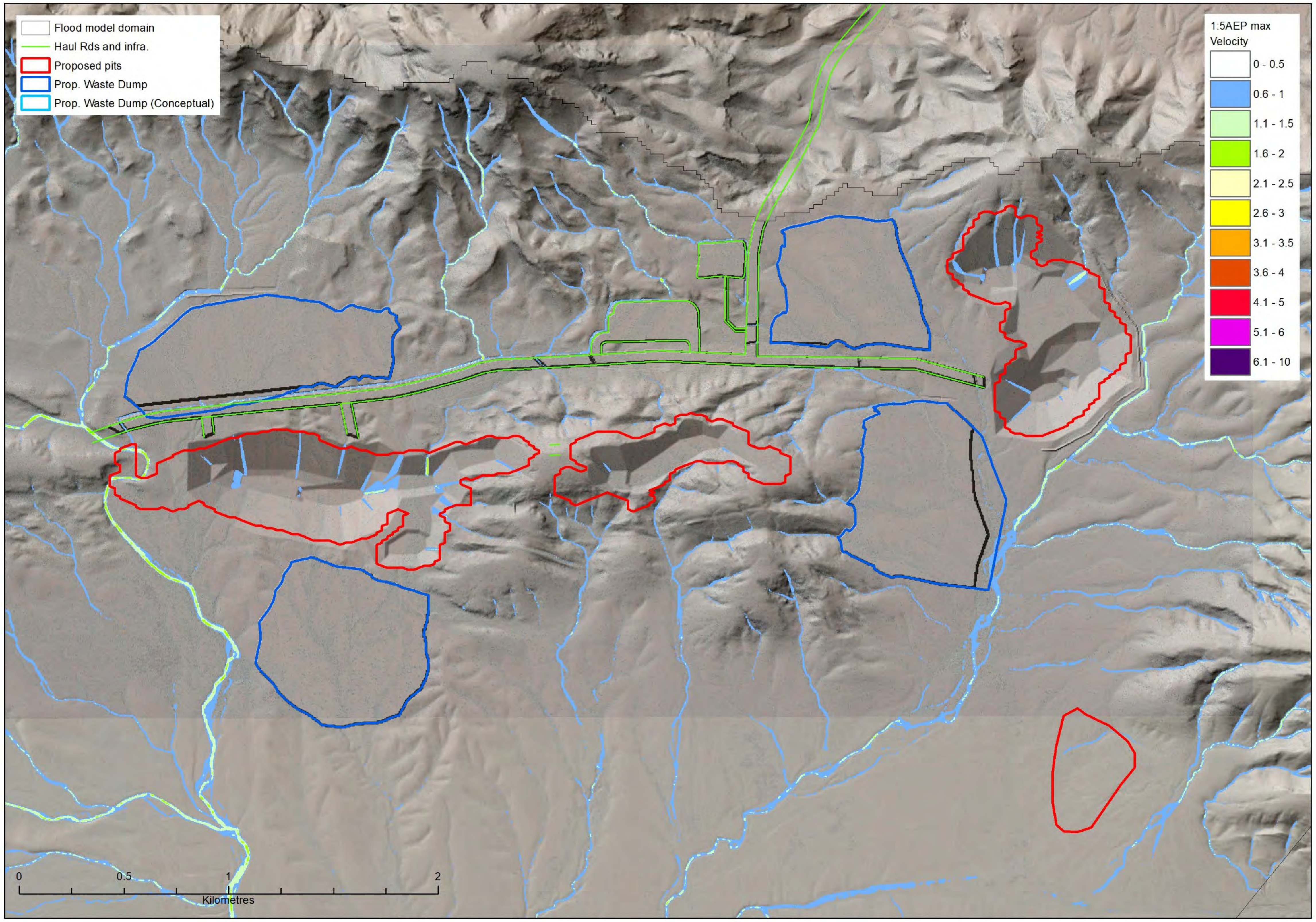

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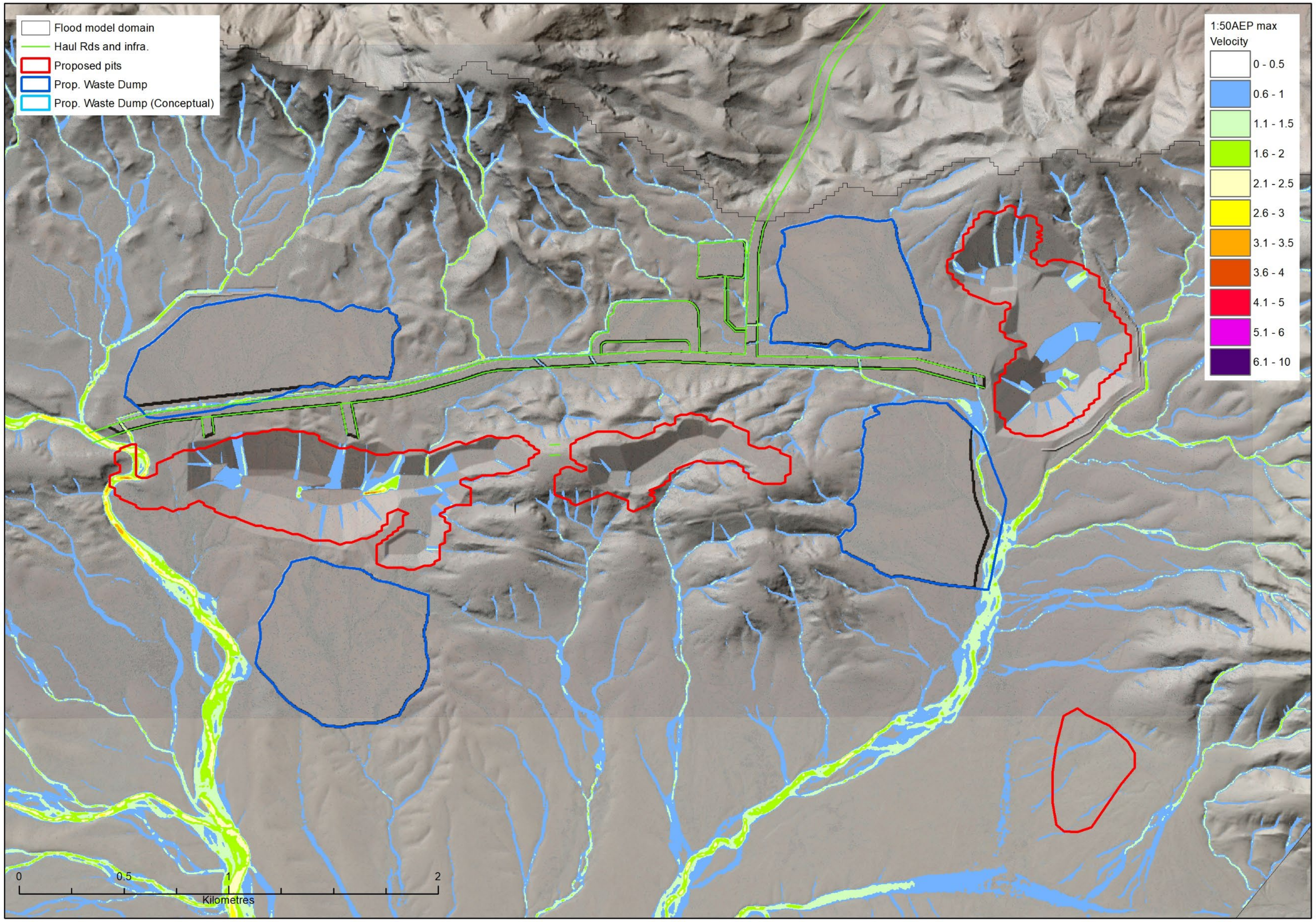

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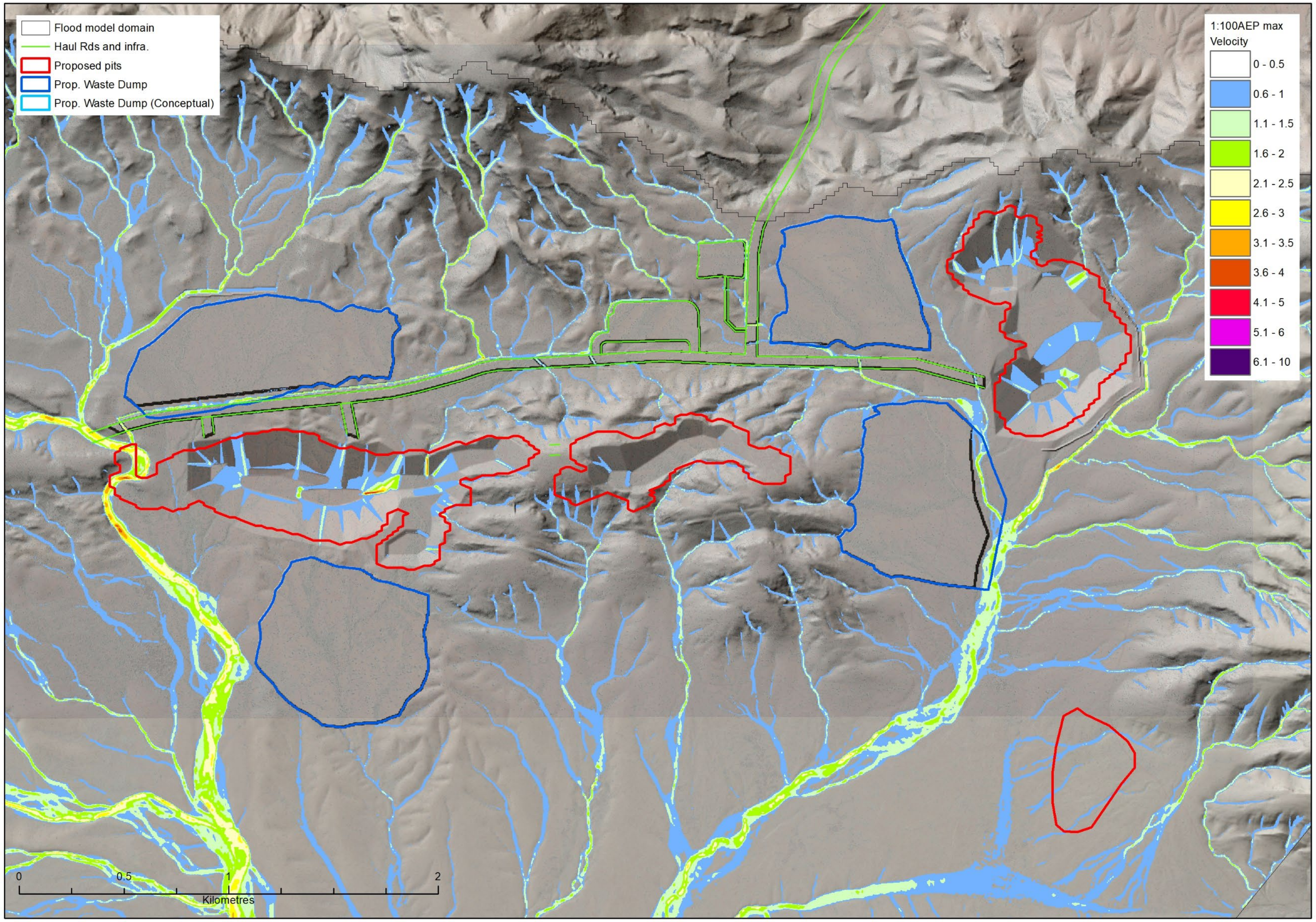

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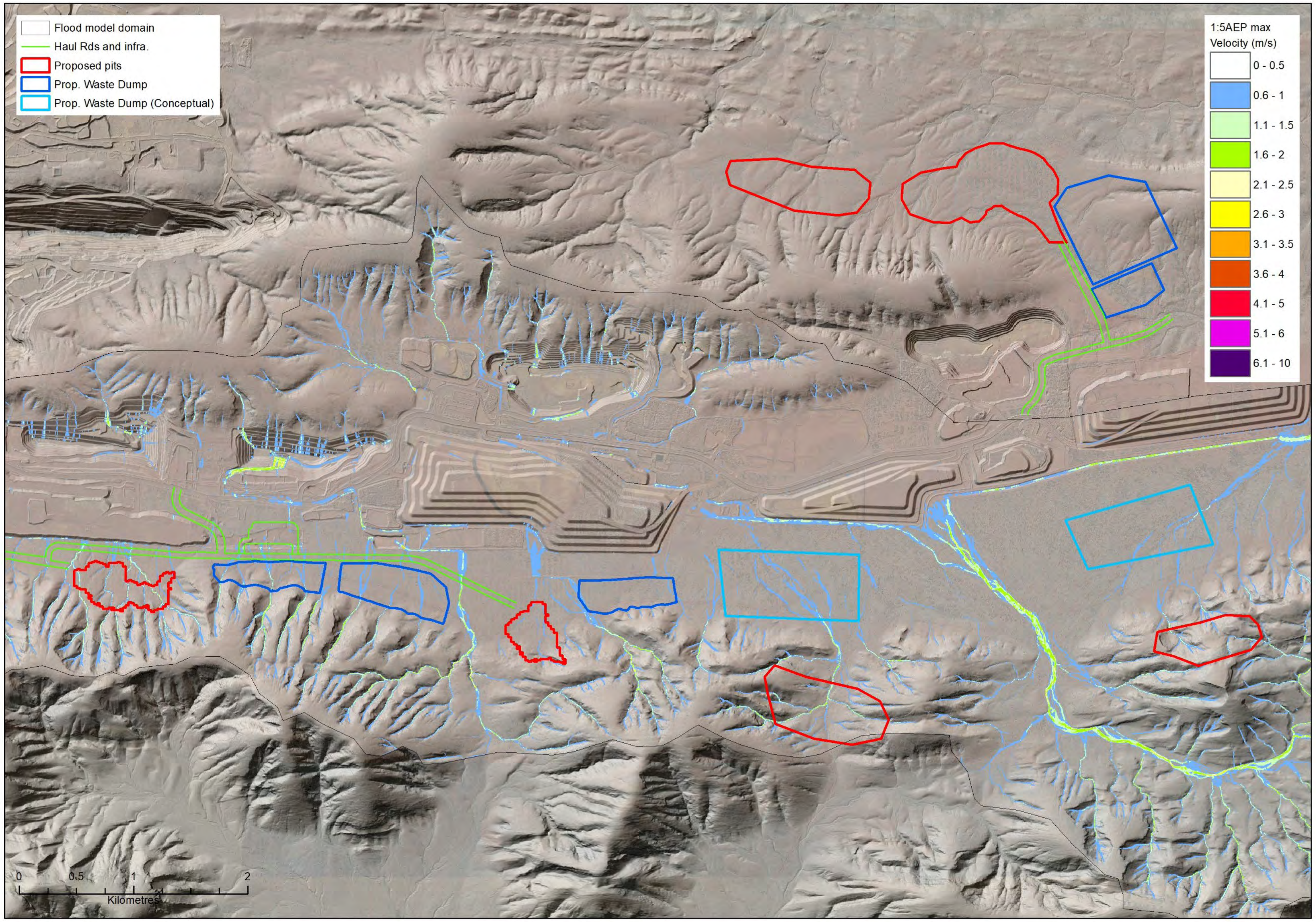
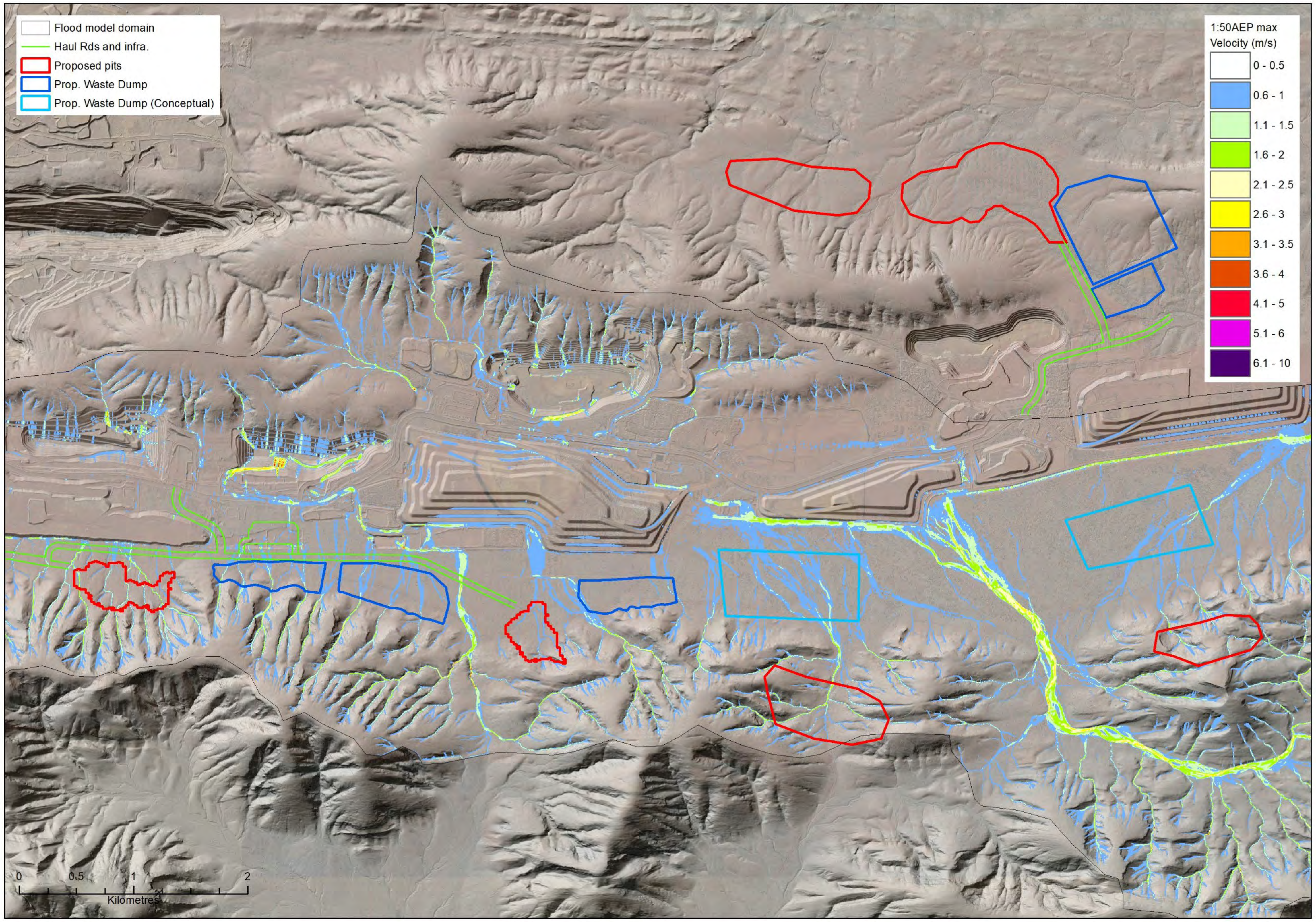


Mount Ella East pre-development maximum velocity mapping 1:5AEP



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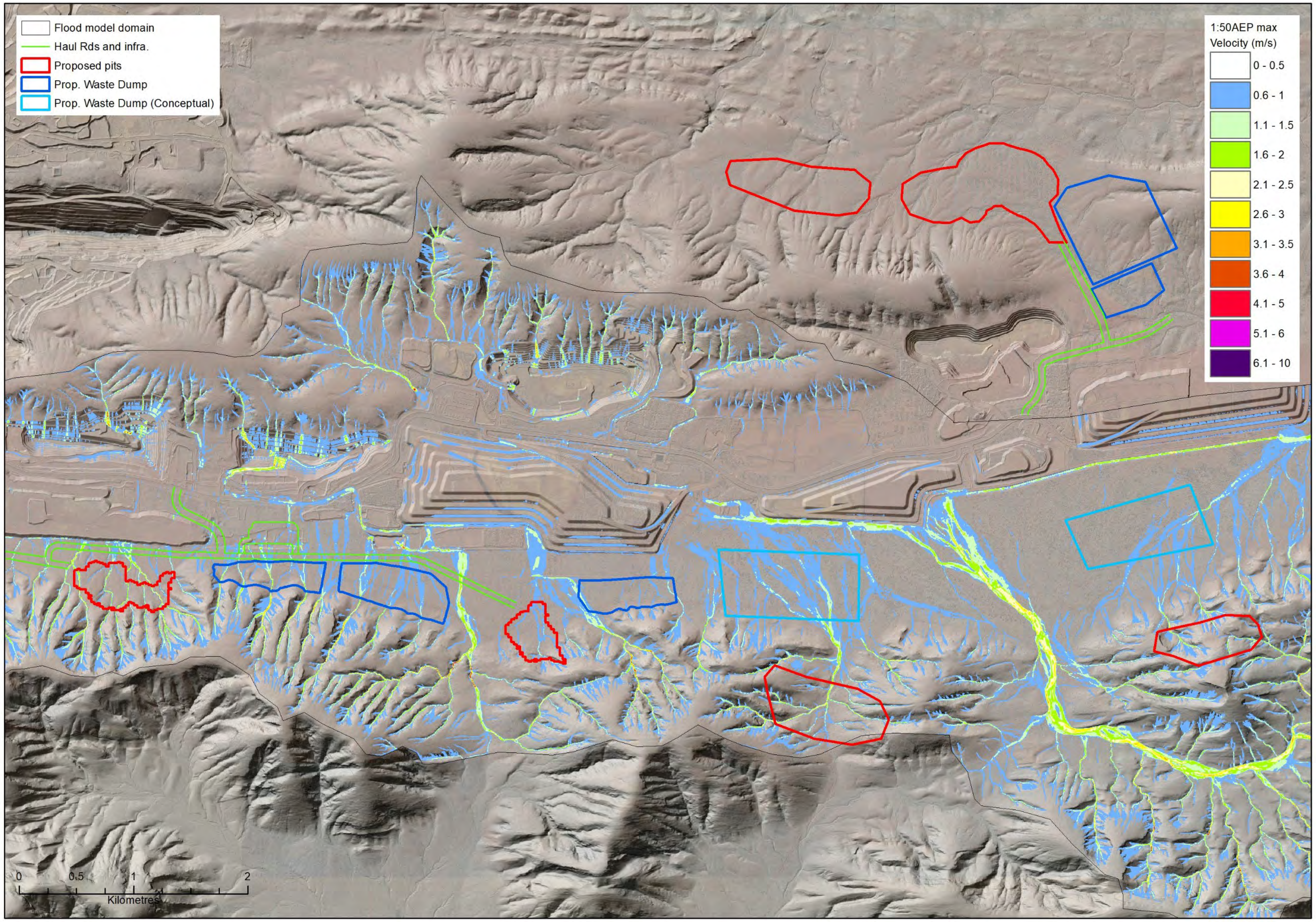

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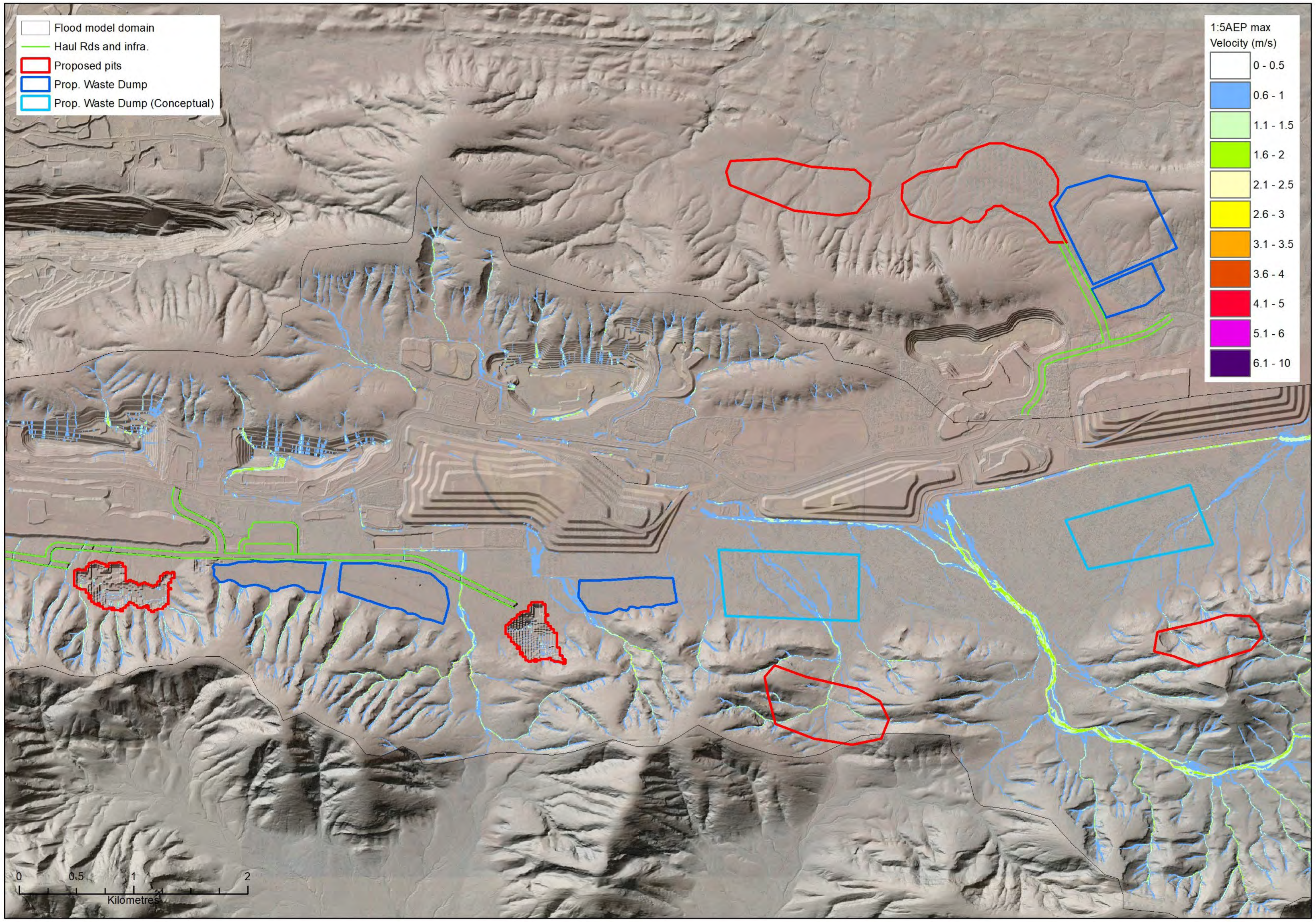

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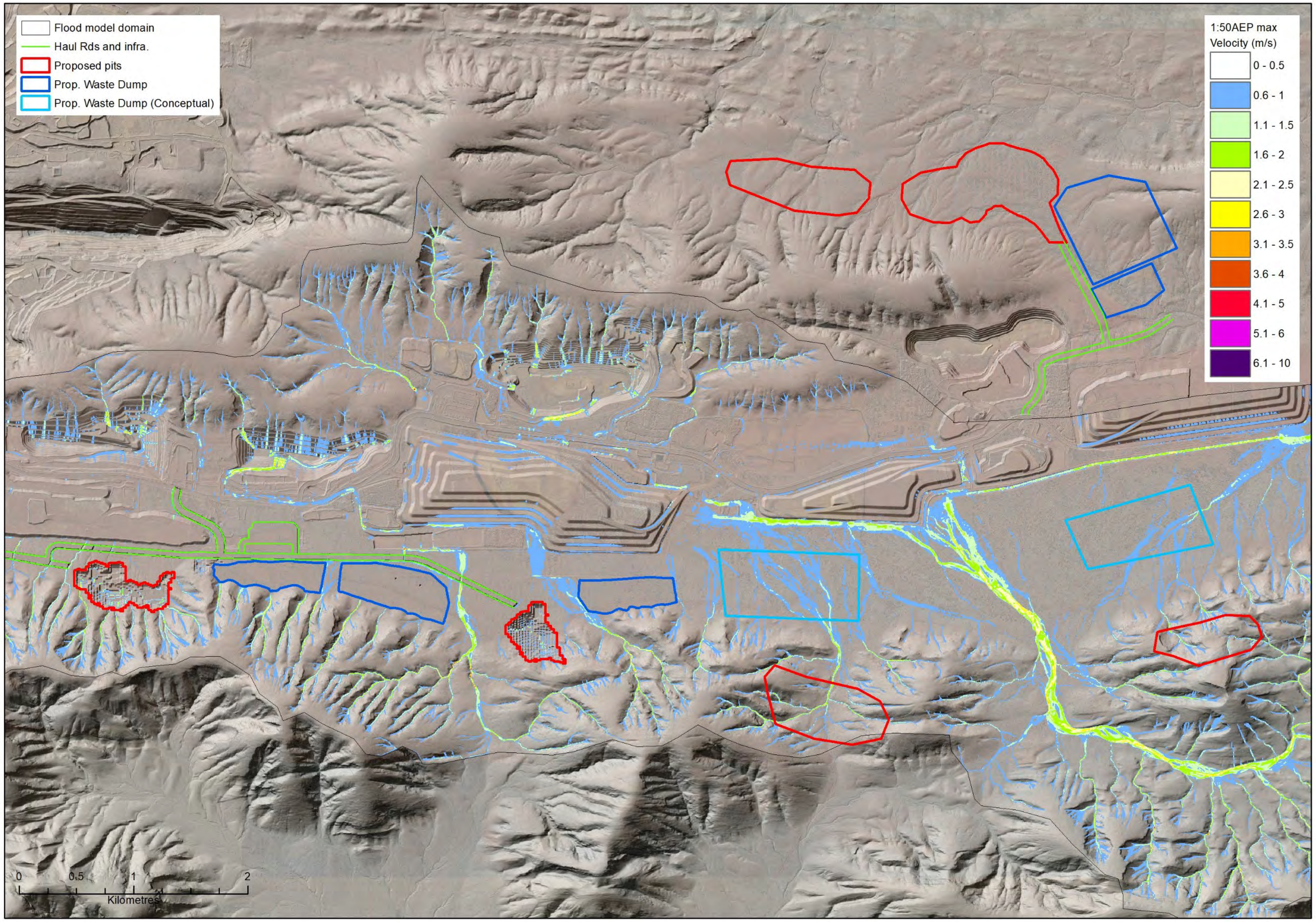

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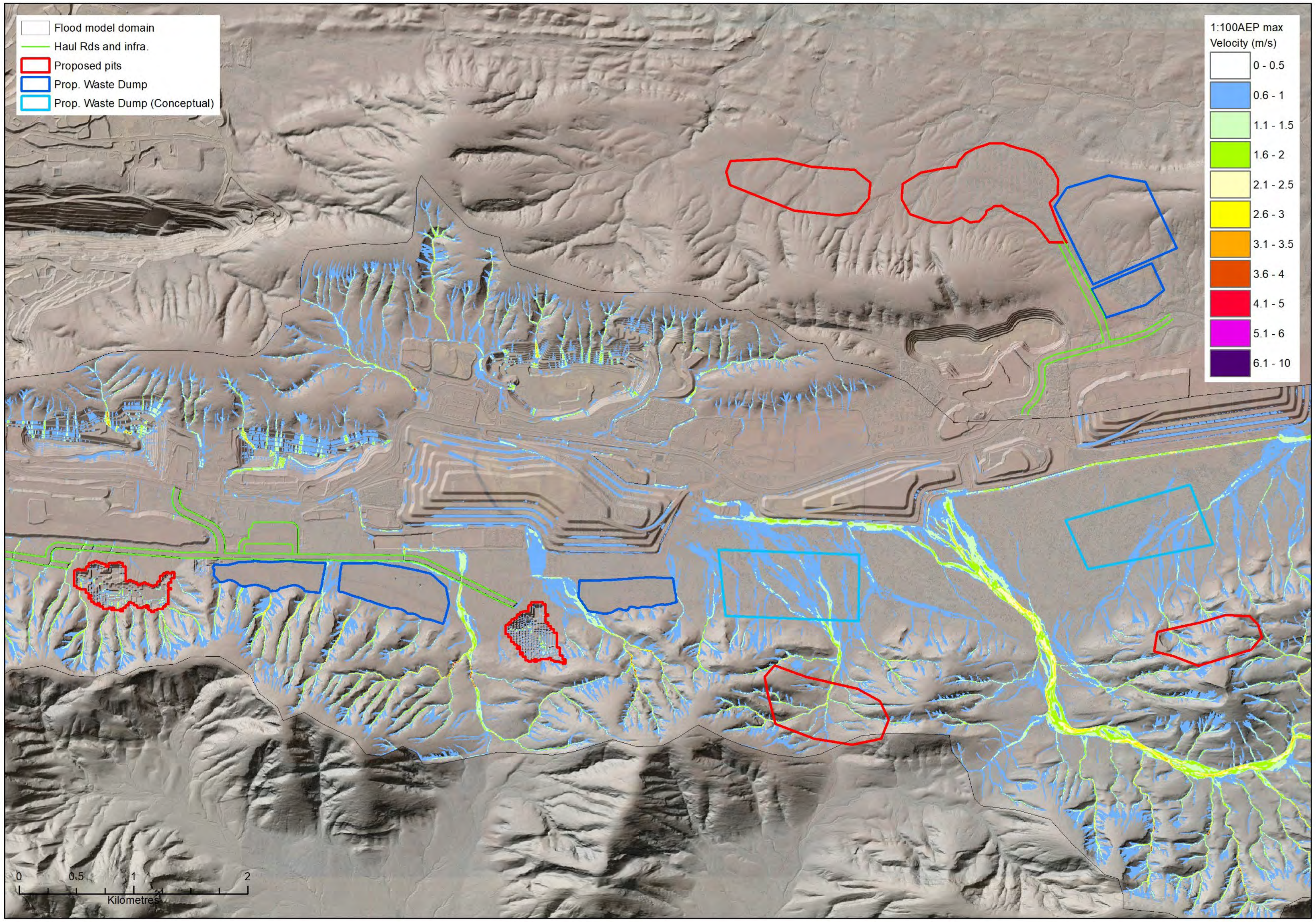


Mount Ella East post-development maximum velocity mapping 1:100AEP

C.2: Site inspection and surface water monitoring at Guburingu heritage area Western Hill

Internal memo

From:	Ben Marillier
Department:	WRES
To:	David Walsh
Copies:	Robert Milton, Johan Van Rensburg, Marek Janas
Reference:	RTIO-PDE-0162191
Date:	31/8/2020

Site Inspection and surface water monitoring at Guburingu heritage area Western Hill

Background

The Guburingu heritage area is located at the far western end of the Western Hill resource, within the Karijini National park (Figure 1). The site was first investigated by WRES in November 2016 with a site walk-over to identify any significant water features, and any dependence on groundwater or surface water flow. The key findings of the investigation (RTIO-PDE-0147208) were:

- No surface water pools were identified.
- Significant depth to GW of >30m BGL and no evidence of compartmentalisation, resulting in a low likelihood of groundwater dependence for vegetation in the area.
- Higher vegetation density is driven by surface water characteristics, specifically multiple tributaries meeting to form a single incised channel with localised depressions.
- Recommendation to install surface water monitoring

Mining of Brockman Ore deposits at Western Hill are being investigated as part of the West Angelas Beyond 2020 study. Given the proximity of the Guburingu site to the mining area it is necessary to confirm these conclusions with additional monitoring. This memo describes the site hydrology in more detail and summarises surface water monitoring between 2018 and 2020.

Yinhawangka group was contacted for permission to install a pressure transducer for monitoring of surface flows within the heritage areal. The group allowed for installation provided that there was no ground disturbance within site with foot access only. The site was visited on the 23rd of July 2018 to identify key drainage features and conceptualise the surface water regime and creek geomorphology of the site.

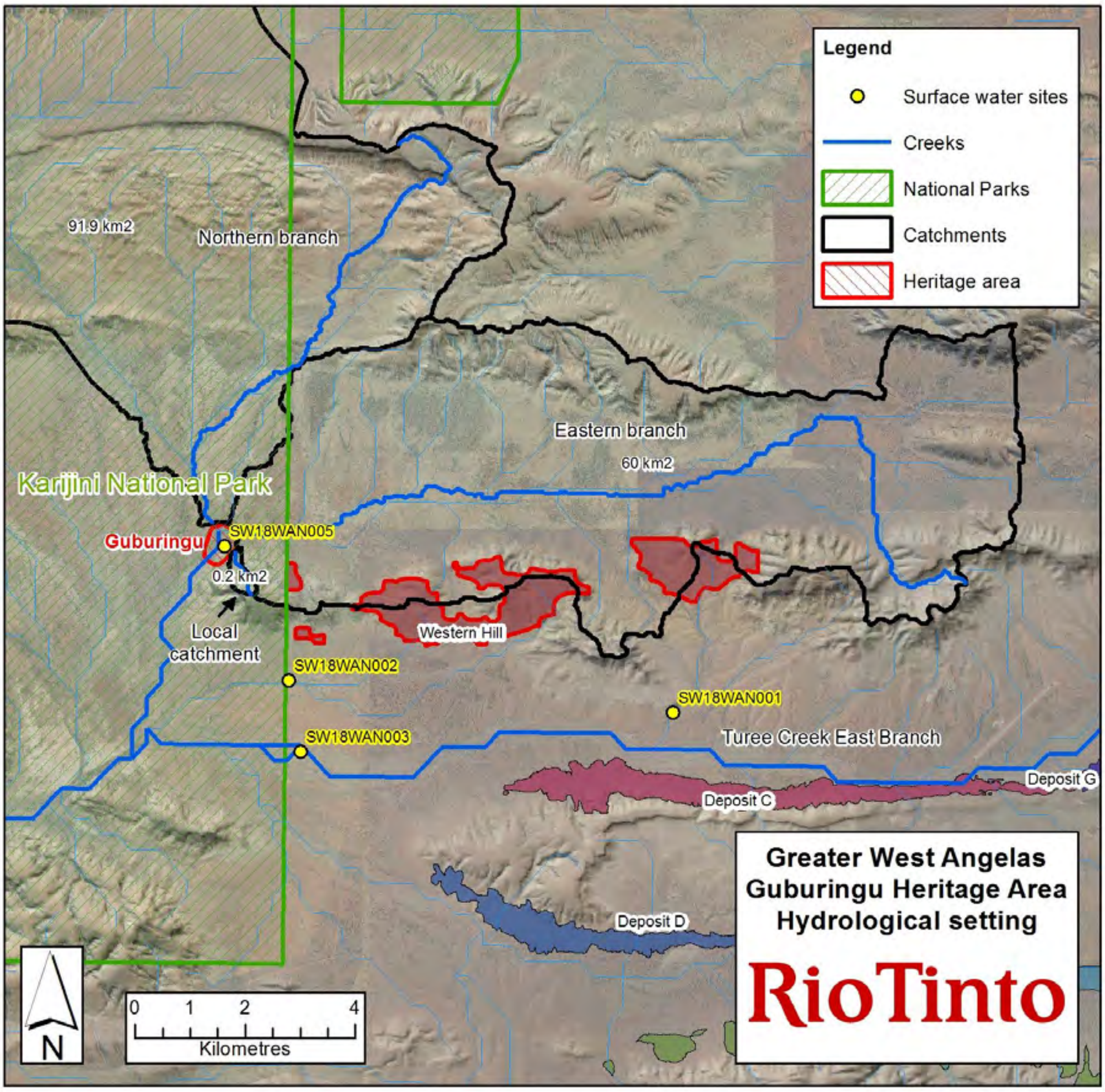


Figure 1: Guburingu site location

Site context, observations and conceptualisation

The heritage area is located within the broader Turee Creek East catchment, at the confluence of two creeks to the north and east (Figure 1).

The northern creek drains an area of 92km^2 including steep ranges, with multiple main tributaries converging on a single channel running north to south through the heritage area. High flow velocities have formed significant gravel bars and wrack accumulation in this channel. The previous investigation (RTIO-PDE-0147208) identified silty deposits through this same reach and inferred a lower energy regime, however by 2018 these had been mobilised downstream, with only coarse material present (see comparisons in Photo 1). It is likely that this reach intermittently acts as a depositional or erosional environment depending on which tributary is flowing and the magnitude of the event, resulting in interbedded clay and gravel layers beneath the channel. This is typical of Pilbara Creek systems in confluence zones with dynamic flow conditions.

The eastern branch drains a larger area of ($60km^2$) which includes the escarpment associated with Western Hill. This branch has a flatter grade relative to the northern tributary with a poorly defined low energy channel. There is also a small, but locally important tributary catchment ($0.2\ km^2$) which runs from the nearby range directly to the low flow channel of the heritage area. Erosion and scouring of the channel was observed in the steep sections of this drainage line, indicating regular high flow velocities (Photo 2).

The main channel running north to south showed no evidence of any water detention. However, the tributary channel which receives flow from the eastern branch, and the local tributary contains several depressions holding fine silty deposits (Photo 3). The longitudinal profile along the channel (Figure 2) highlights these depressions. This area is associated with enhanced vegetation growth (Photo 4) that is consistent with vegetation persistence mapping and satellite imagery (Figure 3). While there was no indication of permanent water, accumulation of recent surface silts in the tributary creek bed indicate that that this reach detains water following flow events. Interbedded silt and gravel layers in the creek bed, and availability of surface water flows from three channel branches most likely increases water availability.

Based on observations made in the field it appears that the smaller local catchment contributes flow regularly to the local depressions, which has led to accumulation of fine material, and vegetation growth. While this area detains water, all evidence suggest that the system is ephemeral, and it is unlikely that surface water is present for significant periods of time. In this respect the site is typical of similar size creeks in the area. Given the cultural significance of the site additional monitoring will be used to better understand the frequency of flow events and better establish pre-mining baseline hydrology.

Monitoring plan

A single pressure transducer (SW18WAN005) was installed in 2018 at a low point within channel (Photo 5) with the intention of long-term monitoring at this location assuming development of Western Hill with ongoing permission from Yinhawangka.

Figure 4 illustrates the water level, flow and rainfall monitoring at SW18WAN005 and West Angelas. Monitoring of the site indicates the following:

- Only one very shallow surface water flow was recorded during the 2018/19 wet season, over which rainfall was well below average, and no significant 24 hour rainfall events were recorded.
- One flow event was recorded with water depth up to 0.5m and flows estimated at ~0.8 m3/s based on a hydraulic rating of the site. Surface water was present at the logger for just under 24 hours and infiltrated rapidly following the initial peak. No significant rainfall was recorded at West Angelas for this event, so it likely resulted from local isolated falls.
- One 40mm event was recorded at West Angelas but did not cause flow in the creeks at Guburingu.
- Significant periods with no data recorded, indicating an ephemeral system.

Based on the site visits and data collected to date there is no evidence for persistently available surface or groundwater at the site. As such this location is representative of a typical ephemeral creek system.

The mining footprint covers less than 10% of the eastern catchment area. Based on site observations it is unlikely that mining in Western Hill will have an appreciable influence on the hydrology of the Guburingu site.

Yours sincerely,
Ben Marillier
Hydrologist WRE

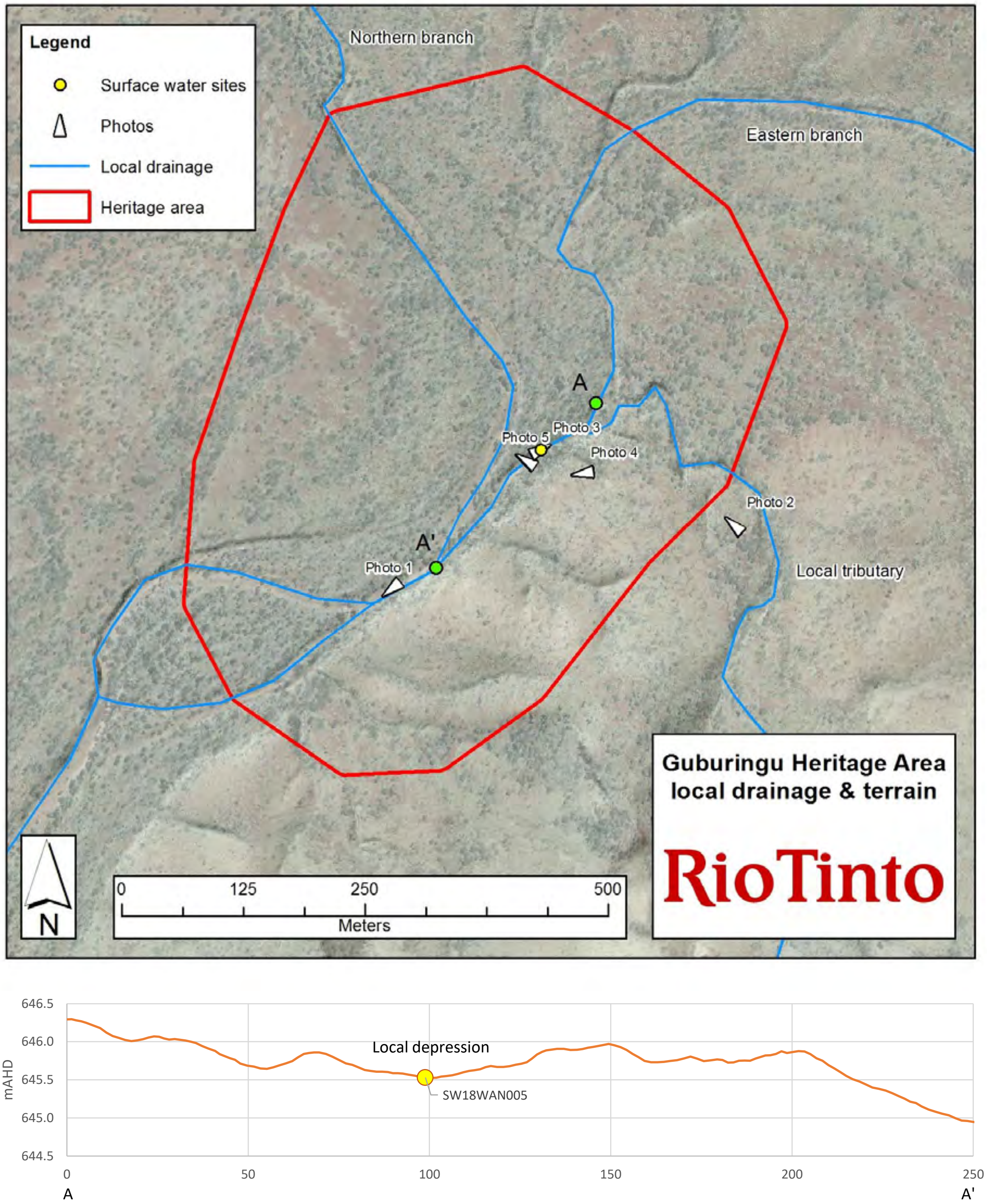


Figure 2: Local drainage within the Guburingu site and channel profile

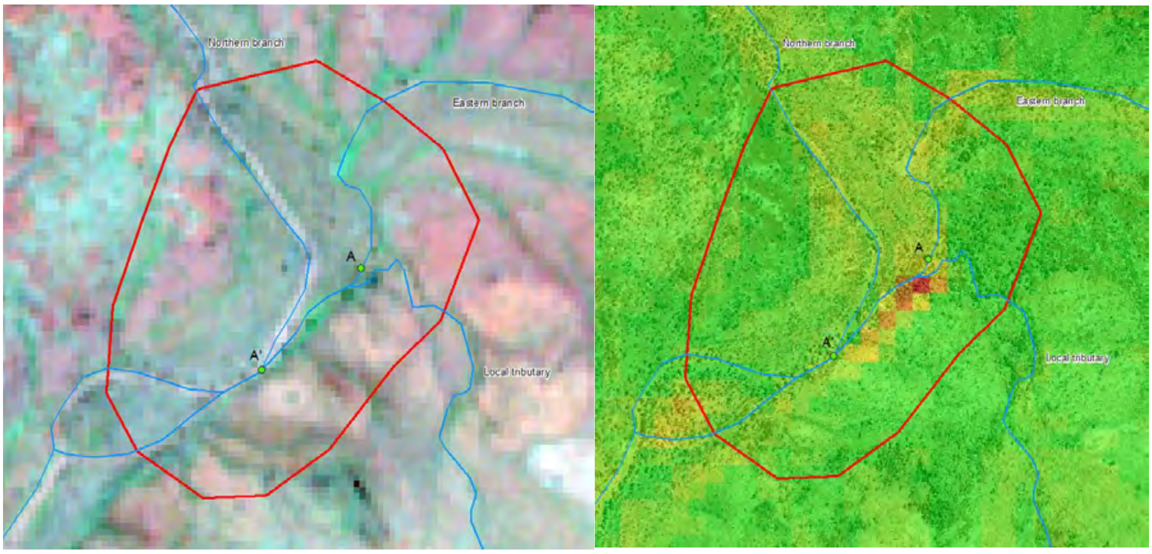


Figure 3: Left - Sentinel satellite imagery from 8 March 2018 (courtesy USGS/ESA). Right - vegetation persistence mapping – red indicates more persistently photosynthetically active vegetation (courtesy CSIRO land and water). Note that the area of enhanced vegetation is on the eastern and tributary branch along profile A-A', and not on the north-south branch.

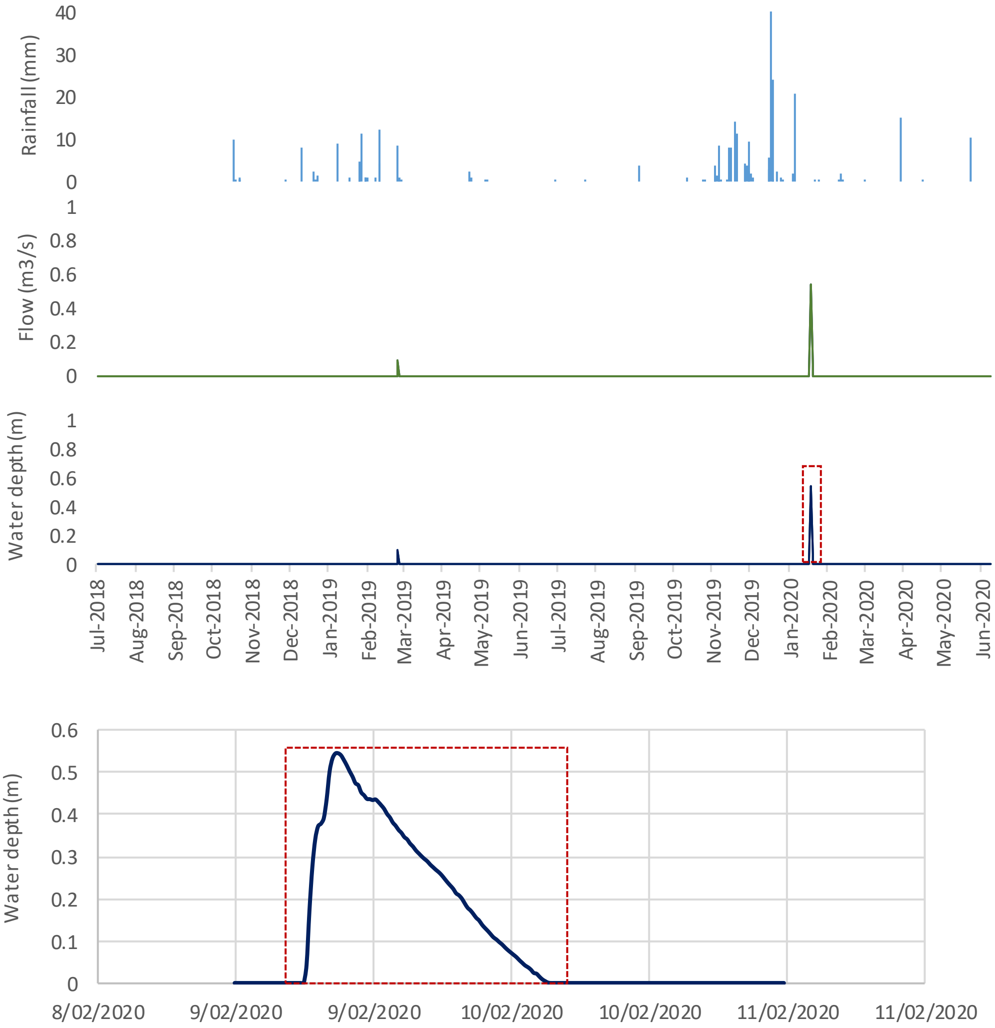


Figure 4: Stage and flow hydrographs at SW18WAN005 2018 to 2020, with rainfall hyetograph recorded at West Angelas.

Photos

July 2018

November 2016

Photo 1: Tree wrack and gravel bars in main north-south channel in 2018 (top), and photography from the same location in 2016 with silty deposits (bottom)

Photo 2: Scoured in steep section of tributary channel with evidence of bank erosion on meander bends

Photo 3: Silty material accumulated in depression

Photo 4: Main drainage line

Photo 5: Logger installation looking upstream (north)

C.3: Site inspection and monitoring of ephemeral pool, Deposit H

Internal memo

From: Ben Marillier
Department: WRES
To: David Walsh
Copies: Robert Milton, Johan Van Rensburg, Marek Janas
Reference: RTIO-PDE-0162189
Date: 1/9/2020

Site Inspection and monitoring of ephemeral pool, Deposit H

Background

The West Angelas Beyond 2020 study is investigating mining of Brockman Ores within the Deposit H mineral resource. A site walk over of the surrounding area was completed in mid-February 2018 to identify any surface water risks to mining in the area with respect to flooding and sensitive receptors. At the time of inspection a pool was sighted to the north of the proposed mining area (Figure 1). Depth to groundwater is significant throughout in the area (>20 mBGL at the lowest points), with the conclusion that is was unlikely that the pool was supported by the regional aquifer. Local terrain clearly indicated that the pool was surface water driven, with an incised gorge and waterfall system resulting in a scoured pool at the catchment outlet.

The location was flagged for further investigation and monitoring to support the approvals process. Biological and heritage surveys have been completed for the site, and it has been identified as an intermittent water source and a heritage site, but was not a significant or unique representation of either in the Pilbara. It was considered appropriate to better characterise the hydrological regime of the pool should mitigation measures or baseline hydrological data be required.

This memo describes the catchment hydrology and monitoring plan at Deposit H, and summarises observations made in the field between 2018 and 2020.

Site context

Deposit H is located in the far upper catchment of Pebble Mouse Creek, part of the regional Weeli Wolli catchment. The resource is located in an open basin of 6.3km^2 with two main catchment outlets draining northwards (Figure 2). The basin sits in an elevated position of ~800 mAHD relative to the plateau further to the north at around 800m. The steep terrain has caused gorge systems to develop along the main flow paths, incised into the surrounding ranges of outcropping Marra Mamba.

The steepest terrain is at the western extent of the deposit, and the first pool identified is located on the main creek draining this area. The hills to the east reach 950 mAHD, with the catchment outlet at an elevation close to 750 mAHD across a longitudinal distance of 3.5km. There is a vertical fall of over 20m immediately above the pool. Ponded surface water was observed at this location in both February and July 2018, .

The eastern extent of the deposit drains to a second creek, with more gently sloping terrain. There is a vertical fall of around 10m at a location which was identified as of interest with a similar topographic setting to the western catchment. However the site visit in July 2018 found that although there was evidence of a scour pool, the underlying creek bed material was unconsolidated, loose and permeable and therefore unlikely to result in any ponded water.

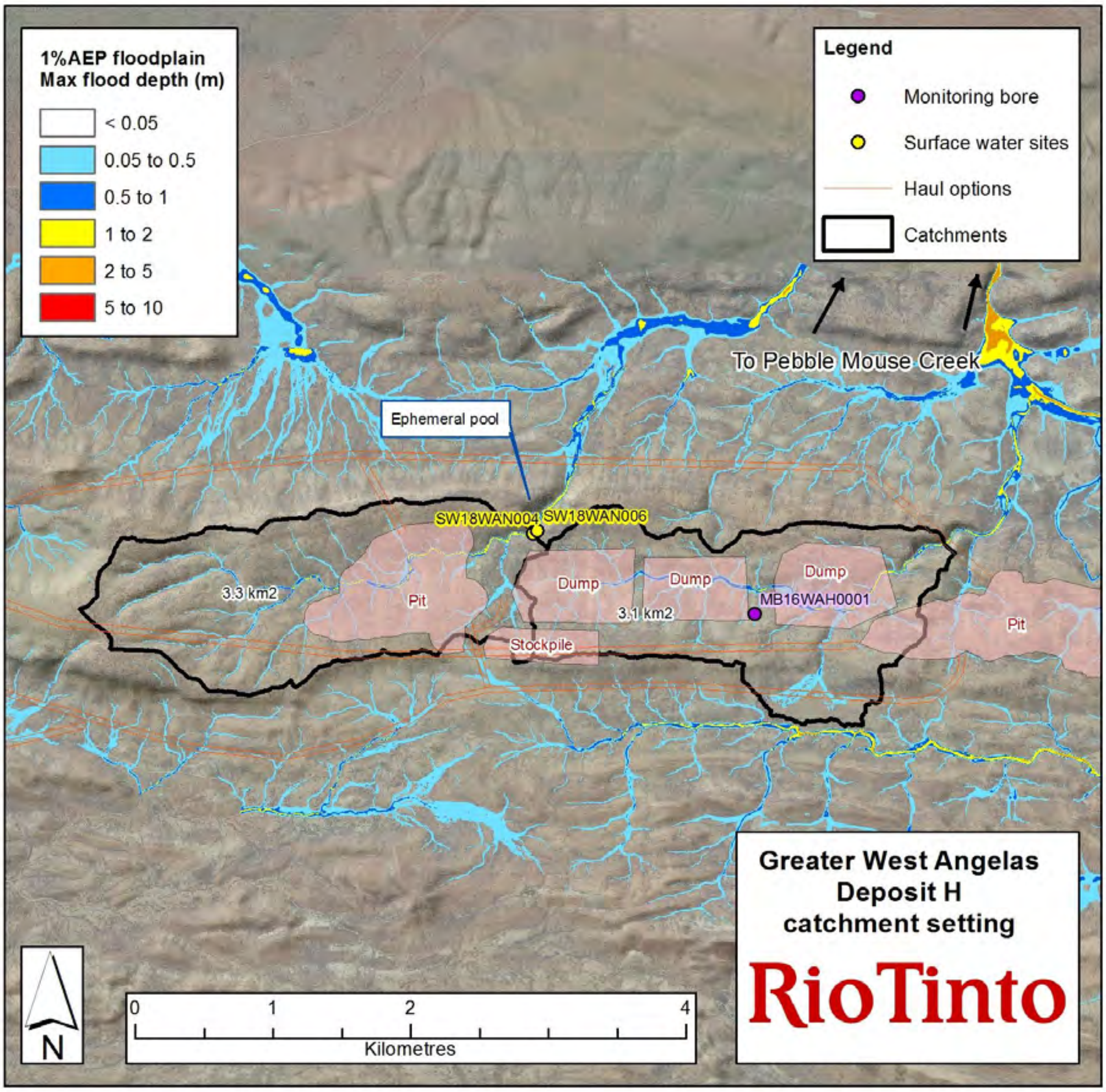


Figure 1: Deposit H ephemeral pool location, mining footprint and catchment setting

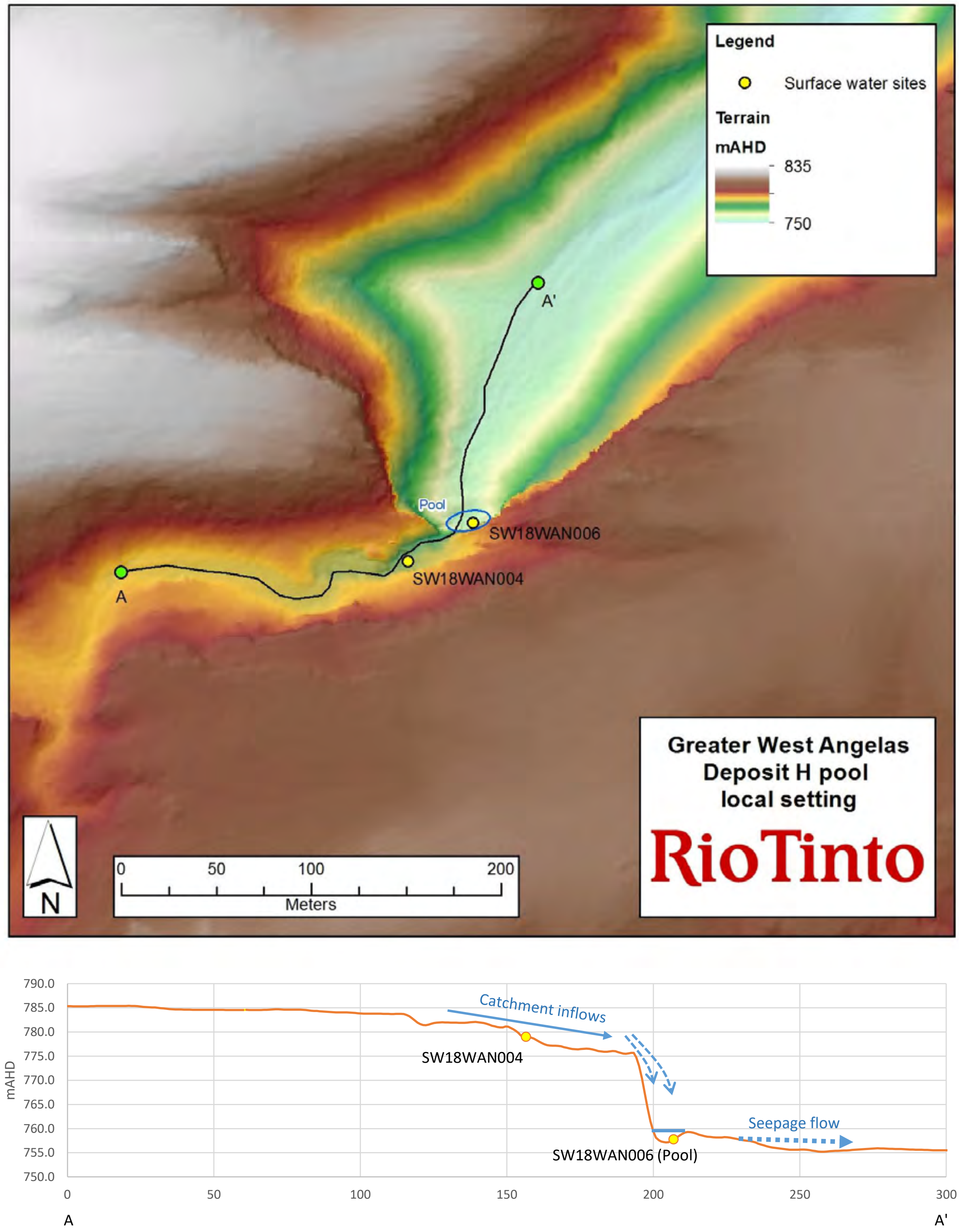


Figure 2: Deposit H local setting and profile of waterfall and scour pool system

Groundwater levels were recorded at WB18WAH0001 at 735.5 mRL which is consistent with geophysics derived water levels across the area. The pool is at 756.6 mAHD indicating that the water table is over 20m beneath the surface, and very unlikely to be providing a water source to the pool.

Observations and supporting data

16 February 2018

The western pool was found at the outlet of the gorge incised by the western creek system at the base of a 20m vertical drop (Photo 1). No flow was observed in the catchment however seepage through detrital material was visible downstream from the pool. Access to the pool is difficult and was not possible on the initial visit, but the extent of surface water was estimated at ~15m when viewed from the top of the waterfall. A pressure transducer (SW18WAN004) was installed in the contributing catchment to record flow events for the remainder of the wet season.

24 July 2018

The site was visited a second time in the dry season to install a second pressure transducer within the pool (SW18WAN006). Surface water was present in the pool, however the extent had reduced significantly from February (see Photo 2). The remnant water was sitting on an impermeable rock ledge, and was observed to be stagnant with an accumulation of algae (Photo 5). The area is enclosed and shaded (Photo 6), and it is likely that the sheltered position reduces evaporation rates, allowing for more extended retention of water following catchment flow events. The area of the impermeable rock is relatively small, and water will drain through the accumulated detrital material above a given depth, as was observed in February.

31 May 2019

The wet season of 2019/20 was very dry, with below average rainfall recorded for the year. The pool was observed to be dry when visited during May.

22 August 2020

In August 2020 water was observed in the pool at a similar extent as the July 2018 visit. The preceding wet season had about average rainfall, however only one significant rainfall event of ~40mm was recorded at West Angelas.

Photos 1-4: Comparison of the extent of water observed in February (top left) and July 2018 (top right), pool was dry in May 2019 (bottom left), and contained water in August 2020 (bottom right).

Rainfall and flow observations

Water level data was recorded between from February 2018 at site SW18WAN004 and from July 2018 at site SW18WAN006. Water levels were converted to discharge with a theoretical rating curve at SW18WAN004 to estimate volumetric inflow from the contributing catchment of the pool. Rainfall observations were available from the West Angelas benchmark weather station. Figure 4 plots rainfall and water levels for the sites over the period monitored.

Only one small flow event was recorded in the contributing catchment during February of 2018, and it is likely that the water observed in the pool resulted from flow events prior to installation of monitoring early in 2018. At the time of the first field visit on the 16th of February, 48mm of rainfall had been recorded in the previous week and it is reasonable to assume that the catchment had contributed some flow in this time. The pool had filled and was draining slowly through the detrital material to the downstream creek. By the time the site was visited in July, only a small portion of the water remained despite significant dry season rainfall in mid-June.

Over the wet season 2018/19 no water was present in the pool, and no catchment inflows were recorded.

In January 2020 wet season a single 40mm rainfall event caused flow in the catchment, with a peak flow of 1.7m^3/s and estimated volume of 2400 kL. This event completely filled the pool to a point of overtopping. Water levels were sustained above the logger level until June 2020. With remnant water observed below the logger level in August during the field visit.

The bed geometry is roughly hemispherical, with a diameter of 15m, a lowest point of 756.6 mAHD, and spill height of 759.1 mAHD, giving a total storage volume of 131 m^3. The total catchment area contributing to the pool is 3.2 km^2. Assuming a runoff coefficient from the contributing catchment of 4%, and a rainfall loss of 20mm before runoff initiation, a 40mm rainfall event would produce ~2500m^3 of water, enough to fill the pool several times over. Given the small volume of storage available in to the pool, it will likely fill on most occasions in which flow is initiated in the catchment.

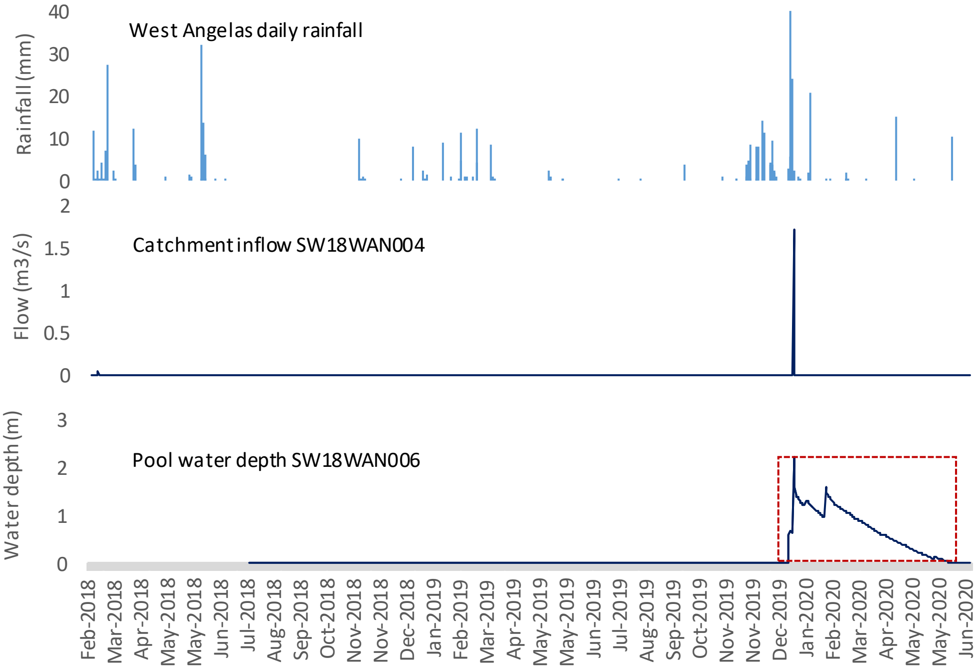


Figure 4: Rainfall, flow and water depths recorded at Deposit H pool and catchment

Potential implications and mitigation measures for mining at Deposit H

All available evidence suggests that the pool is a surface water driven feature, which operates as an ephemeral system supported by intermittent wet season rainfall and flow events. The pool is in a sheltered position, with a rock shelf covering a portion of the bed, and this results in an extended period of inundation following flow events.

Mining at Deposit H will inevitably lead to a reduction in catchment area contributing to the pool. If required, mitigation measures could be implemented to limit the reduction of catchment area and maintain flow connectivity to the pool. Two options considered during the study shown in Figure 3:

A) Retention of part-catchment area by selective dump placement and maintaining drainage lines. This option would retain 0.3km^2 of the catchment (9%)

B) Diversion of western catchment to the north of the pit. This would retain 2km^2 of the catchment (62%) with the additional benefit of providing flood protection to the western pit.

Any requirement to maintain flows will depend on the final outcomes of biological and heritage surveys, but may not be necessary. This investigation was completed as a precautionary measure, should additional information be required to support project approvals.

Monitoring plan

Two pressure transducers are installed at Deposit H. One in the low flow channel of the contributing catchment (SW18WAN004, Photo 7) to record flow. A second is installed approximately 30cm above the lowest point of the pool (SW18WAN006, Photo 8) to record pool water levels for as long as required.

Monitoring of these sites will enable further baseline hydrological characterisation if required. It is expected that the pool water level will be well correlated with surface water flows recorded upstream, with declines in storage immediately following flow events as water seeps to the downstream creek. Depending on study requirements, the data collected may be used to inform water balance modelling of the pool.

Yours sincerely,
Ben Marillier
Hydrologist WRES

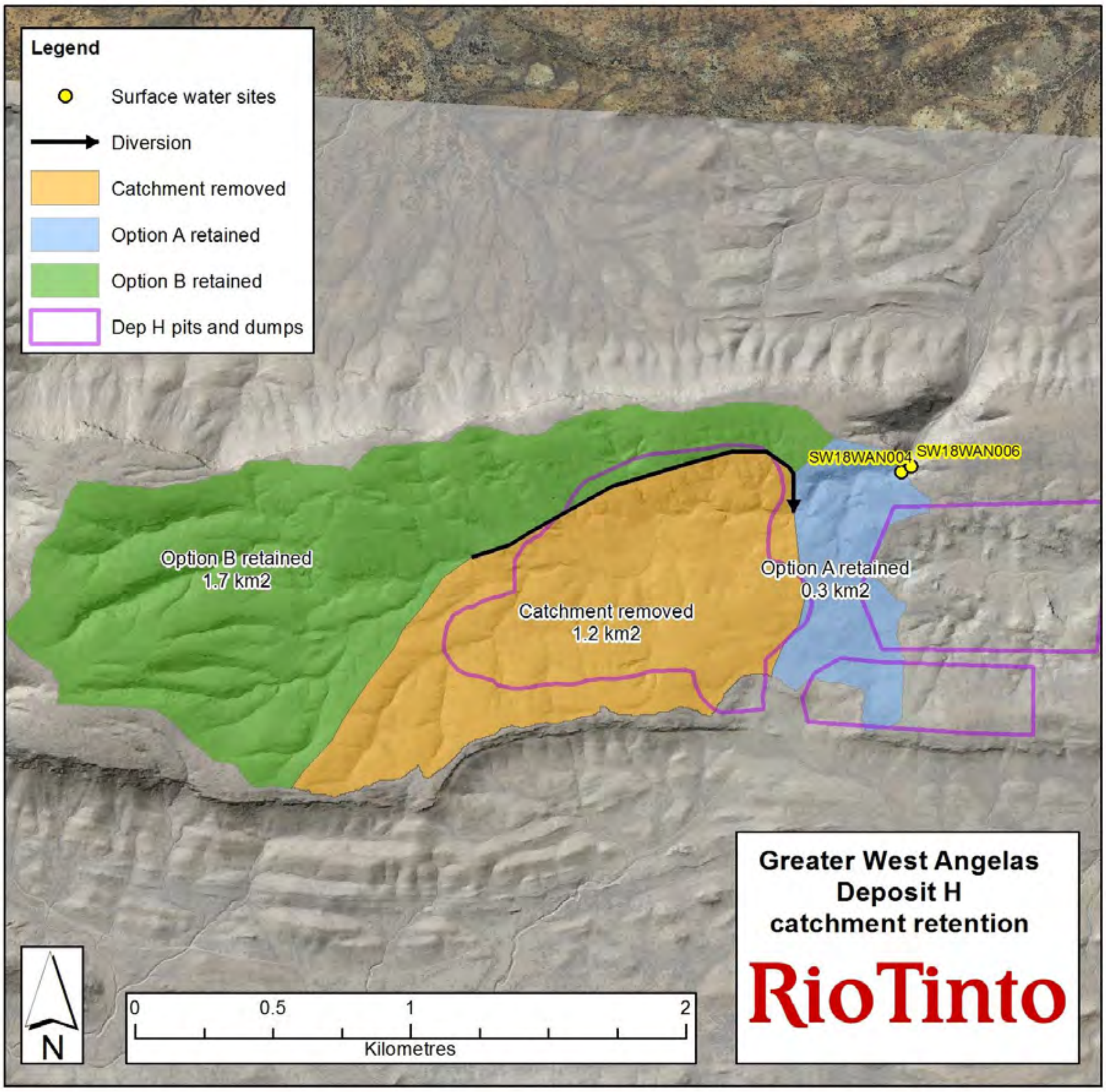


Figure 3: Options for partial catchment retention if required

Photos

Photo 5: Algae accumulating at pool (July 2018)

Photo 6: Cliffs surrounding pool area

Photo 7: Installation of SW18WAN004

Photo 8: Installation of SW18WAN006

C.4: Western Hill Hydrogeological Impact Assessment

Hydrogeological Assessment

West Angelas – Western Hill Hydrogeological Impact Assessment

10th December 2021

Water Resource Evaluation

Stakeholders:	Studies and Technology, Environmental Approvals, Department of Water and Environmental Regulation
Accountability:	Water Resource Evaluation

Version History				
Version	**Description of Changes**	**Custodian**	**Approved**	**Date**

Executive Summary

This report summarises hydrogeological investigations and supporting groundwater impact assessment modelling in support of water supply abstraction at the proposed Western Hill deposit, part of Rio Tinto Iron Ore's West Angelas Operations.

Western Hill is located 17 km north-west of the Deposit A hub at West Angelas. Western Hill is a Brockman Iron Formation deposit consisting of several ore bodies along an ~8 km E-W trending synclinal structure. Three distinct above water table (AWT) pits are planned at Western Hill, and whilst mineralisation below water table (BWT) does exist at two of these pits, no mine dewatering is proposed at Western Hill due to the potential for impact to the nearby, high conservation significance, Karijini National Park (KNP) ~1.5 km to the west of the western-most pit.

Conceptually, the hydrostratigraphy of Western Hill is rather unique, in large part due to the synclinal nature of the deposit and multiple cross-cutting faults with varying offsets. Underlying the western (Pit 1) and eastern (Pit 3) pits is mineralised Brockman Iron Formation (principally Dales Gorge member) orebody aquifer, that is surrounded almost entirely by Mount McRae shale, a low-permeability shale unit with known ability to impede groundwater flow (Hope Downs 4, Brockman 2). In select locations where significant offset of fault blocks have been identified through exploration, aquifer units of the Brockman Iron Formation is likely to be in contact with the Wittenoom Formation, which may indicate a potential for drawdown to propagate into the surrounding Wittenoom aquifer units in these areas. The Wittenoom Formation surrounding Western Hill is a regionally significant aquifer known (based upon clear groundwater level offsets of 10-15m) to be bounded to the east by a dolerite dyke, with a gradient in a westerly direction across the KNP boundary. Groundwater is shallowest in an area within Karijini National Park which is expected to be a result of local evapotranspiration loss, via a potential Groundwater Dependent Ecosystem (pGDE) and sub-surface alluvial flow beneath Turee Creek East.

Abstraction for water supply at the proposed Western Hill borefield at a rate of 1 ML/d (0.36 GL/a) is proposed to support 5 years of construction and early year operational water demand. Given the importance of KNP as a significant receptor, an assessment of drawdown potential outside of the Western Hill area is necessary. Uncertainty analysis performed on relevant aquifer hydraulic parameters found that 95% of the ~1,000 model runs that met tolerance bounds predicted no reduction in groundwater level below historic ranges at the KNP boundary. Of the 5% of model runs that returned lower groundwater levels, the minimum level reported level was 9 cm below the historically recorded lowest groundwater level at the KNP boundary.

The likelihood of drawdowns associated with proposed supply abstraction at Western Hill is considered low, with very low potential environmental consequence and high social (public and international opinion) consequence from drawdown at KNP. Therefore, to manage this risk, a Trigger Action Response Plan is proposed to ensure real aquifer response during operation is within or less than the expected range.

The proposed water supply abstraction rate was conservatively selected to minimise drawdown potential. This, in addition to the assumption that hydraulic connection between the Brockman Iron Formation and Wittenoom Formations occurs through low permeability units of the Mt McRae Shale or Wittenoom Formation means that modelling follows a risk-averse approach.

In the event of unlikely drawdowns from proposed water supply abstraction, drawdown propagation into KNP will be managed through:

- Monitoring of substantial existing and planned monitoring bores to further inform natural groundwater level variation (baseline) and validate against modelled groundwater levels.
- Commitment to adaptively manage borefield operation and react well in advance of any drawdown propagation outside of the Western Hill deposits given simulated ranges.
- Annual review and re-calibration (as required) of groundwater modelling based on actual groundwater levels, and subsequent re-assessment of uncertainty analysis if deemed necessary.
- Reporting of relevant groundwater levels, production and chemistry data in annual aquifer reviews.

Contents page

1. Introduction

This report summarises hydrogeological investigations and groundwater impact assessment modelling in support of water supply abstraction at the proposed Western Hill deposit, part of Rio Tinto Iron Ore's West Angelas Operations.

The Western Hill Deposit is within Rio Tinto Iron Ore's West Angelas mining hub. Three distinct pits (Pits 1, 2 & 3) are proposed within the deposit to be mined from 2024 to 2036. None of the pits progress below the water table. This report provides an assessment of the potential impacts stemming from proposed local mine water supply abstraction at Western Hill. The general layout of Western Hill and its location within the West Angelas mining hub is shown in Figure 1.

Groundwater is present within the mineralised areas of each pit typically at a depth of greater than 50 m below ground level across Western Hill. Whilst depth to groundwater varies substantially due to deposit topography, the groundwater level is relatively consistent within and outside the deposit area, from 624.5 m AHD in the east to 623.5 m AHD in the west, inferring a westerly flow direction. These groundwater levels are consistent with groundwater levels at Deposit C (with mineralisation hosted in the Marra Mamba Iron Formation) immediately South of Western Hill.

Groundwater abstraction at West Angelas is licenced under Groundwater Licence GWL98740(12) issued under the Rights in Water and Irrigation Act 1914 (RiWi Act) and administered by the Department of Water and Environmental Regulation (DWER). GWL98740(12) permits groundwater abstraction over the West Angelas mining hub (AML 70/248) for purposes including dewatering, dust suppression, exploratory drilling, campsite purposes, power generation, reinjection and industrial processing. The licence was granted in October 2019 and is licenced to 31st of October 2029. The West Angelas GWL licence allows for abstraction of 14 GL/year, with operating commitments for the GWL outlined in the West Angelas Groundwater Operating Strategy (GWOS).

This assessment summarises investigations undertaken to date, and, provides a hydrogeological framework that was used to inform a conceptual model in-turn to support the development of a sub-regional scale analytical impact assessment model of water supply abstraction associated with the Western Hill deposit.

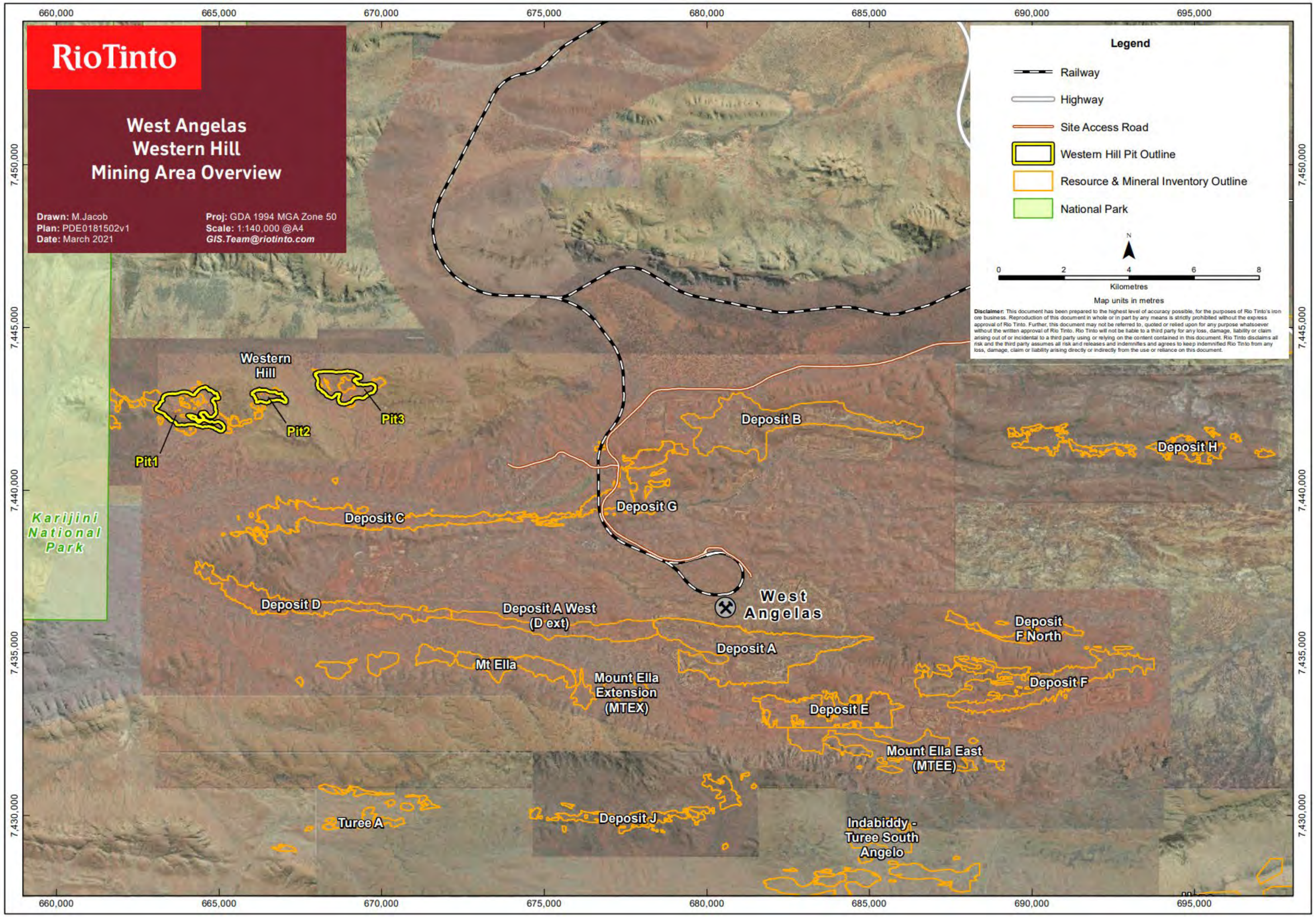


Figure 1: West Angelas Western Hill mining area overview.

2. Physical Setting of Study Area

2.1 Geology and Topography

2.1.1 West Angelas

The West Angelas mining hub is located on the western hinge of the Wonmunna Anticline with deposits situated on the northern and southern limbs of the anticline. Locally, the Nammuldi Member of the Marra Mamba Iron Formation (MMIF) presents in the outcropping hinge of the anticline, overlying the Fortescue Group basement formation. The limbs are characterised by steeply plunging MMIF including Nammuldi, MacLeod and Mt Newman Members. Wittenoom Formation, that is often overlain by detrital cover, characterises the valley between the MMIF anticline and the higher elevation Brockman Iron Formation (BIF) that encompasses the Wonmunna Anticline.

The stratigraphic sequence of the Hamersley Group is summarised in Table 1. Mineralisation occurs in both the Brockman Iron Formation (primarily the Dales Gorge Member) and the MMIF (primarily the Mount Newman Member). A regional north-east to south-west trending dolerite dyke has been mapped and is known to act as aquitard and compartmentalise bedded stratigraphies on the northern limb of the anticline. Several localised dolerite dykes, trending north-west to south-east have also intruded the MMIF, Wittenoom and BIF formation in the area, with these dykes capable of acting as aquitards compartmentalising aquifer units.

Several mineralised orebodies (both green and brownfield development) exist at West Angelas, with the pits at various stages of mining, including: Deposit A, B, C, D, E, F and G , all of which are Marra Mamba deposits, in contrast to Western Hill, a Brockman Iron Formation deposit. Refer to Figure 1 for pit locations.

Table 1: West Angelas – Stratigraphy.

Group	Formation	Member	Description
Hamersley Group	Brockman Iron	Joffre	Planar bedded to poddy BIF with minor shale interbeds
		Whaleback Shale	Shale, BIF and chert
		Dales Gorge	BIF and shale interbedded. Primary ore horizon.
	Mount McRae Shale	-	Carbonaceous shale, chert and minor dolomitic shale.
	Mount Sylvia	-	BIF / chert and shales. Uppermost BIF unit – Bruno's Band.
	Wittenoom	Bee Gorge	Calcareous shales, with minor cherts, volcaniclastics and BIF
		Paraburdoo	Predominantly crystalline dolomite with minor chert bands
		West Angela	Shale, chert, dolomite with a BIF dominant zone toward its base
	Marra Mamba Iron	Mount Newman	Podded BIF with interbedded carbonates and shales. Major ore bearing horizon.
		MacLeod	BIF, chert, carbonates and shales
		Nammuldi	Thick bedded, poddy, cherty BIF
Fortescue Group	Jeerinah	-	Interbedded chert, shale, dolomite and a high density of intruded dolerite sills (up to 50%).

2.1.2 Western Hill

The Western Hill deposit is a Brockman Iron Formation (Mineralised Dales Gorge Member) hosted deposit with minor mineralisation present in overlying mature detritals. The deposit itself consists of several orebodies along an ~8 km E-W trending synclinal structure and is situated 3 km north of the planned Deposit C crusher hub at West Angelas.

There are two discrete ore bodies of the Western Hill deposit (west and east) (Figure 2). The western ore body (Pits 1 and 2) comprises an east-west trending syncline with a significant normal fault offsetting the eastern half upwards relative to the western half, resulting in a deep mineralised valley of Dales Gorge Member overlain by detrital units. The eastern ore body (Pit 3) consists of a northwest-southeast-east trending syncline of mineralised Dales Gorge Member overlain by a thick (up to 50 m) sequence of detritals. Northwest-southeast trending dolerite dykes are known to intersect the deposit.

Each ore body is surrounded in all directions by Mount McRae Shale, with the underlying Wittenoom Formation comprising the regional aquifer unit. Significant faults existing in each ore body result in offsets between geological units, as evidenced by modelled offset gaps in the Mount McRae Shale (cross-section view in Figure 7, plan view in Figure 11).

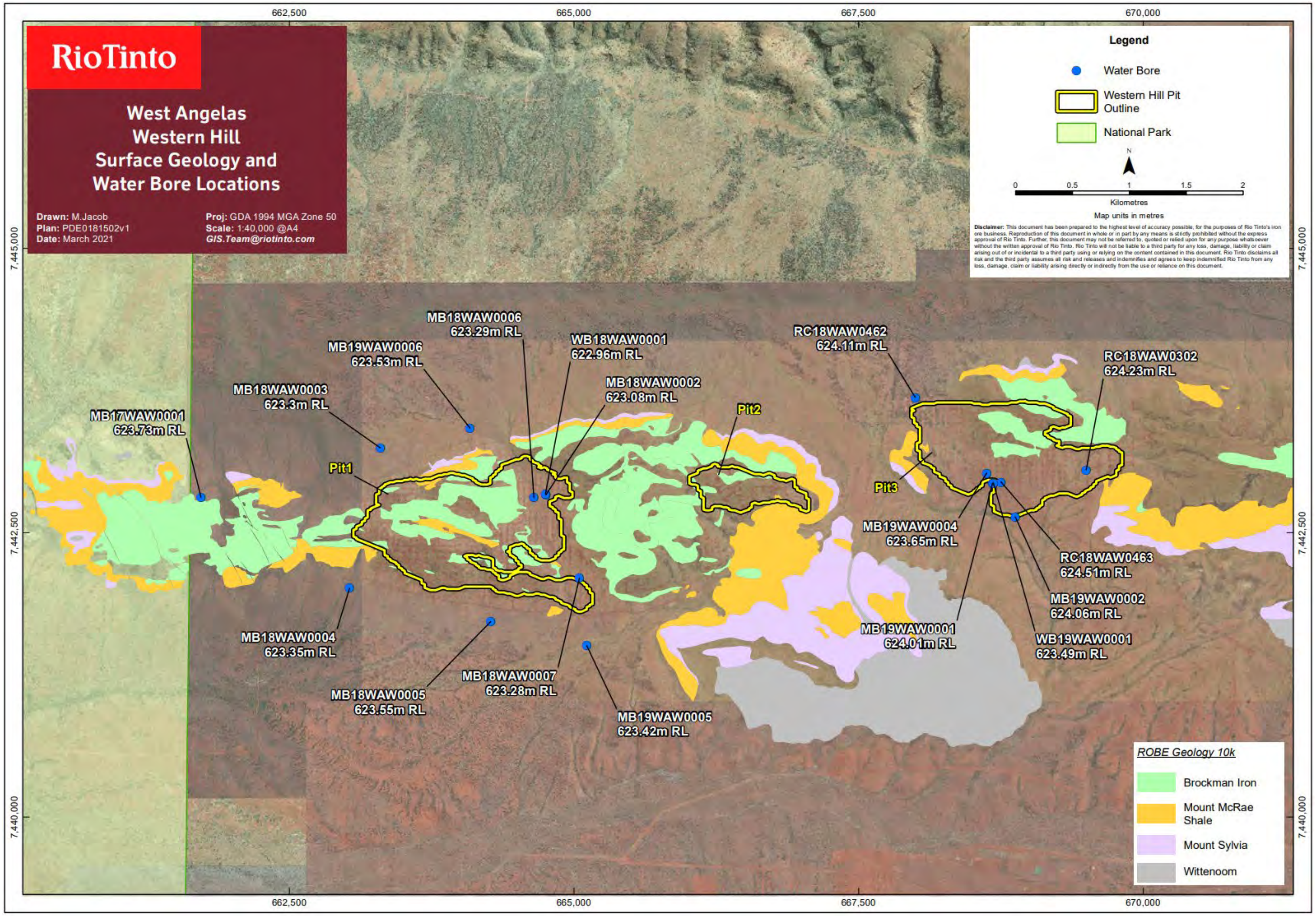


Figure 2: Marra Mamba West mapped surface geology and water bore locations.

2.2 Climate and Rainfall

The Pilbara region is classified as a semi-arid climate, typed as BWh under the Köppen climate system. The region is characterised by very hot summers with daily temperatures often in excess of 35° C and mild winters with low overnight temperatures. Rainfall is dominated by a wet-dry cyclical pattern, rainfall occurs predominantly through the months of December to March with the winter months experiencing little to no rainfall. Rainfall is predominantly through localised thunderstorms and tropical depressions that form off the north-west coast of Western Australia. Extreme rainfall events associated with tropical cyclones can result in rainfall of over 200 mm within a 24-hour period, which can often lead to large excess of runoff, generating large flood events that drive stream flow in the region. Pan-evaporation in the region can reach in excess of 3,000 mm/year, far exceeding rainfall.

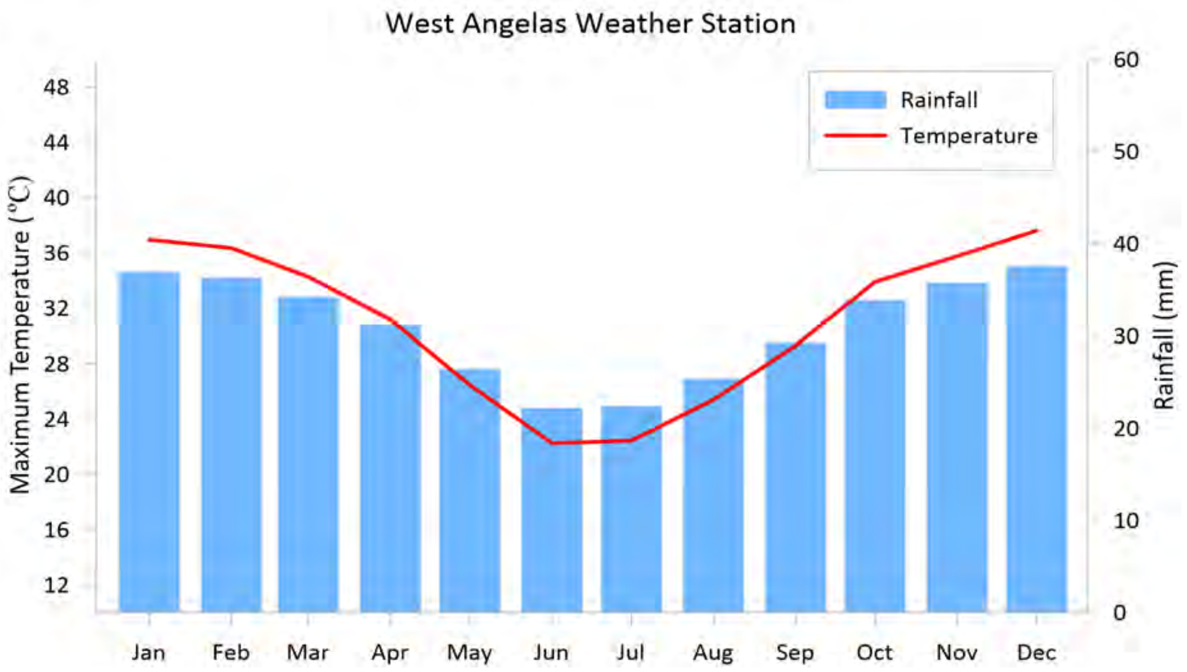


Figure 3: West Angelas Weather Station Rainfall Data (January 2004 to December 2019).

2.3 Hydrology

Western Hill is in the upper reaches of the Turee Creek East catchment – a tributary of Turee Creek. The deposit sits in an elevated position and intercepts a few minor catchments (<0.5 km^2 in area) associated with steep drainage that convey runoff to two main creeks located to the north and south of the deposit. These creeks flow in a westerly direction into Karijini National Park.

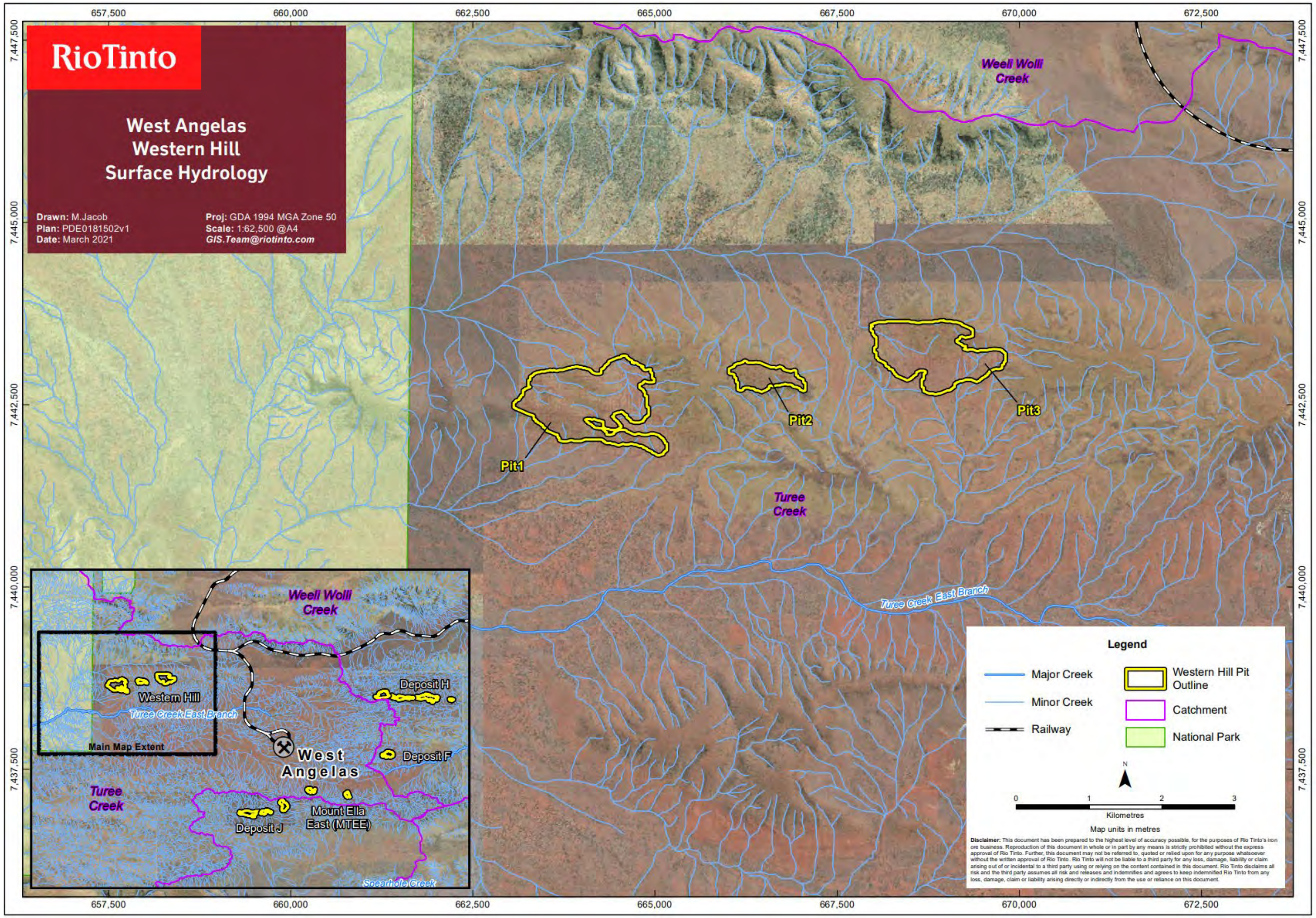


Figure 4: Pre-mining surface water hydrology in the Western Hill vicinity.

3. Hydrogeology

3.1 Hydrostratigraphy

Groundwater occurrence within Western Hill has been informed through information garnered from hydrogeological drilling campaigns undertaken between 2016 and 2019, and from other groundwater related data sourced from grade hole geophysics, test pumping activities, and assessment of deposits with analogue hydrogeological settings to inform the broader conceptualisation.

The relevant geological formations and their hydrogeological characteristics are detailed below, illustrated in cross-section in Figure 5 to Figure 8, and in plan view in Figure 11:

- **Detritals**: A thin layer of sediment comprising gravels, mudstone and clays overlying the Hamersley Group bedrock. The detritals are unsaturated throughout the Marra Mamba West area however may partially saturate in areas following significant rainfall events.
- **Brockman Iron Formation**: Comprised of interbedded BIF, chert and shale. Groundwater is predominantly associated with secondary porosity developed through mineralisation of BIF and fractures. Where mineralised, Brockman Iron Formation orebodies tend to form discrete orebody aquifer units surrounded by relatively less permeable BIF and shale units. The Brockman Iron Formation comprises the Joffre (JOF), Whaleback Shale (WBS), Dales Gorge and Footwall Zone (FWZ) members. Where unmineralised, generally associated to be of low permeability and low storage, and even act as an aquitard to groundwater flow.
- **Mount McRae Shale (MCS) / Mount Sylvia Formation (MTS)**: The Mount McRae Shale is generally observed to have low permeability and act as an aquitard. At Western Hill, the Mount McRae Shale almost entirely surrounds both the western and eastern pits, with the exception of where fault blocks have caused significant offset gaps in the shale.
- **Wittenoom Formation**: A thick succession of chert, shale and dolomite that lies to the north and south of the Western Hill area. Groundwater is generally associated with secondary porosity associated with fractures and faulting, and subsequent karstic dissolution predominantly within the dolomitic Paraburdoo member.
- **Marra Mamba Iron Formation**: A predominantly BIF formation and where un-mineralised is of low permeability. Where mineralised or fractured, permeability is significantly increased. Mineralised Marra Mamba Iron Formation may be in hydraulic connection to the overlying Wittenoom Formation, however this can be variable depending on the dip, mineralisation and hydraulic properties of the West Angela Member (Wittenoom Fm). The unmineralised lower members of the Marra Mamba Iron Formation (MacLeod and Nammuldi Members) typically create a hydraulic barrier between the Fortescue Group and the Marra Mamba Iron Formation/Wittenoom Formation aquifer units as has been observed to the south of Western Hill in the Deposit C area.
- **Dolerite Dykes**: Intrusive dolerite dykes are known to have potential to compartmentalise groundwater systems and act as impermeable barriers to groundwater flow.

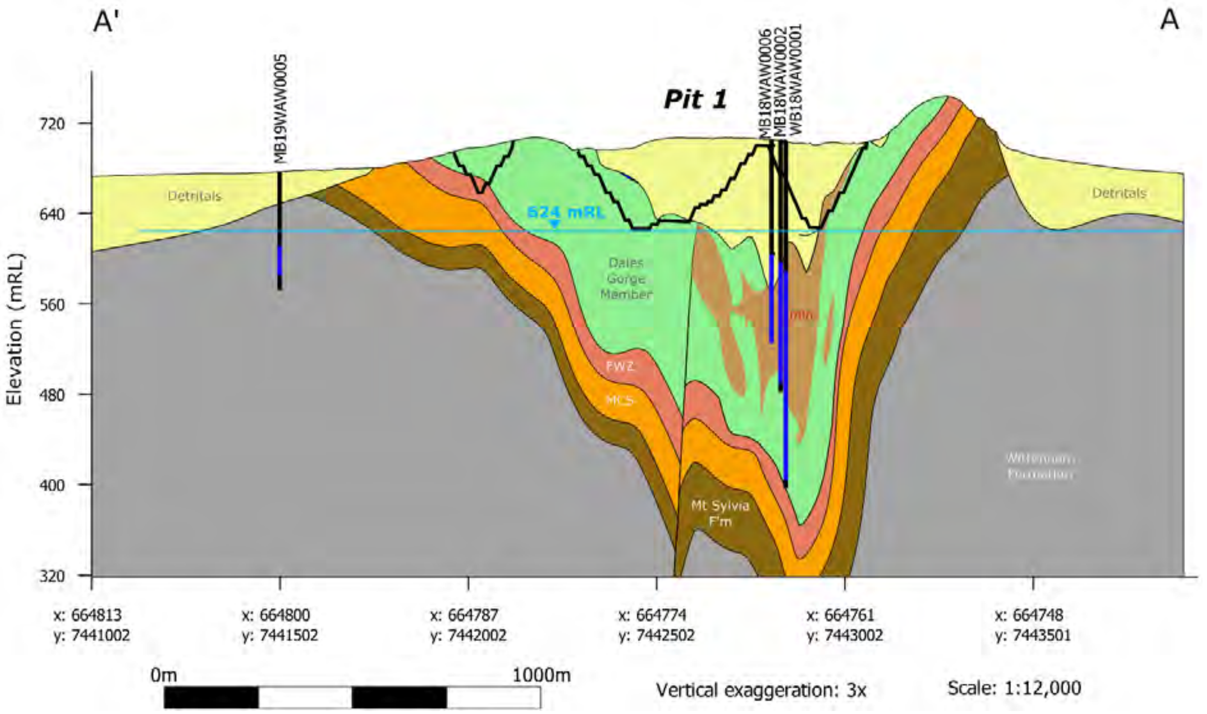


Figure 5: Geological north-south cross-section of Western Hill Pit 1 (cross-section alignment shown in Figure 11), looking west. Bore slotted intervals shown in blue.

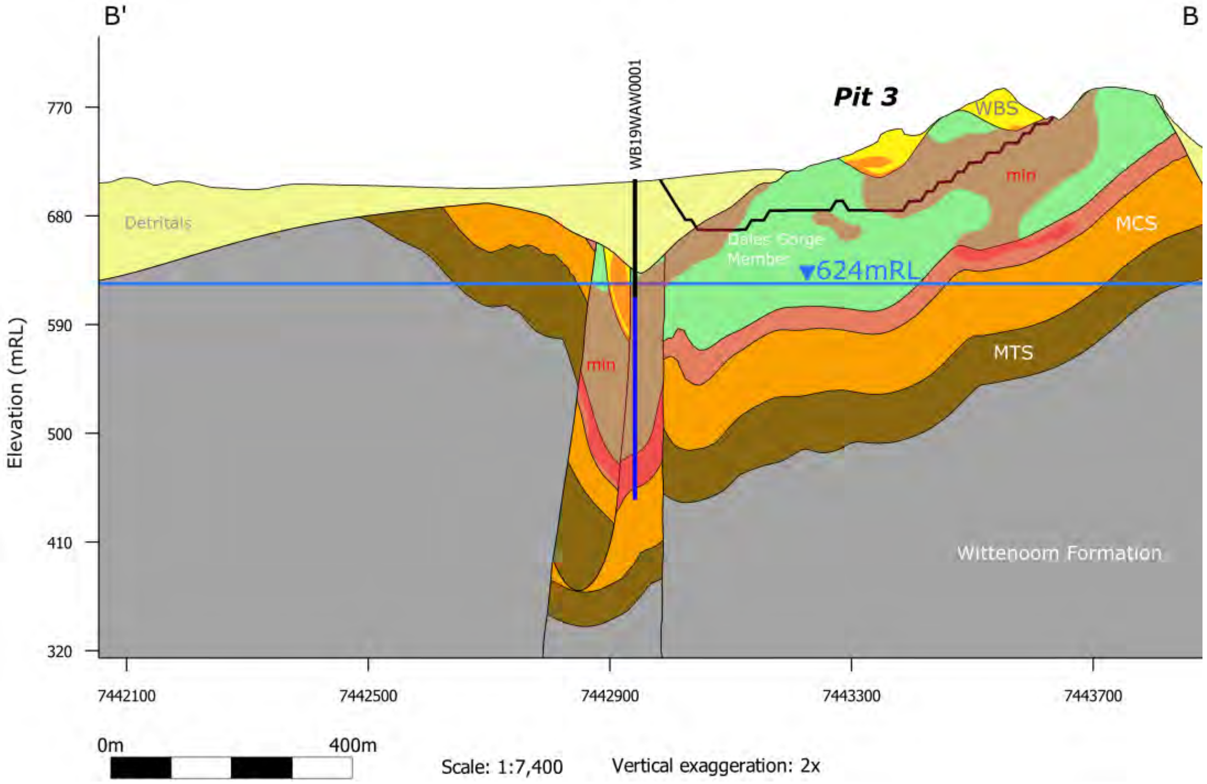


Figure 6: Geological north-south cross-section of Western Hill Pit 3 (cross-section alignment shown in Figure 11), looking west. Bore slotted intervals shown in blue.

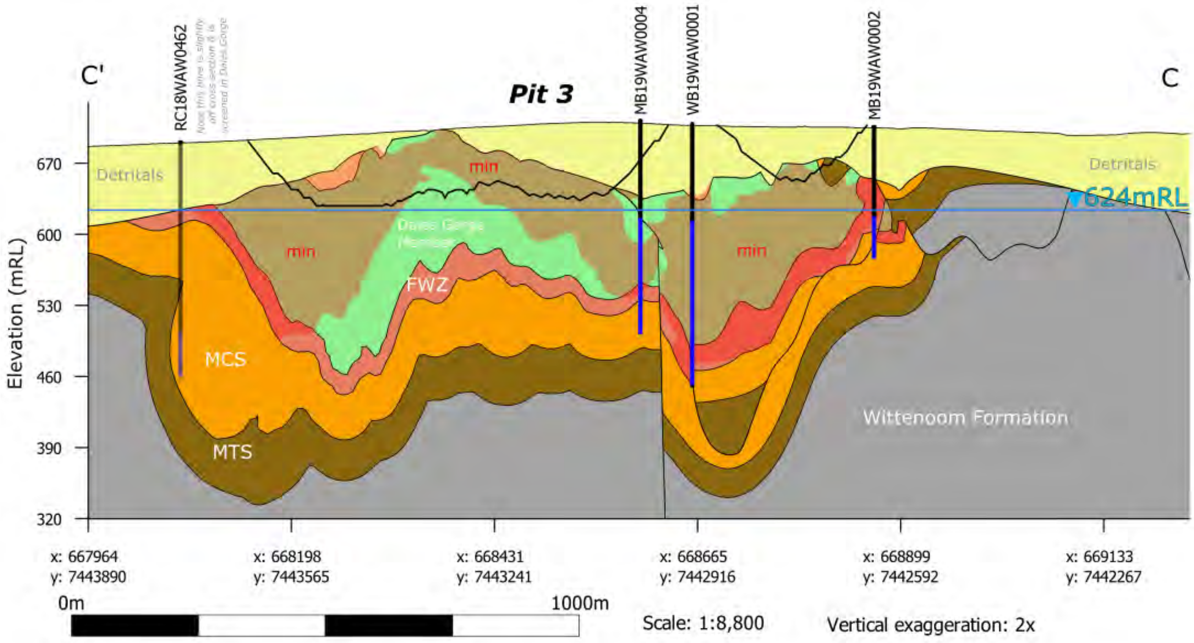


Figure 7: Geological cross-section of Western Hill Pit 3 through offset gap in Mount McRae shale (cross-section alignment shown in Figure 11), looking west. Bore slotted intervals shown in blue.

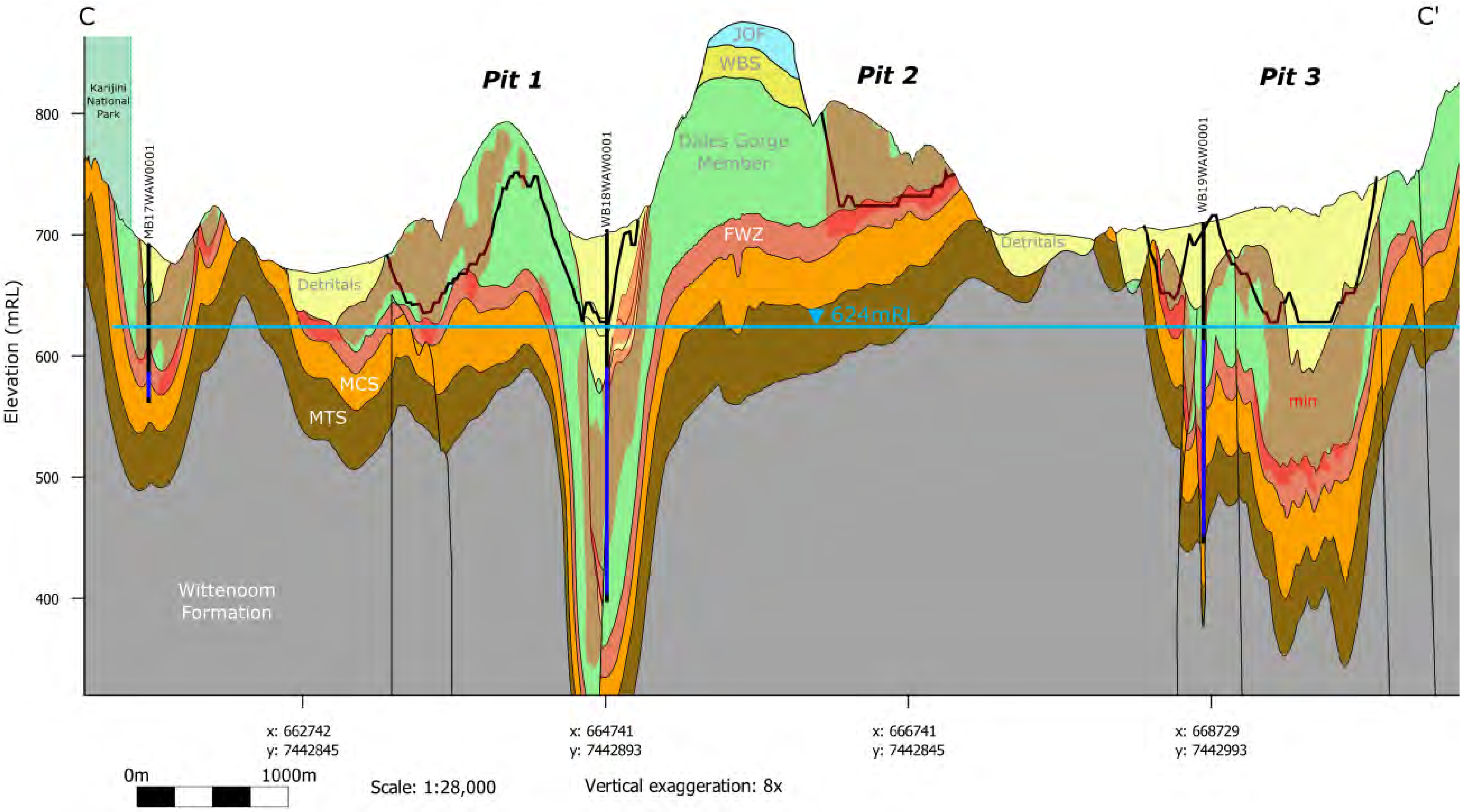


Figure 8: West to east cross-section through Western Hill pits. Bore slotted intervals shown in blue.

3.2 Groundwater Flow Regime

Groundwater levels at Western Hill are known to be in hydraulic connection to some extent with the regional Wittenoom Formation that surrounds the Brockman Iron Formation deposit. The Wittenoom Formation surrounds each pit on all sides on the exterior of the Mount McRae Shale. The southern Wittenoom Formation is hydraulically connected to the Deposit C orebody aquifer, and the Wittenoom Formation to the north is conceptually bounded by a Marra Mamba Iron Formation range 3.5 km to the north of the pits.

A regionally significant dolerite dyke exists to the east of Western Hill that is known to impart a 13 m head difference across it and act as an aquitard (REF WADCD H3 Report). The groundwater table relatively flat across the Western Hill area at approximately 624 mAHD, however a slight gradient can be interpreted in a westerly direction (Figure 11). The Wittenoom Formation surrounding Western Hill is inferred to flow through an alluvial channel beneath Turee Creek East approx.. 9 km south-west of Pit 1 in an area of shallow groundwater within KNP.

No abstraction induced drawdown has yet been observed in the Wittenoom Formation domain that is hydraulically connected to Western Hill. However, from 2021 the Deposit D managed aquifer recharge (MAR) scheme is scheduled for implementation (RTIO, 2021 WA EMP), which will act to support groundwater levels in the area of the MAR scheme to ensure no drawdown across the KNP boundary.

Groundwater levels in the Pit 1 area range from 623.0 - 623.7 mRL, as illustrated in Figure 9. Groundwater level data is informed from monitoring bores, however lower confidence grade hole geophysics intercepts were used initially to inform the conceptualisation. The groundwater level trend (Figure 9) shows minor variation across the monitoring bores attributed to natural variations in barometric pressure.

Hydrographs for bore’s show no water level difference attributable to the screened formation (Figure 10), as opposed to the location (east or west) of the monitoring bore (Figure 9). The inference from this observation being that both pits are hydraulically connected to some extent with surrounding formations.

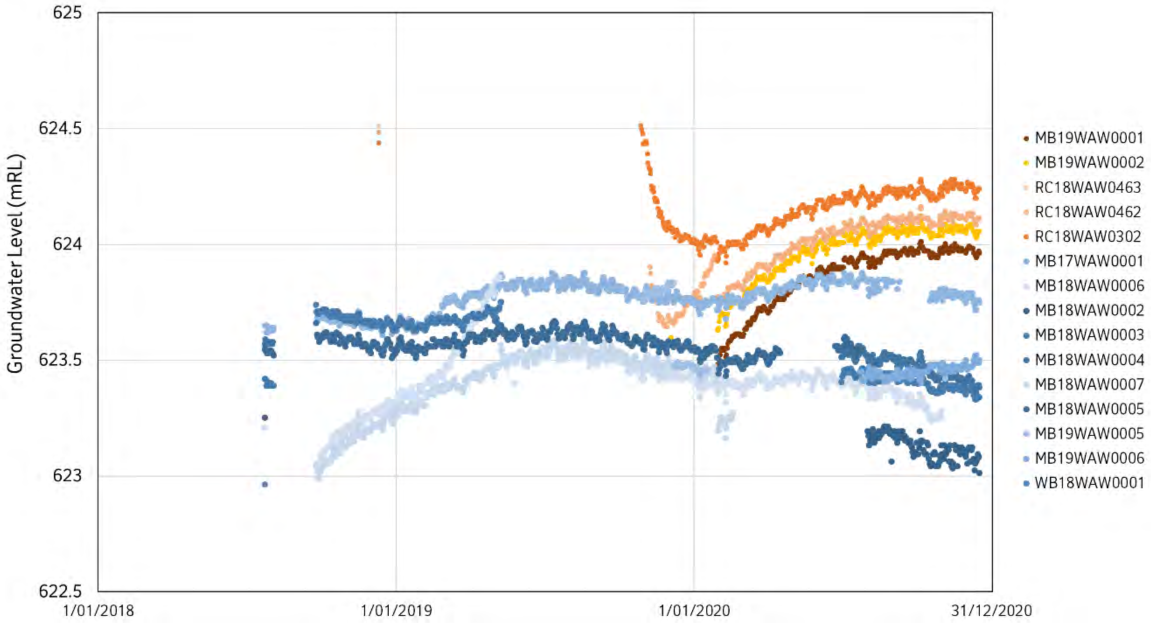


Figure 9: Hydrograph of Western Hill groundwater levels split between bores located near the eastern pit 3 (orange accent) and western pit 1 (blue accent).

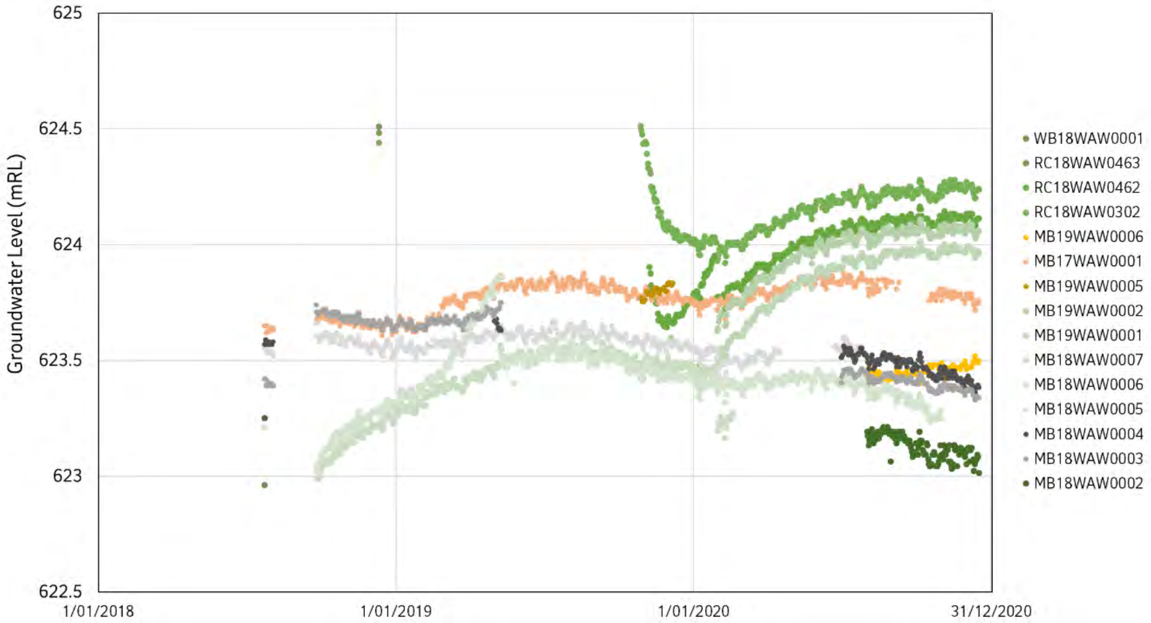


Figure 10: Hydrograph of Western Hill groundwater levels split between bores screening Wittenoom Formation (grey accent), Brockman Iron Formation (green accent), Mount McRae Shale (orange accent) and detritals overlying the Wittenoom Formation (yellow accent).

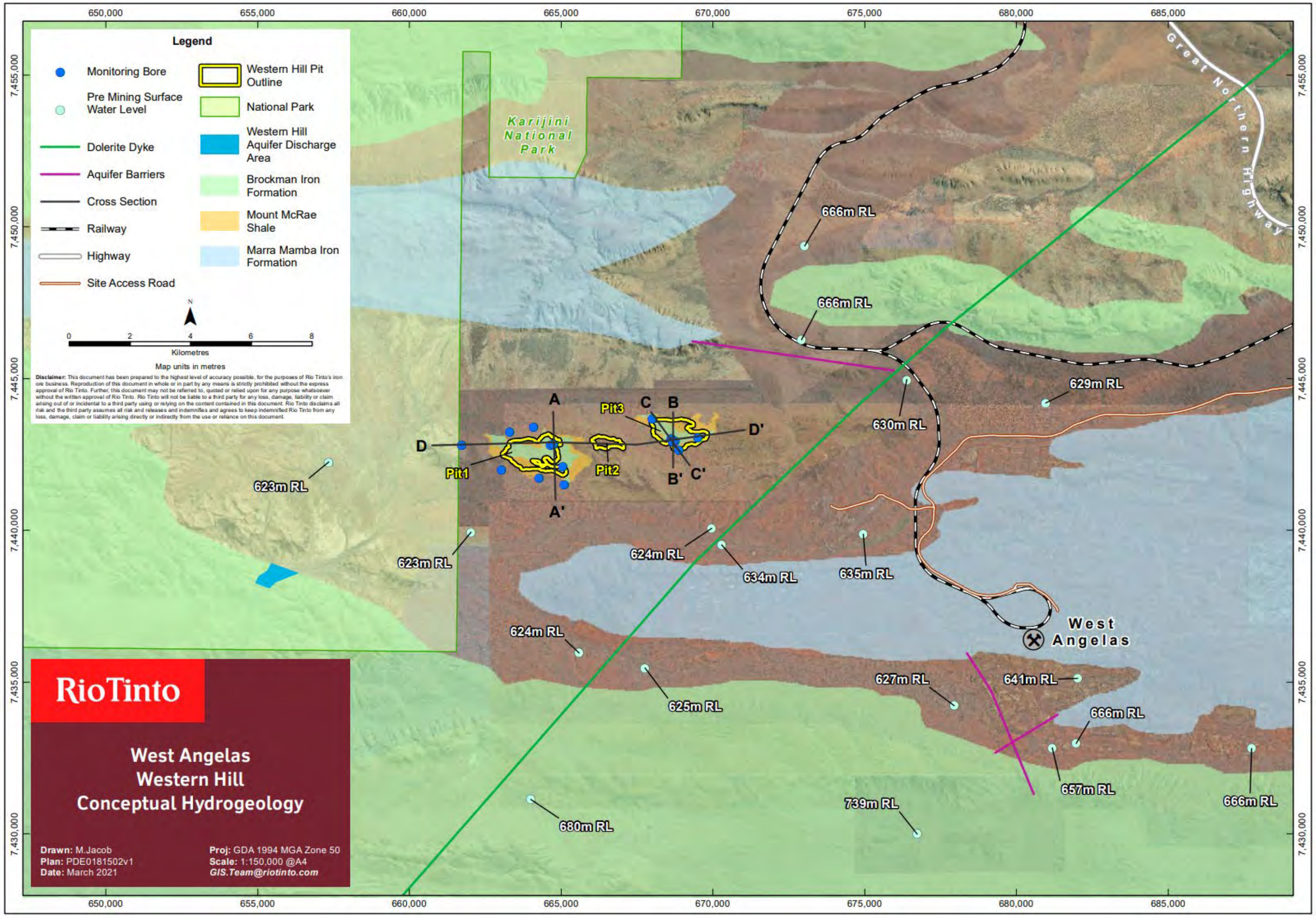


Figure 11: Plan view of conceptual hydrogeology of area surrounding Western Hill with representative pre-mining groundwater levels shown.

3.3 Hydrochemistry

3.3.1 Sample collection / analysis method

The following are the available hydrochemical analysis datasets for Western Hill:

- 2018: Samples collected during test pumping of the 2018 drilled production bore WB18WAW0001.
- 2019: Samples collected during airlifting of monitoring bore MB19WAW0002 and test pumping of the 2019 drilled production bore WB19WAW0001.

A summary of the major ions analysed is presented in Table 2. Analyses of available hydrochemical data was conducted using an expanded Durov plot (Figure 12), which is used to broadly classify hydrochemistry to ascertain relatively dominant ionic species.

3.3.2 Results of hydrochemical sampling

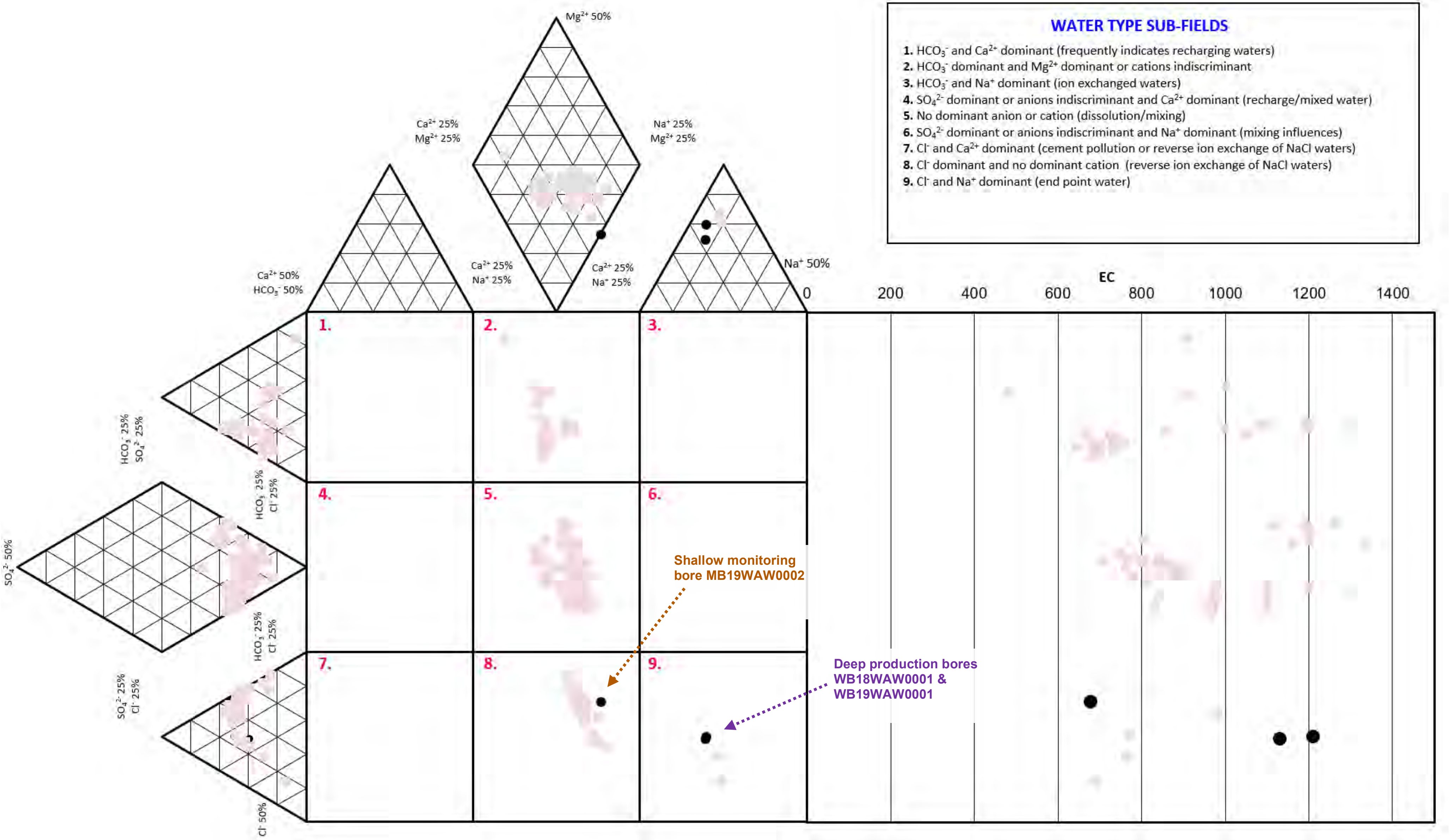
The limited groundwater chemistry available for Western Hill was sampled from three bores screened over the Brockman Iron Formation. All three of these samples indicate that chloride (Cl) is a dominant anion as indicated in Figure 12. The two production bores located in separate east and west ore bodies of Western Hill have very similar groundwater chemistry (Table 2 & Figure 12), with elevated electrical conductivity, chloride and sodium in comparison to the monitoring bore MB19WAW0002. Referring to Figure 7 and Figure 8, in addition to Table 9, the major difference between the production and monitoring bores is the screened depth. The monitoring bore is screened at a shallow depth of 88 – 130 m across the Dales Gorge Member, whilst the nearby production bore WB19WAW0001 is screened from 114 – 300 m, and WB18WAW0001 in the western ore body is screened from 96 – 258 m. The increased conductivity and chloride concentration in the deeper production bores is inferred to be caused by the encasing low permeability Mount McRae Shale that largely limits groundwater throughflow to the deeper Brockman Iron Formation, thereby groundwater residence time is increased. In contrast, the shallow monitoring bore is screened just below the groundwater level (~ 82 m depth to water) and is likely to experience a greater velocity of groundwater throughflow.

It is notable that the Durov grouping (Figure 12) of the deeper production bores is relatively unique (shared only with groundwater samples from a hydraulically isolated deposit) compared to the remainder of Greater West Angelas groundwater quality samples. Whereas the shallower monitoring bore has a groundwater chemistry more akin to elsewhere across Greater West Angelas (Figure 12).

The groundwater chemistry informs the conceptualisation by indicating there is a likelihood that groundwater within Western Hill is connected at least to some extent to groundwater outside Western Hill as shown by the similarity in chemistry between the shallow monitoring bore and other regional bores. However, the chemistry from the deeper production bores indicates that connectivity to the surrounding Wittenoom Formation may decrease with depth.

Table 2: Summary of chemical characteristics of groundwater for Western Hill.

Bore ID	Screened Formation	Sample Date	EC	Cl	SO_4	HCO_3	Ca	Mg	K	Na
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
WB18WAW0001	Brockman Iron	2/08/2018	1,210	264	143	46	30	36	15	116
WB19WAW0001	Brockman Iron	1/11/2019	1,130	272	110	52	39	32	17	131
MB19WAW0002	Brockman Iron	4/12/2019	677	130	90	48	31	21	12	68



WATER TYPE SUB-FIELDS

1. HCO$_3^-$ and Ca^{2+} dominant (frequently indicates recharging waters)
2. HCO$_3^-$ dominant and Mg^{2+} dominant or cations indiscriminant
3. HCO$_3^-$ and Na^{+} dominant (ion exchanged waters)
4. SO$_4^{2-}$ dominant or anions indiscriminant and Ca^{2+} dominant (recharge/mixed water)
5. No dominant anion or cation (dissolution/mixing)
6. SO$_4^{2-}$ dominant or anions indiscriminant and Na^{+} dominant (mixing influences)
7. Cl$^-$ and Ca^{2+} dominant (cement pollution or reverse ion exchange of NaCl waters)
8. Cl$^-$ dominant and no dominant cation (reverse ion exchange of NaCl waters)
9. Cl$^-$ and Na^{+} dominant (end point water)

Figure 12: Expanded Durov plot of Western Hill groundwater chemistry (black) compared to all historic groundwater chemistry sampled across West Angelas (pale pink).

4. Groundwater Investigation

4.1 Hydrogeological Drilling Investigations

Multiple hydrogeological investigations have been undertaken at Western Hill from 2017 – 2019. Investigations have been undertaken specifically to build knowledge and improve conceptual understanding of the area. Table 3 summarises drilling completed to date, with a summary of current active bores detailed in Table 9 in Appendix A.

Table 3: Drilling investigations – Western Hill

Installation Year	Bore IDs	Commentary
2017	MB17WAW0001	Initial hydrogeological monitoring, bore drilled as a grade hole and converted to a monitoring bore in the vicinity of the Karijini National Park boundary.
2018	MB18WAW0002-7 RC18WAW0303 RC18WAW0462 RC18WAW0463 WB18WAW0001	Substantial hydrogeological drilling programme predominantly focused on the western ore body (Pit 1 area) of Western Hill. Monitoring bores were completed both within the future pit area (the Brockman Iron Formation aquifer) and outside the Mount McRae Shale. A total of nine monitoring bores and one production bore were drilled across the Western Hill deposit. Groundwater yield from the test production bore was high at >50 L/s. Three grade hole conversion monitoring bores were also completed in the eastern ore body and were used to inform test pumping in the 2019 drilling campaign.
2019	MB19WAW0001-2 MB19WAW0004-6 WB19WAW0001	Hydrogeological drilling programme focused predominantly on the eastern ore body, with three monitoring bores and one production bore completed. Yield in the deep production bore was similar to the 2018 bore, with test pumping able to sustain 50 L/s. Two monitoring bores were also completed to the south and north of the western ore body and screened in Detrital units.

5. Aquifer Pumping Testing

Aquifer test pumping was undertaken for the two Western Hill production bores in 2018 (WB18WAW0001) and 2019 (WB19WAW0001), as summarised in Table 4. Results from pumping test analyses are detailed in Table 6 for each production bore. Detail regarding each pumping test and associated drawdown observed is presented in TABLE 5 and illustrated in Figure 13.

The key overall points from these pumping test activities are summarised below:

- Long term test pumping in each production bore was conducted at high rates of 40 – 50 L/s, with limited drawdown of 20-30 m observed, indicating a high yielding Brockman Iron Formation aquifer with good water supply potential.

- Increased drawdown in latter stages of test for WB18WAW0001 inferred to be a result of drawdown encountering the low permeability Mount McRae Shale, acting as an aquifer boundary. The identification of this boundary in the drawdown trend supports the conceptualisation of the Mount McRae Shale as a low permeability unit, however it reduces the quality of the curve match in the western ore body.
- Hydraulic conductivity for the Brockman Iron Formation aquifer ranged between 1.3 – 1.5 m/d in the western ore body and returned a lower 0.7 m/d in the eastern ore body.
- Specific yield was higher in the western ore body (5-7%) compared to the eastern ore body (1-2%). Noting some reduced confidence in the curve matching in the western ore body.
- No drawdown outside of the Brockman Iron Formation aquifer was observed for either long term pumping test.

Table 4: Pumping testing overall summary.

Bore Name	**Screened Aquifer Unit**	**Cased Depth (mbgl)**	**SRT Rates (L/s)**	**CRT Duration (days)**	**CRT Rate (L/s)**	**Max Drawdown (m)**
WB18WAW0001	Brockman Iron	306	10,20,30,40,50	10	50	30.07
WB19WAW0001	Brockman Iron	264.5	10,20,30,40,50	10	40	20.14

Table 5: CRT Drawdown results for Western Hill.

Bore ID	**Duration (days)**	**CRT Rate (L/s)**	**Monitoring Point**	**Aquifer Screened**	**Direction from PB**	**Dist. from PB (m)**	**SWL Start Test (mbTOC)**	**Max Drawdown (m)**
WB18WAW0001	10	50	WB18WAW0001	Brockman	-	-	80.26	30.07
			MB18WAW0002	Brockman	S	11	80.13	8.48
			MB18WAW0006	Brockman	SW	108	76.77	0.95
			MB18WAW0007	Brockman	S/SW	800	75.9	0.75
			MB18WAW0003	Wittenoom	NW	1506	47.25	*no response*
			MB17WAW0001	Brockman	W	3025	67.88	*no response*
			MB18WAW0005	Wittenoom	S/SW	1224	46.67	*no response*
			MB18WAW0004	Wittenoom	SW	1911	38.16	*no response*
WB19WAW0001	10	40	WB19WAW0001	Brockman	-	-	85.11	20.14
			MB19WAW0001	Brockman	SW	10	84.77	12.82
			MB19WAW0002	Brockman	SE	360	81.38	0.78
			MB19WAW0004	Brockman	NW	100	88.22	9.03
			RC18WAW0462	Brockman	NW	1000	66.22	0.16
			RC18WAW0463	Brockman	E	70	86.90	5.56
			RC18WAW0302	Brockman	E	825	95.32	0.14

Table 6: Summary of CRT Analyses.

Pumping Bore ID	**Bore ID**	**Aquifer Type**	**Aquifer Screened**	**Saturated Aquifer Thickness b (m)**	**Analyses Method**	**T (m²/day)**	**K (m/day)**	**S_y**
WB18WAW0001	MB18WAW0002	*Unconfined*	Brockman Iron Formation	200	Neuman	316	1.5	0.05
					Moench	263	1.3	0.07
WB19WAW0001	MB19WAW0001	*Unconfined*	Brockman Iron Formation	220	Neuman	161	0.7	0.02
					Moench	155	0.7	0.01

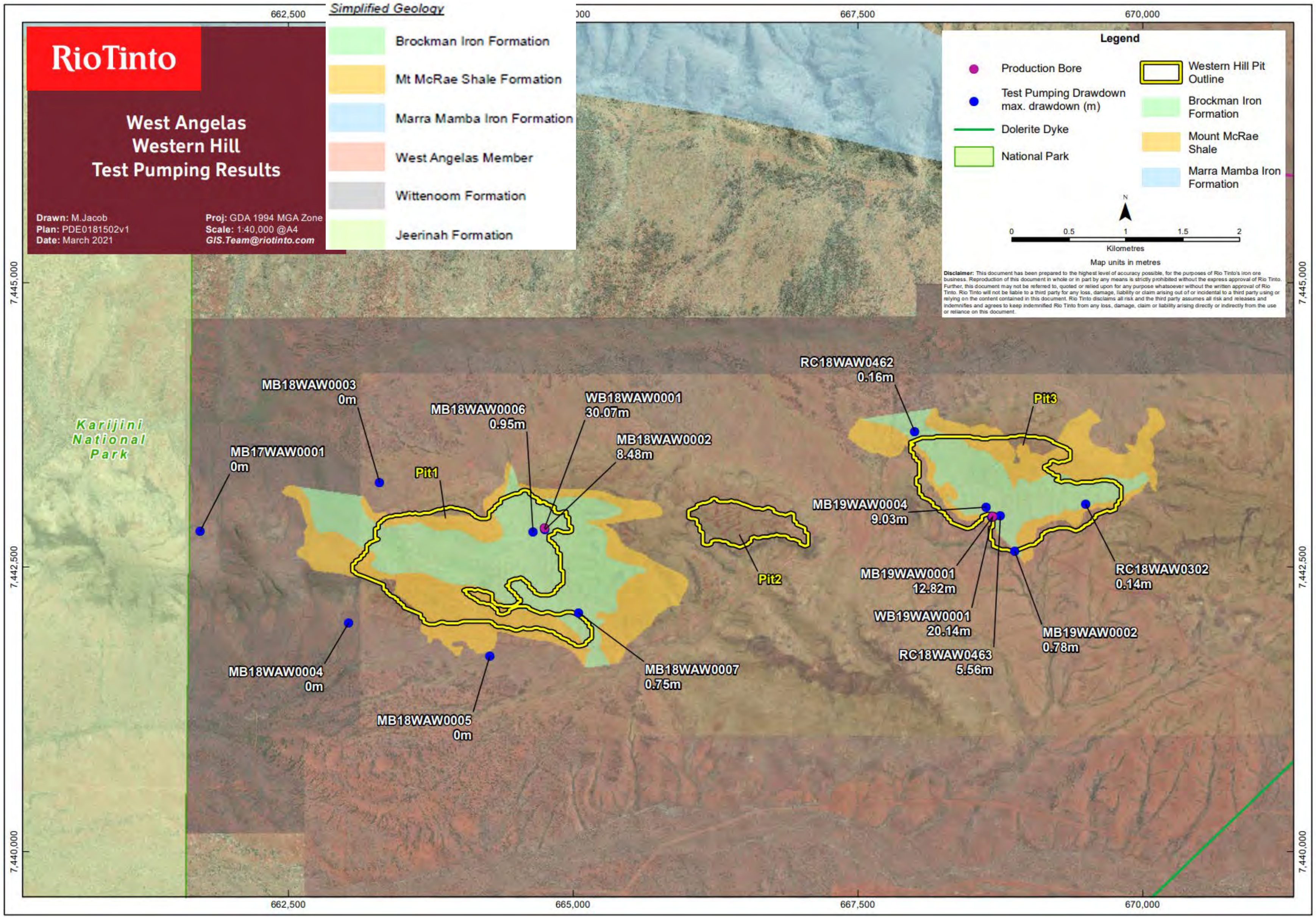


Figure 13: Drawdown responses (in metres below the static water level) in monitoring bores from the WB18WAW0001 and WB19WAW0001 CRT's.

6. Conceptual Hydrogeology

The conceptual hydrogeology of Western Hill is summarised as follows.

6.1 Aquifer characterisation

The conceptual model has been defined with three aquifer domains combining the relevant hydrostratigraphic units. In summary, the two mineralised Brockman Iron Formation orebody aquifers (east/west ore body) are assigned Domain 1 and are constrained in most directions by very low permeability units of the Mount McRae Shale (Domain 2). Surrounding the McRae Shale is the Wittenoom Formation regional aquifer assigned Domain 3,

The relevant hydrostratigraphic units are detailed in section 3.1 above, with these units presented in the various cross-sections as illustrated in Figure 5, Figure 6, Figure 7 and Figure 8. Additionally, Figure 4 shows a plan view representation of each aquifer domain.

Aquifer Domain 1: *Mineralised Brockman Iron Formation*

- Exists in two separate eastern and western lenses, with a single production bore located in each ore body.
- Bound on all sides by very low permeability Mount McRae Shale except where significant fault offsets exist.
- Where mineralised, Brockman Iron Formation has increased permeability.
- The western ore body is potentially hydraulically open to the surrounding Wittenoom Formation in three directions (north, south, north-west).
- The eastern ore body is potentially hydraulically open to the surrounding Wittenoom Formation in two directions (north and south).
- Noting that it is assumed this entire domain is *mineralised* Brockman Iron Formation, whereas in reality a significant portion of the domain is unmineralised Brockman likely to have a lower conductivity, see Figure 5, Figure 6 and Figure 7 for illustrations of mineralised versus unmineralised portions of Brockman Iron Formation inside the Mount McRae Shale aquitard.

Aquifer Domain 2: *Mount McRae Shale*

- Very low permeability shale unit that generally acts as an aquitard.
- Shale intersection derived from 2020 geological model with groundwater table.
- Mount McRae Shale almost entirely surrounds both eastern and western lens of mineralised Brockman Iron Formation aquifer and acts as an aquitard where present.
- Where faulting has offset the Mount McRae shale, gaps may occur, providing potential for hydraulic connection between the Wittenoom and Brockman Iron Formations.

Aquifer Domain 3: *Wittenoom Formation*

- Regional aquifer unit that surrounds Domains 1 & 2 on all sides. Potential for higher permeability, particularly where karstic dissolution within the dolomitic Paraburdoo Member has occurred.
- Aquifer boundaries are depicted in Figure 11, and summarised below:
    - Bound to east by known dolerite dyke that causes a 13 m head difference on either side.
    - Bound to north and south by unmineralised Marra Mamba Iron Formation.
    - Bound to north-east by anticline of unmineralised Marra Mamba Iron Formation, resulting in a head difference of ~40 m.

    - Bound to west Mount McRae Member at the base of Brockman Iron Formation mountain range.
  - Discharge zone to southwest along Turee Creek East creek line, where creek line cuts through the Brockman Iron Formation
  - Minor recharge was modelled, with recharge used being equivalent to recent numerical groundwater modelling for Deposit C and D, i.e. equivalent to 0.54 mm/a across each model domain.

6.2 Boundaries

The regional scale boundaries of the domains described in Section 6.1 are depicted in Figure 14 and detailed in Table 8 below. Regional boundaries of the Wittenoom Formation include:

- Dolerite dyke to the east with 13 m head difference.
- Unmineralised Marra Mamba Iron Formation (with Fortescue Group beyond) to north, and to south-east.
- Mount McRae Shale of the Brockman Iron Formation at the base of unmineralised Brockman Iron Formation mountain range.
- Discharge area to west along creekline where potential GDE is mapped.

Model internal line boundaries comprise the delineation of the Mount McRae Shale and Brockman Iron Formation domains. The Mount McRae Shale and Brockman Iron Formation domains were modelled as shown in Figure 14. The Brockman Iron Formation domain was essentially the area inside the Mount McRae Shale domain, consistent with the conceptual model, and based off the Leapfrog geological model.

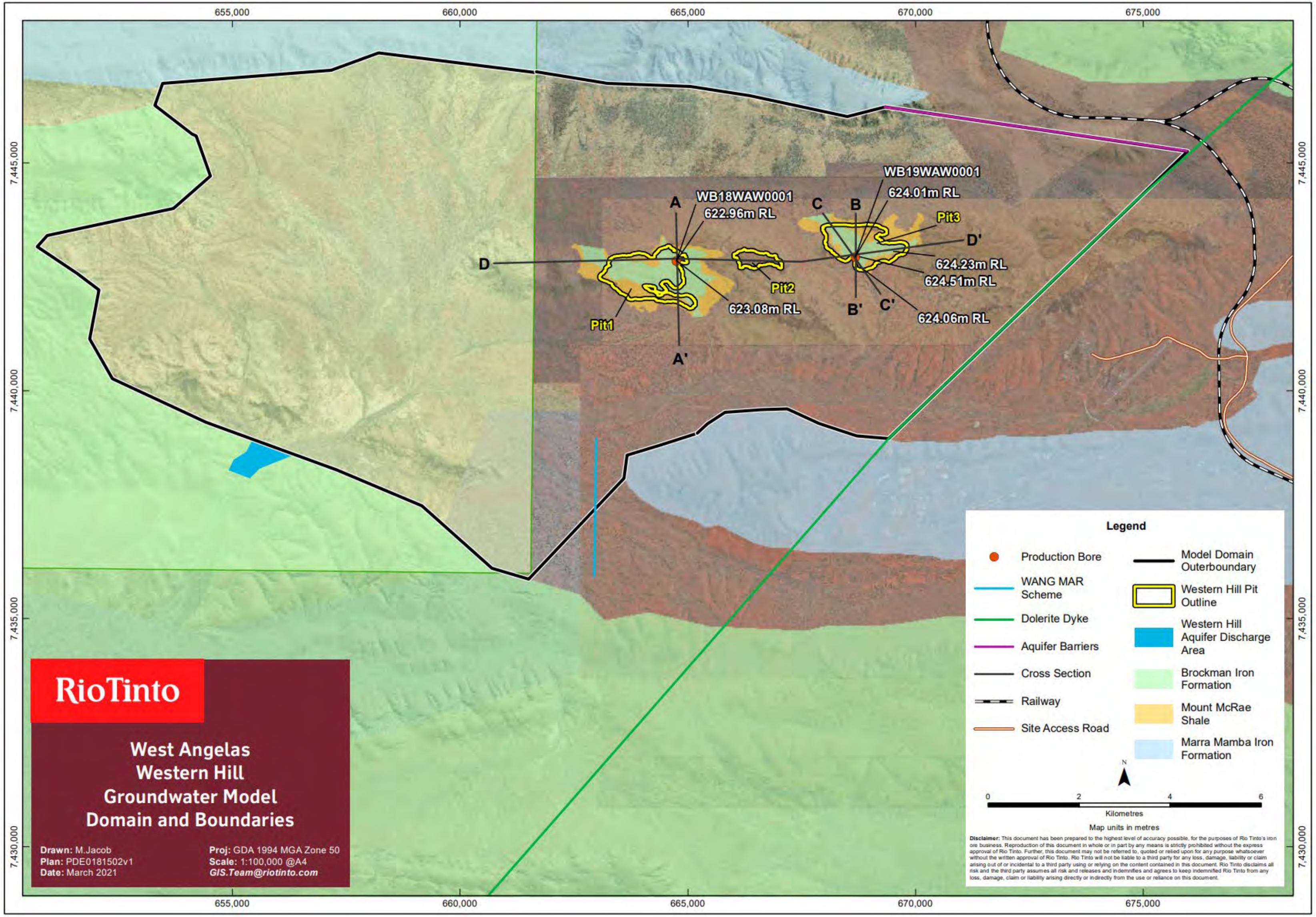


Figure 14: Western Hill model domains and boundaries.

6.3 Recharge

As is typical of the Pilbara, recharge rates at depth are generally a low percentage of annual rainfall. Recharge was assumed to be equivalent to numerical modelling completed for the Deposit CD project in 2017, which when in steady state was deemed to be equivalent to outflow at the KNP GDE boundary of 137 kL/d. Over the aquifer domain that contributed to discharge at the GDE, the defined 137 kL/d was equivalent to 0.54 mm/yr. This recharge rate was converted into m/d and used in the AnAqsim model across all domains. This recharge rate does not consider climate change however the model is not expected to be sensitive to rainfall variability during the life of mine.

7. Groundwater Modelling

7.1 Model Setup

Groundwater modelling was undertaken with AnAqSim to model drawdown as a result of water supply abstraction at each of the Western Hill ore bodies (eastern and western). The following section details the groundwater modelling methodology.

The aquifer dimensions used in the model were approximated based on the geological units in the most recent geological modelling (2020) completed in Leapfrog. Visualisation and intersection of relevant geological units with the groundwater table was conducted to accurately define aquifer boundaries in two dimensions.

The overall model domain spans an area of 61 km^2, with the three aquifer domains detailed in Section 6.1 represented in the model as illustrated in Figure 14. Each aquifer domain was assumed to have an average thickness of 224 m based on the estimated saturated depth at the base of mineralisation.

7.2 Conceptual Model Summary

The hydrogeological conceptualisation presented in Section 6 was used to define the hydraulic boundaries of the groundwater model. Aquifer units and associated hydraulic parameters related to this hydrogeological conceptualisation are detailed below.

7.2.1 Aquifer Parameters

Parameter uncertainty analyses was conducted as part of this modelling exercise, with a set of hydraulic parameters derived for each model domain. A Monte Carlo randomisation of hydraulic parameters with their defined statistical ranges (see Table 7) was undertaken. For hydraulic conductivity (k), a log-normal distribution was assumed, while for specific yield (S_y) a normal distribution was assumed. Using the defined distributions for the six variables, a total of 1,000 parameter sets were generated. Model parameters were assigned minimum and maximum tolerance limits to restrict very low likelihood parameter sets from being modelled.

Mean hydraulic parameters for the three aquifer domains are detailed in Table 7. The hydraulic parameters were informed from both test pumping activities and recent groundwater modelling work for the neighbouring Deposit C and D deposits.

The Wittenoom Formation in the Western Hill region was assigned a mean hydraulic conductivity of 5 m/day, and a specific yield (Sy) of 3% as the base case scenario. These values vary from the values derived from aquifer testing to provide a conservative assessment. Aquifer parameters for the Mount McRae Shale were not informed by test pumping given the units' very low permeability. Instead, these values were assigned low permeabilities as informed by knowledge gained from analogue deposits. It was considered to assign the Mount McRae Shale as a no-flow zone given the known low permeability of the Mount McRae Shale, but for completeness and conservatism, this domain was included in the model.

Illustrations of each individual parameter distribution from the Monte Carlo randomisation is presented in histogram form in Figure 15.

Table 7: Hydraulic parameter ranges for Monte Carlo analysis.

Domain	Brockman Iron Formation		Mount McRae Shale		Wittenoom Formation	
Parameter	k	S_y	k	S_y	k	S_y
Units	m/d	%	m/d	%	m/d	%
Mean	1	3%	0.005	0.15%	5	3%
Maximum	3	5%	0.010	0.2%	8	5%
Adopted Standard Deviation	1	1%	0.0025	0.025%	1.5	1%

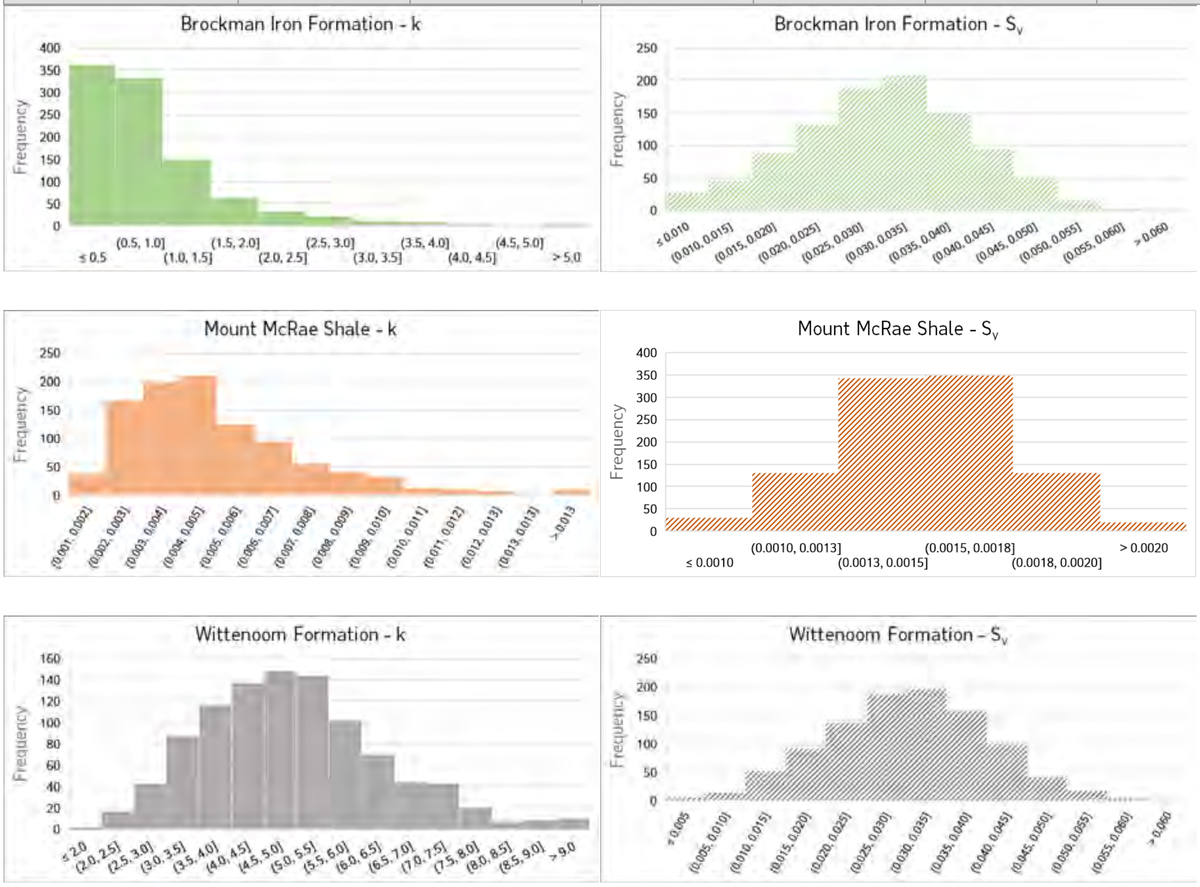


Figure 15: Histograms of hydraulic parameter distribution for each domain, prior to tolerance limits.

7.2.2 Boundary Conditions

The model external domain boundaries are depicted in Figure 14 and detailed in Table 8 below. Model internal line boundaries comprise the delineation of the Mount McRae Shale and Brockman Iron Formation domains. The Mount McRae Shale and Brockman Iron Formation domains are illustrated in Figure 16. The Brockman Iron Formation domain was essentially the area inside the Mount McRae Shale domain, consistent with the conceptual model, and based off the Leapfrog geological model.

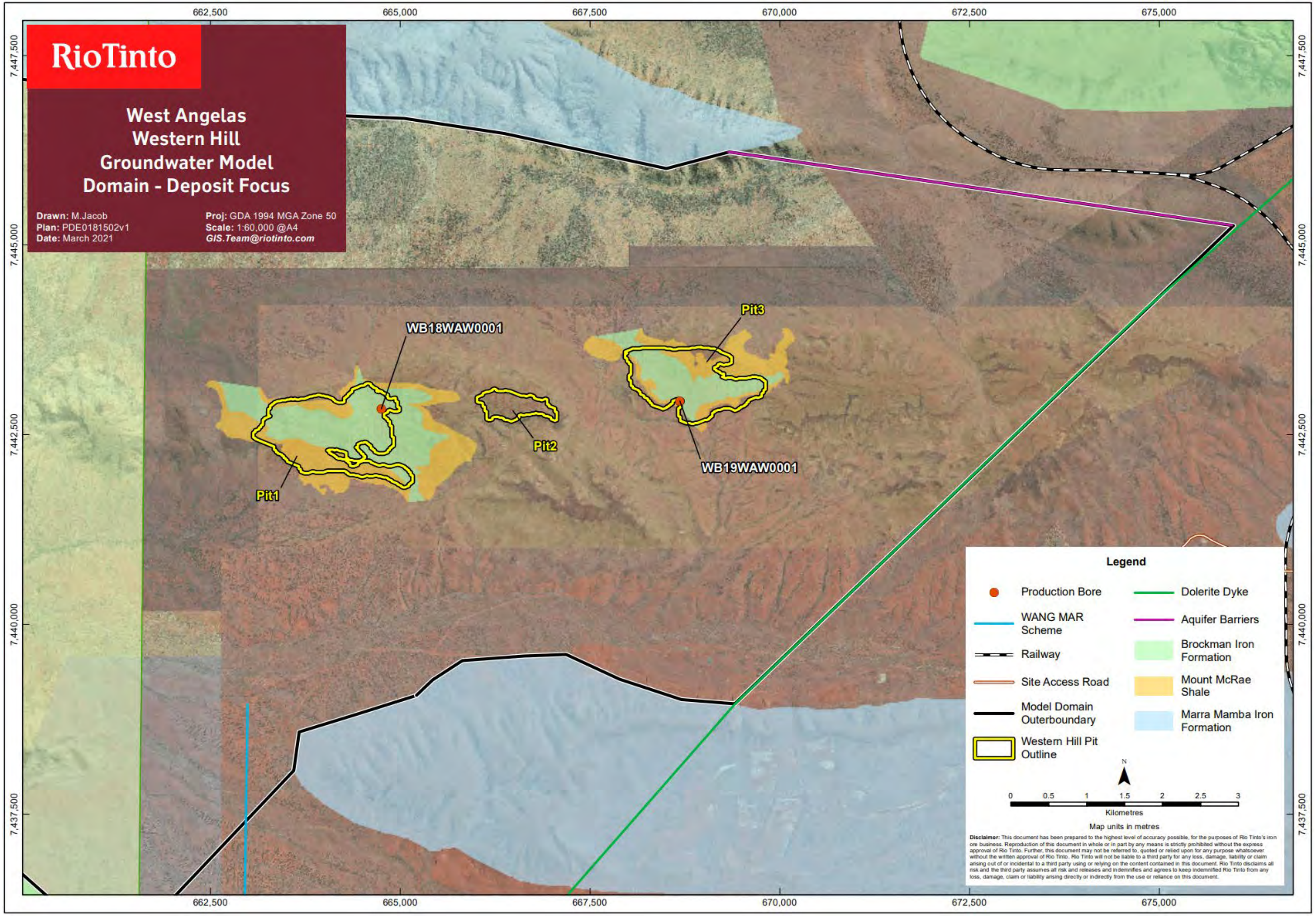


Figure 16: Model domain centred on Western Hill area.

Table 8: Model boundary conditions (boundaries illustrated in Figure 14).

Boundary	Condition	Comment
Wittenoom Formation boundary to north, east and west	Flux = 0 kL/d	To north, Wittenoom Formation is bound by unmineralised Marra Mamba Iron Formation To west, Wittenoom Formation is bound by Mount McRae Shale at base of Brockman Iron Formation mountain range. To east, known north-east to south-west trending dolerite dyke aquitard.
KNP GDE boundary	Discharge = 137 kL/d	Discharge boundary at rate of 137 kL/d. Flow rate based on estimated groundwater usage by vegetation in the GDE area, and is consistent with groundwater modelling for the Deposit C and D.
Deposit D MAR internal boundary	Head-specified: 623.7mRL	MAR scheme in operation will ensure that groundwater level along these boundaries will not drop below pre-mining level.
Deposit D Wittenoom Formation	Head-specified: 623.7mRL	
Southern Brockman Iron Formation	Flux = 0 kL/d	Wittenoom Formation to south-east of GDE is bound by McRae shale at base of Brockman Iron Formation range.
Southern Marra Mamba Iron Formation boundary	Flux = 0 kL/d	Wittenoom Formation to south of Western Hill is bound by low permeability unmineralised Marra Mamba Iron Formation and Fortescue Group.

7.2.3 Transient Simulation

The transient simulation considered the domains and boundaries as described above, with the addition of the proposed pumping scenario at Western Hill for water supply and the CD MAR scheme as an internal constant head boundary condition.

Two pumping bores exist in the AnAqsim model, with one in each of the Brockman Iron Formation domains (Figure 14). A single pumping scenario of 1 ML/d was assessed and used in all model simulation runs. This pumping scenario is detailed below:

- Western Pit – WB18WAW0001: 500 kL/d
- Eastern Pit – WB19WAW0001: 500 kL/d

The transient simulation was run over a 5-year period to allow for construction supply and augmentation of local water during the initial years of operation. Groundwater level tracking points were added as calibration targets at each existing monitoring bore, in addition to tracking points at the KNP boundary to the west of Western Hill.

7.3 Model Results

Results for the KNP tracking point (see Figure 17) show that 95% of the 981 model runs that met tolerance limits at the 1 ML/d pumping rate did not impact the KNP boundary outside of natural recorded variation in groundwater level (623.6 mRL) by the end of the simulation limit. Furthermore, of the 5% of model runs that did show groundwater level reducing below the 623.6 mRL, the maximum reduction was only 9 cm below this level, i.e. to the 623.51 mRL (Figure 17). Simulated drawdown contours for the P50 and P80 scenarios are shown in Figure 18 and Figure 19 respectively.

The P50 simulation is considered the most likely and has been used for the purposes of generating groundwater contours. The P95 simulations with respect to drawdown near the KNP boundary are dominated by simulations with low specific yield in the Wittenoom Formation (Figure 17).

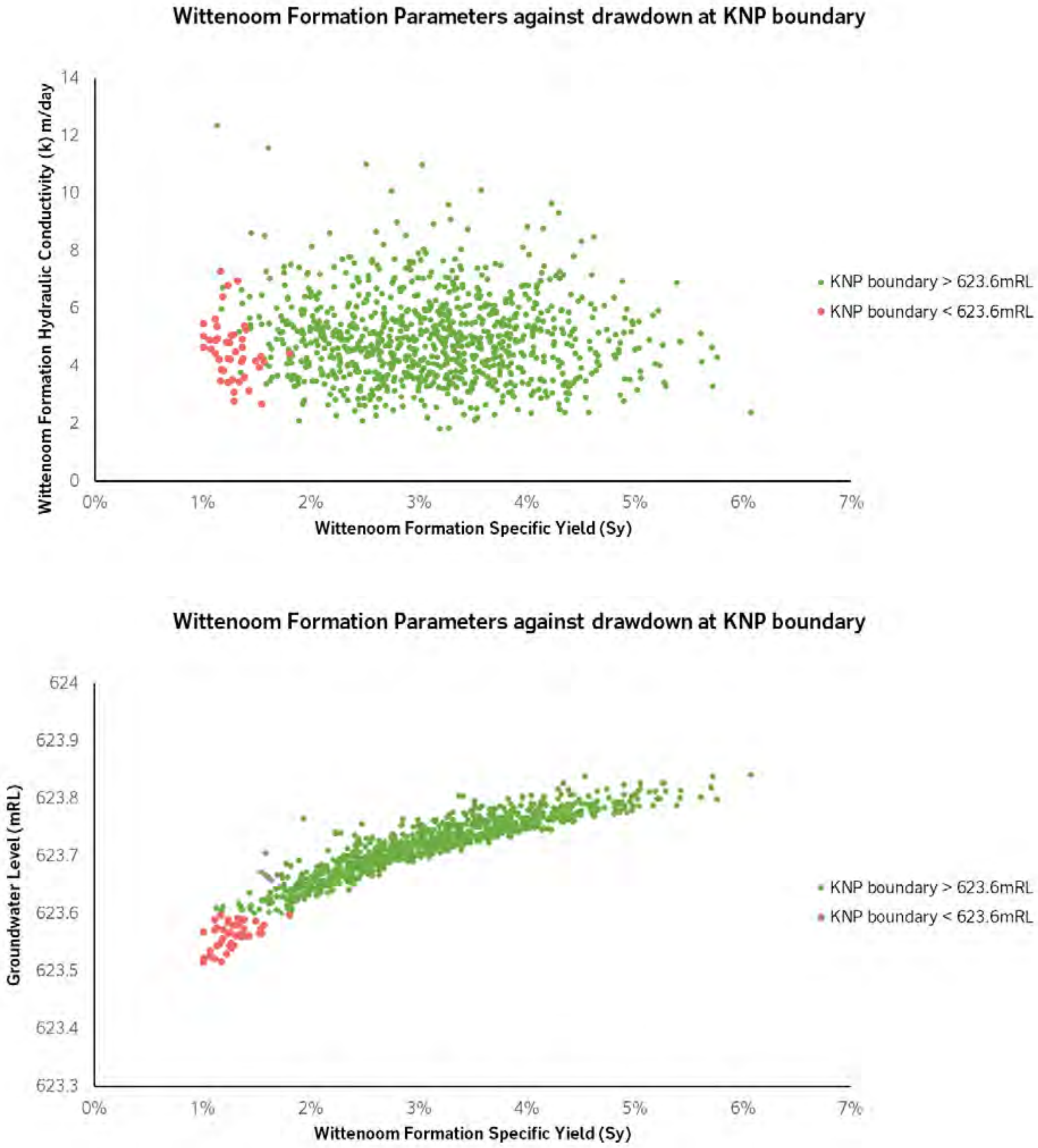


Figure 17: KNP boundary groundwater level sensitivity to Wittenoom Formation hydraulic parameters.

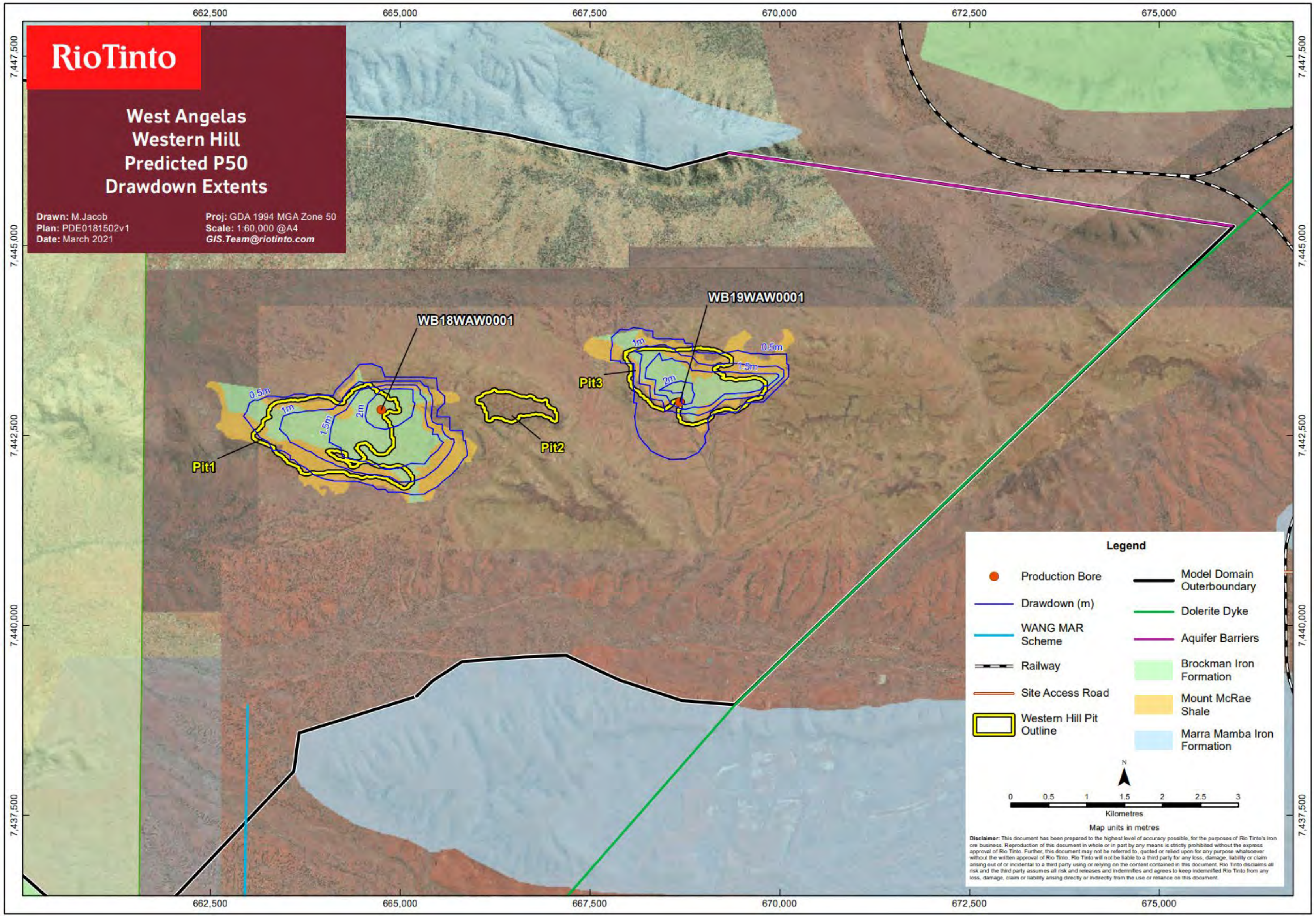


Figure 18: Predicted drawdown contours for the P50 simulation.

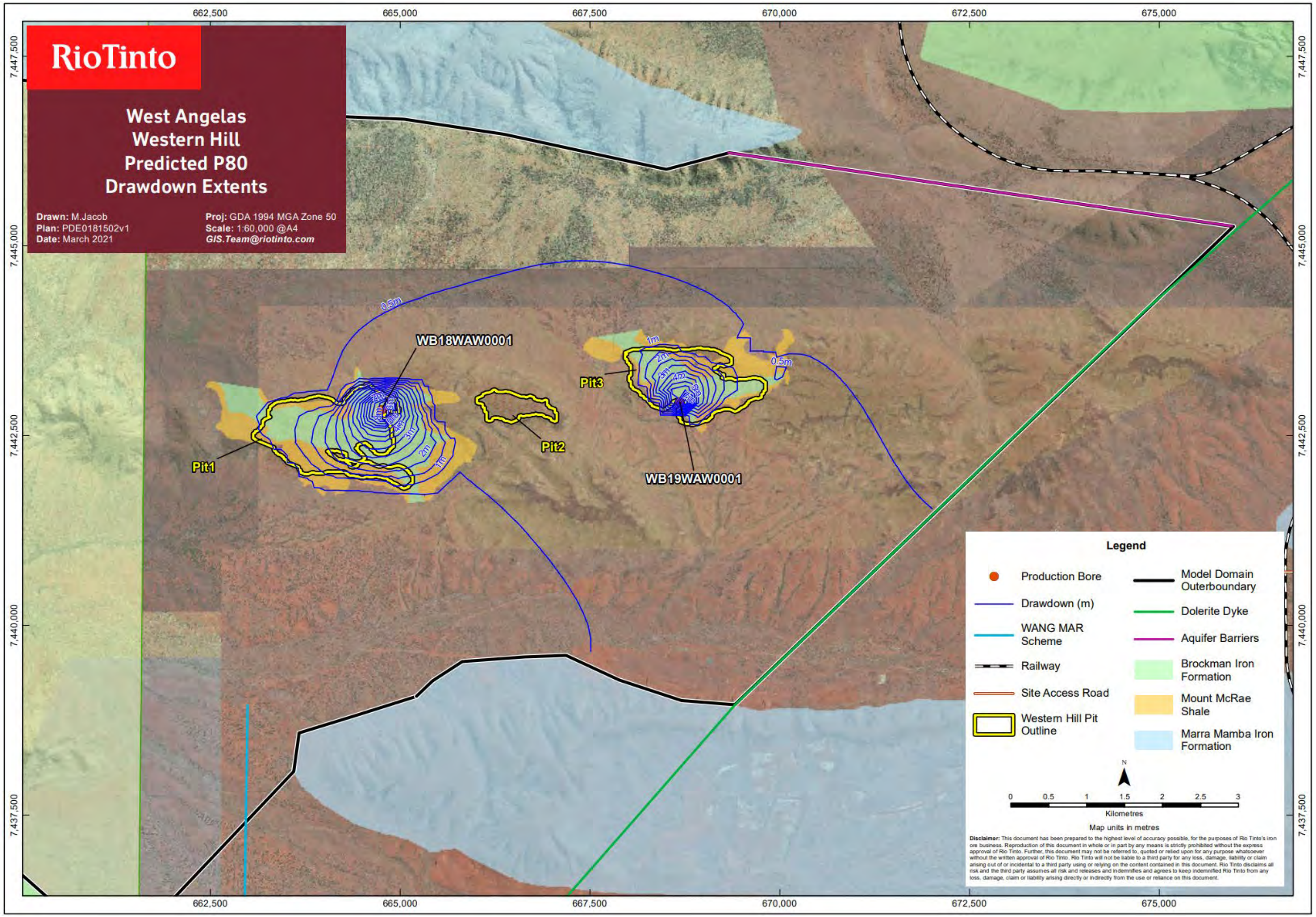


Figure 19: Predicted drawdown contours for the P80 simulation.

8. Existing Groundwater Use

The only existing groundwater user in the vicinity of Western Hill is the proponent (Rio Tinto) undertaking groundwater abstraction for mine dewatering and water supply purposes for the Greater West Angelas mining operations. The water supply abstraction proposed at Western Hill is intended to be undertaken under the same Groundwater Licence as current existing activities. The Groundwater abstraction licence is:

- GWL98740(12) West Angelas – 14 GL/yr.

No other groundwater users or receptors have been identified in the surrounding area.

9. Assessment of Potential Impacts

The proposed abstraction for water supply at Western Hill has been specifically designed to prevent a reduction in groundwater level at the KNP boundary. The potential drawdown impact at the KNP boundary is the driving receptor that has been used to derive the proposed pumping regime to support local water demand at Western Hill (1 ML/d). Abstraction for supply purposes will be monitored and managed throughout operation to ensure no drawdown at the KNP boundary occurs.

The P50 scenario of predicted drawdown in the Western Hill area is as indicated in Section 7 and illustrated in Figure 18, with drawdown not predicted to approach the KNP boundary.

The modelling conducted indicates that 95% of the derived parameter sets results in no drawdown at the KNP boundary. The maximum drawdown at the KNP boundary from the 5% of modelled parameter sets with some drawdown is 9 cm. this is less than the historic natural range of groundwater levels observed in nearby monitoring bores. All the parameter sets with drawdown at the KNP boundary had low specific yield in the Wittenoom Formation (Figure 17), therefore refinement of this parameter through initial operation will further reduce uncertainty.

It is important to consider that a conservative approach has been adopted in the groundwater model, whereby hydraulic connection between the Brockman Iron Formation and the Wittenoom Formation (i.e. through gaps in the Mount McRae Shale) is assumed to exist in every location where it is possible, which has not been proven through either long term pumping test that has been conducted to date.

Given Rio Tinto's commitment to not induce drawdown at the KNP boundary, a focus on monitoring drawdown response both within and outside the Brockman Iron Formation to ensure it is tracking in line with the modelled predictions is a requirement post-commenced groundwater abstraction at Western Hill.

10. Management Approach / Conclusions

Rio Tinto Iron Ore has a defined Water Strategy that guides water management within the group. This strategy requires an integrated approach to water management that promotes, maintains or improves water quality, minimises fresh water use and maximises reuse and recycling. Groundwater abstracted from the Western Hill area will be used as supply for local mining operations, primarily as dust suppression.

As detailed above, it is proposed that the West Angelas Environmental Management Plan, which includes groundwater management triggers and responses, by reviewed to include monitoring of drawdowns to the North of Western Hill. This will ensure that the low likelihood for drawdown at KNP is managed well in advance of it proceeding towards the KNP boundary. The management plan with respect to minimising potential impact will focus upon monitoring groundwater levels in Wittenoom Formation bores between Western Hill and KNP, with responses inclusive of reverting supply at Western Hill to actively pumped deposits at the time (i.e. Deposit C initially). Regular review and calibration (as needed) of the groundwater model with measured drawdown after 6-months, 12-months and annually thereafter are recommended to ensure alignment and updates to uncertainty predictions.

The monitoring of long-term abstraction at a low level (500 kL/d at each bore) will inform the extent of hydraulic connection between the Wittenoom and Brockman Iron Formations which has not been observed to date in long term test pumping. The magnitude of any drawdown response in these bores over long-term pumping will allow for further refinement in the hydraulic parameters of the Wittenoom Formation, which have been shown to be the dominant factor influencing the potential for groundwater drawdown at the KNP boundary.

All production bores will be commissioned with automated telemetry systems to optimise water abstraction and manage drawdown throughout the borefield.

11. References

RTIO, 2019, Groundwater Operating Strategy – West Angelas Iron Ore Mine, RTIO-HSE-0017344.

RTIO, 2021, Groundwater Environmental Management Plan-West Angelas Revised Proposal, RTIO-HSE-0349522

RTIO, 2018, West Angelas – Deposit C, D and G, H3 Hydrogeological Assessment

Appendix A: Bore Construction Details

Table 9: Monitoring and Production bore construction summary table.

Bore Name	Easting	Northings	TOC Elevation	Ground Level (mRL)	Cased Depth (m)	Casing Internal Diameter (mm)	Inlet Interval	Screened Unit	Screened Formation
	(MGA94)	(MGA94)	(mRL)						
Monitoring Bores									
MB17WAW0001	661724.66	7442812.18	691.51	690.66	130	50	106-124	Footwall Zone, McRae Shale	Brockman Iron, McRae Shale
MB18WAW0002	664752.81	7442831.41	703.38	702.79	221.5	50	107.5-215.5	Whaleback Shale, Dales Gorge	Brockman Iron
MB18WAW0003	663297.89	7443245.26	670.66	670.10	83	50	59-77	Wittenoom (undifferentiated)	Wittenoom
MB18WAW0004	663028.68	7442010.54	661.73	660.95	81	50	57-75	Wittenoom (undifferentiated)	Wittenoom
MB18WAW0005	664267.31	7441716.82	670.21	669.44	95	50	65-89	Wittenoom (undifferentiated)	Wittenoom
MB18WAW0006	664646.79	7442807.03	699.97	699.48	180	100	96-174	Dales Gorge	Brockman Iron
MB18WAW0007	665047.26	7442099.04	699.07	698.50	196	50	172-190	Dales Gorge	Brockman Iron
MB19WAW0001	668676.37	7442933.15	708.49	707.73	224	100	98-224	Dales Gorge	Brockman Iron
MB19WAW0002	668875.39	7442639.45	705.65	705.09	130	100	88-130	Dales Gorge	Brockman Iron
MB19WAW0004	668624.77	7443026.10	711.87	711.07	210	100	96-210	Dales Gorge	Brockman Iron
MB19WAW0005	665110.45	7441508.95	681.35	680.71	110	100	68-98	Detrital	Detrital
MB19WAW0006	664083.40	7443423.33	681.65	680.96	99	100	69-93	Detrital	Detrital
RC18WAW0302	669499.70	7443051.03	719.76	718.79	226	50	202-220	Footwall Zone	Brockman Iron
RC18WAW0462	667997.15	7443690.37	690.61	689.69	232	50	208-226	Dales Gorge, Footwall Zone	Brockman Iron
RC18WAW0463	668751.35	7442947.96	710.96	710.05	184	50	160-178	Footwall Zone, McRae Shale	Brockman Iron, McRae Shale
Production Bores									
WB18WAW0001	664749.76	7442842.28	703.22	702.66	306	305	114-300	Whaleback Shale, Dales Gorge	Brockman Iron
WB19WAW0001	668682.77	7442941.48	708.60	707.98	264.5	305	95.6-257.6	Dales Gorge, Footwall Zone, McRae Shale	Brockman Iron

C.5: Deposit H Hydrogeological Impact Assessment

RioTinto

Hydrogeological Assessment

West Angelas – Deposit H Hydrogeological Impact Assessment

April 2023

RTIO-0988636

Water Resource Evaluation

	Name	Signature	Date
Prepared By:	Carolina Sardella		06/04/2023
Checked By:	Kevin Vermaak		06/04/2023
Approved By:	Paul Hedley		06/04/2023

Stakeholders: Studies and Technology, Environmental Approvals, Department of Water and Environmental Regulation

Accountability: Water Resource Evaluation

Version History				
Version	**Description of Changes**	**Custodian**	**Approved**	**Date**
FINAL	Issued for distribution	WRE	Paul Hedley	06/04/2023

Executive Summary

Deposit H is a greenfield Marra Mamba deposit located in the West Angelas mining hub, approximately 90 km north-west of Newman. The proposed Deposit H operations include above water table (AWT) mining at all pits except for the eastern portion of East Pit 1, where below water table (BWT) mining is planned (21.5 m BWT). Current groundwater levels at Deposit H are approximately 735.5 m Australian Height Datum (AHD).

This report summarises the hydrogeological investigations completed to date at Deposit H and the current hydrogeological conceptualisation for the deposit. It also provides an assessment of the potential hydrogeological impacts from water supply activities required to support the proposed mining operations.

Groundwater abstraction at West Angelas is licenced under Groundwater Abstraction Licence GWL98740(13) which allows for groundwater abstraction of up to 14 GL per year over the West Angelas mining hub (AML 70/248) for purposes including dewatering for mining purposes and dust suppression for earth works and construction. Existing groundwater use in the Deposit H area is primarily for exploratory drilling under GWL98740(13), with no other users identified. Operational water demand at Deposit H is estimated to be 3.6 GL over the life of mine of this deposit, with the maximum operational water demand estimated to be 1.0 GL/yr.

The mineralised portion of the Mount Newman and MacLeod Members of the Marra Mamba Iron Formation as well as the mineralised portion of the West Angelas Member of the Wittenoom Formation form an unconfined aquifer (the orebody aquifer) with low transmissivity and storage parameters compared to other West Angelas deposits. The aquifer is surrounded on all sides by the impermeable unmineralized portion of the Marra Mamba Iron Formation which is surrounded by Fortescue Group. Due to the substantial depths to groundwater, recharge is usually negligible and estimated to be approximately a small percentage of rainfall.

Turtle Pool is an ephemeral feature directly to the east of the Deposit H east pits. The pool is ephemeral and groundwater dependent ecosystem (GDE) assessments suggest that the vegetation is not groundwater dependant. However, it was observed that a pool forms after rainfall and subsequent streamflow events and the elevation of the resulting pool is 735 metres above Australian Height Datum (mAHD) similar to the elevation of groundwater levels within the deposit. There is limited information at Deposit H to confirm the low permeability of the hydrostratigraphy surrounding the deposit, therefore a cautionary approach has been taken, and a possible connection between the groundwater system and Turtle Pool has not been ruled out.

No abstraction or dewatering is proposed for Deposit H to ensure no potential impact is recorded at Turtle Pool. BWT mining of the final benches is proposed to be achieved though sump pumping and top loading. Any water removed through sump pumping is to be pumped to a backfilled area within the same pit and allowed to infiltrate through a box cut.

Operational water demands are to be met from water supplied from other deposits at West Angelas. All water supplied to Deposit H is to be used for dust suppression within the deposit and is not expected to be discharged, therefore there is no requirement for management of excess water.

Backfilling to two metres above pre-mining groundwater table will be completed once mining is finished. Groundwater levels will be reinstated to pre-mining groundwater levels (735 mAHD) where necessary.

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1. Introduction

Deposit H (the deposit) is a greenfield Marra Mamba deposit located in the West Angelas mining hub, approximately 90 km north-west of Newman. The deposit is approximately 10 km east of the active mining area of Deposit B (Figure 1-1). The proposed Deposit H operations include above water table (AWT) mining at all pits except for the eastern portion of East Pit 1, where below water table (BWT) mining is planned (21.5 m BWT). Current groundwater levels at Deposit H are approximately 735.5 m Australian Height Datum (AHD).

Groundwater abstraction at West Angelas is licenced under Groundwater Abstraction Licence GWL98740(13) which allows for groundwater abstraction of up to 14 GL per year. The licence permits groundwater abstraction over the West Angelas mining hub (AML 70/248) for purposes including dewatering for mining purposes, dust suppression for earth works and construction purposes, exploratory drilling, general campsite purposes, power generation, groundwater reinjection and industrial processing. The licence was granted on 3 February 2023 and is active until 21 October 2029.

This report summarises the hydrogeological investigations completed to date at Deposit H and the current hydrogeological conceptualisation for the deposit. It also provides an assessment of the potential hydrogeological impacts from water supply activities required to support the proposed mining operations.

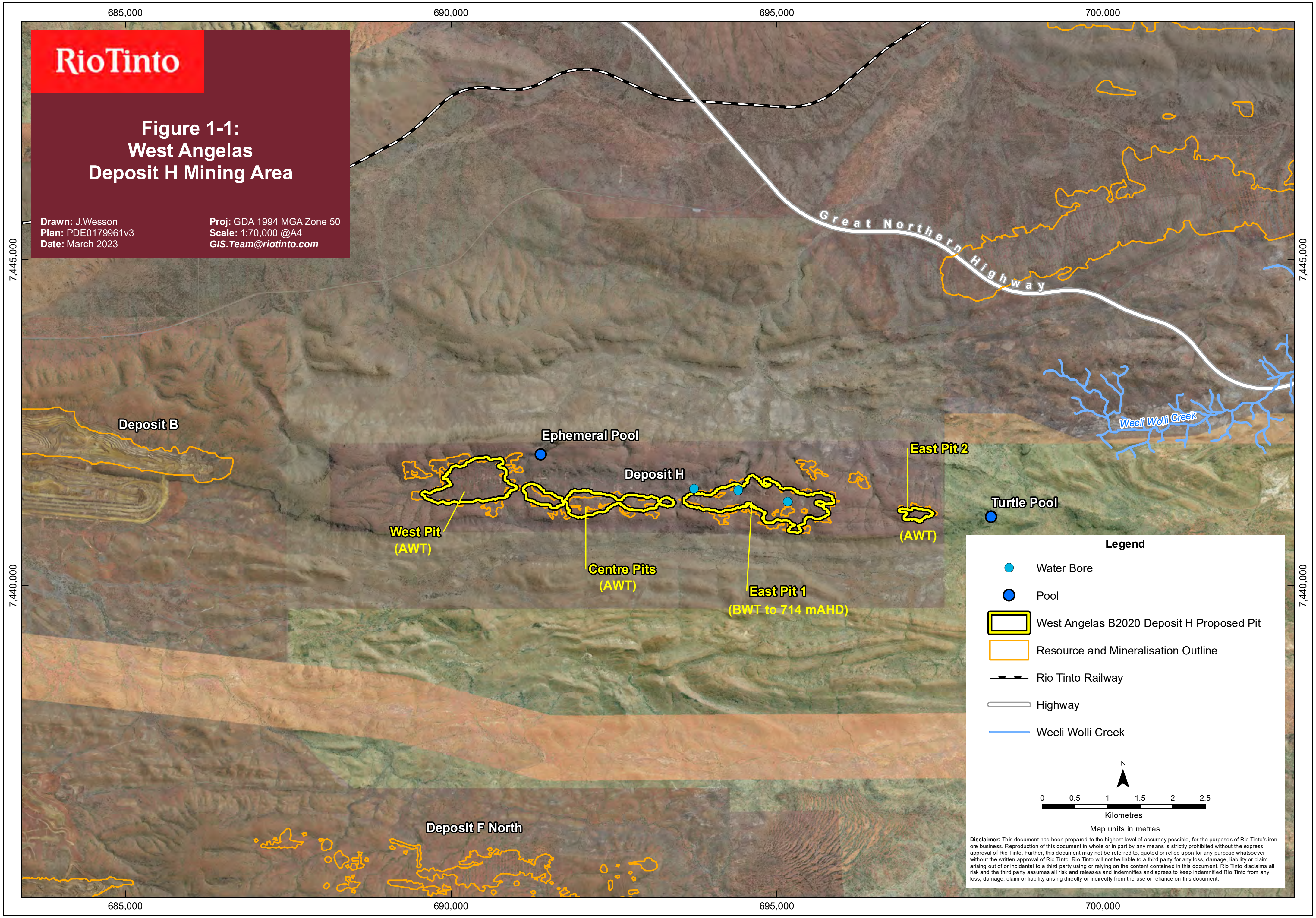

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Figure 1-1: West Angelas Deposit H Mining Area

Drawn: J.Wesson
Plan: PDE0179961v3
Date: March 2023

Proj: GDA 1994 MGA Zone 50
Scale: 1:70,000 @A4
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2. Description of Environment

2.1 Climate and Rainfall

West Angelas is in the east Pilbara region of West Australia and has an arid climate typical of the region, with average rainfall of 324 mm/yr (1981-2022), and most rainfall occurring between December and April during the wet season. Rainfall is also highly variable between years meaning that periods of extended drought and well above average rainfall conditions are possible. Potential evaporation is very high, with Class A pan evaporation averaging 3,050 mm per year, an order of magnitude higher than rainfall. Figure 2-1 illustrates the average monthly rainfall and Figure 2-2 illustrates the evaporation distribution for the period 1981 to present using SILO gridded climate data.

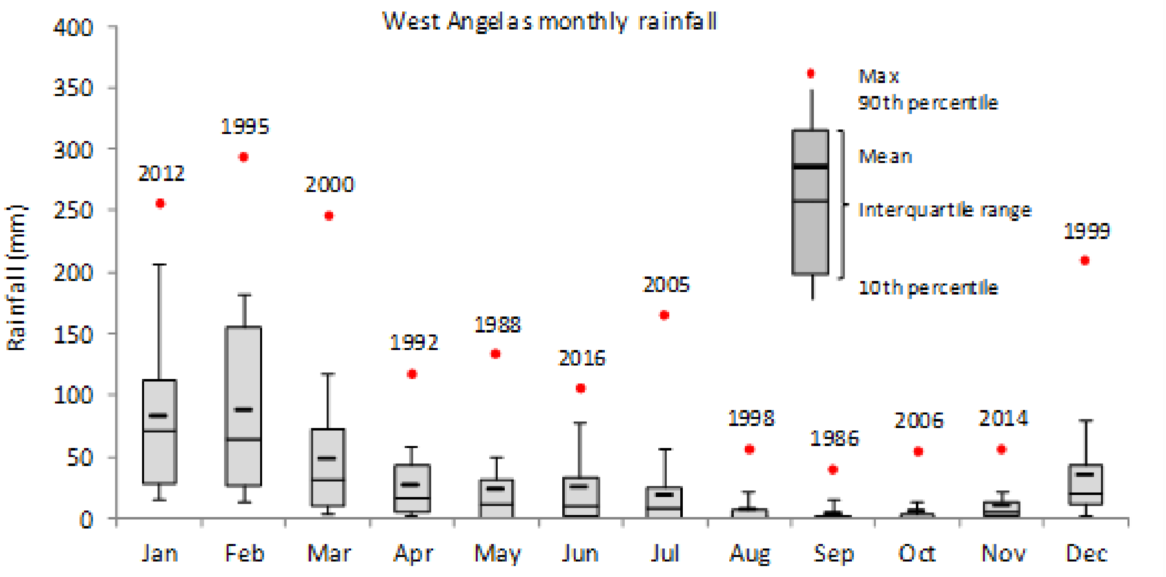

Figure 2-1: Monthly rainfall distribution at West Angelas (SILO gridded data, accessed 2022)

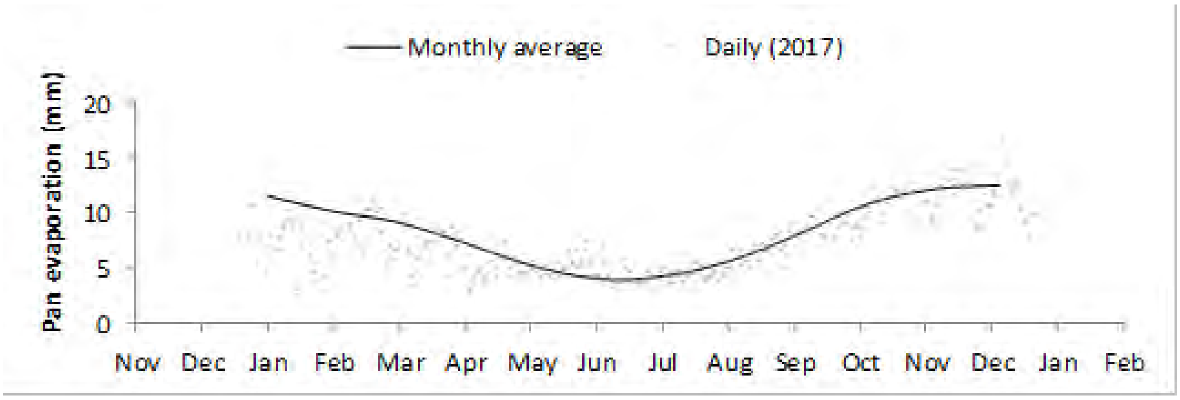

Figure 2-2: Monthly average class A pan evaporation (bottom) at West Angelas (SILO gridded data, accessed 2022)

West Angelas is periodically prone to very high intensity rainfall events associated with tropical low-pressure systems, cyclones and convective storms. Point design rainfall is available across Australia from the Bureau of Meteorology design rainfall data system. Figure 2-3 illustrates the 24-hour duration storm depth and frequency data against daily rainfall records at West Angelas since 1981 (site data infilled with SILO gridded data). The largest single day total is approximately 150 mm, equivalent to a 1:10 annual exceedance probability (AEP) event, noting that continuous 24-hour totals will be larger than calendar day totals.

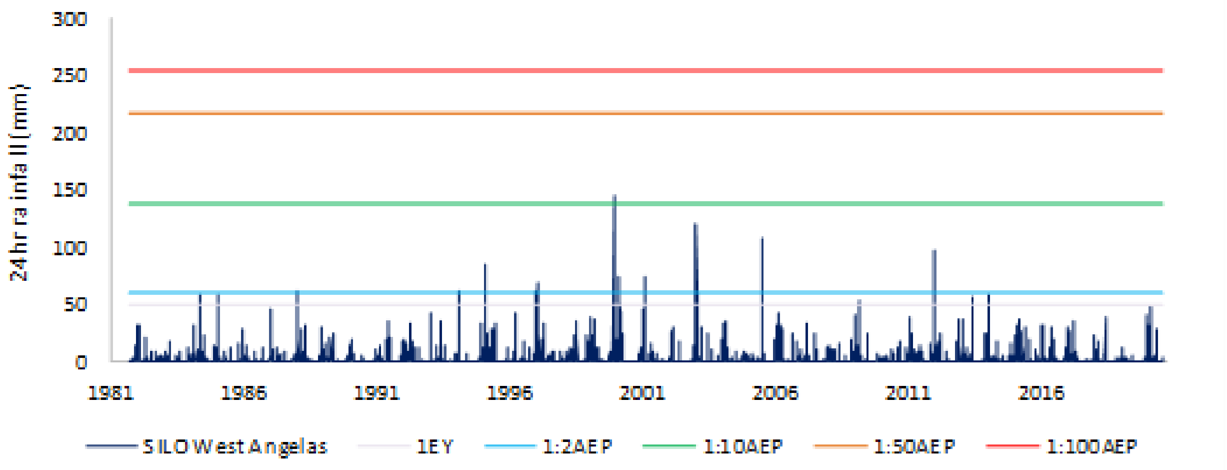

Figure 2-3: Point design rainfall for 24-hour duration events against daily rainfall records at West Angelas,(SILO gridded data, accessed 2022)

2.2 Hydrology

Regionally, the majority of the West Angelas deposits are located within the upper reaches of the Turee Creek Catchment, which forms part of the regional Ashburton River Catchment. The upper catchment has a complex drainage pattern characterised by intermittent flow and infrequent wide-spread flooding, depending on the occurrence of high intensity rainfall events. The east branch of Turee Creek (Turee Creek East) represents the most significant named watercourse in the area (Figure 2-4). Turee Creek East flows generally westward across the West Angelas operation, continuing west south-west through the Karijini National Park, before merging with Turee Creek.

Deposit H is located in the Pebble Mouse Creek catchment, a tributary to Weeli Wolli Creek, which drains into the Fortescue Marsh. The deposit is within the headwaters of two minor tributaries that converge approximately 5 km downstream. The confluence with Weeli Wolli Creek is approximately 37 km downstream (Figure 2-4). Drainage within Deposit H is predominantly to the north, via several gullies incised through the surrounding outcropping Nammuldi Member.

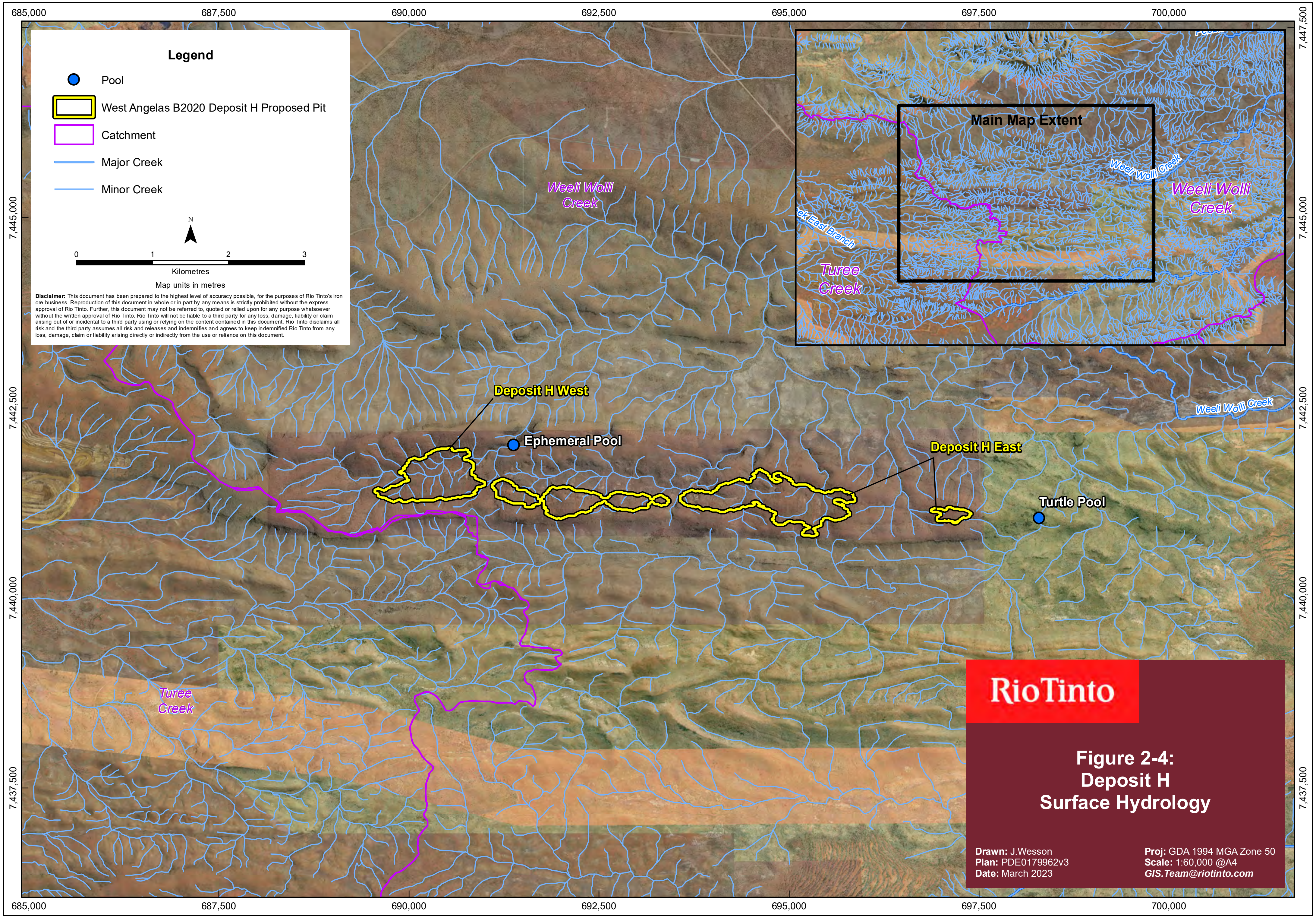

Figure 2-4:
Deposit H
Surface Hydrology

Drawn: J.Wesson
Plan: PDE0179962v3
Date: March 2023

Proj: GDA 1994 MGA Zone 50
Scale: 1:60,000 @A4
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2.3 Geology

2.3.1 Regional Geological Setting

The West Angelas mining hub is located on the Western hinge of the Wonmunna Anticline with deposits situated on the north and southward plunging axes of the anticline. Locally, the Nammuldi Member of the Marra Mamba Iron Formation presents in the outcropping hinge of the anticline, overlying the Fortescue Group basement formation. The limbs are characterised by steeply plunging Marra Mamba Iron Formation including Nammuldi, MacLeod and Mount Newman Members. The Wittenoom Formation, that is often overlain by detrital cover, characterise the valley between the Marra Mamba Iron Formation anticline and the relatively higher elevation Brockman Iron Formation (BIF) that encompasses the Wonmunna Anticline.

The stratigraphic sequence of the Hamersley Group is summarised in Table 2-1 Mineralisation occurs in both the Brockman Iron Formation (primarily the Dales Gorge Member) and the Marra Mamba Iron Formation (primarily the Mount Newman Member). A regional north-east to south-west trending dolerite dyke has been mapped on the northern limb of the anticline. This intrusion is known to act as an aquitard and compartmentalises the aquifer on the northern limb. Several localised dolerite dykes, trending north-west to south-east have also intruded the Marra Mamba Iron Formation, Wittenoom and BIF formation in the area, with these dykes capable of acting as aquitards compartmentalising aquifer units. Several mineralised orebodies (both green and brownfield development) exist at West Angelas, with the pits at various stages of mining.

Table 2-1: West Angelas – Stratigraphy

Group	Formation	Member	Description
Hamersley Group	Brockman Iron	Joffre	Planar bedded to poddy BIF with minor shale interbeds.
		Whaleback Shale	Shale, BIF and chert.
		Dales Gorge	BIF and shale interbedded. Primary ore horizon.
	Mount McRae Shale	-	Carbonaceous shale, chert and minor dolomitic shale.
	Mount Sylvia	-	BIF / chert and shales. Uppermost BIF unit – Bruno's Band.
	Wittenoom	Bee Gorge	Calcareous shales, with minor cherts, volcaniclastics and BIF.
		Paraburdoo	Predominantly crystalline dolomite with minor chert bands.
		West Angela	Shale, chert, dolomite with a BIF dominant zone toward its base.
	Marra Mamba Iron	Mount Newman	Podded BIF with interbedded carbonates and shales. Major ore bearing horizon.
		MacLeod	BIF, chert, carbonates, and shales.
		Nammuldi	Thick bedded, poddy, cherty BIF.

Group	Formation	Member	Description
Fortescue Group	Jeerinah	-	Interbedded chert, shale, dolomite, and a high density of intruded dolerite sills (up to 50%).

2.3.2 Local Geological Setting

Deposit H is encapsulated within the Nammuldi Member of the Marra Mamba Iron Formation in a bowl like synclinal structure. The deposit is located within an isolated lens of Marra Mamba Iron Formation surrounded by Fortescue Group strata. The deposit is an asymmetric doubly plunging syncline of mineralised and unmineralised Marra Mamba. The deposit shape means outcropping Nammuldi, Macleod and Newman Members surround a long narrow centre of West Angela Shale Member of the Wittenoom Formation, which is mostly covered by thin detrital (Figure 2-5).

Bedded mineralisation is primarily observed in the upper Newman Member, with low grade mineralisation also found in the West Angela Shale and MacLeod Members. Mineralisation is typically hydrated at surface and has increasing grade toward the hinge of the syncline.

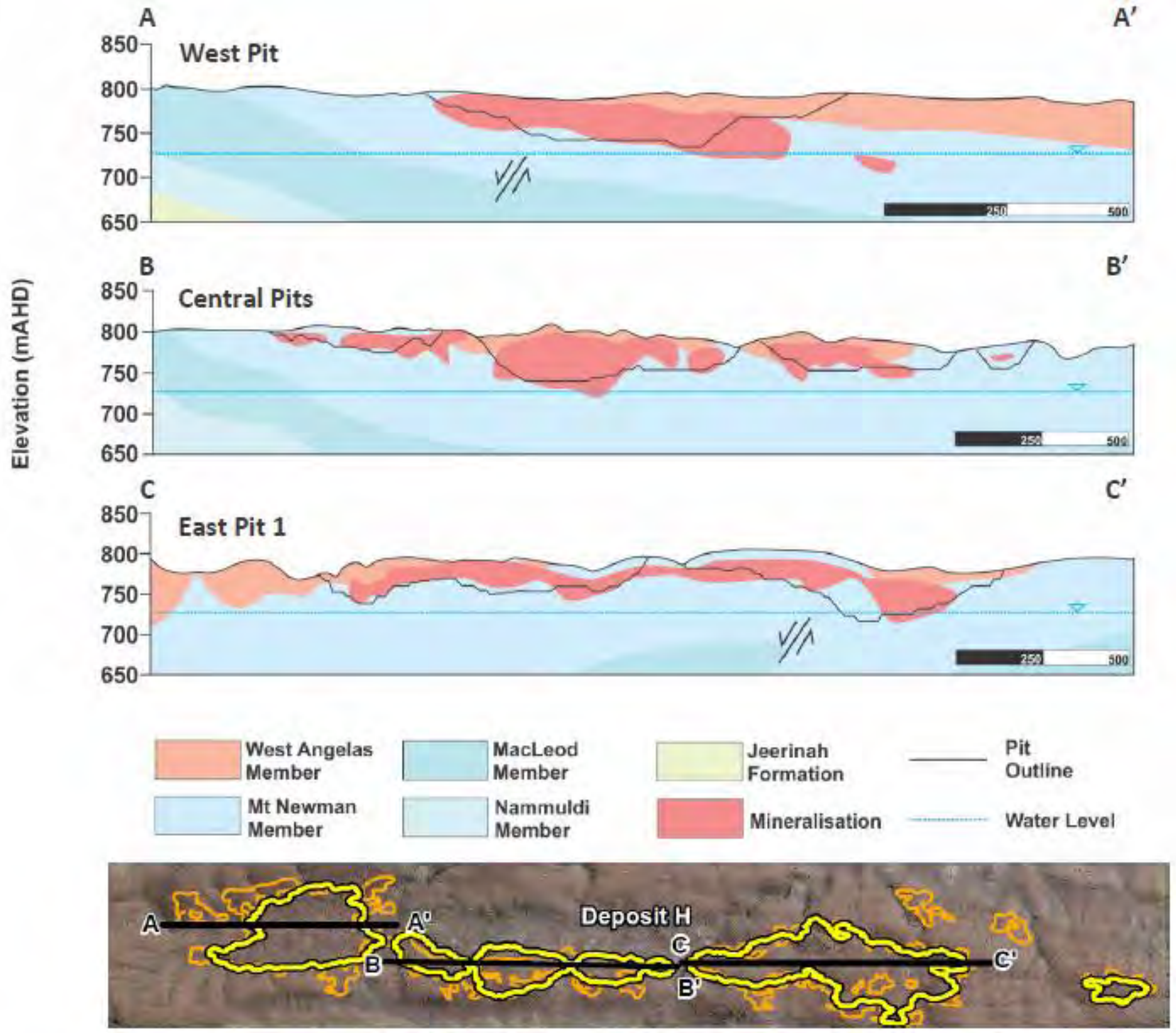

Figure 2-5: Geological cross-sections of Deposit H

2.4 Hydrogeological Setting

2.4.1 Regional Hydrogeological Setting

The regional hydrogeological understanding at West Angelas has been developed by groundwater observations from existing operations from monitoring data since 1998.

The regional groundwater system at West Angelas is characterised as a large basin-type aquifer with water storage within the weathered Wittenoom Formation, mineralized Marra Mamba Iron Formation and overlying alluvial dolecrete/dolerite units.

Permeability within the Wittenoom Formation can be enhanced through development of secondary permeability associated with dissolution of dolomitic units. These secondary features have significant hydraulic conductivity and storage.

The Wittenoom Formation is generally overlain by a detrital sequence of variable thickness which, when saturated, forms part of the regional aquifer. Aquifers also occur in the mineralised sections of the Marra Mamba Iron Formation and the overlying West Angelas Member of the Wittenoom Formation. Where hydraulic connection with the Wittenoom Formation or saturated detritals exists, the orebody aquifer forms part of the regional aquifer.

In other situations, the synclinal structure of the Marra Mamba Iron Formation which contains the mineralised (and permeable) Mt Newman Member is underlain and bounded by low permeability, non-mineralised units including the Macleod and Nammuldi Members of the Marra Mamba Formation and the Jeerinah Formation of the Fortescue Formation. This results in localised orebody aquifers commonly referred to as “bathtubs” that are generally only connected to the regional aquifer when they overflow.

The water table within the regional aquifer is relatively deep (between 50 – 120 mbgl) with a relatively flat gradient from east to west for most mining areas. Due to a groundwater divide, possibly associated with a dolerite dyke between Deposit C2 and C3 (approximately 20 km south-west of Deposit H), the groundwater flow direction in the area of Deposit C3, G and B (West of Deposit E) is reversed, from west to east, with the same relatively flat lying gradient.

Due to the substantial depths to groundwater, recharge is usually negligible and estimated to be approximately a small percentage of rainfall.

2.4.2 Local Hydrogeological Setting

Groundwater occurrence within Deposit H is understood largely from hydrogeological drilling campaigns undertaken between 2016 and 2021 and validated borehole geophysical groundwater data from mineral exploration drilling.

Groundwater occurrence in the surrounding lower permeability, unmineralised Marra Mamba Iron Formation is less understood, with information mostly from unvalidated borehole geophysical data at the fringes of mineral exploration drilling.

Current groundwater levels at Deposit H are approximately 735.5 mAHD and fairly consistent across the deposit (Figure 2-6). A very slight hydraulic gradient may be present towards the north-east, which suggest some through flow, consistent with the occurrence of some recharge and outflow from the bowl-like aquifer basin.

The relevant formations and their hydrogeological characteristics are detailed below and illustrated in cross-section in Figure 2-5, and in plan view in Figure 2-7:

- **Detritals**: a thin layer of sediment comprising gravels, mudstone and clays overlying the Hamersley Group bedrock. The detritals are generally unsaturated throughout the Deposit H area, however, may partially saturate in areas following significant rainfall events.
- **Wittenoom Formation**: the Wittenoom Formation weathers readily to form the sub crop in most low-lying areas such as valley floors and alluvial plains. It is comprised of three members, of which only one exists at Deposit H, the West Angela Member:
    - **West Angela Member**: comprised of shales and clays, is typically less permeable on a regional scale, and can serve as an aquitard between the Paraburdoo Member and the underlying Marra Mamba Iron Formation. The West Angela Member can become mineralized, as is the case in some areas of Deposit H, which increases permeability and hydraulic connection between adjacent units.
- **Marra Mamba Iron Formation**: a predominantly BIF formation of low permeability where un-mineralised. Where mineralised or fractured, permeability is significantly increased. Mineralised MMIF may be in hydraulic connection to the overlying Wittenoom Formation; however, this can be variable depending on the dip, mineralisation and hydraulic properties of the West Angela Member. The synclinal nature of the un-mineralized lower members of the Marra Mamba Iron Formation (MacLeod and Nammuldi Members) act to create a hydraulic barrier between the Fortescue Group surrounding Deposit H and the MMIF/West Angela Member aquifer units within the Deposit H area.
- **Fortescue Group**: Hosts interbedded chert, shale, dolomite, and significant massive dolerite, and is typically characterised by low primary permeability and low aquifer yields. The Fortescue Group is commonly considered hydraulically disconnected from Hamersley Group units. At Deposit H, the Fortescue group surrounds Deposit H on all sides, with outcropping Marra Mamba Iron Formation units acting as a hydraulic barrier between the Marra Mamba Iron Formation and Fortescue Group.

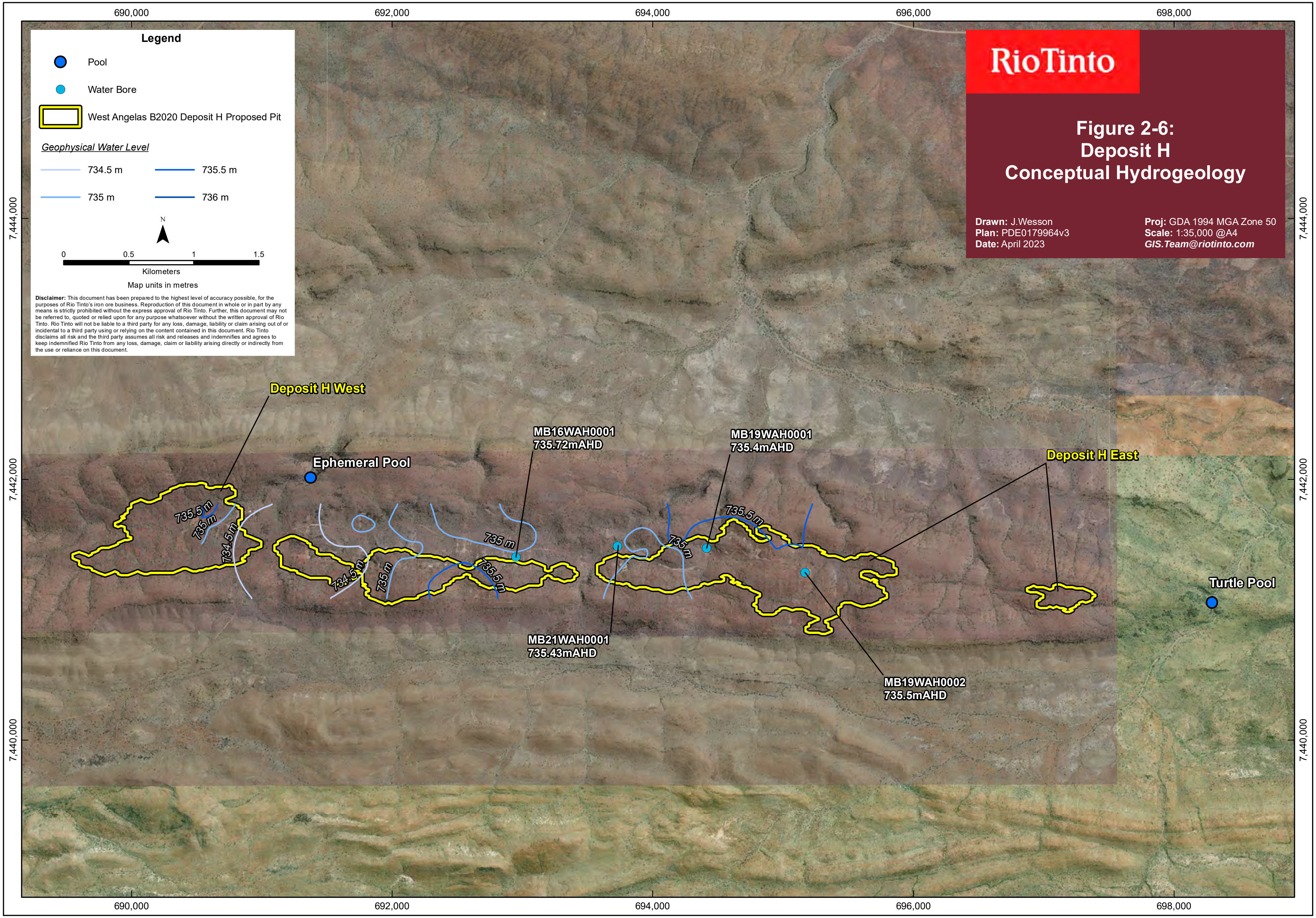

Figure 2-6:
Deposit H
Conceptual Hydrogeology

Drawn: J.Wesson
Plan: PDE0179964v3
Date: April 2023

Proj: GDA 1994 MGA Zone 50
Scale: 1:35,000 @A4
GIS.Team@riotinto.com

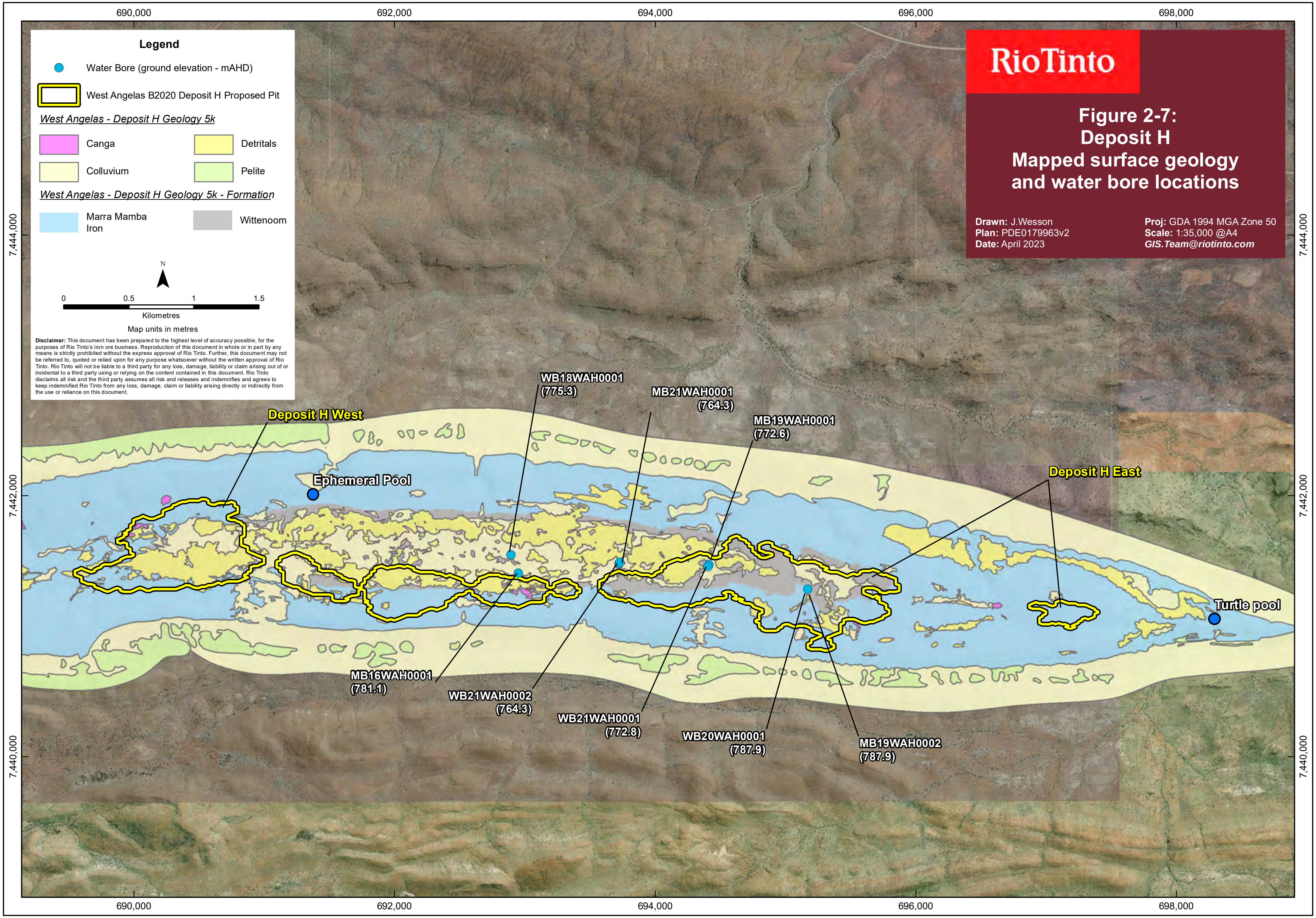

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Figure 2-7:
Deposit H
Mapped surface geology and water bore locations

Drawn: J.Wesson
Plan: PDE0179963v2
Date: April 2023

Proj: GDA 1994 MGA Zone 50
Scale: 1:35,000 @A4
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2.5 Hydrochemistry

2.5.1 Regional Hydrochemistry

Groundwater within the Marra Mamba Formation in the Greater West Angelas area is generally circum-neutral (field pH between 6.5 and 8.1 pH units) and fresh (median total dissolved solids are 584 mg/L). Metal concentrations are variable and overall low. Nitrate concentrations vary and are generally smaller than 35 mg/L [Ref: 1].

2.5.2 Local Hydrochemistry

The groundwater at Deposit H is dominated by sodium and chloride type waters (Figure 2-8). The pH is near neutral, ranging from 6.76 to 8.03 pH units. EC ranges from 690 to 881 uS/cm, which fall within the ANZECC fresh-water category [Ref: 2]. Chloride (known to be a conservation ion in the Pilbara) ranges from 189 to 256 mg/L. Nitrate concentrations are fairly consistent and range from 1.24 to 2.74 mg/L.

Dissolved metal concentrations are generally low and indicative of limited rock-water interaction and hydrochemical development.

The groundwater chemistry of Deposit H is markedly fresher, or of lower ionic concentration, than typical (deep) fractured rock aquifers in the Pilbara [Ref: 3]. Overall, the groundwater chemistry is characteristic of a regionally isolated aquifer, with limited throughflow to or from the system.

Hydrochemistry results for the samples collected at Deposit H is presented in Appendix A.

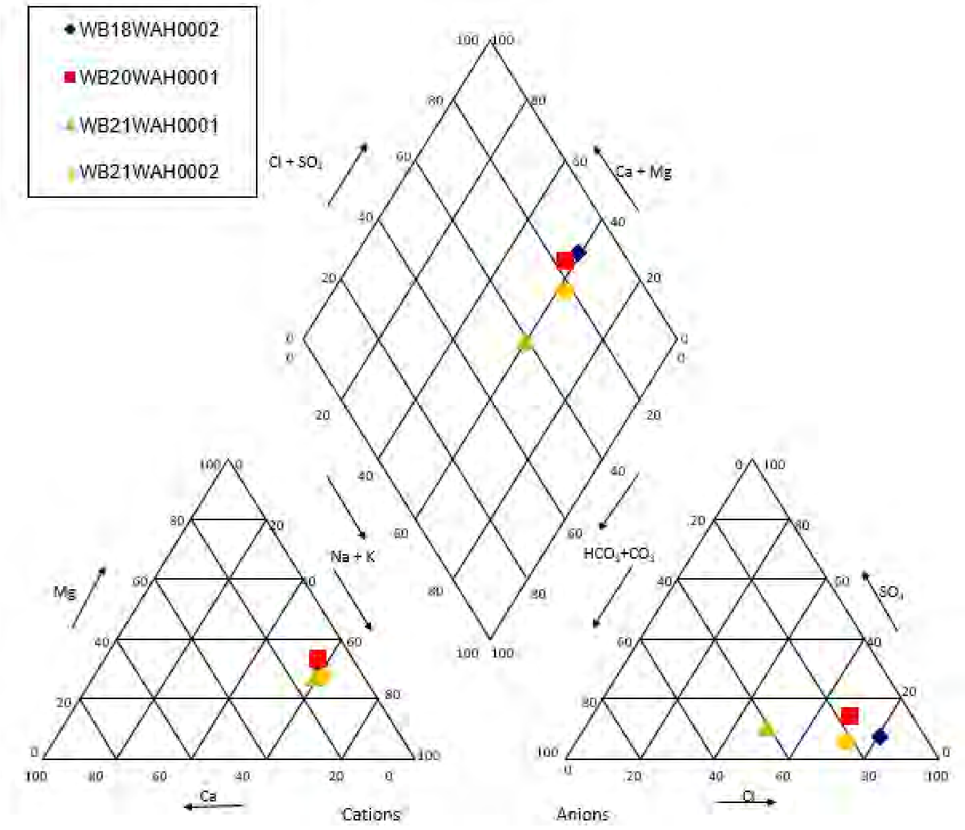

Figure 2-8: Piper plot

2.6 Groundwater use

2.6.1 Existing Use

Existing groundwater use in the Deposit H area has been primarily for exploratory drilling purposes under GWL98740(13).

The existing borefield comprises four production bores and four monitoring bores. The production bores are not equipped. Details of the bores are provided in Table 2-2 and shown on Figure 2-7, with bore completion reports provided in Appendix B and bore construction details summarized in Appendix C.

Table 2-2: Existing monitoring and production bore details

Bore Name	**Bore type**	**Easting (MGA94)**	**Northing (MGA94)**	**Ground level (mAHD)**	**Screened interval**	**Screened unit**
WB18WAH0001	Production	692,895	7,441,551	775.3	60 – 138	NEW
WB20WAH0001	Production	695,166	7,441,289	788.3	58 – 94	NEW
WB21WAH0001	Production	694,404	7,441,457	772.8	51.5 – 143.5	NEW
WB21WAH0002	Production	693,723	7,441,482	670.2	61.5 – 121.5	NEW
MB16WAH0001	Monitoring	692,950	7,441,406	781.0	92 – 110	NEW
MB19WAH0001	Monitoring	694,414	7,441,473	722.6	40 – 100	WAN
MB19WAH0002	Monitoring	695,170	7,441,286	788.0	70 – 100	NEW
MB21WAH0001	Monitoring	693,730	7,441,489	764.3	111 – 147	NEW

Note: mAHD = metres Australian Height Datum; NEW = Mount Newman; WAN = West Angela.

There are no nearby groundwater users other than Rio Tinto operated water supply and dewatering operations.

2.6.2 Future Use

No abstraction or dewatering is proposed for Deposit H. It is proposed that water to meet operational demands is supplied from other deposits at West Angelas under the existing groundwater licence (GWL98740(13)). Therefore, the existing production bores are not planned to be equipped and no additional production bores are planned in the deposit.

2.7 Surface water features

Two ephemeral pools were identified around Deposit H, one to the north and one to the east of Deposit H (Turtle Pool) (Figure 2-4).

2.7.1 Ephemeral Pool

A creekline in one of the Deposit H sub catchments includes a small ephemeral pool (the Ephemeral Pool) located at the base of a gorge to the north of Deposit H. The pool has a rocky floor and sits at the base of a steep waterfall at the outlet of the main creek line. High velocity plunging flows scour sediment from the pool and maintain depth and water. Water has persisted in the pool for more than six months following flow events. The water level in the pool has been monitored since 2018 and indicates it is a surface water system supported by rainfall and catchment inflows. The elevation of this ephemeral pool has been surveyed and has placed this pool approximately 22 m above the Deposit H groundwater level (757 mAHD and 735 mAHD, respectively).

2.7.2 Turtle Pool

Turtle pool is a semi-permanent surface water feature that forms approximately 700 m to the east of Deposit H. The hydrology of Turtle Pool indicates it is unlikely to be groundwater fed and is likely dependent on rainfall and direct surface flows for replenishment. Groundwater dependent ecosystems (GDE) assessments undertaken suggest that the vegetation is not groundwater dependant. However, a pool forms after rainfall and subsequent streamflow events and the elevation of the resulting pool is similar to the elevation to groundwater levels within the deposit (i.e. 735 mAHD) (Figure 2-9). Therefore, a cautionary approach is taken and the groundwater connection has not been formally ruled out.

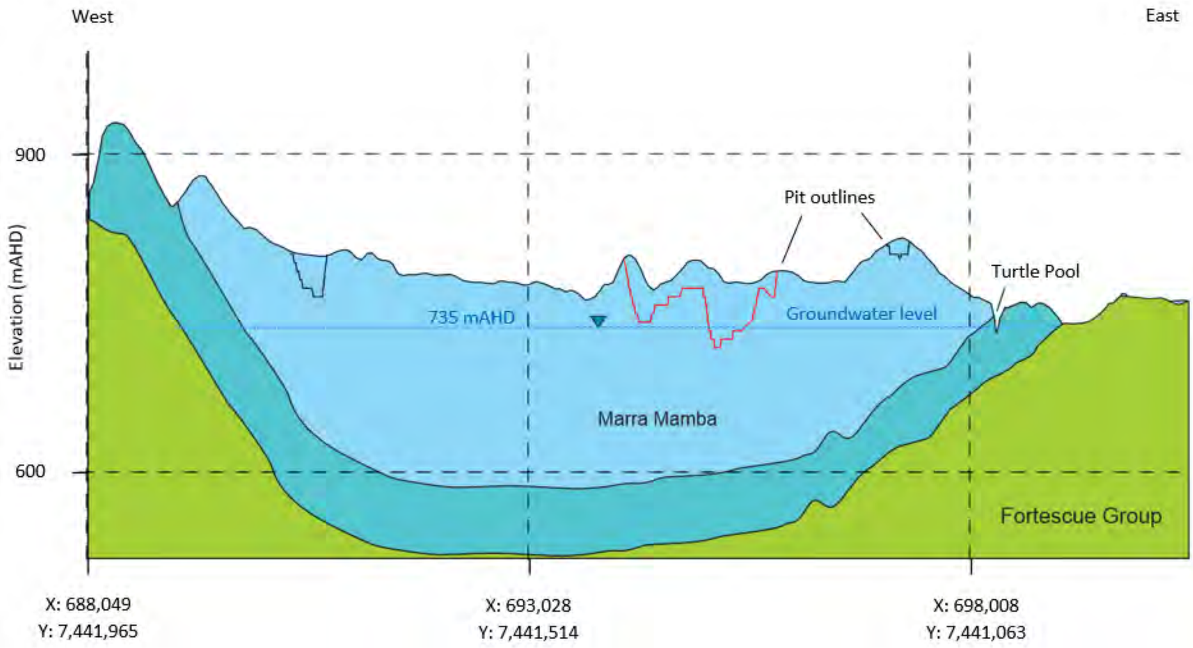

Figure 2-9: West-East cross-section though Deposit H to Turtle Pool

3. Hydrogeological Investigations

3.1 Drilling Investigations

Hydrogeological investigations have been undertaken at Deposit H between 2016 and 2021 to refine the conceptual model and develop the dewatering strategy. Table 3-1 summarises the drilling investigations completed to date.

The hydrogeological drilling has targeted the mineralised portion of the Mount Newman and MacLeod Members of the Marra Mamba Iron Formation as well as the mineralised portion of the West Angelas Member of the Wittenoom Formation. All bores are hydrogeologically open to the overlying West Angelas Member (no bentonite seal was installed at the contact between formations to maintain the connection).

It is worth noting that hydrogeological investigation in the surrounding Fortescue Group has been impeded by tenure constraints.

Bore completion reports for each monitoring and production bore are provided in Appendix B, with locations shown on Figure 2-7.

Table 3-1: Summary of drilling investigations

Drilling program year	Bore ID	Commentary
2016	MB16WAH0001	Initial hydrogeological drilling investigation.
2018	WB18WAH0001 WB18WAH0002	First production bore was unable to be completed, second bore was a redrill.
2019	MB19WAH0001 MB19WAH0002	Further drilling to understand water levels across the deposit.
2020	WB20WAH0001	Production bore drilled for test pumping.
2021	MB21WAH0001 WB21WAH0001 WB21WAH0002	Pilot hole for production bore WB21WAH0002. Production bore drilled for water supply. Production bore drilled for water supply.

*Note: *2023 drilling program has not been completed yet.*

3.2 Aquifer Testing

Test pumping was conducted on Deposit H production bores to determine hydraulic parameters (permeability and storage), provide information for engineering design (i.e. pump type, pump install depth, optimal abstraction rates, and pumping water level), and evaluate the efficacy of dewatering in Deposit H. Details of the tests are summarized in Table 3-2 and locations shown on Figure 3-1. Additional details are provided in Appendix D.

Table 3-2: CRT Drawdown Results

Pumping Bore Name	CRT duration (hours)	CRT Rate (L/s)	Monitoring Bore ID	Direction from Prod. Bore	Distance from Prod. Bore	Screened Unit	Maximum Observed Drawdown (m)
WB20WAH0001	72	17	WB20WAH0001	Pumping bore		Mt Newman	27.4
			MB19WAH0002	South-east	10	Mt Newman	8.60
			MB19WAH0001	North-west	722	Mt Newman	0.10
WB21WAH0001	6.5	20	WB21WAH0001	Pumping bore		Mt Newman	49.6
			MB19WAH0001	North	10	Mt Newman	2.89
			MB19WAH0002	East	800	Mt Newman	0.02
			MB21WAH0001	West	670	Mt Newman	0.29
WB21WAH0002	No CRT was performed due to approval limitations						

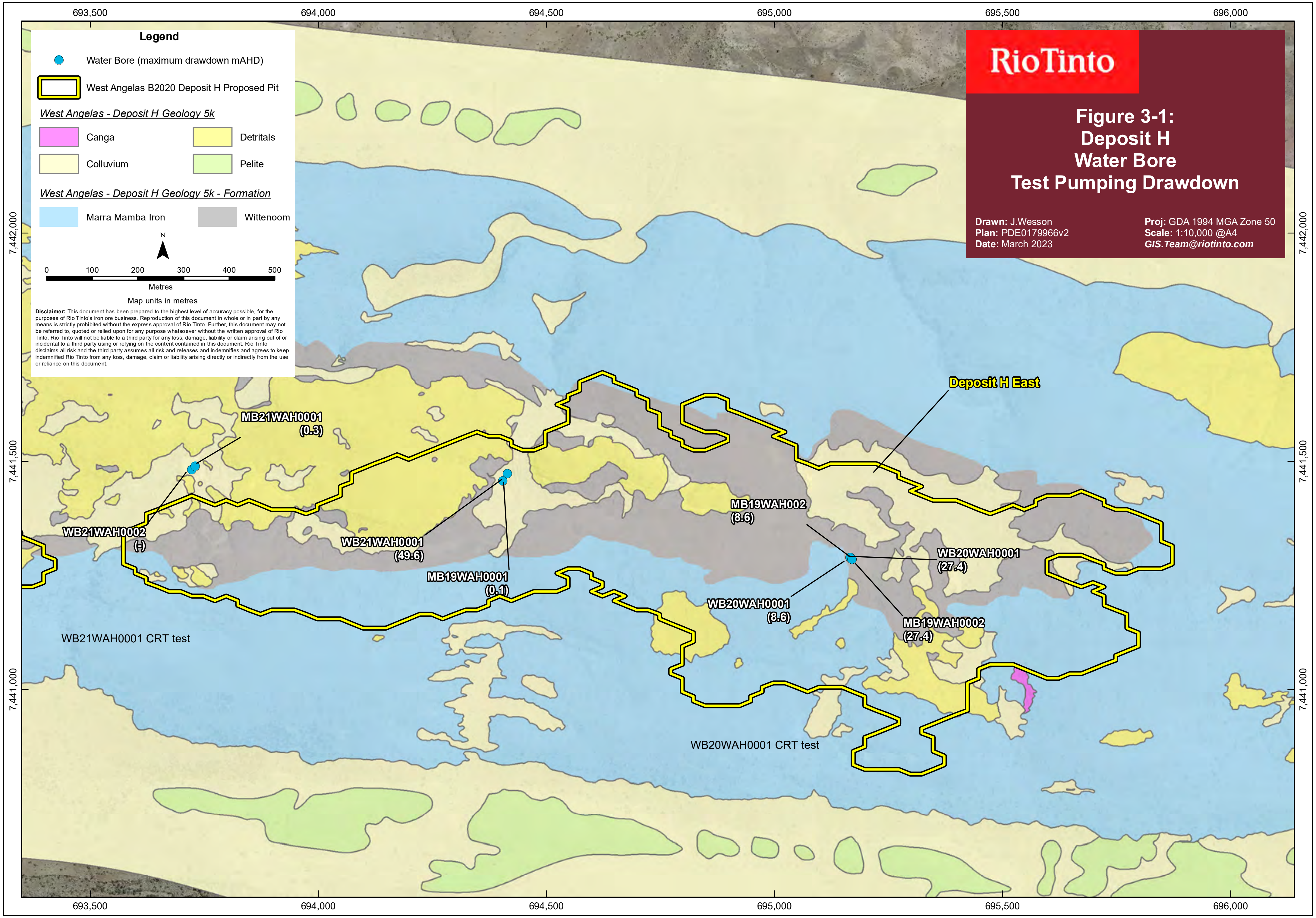

Figure 3-1:
Deposit H
Water Bore
Test Pumping Drawdown

Drawn: J.Wesson
Plan: PDE0179966v2
Date: March 2023

Proj: GDA 1994 MGA Zone 50
Scale: 1:10,000 @A4
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3.3 Groundwater Level Observations

Surface elevation is roughly 800 mAHD, making depth to water table approximately 65 m. Evapotranspiration is therefore not considered a major component of the water balance. The greatest known aquifer thickness from drill logs is approximately 135 m, implying a maximum potential saturated thickness of 70 m. It is noteworthy that aquifer base is assumed to be the contact between the Nammuldi and the MacLeod Formations. The aquifer is considered to be unconfined throughout Deposit H.

The water levels in Deposit H are distinctly different to adjacent deposits (e.g. pre-mining groundwater level of 630 mAHD in the Marra Mamba Iron Formation in Deposit B, 5 km to the west) further supporting that Deposit H is largely disconnected from the regional system.

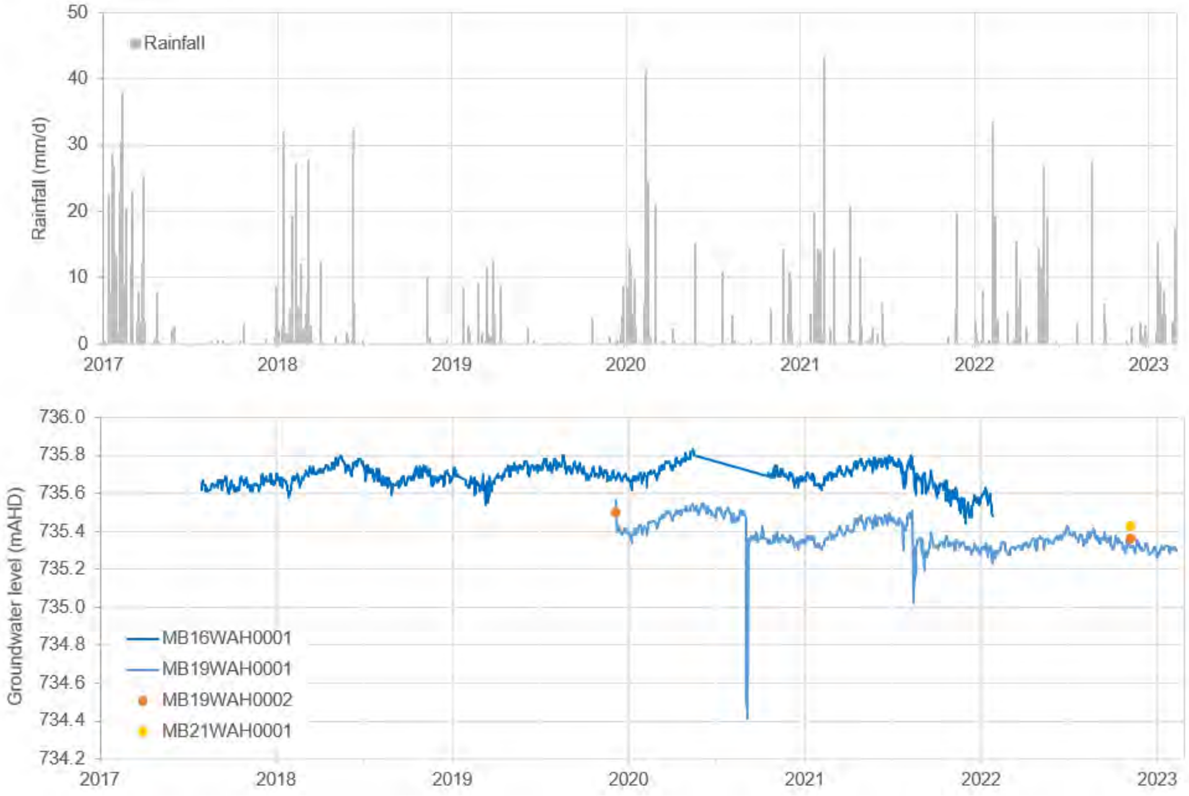


Figure 3-2: Rainfall and groundwater level data for monitoring bores in Deposit H

4. Conceptual Hydrogeological Model

The conceptual hydrogeology of Deposit H forms the basis of groundwater modelling with the objective of assessing dewatering requirements/impacts. The conceptual model is summarised below and shown on Figure 4-1.

Key aquifer characterisation:

- The mineralised portion of the Mount Newman and MacLeod Members of the Marra Mamba Iron Formation as well as the mineralised portion of the West Angelas Member of the Wittenoom Formation form an unconfined aquifer with low transmissivity and storage parameters compared to other West Angelas deposits;
- The aquifer is surrounded on all sides by the assumed impermeable unmineralized portion of the Marra Mamba Iron Formation, which has an east-west striking synclinal structure;

- The vertical aquifer extent varies (maximum depth of approximately 135 m) across the deposit due to the depth of mineralisation and the shape of the unmineralised MacLeod and Nammuldi members which form the basal extent of the aquifer (i.e. they encapsulate the aquifer);
- Groundwater recharge is minimal and occurs with infiltration of rainfall as point source recharge. Observed groundwater level variation of up to 0.2 m correlates with site rainfall and is consistent with the stated groundwater flow and recharge processes;
- Groundwater through-flow through the deposit is likely to be minimal, with the low permeability hydrostratigraphy surrounding the deposit having limited connection to the orebody aquifer. Similarly, outflow from the orebody aquifer is likely minimal and would most likely consist of shallow groundwater flow through alluvials in eroded channels that incise the low permeability material that bounds the deposit; and
- The large differences recorded in groundwater levels between Deposit H and proximal deposits further support the idea that Deposit H is largely disconnected from the regional system.

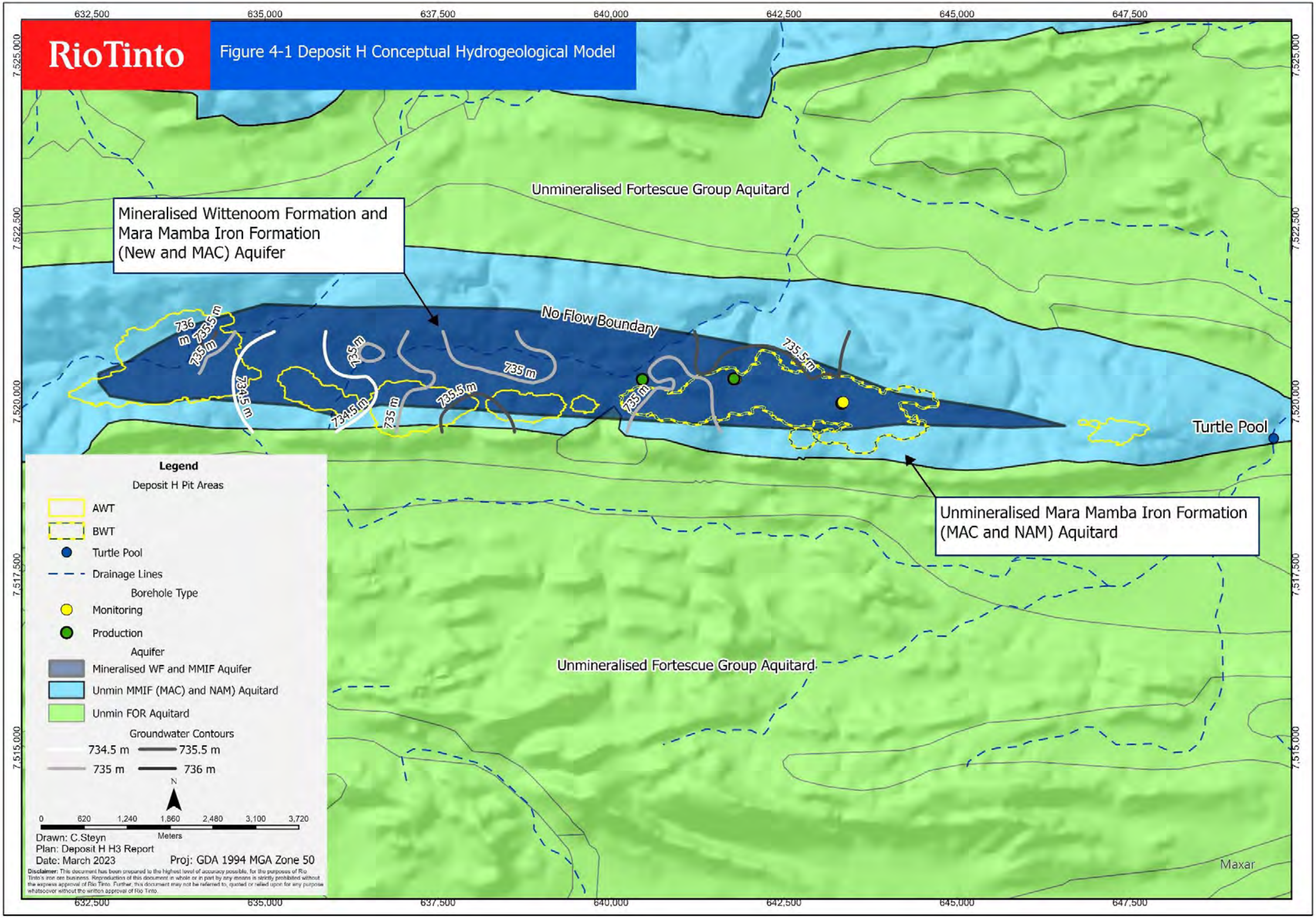


Figure 4-1 Deposit H Conceptual Hydrogeological Model

Drawn: C.Steyn
Plan: Deposit H H3 Report
Date: March 2023
Proj: GDA 1994 MGA Zone 50

5. Assessment of Potential Impacts

5.1 Ephemeral Pool - Turtle Pool

Due to the surrounding unmineralised and impermeable Nammuldi Member of the Marra Mamba Iron Formation the simulated drawdown at Deposit H does not propagate beyond the Deposit H aquifer.

However, modelling results suggest that if the surrounding stratigraphy is more permeable than anticipated, there will be drawdown of groundwater beneath Turtle Pool. The results indicate a large range of variability between modelled ensembles. Management of potential outcomes is presented in section 7.1

5.2 Ephemeral Pool – North of Deposit H

The ephemeral pool to the north of Deposit H (Figure 1-1) is beyond the groundwater model boundaries as it was understood that this pool is dominated and supplied by surface water flow. Periodic observation of water levels within this pool show its ephemeral nature and demonstrate its surface water dependence.

6. Groundwater Monitoring

It is recommended groundwater level and quality monitoring is conducted at the locations and frequencies listed in Table 6-1 and that monitoring bores are added to the West Angelas Groundwater Operating Strategy (GWOS) prior to mining commencing.

Table 6-1: Recommended Monitoring Program

Bore ID	Groundwater levels	Groundwater quality
MB16WAH0001	Continuous	Annual
MB19WAH0001	Continuous	Annual
MB19WAH0002	Continuous	Annual
MB21WAH0001	Continuous	Annual
WB18WAH0002	Continuous	-
WB20WAH0001	Continuous	-
WB21WAH0001	Continuous	-
WB21WAH0002	Continuous	-
WAH-M03*	Continuous	-

*Note: * Planned monitoring bore to be drilled in 2023.*

7. Groundwater Management Strategy

7.1 Below Water Table Mining

No abstraction or dewatering is proposed for Deposit H to ensure no potential impact is recorded at Turtle Pool. BWT mining of the final benches is proposed to be achieved though sump pumping and top loading. Any water removed through sump pumping is to be pumped to a backfilled area within the same pit and allowed to infiltrate through a box cut.

7.2 Operational Water Demands

The operational water demand at Deposit H is estimated to be 3.6 GL over the life of mine of this deposit (based on the 2022 Life of Mine (LoM) plan) (Figure 7-1). The maximum operational water demand will be in 2030, with 1.0 GL required. Operational dust water demands have been estimated using 17 litres per tonne total material movement (TMM) factor, based on the cumulative total of water used for dust suppression divided by the cumulative total of tonnes moved for 2022 TMM volumes at West Angelas.

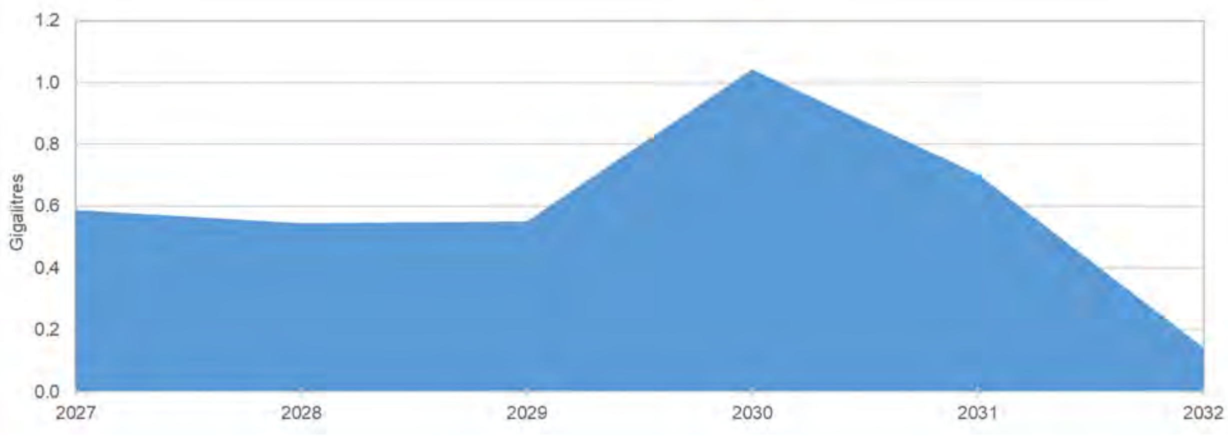


Figure 7-1: Operational water demand over the life of mine of Deposit H

7.3 Water Supply and Discharge

Operational water demands are to be met from water supplied from other deposits at West Angelas. This option is being assessed as a separate project.

All water supplied to Deposit H is expected to be used for dust suppression within the deposit and is not expected to be discharged, therefore there is no requirement for management of excess water.

7.4 Closure

Backfilling to two metres above pre-mining groundwater table will be completed once mining is finished in the deposit. Groundwater levels will be reinstated to pre-mining groundwater levels (735 mAHD) where necessary.

8. References

[Ref: 1] RTIO 2019, *Review of existing water quality data – Greater West Angelas*. RTIO-PDE-0167001. Dated February 2019.

[Ref: 2] ANZECC fresh water category (ANZG 2018): Australian and New Zealand Guidelines for Fresh and Marine Water Quality, https://www.waterquality.gov.au/guidelines/anz-fresh-marinev

[Ref: 3] Dogramaci, S., Skrzypek, G., Dodson, W. and Grierson, P.F., 2012, *Stable isotope and hydrochemical evolution of groundwater in the semi-arid Hamersley Basin of subtropical northwest Australia*. Journal of Hydrology, 475, pp.281-293.

[Ref: 4] IGS, 2023, *Simulating the effects of aquifer depletion at West Angelas Deposit-H*. A report prepared for Rio Tinto Iron Ora by Innovative Groundwater Solutions. Report dated 22 March 2023.

[Ref: 5] Langevin, C.D., Hughes, J.D., Banta, E.R., Niswonger, R.G., Panday, S. and Provost, A.M., 2017, *Documentation of the MODFLOW-6 Groundwater Flow Model: U.S. Geological Survey Techniques and Methods*, book 6, chap. A55, 197 p., https//doi.org/10.3133/tm6A55

[Ref: 6] Bakker, M., Post, V., Langevin, C. D., Hughes, J. D., White, J. T., Starn, J. J. and Fienen, M. N., 2016, *Scripting MODFLOW Model Development Using Python and FloPy: Groundwater*, v. 54, p. 733–739, doi:10.1111/gwat.12413.

[Ref: 7] QGIS.org, 2022, *QGIS Geographic Information System*. QGIS Association. http://www.qgis.org

[Ref: 8] Field, G. 2022, East Pilbara Strategic Water Plan.

Appendix A – Water quality results

Table A.1: Summary of water quality results at Deposit H

Water Quality	Unit	WB18WAH0002	WB20WAH0001	WB21WAH0001	WB21WAH0002
Alkalinity	mg/L	16	28	113	44
EC	uS/cm	690	762	991	872
Ionic Balance	%	2.25	1.41	5.29	3.79
pH	pH unit	7.42	6.76	8.03	7.71
TDS	mg/L	426	428	556	544
TSS	mg/L	220	<5	92	212
Aluminium	mg/L	<0.005	<0.01	0.03	0.04
Antimony	mg/L	<0.0002	<0.001	< 0.001	< 0.001
Arsenic	mg/L	<0.0002	<0.001	< 0.001	< 0.001
Barium	mg/L	0.0693	0.046	0.16	0.27
Bicarb. Alk. $CaCO_3$	mg/L	16	28	113	44
Boron	mg/L	0.163	0.19	0.15	0.21
Cadmium	mg/L	<0.00005	<0.0001	0.0001	< 0.0001
Calcium	mg/L	12	14	25	17
Chloride	mg/L	189	201	239	256
Chromium	mg/L	0.0006	<0.001	< 0.001	< 0.001
Cobalt	mg/L	<0.0001	<0.001	0.016	0.002
Copper	mg/L	<0.0005	<0.001	0.005	< 0.001
Fluoride	mg/L	<0.1	0.1	0.2	< 0.1
Iron	mg/L	0.005	0.17	1.61	0.25
Lead	mg/L	<0.0001	<0.001	0.003	< 0.001
Magnesium	mg/L	22	29	31	27
Manganese	mg/L	0.0011	0.008	1.15	0.456
Mercury	mg/L	<0.0001	<0.0001	< 0.0001	< 0.0001
Molybdenum	mg/L	<0.0001	<0.001	0.001	< 0.001
Nickel	mg/L	<0.0005	<0.001	0.005	0.002
Nitrate	mg/L	1.59	2.74	1.24	2.21
Ammonia	mg/L	<0.01	<0.01	< 0.01	< 0.01
Ammonium NH_4-N	mg/L	<0.01	<0.01	< 0.01	< 0.01
Nitrate	mg/L	0.36	0.62	0.28	0.50
Nitrite	mg/L	<0.01	<0.01	0.01	< 0.01
Nitrogen NOX	mg/L	0.36	0.62	0.29	0.5
Nitrogen	mg/L	0.4	0.8	1.6	0.5
DO	% Sat	-	103	80.2	92.6
Phosphorus	mg/L	0.04	0.03	0.1	0.1
Potassium	mg/L	10	10	11	11
Selenium	mg/L	0.0006	<0.01	< 0.01	< 0.01
Silicon	mg/L	8.2	6.88	5.83	5.81
Dioxide	mg/L	17.6	-	-	-
Silver	mg/L	<0.00001	<0.001	< 0.001	< 0.001
Sodium	mg/L	73	88	122	108
Sulphate	mg/L	22	55	69	28
Tin	mg/L	-	<0.001	< 0.001	< 0.001
Uranium	mg/L	<0.00005	<0.001	< 0.001	< 0.001
Zinc	mg/L	<0.001	0.009	0.115	0.092

Appendix B – Bore Completion Reports

Well Completion Details - MB16WAH0001

HOLE DETAILS

PROJECT: West Angelas
LOCATION: DEPH
DATE COMMENCED: 04/10/2016
DATE COMPLETED: 04/10/2016

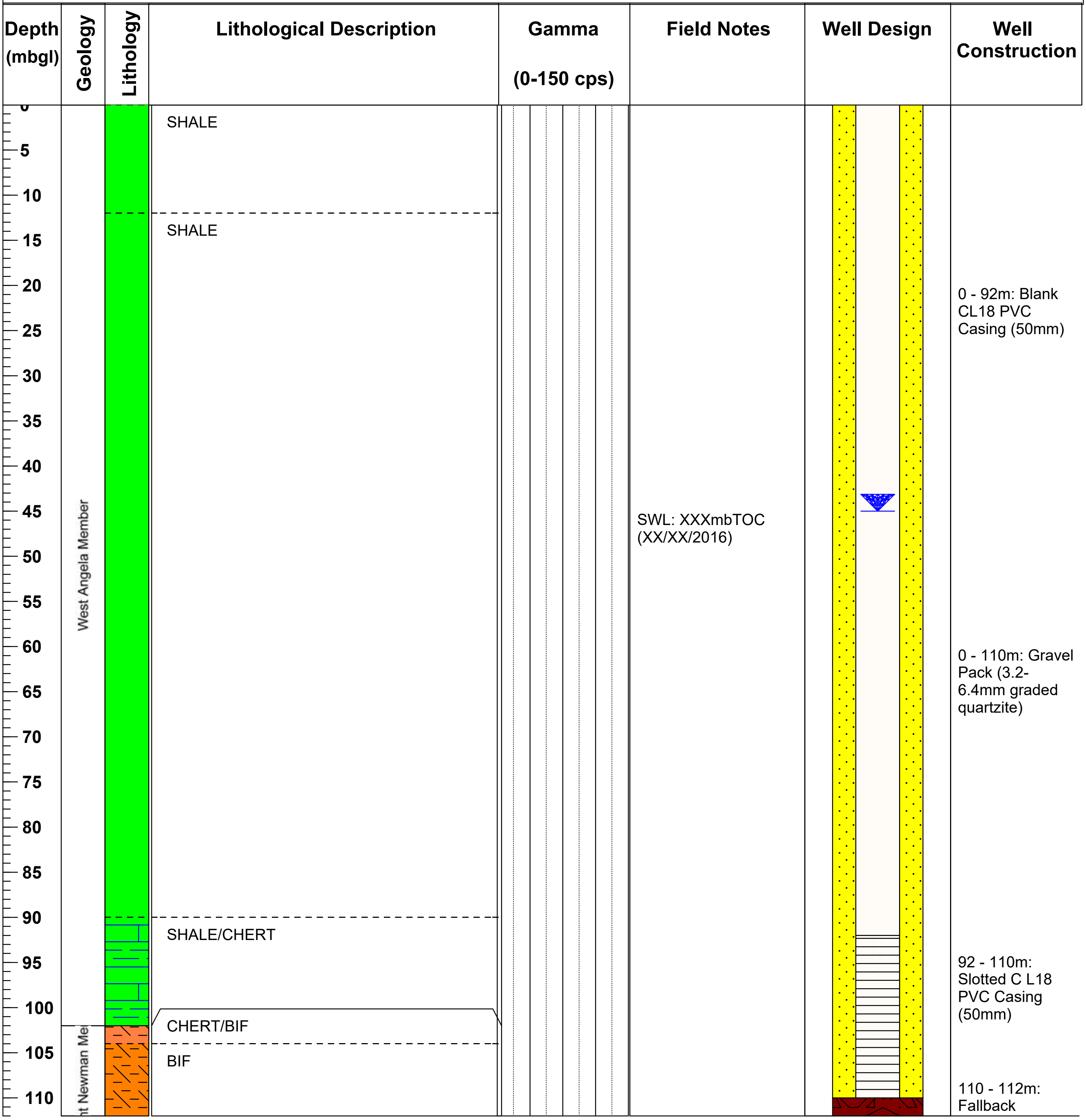
DRILLING DETAILS

DRILLING COMPANY: WALLIS
DRILLER: WALLIS
DRILLING METHOD: RC
HYDROGEOLOGIST: RE Geologist

LOCATION

GRID NAME: MGA94_Z50
EASTING: 692950.33 mE
NORTHING: 7441405.71 mN
ELEVATION: 781.97 mRL (TOC)

Hole drilled and installed by RE (original Peg ID: RC16WAH0093)
Inferred WL ~45mbgl (taken from downhole resistivity)



MB19WAH0001

PROJECT: WANG
DEPTH (mbgl): 102.0
DATE COMMENCED: 13/09/2019
DATE COMPLETED: 20/09/2019
FIBRES: No

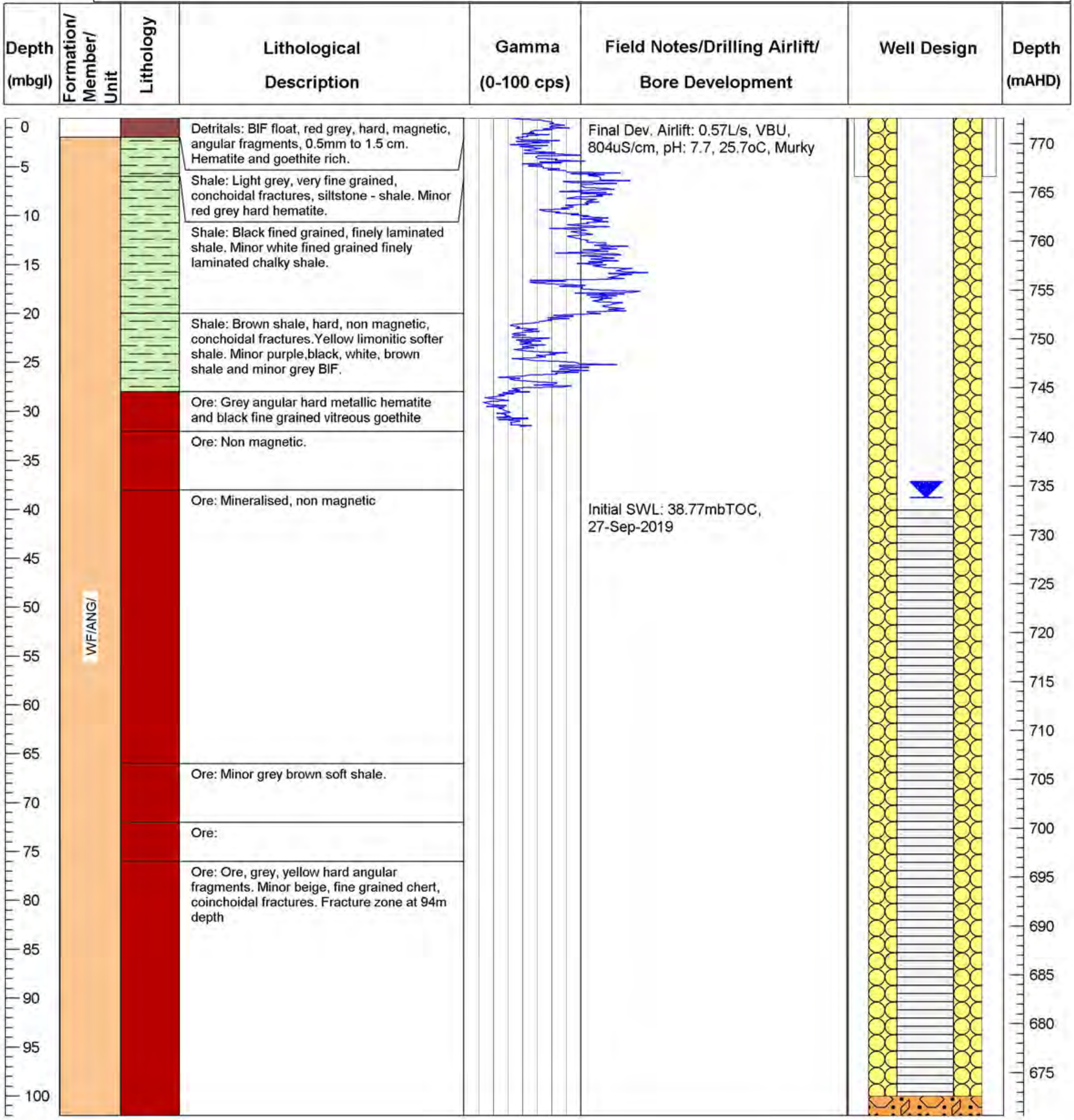
DRILLING COMPANY: EAST
DRILL RIG: HYD7
DRILLING METHOD: CONVAIR
DRILLER: Mark Foster
HYDROGEOLOGIST: Consultant

GRID NAME: GDA94_Z50
EASTING: 694,413.871
NORTHING: 7,441,473.151
ELEVATION (mRL): 772.611
TOC (mRL): 773.464

Ex-pit dewatering exploration prior to 19WAH_P1.

0-6m, Blank, PVC18, 254mm; 0-40m, Blank, PVC18, 50mm; 40-100m, Slotted, PVC18, 50mm

0-102m, 12.25", CONVAIR, HAM



Lithological Description

Detritals: BIF float, red grey, hard, magnetic, angular fragments, 0.5mm to 1.5 cm. Hematite and goethite rich.

Shale: Light grey, very fine grained, conchoidal fractures, siltstone - shale. Minor red grey hard hematite.

Shale: Black fined grained, finely laminated shale. Minor white fined grained finely laminated chalky shale.

Shale: Brown shale, hard, non magnetic, conchoidal fractures.Yellow limonitic softer shale. Minor purple,black, white, brown shale and minor grey BIF.

Ore: Grey angular hard metallic hematite and black fine grained vitreous goethite

Ore: Non magnetic.

Ore: Mineralised, non magnetic

Ore: Minor grey brown soft shale.

Ore:

Ore: Ore, grey, yellow hard angular fragments. Minor beige, fine grained chert, coinchoidal fractures. Fracture zone at 94m depth

Field Notes/Drilling Airlift/ Bore Development

Final Dev. Airlift: 0.57L/s, VBU, 804uS/cm, pH: 7.7, 25.7oC, Murky

Initial SWL: 38.77mbTOC, 27-Sep-2019

MB19WAH0002

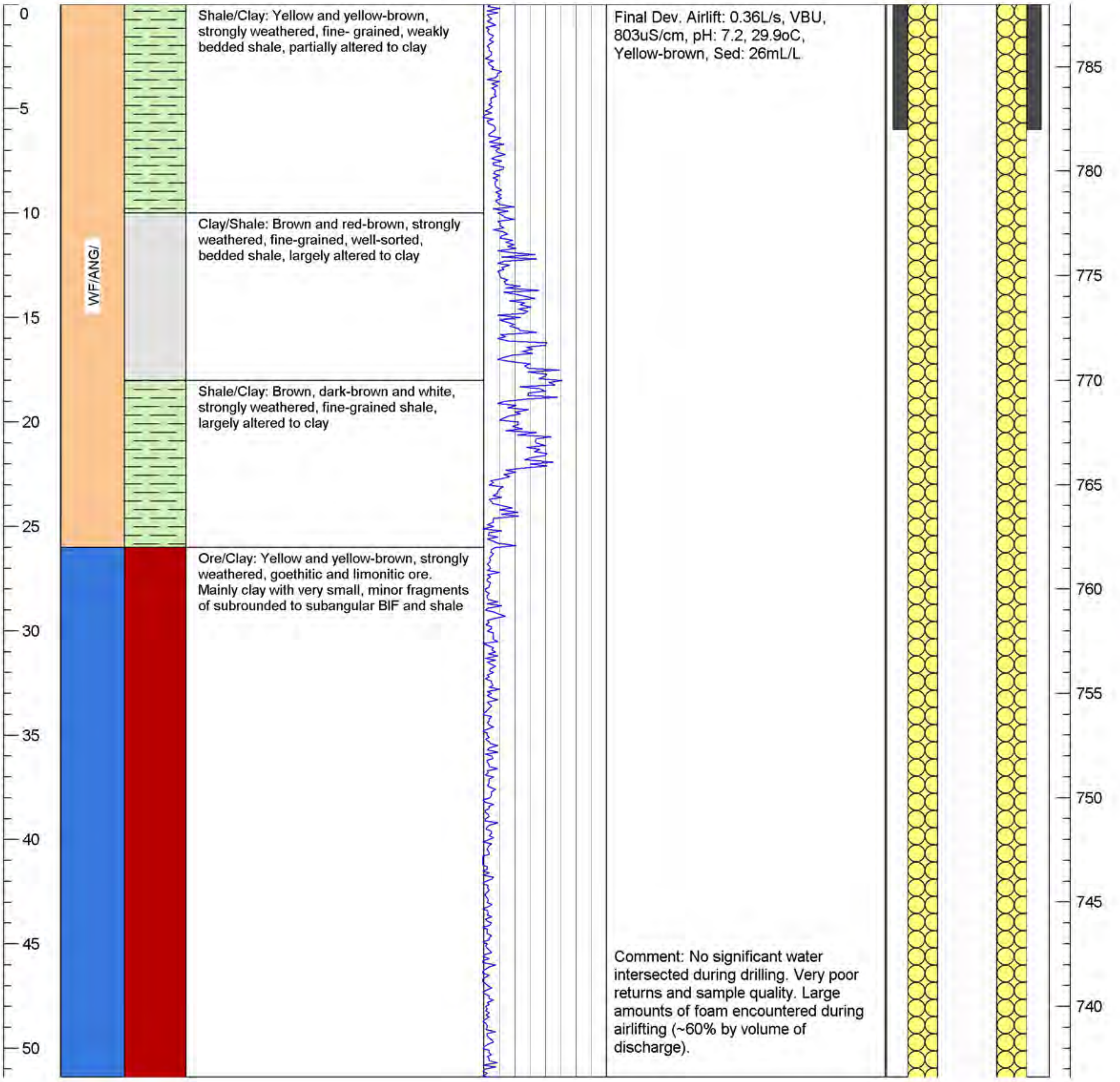
PROJECT:	WANG	**DRILLING COMPANY:**	EAST	**GRID NAME:**	GDA94_Z50
DEPTH (mbgl):	126.0	**DRILL RIG:**	HYD7	**EASTING:**	695,170.139
DATE COMMENCED:	23/09/2019	**DRILLING METHOD:**	CONVAIR	**NORTHING:**	7,441,285.845
DATE COMPLETED:	30/09/2019	**DRILLER:**	Shaun Johnstone,Mark Foster	**ELEVATION (mRL):**	787.998
FIBRES:	No	**HYDROGEOLOGIST:**	Consultant	**TOC (mRL):**	788.598

In-pit dewatering exploration prior to 19WAH-P1.

0-6m, Surface, STEEL, 250mm; 0-69.8m, Blank, STEEL, 50mm; 69.8-99.8m, Slotted, STEEL, 50mm; 99.8-99.9m, Blank, STEEL, 50mm

0-6m, 12.25", CONVAIR, HAM; 6-126m, 6.5", CONVAIR, HAM

Depth (mbgl)	**Formation/ Member/ Unit**	**Lithology**	**Lithological Description**	**Gamma (0-100 cps)**	**Field Notes/Drilling Airlift/ Bore Development**	**Well Design**	**Depth (mAHD)**



Shale/Clay: Yellow and yellow-brown, strongly weathered, fine- grained, weakly bedded shale, partially altered to clay

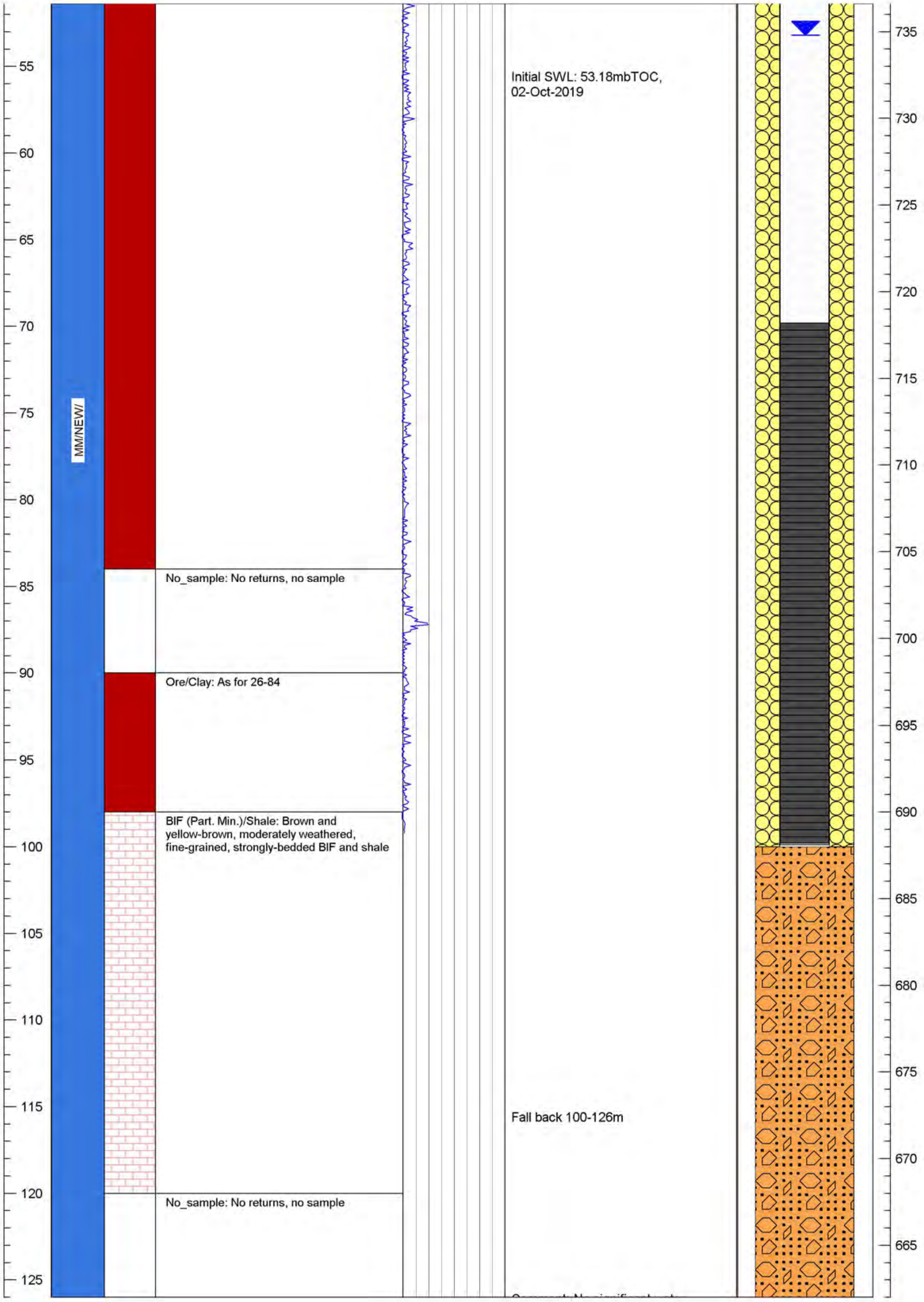
Clay/Shale: Brown and red-brown, strongly weathered, fine-grained, well-sorted, bedded shale, largely altered to clay

Shale/Clay: Brown, dark-brown and white, strongly weathered, fine-grained shale, largely altered to clay

Ore/Clay: Yellow and yellow-brown, strongly weathered, goethitic and limonitic ore. Mainly clay with very small, minor fragments of subrounded to subangular BIF and shale

Final Dev. Airlift: 0.36L/s, VBU, 803uS/cm, pH: 7.2, 29.9oC, Yellow-brown, Sed: 26mL/L

Comment: No significant water intersected during drilling. Very poor returns and sample quality. Large amounts of foam encountered during airlifting (~60% by volume of discharge).



Initial SWL: 53.18mbTOC, 02-Oct-2019

No_sample: No returns, no sample

Ore/Clay: As for 26-84

BIF (Part. Min.)/Shale: Brown and yellow-brown, moderately weathered, fine-grained, strongly-bedded BIF and shale

Fall back 100-126m

No_sample: No returns, no sample

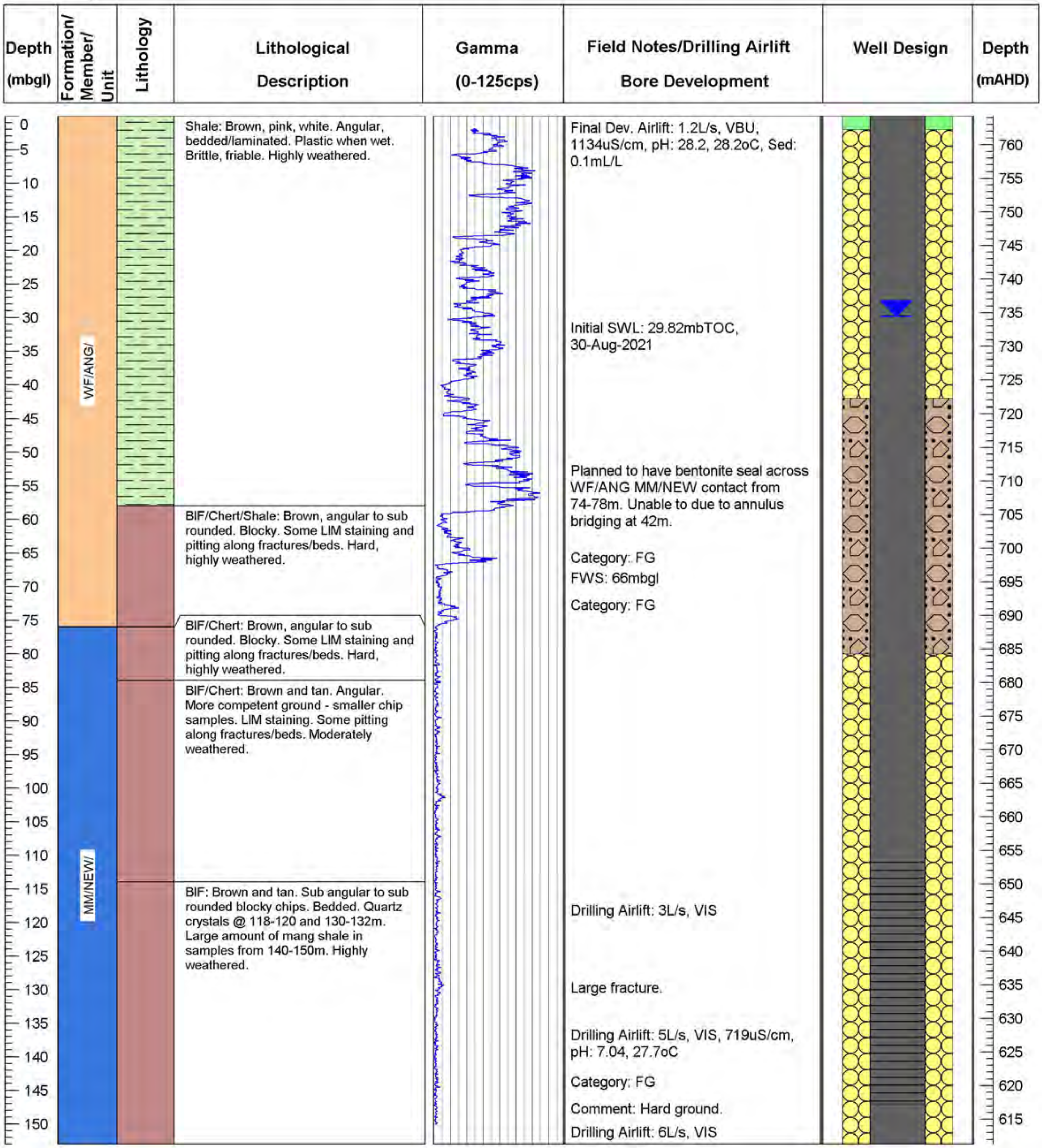
MB21WAH0001

PROJECT:	WANG	**DRILLING COMPANY:**	BDC	**GRID NAME:**	GDA94_Z50
DEPTH (m):	153.0	**DRILL RIG:**	BDC140	**EASTING:**	693,730.022
DATE COMMENCED:	21/07/2021	**DRILLING METHOD:**	CONVAIR	**NORTHING:**	7,441,489.41
DATE COMPLETED:	27/07/2021	**DRILLER:**	Gavan Brodie	**ELEVATION:**	764.298
FIBRES:	No	**HYDROGEOLOGIST:**	Benjamin.Snowdon	**TOC:**	765.216

Monitoring bore for WB21WAH0002.

0-6m, Surface, STEEL, 203.2mm; 0-111m, Blank, STEEL, 50mm; 111-147m, Slotted, STEEL, 50mm; 147-153m, Blank, STEEL, 50mm; 153-153m, Blank, STEEL, 50mm

0-6m, 12.25", CONVAIR, TRC; 0-36m, 6.5", CONVAIR, HAM; 36-153m, 6.5", CONVAIR, HAM



Lithological Description

Shale: Brown, pink, white. Angular, bedded/laminated. Plastic when wet. Brittle, friable. Highly weathered.

BIF/Chert/Shale: Brown, angular to sub rounded. Blocky. Some LIM staining and pitting along fractures/beds. Hard, highly weathered.

BIF/Chert: Brown, angular to sub rounded. Blocky. Some LIM staining and pitting along fractures/beds. Hard, highly weathered.

BIF/Chert: Brown and tan. Angular. More competent ground - smaller chip samples. LIM staining. Some pitting along fractures/beds. Moderately weathered.

BIF: Brown and tan. Sub angular to sub rounded blocky chips. Bedded. Quartz crystals @ 118-120 and 130-132m. Large amount of mang shale in samples from 140-150m. Highly weathered.

Field Notes/Drilling Airlift Bore Development

Final Dev. Airlift: 1.2L/s, VBU, 1134uS/cm, pH: 28.2, 28.2oC, Sed: 0.1mL/L

Initial SWL: 29.82mbTOC, 30-Aug-2021

Planned to have bentonite seal across WF/ANG MM/NEW contact from 74-78m. Unable to due to annulus bridging at 42m.

Category: FG

FWS: 66mbgl

Category: FG

Drilling Airlift: 3L/s, VIS

Large fracture.

Drilling Airlift: 5L/s, VIS, 719uS/cm, pH: 7.04, 27.7oC

Category: FG

Comment: Hard ground.

Drilling Airlift: 6L/s, VIS

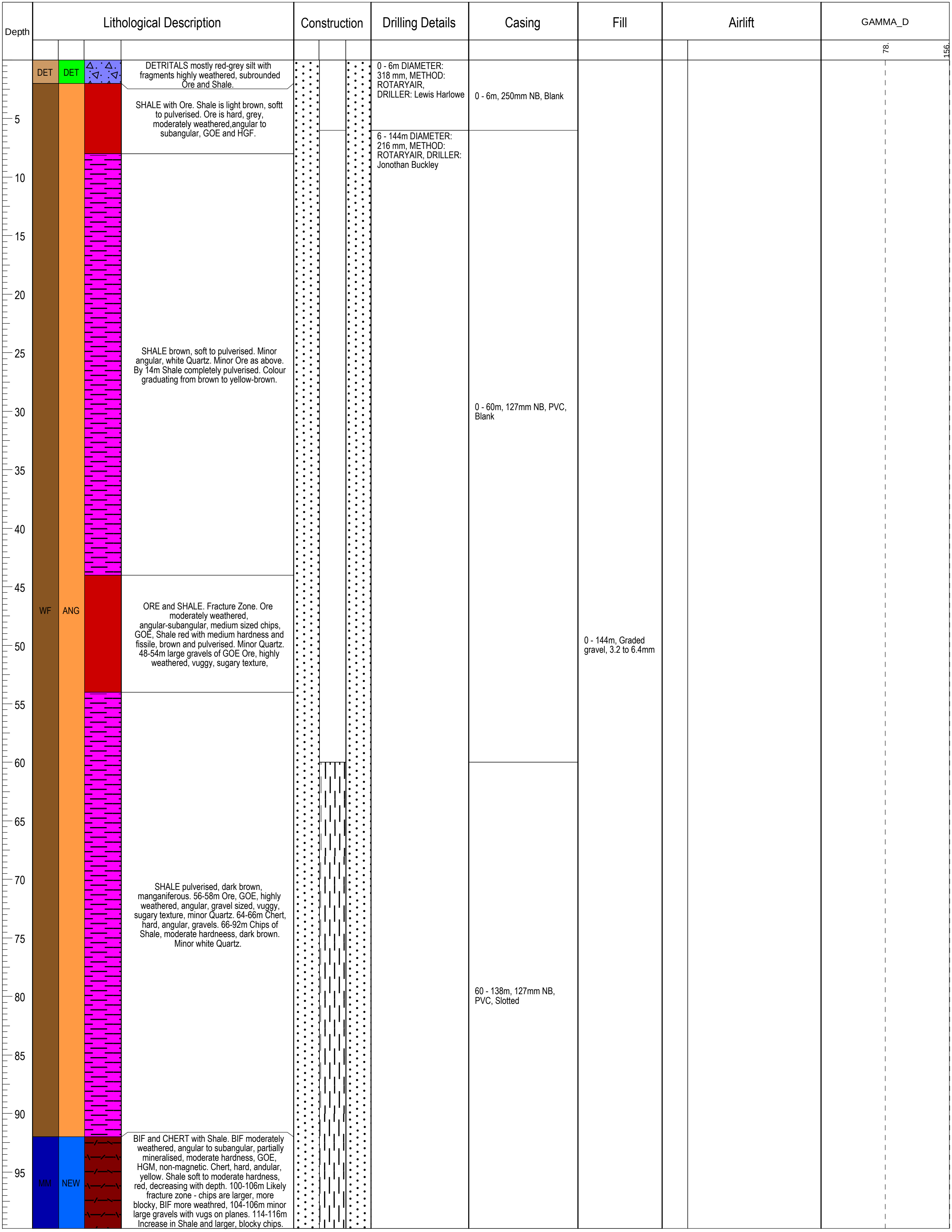
BORE COMPLETION DETAILS: WB18WAH0002

Project Name: WANG
Depth (m): 144
Start Date: 2/07/2018
Completion Date: 8/07/2018

Drilling Company: FOC
Hydrogeologist: Rachell.Fuller
Initial Water (m): 41.03
Initial Water Date: 8/07/2018

Easting: 692895.259
Northing: 7441551.302
Top of Collar:
Ground RL: 775.301
Grid Name: GDA94_Z50

Comments: Water supply bore for Resource Evaluation drilling. WB18WAH0001 drilled by RE but hole abandoned as rig could only drill to 100m and not enough water. WB18WAH0002 is a re-drill on same pad by WRES. RE requested no geophyisical surveys. No lessons learnt.   Orig hole name - WB18WAH0001. Renamed to WB18WAH0002. 02-Aug-2018. OK. ST14709



DETRITALS mostly red-grey silt with fragments highly weathered, subrounded Ore and Shale.

SHALE with Ore. Shale is light brown, softt to pulverised. Ore is hard, grey, moderately weathered,angular to subangular, GOE and HGF.

SHALE brown, soft to pulverised. Minor angular, white Quartz. Minor Ore as above. By 14m Shale completely pulverised. Colour graduating from brown to yellow-brown.

ORE and SHALE. Fracture Zone. Ore moderately weathered, angular-subangular, medium sized chips, GOE, Shale red with medium hardness and fissile, brown and pulverised. Minor Quartz. 48-54m large gravels of GOE Ore, highly weathered, vuggy, sugary texture,

SHALE pulverised, dark brown, manganiferous. 56-58m Ore, GOE, highly weathered, angular, gravel sized, vuggy, sugary texture, minor Quartz. 64-66m Chert, hard, angular, gravels. 66-92m Chips of Shale, moderate hardness, dark brown. Minor white Quartz.

BIF and CHERT with Shale. BIF moderately weathered, angular to subangular, partially mineralised, moderate hardness, GOE, HGM, non-magnetic. Chert, hard, andular, yellow. Shale soft to moderate hardness, red, decreasing with depth. 100-106m Likely fracture zone - chips are larger, more blocky, BIF more weathred, 104-106m minor large gravels with vugs on planes. 114-116m Increase in Shale and larger, blocky chips.

0 - 6m DIAMETER: 318 mm, METHOD: ROTARYAIR, DRILLER: Lewis Harlowe

6 - 144m DIAMETER: 216 mm, METHOD: ROTARYAIR, DRILLER: Jonothan Buckley

0 - 6m, 250mm NB, Blank

0 - 60m, 127mm NB, PVC, Blank

60 - 138m, 127mm NB, PVC, Slotted

0 - 144m, Graded gravel, 3.2 to 6.4mm

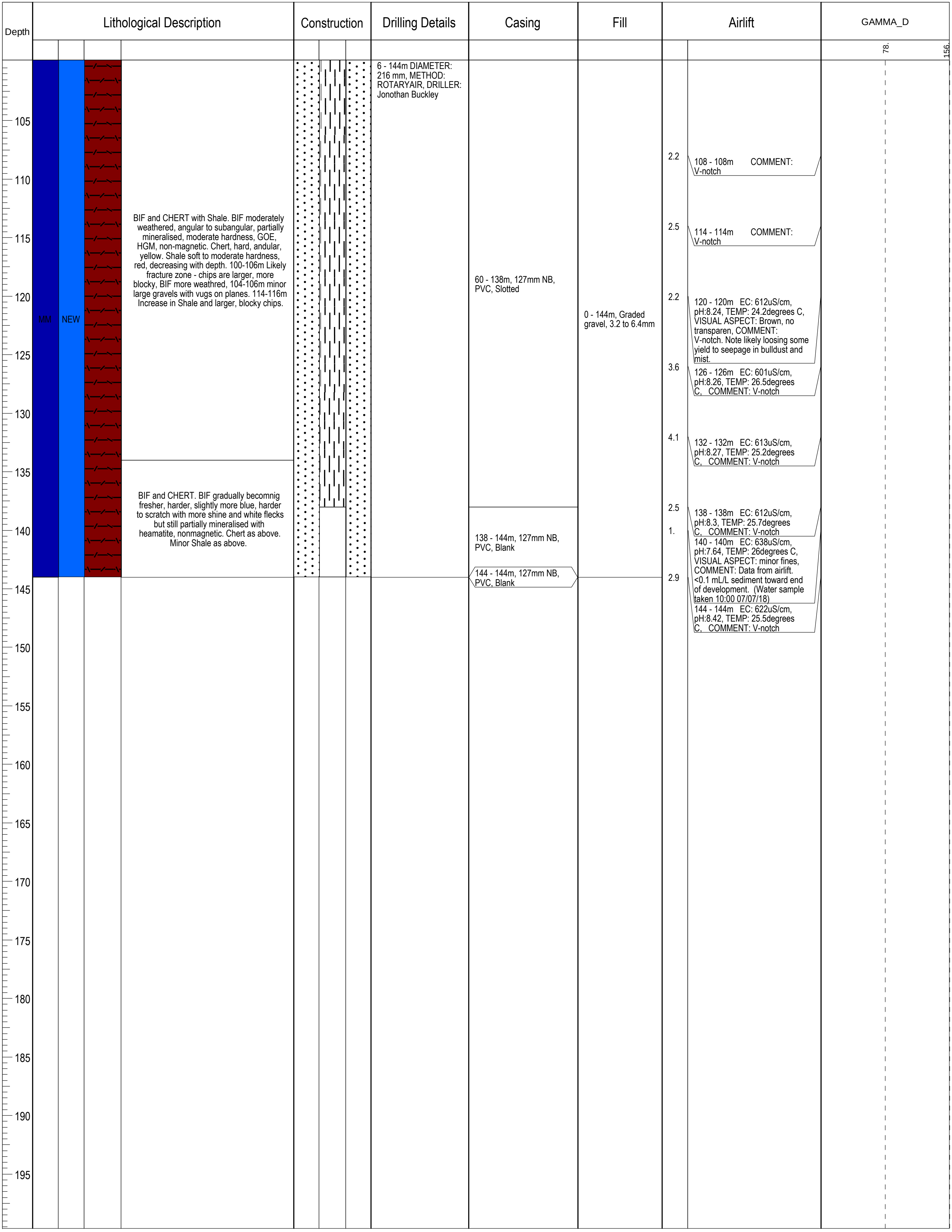
BORE COMPLETION DETAILS: WB18WAH0002

Project Name: WANG
Depth (m): 144
Start Date: 2/07/2018
Completion Date: 8/07/2018

Drilling Company: FOC
Hydrogeologist: Rachell.Fuller
Initial Water (m): 41.03
Initial Water Date: 8/07/2018

Easting: 692895.259
Northing: 7441551.302
Top of Collar:
Ground RL: 775.301
Grid Name: GDA94_Z50

Comments: Water supply bore for Resource Evaluation drilling. WB18WAH0001 drilled by RE but hole abandoned as rig could only drill to 100m and not enough water. WB18WAH0002 is a re-drill on same pad by WRES. RE requested no geophyisical surveys. No lessons learnt. Orig hole name - WB18WAH0001. Renamed to WB18WAH0002. 02-Aug-2018. OK. ST14709



Lithological Description

BIF and CHERT with Shale. BIF moderately weathered, angular to subangular, partially mineralised, moderate hardness, GOE, HGM, non-magnetic. Chert, hard, andular, yellow. Shale soft to moderate hardness, red, decreasing with depth. 100-106m Likely fracture zone - chips are larger, more blocky, BIF more weathred, 104-106m minor large gravels with vugs on planes. 114-116m Increase in Shale and larger, blocky chips.

BIF and CHERT. BIF gradually becomnig fresher, harder, slightly more blue, harder to scratch with more shine and white flecks but still partially mineralised with heamatite, nonmagnetic. Chert as above. Minor Shale as above.

Drilling Details

6 - 144m DIAMETER: 216 mm, METHOD: ROTARYAIR, DRILLER: Jonothan Buckley

Casing

60 - 138m, 127mm NB, PVC, Slotted

138 - 144m, 127mm NB, PVC, Blank

144 - 144m, 127mm NB, PVC, Blank

Fill

0 - 144m, Graded gravel, 3.2 to 6.4mm

Airlift

2.2	108 - 108m COMMENT: V-notch
2.5	114 - 114m COMMENT: V-notch
2.2	120 - 120m EC: 612uS/cm, pH:8.24, TEMP: 24.2degrees C, VISUAL ASPECT: Brown, no transparen, COMMENT: V-notch. Note likely loosing some yield to seepage in bulldust and mist.
3.6	126 - 126m EC: 601uS/cm, pH:8.26, TEMP: 26.5degrees C, COMMENT: V-notch
4.1	132 - 132m EC: 613uS/cm, pH:8.27, TEMP: 25.2degrees C, COMMENT: V-notch
2.5	138 - 138m EC: 612uS/cm, pH:8.3, TEMP: 25.7degrees C, COMMENT: V-notch
1.	140 - 140m EC: 638uS/cm, pH:7.64, TEMP: 26degrees C, VISUAL ASPECT: minor fines, COMMENT: Data from airlift. <0.1 mL/L sediment toward end of development. (Water sample taken 10:00 07/07/18)
2.9	144 - 144m EC: 622uS/cm, pH:8.42, TEMP: 25.5degrees C, COMMENT: V-notch

WB20WAH0001

PROJECT: WANG
DEPTH (m): 100.0
DATE COMMENCED: 11/06/2020
DATE COMPLETED: 20/06/2020
FIBRES: No

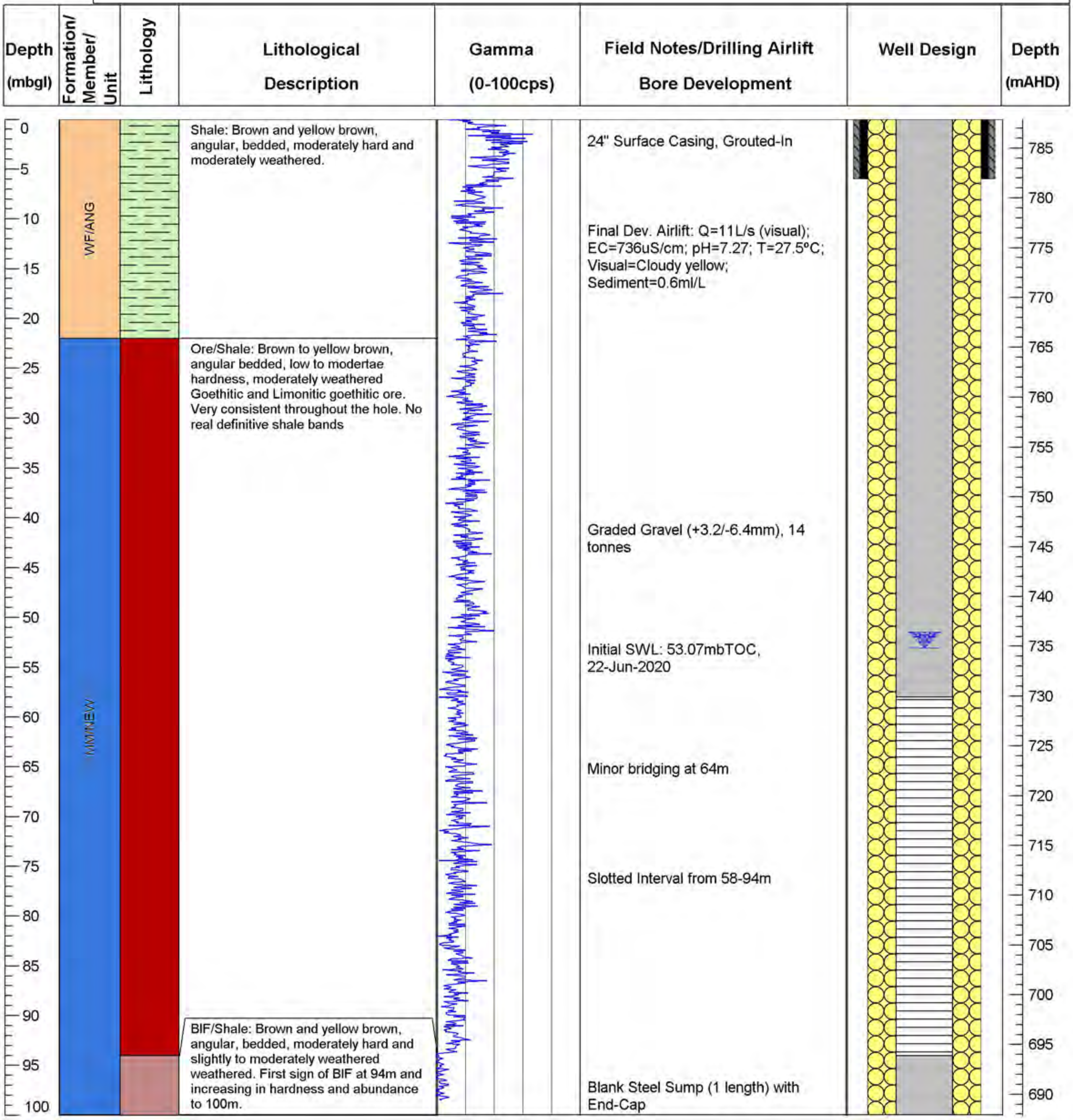
DRILLING COMPANY: Boart Longyear
DRILL RIG: WW06
DRILLING METHOD: DTFR,CONVMUD
DRILLER: Glenn Foreman
HYDROGEOLOGIST: T. Venables/A. Murfet

GRID NAME: GDA94_Z50
EASTING: 695,165.74
NORTHING: 7,441,289.4
ELEVATION: 787.896
TOC: 788.34

Deposit H dewatering and supply bore

0-6m: 24", Surface Steel Casing; 0-58m: 12" Blank Steel; 58-94m: 12" Slotted Steel; 94-100m: 12" Blank Steel Sump with End-Cap

0-6m: 28", Conventional Mud/Tricone; 6-45m: 17.5", Conventional Mud/Tricone; 45-100m: 17.5", DTFR/Tricone



Shale: Brown and yellow brown, angular, bedded, moderately hard and moderately weathered.

Ore/Shale: Brown to yellow brown, angular bedded, low to modertae hardness, moderately weathered Goethitic and Limonitic goethitic ore. Very consistent throughout the hole. No real definitive shale bands

BIF/Shale: Brown and yellow brown, angular, bedded, moderately hard and slightly to moderately weathered weathered. First sign of BIF at 94m and increasing in hardness and abundance to 100m.

24" Surface Casing, Grouted-In

Final Dev. Airlift: Q=11L/s (visual); EC=736uS/cm; pH=7.27; T=27.5°C; Visual=Cloudy yellow; Sediment=0.6ml/L

Graded Gravel (+3.2/-6.4mm), 14 tonnes

Initial SWL: 53.07mbTOC, 22-Jun-2020

Minor bridging at 64m

Slotted Interval from 58-94m

Blank Steel Sump (1 length) with End-Cap

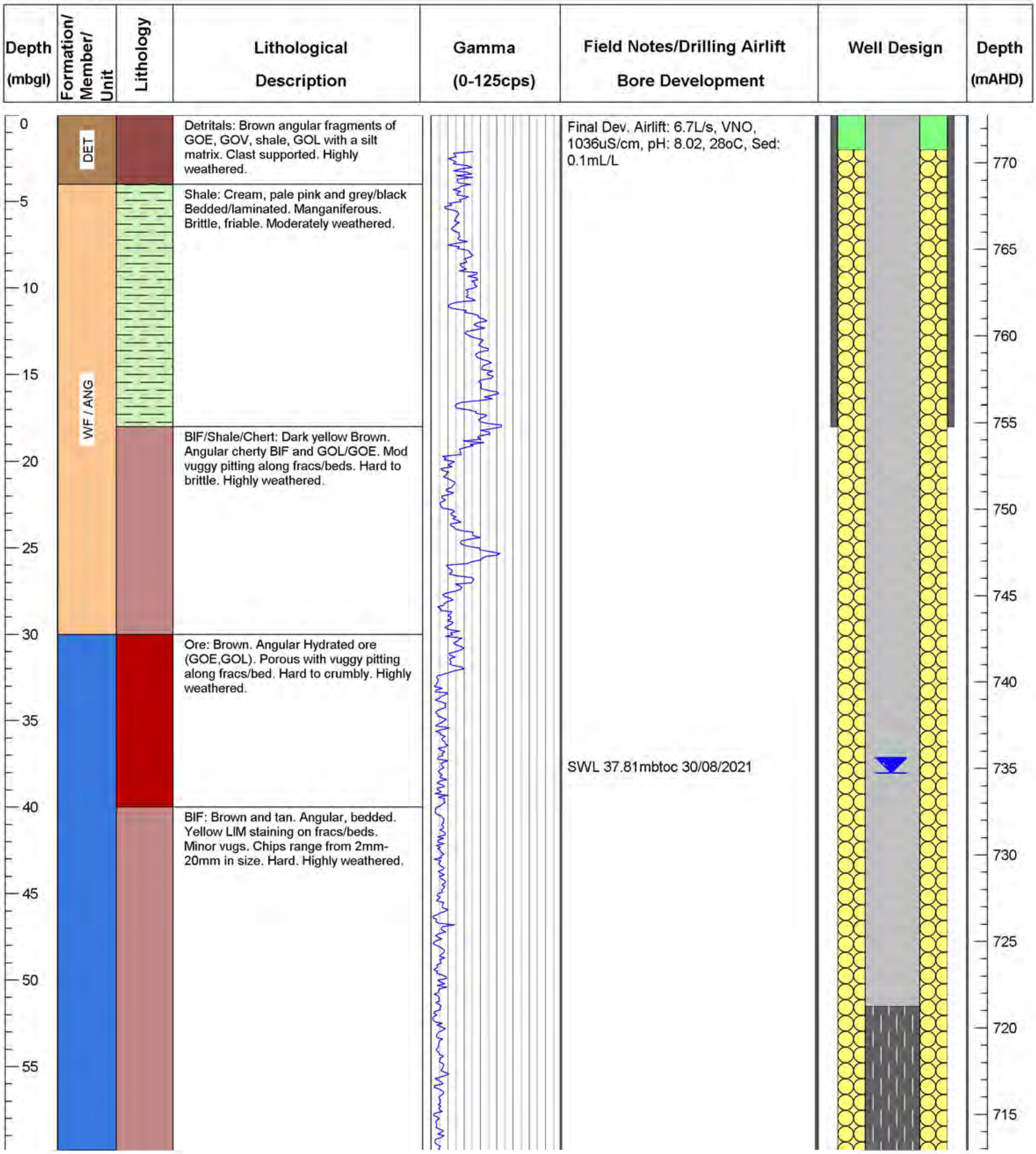
WB21WAH0001

PROJECT:	WANG	**DRILLING COMPANY:**	BDC	**GRID NAME:**	GDA94_Z50
DEPTH (m):	146.0	**DRILL RIG:**	BDC194	**EASTING:**	694,404.176
DATE COMMENCED:	24/07/2021	**DRILLING METHOD:**	CONVMUD	**NORTHING:**	7,441,457.584
DATE COMPLETED:	16/08/2021	**DRILLER:**	Shanan Leach	**ELEVATION:**	772.762
FIBRES:	No	**HYDROGEOLOGIST:**	Benjamin.Snowdon	**TOC:**	773.208

DEPH water supply bore

0-18m, Surface, STEEL, 473mm; 0-51.5m, Blank, STEEL, 305mm; 51.5-143.5m, Slotted, STEEL, 305mm; 143.5-144m, Blank, STEEL, 305mm

0-18m, 22", CONVMUD, TRC; 18-146m, 17.5", CONVMUD, TRC



Detritals: Brown angular fragments of GOE, GOV, shale, GOL with a silt matrix. Clast supported. Highly weathered.

Shale: Cream, pale pink and grey/black Bedded/laminated. Manganiferous. Brittle, friable. Moderately weathered.

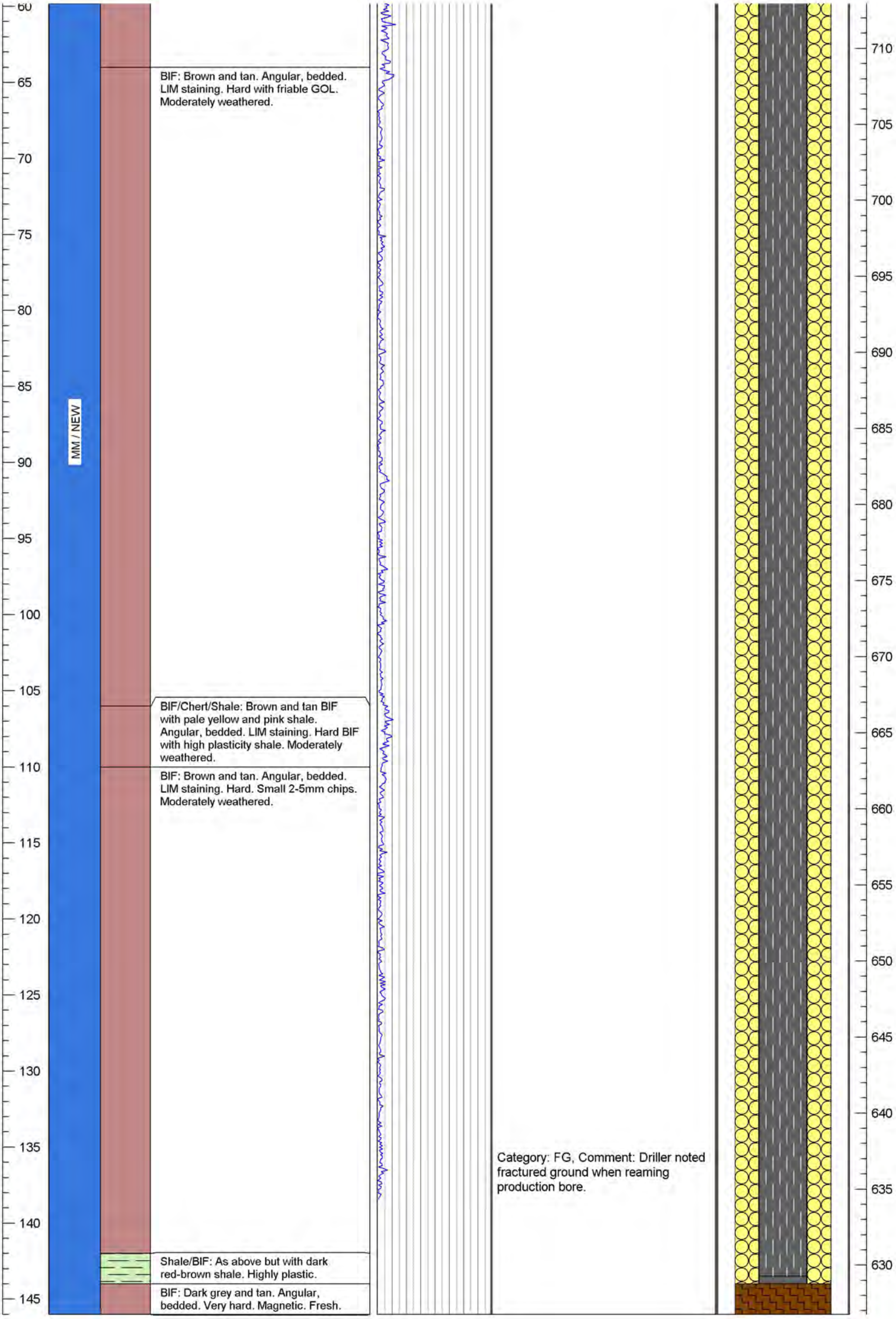
BIF/Shale/Chert: Dark yellow Brown. Angular cherty BIF and GOL/GOE. Mod vuggy pitting along fracs/beds. Hard to brittle. Highly weathered.

Ore: Brown. Angular Hydrated ore (GOE,GOL). Porous with vuggy pitting along fracs/bed. Hard to crumbly. Highly weathered.

BIF: Brown and tan. Angular, bedded. Yellow LIM staining on fracs/beds. Minor vugs. Chips range from 2mm-20mm in size. Hard. Highly weathered.

Final Dev. Airlift: 6.7L/s, VNO, 1036uS/cm, pH: 8.02, 28oC, Sed: 0.1mL/L

SWL 37.81mbtoc 30/08/2021



BIF: Brown and tan. Angular, bedded. LIM staining. Hard with friable GOL. Moderately weathered.

BIF/Chert/Shale: Brown and tan BIF with pale yellow and pink shale. Angular, bedded. LIM staining. Hard BIF with high plasticity shale. Moderately weathered.

BIF: Brown and tan. Angular, bedded. LIM staining. Hard. Small 2-5mm chips. Moderately weathered.

Shale/BIF: As above but with dark red-brown shale. Highly plastic.

BIF: Dark grey and tan. Angular, bedded. Very hard. Magnetic. Fresh.

Category: FG, Comment: Driller noted fractured ground when reaming production bore.

WB21WAH0002

PROJECT: WANG
DEPTH (m): 122.0
DATE COMMENCED: 28/07/2021
DATE COMPLETED: 21/08/2021
FIBRES: No

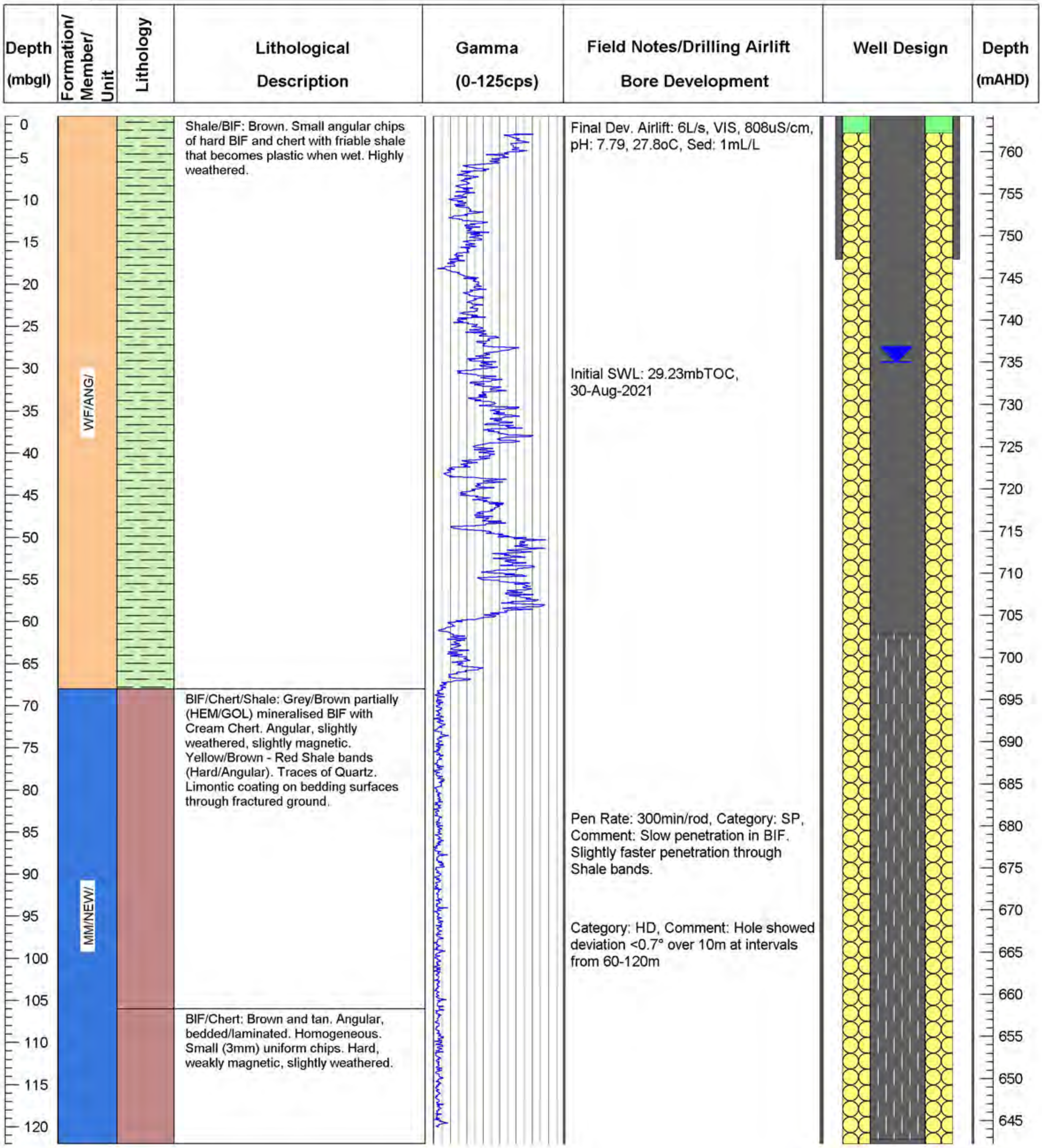
DRILLING COMPANY: BDC
DRILL RIG: BDC140
DRILLING METHOD: CONVMUD
DRILLER: Brad Graham
HYDROGEOLOGIST: Ben Snowdon,Wayne.Hick

GRID NAME: GDA94_Z50
EASTING: 693,722.513
NORTHING: 7,441,482.145
ELEVATION: 764.266
TOC: 764.653

DEPH water supply bore

0-17m, Surface, STEEL; 0-61.5m, Blank, STEEL, 305mm; 61.5-121.5m, Slotted, STEEL, 305mm; 121.5-122m, Blank, STEEL, 305mm

0-17m, 22", CONVMUD, TRC; 17-122m, 17.5", CONVMUD, TRC



Shale/BIF: Brown. Small angular chips of hard BIF and chert with friable shale that becomes plastic when wet. Highly weathered.

BIF/Chert/Shale: Grey/Brown partially (HEM/GOL) mineralised BIF with Cream Chert. Angular, slightly weathered, slightly magnetic. Yellow/Brown - Red Shale bands (Hard/Angular). Traces of Quartz. Limontic coating on bedding surfaces through fractured ground.

BIF/Chert: Brown and tan. Angular, bedded/laminated. Homogeneous. Small (3mm) uniform chips. Hard, weakly magnetic, slightly weathered.

Final Dev. Airlift: 6L/s, VIS, 808uS/cm, pH: 7.79, 27.8oC, Sed: 1mL/L

Initial SWL: 29.23mbTOC, 30-Aug-2021

Pen Rate: 300min/rod, Category: SP, Comment: Slow penetration in BIF. Slightly faster penetration through Shale bands.

Category: HD, Comment: Hole showed deviation <0.7° over 10m at intervals from 60-120m

Appendix C - Bore Construction Details

Table C.1: Monitoring and production bores construction details

Bore Name	Easting (MGA94)	Northing (MGA94)	TOC elevation (mAHD)	Ground level (mAHD)	Cased Depth (m)	Casing internal diameter (mm)	Screen interval	Screened unit	Screened formation
MB16WAH0001	692,950	7,441,406	782.0	781.0	110.0	50	92-110	Mt Newman	Marra Mamba
MB19WAH0001	694,414	7,441,473	773.5	722.6	100.0	50	40-100	West Angelas	Wittenoom
MB19WAH0002	695,170	7,441,286	788.6	788.0	100.0	50	70-100	Mt Newman	Marra Mamba
MB21WAH0001	693,730	7,441,489	765.2	764.3	153.0	50	111-147	Mt Newman	Marra Mamba
WB18WAH0001	692,895	7,441,551	-	775.3	145.0	127	60-138	Mt Newman	Marra Mamba
WB20WAH0001	695,166	7,441,289	787.9	788.3	100.0	305	58-94	Mt Newman	Marra Mamba
WB21WAH0001	694,404	7,441,457	773.3	772.8	144.0	305	51.5 – 143.5	Mt Newman	Marra Mamba
WB21WAH0002	693,723	7,441,482	671.0	670.2	122.0	305	61.5-121.5	Mt Newman	Marra Mamba

Note: TOC = top of casing.

Appendix D - Pumping Test Details and Results

Table D.1: Pumping test activities summary

Bore Name	Screened Aquifer Unit	Cased depth (m below ground level)	SRT rates (L/s)	CRT duration (hrs)	CRT rate (L/s)	Max drawdown (m)
WB20WAH0001	Marra Mamba Iron Formation	100	8, 12, 16, 20	72	17	27
WB21WAH0001	Marra Mamba Iron Formation	144	12, 14,16, 18, 20	6.5	20	49.62
WB21WAH0002	Marra Mamba Iron Formation	122	5,7,9,11,13	No CRT due to approval restrictions		

Table D.2: CRT Drawdown Results

Bore Name	CRT start date	CRT finish date	Duration (hours)	CRT Rate (L/s)	Recovery Duration (mins)	Bore ID	Direction from Prod. Bore	Distance from Prod. Bore	Screened Unit	Maximum Observed Drawdown (m)
WB20WAH0001	03/10/2011	05/10/2011	75	17	20	WB20WAH0001	Pumping bore		Mt Newman	27.4
						MB19WAH0002	SE	10	Mt Newman	8.6
						MB19WAH0001	NW	722	Mt Newman	0.1
WB21WAH0001	09/06/2021	09/06/2021	6.5	20	60	MB19WAH0001	North	10	Mt Newman	2.89
						MB19WAH0002	East	800	Mt Newman	0.02
						MB21WAH0001	West	670	Mt Newman	0.29

Table D.3: Summary of CRT analyses results

Pumping Bore Name	Monitoring Bore Name	Aquifer Type	Aquifer Screened	Saturated Aquifer Thickness (m)	Analyses Method	Transmissivity (m²/day)	S
WB20WAH0001	MB19WAH0002	Unconfined	Marra Mamba	50	Cooper Jacob	143	0.0012
					Neuman	143	0.0012

C.6: Deposit F North Hydrogeological Conceptualisation

RioTinto

Water Resource Evaluation

West Angelas - Deposit F North Hydrogeological Conceptualisation

November 2022

Prepared by Gary Brownds

Document Acceptance

	Name	Signature	Date
Senior Hydrogeologist	Gary Brownds	Gary Brownds	18/10/2022
Superintendent WRE	Kevin Vermaak		16/11/2022
Principal Hydrogeology	Graham Smith	Graham Smith	30/11/2022

Executive Summary

RTIO are planning to commence mining Deposit F North beginning in 2027 with completion estimated to be during early 2028. Deposit F North is located directly to the north of Deposit F. The planned pit is approximately 800m long (East-West) and 500m wide (North-South).

The Dep F North aquifer is hosted within the Mount Newman Member of the MMIF and is encompassed by the impermeable Macleod Member of the MMIF. The groundwater surface within the compartmentalised aquifer appears flat at approximately 716m AHD with no appreciable recharge or lateral groundwater flow indicated. There is no water quality data specifically for the Deposit F North aquifer, but it is assumed that the water quality is similar to the water quality of Greater West Angelas.

The current proposal plans to mine to a below water table pit base at 696m AHD This will require dewatering of approximately 20m to provide dry mining conditions with an estimated total dewatering volume of 66 ML.

Dust suppression demand for Deposit F North is estimated at 200 ML for 2027 and 760 ML for 2028. As demand is greater than that available from the Deposit North Aquifer, mine water supply will be required from other sites within West Angelas.There are no environmental receptors associated with the aquifer at the proposed Deposit F North site and no other users thus there are no anticipated impacts associated with partial dewatering of the aquifer for mining purposes.

Contents page

Table of Figures

1. Introduction

Deposit F North is located within Rio Tinto Iron Ore's West Angelas mining hub (Figure 1-1). Mining of Deposit F North is proposed to be undertaken over a two-year period. A single pit is proposed with only 20m of below water table mining planned.

Groundwater abstraction at West Angelas is licensed under Groundwater Licence GWL98740(12) issued under the Rights in Water and Irrigation Act 1914 (RiWi Act) and administered by the Department of Water and Environmental Regulation (DWER). GWL98740(12) permits groundwater abstraction over the West Angelas mining hub (AML 70/248) for purposes including dewatering, dust suppression, exploratory drilling, campsite purposes, power generation, reinjection and industrial processing. The licence was granted in October 2019 and is licensed to 31st of October 2029. The West Angelas GWL licence allows for abstraction of 14 GL/year, with operating commitments for the GWL outlined in the West Angelas Groundwater Operating Strategy (GWOS).

This document addresses the hydrogeology of Deposit F North in context of the proposed mine plan with respect to below watertable mining and mine water demand for dust suppression. An assessment of the potential impacts stemming from proposed dewatering abstraction at Deposit F North is also included.

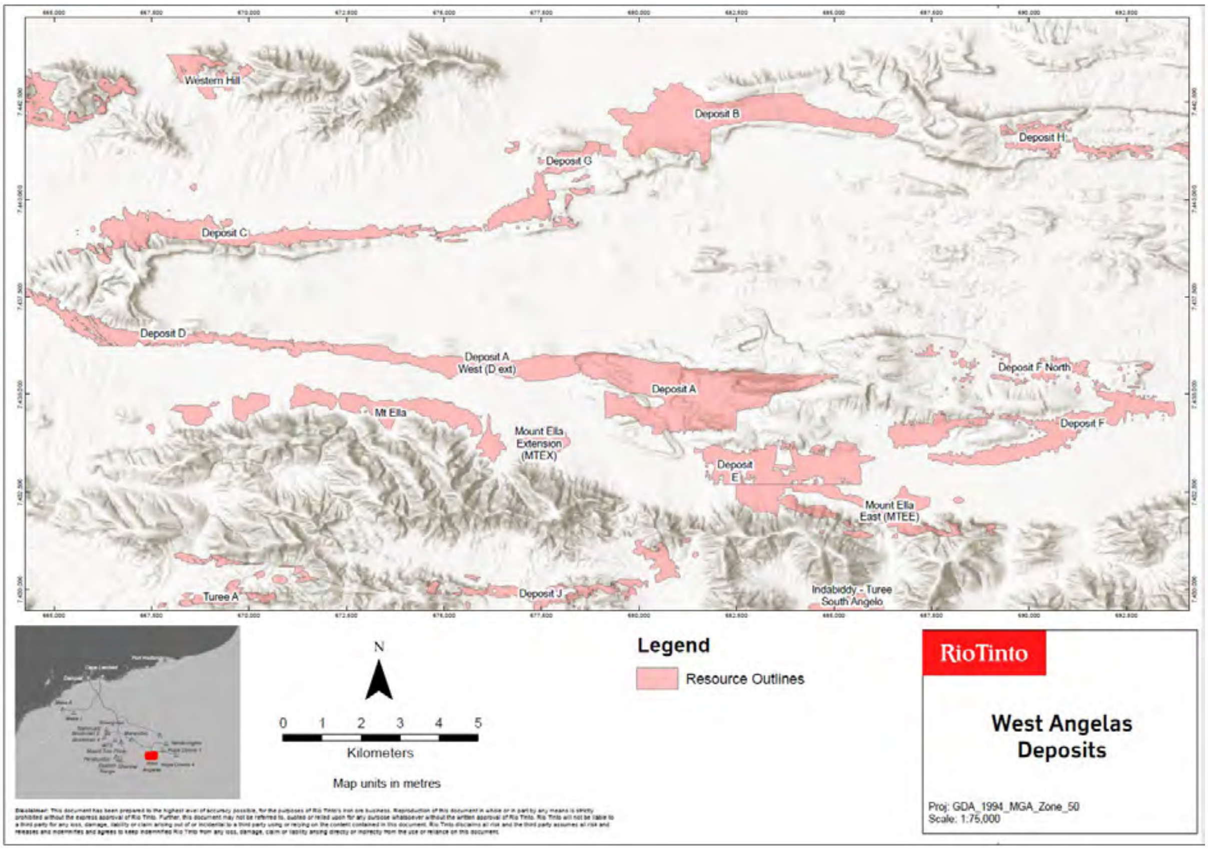


Figure 1-1 West Angelas Location and Layout

2. Background

2.1 Climate and Rainfall

West Angelas is in the east Pilbara and has the arid climate typical of the region with average rainfall of 324 mm/yr (1981-2020). Most rainfall occurs between December and April during the wet season. Rainfall is highly variable between years meaning that periods of extended drought and well above average rainfall conditions are possible. Potential evaporation is very high in the region, with Class A pan evaporation averaging 3050 mm per year, an order of magnitude higher than rainfall.

2.2 Hydrology

Deposit F North sits in the headwaters of the Weeli Wolli Creek Catchment and is drained by several predominantly east flowing ephemeral unnamed tributaries of Weeli Wolli Creek.

2.3 Geology

2.3.1 West Angelas Regional Geology

The West Angelas mine area consists of discrete iron mineralisation deposits A, B, C, D, E, F, G, H, A-West & Western Hill. These deposits lie on the limbs of the east-west trending, west plunging Wonmunna Anticline located in the eastern part of the Opthalmia Fold Belt. Deposits B, C, G, H and Western hill are situated along the north limb of the Wonmunna Anticline while deposits A, D, E, F and A-West are on the south limb Figure 1-1.

The stratigraphic sequence of the Hamersley Group is summarised in Table 1. Mineralisation occurs in both the Brockman Iron Formation (primarily the Dales Gorge Member) and the MMIF (Marra Mamba Iron Formation) (primarily the Mount Newman Member). A regional north-east to south-west trending dolerite dyke has been mapped on the northern limb of the anticline. This intrusion is known to act as an aquitard and compartmentalises the aquifer on the northern limb. Several localised dolerite dykes, trending north-west to south-east have also intruded the MMIF, Wittenoom and BIF formation in the area, with these dykes capable of acting as aquitards compartmentalising aquifer units.

Table 1 Regional Stratigraphic Sequence

Group	Formation	Member	Description
Hamersley Group	Brockman Iron	Joffre	Planar bedded to poddy BIF with minor shale interbeds
		Whaleback Shale	Shale, BIF and chert
		Dales Gorge	BIF and shale interbedded. Primary ore horizon.
	Mount McRae Shale	-	Carbonaceous shale, chert and minor dolomitic shale.
	Mount Sylvia	-	BIF / chert and shales. Uppermost BIF unit – Bruno's Band.
	Wittenoom	Bee Gorge	Calcareous shales, with minor cherts, volcaniclastics and BIF
		Paraburdoo	Predominantly crystalline dolomite with minor chert bands
		West Angela	Shale, chert, dolomite with a BIF dominant zone toward its base
	Marra Mamba Iron	Mount Newman	Podded BIF with interbedded carbonates and shales. Major ore bearing horizon.
		MacLeod	BIF, chert, carbonates, and shales
		Nammuldi	Thick bedded, poddy, cherty BIF
Fortescue Group	Jeerinah	-	Interbedded chert, shale, dolomite and a high density of intruded dolerite sills (up to 50%).

Locally, the Nammuldi Member of the Marra Mamba Iron Formation (MMIF) presents in the outcropping hinge of the anticline, overlying the Fortescue Group basement formation. The limbs are characterised by steeply plunging MMIF including Nammuldi, MacLeod and Mt Newman Members. Wittenoom Formation, that is often overlain by detrital cover, characterises the valley between the MMIF anticline and the high elevation Brockman Iron Formation (BIF) that encompasses the Wonmunna Anticline.

2.3.2 Deposit F North Geology

Deposit F North is located approximately 5 km East of Deposit A and directly north of Deposit F, with Deposit E located to the south-west (Figure 1-1). The orebody has a strike length of approximately 4.2 km and is up to 600 m in wide, however, the proposed pit extent is limited to the east and will be approximately 800m long (East-West) and 500m wide (North-South), as shown in Figure 2-1.

The iron ore resource at Deposit F North is hosted within the Mature Tertiary Detritals that blanket the palaeo-topography as well as the E-W striking folded Marra Mamba Iron Formation with mineralisation hosted within the Mt Newman Member. A WNW-ESE striking thrust fault has been interpreted from geophysics and geological mapping. This fault has been intersected by drilling, and confidence in the location of this fault is high. This structural feature along with a series of synclines and anticlines with similar strike match the regional West Angelas structural context and are consistent with other deposits in the area e.g., Deposit F.

Deposit F North is a typical in-situ Marra Mamba Formation 'supergene' deposit. Ore boundaries are both conformable with and crosscut the stratigraphy. The better mineralisation is hosted within strands of the Mount Newman Member. Poorer mineralisation is associated with the upper MacLeod Member, and the lower portion of West Angela Member of the Wittenoom Formation.

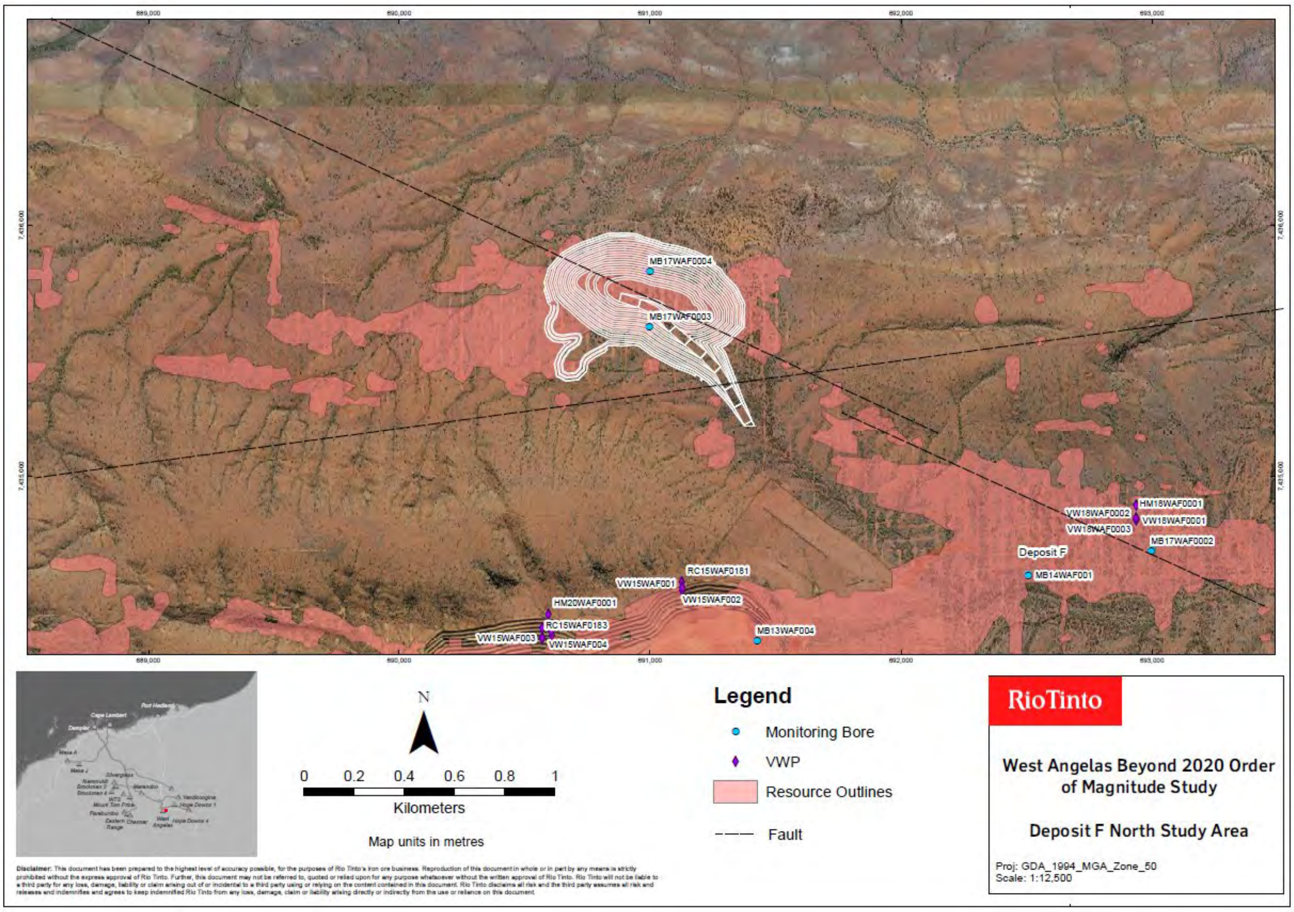


Figure 2-1 Deposit F North

3. Hydrogeology

3.1 West Angelas

At West Angelas, significant regional aquifers are associated with the Wittenoom Formation in the valleys between the low-lying sub-cropping Marra Mamba Iron Formation and Fortescue Group core of the Wonmunna anticline and the higher relief Brockman Iron Formation hills to the north and south. Permeability within the Wittenoom Formation can be enhanced through development of secondary permeability associated with dissolution of dolomitic units. These secondary features have significant hydraulic conductivity and storage.

The Wittenoom Formation is generally overlain by a detrital sequence of variable thickness which, when saturated, forms part of the regional aquifer.

Orebody aquifers also occur in the mineralised sections of the Marra Mamba Iron Formation and the overlying West Angelas Member of the Wittenoom Formation. Where hydraulic connection with the Wittenoom Formation or saturated detritals exists then the orebody aquifer forms part of the regional aquifer which may result in increased dewatering volumes and extended propagation of water level drawdown impacts resulting from abstraction.

In other situations (such as at the deposit F north), the synclinal structure of the Marra Mamba Iron Formation which contains the mineralised (and permeable) Mt Newman Member is underlain and bounded by low permeability, non-mineralised units including the Macleod and Nammuldi Members of the Marra Mamba Formation and the Jeerinah Formation of the Fortescue Formation. This results in localised, compartmentalised orebody aquifers, commonly referred to as "bathtubs" , that are not connected to the regional aquifer.

Groundwater in the West Angelas mining area is neutral to mildly alkaline with field pH ranging from 6.1 to 8.9. Groundwater is generally fresh (<1500 mg/L total dissolved solids (TDS)) and is most fresh in Deposit E and F bores which has median TDS <500 mg/L (RTIO 2019). The Piper plot (Figure 3-1) displays major ions for Greater West Angelas showing that waters are generally classified as calcium sulphate and calcium Bicarbonate waters

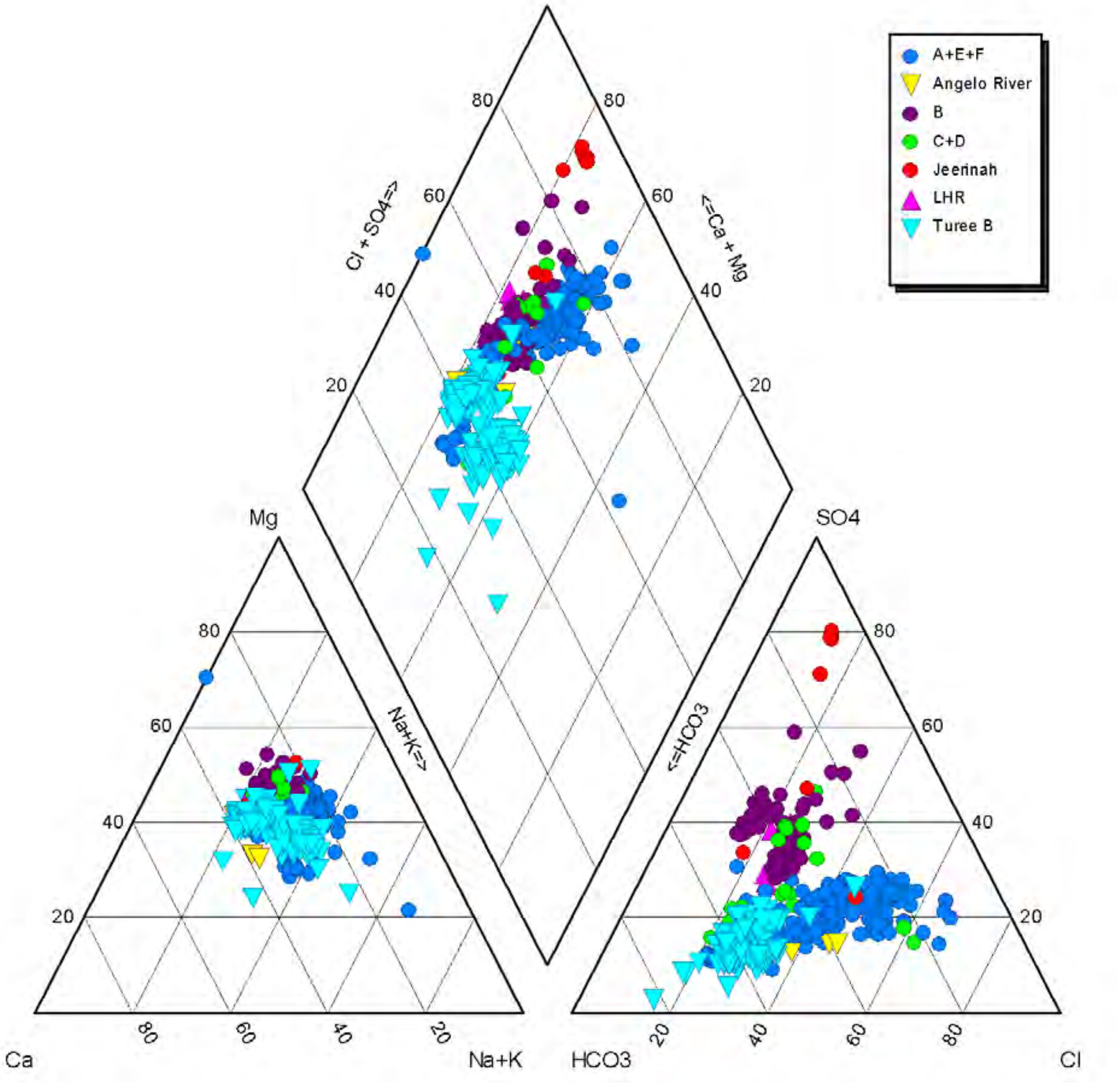


Figure 3-1 Greater West Angelas water quality

3.2 Deposit F North

In the area of the proposed pit, the Deposit F North orebody forms a compartmentalised 'bathtub' style aquifer surrounded by impermeable Namuldi & Macleod members of the Marra Mamba Iron

Formation. Groundwater levels from two monitoring bores (MB17WAF0003 & MB17WAF0004) are both about 716.8mAHD (Figure 3-2) approximately 77m below ground level. The uniformity of the water level measurements are supported by water level data collected as part of downhole geophysical surveys (Figure 3-3).

There is no water quality data specifically for the Deposit F North aquifer however it is assumed to be similar to that of the regional West Angelas water quality described above.

Figure 3-2 Hydrograph - MB17WAF0003 & MB17WAF0004

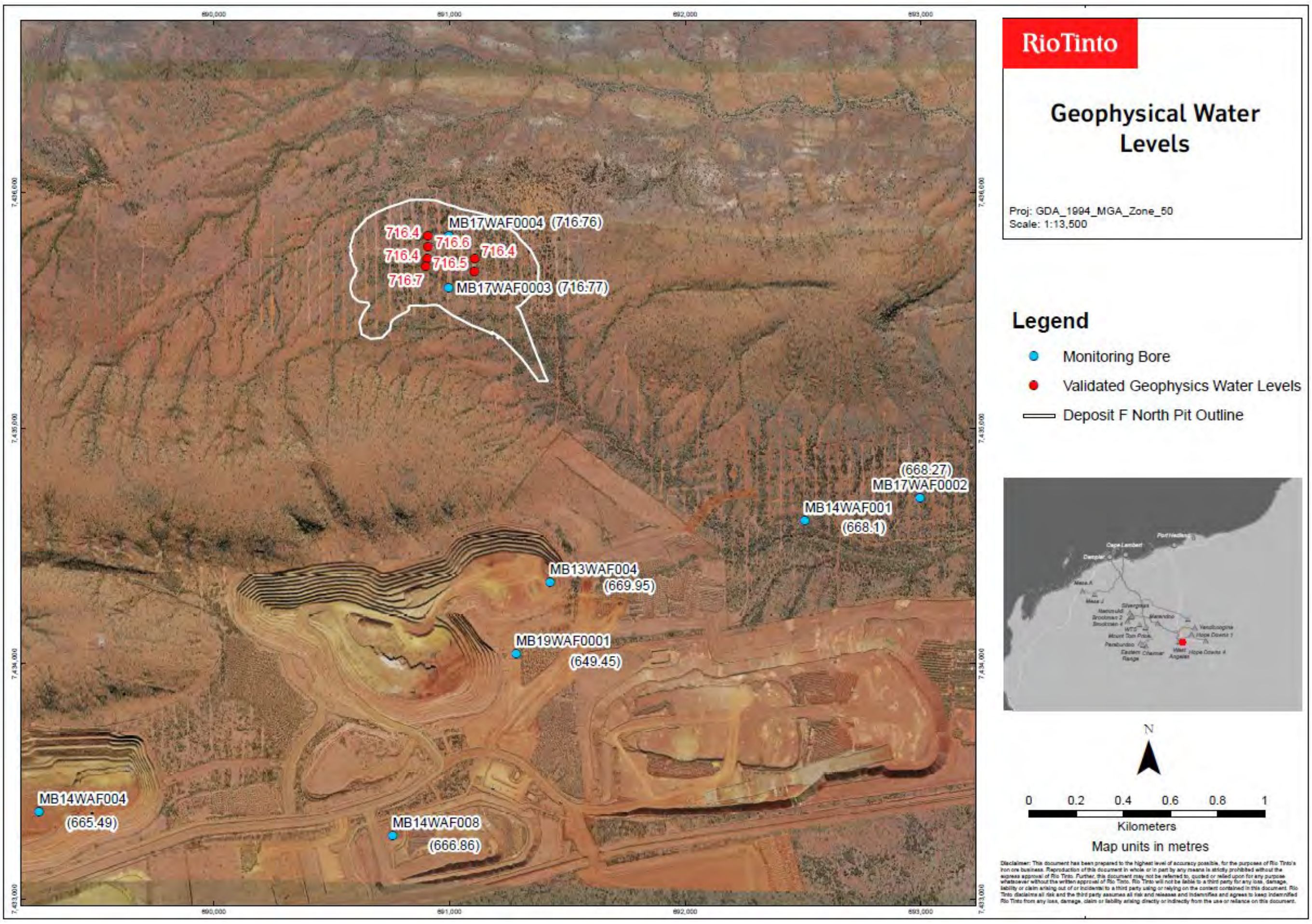


Figure 3-3 Deposit F North Pit Outline & Water Levels

3.2.1 Hydrostratigraphy

Figure 3-4, Figure 3-5 and Figure 3-6 show the geology at the watertable (~716mAHD), base of proposed pit (696mAHD) and base of aquifer (642mAHD) respectively, illustrating the laterally restricted extent of the Mt Newman aquifer unit.

Figure 3-7, Figure 3-8, Figure 3-9 and Figure 3-10 show west facing north-south cross sections while Figure 3-11, Figure 3-12 and Figure 3-13 show north facing east-west sections. Collectively these sections illustrate the limited vertical and lateral extent of the compartmentalised orebody aquifer, and the bounding low permeability units that surround it. Note several faults are evident that have resulted in impermeable strata juxtaposed with the aquifer.

The volume of the Mount Newman Member below the watertable is approximately 2.6 x 10^6 m^3. Assuming a specific yield of 5% the total volume released from storage will be approximately 66 ML.

3.2.2 Groundwater Flow / Recharge

Groundwater surface is flat and consistently at 716m AHD. The hydrographs shown in Figure 3-2 show relatively static water levels with no response to rainfall events. With no evidence of a hydraulic gradient no appreciable lateral groundwater flow is indicated as would be expected with a compartmentalised aquifer.

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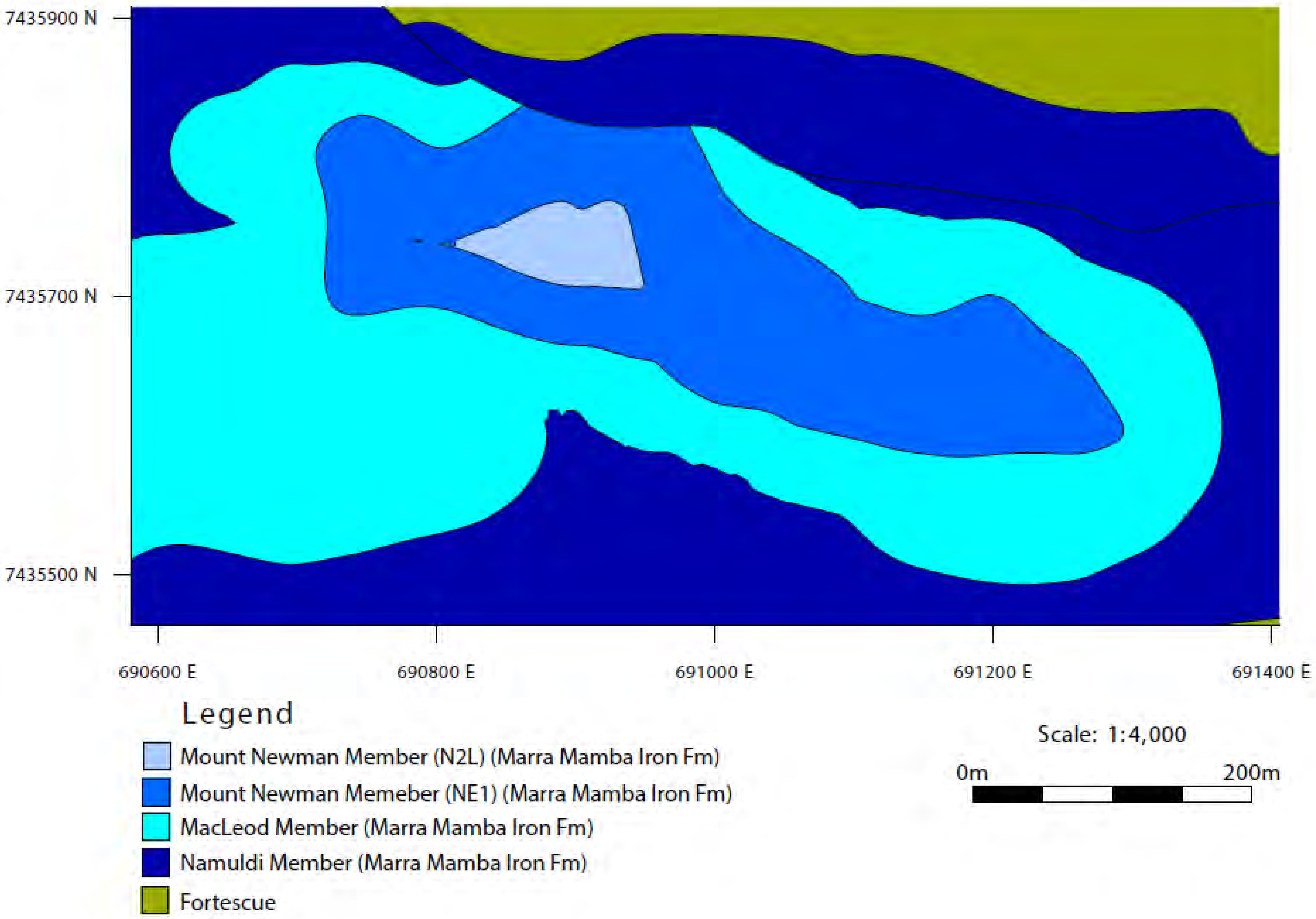

Figure 3-4 Plan View Hydrostratigraphy at the watertable (716m AHD)

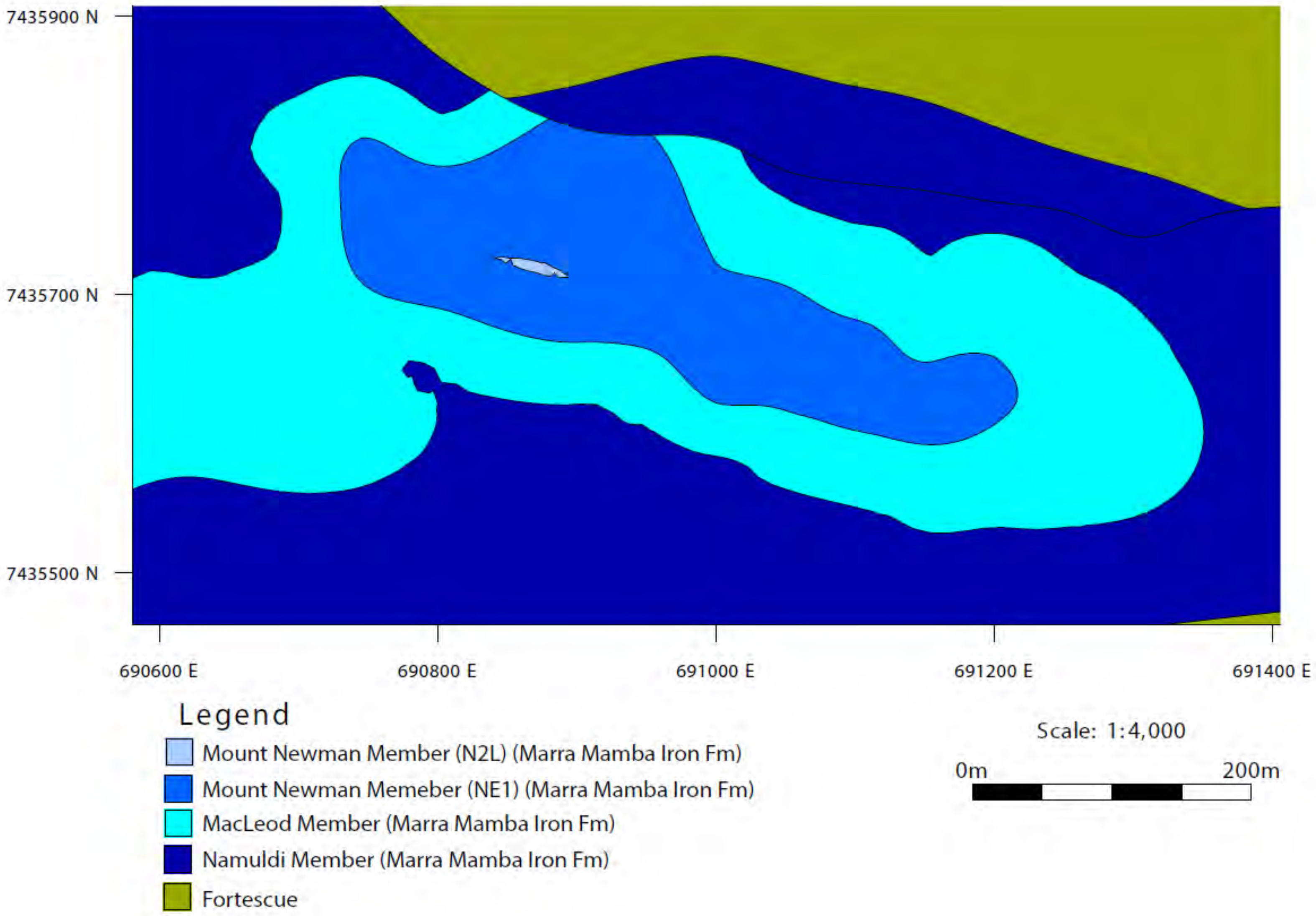

Figure 3-5 Plan View Hydrostratigraphy at the Pit Base (696m AHD)

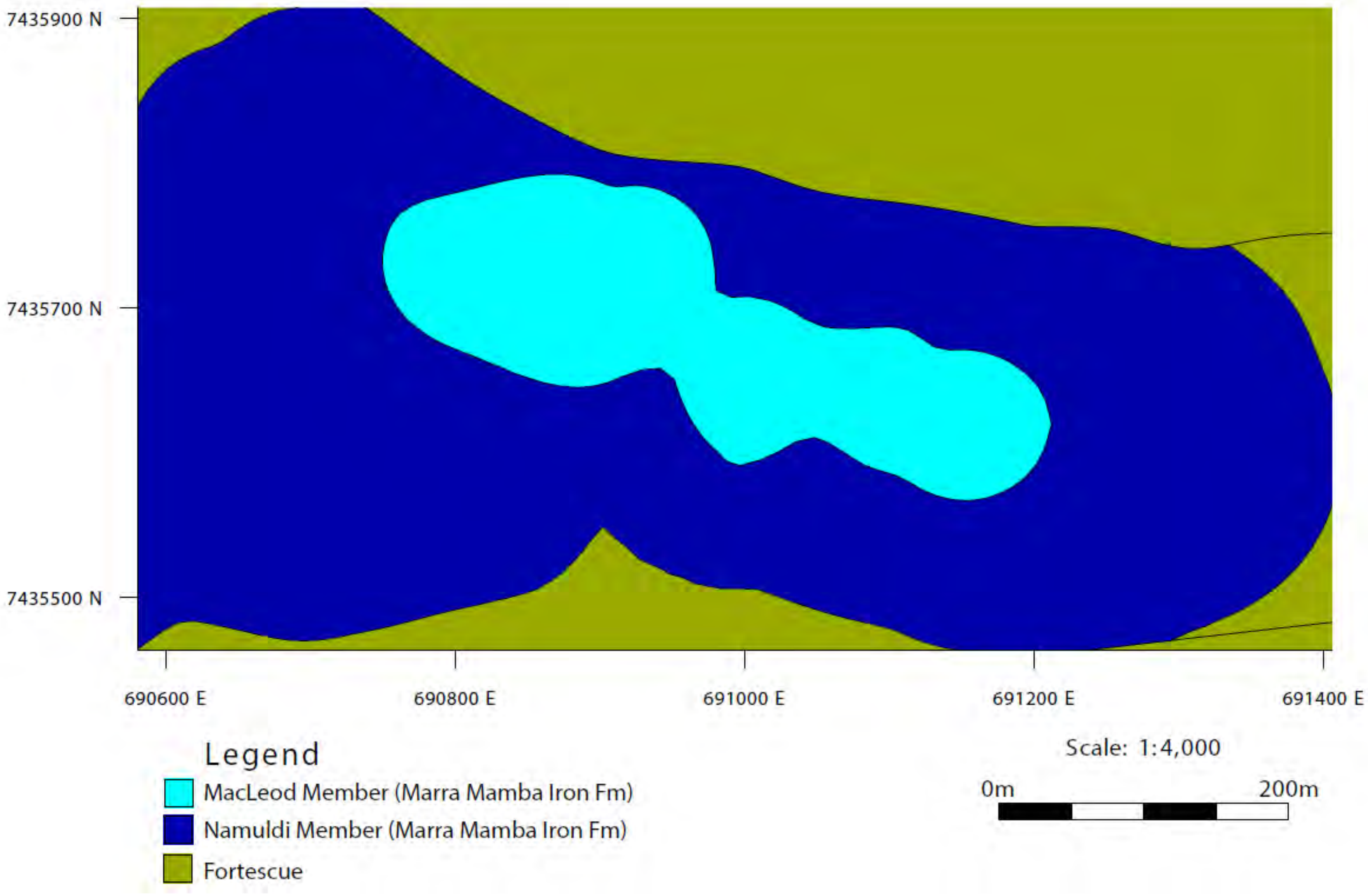

Figure 3-6 Plan View Hydrostratigraphy at the Base of Aquifer (642m AHD)

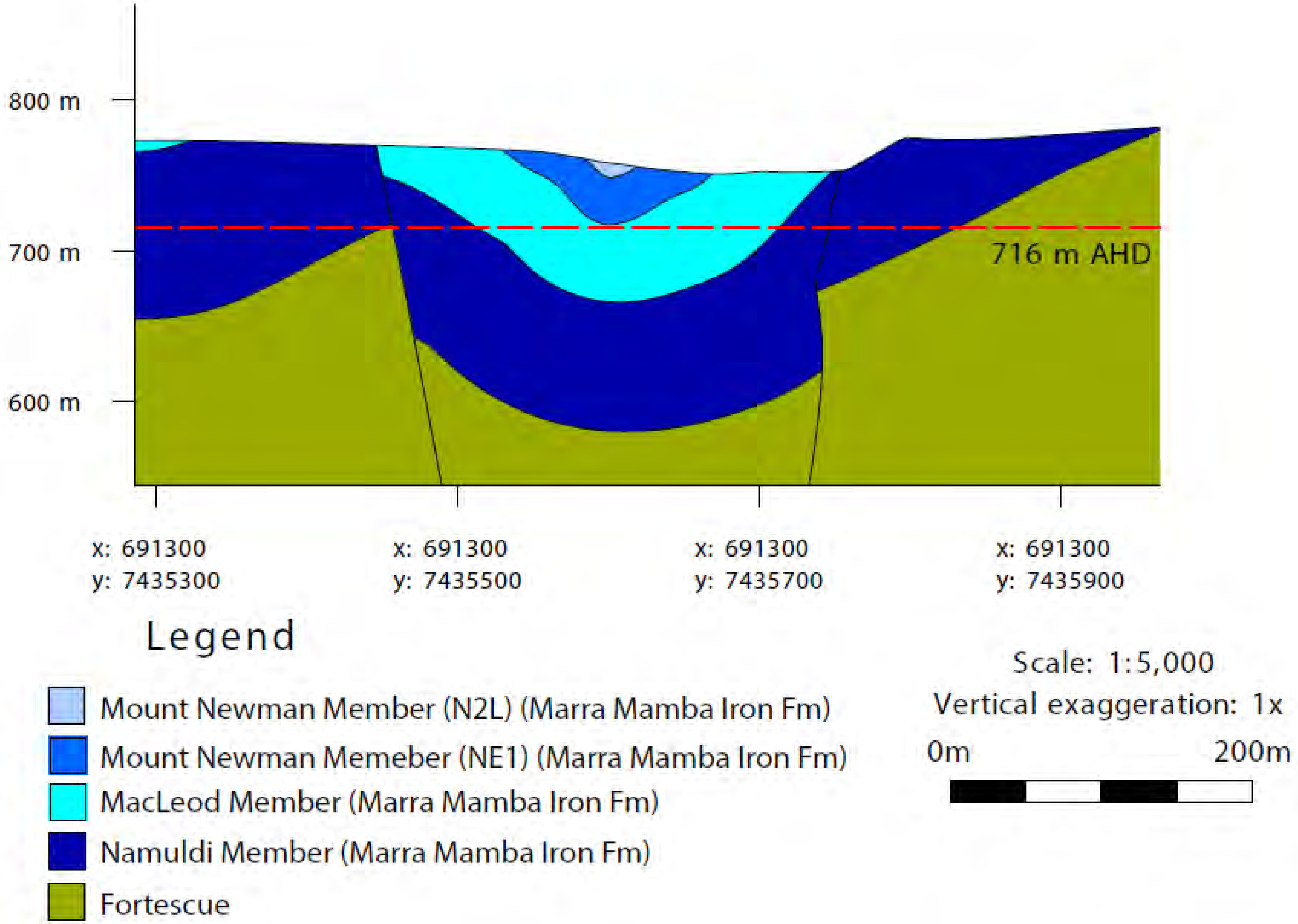

Figure 3-7 Section 691300m E Hydrostratigraphy - Facing West

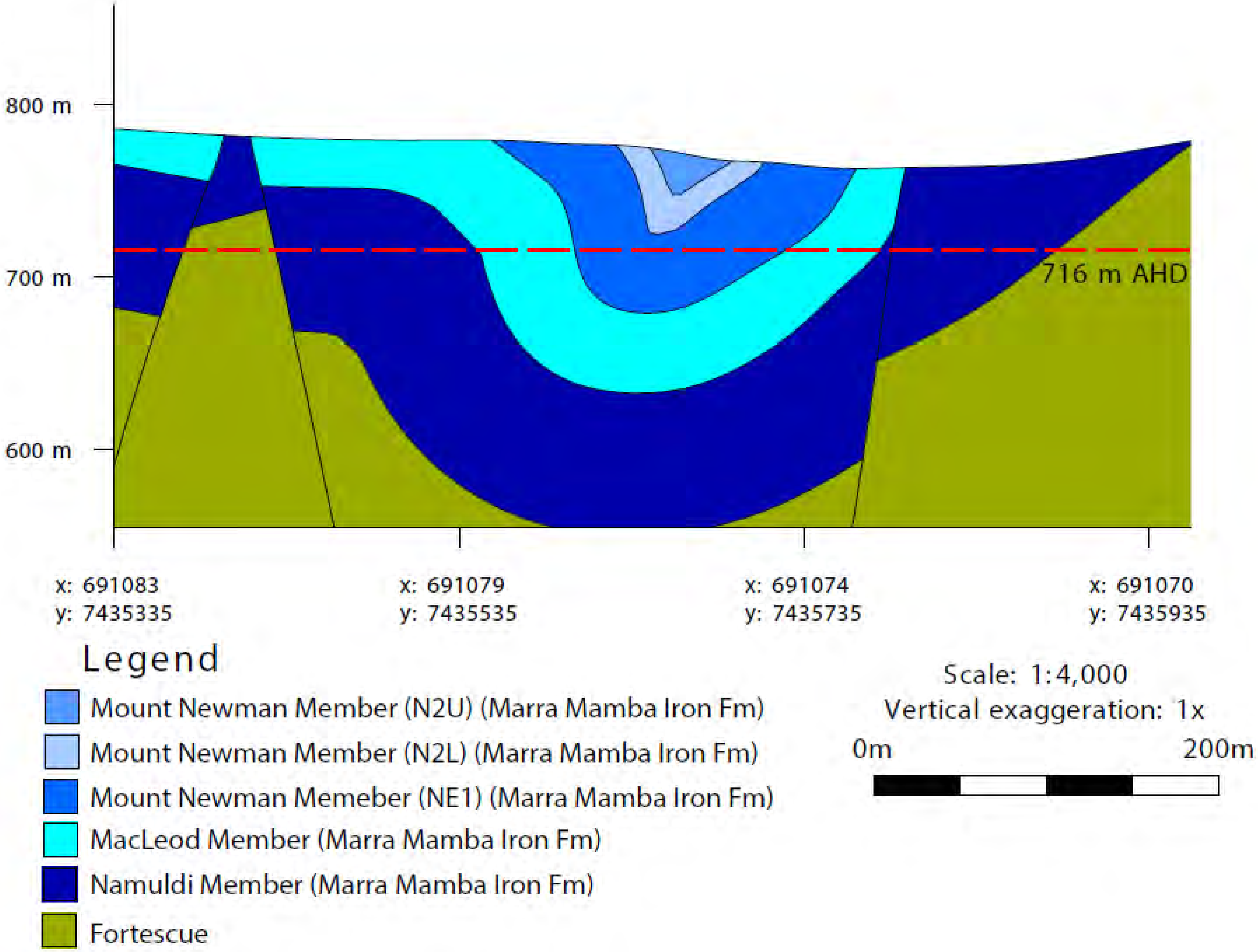

Figure 3-8 Section 691100m E Hydrostratigraphy - Facing West

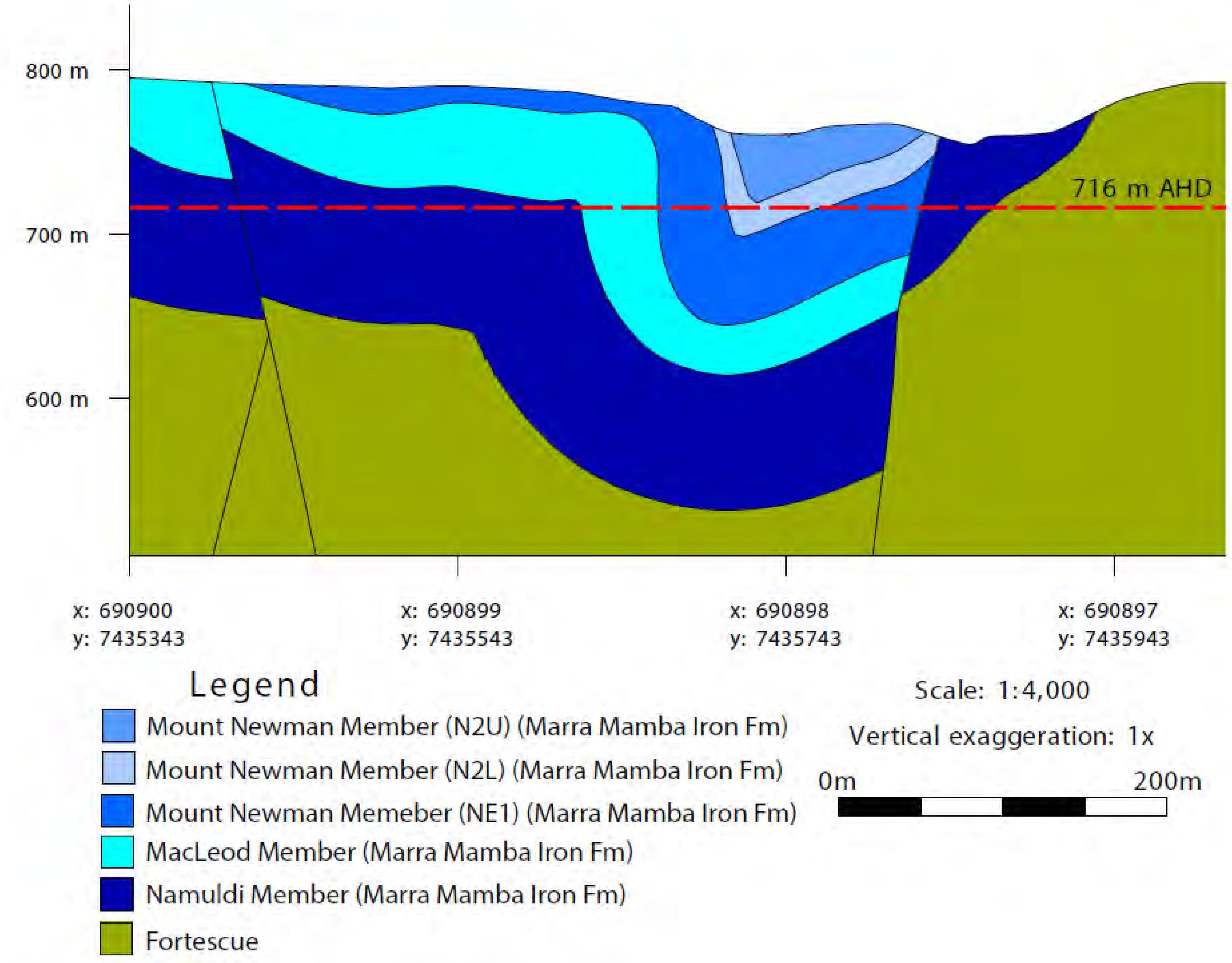

Figure 3-9 Section 690900m E Hydrostratigraphy - Facing West

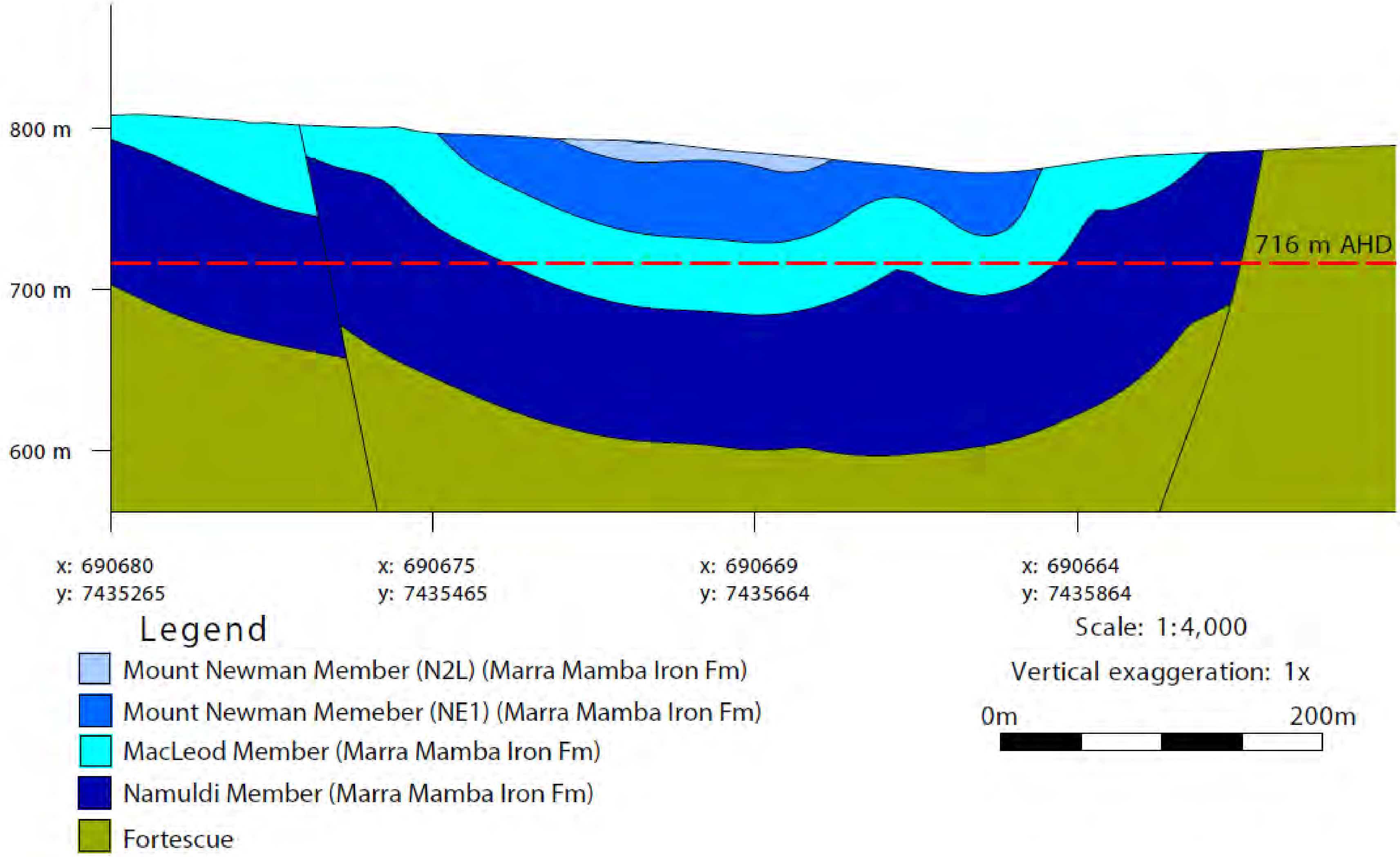

Figure 3-10 Section 690700m E Hydrostratigraphy - Facing West

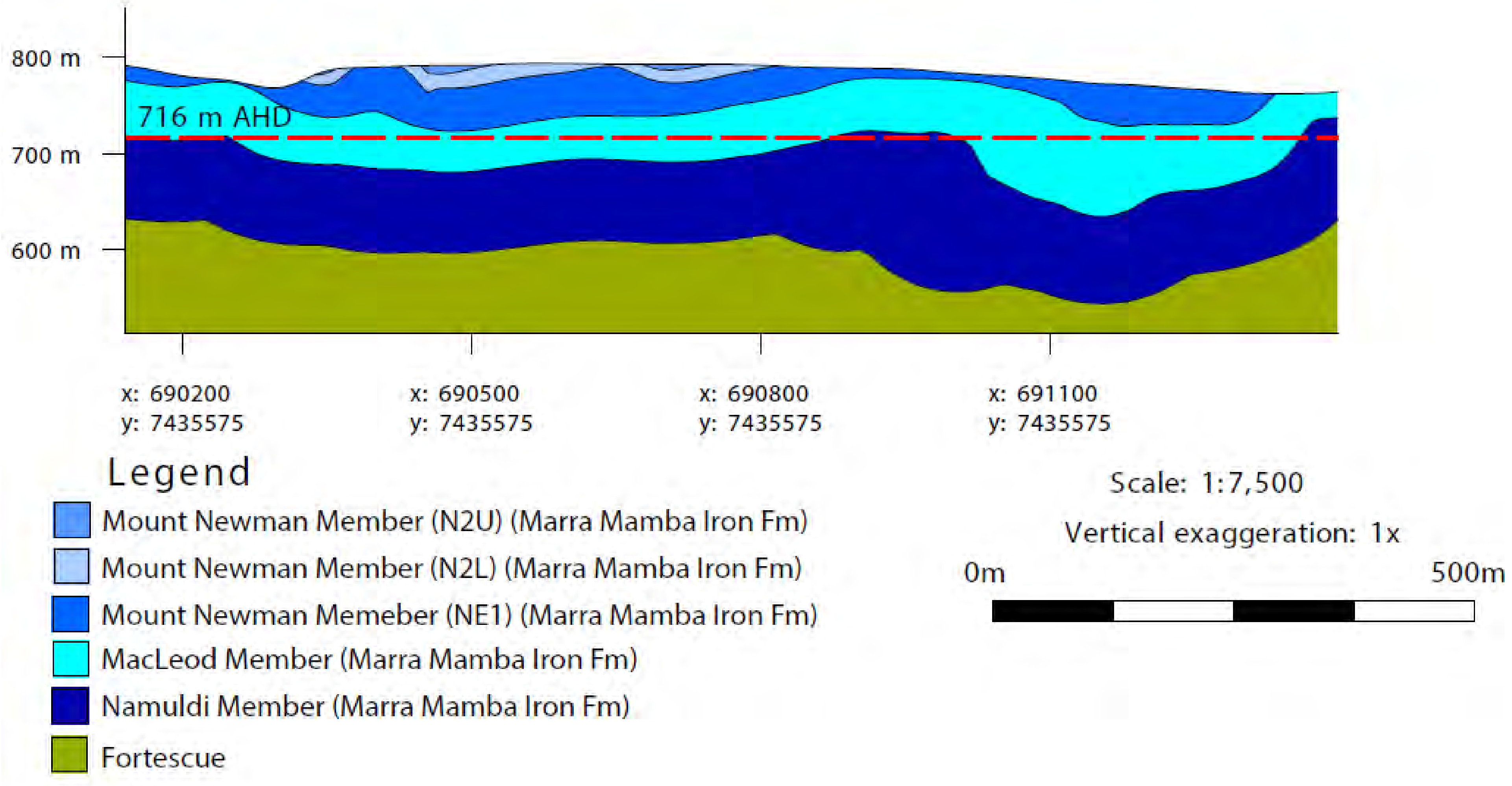

Figure 3-11 Section 7435575m S Hydrostratigraphy - Facing North

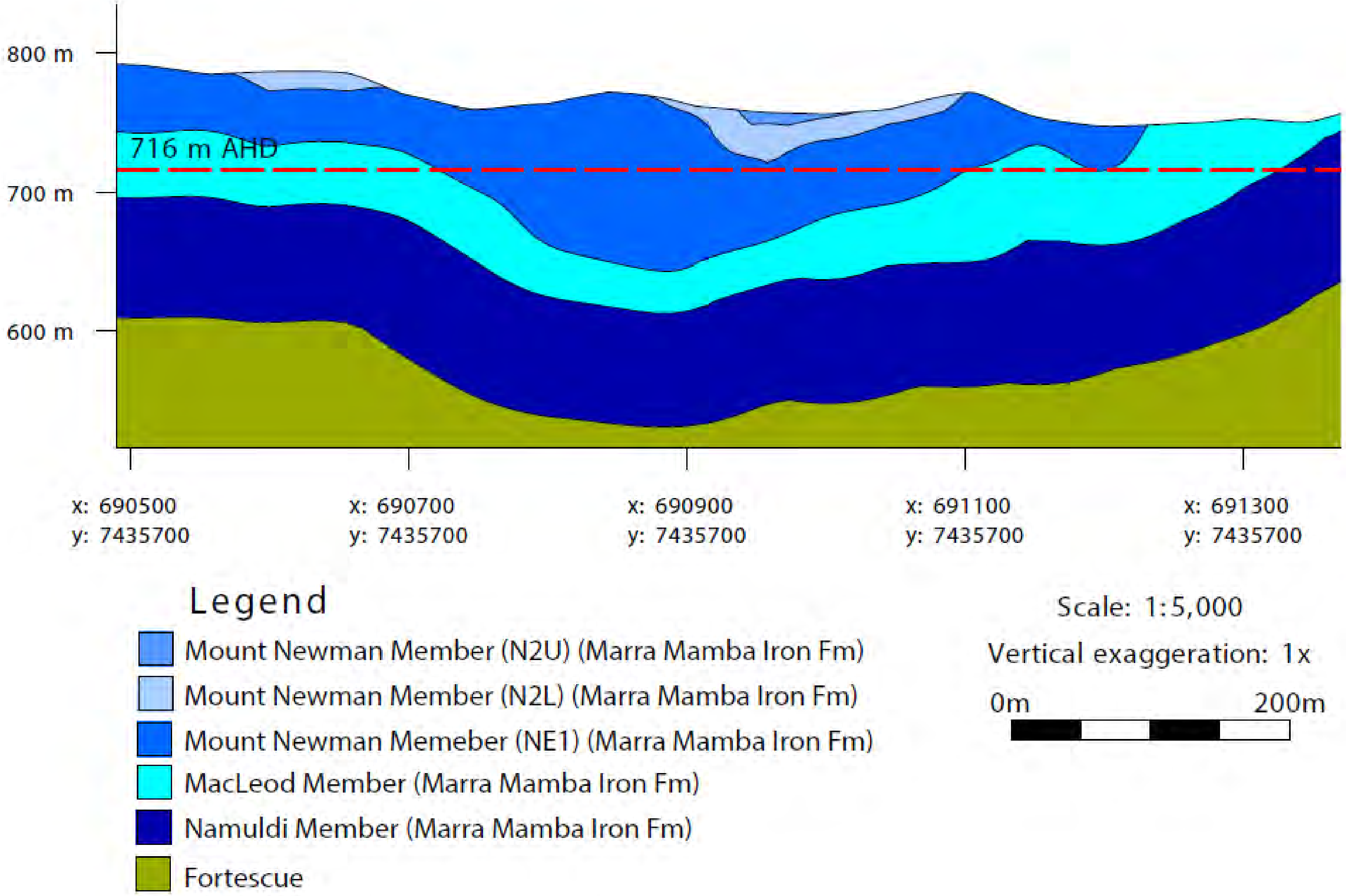

Figure 3-12 Section 7435700m S Hydrostratigraphy - Facing North

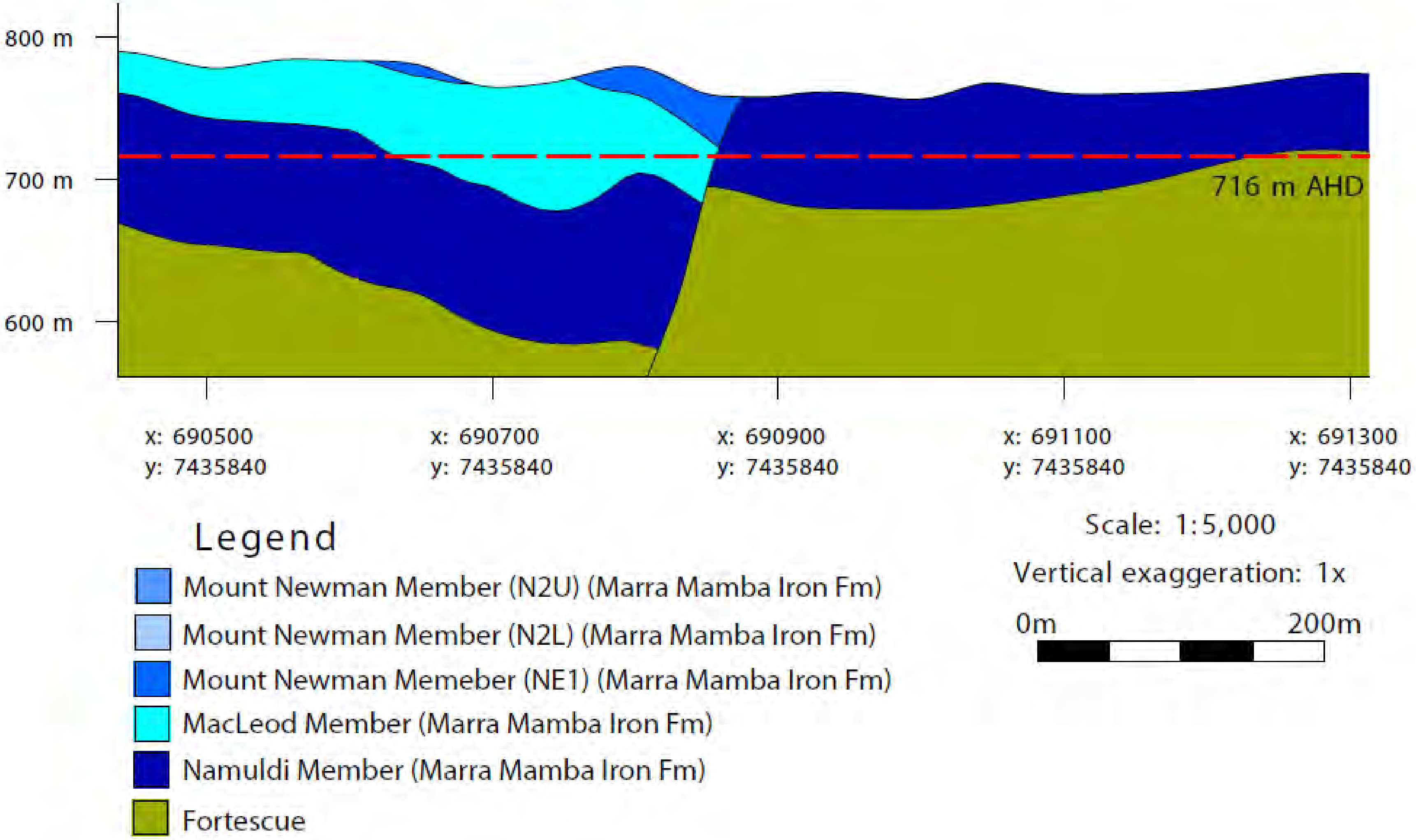

Figure 3-13 Section 7435840m S Hydrostratigraphy - Facing North

4. Existing Use

There are no existing users of the aquifer at the proposed Deposit F North site. 360 Environmental (360 Environmental, 2022),undertook a detailed biological study and found that there was a very low likelihood of any features being dependant on groundwater given the prevailing depth to water in the vicinity.

As there are no environmental receptors or existing users of the Dep F North aquifer, there are no potential impacts associated with the partial dewatering of the aquifer for mining purposes.

5. Proposed Mining / Dewatering

The current proposal (Case 21) is to mine to a below watertable pit base of 696 mAHD with mining beginning in 2027 and ending in 2028. Figure 5-1 presents an idealised quarterly bench progression. Dewatering will be required to lower the aquifer water levels by about 20m (696m AHD) to provide dry mining conditions.

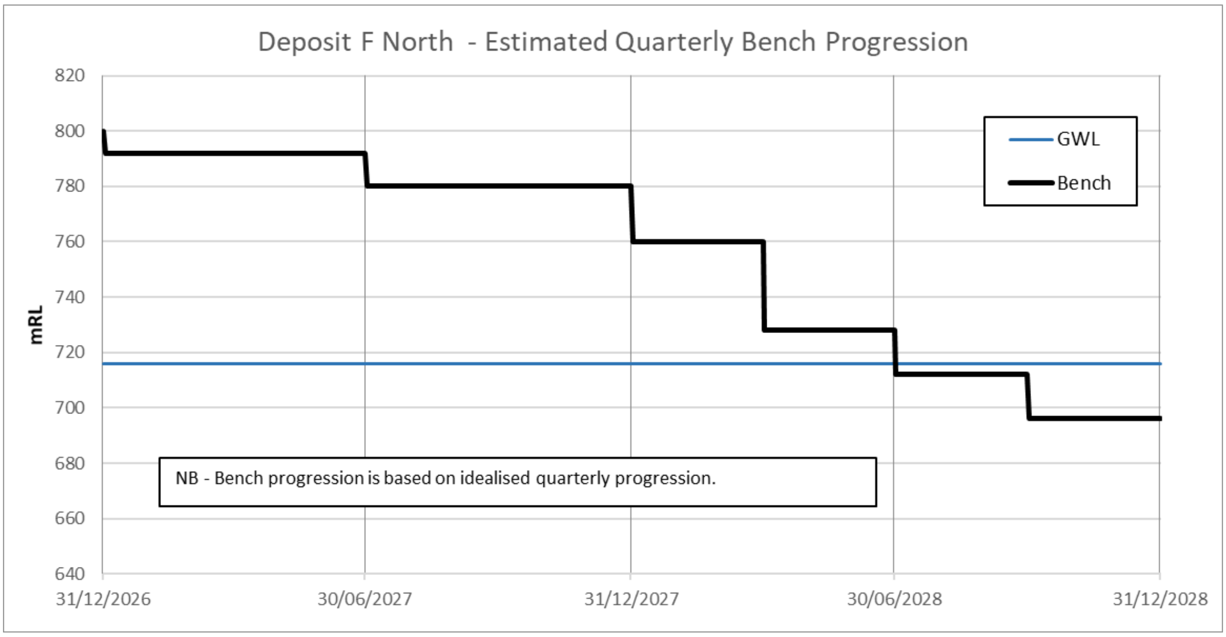

Figure 5-1 Estimated quarterly bench progression

Due to the restricted extent and compartmentalisation of the aquifer, dewatering will likely lower the water level to 696m AHD throughout the aquifer.

As previously stated, the Mt Newman aquifer unit has a volume of approximately 2.6 x 10^6 m^3. Dewatering to the pit base (696m AHD) will require abstraction of estimated 66 ML from aquifer storage (assuming a specific yield of 5%).

Annual mining water demand (dust suppression) is estimated at 200 ML for 2027 and 760 ML for 2028 (Figure 5-2). As demand is greater than that available from the Deposit North Aquifer, mine water supply will be required from other sites within West Angelas. This is readily available as West Angelas has a surplus volume of groundwater from dewatering activities at other pits.

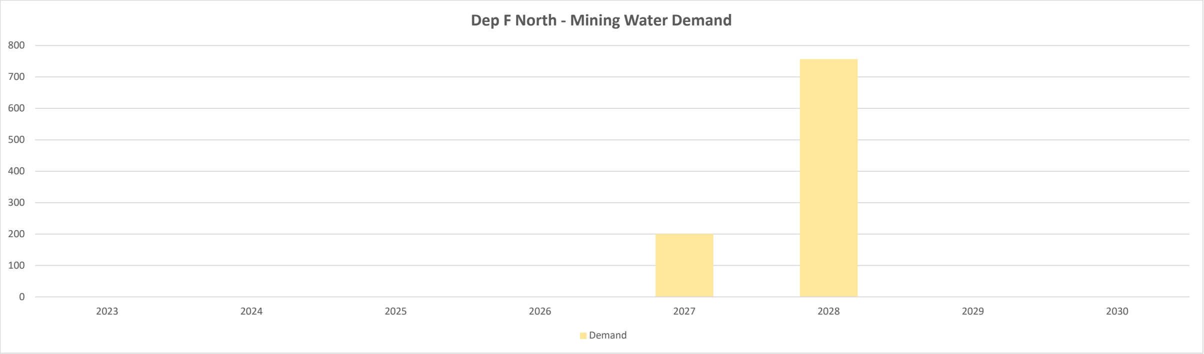

Figure 5-2 2022 5 Year Mine Plan Dust Suppression Water Demand

6. Conclusions / recommendations

The Dep F North aquifer is a relatively small compartmentalised ‘bathtub’ orebody aquifer with a depth to water table of 70m that is surrounded by low permeability units and is not hydraulically connected to the regional aquifer. A maximum reduction of water level of about 20 m will be required to dewater to the base of the proposed pit. Given the compartmentalisation of the aquifer, the limited dewatering (depth and duration) required for mining purposes will not impact any environmental receptors and there are no existing users. Aquifer parameters and water quality have been assumed to be similar to other West Angelas deposits, and experience there shows that shallow dewatering drawdown effects do not extend very far beyond the surrounding low conductivity units

7. References

RTIO, Hydro Wiki - West Angelas - Hydro Wiki - Wiki

RTIO, Resource Evaluation Wiki - West Angelas - Resource Evaluation Wiki - Wiki

RTIO, Resource Estimation Wiki - Resource Estimation Wiki - Resource Estimation - Wiki

RTIO, Resource Handbook Wiki West Angelas - Deposit F - Resource Handbook - Wiki

RTIO, Resource Handbook Wiki West Angelas - Deposit F North* - Resource Handbook - Wiki

RTIO, 2019, Review of Existing Water Quality Data – Greater West Angelas

RTIO,2018, DepFN Hydrogeological Conceptualisation – Pore Pressure Review

360 Environmental, 2022, Baseline Groundwater Dependent Ecosystem Assessment for the Greater West Angelas Area

HydroGeoLogic

HydroGeoLogic Pty Ltd (ABN 51 877 660 235)
PO Box 383, Highgate 5063, South Australia
0438 983 005 / hugh@hydrogeologic.com.au

INDEPENDENT PEER REVIEW STATEMENT

SUBJECT:	West Angelas Deposit F North hydrogeological conceptualisation - review
ATTENTION:	Mr Kevin Vermaak, Superintendent Hydrogeology GHD/RR/WAN, Rio Tinto
FROM:	Hugh Middlemis, Principal Groundwater Engineer, HydroGeoLogic Pty Ltd

This brief statement summarises the outcomes of an independent peer review of the 24-page draft report on the West Angelas Deposit F North Hydrogeological Conceptualisation (Rio Tinto, November 2022), to support a Part IV approval for a proposed plan for mining below the water table. The review was conducted by Hugh Middlemis, an independent engineer and hydrogeologist with more than 40 years' experience, including on projects in the Pilbara.

The hydrogeological conceptual report is well-written and provides high quality graphics and explanations of the geological and hydrogeological setting. The West Angelas mine area consists of several discrete iron mineralisation deposits on the limbs of the east-west trending, west plunging Wonmunna Anticline located in the eastern part of the Opthalmia Fold Belt. Deposit F north is situated along the south limb of the Wonmunna Anticline, and the supergene orebody forms an isolated aquifer within the synclinal structure of the Marra Mamba Iron Formation.

The conceptualisation report provides an integrated understanding of the data on stratigraphy, geology, hydrogeology, geophysics and hydrochemistry, including the influences of regional and localised dolerite dykes that act to compartmentalise the orebody aquifer. The orebody aquifer is underlain and laterally bounded by low permeability, non-mineralised units including the Macleod and Nammuldi Members of the Marra Mamba Formation and the Jeerinah Formation of the Fortescue Formation. Orebody aquifer groundwater level data show no material responses to rainfall events, a flat hydraulic gradient across the orebody, and there is no evidence of hydraulic connections to any regional aquifer.

The geological and hydrogeological setting and other attributes are very similar to other discrete orebodies in the area, such as documented in the West Angelas Western Hill Hydrogeological Impact Assessment (Rio Tinto, Dec. 2021). The Western Hill investigation, recently reviewed by this author, is at a more mature stage of investigation. That included detailed analytical element modelling and quantitative uncertainty analysis, which demonstrated that the drawdown effects associated with dewatering of the compartmentalised orebody aquifers are almost entirely limited to the orebody aquifer extents. Similar effects are expected at Deposit F North.

The Deposit F hydrogeological conceptualisation has been competently investigated and documented, and it forms a suitable basis for groundwater assessments to support the Part IV application for mining below the water table.

Yours sincerely, Hydrogeologic Pty Ltd

Hugh

Hugh Middlemis (Principal Groundwater Engineer).

24 November 2022