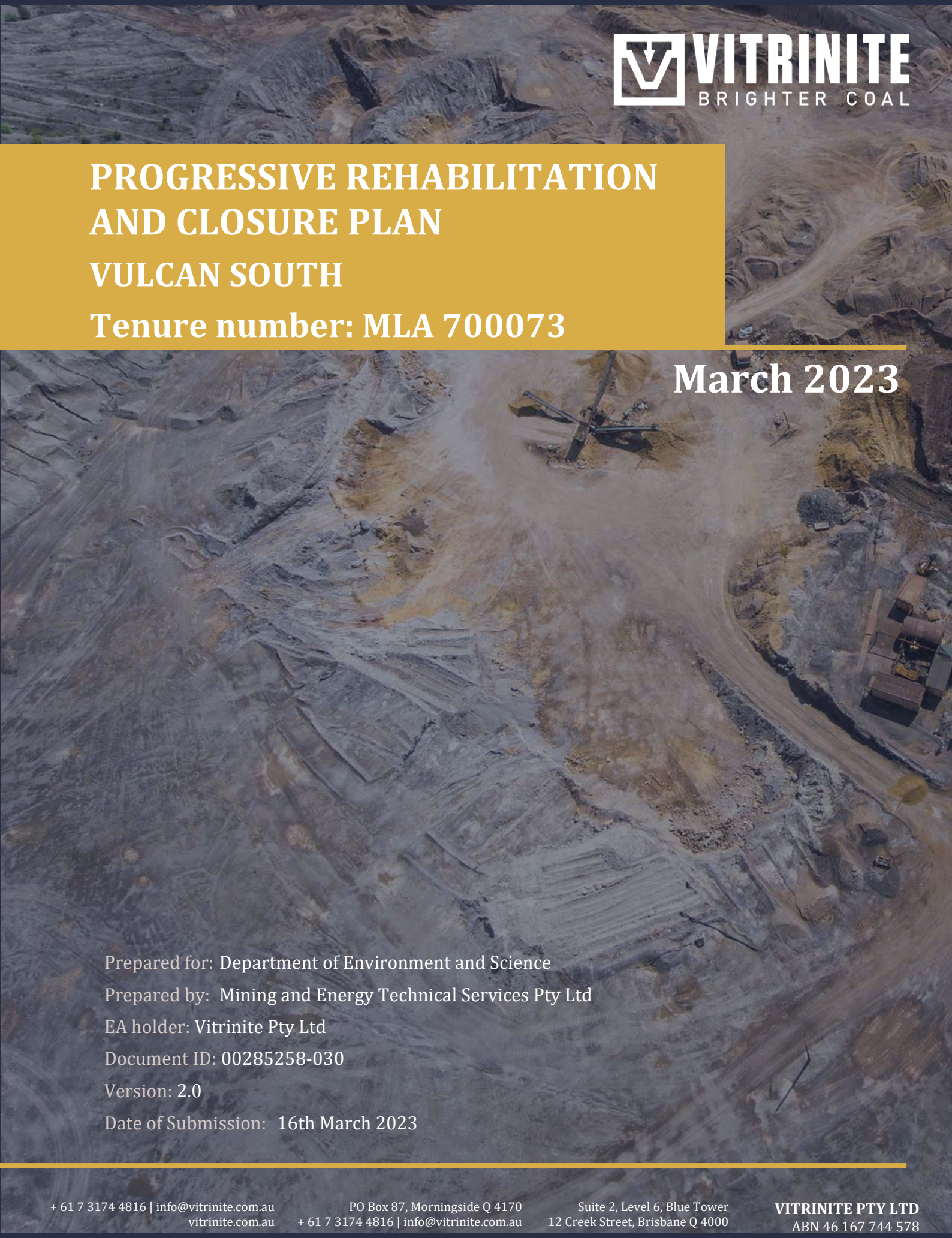

PROGRESSIVE REHABILITATION AND CLOSURE PLAN

VULCAN SOUTH

Tenure number: MLA 700073

March 2023

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1 INTRODUCTION

Vulcan South (the Project) is a new small-scale coal-mining operation proposed by Vitrinite Pty Ltd owner of Qld Coal Aust No.1 Pty Ltd and Queensland Coking Coal Pty Ltd (Vitrinite). This Progressive Rehabilitation and Closure Plan (PRC Plan) is to accompany a site-specific application for an environmental authority (EA) to undertake the project. This PRC Plan has been developed to meet the requirements specified in the Queensland Government's *Progressive Rehabilitation and Closure Plans Guideline* and Sections 126C and 126D of the *Environmental Protection Act 1994.*

This PRC Plan comprises two main components. The rehabilitation planning component (**Sections 1** to **9**) provides information on the characteristics of the site, legislative requirements, stakeholders, post-mining land use, rehabilitation goals, schedule of land availability, rehabilitation methodology, risk assessment and monitoring program. The PRCP schedule component (**Section 10**) provides a detailed schedule of works, including a final site design and rehabilitation milestones.

This PRC Plan provides a strategy for Vitrinite to manage their mining lease in a way that maximises the progressive rehabilitation of the land to a stable condition, as well as specifying the condition to which Vitrinite must rehabilitate the land before the EA may be surrendered.

1.1 Project Location

The Project is located north of Dysart and approximately 45 km south of Moranbah in Queensland's Bowen Basin (**Figure 1-1**). The Project lies to the immediate west of several established mining operations, including BHP's Peak Downs and Saraji mines, and south of Vitrinite's Vulcan Coal Mine.

1.2 Site Description

1.2.1 Resource Tenures

The Project's mining lease application (MLA) covers an area of approximately 3800 ha and is situated over multiple underlying resource tenures:

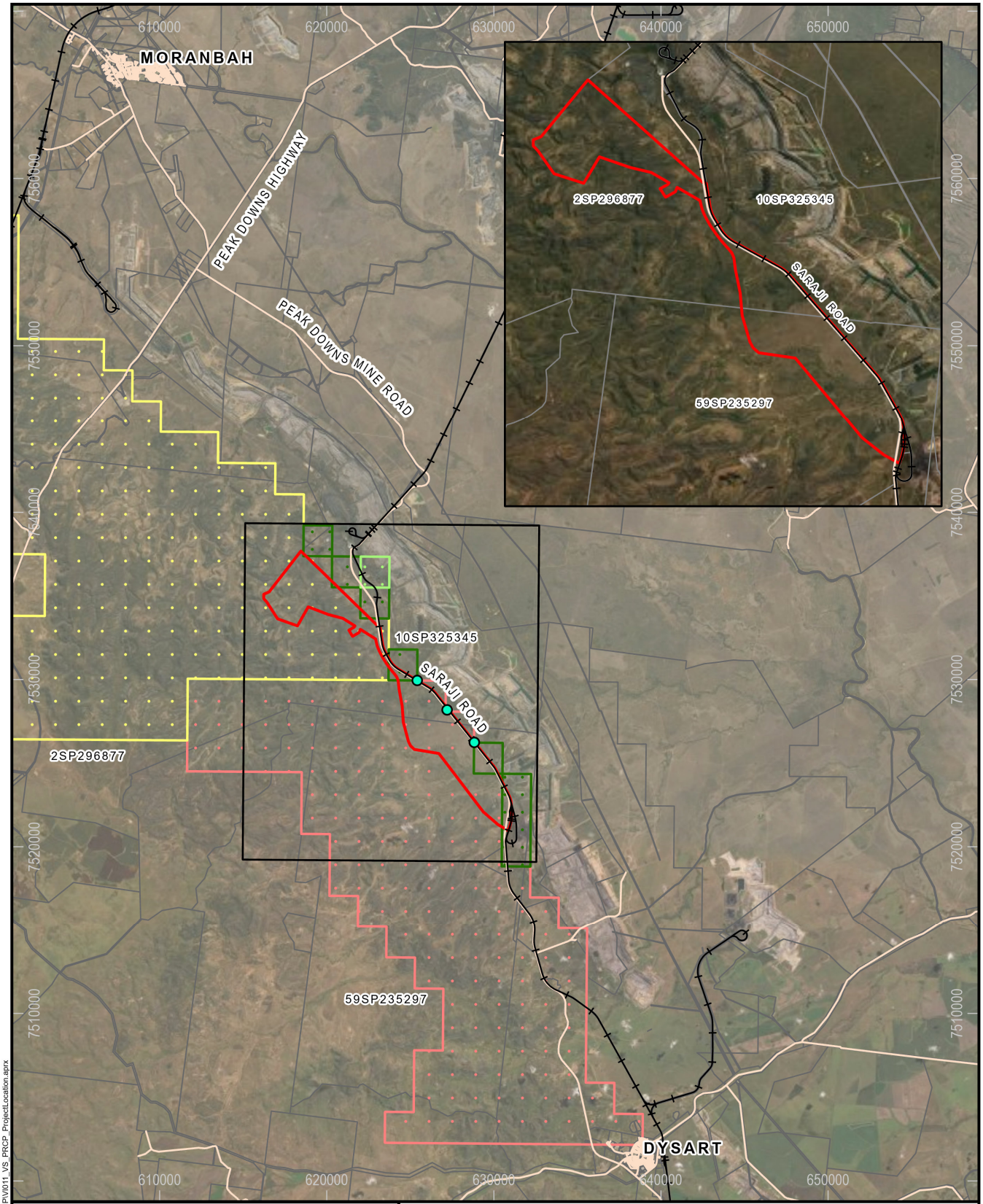
- Exploration Permits Coal (EPC):
  - 1732;
  - 1233; and
  - 1234.
- Parcel Prospecting Permits (PPP):
  - Vulcan South Area 1 and Area 2- Lot 26 on CNS125;
  - Vulcan South Area 2 and Area 3- Saraji Road (Road Reserve);
  - Vulcan South Area 2- Lot 2 on SP296877; and
  - Vulcan South Area 3- Lot 2 on CNS109.

These EPCs and PPPs are held by companies owned by Vitrinite and are shown in **Figure 1-1.**

The existing underlying properties, non-resource tenures, usage and owners/managers within the proposed ML boundary are discussed in **Section 1.2.11**.

1.2.2 Topography

The Project lies on plains and footslopes along the eastern edge of the Harrow Range. The Harrow Range (immediately west of Vulcan South) is generally 100-170 m higher than the surrounding plain. The plain itself slopes gently towards to the east, and varies in elevation from 210 metres Australian Height Datum (mAHD) in the south to 350 mAHD in the north (**Figure 1-2**).



Legend

- Prospecting Permits
- Railway
- Road
- MLA Boundary
- Cadastral Boundary
- EPC 1233
- EPC 1234
- EPC 1732
- Historical EPC 1732

Source: State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Location Map Showing Resource Tenures of Vulcan South

0 3 6 12

Kilometers

Scale: 1:330,000 (A4)

13/05/2022

Datum: GDA2020
Projection: MGA55

FIGURE 1-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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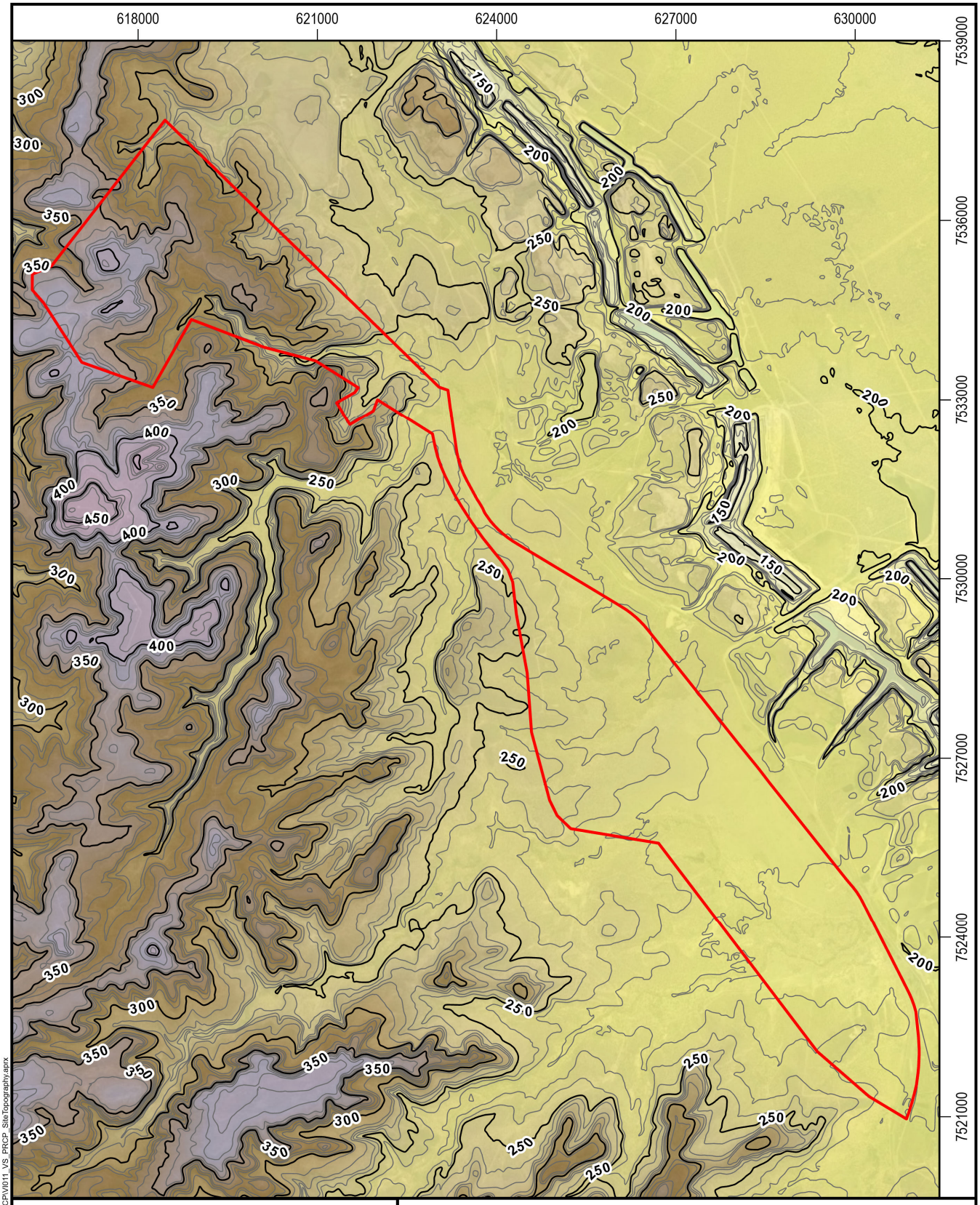


Legend

MLA Boundary

Elevation (m)

Contours

481.988

10m

87.4393

50m

Source: State of Queensland (Department of Resources) 2019, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_SiteTopography.aprx

Vulcan South

Site Topography

0 1.5 3

Kilometers

Scale: 1:92,000 (A4)

14/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 1-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

1.2.3 Climate

The Project area is subtropical, with hot summers and mild winters. The nearest Bureau of Meteorology (BoM) weather stations are Mount Lebanon (29 km northwest) and Seloh Nolem (29 km east), both of which are currently closed. The nearest active weather station is Moranbah Airport (35 km north-northwest), which only commenced operations in 2012. Given the inconsistency of locally available data for discerning long-term average weather patterns, the Queensland Department of Environment and Science's SILO database was used for estimating average rainfall on site. The SILO database uses mathematical interpolation techniques to fill temporal and spatial data gaps from BoM's weather stations. Based on data generated for the SILO grid point -22.35, 148.20, the mean and median annual rainfall for the Project is 590.6 mm and 575.1 mm, respectively. However, this varies widely between years: standard deviation = 204.2, range = 275.5 to 1,152.7 mm. On average, 70% of the annual rainfall occurs between November and March (**Figure 1-3**).

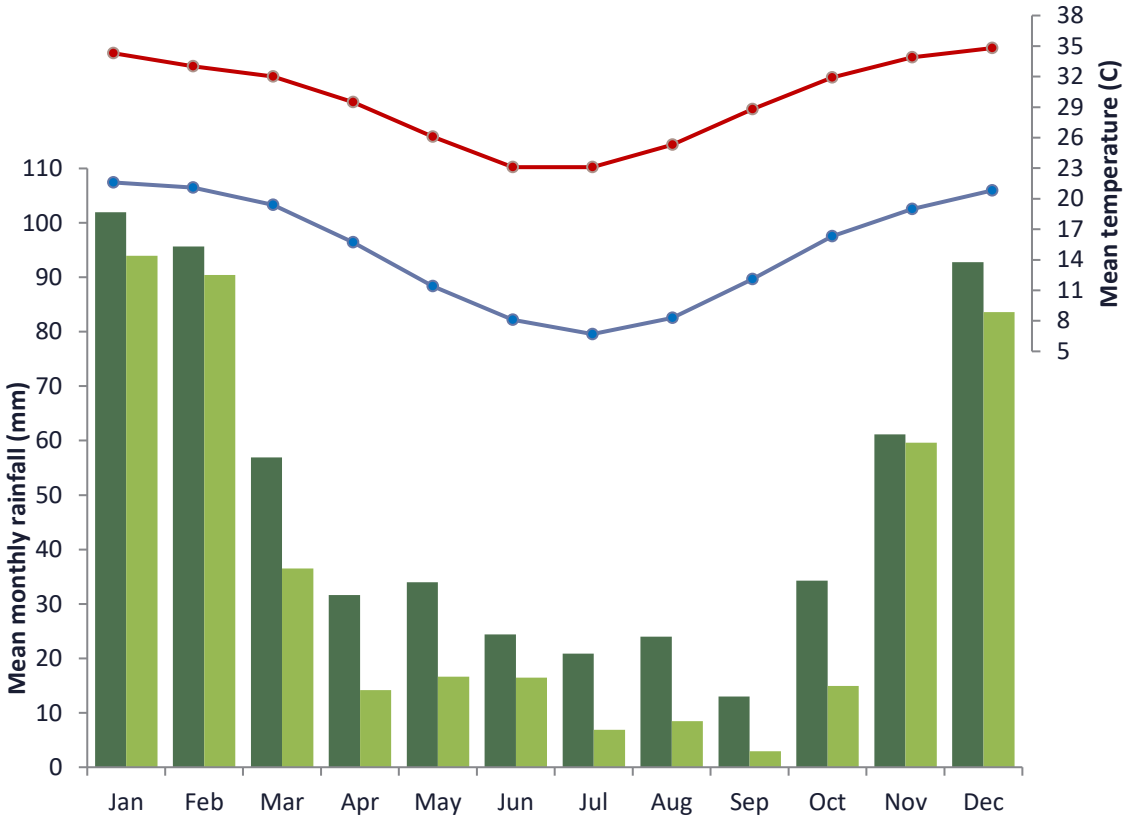


Figure 1-3 Average weather conditions at Vulcan South.
Green bars refer to the mean (dark) and median (light) monthly rainfall over the past 50 years, as interpolated in the SILO database (Bureau of Meteorology 2019) for the SILO grid point -22.35, 148.20. Mean monthly maximum (red) and minimum (blue) temperatures over the past 50 years come from the Clermont Post Office meteorological station.

The mean potential evaporation rate for every month exceeds the mean rainfall for the respective month. However, the size of this deficit varies with season. The period between September and December is historically the driest (**Table 1-1**), which has been considered when planning earthworks and planting programs as part of this PRC Plan.

Table 1-1 Mean potential evaporation rates and mean water deficits in the project vicinity throughout the year

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall (mm)	102	95.65	56.94	31.64	33.96	24.38	20.86	23.99	13	34.26	61.17	92.78
Mean evaporation (mm)	220.2	178.9	182.9	145.3	115.5	91.85	102.2	132.7	173.3	216	225.6	237
Mean water deficit (mm)	118.3	83.25	126	113.6	81.56	67.47	81.33	108.8	160.3	181.7	164.5	144.2

(from the SILO grid point -22.35, 148.20).

Climate change models produced by the CSIRO (2015) suggest with medium confidence that there will be long-term decreases in average winter and spring rainfall over the next 80 years. Long-term changes in summer and autumn rainfall are also possible, but the direction is unclear (CSIRO 2015). On the short timescales of the Project, the influence of natural rainfall variability is projected to predominate over trends due to increasing greenhouse gas emissions (CSIRO 2015), and the rainfall data presented in **Figure 1-3** is therefore most relevant to the Project during the rehabilitation and vegetation establishment stage. Over the next 80 years, however, an increase in the intensity of extreme rainfall events is projected with high confidence, and the time spent in drought is projected to increase with medium confidence. These long-term changes can affect the prospect of survival for long-lived trees.

The effect of climate change on temperature is projected to be more apparent short-term than for rainfall. For the near future (2030), the annually averaged warming across all emission scenarios is projected to be around 0.5 to 1.4 °C above the climate of 1986-2005 (CSIRO 2015); note that the current climate (as at the end of 2019) is already 0.24 °C warmer than the 1986-2005 average (CSIRO 2015). This warming is projected to be 1.3 to 5.0 °C by 2090 (CSIRO 2015). Temperature changes have been considered both for the vegetation establishment phase of rehabilitation and for the long-term survival of trees post-relinquishment. Species to be used in revegetation all have widespread geographic distributions (including hotter and drier locations than the Project area). It is therefore unlikely that the Project area currently represents the limit of environmental tolerance for any of the species utilised.

1.2.4 Geology

The geology of the Project area is influenced by its position within the Bowen Basin, one of Queensland's largest depositional zones, formed through a period of rifting and subsidence lasting from the Early Permian to the Mid-Triassic. The area surrounding the Project is dominated by clastic sedimentary rocks of marine and lacustrine origin, including sandstones, mudstones, siltstones and coal (Geoscience Australia 2019). Rock strengths range from extremely-low-strength weathered sandstone to high-strength fresh sandstone.

The solid geology of the region includes the:

- Moranbah Coal Measures - Permian, comprising coal and inter-seam material composed of sandstone, shale, siltstone with minor clay stone; and
- Back Creek Group - Early to Late Permian, comprising quartzose to lithic sandstone, conglomerate, siltstone, carbonaceous shale and coal. Occurs beneath the Moranbah Coal Measures, and outcrops to the west of the disturbance footprint.

The Permian and Triassic sediments are covered by a thin veneer of unconsolidated to semi-consolidated Cainozoic sediments (Tertiary to Quaternary alluvium and colluvium):

- Qr –(QLD) (Qr) – Quaternary clay, silt, sand, gravel and soil with colluvial and residual deposits; and
- TQa - QLD (TQa) - Late Tertiary to Quaternary poorly consolidated sand, silt, clay, minor gravel and high level alluvial deposits.

Across the Project area, the uppermost stratum is generally a highly weathered regolith comprising a heterogeneous distribution of fine- to coarse-grained sand, clay, sandstone and claystone. These are either Tertiary sediments or a weathering profile that had developed during the Tertiary on Permian strata.

The base of weathering typically extends to depths of 15 to 45 mbgl (metres below ground level), where the unweathered Moranbah Coal Measures commence. Near the Project area the cumulative thickness of coal appears to be between 5 m and 15 m. The intention is to mine the lower seams of the Moranbah Coal Measures (the ALEX and Dysart Lower-Lower (DLL) coal seams).

Outcropping to the west of the Project is the basal section of the Moranbah Coal Measures, a sequence of sandstones and siltstones, with imbedded coal. The ALEX coal seam lies near the top of this sequence, just below the base of weathering. It is of high quality and low ash content, and is about 1 m thick. It overlies resistant, quartzose, medium- to coarse-grained sandstone, locally referred to as the Mesa Sandstone due to the characteristic mesa plateaus that have formed in the region. At its base, the Mesa Sandstone grades into the Mesa Siltstone.

The DLL coal seam lies immediately below the Mesa Siltstone. It lies near the base of the Moranbah Coal Measures. The DLL consists of a 2.5-m-thick seam with four plies, and contains high-ash and good-quality coal. An additional and a separate 1-m-thick coal seam beneath the main seam makes the entire sequence to be mined approximately 3.5 m thick.

Beneath the Moranbah Coal Measures are the Exmoor and Blenheim formations of the Back Creek Group. The top of the Exmoor formation is characterised by prominent, coarse-grained, siliceous boulder sandstone in outcrop, whilst the top of the Blenheim Formation is characterised by fossiliferous and worm-burrowed sandstone.

No igneous intrusions have been encountered within the Project to date in either drilling or field mapping exercises. However, neighbouring mining operations (the north and far west of EPC1234 and EPC1729) have localised basalt dykes and potential sills within their leases.

A conceptual diagram of the main geological units is shown in **Figure 1-4**, and representative stratigraphy of the Project geology is shown in **Figure 1-5**.

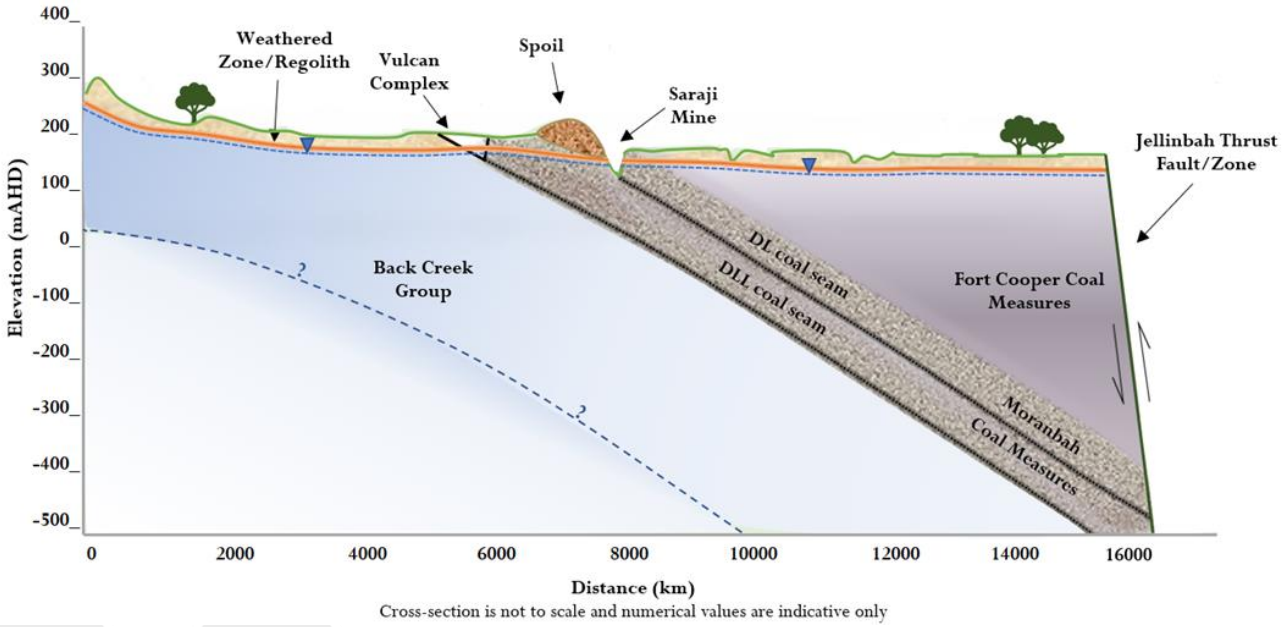


Figure 1-4 *West-to-east conceptual geological model of the Project area*

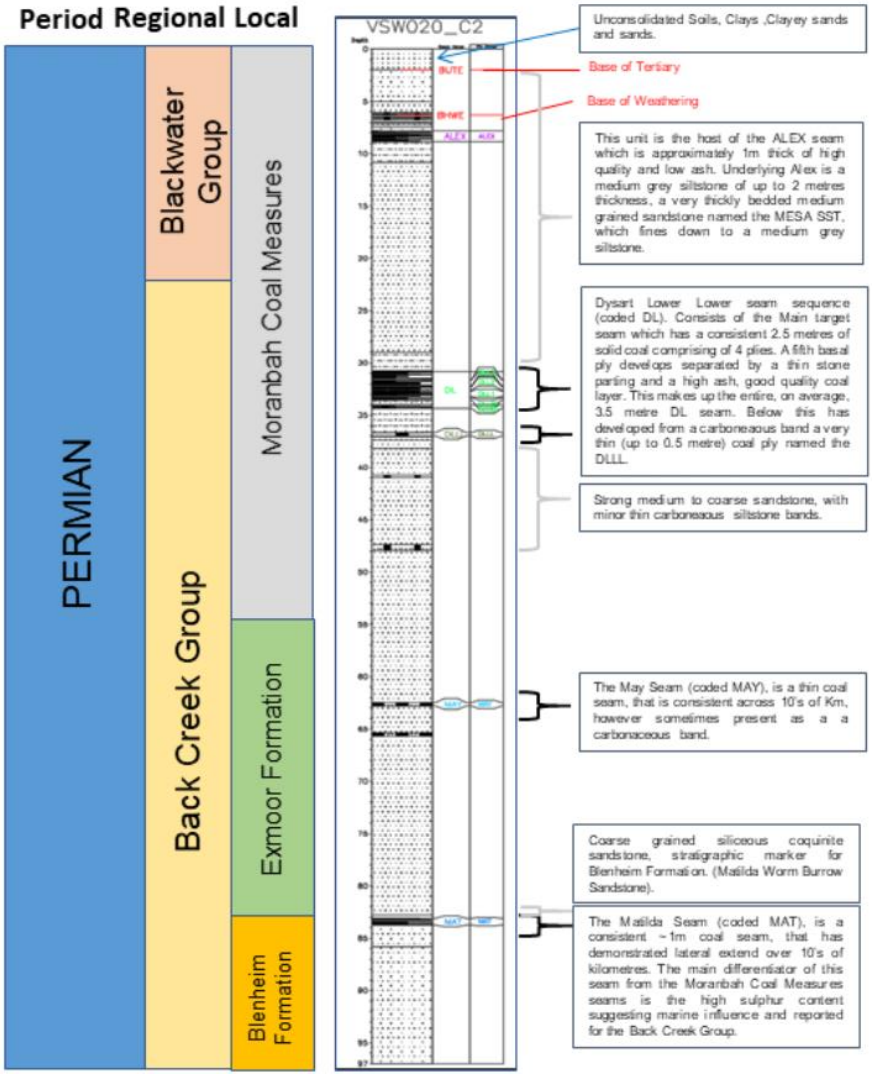


Figure 1-5 Representative stratigraphy of the Vulcan South area

1.2.5 Hydrology

A surface water assessment of Vulcan South has been carried out by WRM Water + Environment (WRM) (**Appendix A**). This is summarised below.

Vulcan South is located within the Isaac River sub-basin of the Fitzroy Basin. **Figure 1-6** depicts the Upper Isaac Catchment to its confluence with Phillips Creek and the proposed Vulcan South MLA.

The Isaac River commences 100 km to the north of Vulcan South in the Denham Range. It drains in a south westerly direction through the Carborough and Kerlong Ranges before turning in a south easterly direction near the Goonyella Riverside Mine. It drains 30 km to the east of Vulcan South, and eventually flows to the Mackenzie River 150 km to the southeast.

Three large open water bodies are located in the Isaac upper catchment, namely Lake Elphinstone, Teviot Creek Dam and Burton Gorge Dam (**Figure 1-6**). Lake Elphinstone is a natural lake formed behind the Carborough Range, whereas Teviot Creek Dam and Burton Gorge Dam are man-made structures that supply water to Burton and North Goonyella mines in the upper catchment.

Other than along the ranges, most of the Isaac River catchment has been cleared for agriculture and mining. There are several existing coal mines in the catchment, including Burton, North Goonyella, Goonyella Riverside,

Broadmeadow, Broadlea North, Isaac Plains, Moranbah North, Millennium, Daunia, Poitrel, Grosvenor, Peak Downs, Saraji, Norwich Park and Lake Vermont mines.

Vulcan South is located in the headwaters of the Boomerang, Hughes, Barrett and Harrow creek catchments (**Figure 1-7**):

- Boomerang Creek, which is a watercourse and tributary of the Isaac River, drains the northern portion of the Vulcan South area;
- Hughes Creek is a watercourse and tributary of Boomerang Creek and drains the majority of the southern Vulcan South area;
- Barrett Creek, which is a watercourse and tributary of Hughes Creek, drains a small portion of the southern Vulcan South area; and
- headwaters of Harrow Creek, which is a tributary of Cherwell Creek and the Isaac River, drain a small portion of the northern Vulcan South area.

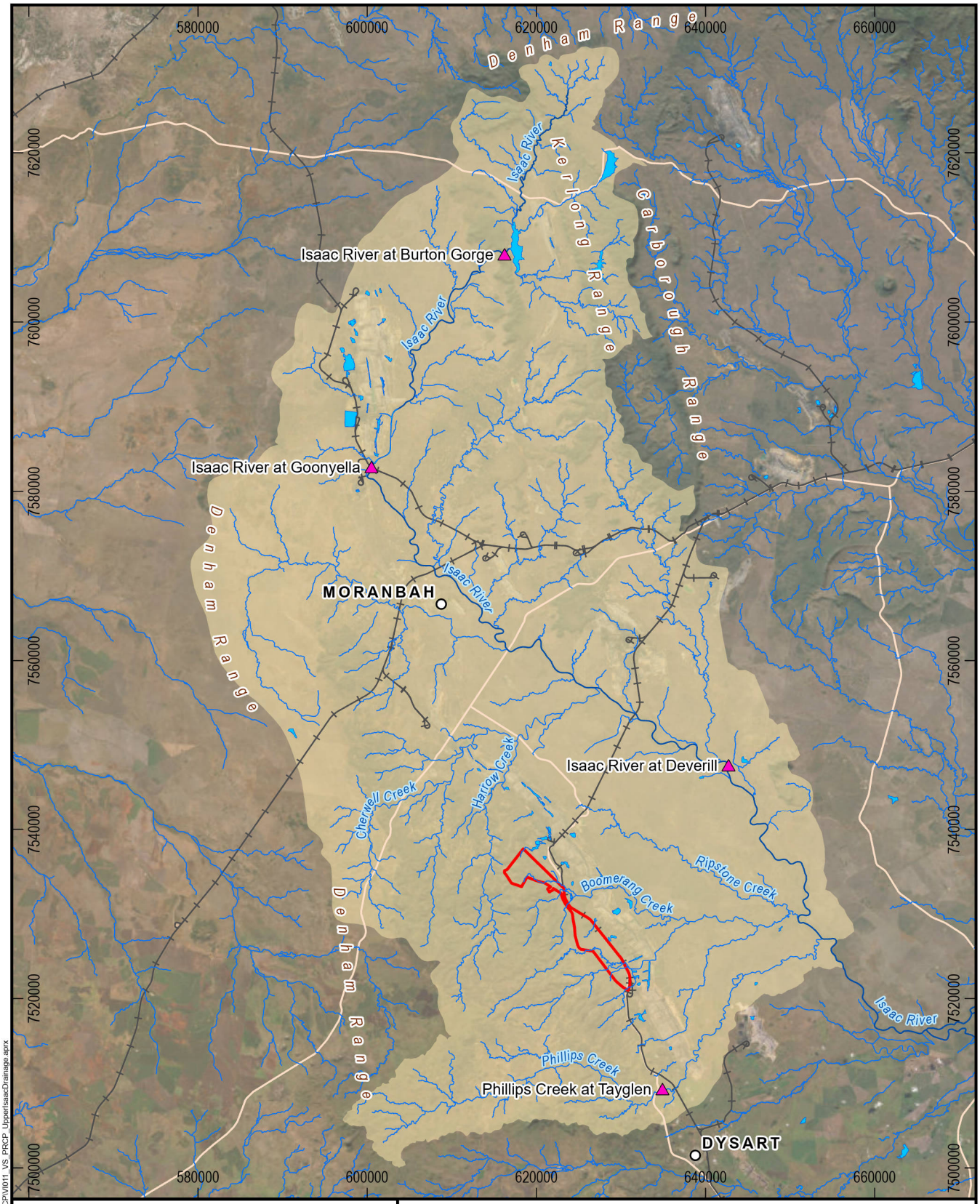
The confluence of Boomerang and Hughes Creek occurs 10 km east of Vulcan South. Boomerang Creek drains into the Isaac River 10 km to the east of Vulcan South.

The catchment area of the Isaac River to Boomerang Creek is approximately 5,226 km^2. The catchment area of Boomerang Creek is 788 km^2, of which 177 km^2 makes up the Hughes Creek catchment.

The catchments of Boomerang Creek, Hughes Creek and Barrett Creek commence to the west of the Vulcan South area and drain in an easterly direction towards Saraji Road and the Norwich Park Branch Railway. The Ripstone Creek catchment lies to the north of the Vulcan South area and drains into Boomerang Creek 30 km southeast of Vulcan South. The headwater tributaries of Boomerang and Hughes Creek are ephemeral streams that experience flow only after sustained or intense rainfall.

The predominant catchment land uses of Boomerang Creek include undeveloped areas with stock grazing to the west of Saraji Road and stock grazing and coal mining to the east. Boomerang Creek, Hughes Creek and Barrett Creek flow into the existing BHP Billiton Mitsubishi Alliance (BMA) operations (Peak Downs and Saraji). The existing BMA operations have diverted the original alignment of Boomerang Creek and its tributaries, as well as Harrow Creek to the north. Additional diversions of Boomerang Creek and its floodplain are also planned for approved operations further to the east.

A small portion of Vulcan South MLA area (in the far northwest) lies within the Harrow Creek catchment (**Figure 1-7**). Harrow Creek flows in a northerly direction. Sawmill Creek and Kennedy Creek are tributaries of Harrow Creek that are located upstream of the Vulcan South MLA area. Harrow Creek flows into Cherwell Creek, which in turn discharges into the Isaac River to the north of Vulcan South.



Legend

- Railway
- Road
- Isaac River
- Drainage Feature
- MLA Boundary
- DES Gauge
- Lakes / reservoirs
- Isaac River to Philips Creek

Source: State of Queensland (Department of Environment and Science 2020, Department of Resources 2021-2022), WRM 2020, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_UpperIsaacDrainage.aprx

Vulcan South

Upper Isaac River Drainage Characteristics

0 5 10 20

Kilometers

Scale: 1:650,000 (A4)

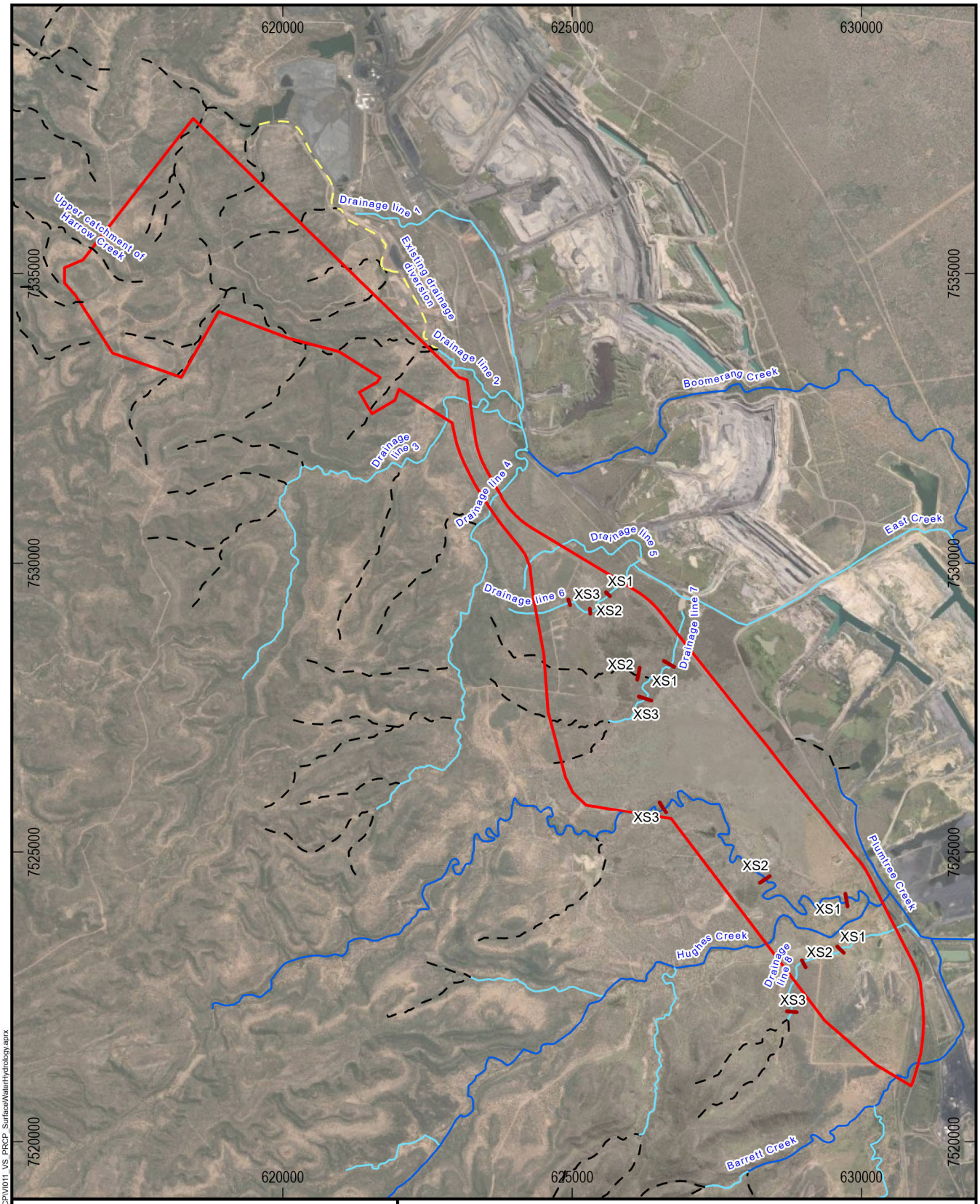
8/02/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-6

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd



Legend

- Railway
- Cross sections
- MLA Boundary

Local Drainage Features

- Minor Drainage Features
- Drainage Features
- Drainage Diversion
- Watercourse

Source: WRM 2020, State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_SurfaceWaterHydrology.aprx

Vulcan South

Local Drainage Features

0 0.75 1.5 3

Kilometers

Scale: 1:95,000 (A4)

9/02/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-7

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Drainage features in the immediate vicinity of the Project are shown in **Figure 1-8** Project overview and drainage features (WRM, 2022) **Figure 1-8**. Those drainage features that intersect mining areas are as follows:

- drainage line 1 (a tributary of Boomerang Creek);
- drainage line 2 (a tributary of Boomerang Creek);
- drainage line 6 (a tributary of Boomerang Creek);
- drainage line 7 (a tributary of Boomerang Creek);
- Hughes Creek; and
- drainage line 8 (a tributary of Hughes Creek).

These features are depicted in **Figure 1-9** to **Figure 1-11**, and their typical channel cross-sections, along with 1% AEP flood levels (i.e. a one in 100 year flood) are presented in **Figure 1-12**. Locations for the cross-sections are given in **Figure 1-10** and **Figure 1-11.**

Drainage lines 1 and 2 are tributaries of Boomerang Creek as shown in Figure 1-7. Minor drainage features that are tributaries of Drainage Line 2 drain most of the Highwall mining area (**Figure 1-9**). Drainage line 2 has a catchment area of approximately 30 km^2. Drainage Line 2 flows east beneath Saraji Road and the Norwich Park branch railway, to the east of the Project area, before discharging into the Peak Downs ML.

What was formerly the upper reaches of Drainage Line 1 now dive-rt (as a result of BHP's actions) along a mine levee wall and form part of the Drainage Line 2 catchment. A haul road is proposed to be constructed across Drainage Line 2 immediately upstream of where the diversion enters.

The typical dimensions of the Drainage Line 2 channel are (WRM, 2022):

- channel bed widths of 3 m to 5 m;
- channel top widths of 10 m to 30 m;
- channel depths 1 to 2 m; and
- overbank floodplain widths of 50 m to 150 m.

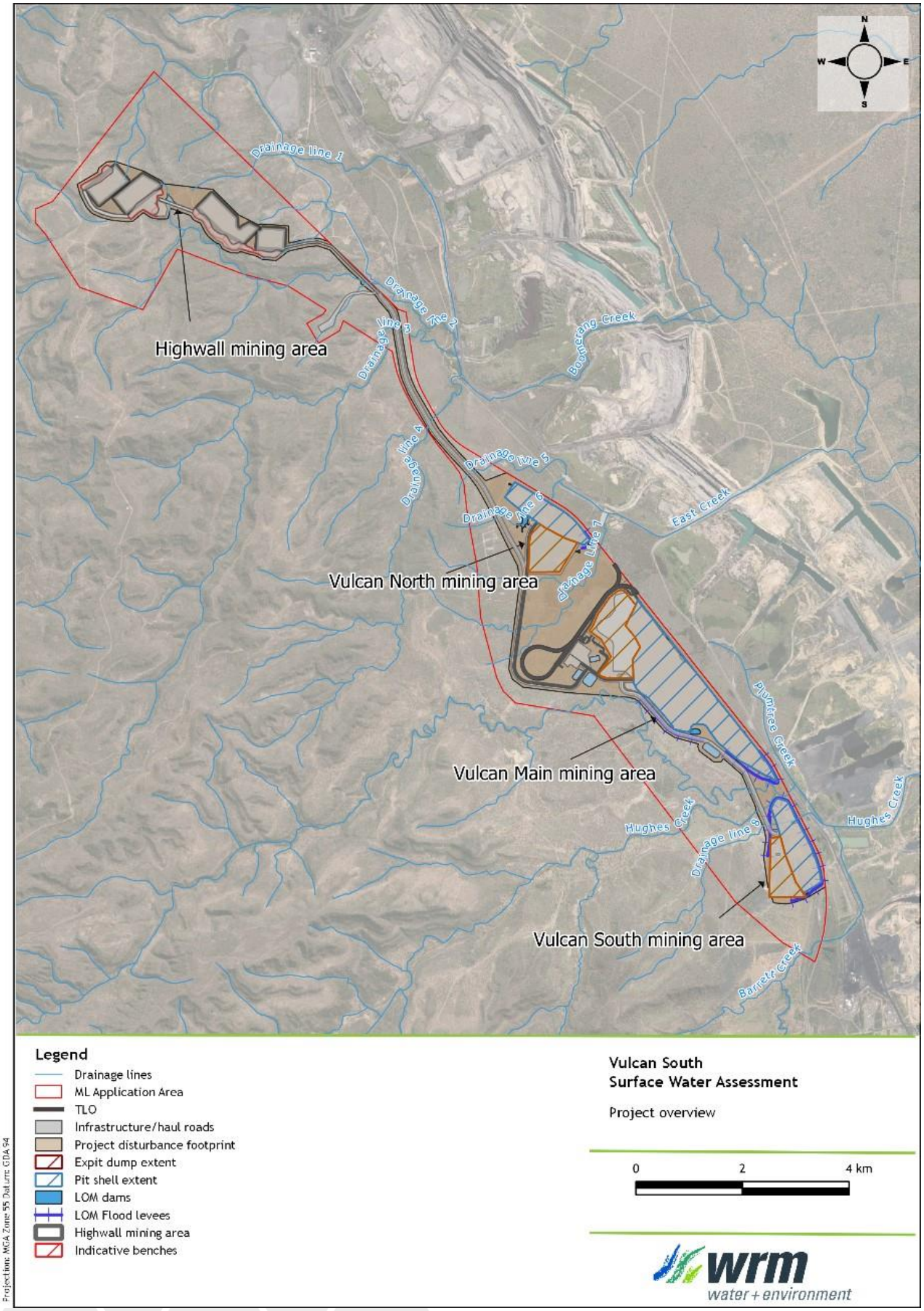


Figure 1-8 Project overview and drainage features (WRM, 2022)

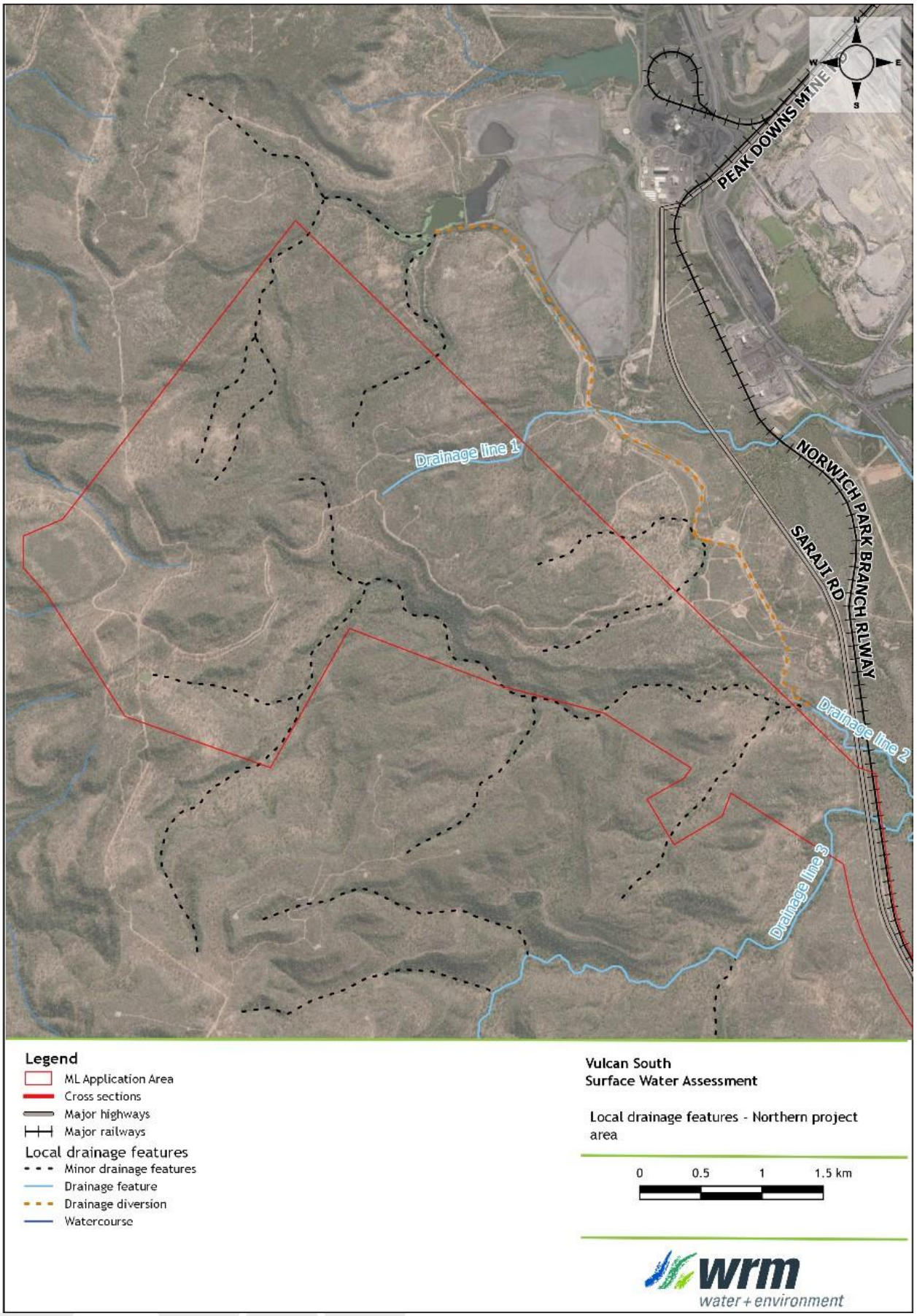


Figure 1-9 Local drainage features - northern Project area (WRM, 2022)

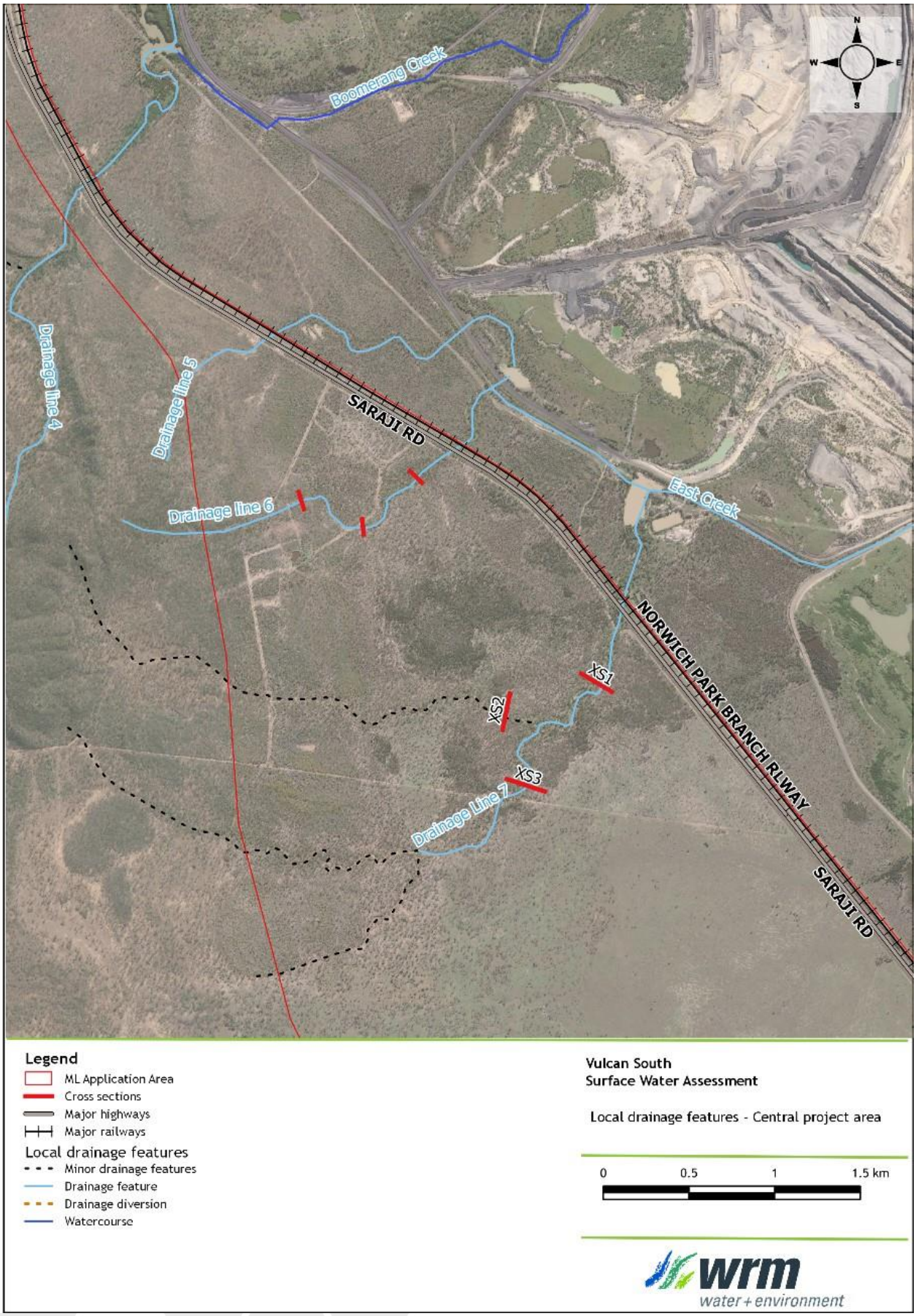


Figure 1-10 Local drainage features - central Project area (WRM, 2022)

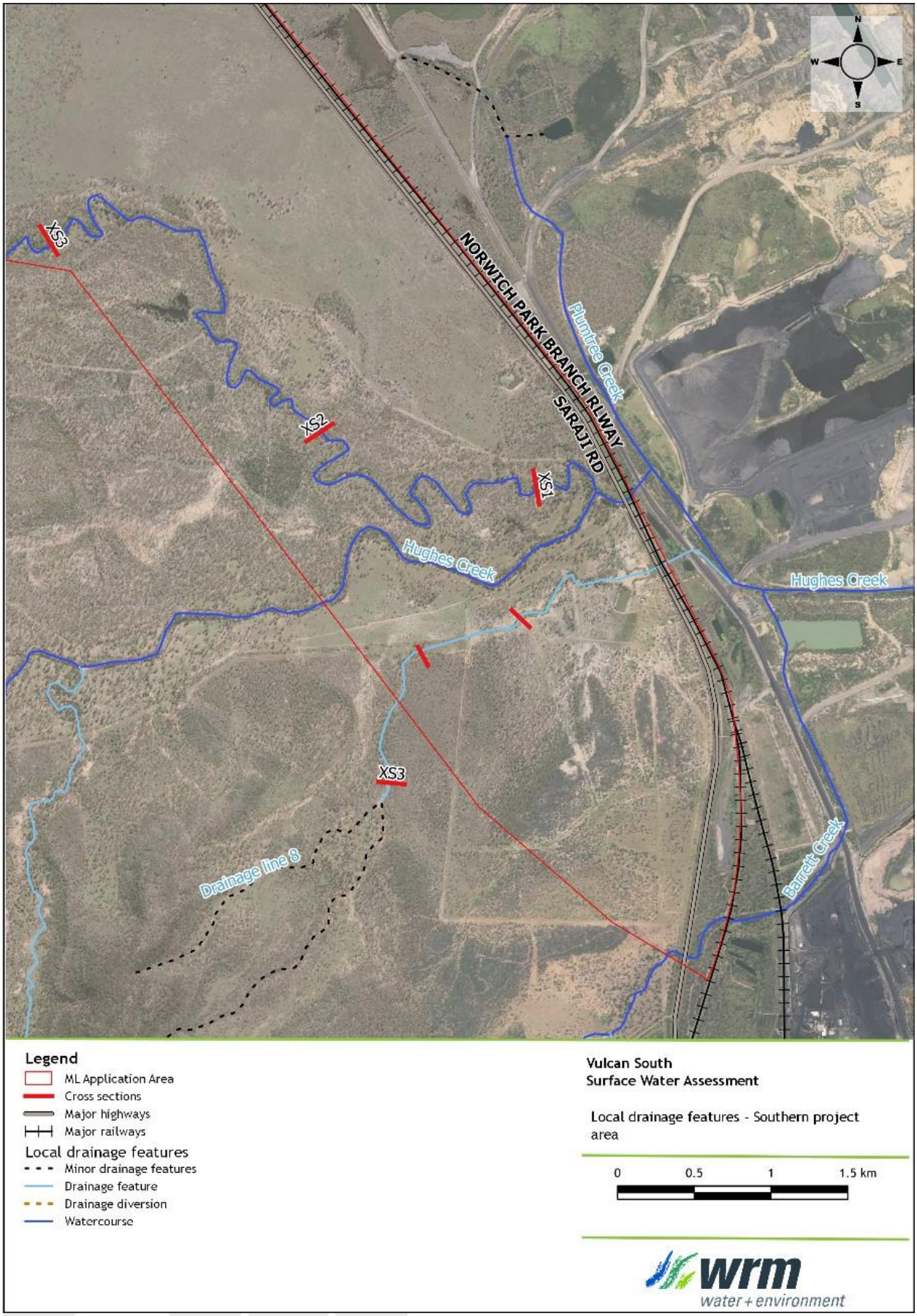


Figure 1-11 Local drainage features - southern Project area (WRM, 2022)

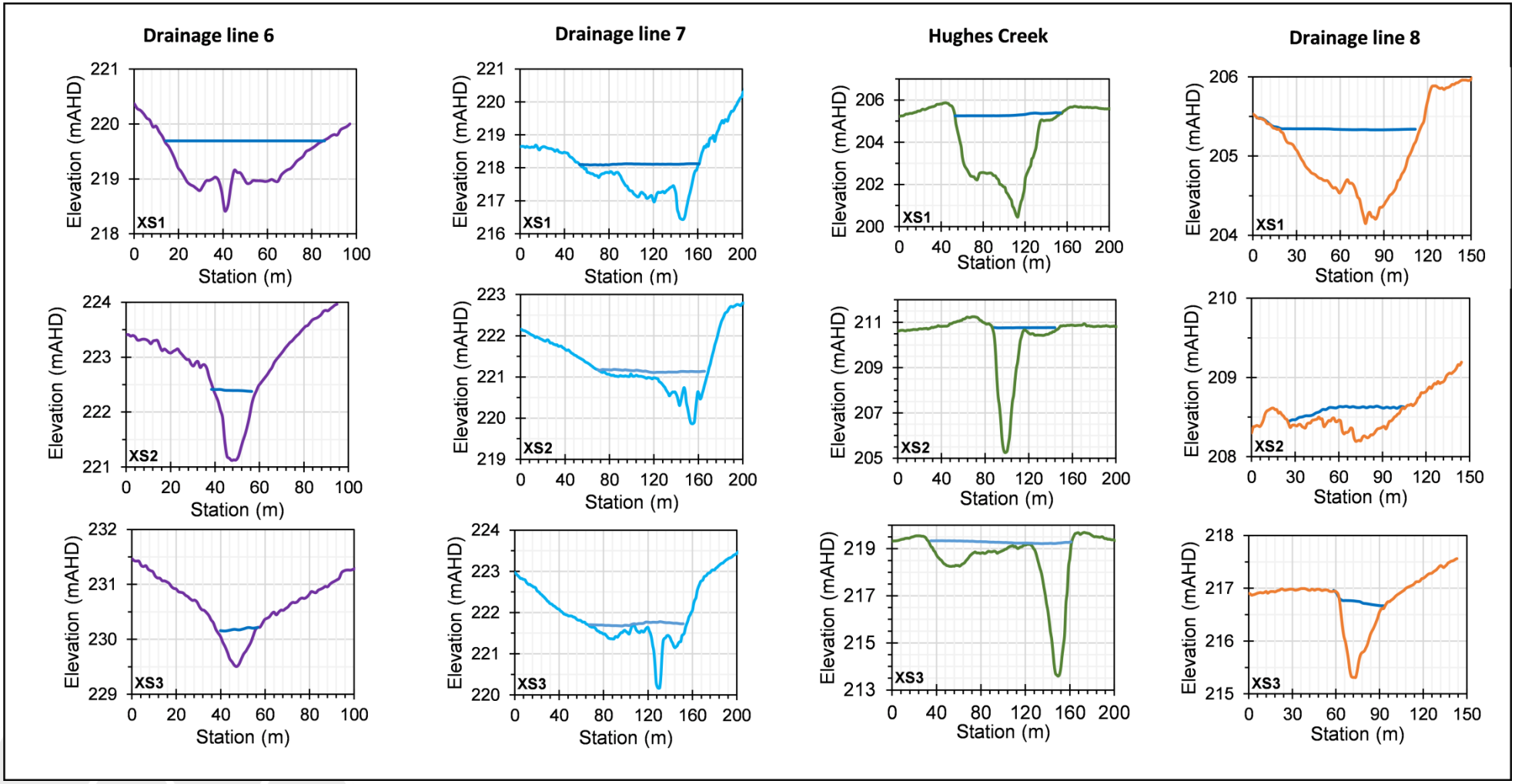


Figure 1-12 Drainage line cross sections with 1% AEP flood levels (WRM, 2022)

Tributaries of East Creek (i.e., Drainage Line 5, Drainage Line 6 and Drainage Line 7) drain the central parts of the Vulcan South MLA area. These drainage lines pass through culverts under Saraji Road and the Norwich Park branch railway within the Vulcan South area. These drainage lines merge to form East Creek on the eastern side of the railway. East Creek passes through the Saraji Mine operation before draining into Boomerang Creek approximately 5 km east of Vulcan South.

The typical dimensions of the Drainage Line 6 channel through the Vulcan South area are (**Figure 1-12**):

- channel bed widths of 1 m to 5 m;
- channel top widths of 5 m to 20 m;
- channel depths 0.5 to 1 m; and
- overbank floodplain widths of 15 m to 80 m.

The typical dimensions of the Drainage Line 7 channel through the Vulcan South area are (**Figure 1-12**):

- channel bed widths of 3 m to 5 m;
- channel top widths of 10 m to 15 m;
- channel depths 1.0 to 2.0 m; and
- overbank floodplain widths of 50 m to 100 m.

Drainage line 6 will be diverted as part of Vulcan South to avoid mining areas. The 1.8 km drainage diversion will divert Drainage line 6 into Drainage line 7 during operations. Drainage Line 6 will be reinstated post-mining by constructing a drainage corridor through backfilled spoil.

Hughes Creek is a watercourse with a largely natural catchment to the west of the Vulcan South area. The creek flows eastwards between proposed mining areas, passing under two bridge crossings of Saraji Road and the Norwich Park branch railway. A number of drainage features discharge into Hughes Creek downstream of the Vulcan South area, including Barrett Creek and Drainage line 8. Hughes Creek passes through the Saraji Mine operation before discharging to Boomerang Creek approximately 10 km east of the Vulcan South area. Hughes Creek has been diverted and significantly modified within the Saraji Mine.

The typical dimensions of the Hughes Creek channel within the Vulcan South area are (**Figure 1-12):**

- channel bed widths of 3 m to 10 m;
- channel top widths of 30 m to 50 m;
- channel depths 2 to 5 m; and
- overbank floodplain widths of 50 m to 150 m.

Drainage line 8 is a tributary of Hughes Creek which flows through the proposed Vulcan South mining area. Drainage line 8 currently passes through box culverts under Saraji Road and the Norwich Park branch Railway before discharging into Hughes Creek to the east of the Vulcan South area. Drainage line 8 is proposed to be diverted during operations around mining areas into Hughes Creek to the north. Drainage Line 8 will be reinstated post-mining by constructing a drainage corridor through backfilled spoil.

The typical dimensions of the Drainage Line 8 channel through/upstream of the Vulcan South area are (**Figure 1-12**):

- channel bed widths of 1 m to 3 m;
- channel top widths of 10 m to 20 m;
- channel depths 0.5 to 1.0 m; and
- overbank floodplain widths of 50 m to 150 m.

Drainage line 8 has been dammed in its lower reaches as a water source for livestock.

No stream flow data was available for East Creek or Hughes Creek at the time of the surface water assessment (**Appendix A**). Two streamflow gauges operated by the Department of Resources (DoR) in the vicinity of Vulcan South were identified as part of the surface water assessment and are located at:

- Isaac River at Deverill (approximately 25 km northeast of Vulcan South); and
- Phillips Creek at Tayglen (approximately 15 km southeast of Vulcan South).

Sediment covers the bottom metre of the stream flow gauge on the Isaac River. In an average year, surface flow above the sediment occurs primarily in wetter months (November-August) with only shallow, sub-surface flows the rest of the year. Phillips Creek is characterised by brief periods of flow interspersed by long periods of no flow. This ephemeral behaviour is typical for streams in this part of the Fitzroy Basin. Further detail of stream flow investigation at these sites is provided in **Appendix A**.

Surface Water Quality

Regional and local water quality has been investigated as part of the surface water assessment (**Appendix A**). Full datasets are available for the Deverill Gauging Station on the Isaac River between 2011 and 2018 (**Table 1-2**). The water quality at the Deverill Gauging Station compares to Water Quality Objectives (WQO) in the following ways:

- the Electrical Conductivity (EC) values for high flows greater than 200 m^3/s are generally below the high flow WQO of 250 µs/cm;
- the EC of flows below 100 m^3/s vary significantly from 50 µS/cm to 1,870 µS/cm, and frequently exceed the low flow WQO of 720 µS/cm. The mean daily EC has exceeded the low flow WQO on a total of 23 days over this period, and all of these days experienced some flow (not stagnant flow); and
- stream flows are highly ephemeral with surface flows ceasing within a few days or weeks of a runoff event.

Further discussion of regional water quality can be found in **Appendix A**.

Table 1-2 Water quality of the Isaac River at Deverill (WRM, 2022)

Parameter	Unit	Median value at Deverill	WQO default guideline value
Aluminium - Total	mg/L	-	< 5 (stock)
Aluminium - Dissolved	mg/L	0.05	< 0.055 (aquatic)
Boron - Total	mg/L	0.06	< 5 (stock)
Calcium - Dissolved	mg/L	16	-
Chloride - Total	mg/L	32	-
Copper - Dissolved	mg/L	0.03	< 0.0014 (aquatic)
EC	µS/cm	261	< 720 (baseflow) < 250 (high flow)
Filterable Reactive Phosphorus	µg/L	0.35	< 20 (aquatic)
Fluoride - Total	mg/L	0.14	< 2 (irrigation)
Iron - Dissolved	mg/L	0.06	-
Manganese - Dissolved	mg/L	0.01	< 1.9 (aquatic)
Nitrate - Total	mg/L	1.4	-
Nitrogen - Total	µg/L	0.76	< 500 (aquatic)
pH	-	7.6	6.5-8.5 (aquatic)
Phosphorus - Total	µg/L	0.35	< 50 (aquatic)
Potassium - Total	mg/L	4.55	-
Sodium - Total	mg/L	22	< 30 (drinking water)
Sulphate - Total	mg/L	10.9	< 25 (aquatic)
Total Alkalinity	mg/L	78	-
Total Dissolved Solids	mg/L	155	< 2,000 (stock)
Total Suspended Solids	mg/L	135	< 55 (aquatic)
Turbidity	NTU	247	< 50 (aquatic)
Zinc - Dissolved	mg/L	0.01	< 0.008 (aquatic)

Local water quality sampling has been undertaken as a component of the baseline surface water quality sampling in early 2020 (**Appendix A**). Analyses for a comprehensive range of physio-chemical parameters were completed at the monitoring sites.

The baseline monitoring locations in addition to the full suite of baseline monitoring undertaken for Vulcan South is presented in **Appendix A**. Monitoring results from the sites most relevant to Vulcan South have been reviewed as part of the surface water assessment (**Appendix A**) and suggest that certain baseline water quality values surrounding Vulcan South do not meet the WQO for the region, these include:

- Suspended solids;
- Turbidity;
- Sulphate;
- Aluminium (filtered);
- Aluminium (total);
- Copper (filtered);
- Iron (total);
- Ammonia;
- Total Nitrogen;
- Total Phosphorous;
- Reactive Phosphorous; and
- Dissolved Oxygen.

To establish local water quality objectives, the Queensland Water Quality Guidelines (QWQG) require that with 3 or more reference sites, 12 samples are collected over at least 12, but preferably 24 months. Vitrinite has established 14 reference sites (as shown in the Vulcan South Surface water Memo **Appendix A**) collected from February 2020 to October 2022, which will continue to be either upstream reference sites or reference sites until mining commences. However, data collection is limited to periods of flow in an ephemeral system. Additional surface water monitoring data will be provided following the completion of the 2023 wet season to capture a more robust and representative dataset and in-turn, ensure updated trigger values are considered in the finalised EA.

Baseline Flooding

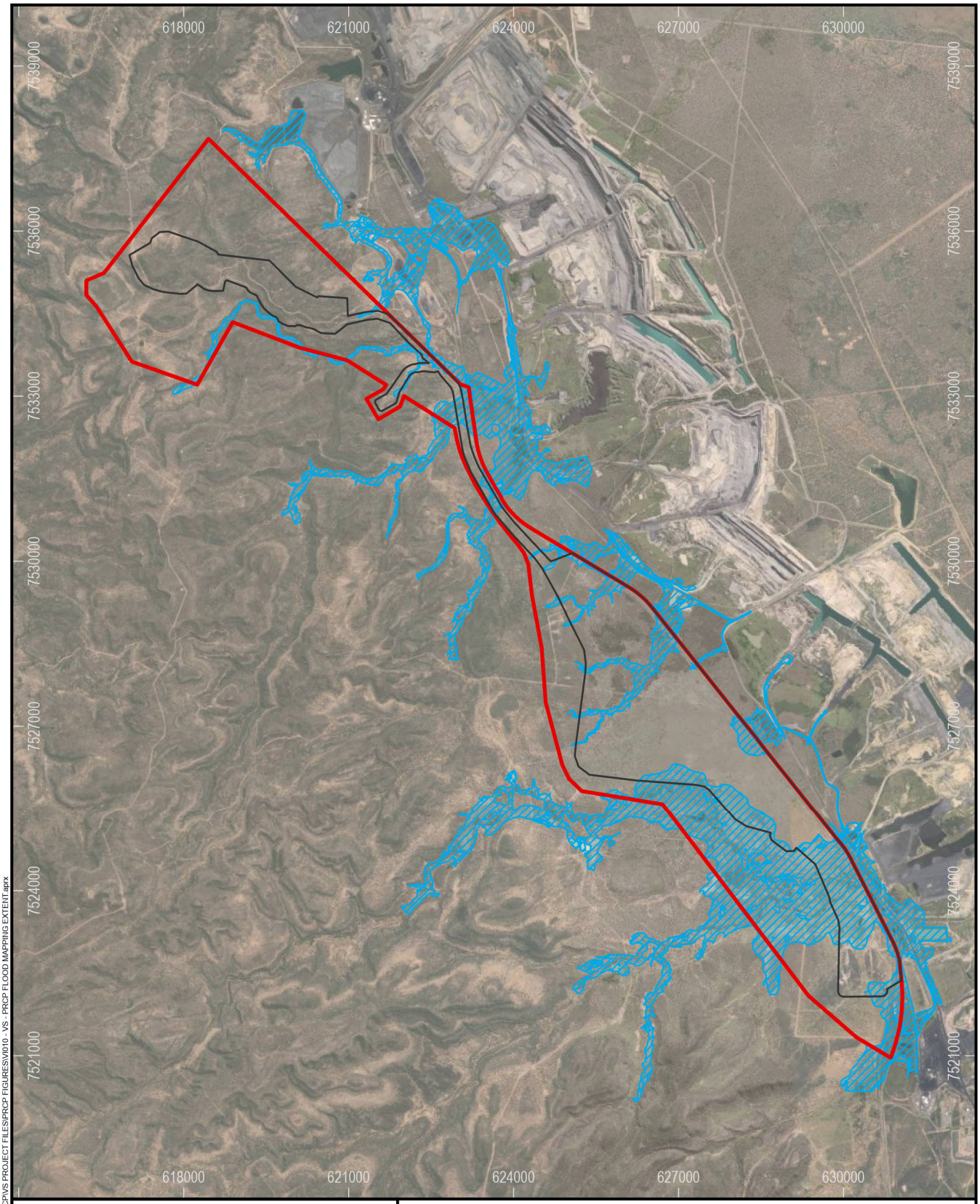
In accordance with Section 126D(3) of the EP Act, any voids situated wholly or partly within a flood plain must be rehabilitated to a post-mining land use (PMLU) with a stable condition. While no non-use management areas (NUMAs) are proposed for Vulcan South, flood plain modelling was undertaken as part of baseline assessments, to inform flood risks during operations and rehabilitation. The flood modelling undertaken, its design, methodology, results, and mapping are presented in detail in **Appendix A**. This flood plain modelling revealed that small parts of the disturbance footprint for the Project occur within a flood plain (**Figure 1-13**), as defined based on pre-mining conditions.

The baseline flooding conditions for the 10% AEP, 1% AEP and 0.1% AEP scenarios are as follows:

- East Creek:
  - For the 10% AEP event:
    - floodwaters through the Vulcan South area are generally conveyed within the channel banks of natural drainage lines. Saraji Road is overtopped at some crossing locations. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey the 10% AEP event;
    - peak flood velocities along natural drainage channels in the vicinity of the Vulcan South area are up to 2.0 m/s in localised areas; and
    - overbank flood depths adjacent to natural drainage lines are generally shallow (less than 0.5 m).
  - For the 1% AEP event:
    - floodwaters through the Vulcan South area are generally conveyed within the channel banks of natural drainage lines with limited overbank flooding. Saraji Road is overtopped at most crossing locations. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey the 1% AEP event;
    - peak flood velocities in natural drainage channels exceed 2.0 m/s in localised areas. Overbank velocities are generally up to 1 m/s; and
    - flood widths and depths adjacent to natural drainage lines are greatest upstream of Saraji Road and Norwich Park Branch Railway where floodwaters are impounded behind the constructed embankments.
  - For the 0.1% AEP event:
    - floodwaters through the Vulcan South area are generally conveyed within the channel banks of natural drainage lines with confined overbank flooding;
    - flood velocities along natural drainage channels are typically elevated (greater than 2.5 m/s in localised areas). Overbank velocities are generally up to 1 m/s; and
    - peak flood widths and depths along the eastern side of the Vulcan South area increase as natural drainage lines drain towards Saraji Road and Norwich Park Branch Railway where floodwaters are impounded behind the constructed embankments. Flood depths impounded behind the railway embankment at the eastern boundary of Vulcan South are up to 5 m.
- Hughes Creek:
    - For the 10% AEP event:

- floodwaters through the Project area are generally conveyed within the Hughes Creek channel. Minor breakouts occur along the Drainage line 8 and Barrett Creek channels upstream of Saraji Road. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey 10% AEP events;
- peak flood velocities along natural drainage channels in the vicinity of the Vulcan South area exceed 2.0 m/s in localised areas. Overbank velocities are generally up to 1 m/s; and
- overbank flood depths adjacent to natural drainage lines are generally shallow (less than 0.5 m). Notwithstanding this, Hughes Creek flood depths are up to 3 m upstream of the railway.

- For the 1% AEP event:
  - overbank flooding occurs at several locations within the Vulcan South area along Hughes Creek, with flood widths of up to 1.6 km just upstream of the railway;
  - overbank flood depths are up to 4.5 m adjacent to Hughes Creek upstream of the railway. The railway embankment is overtopped during this event; and
  - peak flood velocities along natural drainage channels are typically elevated (up to 3.2 m/s in localised areas). Overbank velocities are generally up to 1.5 m/s.
- For the 0.1% AEP event:
  - significant overbank flooding occurs along Hughes Creek within the Vulcan South area along Hughes Creek and Barrett Creek, with flood widths of up to 2 km;
  - overbank flood depths are up to 5 m adjacent to Hughes Creek, with some localised areas that exceed 5 m; and
  - peak flood velocities along natural drainage channels are typically elevated (up to 4 m/s in localised areas). Overbank velocities are generally up to 2.0 m/s.



Legend

- MLA Boundary
- Maximum Disturbance Footprint
- 0.1% Annual Exceedence Probability (AEP) Peak Flood

Source: State of Queensland (Department of Resources) 2021, METServe 2020-2022, WRM 2022, Earthstar Geographics.

Vulcan South

Flood Mapping Extent

0 2 4

Kilometers

Scale: 1:100,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-13

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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1.2.6 Hydrogeology

In the vicinity of the Project, all geological formations yield low volumes of groundwater and hence would not typically be classified as aquifers in most hydrogeological settings. However, as individual lithological units within these formations have higher hydraulic conductivities than the intervening units, and groundwater in these formations was assessed for the determination of impact, they are referred to as aquifers for the purposes of this assessment. A detailed hydrogeological impact assessment has been carried out by hydrogeologist.com.au for Vulcan South and is provided in **Appendix B.** This is summarised below.

The following geological formations within the Project area may contain groundwater:

1) Quaternary alluvium: Confined to discrete channels in the beds of existing watercourses. These alluvial sediments are unsaturated and disconnected laterally.
2) Tertiary sediments and weathered regolith: Silts and clays, which comprise the bulk of the regolith overlying the coal measures, are densely compacted, hard and generally dry. Sand and gravel lenses embedded within the regolith are permeable but have low hydraulic conductivity and limited lateral and vertical extent. These have a potential to represent unconfined to confined aquifers, depending on location.
3) Permian coal measures: The ALEX and DLL coal seams are poor aquifers of low hydraulic conductivity. They are confined above and below by low-permeability regolith and sedimentary rocks. Nevertheless, these represent the largest and uppermost aquifers across most of the Project.
4) Back Creek Group: This formation of sandstones, siltstones and shale forms a largely impervious layer beneath the DLL coal seam aquifer. However, the Back Creek Group also contains narrow coal seams that can act as poor aquifers.

Hydrogeologist.com.au (2019) established a groundwater monitoring network across the Project area in June 2019 to support the Project (**Appendix B**). The groundwater monitoring network was equipped with data loggers to enable high frequency (daily) groundwater level measurements to be captured. On-going monitoring and sampling of the groundwater monitoring network is being carried out to further supplement the groundwater level and quality data included in the groundwater impact assessment (**Appendix B**). The monitoring and sampling of the groundwater monitoring network is planned for and carried out in consideration of the Queensland Monitoring and Sampling Manual (Department of Environment and Science, 2018).

The rationale of the monitoring network is to capture groundwater flow upstream and downstream of the Project, as well as provide data to the north and south. Permian coal measures and Tertiary sediments are the targets of the monitoring network as no Quaternary alluvium was identified within the study area (hydrogeologist.com.au, 2022). The monitoring bore network has been designed to also monitor other Vitrinite projects, such as the abutting VCM, and data gathered through the lifetime of the VCM will provide hydrogeological data for Vulcan South.

Proximity of adjacent mining operations restricts bore placement, particularly for off-lease downstream monitoring. Some of the established groundwater monitoring bores for baseline groundwater investigation are in future Vulcan South mining areas and as such will be replaced during the Project.

Groundwater Quality

The pH of local groundwater is neutral to slightly acidic (hydrogeologist.com.au 2022). Groundwater is brackish to highly saline (electrical conductivity of 2,700 to above 20,000 µS/cm) (hydrogeologist.com.au 2022). This is driven mostly by high concentrations of sodium and chloride (with moderate bicarbonate in some samples). This groundwater is generally unsuitable for irrigation, but it may be used in limited quantities as water for livestock. Electrical conductivity above 7,463 µS/cm is associated with decline in animal health if consumed for prolonged periods (ANZG 2018). All groundwater on site fails to meet guidelines for drinking water suitability for humans. Overall, groundwater on site has no or limited value for most uses, with the exception of limited stock watering and potential industrial purposes related to mining.

An assessment of groundwater use in the vicinity of Vulcan South (hydrogeologist.com.au, 2022) found that mining, petroleum and gas use is by far the most common, followed by water supply (for mining and also private use) then exploration and monitoring purposes. Other nearby groundwater bores are also brackish to highly saline (**Appendix B**).

Surface-groundwater interaction.

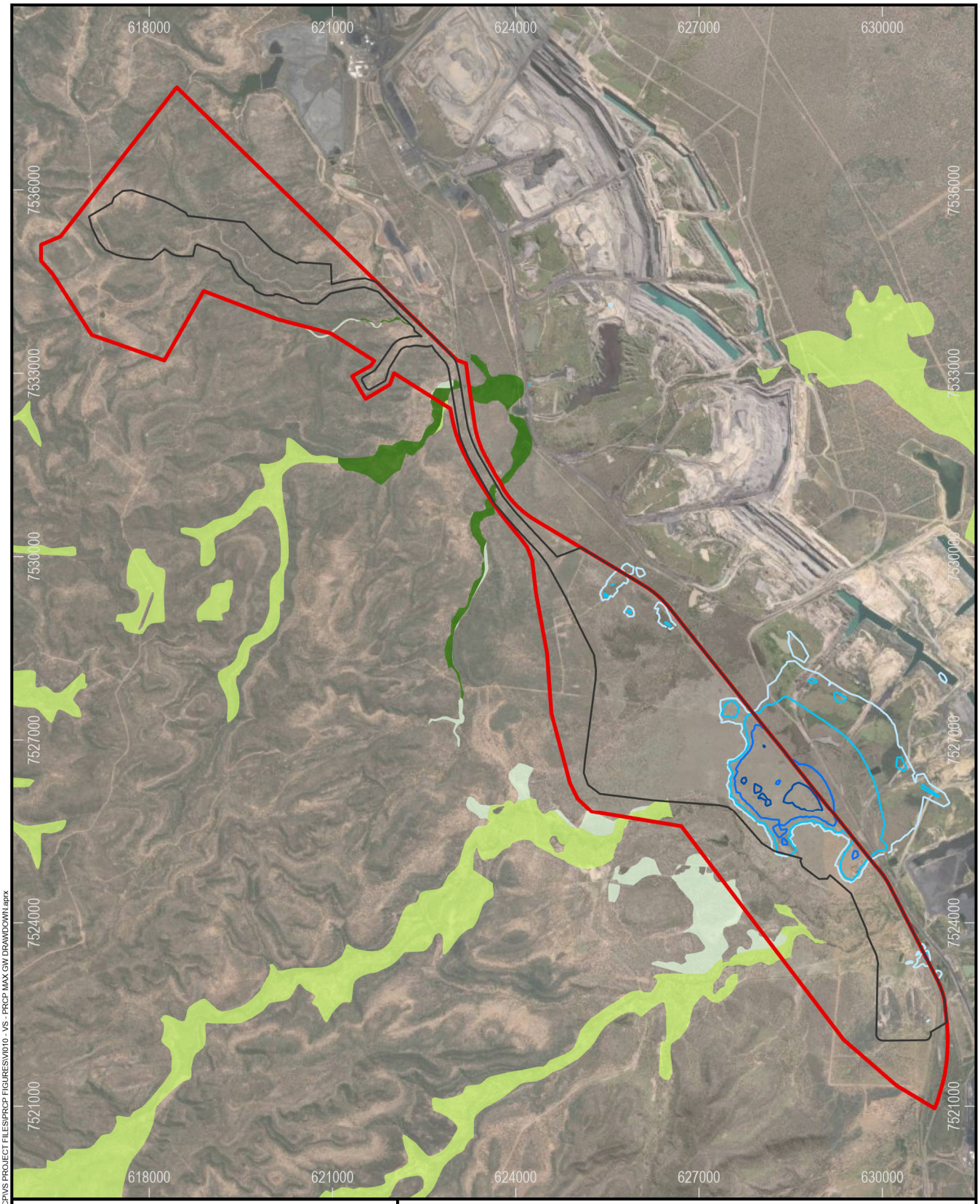
A desktop assessment of potential interaction between surface water and groundwater has been conducted (hydrogeologist.com.au, 2022) on the basis of the Project's surface water and groundwater regimes and comparison with similar investigations conducted at similar projects.

This assessment determined that due to the ephemeral nature of surface water systems in the Project area, creeks are dry for most of time, and, if present, the Quaternary alluvium would be unsaturated. The groundwater table occurs in the Tertiary sediments or the Permian coal measures at depths greater than 10 m below ground level. It was determined that a significant layer (>10 m) of unsaturated material occurs between surface water features and the groundwater table. Therefore, it is considered that there is no significant interaction between surface water and groundwater in the vicinity of the Project.

Groundwater Dependent Ecosystems

Aquatic Groundwater Dependent Ecosystem (GDE) mapping was conducted by hydrogeologist.com.au (2022). Small pockets of high- and moderate-potential aquatic GDEs mapped as occurring within the maximum drawdown associated with the Vulcan South pits are probably erroneous. This is because aquatic GDEs with high or moderate potential for groundwater interaction are most likely to occur in areas where the seasonally high groundwater potentiometric heads are above or close to the corresponding surface water level. This is necessary to maintain a hydraulic gradient from the groundwater to surface water, or at least to have a hydraulically connected system. Within or adjacent to the Project, the surface water systems is hydraulically disconnected from the groundwater system. In addition, groundwater in the Project area is brackish to saline, which contrasts markedly to the quality of local surface water (hydrogeologist.com.au, 2022).

Terrestrial GDE mapping (terrestrial regional ecosystems that are potentially dependent on groundwater) was conducted by METServe (2022) (**Figure 1-14**). No remnant vegetation outside the Project footprint is found within the zone of drawdown. Furthermore, any non-remnant vegetation within this zone is highly disturbed by existing mining operations. The groundwater quality is unlikely to be significantly altered by Vulcan South, and all local potentially groundwater-dependent ecosystems occur up-gradient of potential effects.



Legend

- MLA Boundary
- Maximum Disturbance Footprint

Groundwater Dependent Ecosystems

- High potential GDE
- Moderate potential GDE
- Low potential GDE

Predicted Drawdown (m)

- 1m
- 2m
- 5m
- 10m

Source: Hydrogeologist.com 2020, Vitrinte 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Maximum Drawdown of Groundwater Predicted

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-14

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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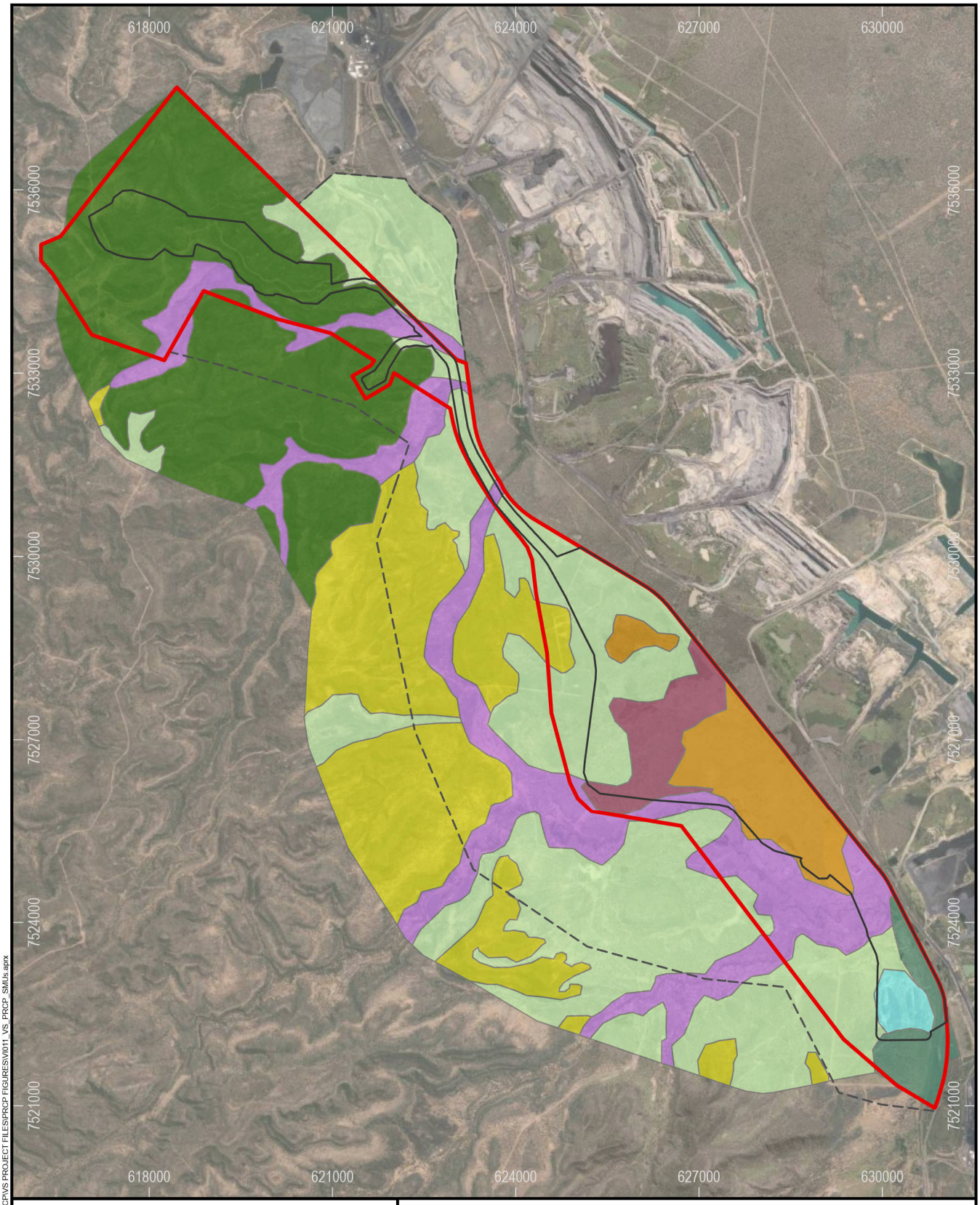
1.2.7 Soil

A Soil and Land Suitability Assessment of Vulcan South has been carried out by AARC (**Appendix C**). This is summarised below.

The *Report on Lands of The Isaac-Comet Area* (Story *et al.* 1967), mapped at a scale of 1:500,000, indicates the Project area contains the following land system units:

- Carborough Land System: The Carborough Land System is characterised by mountains and hills with broken and dissected local relief ranging between 30 m to 400 m. Structural benches and cliffs are common landforms with severe weathering occurring in some areas. This mountainous land system has formed shallow, coarse-textured, rocky soils. A small area of the Carborough Land System is also characterised by lower slopes and hills and alluvial flats with a local relief between 10 m to 60 m. Texture-contrast soils have formed in these areas and possess a thick sandy topsoil. Geology in this land system is comprised of partly weathered, quartz sandstone.
- Connors Land System: The Connors Land System is characterised by alluvial plains composed of terraces and levees up to 3 km wide. Texture-contrast soils have developed in this area, which are characterised by a thick sandy topsoil and neutral to strongly alkaline subsoil.
- Cotherstone Land System: The Cotherstone Land System is characterised by hills and prominent strike ridges as well as gentler undulating terrain associated with low indefinite strike ridges and colluvial foot slopes. The more prominent strike ridges possess a local relief varying between 10 m to 30 m and have developed shallow course-textured to rocky soils. The gentler undulating terrain has a local relief of less than 15 m and is associated with texture-contrast soils with a sandy upper-horizon. The geology in this land system is weathered Permian sandstone and shale.
- Monteagle Land System: The Monteagle Land System is predominantly characterised by low-lying plains and colluvial foot slopes with local relief generally below 6 m. This land system is associated with texture-contrast soils composed of a thick sandy topsoil and neutral to strongly alkaline subsoils. Geology in this land system is comprised of undissected Tertiary sandstones and clays.

Mapping at a scale of 1:85,000, based on soil surveys undertaken on site, identified eight soil management units (SMUs) within the Project MLA area (**Figure 1-15**). These are described in the following subsections.



Legend

- MLA Boundary
- Maximum Disturbance Footprint
- Survey Boundary

Soil Management Units

- Crocodile
- Fish
- Kei
- Komati
- Limpopo
- Orange
- Sabie
- Zambezi

Source: AARC Environmental Solutions 2019, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Soil Management Units of Vulcan South

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-15

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VS PROJECT FILES\PROP FIGURES\VI011_VS_PRCP_SMUs.aprx

Crocodile SMU

This unit contains shallow, rocky soils associated with hill slopes and plateaus. Soils are classed as arenic rudosols. Soil textures grade from surface loams to loamy sands with depth. Soils often contain rock material with little to no pedologic development throughout the solum. The Crocodile SMU belongs to the Carborough land System and the Back Creek Geological Group.

The Crocodile SMU is strongly acidic throughout the solum with only a minor increase in pH at depth. It has very low salinity. Soils in this SMU are non-sodic and not dispersive (Emerson Class 7 or 8). The topsoil is dominated by sand (52%) and gravel (30%), with 10% silt and 8% clay. This coarse texture limits the soil's water-holding capacity and extractable nutrient levels, with soils being deficient in phosphorus, nitrates, sulphates, copper and zinc.

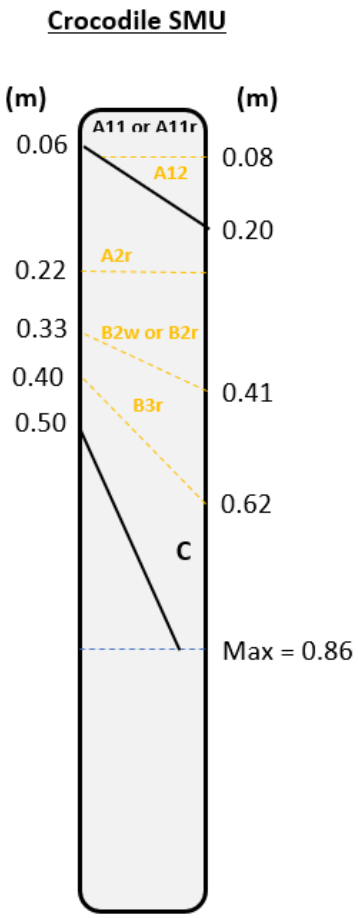
The Crocodile SMU typically has the following soil profile:

The **surface soil** (A11/A11r/A12) is a black to very dark greyish brown (10YR2/1, 10YR3/2) sand to sandy loam with loose to weak polyhedral structure with some profiles containing moderately strong to strong sub-angular rock material. The soil unit has a field pH of 4.5 - 5.5, demonstrating an abrupt to clear change to;

The **lower surface soil** (A2r) is not a common horizon observed for this SMU. It is a dark brown (10YR3/3) loamy sand with an abundance (comprising 50 - 90% of this horizon) of moderately strong coarse fragments approximately 2 - 6 cm in diameter. It has loose structure and a field pH of 5.5 to 5.0. Gradual change to;

The **subsoil** (B2w/B2r) is a dark greyish to reddish brown (10YR3/2, 2.5YR2.5/4) loamy sand to clay loam with weak to moderate polyhedral structure. It can contain rounded to angular course fragments which make up < 10% of the horizon. This horizon has a field pH of 4.5 to 5.5, with a gradual change to;

The **lower profile** (C) contains either consolidated or unconsolidated partly weathered rock material that appears to have originated from underlying sandstone and siltstone, with some profiles possessing an overlying transitionary horizon (B3r). Depending on the rock material present, this horizon can range from dark red to light yellow-brown colour.



Fish SMU

Occurring in flats on the south-eastern side of the study area, the Fish SMU is a grey kurosol. The Fish SMU belongs to the Cotherstone Land System and is part of the Back Creek Group. It is moderately permeable.

The Fish SMU is moderately to strongly acidic and increases in acidity with depth. Some pH values are below 5.5, which indicate a potential risk of aluminium toxicity. Salinity (EC) is observed to be very low throughout the profile, as are chloride values. Soil is generally nutrient-deficient. Below 10 cm, the SMU is sodic and at risk of dispersion.

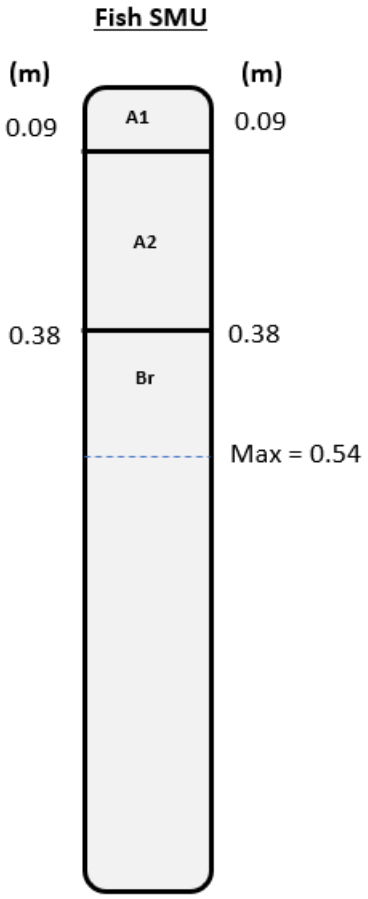
Fish SMU topsoil is dominated by sand (60%), with some silt (20%), clay (15) and gravel (2%). Organic matter content is moderate.

The Fish SMU typically has the following soil profile:

The **surface soil** (A1) is a dark-grey (10YR4/1), loamy sand with weak platy structure, and the deeper horizons exhibit diffuse red to orange mottling. It has a field pH of 5.5 to 6, demonstrating a clear change to;

The **lower surface soil** (A2) is a grey (10YR5/1) clayey loam sand. This horizon has a weak polyhedral structure and a field pH of 5.5. Abrupt change to;

The **subsoil** (Br) is a grey (10YR5/1), silty clay loam with moderate polyhedral structure. This horizon has minor, indistinct, red and orange mottling with diameters of <1.5 cm. This horizon has a field pH of 4.5 to 5.5.



Kei SMU

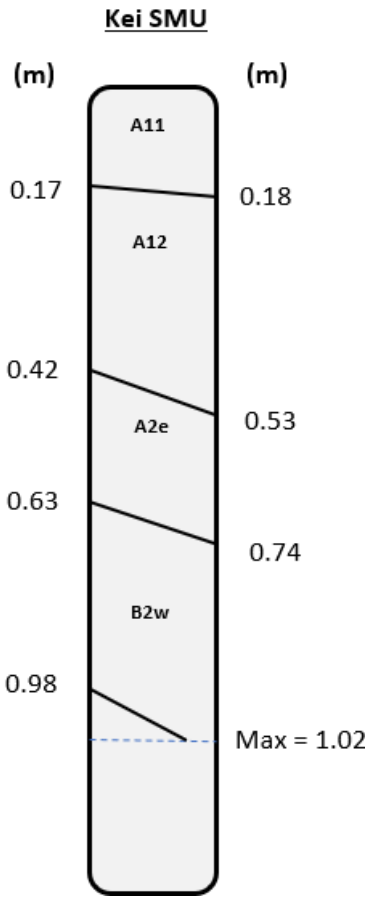
The Kei SMU is a brown chromosol occurring mostly in flats on the south-eastern side of the Project area. It belongs to the Cotherstone Land System and Back Creek Group. Its texture grades from clayey to loamy sands at the surface, to medium clay with depth. Orange to yellow mottling is observed in its deeper horizons.

The Kei SMU is moderately permeable. It is neutral to slightly acidic in its upper horizons and becomes neutral to slightly alkaline with depth. This alkalinity may be a limiting factor to plant growth at depth but not in the upper horizons. Salinity (EC) is very low to low (at depth), as is chloride. Dispersion is expected to be a low risk, as this SMU is non-sodic. The Kei SMU has low cation exchange capacity (CEC), reflecting infertility of the soil.

Particle size analysis shows that the topsoil of the Kei SMU is comprised of 62% sand, 25% silt, 12% clay and 1% gravel. Organic matter is 2.4% in the top 0-10 cm.

The Kei SMU typically has the following soil profile:

The **surface soil** (A11/A12) is a very dark greyish-brown to dark yellowish-brown (7.5YR3/2, 7.5YR3/4), clayey sand to sandy loam, with a loose to weak platy structure. It has a field pH of 6 to 7. This horizon gradually to diffusely changes to:



The **lower surface soil** (A2e) is a bleached brown (10YR4/4) loamy sand. This horizon has a loose structure and a field pH of 7-7.5. There is a clear to gradual change to:

The (B2w) is a dark greyish-brown (10YR4/2), silty clay loam to medium clay, with moderate-strength, polyhedral structure. This horizon has faint yellow and orange mottles with diameters of <1.5 cm. This horizon has a field pH of 7 to 7.5.

Komati SMU

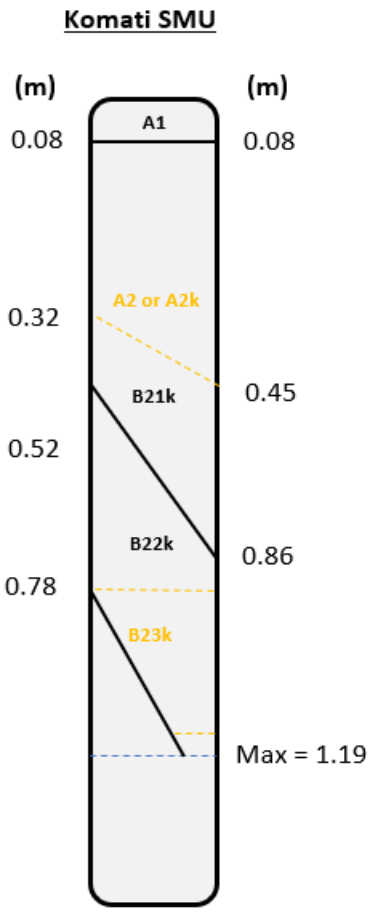
The Komati SMU is a brown vertosol belonging to the Monteagle Land System and is of Quaternary origin. It is a light to medium clay with calcareous segregations in deeper horizons. It is slowly permeable and is imperfectly to moderately well drained.

The Komati SMU is neutral at its surface but becomes strongly alkaline with depth, with pH values up to 9.5 in the subsoil. This higher pH may be a severely limiting factor in the availability of essential plant nutrients. EC values are low in upper horizons becoming high with depth. Likewise, chloride increases dramatically to the level of toxicity in the subsoil, potentially detrimentally interfering with plant osmosis.

Exchangeable sodium percentage increases with depth to highly sodic. However, the risk of dispersion is low due to the presence of calcium carbonate at depth.

The topsoil is observed to be comprised of 55% sand, 32 % clay, 11% silt, 2% gravel, and 2.7% organic matter. While non-sodic, the topsoil may be at risk of dispersion, indicated by an Emerson class number of 3 and a calcium/magnesium ratio of 1:2. Extractable nutrient content is poor in surface soil.

The Komati SMU typically has the following soil profile:



The **surface soil** (A1) is black to a very dark brown (7.5YR2.5/1, 7.5YR3/3), sandy clay loam to light medium clay, with a polyhedral structure of moderate strength. It has a field pH of 7 to 8.5. This horizon clearly and abruptly changes to:

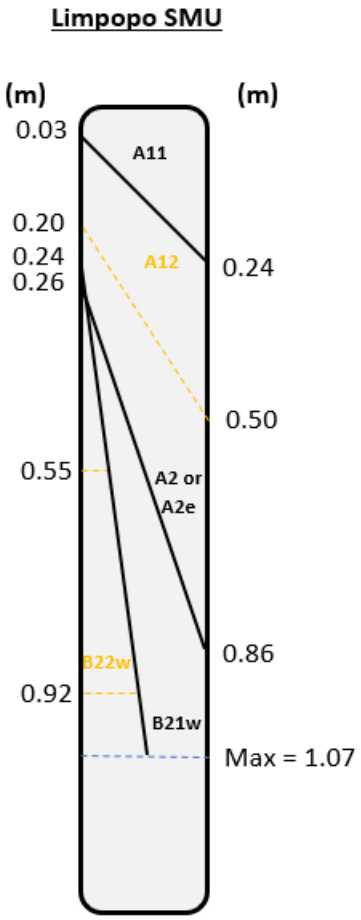
The **lower surface soil** (A2 or A2k), which was not observed in all profiles of this SMU, is a brown to very dark brown (7.5YR4/4, 10YR2/2), light medium to medium clay, with a moderately strong, polyhedral structure and a field pH of 8 to 8.5. Some profiles display a minor occurrence (<10%) of calcareous segregations. There is a clear to gradual change to:

The **subsoil** (B21k, B22k, B23k) is separated into several B2 horizons depending on colour. However, all contain an abundance of calcareous segregations (20-50% of the horizon). Colours range from strong browns (7.5YR4/6, 7.5YR5/6) to browns and light browns 7.5YR4/4, 7.5YR6/4). The texture is a medium clay, with moderate-strength, lenticular to polyhedral structure. This horizon has a field pH of 8.5 to 9.

Limpopo SMU

This is a brown, texture-contrast soil unit. Soils are classed as brown sodosols. Soil textures grade from sands to clay sands in the surface soils to light clays in deeper horizons. The Limpopo SMU belongs to the Monteagle land System and the Back Creek Geological Group.

The Limpopo SMU has a moderately acidic soil profile (pH 5.5-5.6). Salinity levels are very low. Sandy surface soils are non-sodic and not vulnerable to dispersion. However, clay subsoils (below 0.5 m) are sodic and susceptible to dispersion. The topsoil is dominated by sand (79%) with 8% silt and 10% clay. This texture may be at risk of slumping. Soils are deficient in phosphorus, nitrates, potassium, copper, zinc and boron.



The Limpopo SMU typically has the following soil profile:

The **surface soil** (A11, A12) is brown to a dark-brown (7.5YR4/4, 7.5YR3/3) sand to loamy sand with a loose structure. It has a field pH that ranges between 5 and 6, with a clear to gradual change to:

The **lower surface soil** (A2 or A2e) is a brown to greyish brown (7.5YR4/4, 10YR5/2), with some profiles within this soil unit displaying bleaching in this horizon (A2e). Predominant textures observed in this horizon range from sandy loams to sandy clay loams, with a loose to weak polyhedral structure and a field pH of 6. There is a clear to gradual change to:

The **subsoil** (B21w, B22w) includes dark yellowish-brown to a dark greyish-brown (10YR4/4, 10YR4/2) clayey or sandy loams and light clays with weak- to moderate-strength polyhedral structure. Mottling was often observed in this horizon, with colours ranging between red, orange and yellow. This horizon has a field pH of 5.5 to 7.

Orange SMU

The Orange SMU is comprised of dark, cracking clay, associated with the flat grassy plains in the middle of the Project area. It belongs to the Monteagle Land System and is of Quaternary origin. Soils predominantly range from light clays in surface soils to light medium clays in deeper horizons. The SMU is classified as a grey vertosol and is slowly permeable.

High pH values characterise the Orange SMU, ranging from 8.1 in the topsoil to 9.6 in the subsoil. These values may restrict plant nutrient availability. EC values increase from low in the topsoil to high in the subsoil. Below 0.2 m depth, the soil is prone to dispersion.

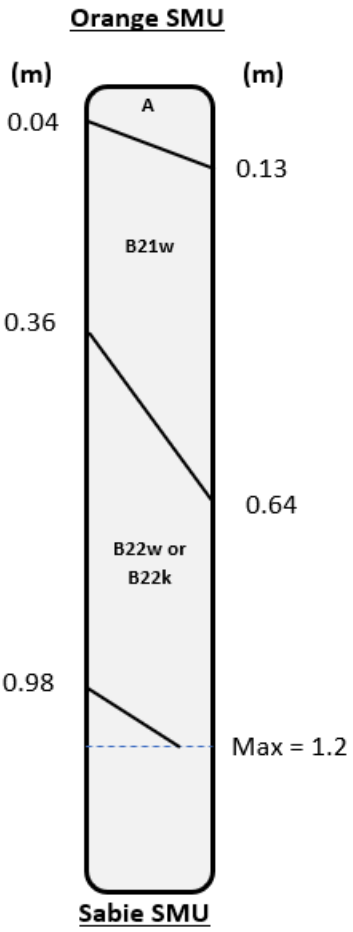
Topsoils comprise 51% sand, 28% clay, 19% silt, and 2% gravel, with 3.6% organic material. Topsoils are not considered at risk of dispersion and have good structural stability. Topsoils have limited nutrient availability. Manganese concentrations are so high as to the point of possible plant toxicity.

The Orange SMU typically has the following soil profile:

The **surface soil** (A) is black (10YR2/1, 2.5Y2.5/1), light clay, with moderate lenticular structure. It has a pH of 6 to 7. This horizon abruptly changes to:

The **upper subsoil** (B21w) is a black to a very dark grey (10YR2.5/1, 2.5Y3/1), light medium clay with strong lenticular structure and a field pH of 7.5 to 8.5. There is a clear to diffuse change to:

The **lower subsoil** (B22w/B22k) is a very dark grey (10YR3/1, 2.5Y3/1), light medium to medium clay, with strong lenticular structure. This horizon has a field pH of 8.5 to 9.



Sabie SMU

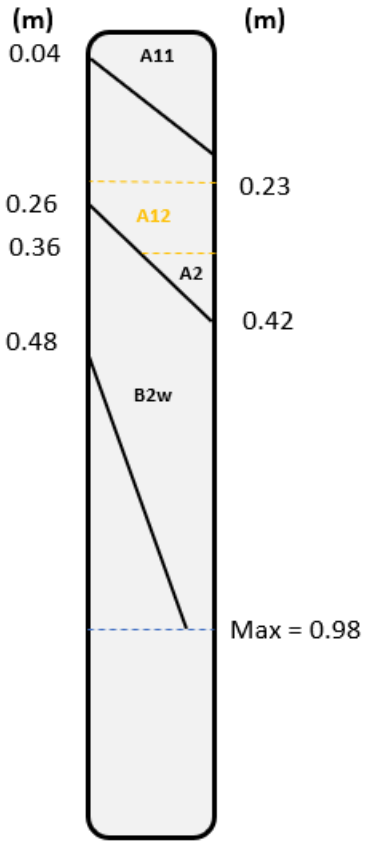
The Sabie SMU is a red sodosol comprised of dark, texture-contrast soils, consisting of sandy topsoil over a clay subsoil. It belongs to the Scarborough Land System and the Back Creek Group. Deep horizons contain red to orange mottles. Permeability is moderate.

Surface soils of the Sabie SMU are strongly acidic (pH <5) down to 0.3 m depth. This potentially restricts plant nutrient availability and increases the risk of aluminium toxicity. Below this, soils are less acidic and do not pose the same issues. EC of the SMU is low, as is chloride concentration. Subsoils can be strongly sodic, posing a high risk of dispersion.

The topsoil contains 75% sand, 12% clay, 10% silt and 3% gravel. It has a loose, single grain to weak platy structure, with high organic matter content (4.1%). Topsoils are not at risk of dispersion. Phosphorus is low in topsoils, but all other nutrients are present at suitable concentrations for plant growth. Iron concentrations are high and may pose a toxicity risk to plants.

The Sabie SMU typically has the following soil profile:

The **surface soil** (A11/A12) is black to very dark brown (2.5YR2.5/1, 7.5YR2.3/3), sand to loamy sand, with loose to very weak platy structure. It has a field pH of 5 to 7. This horizon clearly and abruptly changes to:

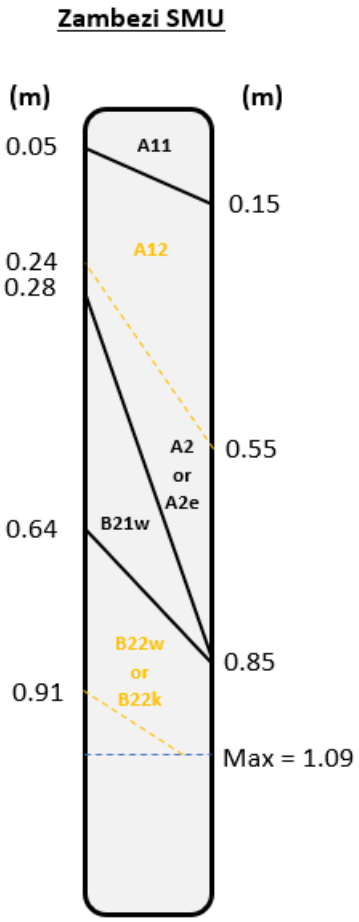


The **lower surface soil** (A2) is a brown to a dark reddish-brown (7.5YR4/4, 5YR3/3), clayey sand to sandy clay loam, with loose or very weak polyhedral structure, and a field pH of 5-6. There is a clear to gradual change to:

The **lower subsoil** (B2w) is a dark reddish-brown to dusky red (5YR3/3, 2.5Y3/2), clayey loam to medium clay, with moderate polyhedral structure. This horizon has a field pH of 5 to 6.

Zambezi SMU

This unit contains grey, texture-contrast soils, with a sandy surface and clay subsoil. Lower horizons display diffuse orange to yellow mottles. Soils are classed as grey sodosols. The Zambezi SMU belongs to the Cotherstone Land System and the TQa geological formation (late-Tertiary to Quaternary poorly consolidated alluvium).



The Zambezi SMU has a slightly acidic (pH 6.4 to 6.7) topsoil (to 0.3 m deep), which becomes progressively alkaline with depth (to pH 9 at >0.8 m depth). Salinity levels are low throughout the soil profile. The subsoil is strongly sodic and the risk of dispersion is high below 0.3 m depth (Emerson Class 2). The topsoil is dominated by sand (77%), with 14% silt, 9% clay and <1% gravel. It has a loose to weak platy structure, and low organic matter content (2%). Soils are deficient in nitrates, sulphates, phosphorus, copper and zinc.

The Zambezi SMU typically has the following soil profile:

The **surface soil** (A11/A12) is dark brown to very dark greyish-brown (7.5YR2.2.5/5, 10YR3/2), coarse-grained, loamy sand with loose to very weak platy structure. It has a field pH of 5.5 to 7. There is a clear and abrupt change to:

The **lower surface soil** (A2/A2e) is a brown to greyish-brown (7.5YR5/4, 10YR5/2), loamy sand, with some profiles displaying this as a bleached horizon with loose single-grained structure and a field pH of 6 to 7.5. There is a clear and abrupt change to:

The **lower subsoil** (B21w and B22w/B22k) is a light grey to grey (10YR7/2, 7.5YR6/1) clayey loam sand to silty clay loam with moderate polyhedral structure. This horizon has a field pH of 7 to 9.

1.2.8 Land Stability

The subsoil of most SMUs identified in the Vulcan South area (**Section 1.2.7**) exhibit some degree of dispersive behaviour, which has the potential to result in erosion when exposed through the clearing of vegetation, stripping or stockpiling of topsoil, and construction of infrastructure, unless management methods are implemented (AARC, 2022). Some of the soil units have a predisposition to stability issues in their baseline state, with gully erosion widespread along minor drainage lines where grazing intensity is highest.

1.2.9 Vegetation

A Terrestrial Ecological Assessment of Vulcan South has been carried out by METServe (**Appendix D**). The Project area contained a variety of remnant, regrowth and cleared vegetation types. The sandstone ranges in the highwall portion of Vulcan South (in the north-west) mostly support remnant vegetation dominated by *Corymbia citriodora, Corymbia aureola, Eucalyptus crebra, Corymbia trachyphloia, Eucalyptus melanophloia* and *Acacia shirleyi.* On the plains that comprise most of the Project area, sandy areas are dominated by woodlands of *Eucalyptus crebra, Eucalyptus melanophloia, Eucalyptus populnea* and/or *Corymbia clarksoniana.* Clay soils supported patches of *Acacia harpophylla, Casuarina cristata* and/or *Eucalyptus cambageana*, although most of this had been cleared for grazing. One patch of clay in the centre of the Project area supported open, grassy woodlands dominated by *Eucalyptus orgadophila.* Watercourses and major drainage lines supported a fringe of *Eucalyptus camaldulensis, Melaleuca leucadendra* and/or *Melaleuca fluviatilis.* Fourteen regional ecosystems occurred (as remnant and/or regrowth) in the Project area (**Table 1-3, Figure 1-16**).

Heavy grazing was a notable feature of plains within the Vulcan South area. This manifested through the altered composition of the understorey vegetation (Fensham *et al*. 1999; Walker *et al*. 2006). Native perennial grasses were scarce, while introduced pasture grasses (especially *Cenchrus ciliaris*, *Bothriochloa pertusa*, *Melinis repens* and *Urochloa mosambicensis*) dominated, along with native annual species (e.g., *Alloteropsis cimicina*, *Setaria surgens*, *Dactyloctenium radulans*, *Perotis rara*).

A total of 142.4 ha of the threatened ecological community listed as "Brigalow (*Acacia harpophylla* dominant and co-dominant)" were contained within the Project area. This was the only threatened ecological community present. This community included remnants and high-quality regrowth of the constituent regional ecosystems, 11.4.8 and 11.4.9.

Two other vegetation communities present on site possessed attributes similar to listed threatened ecological communities but did not meet the criteria for these listed communities. Of these, the "Poplar Box Grassy Woodland on Alluvial Plains" did not achieve a sufficient condition class to qualify as a threatened ecological community due to being dominated by weeds. A small patch of vine thicket near the highwall component of Vulcan South did not qualify as "Semi-evergreen Vine Thickets of the Brigalow Belt (North and South) and Nandewar Bioregions" as it was on an inappropriate sandstone geology.

A total of 429 species of vascular plants were recorded in or near the Project area. None of these are listed as threatened species. Of these, 56 species are non-native plants. The following weeds were most widespread, occurring at 30% or more of sampling sites:

- *Bothriochloa pertusa* (Indian Couch);
- *Sida spinosa* (Spiked Sida);
- *Cenchrus ciliaris* (Buffel Grass);
- *Melinis repens* (Natal Grass);
- *Portulaca pilosa* (Hairy Portulaca);
- *Stylosanthes scabra* (Shrubby Stylo); and
- *Urochloa mosambicensis* (Sabi Grass).

Seven species of weeds present within the survey area are category 3 restricted matters under the *Biosecurity Act 2014*, which prohibits their sale, trade or spread. These restricted weeds are:

- *Cryptostegia grandiflora* (Rubber Vine);
- *Harrisia martinii* (Harrisia Cactus);
- *Hymenachne amplexicaulis* (Olive Hymenachne);
- *Jatropha gossypiifolia* (Bellyache Bush);
- *Opuntia stricta* (Prickly Pear);

- *Opuntia tomentosa* (Velvet Pear); and
- *Parthenium hysterophorus* (Parthenium).

All of the above, except *H. martinii*, are also classed as Weeds of National Significance. While this classification does not introduce additional restrictions, it acts to coordinate management across states.

Table 1-3 Regional ecosystems present within the footprint of the Vulcan South prior to disturbance

Regional Ecosystem	BVG*	Short description	VM class†	Biodiv. Status‡	Hectares within project area	
					Remnant	Regrowth
11.3.2	17a	*Eucalyptus populnea* woodland on alluvial plains	OC	OC	55.4	63.9
11.3.7	9e	*Corymbia* spp. woodland on alluvial terraces	LC	OC	31.3	0
11.3.25	16a	*E. camaldulensis* forest fringing drainage lines.	LC	OC	71.9	2.0
11.3.27e	34d	Open water freshwater wetland with fringing trees	LC	OC	6.5	0
11.4.8	25a	*Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* on Cainozoic clay plains.	E	E	124.5	4.0
11.4.9	25a	*Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains.	E	E	13.9	0
11.5.3	17a	*Eucalyptus populnea* woodland on Cainozoic sand plains and/or remnant surfaces.	LC	NC	33.1	140.1
11.5.9	18b	*Eucalyptus crebra* and other *Eucalyptus* spp. and *Corymbia* spp. woodland on Cainozoic sand plains and/or remnant surfaces.	LC	NC	488.6	17.0
11.9.2	17b	*Eucalyptus orgadophila* woodland on fine-grained sedimentary rocks.	LC	NC	267.8	0
11.10.1	10a	*Corymbia citriodora* woodland on coarse-grained sedimentary rocks.	LC	NC	161	0
11.10.1x1	12a	*Corymbia aureola and Eucalyptus melanophloia open forest on scarps and sandstone tablelands.*	LC	NC	227.8	0
11.10.3	24a	*Acacia shirleyi* open forest on coarse-grained sedimentary rocks. Crests and scarps.	LC	NC	849.9	47.1
11.10.7	12a	*Eucalyptus crebra* woodland on coarse-grained sedimentary rocks.	LC	NC	181.9	10.3
11.10.8	7a	Semi-evergreen vine thicket in sheltered habitats on medium to coarse-grained sedimentary rocks.	OC	OC	1.3	0
Non-remnant	-	Cleared pasture, +/- scattered trees or young regrowth	-	-	1020.0	

*BVG = broad vegetation group

†VM class = classification under the *Vegetation Management Act 1999*: E = endangered, OC = of concern. LC = least concern.

‡Biodiversity status relates to environmentally sensitive areas under the *Environmental Protection Act 1994*: E = endangered, OC = of concern, NC = no concern at present.

618000 621000 624000 627000 630000

7539000 7536000 7533000 7530000 7527000 7524000 7521000

Legend

- Maximum Disturbance Footprint
- Survey Boundary
- MLA Boundary

Field-verified RE mapping

- 11.10.1
- 11.10.1x1
- 11.10.3
- 11.10.7
- 11.10.7/11.5.9
- 11.10.8
- 11.3.1
- 11.3.2
- 11.3.2/11.3.7
- 11.3.25
- 11.3.27c
- 11.3.27e
- 11.3.7
- 11.3.7/11.3.2
- 11.4.8
- 11.4.9
- 11.5.3
- 11.5.9
- 11.5.9/11.10.13
- 11.9.2
- HVR 11.10.13
- HVR 11.10.3
- HVR 11.10.7
- HVR 11.10.7/11.10.3
- HVR 11.3.2
- HVR 11.3.25
- HVR 11.4.8
- HVR 11.5.3
- HVR 11.5.3/11.3.2
- HVR 11.5.9

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Vulcan South

Field-verified Regional Ecosystem Map of Vulcan South

0 1 2

Kilometers

Scale: 1:60,000 (A3)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-16

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VS PROJECT FILES\PRCP FIGURES\VI010 - VS - PRCP FV REGIONAL ECOSYSTEMS.aprx

1.2.10 Threatened species

Field surveys of a 6,762-ha area surrounding and including the Project detected 41 species of mammal, 135 species of bird, 36 species of reptile, 14 species of frog and 429 species of vascular plants. Twenty-seven species of plants and animals listed as threatened species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) were flagged by database searches as being potentially present in the region. An additional two threatened species protected under the *Nature Conservation Act 1992* (NC Act), but not the EPBC Act. The following five of these threatened species have been recorded within the Project area:

- Koala (*Phascolarctos cinereus*) (endangered under the EPBC Act and NC Act);
- Squatter Pigeon *(Geophaps scripta scripta*) (vulnerable under the EPBC Act and NC Act);
- Central Greater Glider (*Petauroides armilatus/volans sensu lato*) (endangered under the EPBC Act and NC Act);
- White-throated Needletail (*Hirundapus caudacutus*) (vulnerable under the EPBC Act and NC Act); and
- Glossy Black-cockatoo (*Calyptorhynchus lathami*) (vulnerable under the NC Act).

Eleven additional threatened species are possible inhabitants or visitors to the Project area (**Table 1-4**).

Table 1-4 Threatened species of national and/or state environmental significance flagged by databases as being potentially present in the local region

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Bird	*Geophaps scripta scripta*	Squatter Pigeon	V	V	Open grassy woodland near water, with areas of bare ground, on land zones 3, 5 and 7.	C	C
Mammal	*Phascolarctos cinereus*	Koala	E	E	Vegetation communities containing food trees (*Eucalyptus* spp.), especially near watercourses.	C	C
Mammal	*Petauroides armillatus*§	Central Greater Glider	E	E	Tall, old-growth eucalypt forest with tree hollows.	C	C
Bird	*Hirundapus caudacutus*	White-throated Needletail	V	V	Airspace containing flying insects, above a diversity of landscapes	C	C
Bird	*Calyptorhynchus lathami*	Glossy Black-cockatoo	-	V	*Casuarina cristata* groves in Brigalow communities	C	C
Reptile	*Denisonia maculata*	Ornamental Snake	V	V	Gilgais on heavy clay soil, especially where *Acacia harpophylla* grows.	L	L
Reptile	*Egernia rugosa*	Yakka Skink	V	V	Potentially any vegetated habitat with fallen timber or rocks. There are no nearby records, but habitat is available locally.	P	P
Mammal	*Dasyurus hallucatus*	Northern Quoll	E	LC	Rugged escarpments in wetter forested areas.	P	P
Bird	*Rostratula australis*	Australian Painted-snipe	E	V	Freshwater wetlands with well-vegetated muddy edges.	P	P
Bird	*Erythrotriorchis radiatus*	Red Goshawk	V	E	Large tracts of undisturbed forest, especially near the ecotone between rainforests, melaleuca swamps and open eucalypt woodlands. Within the survey area, it is most likely in densely forested riparian habitats.	P	P
Grass	*Aristida annua*	Annual Wiregrass	V	V	Open eucalypt woodlands and pastures on basalt-derived clay. The survey area lies outside the known distribution of the species; the most northern record is 35 km south.	P	P
Mammal	*Macroderma gigas*	Ghost Bat	V	E	Primarily coastal ranges, where large cave systems occur near extensive forests. The nearest record is 85 km northeast.	P	P
Reptile	*Furina dunmalli*	Dunmall's Snake	V	V	Associated with *Acacia harpophylla* and eucalypt forests. The survey area is outside the known distribution of the species.	P	P
Reptile	*Lerista allanae*	Allan's Lerista	E	E	Inhabits root systems of grass tussocks growing on black clay soils.	P	P
Grass	*Dicanthium queenslandicum*	King Blue-grass	E	V	Grasslands or open woodland on clay soils, with low grazing pressure. Favourable soils within the survey area were subject to high grazing pressure.	P	P
Grass	*Dicanthium setosum*	Hairy Bluegrass	V	LC	Grasslands or open woodland on clay soils, with low grazing pressure.	P	P
Reptile	*Acanthophis antarcticus*	Common Death Adder	-	V	Forests with abundant litter, woody debris and rocks, especially in areas with few Cane Toads	P	P
Bird	*Calidris ferruginea*	Curlew Sandpiper	CE	E	Primarily coastal mudflats, but occasionally also uses the muddy margins of large freshwater wetlands.	U	U
Bird	*Grantiella picta*	Painted Honeyeater	V	V	Open woodlands, especially dominated by *Acacia harpophylla* or other *Acacia* species. They are dependent on an abundance of mistletoe, a resource that was scarce in the survey area.	U	U
Bird	*Neochmia ruficauda ruficauda*	Star Finch	E	E	Probably extinct in the Bowen Basin. Formerly inhabited grassy edges of rivers and wetlands.	U	U
Bird	*Poephila cincta cincta*	Southern Black-throated Finch	E	E	Grassy eucalypt forests, especially near water, where the understorey of native perennial grasses has not been compromised by grazing. No records within 100 km.	U	U

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Mammal	*Nyctophilus corbeni*	Corben's Long-eared Bat	V	V	Only known from three cave systems, all south of Bundaberg. The survey area lies well outside the known distribution of the species.	U	U
Mammal	*Pteropus poliocephalus*	Grey-headed Flying-fox	V	LC	Rainforests and wet eucalypt forests well south and east of the survey area. No records within 100 km.	U	U
Reptile	*Elseya albagula*	Southern Snapping Turtle	CE	E	Large permanent to semi-permanent river systems. The survey area lies outside the known distribution of the species, and suitable habitat is lacking.	U	U
Reptile	*Rheodytes leukops*	Fitzroy River Turtle	V	V	Inhabits deep pools with fallen timber in rivers with fast-flowing water. Suitable habitat is absent from the survey area.	U	U
Fish	*Maccullochella peelii*	Murray Cod	V	-	Clear, rocky streams, slow-flowing or turbid lowland rivers and billabongs. The survey area lies well outside the natural range of the species.	U	U
Cycad	*Cycas ophiolitica*	Marlborough Blue Cycad	E	E	Grows on steep slopes and hill tops in coastal areas over 100 km east of the survey area.	U	U
Tree	*Cadellia pentastylis*	Ooline	V	V	Edges of sandstone or basalt escarpments within *Acacia harpophylla*, vine-thicket, poplar box and bendee vegetation communities. The survey area lies outside the known distribution of the species. A very small amount of suitable habitat for the species exists on site, and this was thoroughly surveyed.	U	U
Tree	*Samadera bidwillii*	Quassia	V	V	Occurs in lowland rainforest 120 km east of the survey area.	U	U

*Status under the *Environment Protection and Biodiversity Conservation Act 1999*: CE = critically endangered, E = endangered, V = vulnerable, M = migratory.
†Status under the *Nature Conservation Act 1992*: E = endangered, V = vulnerable, LC = least concern, SL = special least concern.
‡Presence within survey area in which the project is contained: C = presence confirmed, L = likely to be present, P = possibly present, U = unlikely to be present.
§Listed under the EPBC Act as *Petauroides volans.*

Koala

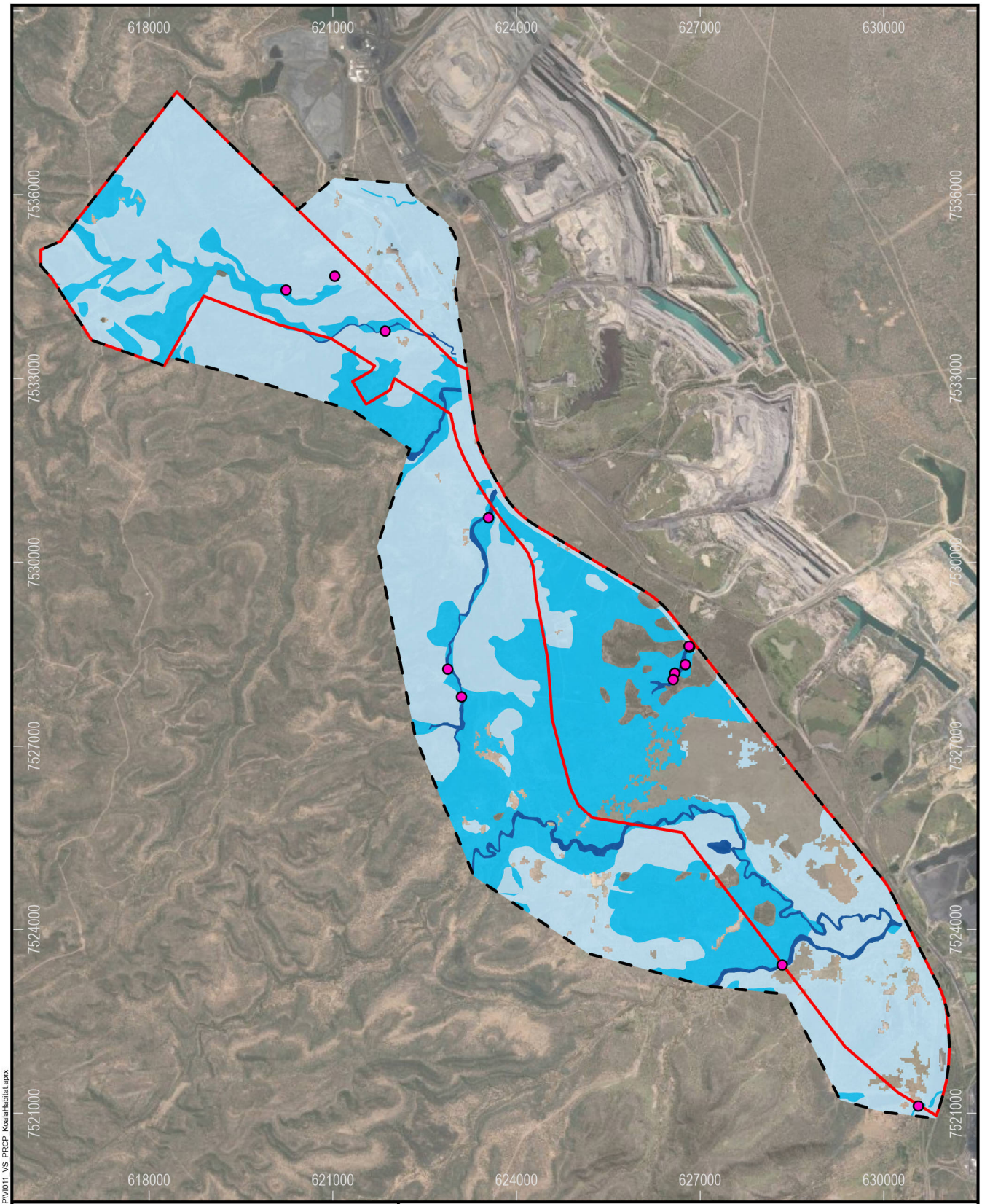
Koalas (*Phascolarctos cinereus*) within Queensland are listed as endangered under the EPBC Act and the NC Act. This species was recorded 14 times within the survey area, involving at least 12 individuals. It is highly likely that more individuals were present than were detected. The Threatened Species Scientific Committee (2012) suggests an average Koala density of 0.005 Koalas/ha across the Brigalow Belt. Assuming this same density across the survey area, 33 individuals are likely to occur within the survey area. This estimate has low reliability, given the lack of local data on population densities.

The Australian Koala Foundation (2015) maintains a database of the food trees known to be used by Koalas in each local government area of Australia. This database lists *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* as the primary food trees in the Isaac Regional Council area. Secondary food trees include *Eucalyptus brownii*, *Eucalyptus coolabah*, *Eucalyptus ochrophloia*, *Eucalyptus orgadophila* and *Eucalyptus populnea*. Of these species, *E. camaldulensis*, *E. orgadophila* and *E. populnea* are found within the survey area (**Table 1-5)**. *Eucalyptus crebra* can sometimes constitute an additional secondary food species in localised areas with better soil and nutrient availability, and is eaten by Koalas at nearby sites (Ellis *et al.* 2002; Melzer *et al.* 2014). The distribution of these habitats across the Project is shown in **Figure 1-17**. The Project area contained 78.4 ha of high-value habitat, 1,152.8 ha of moderate-value habitat and 1,937.8 ha of low-value habitat.

Table 1-5 Distribution of Koala food trees across vegetation units

Regional Ecosystem*	Area (ha)*	Primary Food Trees	Secondary Food Trees	Overall Value to Koalas†	N_{Koalas}/100ha‡
11.3.2	276.2	Absent	*E. populnea* dominant	Moderate	0
11.3.7	86.4	*E. camaldulensis* occasionally present	*E. populnea* and/or *E. crebra* sometimes subdominant	Moderate	0
11.3.25	153.0	*E. camaldulensis* dominant	*E. populnea* and/or *E. crebra* sometimes subdominant	High	7.19
11.3.27e	6.5	*E. camaldulensis* dominant	*E. populnea* and/or *E. crebra* sometimes subdominant	High	0
11.4.8	131.4	Absent	Absent	Nil	0
11.4.9	16.2	Absent	Absent	Nil	0
11.5.3	517.6	Absent	*E. populnea* dominant	Moderate	0
11.5.9	1,152.5	Absent	*E. crebra* sometimes dominant, but some variants of this RE lack secondary food trees.	Moderate	0
11.9.2	326.4	Absent	*E. orgadophila* dominant	Moderate	0
11.10.1	265.9	Absent	*E. crebra* usually subdominant	Moderate	0.38

11.10.1x1	412.3	Absent	*E. crebra* occasionally present in low densities	Low	0
11.10.3	1,642.1	Absent	*E. crebra* occasionally present as a scattered emergent	Low	0.06
11.10.7	341.6	Absent	*E. crebra* dominant	Moderate	0.29
11.10.8	1.3	Absent	Absent	Nil	0



Legend

- Koala Sighting
- Survey Area
- MLA Area

Koala Habitat

- High Quality
- Moderate Quality
- Low Quality

Source: Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2020-2022, Vitrinite 2022, Earthstar Geographics. Koala habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_KoalaHabitat.aprx

Vulcan South

Koala Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-17

VITRINITE BRIGHTER COAL

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Central Greater Glider

The Greater Glider (*Petauroides volans*) is listed as an endangered species under the EPBC Act and NC Act. Recent studies have suggested that this taxon comprises three genetically distinct species, with the Central Greater Glider (*P. armillatus*) being present in the survey area (McGregor *et al.* 2020). Its taxonomy under the EPBC Act and NC Act is yet to be revised in accordance with this recent study.

Greater Gliders feed on the young leaves of *Eucalyptus* and *Corymbia*, and inhabit tall forests with abundant large hollow branches, in which they shelter during the day. Local populations are largely restricted to riparian environments, where large, hollow trees are most abundant, and subsoil moisture allows food trees to grow fresh leaves over extended periods of the year.

A total of 20 individual Central Greater Gliders were recorded across the survey area (**Figure 1-18**). With the exception of a single record in regional ecosystem 11.10.1, all of these records were in riparian environments (regional ecosystems 11.3.25, 11.3.7, 11.3.27e and regrowth 11.3.25 with many retained large trees), despite these habitats comprising only a small percentage of the survey area. This is clear evidence for the importance of riparian habitats for local populations of the Central Greater Glider. The Vulcan South MLA area contained 328.2 ha of habitat for the Central Greater Glider.

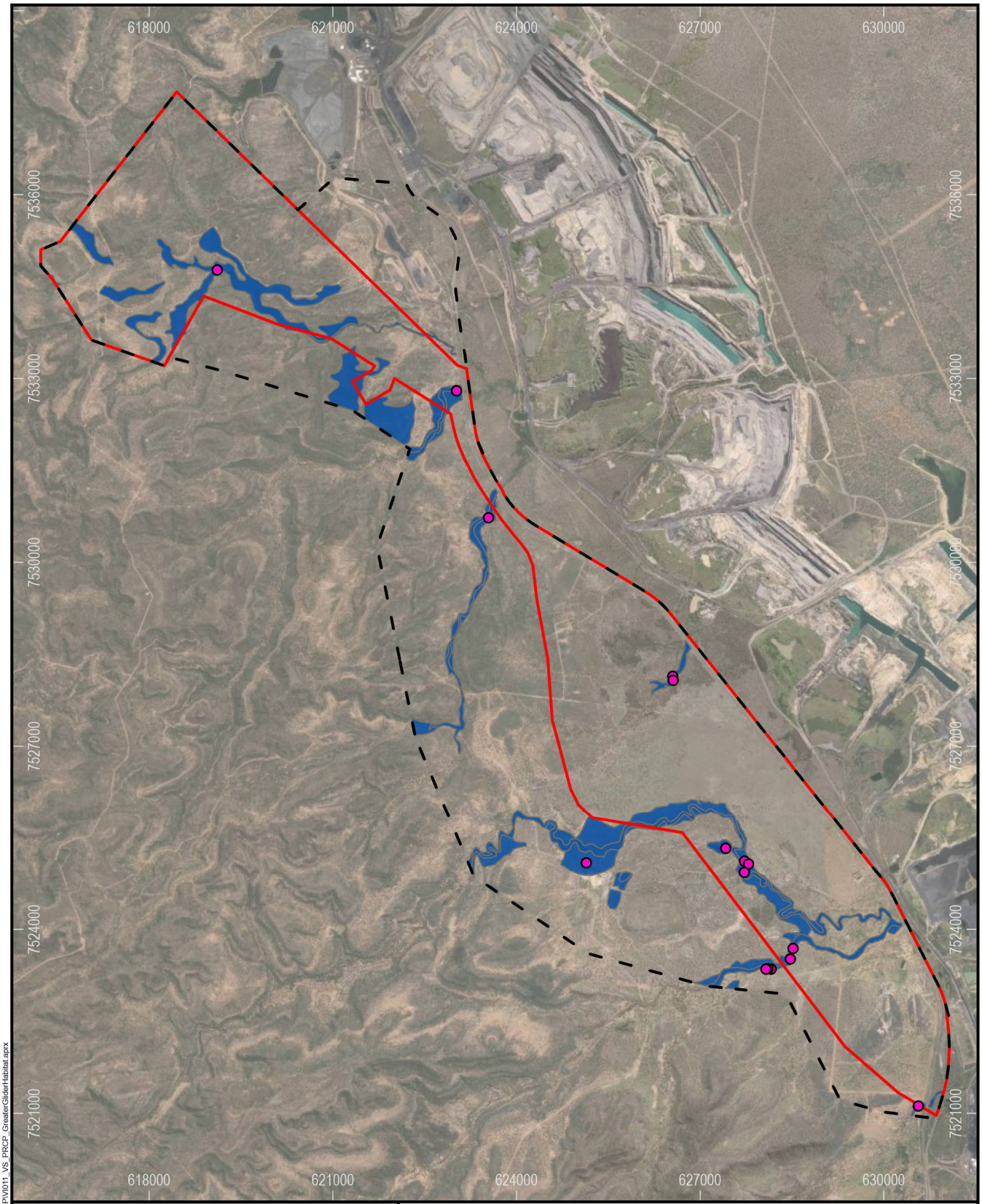
Squatter Pigeon

The southern subspecies of the Squatter Pigeon (*Geophaps scripta scripta*) is listed as vulnerable under the EPBC Act. This species was recorded on numerous occasions throughout the survey area (66 individual records at 28 locations).

Squatter Pigeons inhabit remnant and regrowth open woodland, or cleared areas with scattered trees and shrubs, on sandy or gravelly soils. Heavy clay soils with dense grass cover and rocky escarpments are largely avoided. Squatter Pigeons breed within 1 km of permanent water and forage within 3 km of water. They feed on the ground on fallen seed, and require a patchy ground cover of tussock grasses, litter and patches of bare ground for optimal foraging.

The distribution of Squatter Pigeon habitat across the area surrounding Vulcan South is shown in **Figure 1-19.** In total, 1,626.5 ha of foraging habitat (1,162.2 ha of which is also breeding habitat) and 1,989.5 ha of dispersal habitat was contained within Vulcan South's MLA area.

Post-mining land uses that are conducive to the long-term conservation of Squatter Pigeons on rehabilitated land (e.g., native habitats or cattle grazing) are preferred. Likewise, the species' ecological needs (e.g., density of tree cover, establishment of grasses) were considered during the development of completion criteria.



Legend

- Survey Area
- MLA Area
- Central Greater Glider Sighting
- Central Greater Glider Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_GreaterGliderHabitat.aprx

Vulcan South

Central Greater Glider Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-18

VITRINITE BRIGHTER COAL

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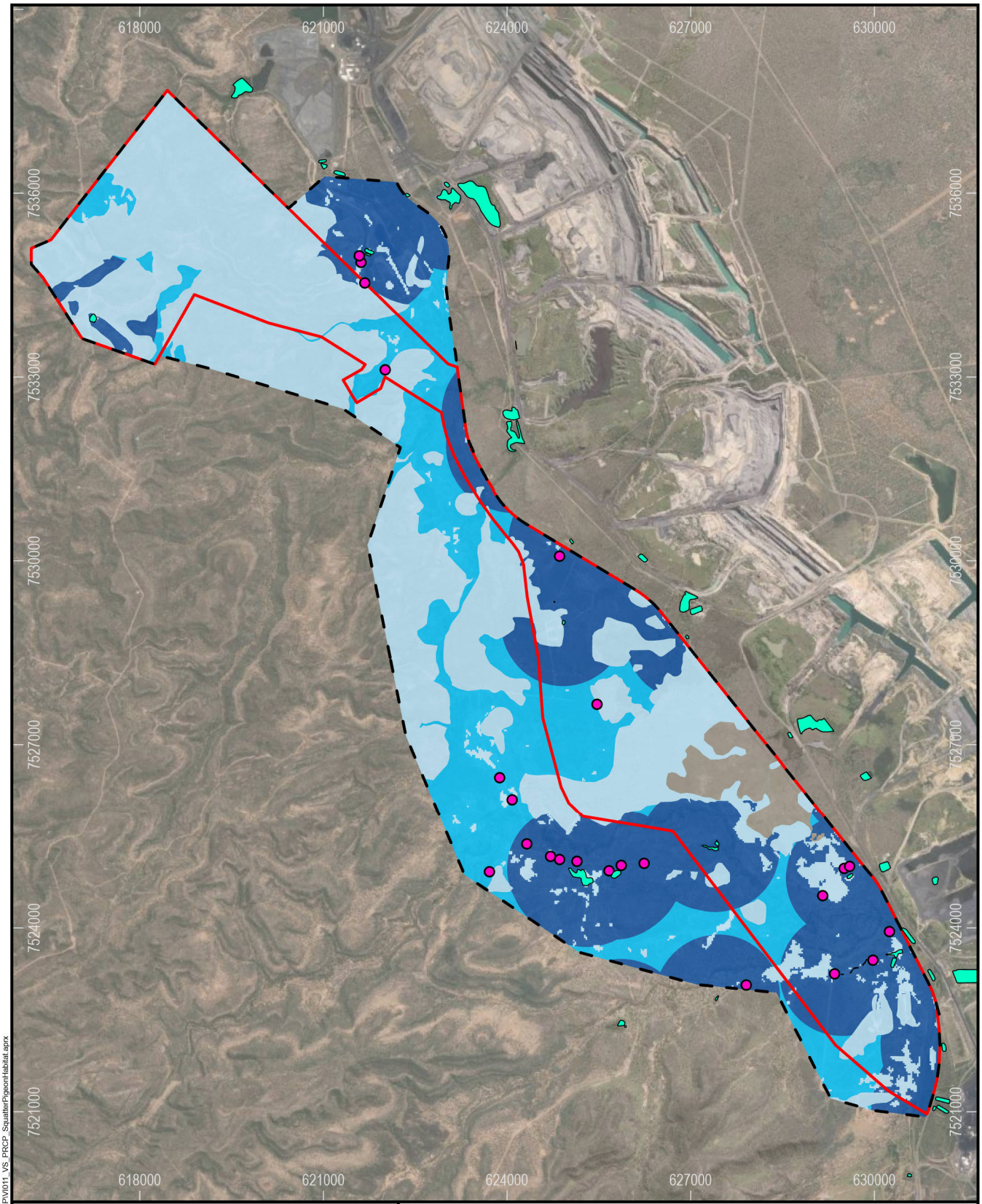

Legend

- Squatter Pigeon Sightings
- Survey Area
- MLA Area
- Waterbodies

Squatter Pigeon Habitat

- Breeding and foraging habitat
- Foraging habitat
- Dispersal habitat

Source: Geoscience Australia 2015, Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2019-2022, Earthstar Geographics. Squatter Pigeon habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Vulcan South

Squatter Pigeon Habitat

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-19

VITRINITE BRIGHTER COAL

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Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_SquatterPigeonHabitat.aprx

White-throated Needletail

White-throated Needletails are migratory birds protected under the China-Australia Migratory Bird Agreement, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. The species is also protected as a vulnerable species under the EPBC Act.

White-throated Needletails have been recorded flying over the adjacent Vulcan Coal Mine during storm activity. Vulcan South is likely to be west of their primary migration route, but flocks occasionally feed in the area when drawn west by low pressure systems. The survey area is of no particular importance to the White-throated Needletail on a local or regional scale, and the Project will not include any wind turbines, tall buildings, airports or other structures that threaten airspace used by the species for foraging and dispersal.

Ornamental Snake

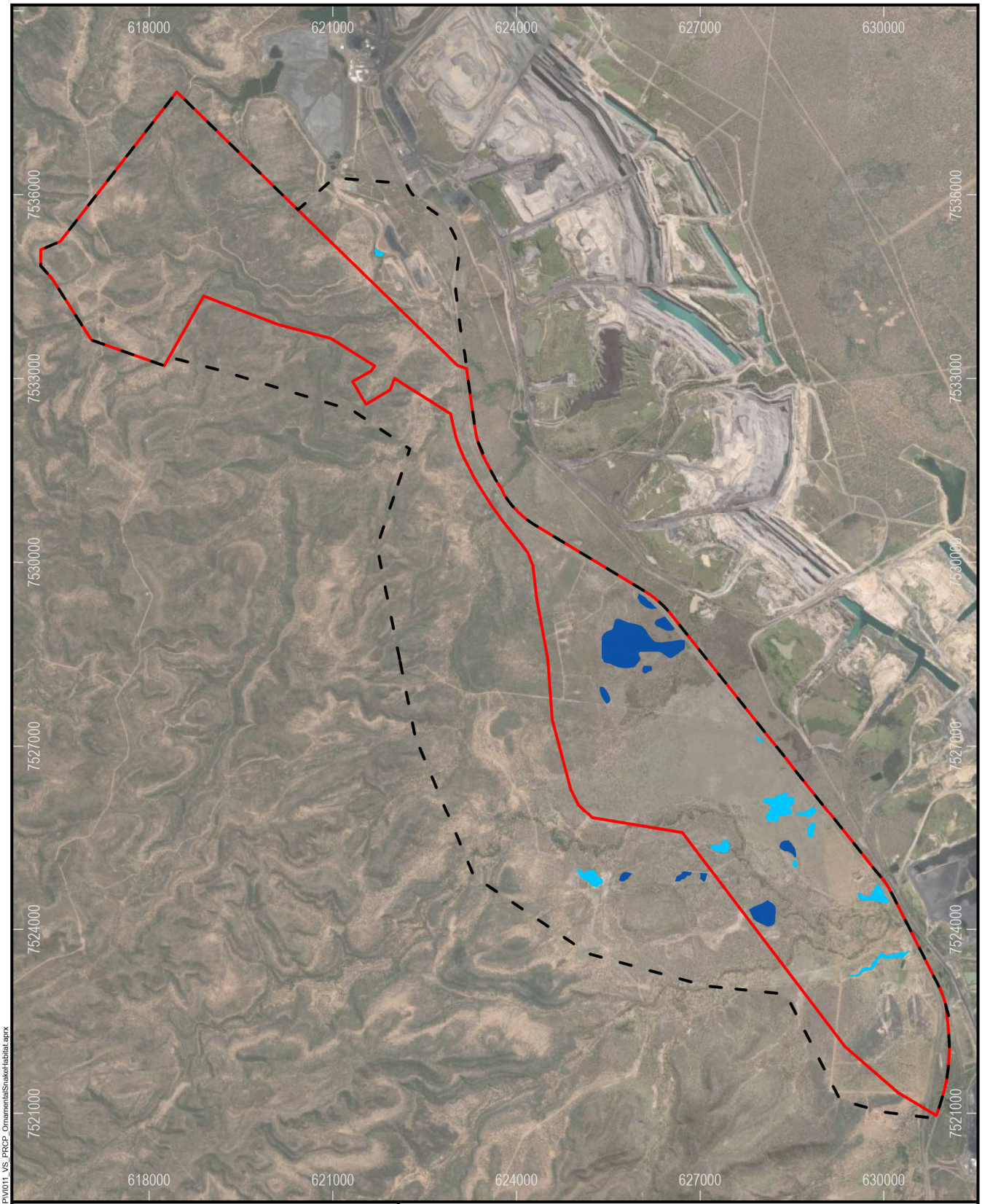
Ornamental Snakes feed on frogs and favour habitats supporting the temporary pooling of water where frogs breed. Ornamental Snakes primarily inhabit gilgai (melon-hole) mounds and depressions in deep-cracking clay plains, but also lake margins and wetlands. Locally, such habitats tend to support vegetation communities dominated by *Acacia harpophylla*. Areas with a diversity of gilgai sizes and depths provide optimal habitat. An abundance of fallen timber is also important for shelter. Cleared grasslands may also be utilised, provided that gilgais are present and some debris remains for shelter.

The Ornamental Snake occurs on the extensive clay plains at the Peak Downs Mine and Saraji Mine, immediately east of Vulcan South. Despite the proximity, favourable habitat was largely absent from the vicinity of Vulcan South. In the Project area, clay soils with *A. harpophylla* (**Figure 1-20**) contained few gilgais, and these were small, patchy and supported few frogs. Patches of *A. harpophylla* that contained gilgais, however small, and natural wetlands with aquatic vegetation were mapped as primary habitat. Dams with aquatic vegetation and cleared pasture with shallow gilgais were considered secondary habitat. No Ornamental Snakes have been located in the Project area, despite surveys coinciding with favourable weather conditions for detection. Failure to detect the species despite optimal survey conditions, combined with the poor quality of habitat present, suggests that the Project area is of marginal importance to the Ornamental Snake. For this reason, restoring habitat for the Ornamental Snake is not an objective of mine rehabilitation at Vulcan South

Australian Painted-snipe

Australian Painted-snipe are shorebirds with similar ecological requirements. This species inhabit the muddy edges of freshwater and brackish wetlands where there exists abundant low, dense vegetation for shelter. The Australian painted Snipe is a vulnerable species.

This species was recorded during ecological surveys, although it is highly mobile and behaves cryptically. This makes detection rare during surveys. Potential habitat for this species was recorded at natural and artificial (dams) wetlands in the southern third of the Project area (**Figure 1-21**).



Legend

- MLA Area
- Survey Area

Potential Ornamental Snake Habitat

- Primary
- Secondary

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_OrnamentalSnakeHabitat.aprx

Vulcan South

Ornamental Snake Potential Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-20

VITRINITE BRIGHTER COAL

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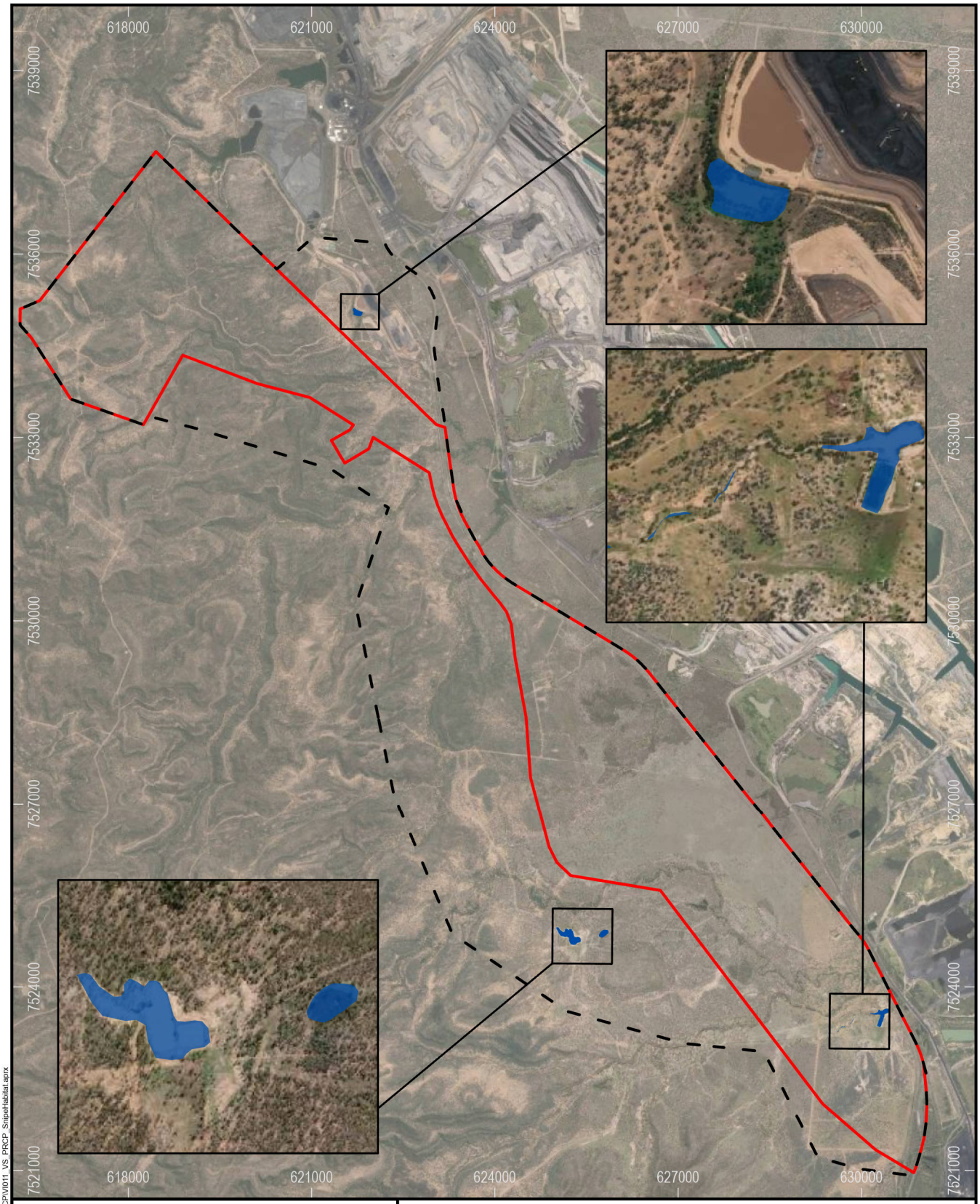

Legend

- Drainage Lines
- Survey Area
- MLA Area
- Potential Australian Painted-snipe Habitat

Source: Vitrinite 2022, METServe 2020-2022, Maxar, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_SnipeHabitat.aprx

Vulcan South

Potential Habitat for Australian Painted-snipe

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-21

VITRINITE BRIGHTER COAL

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Common Death Adder

The Common Death Adder is a snake that inhabits a broad range of habitats across eastern Australia. Its chief habitat requirement is abundant shelter in the form of leaf litter, woody debris and/or rocks. A low density of Cane Toads (*Rhinella marin*a) is important, as ingested toads cause lethal poisoning. Habitats well away from permanent water (where toads congregate and breed) are therefore likely to be most important for the species.

No Common Death Adders were recorded during ecological surveys. However, the species was recorded (in 2012) 25 km northeast of the Project, and it is possible that populations persist on site despite high densities of Cane Toads. Within the survey area, the sandstone ridges in the western half probably contain the most valuable habitat for the species (**Figure 1-22**). Such habitats have the highest density of shelter sites and lowest densities of toads. However, the quality of most of the existing habitat is still considered to be low. Overall, the low quality of most habitat, the small scale of disturbance to potentially important habitat corridors, and the fact that no Common Death Adders were detected despite extensive survey effort in optimal conditions, means that this species has not been considered in rehabilitation criteria (Terrestrial Ecology - **Appendix D**).

Glossy Black Cockatoo

The Glossy Black-cockatoo is listed as vulnerable under the NC Act. The Glossy Black-cockatoo was not recorded on site during ecology surveys and there were no recent records (from last 50 years) within 100 km of the survey area. Desktop reviews therefore did not flag it as a species that potentially occurred in the vicinity of the Project. Nevertheless, one pair was observed during weed monitoring undertaken within the Project area in March 2022 (**Figure 1-23**).

The cockatoo subspecies found in central Queensland (*C. L. erebus*) is known to feed primarily on *Casuarina cristata, Allocasuarina torulosa* and *Allocasuarina littoralis.* Of these food trees, only *C. cristata* (Belah) occurs within the survey area, where it grows within small patches of Brigalow. The pair of Glossy Black-cockatoos was observed feeding in one of these small groves of Belah. The site provides foraging habitat used occasionally by transient individuals, rather than a locally resident breeding population.

Red Goshawk

The Red Goshawk formerly had a wide distribution across northern and eastern Australia, occupying a variety of forested environments, but favouring the ecotone between dense forest and open woodland, especially near rivers and wetlands. In partly cleared parts of eastern Queensland it is associated with gorge and escarpment country. Within the last two decades, it has largely disappeared from the southern half of its former distribution.

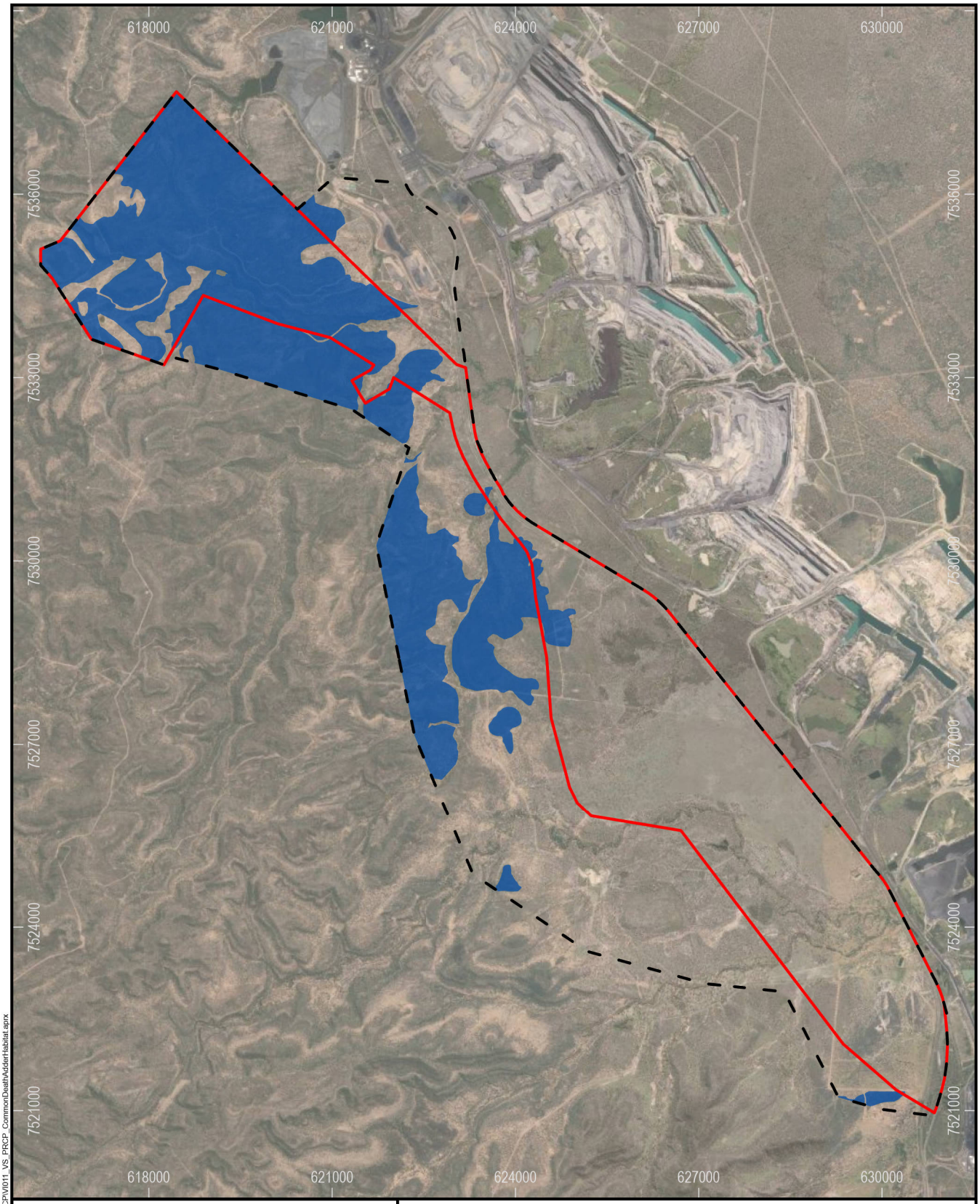
The survey area occurs within the historical distribution of the Red Goshawk. Potential habitat for the species occurs on site, although it is not of high quality; escarpments and nearby waterways mostly lack surface water, and the surrounding landscape is highly modified through mining and clearing for grazing. The Red Goshawk rarely breeds in areas with fragmented native vegetation, and never more than 1 km from water. While it is considered possible that dispersing Red Goshawks may occasionally use the survey area, the importance of the site to the species is considered to be low. Therefore, the needs of the species have not been considered specifically when designing the rehabilitation program and completion criteria at Vulcan South.

Yakka Skink

Yakka Skinks live in colonies in burrows beneath rocks, fallen timber and tree trunks. No Yakka Skinks were recorded during surveys on site. Detectability is greatest during warm, humid conditions, and surveys were under optimal conditions. Nevertheless, given the large size of the survey area, it was not practical to inspect every possible burrow location within it.

Despite numerous surveys undertaken across the northern Bowen Basin (Dysart-Moranbah-Collinsville) as part of various mining projects, Yakka Skinks have never been recorded there. The nearest record (a Queensland Museum specimen) of this species is from the vicinity of Blackwater, 130 km to the south.

Nevertheless, there are scattered records of Yakka Skinks as far north as Cape York, and there remains a slight possibility that the species occurs within the Project area. If the species is present, any remnant or regrowth habitat could be occupied. Given the low likelihood of occurrence, the ecological needs of the Yakka Skink have not been considered specifically when designing the rehabilitation program and completion criteria at Vulcan South. Nevertheless, by selecting post-mining land uses that support tree cover, potential habitat for the species is likely to be introduced to mined areas.



Legend

- Survey Area
- MLA Area
- Potential Common Death Adder Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Vulcan South

Potential Common Death Adder Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-22

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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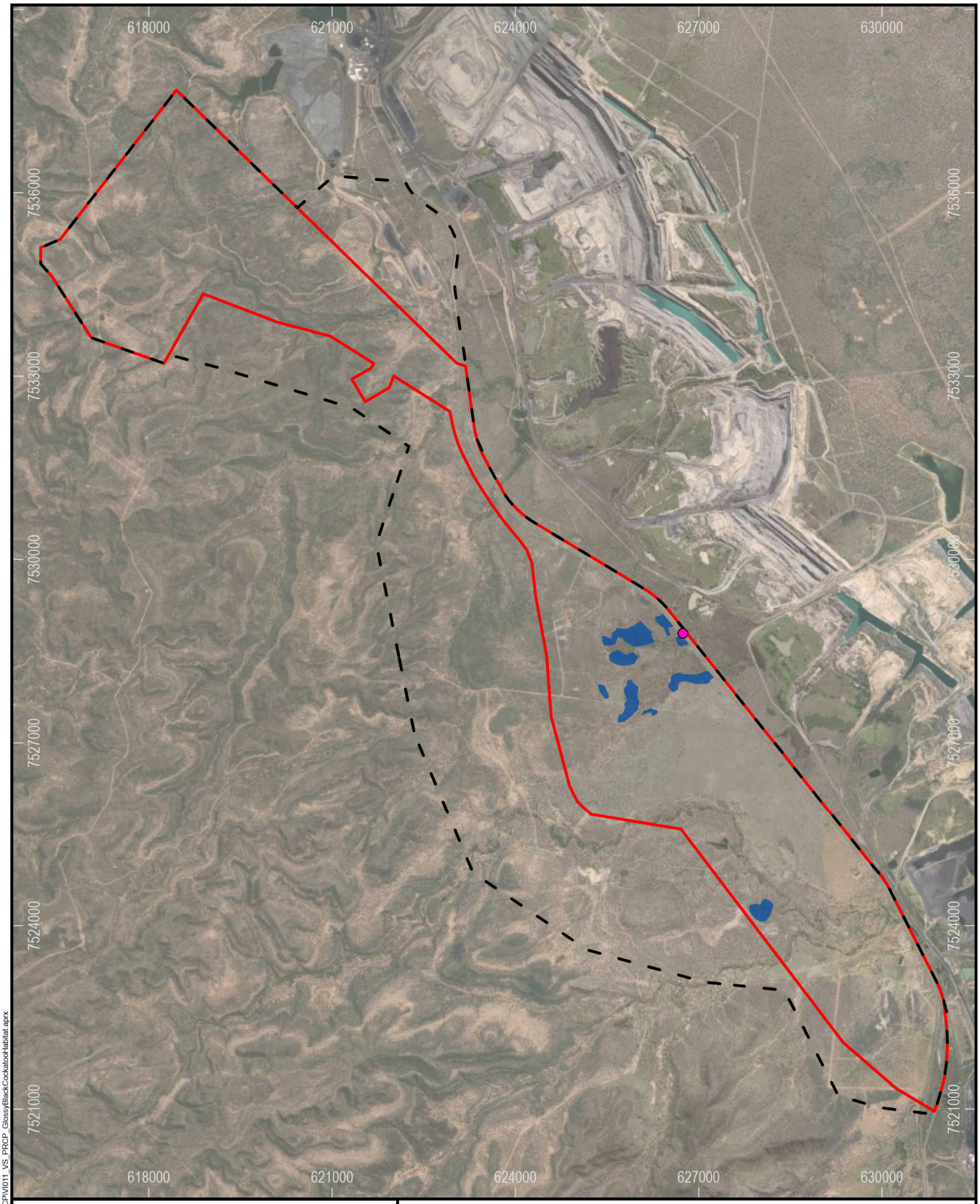


Legend

- Glossy Black-Cockatoo Sighting
- Survey Area
- MLA Area
- Glossy Black-Cockatoo Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_GlossyBlackCockatoohabitat.aprx

Vulcan South

Glossy Black-Cockatoo Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-23

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Annual Wiregrass

Annual Wiregrass inhabits black clay soils, primarily those derived from basalt. It usually grows in native grasslands or open, grassy woodlands dominated by *Eucalyptus orgadophila, Eucalyptus crebra* or *Eucalyptus melanophloia.* No Annual Wiregrass was recorded during flora surveys, despite these surveys coinciding with ideal seasons for detection. No basalt-derived soil occurs on site, but black clay soils derived from sedimentary rock are present in the central part of the Project area. These areas were heavily degraded by grazing and were dominated by the exotic pasture grass, *Bothriochloa pertusa.* No areas dominated by native grasses were observed on clay soil.

The survey area lies outside the known distribution of Annual Wiregrass; however, the nearest record is only 35 km southwest. Given that potential habitat for this threatened grass exists within the survey area, its occurrence on site is considered possible. However, based on the highly degraded nature of the habitat present, the survey area is likely to be of negligible importance to the species. The needs of the species were therefore not considered during rehabilitation planning.

Ghost Bat

Ghost Bats are large, carnivorous bats whose distribution is primarily limited by suitable roost sites. Ghost bats roost and breed in caves with a small entrance hole and a large chamber, where conditions remain warm and humid year-round. Roost sites are often 30-50 m deep within the cave, where conditions are most stable.

The survey area is well outside the known winter dispersal and foraging zones of the two known central Queensland populations of Ghost Bats. However, given that the existence of unknown breeding sites is possible, and the proliferation of mining across the Bowen Basin may have inadvertently created new roosting habitats (in disused mines), it is considered possible that the survey area may be used intermittently by Ghost Bats. This use would solely be in a foraging capacity, as none of the sandstone ridges on site supported caves of a size and structure suitable as a roost site. No Ghost Bats were recorded during surveys, and the needs of the species were not considered during rehabilitation planning.

Dunmall's Snake

The Dunmall's Snake is poorly known and rarely recorded. The species inhabits a variety of wooded habitats, ranging from *Acacia harpophylla* on cracking clay soil to *Eucalyptus citriodora*, *Eucalyptus crebra* and *Eucalyptus melanophloia* open forest on sandstone-derived soil.

Despite containing potential habitat for the species, the survey area lies outside the known/likely distribution of the Dunmall's Snake. It is, therefore, not considered "important habitat" for the species. Nevertheless, the survey area lies within the modelled "may occur" zone, and given the difficulty associated with detecting this highly cryptic species, its presence on site is considered possible. No Dunmall's Snakes were detected during surveys. The nearest record is from Clermont, 80 km southwest of the survey area. The needs of the species were not considered during rehabilitation planning.

Allan's Lerista

Allan's Lerista is a skink that is confined to black soil downs (undulating plains formed primarily on basalt) in the vicinity of Clermont. It burrows within the upper profile of heavy clay soil under tussocks of grass. It is typically recorded from *Eucalyptus orgadophila* and *Corymbia erythrophloia* open woodlands.

No Allan's Leristas were found during surveys. The nearest known population to the survey area is 30 km west. However, it is separated from the survey area by a 130-km long sandstone ridge, which likely constitutes an important barrier to dispersal. The species has never been recorded east of this ridge.

Suitable habitat for the species is defined as being regional ecosystems 11.8.5 and 11.8.11, both of which are lacking from the Project area. Nevertheless, regional ecosystem 11.9.2 (*E. orgadophila* open woodland on soil derived from fine-grained sedimentary rock) occurs on site, and closely resembles 11.8.5 in its floristics and soil attributes. Furthermore, models indicate that the species may occur within the survey area, despite the site being outside the modelled "known/likely to occur" zone.

Taken together, it remains possible that the Allan's Lerista occurs within the survey area, but based on current understanding the survey area does not contain important habitat for the species. For this reason, the species was not considered during rehabilitation planning.

King Blue-grass

King Blue-grass inhabits native grasslands and open woodlands on black cracking clay soil derived from basalt. The species also colonises pastures established following the clearance of *Acacia harpophylla* and other dense vegetation communities growing on heavy clay soil. King Blue-grass cannot tolerate continual heavy stocking regimes, and is outcompeted by exotic grass species and weeds, which tend to dominate heavily grazed pastures. For this reason, most extant populations are confined to road reserves and other sites semi-protected from grazing livestock.

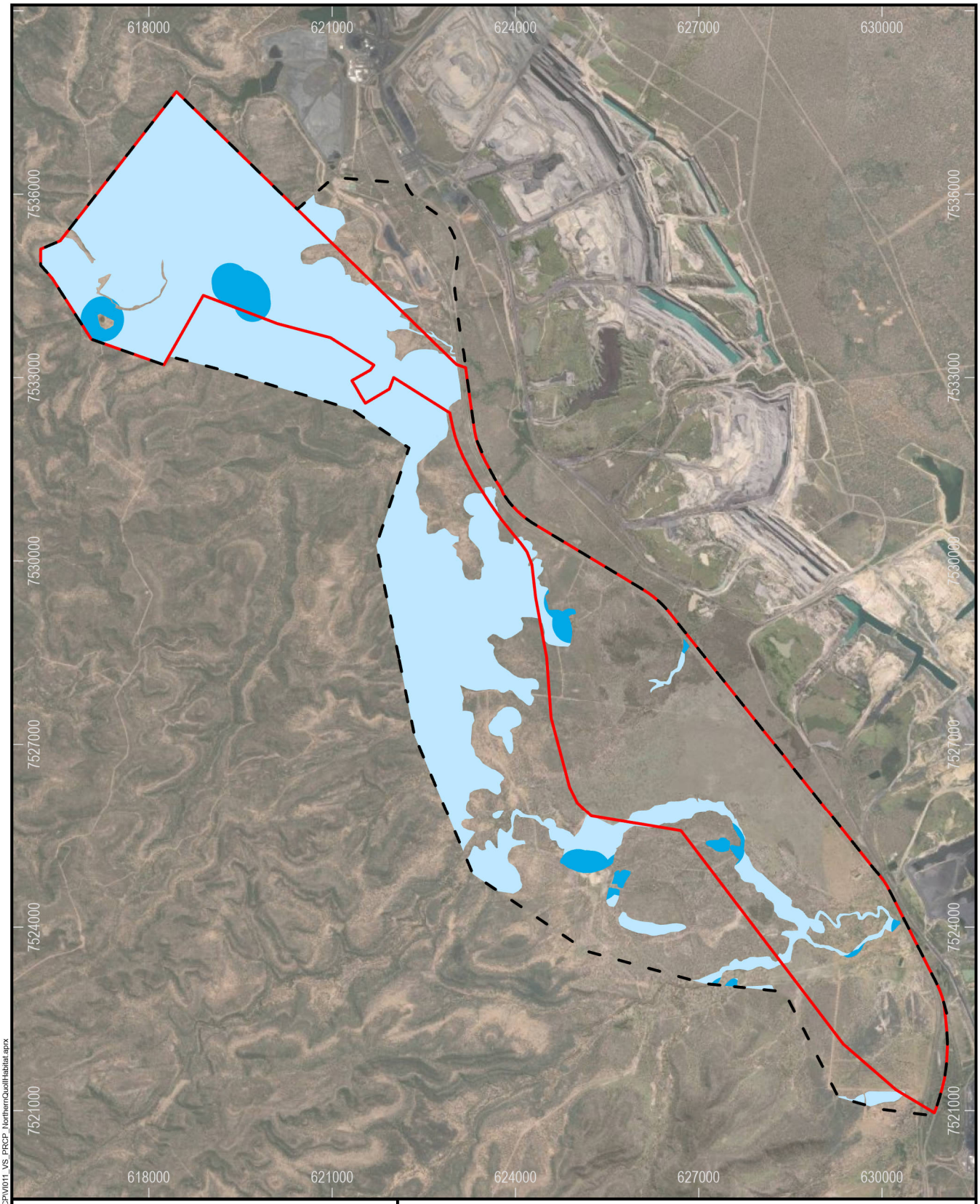
Heavy clay soils supporting grasses are represented within the survey area by remnant regional ecosystem 11.9.2 and cleared pastures that formerly supported regional ecosystem 11.4.9. Both habitats have been subjected to long periods of heavy grazing. This has led to the almost complete replacement of native perennial grasses with the exotic *Bothriochloa pertusa.* Road verges protected from grazing livestock were dominated by other weed grasses, such as *Cenchrus ciliaris, Megathyrsus maximus, Chloris* spp. and *Hyparrhenia rufa*. Nowhere within the survey area were clay soils observed to support a native grassland community.

The nearest recorded King Blue-grass is in the vicinity of Moranbah Airport, 30 km north of the survey area. While the species possibly once inhabited the survey area, its continued existence is unlikely considering current grazing regimes. The needs of the species were therefore not considered during rehabilitation planning.

Northern Quoll

Important habitat for the Northern Quoll is located in "rocky habitats, treed creek lines and structurally diverse forest with large trees, termite mounds and hollow logs" (Department of the Environment 2016), which is locally restricted to the Harrow Range and major watercourses (**Figure 1-24**)

It is unknown whether any of the potential habitat for Northern Quolls is occupied by the species. Extensive survey efforts, in optimal conditions, failed to detect one. There are also no records of the species west of the Clarke Range or Redcliffe Plateau in the past 40 years. It is therefore most likely that the Northern Quoll is absent from the vicinity of Vulcan South. In the unlikely event that the species does occur on site, the vicinity of the highwall mining trial, and other parts of the Harrow Range, contains sandstone outcrops and gorges that potentially harbour den sites for the species. Overall, it is considered unlikely that the Northern Quoll occurs at Vulcan South, and the species was not considered in rehabilitation planning.



Legend

- MLA Area
- Survey Area

Potential Northern Quoll Habitat

- Habitat Within 300m of Water
- Landzone 3 and 10

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Vulcan South

Potential Northern Quoll Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-24

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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1.2.11 Pre-mining land use

The land within the Project is zoned as Rural under the Isaac Regional Council Planning Scheme. It is currently primarily used for low-intensity cattle grazing.

Forty-two percent of the proposed Project footprint had been previously cleared of its natural vegetation; the remaining 58% comprises native remnant vegetation with an understorey that has been highly modified by grazing (see **Section 1.2.9**). The dominant land use adjacent to the Project (to the north and east) is coal mining.

The land has an agriculture land class of C2 (land suitable for grazing on native pastures on lower fertility soils) or C3 (land suitable for light grazing on native pastures in accessible areas, and includes steep land), in accordance with the *Guidelines for Agricultural Land Evaluation in Queensland* (DSITI and DNRM 2015).

The Project does not contain areas of regional interest (priority living areas, priority agricultural areas, strategic cropping land and strategic environmental areas) protected under the *Regional Planning Interests Act 2014.*

The project location also contains Saraji Road and an existing rail corridor to the east.

Based on the pre-mining land use and the results of the soil and land suitability assessment, it is anticipated that most rehabilitated landforms will be able to support a post-mining land use of cattle grazing (AARC, 2022).

For the purposes of this PRCP, the pre-mining land uses are:

- low-intensity cattle grazing
- low intensity cattle grazing with habitat for threatened fauna
- native ecosystems; and
- public road.

Land Suitability Ratings

An assessment of land suitability for cattle grazing was undertaken in accordance with the *Guidelines for Agriculture Land Evaluation in Queensland* (DSITI and DNRM 2015) and *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland - Land Suitability Assessment Techniques* (DME, 1995). This assessment considered water availability, nutrient deficiency, soil physical factors, salinity, rockiness, microrelief, pH, exchangeable sodium percentage, wetness, water erosion, flooding and vegetation regrowth. The results of this assessment are summarised for the Project area in **Table 1-6**, , **Figure 1-25** and **Figure 1-26**. Land suitability class by soil management unit (SMU) (**Section 1.2.7**) is presented in **Table 1-7** for rain-fed broadacre cropping and **Table 1-8** for grazing. None of the land assessed in the Project area, or the encompassing study area attained a land suitability score better than Class 3 for either of the considered land uses of rain-fed broadacre cropping or grazing.

Table 1-6 Pre-mining Land Suitability Classes (Vulcan South MLA)

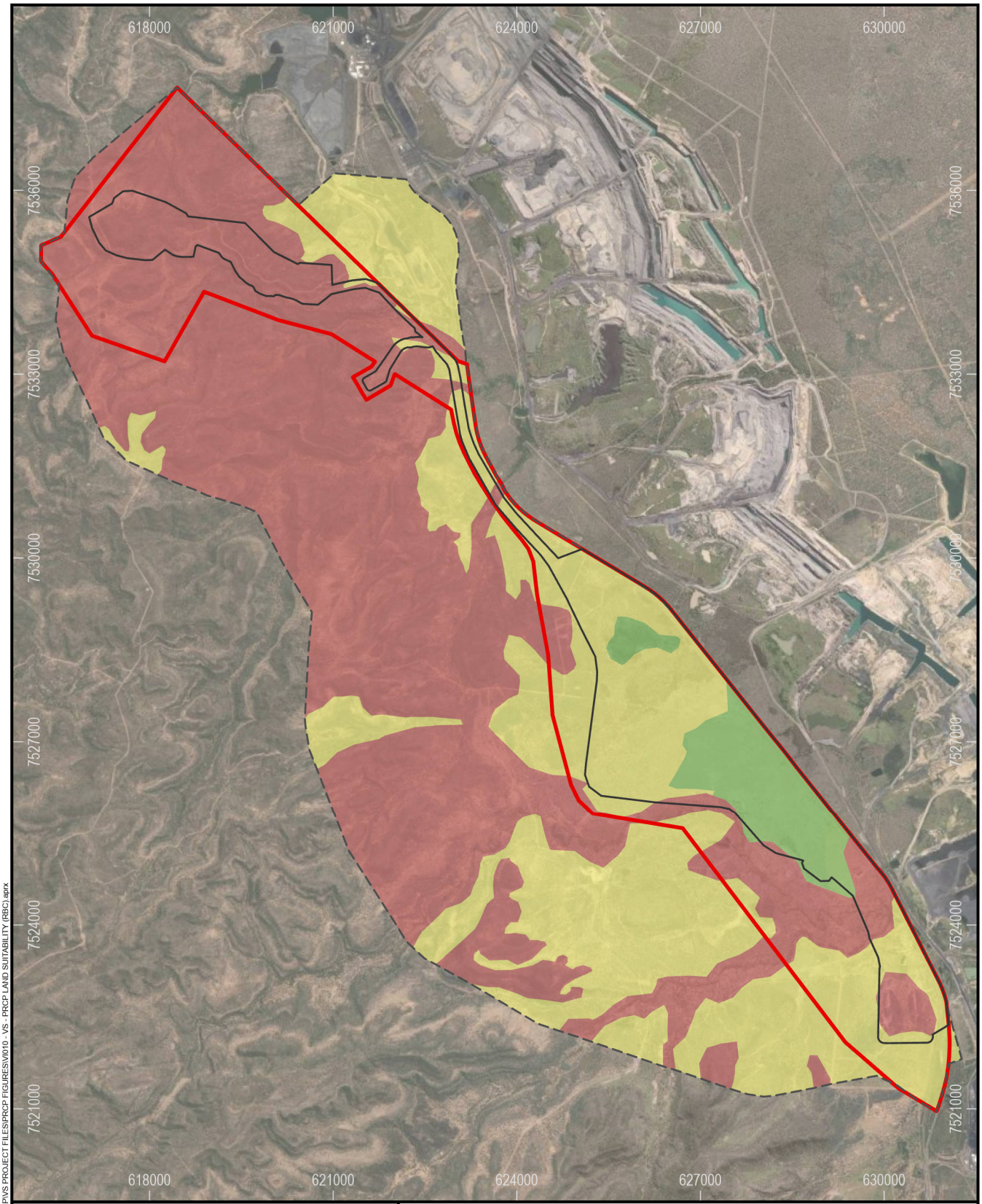
Land Use	**Class 1** Suitable land with negligible limitations	**Class 2** Suitable land with minor limitations	**Class 3** Suitable land with moderate limitations	**Class 4** Marginal land	**Class 5** Unsuitable land
Rain-fed Broadacre Cropping	0%	0%	5%	37%	58%
Grazing	0%	0%	7%	68%	25%

Table 1-7 Pre-mining Rain-fed Broadacre Cropping Landuse Suitability Classes by SMU

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	5	4	3	4	3	4	5
Nutrient deficiency	3	4	4	4	4	3	5	4
Soil physical factors	3	1	1	2	1	2	3	1
Soil workability	2	1	1	2	1	2	1	1
Salinity	1	1	1	3	1	3	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	2	1	2	1	1
Wetness	1	3	2	3	2	3	2	3
Topography	4	1	1	1	1	1	2	2
Water Erosion	5	2	2	1	2	1	2	2
Flooding	1	1	1	2	1	2	1	3
Overall Suitability Class	**5**	**5**	**4**	**4**	**4**	**3**	**5**	**5**

Table 1-8 Pre-mining Grazing Landuse Suitability Classes by SMU

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	4	3	2	3	3	3	4
Nutrient deficiency	4	4	4	3	4	4	4	4
Soil physical factors	1	1	1	2	1	1	3	1
Salinity	1	1	1	3	1	1	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	1	1	1	1	1
pH	2	2	2	2	2	2	3	2
ESP	1	2	1	1	1	1	1	1
Wetness	1	2	2	2	2	2	1	2
Water erosion	2	1	1	1	1	1	1	1
Flooding	1	1	1	2	1	1	1	2
Vegetation Regrowth	1	1	1	2	2	2	1	2
Overall Suitability Class	**5**	**4**	**4**	**3**	**4**	**4**	**4**	**4**



Legend

- MLA Boundary
- Maximum Disturbance Footprint
- Survey Boundary

Land Suitability (Rainfed Broadacre Cropping)

- Class 3
- Class 4
- Class 5

Source: AARC Environmental Solutions 2019, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VS PROJECT FILES\PRCP FIGURES\VI010 - VS - PRCP LAND SUITABILITY (RBC).aprx

Vulcan South

Land Suitability Classes for Rainfed Broadacre Cropping

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

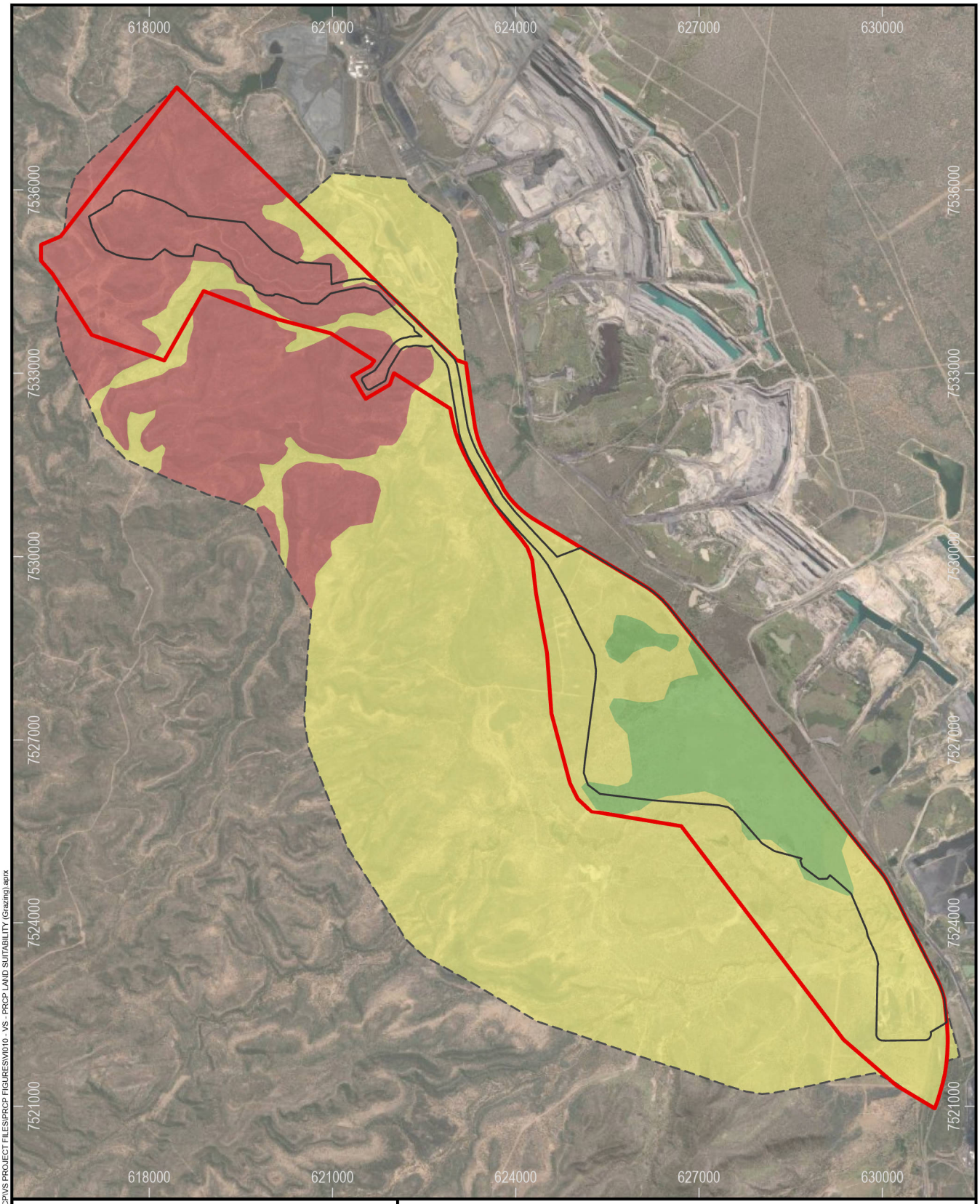
14/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-25

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd



Legend

- MLA Boundary
- Maximum Disturbance Footprint
- Survey Boundary

Land Suitability Class (Grazing)

- Class 3
- Class 4
- Class 5

Source: AARC Environmental Solutions 2019, Vitrinite 2022, METServe 2022, Earthstar Geographics.

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Vulcan South

Land Suitability Classes for Grazing

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

14/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-26

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

1.2.12 Land Holders

Land Holders

A list of the properties, tenure, usage and owners/managers within the proposed ML boundary are provided in **Table 1-9**.

Table 1-9 Land Tenure and Real Property Descriptions for Vulcan South

Lot/Plan	Tenure	Usage	Owner
2/SP296877	Lands Lease	Pastoral	O'Sullivan
59/SP235297	Lands Lease	Pastoral	O'Sullivan
72/SP137467	Reserve	Railway	Aurizon
Saraji Road	Road Licence	Road for public use	Isaac Regional Council
26/CNS125	Lands Lease	Norwich Park Branch Railway	Aurizon
2/CNS109	Lands Lease	Norwich Park Branch Railway	Aurizon
3/CNS109	Lands Lease	Saraji Mine Balloon Loop Railway	Aurizon

1.3 Relevant Activities

1.3.1 Environmentally Relevant Activities

An Environmental Authority (EA) application for the Project has been submitted primarily for Environmentally Relevant Activity (ERA) 13: Mining black coal (as per schedule 3, column 1 of the EP Regulation). Ancillary ERAs listed under schedule 2 of the EP Regulation will also be required. ERAs for the Project are listed in **Table 1-10**

Table 1-10 Environmentally Relevant Activities Requiring Approval

Activity	Environmentally Relevant Activity	Project Requirement
Mining black coal	ERA 13	The Project will extract up to 13.5 Mt of coal through an open cut operation
Crushing, milling, grinding or screening	ERA 33 Crushing, grinding, milling or screening more than 5,000 t of material in a year	The Project will crush and screen up to 1.95 Mtpa of ROM coal

1.3.2 Project Description

The Vulcan South hard coking coal target will be extracted via three separate open-cut pits, which form the primary mining focus of the Project. The Project will operate for approximately seven years, including primary rehabilitation works, following a two-year construction period and will extract approximately 13.5 Mt of Run of Mine (ROM) coal consisting predominately of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 Mtpa.

The Project will target the Alex and multiple Dysart Lower coal seams. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO) at a location between the northern and central pits. The CHPP will include solid bowl centrifuges to maximise water recycling and to produce a dry tailings waste product for permanent storage within waste rock dumps.

Ex-pit waste rock dumps will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. Ancillary infrastructure, including a ROM pad, offices, roads and surface water management infrastructure will be established to support the operation.

A realignment of the existing Saraji Road and services infrastructure to the eastern boundary of the proposed Mining Lease Application (MLA) area, adjacent to the existing rail easement, is also proposed in a number of locations. The re-alignment will occur within the MLA area.

In-pit dumping will fill the majority of the pits during operations, with the remaining voids to be backfilled upon cessation of mining, resulting in the establishment of waste rock dump landforms over the former pit areas. Following backfill of the final voids, the remaining material stored in the initial ex-pit waste rock dumps will be rehabilitated in-situ.

The Project includes a small-scale highwall mining trial program in the north of the MLA area. The trial will involve the establishment of four highwall mining benches across a number of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner. The highwall mining trial will target up to 750 kt of coal which will be transported by truck to the CHPP via a dedicated haul road within the MLA area. The trial is scheduled to be completed within the first year of mining operations.

The Project is a small-scale mining operation, with coal extraction planned for approximately seven years, followed by completion of primary rehabilitation activities in year nine. Construction of infrastructure associated with the mining operation, including the CHPP and the rail loop, is expected to be completed within two years. Construction of the realigned Saraji Road sections will be completed progressively as the pits advance towards the location of the existing road. Ongoing establishment of internal road networks, surface water management infrastructure and other ancillary infrastructure will continue to be developed as the pits and in-pit dumps advance. The Project site layout plan is displayed in **Figure 1-27**.

Open Cut Mining Activities

The three open cut pits will extend to a depth of approximately 60 m, following the seams as they dip eastwards. The footprints of the proposed open cut pits are provided in **Table 1-11**. Truck-and-shovel mining methods will be employed to extract waste rock and coal.

Table 1-11 Open cut pit characteristics

Open Cut Pit Name	Approximate Footprint (ha)	Mining Direction	Target Seams
Vulcan North	66	North to south	Alex and multiple Dysart Lower
Vulcan Main	334	North to south	Alex and multiple Dysart Lower
Vulcan South	77	North to south	Alex and multiple Dysart Lower

Blasting

Blasting is expected to be required to access resources below unweathered rock. Approximately 24 blasts per year are expected. Blasts would be planned and scheduled to manage potential impacts on Saraji Road and nearby infrastructure and landholders.

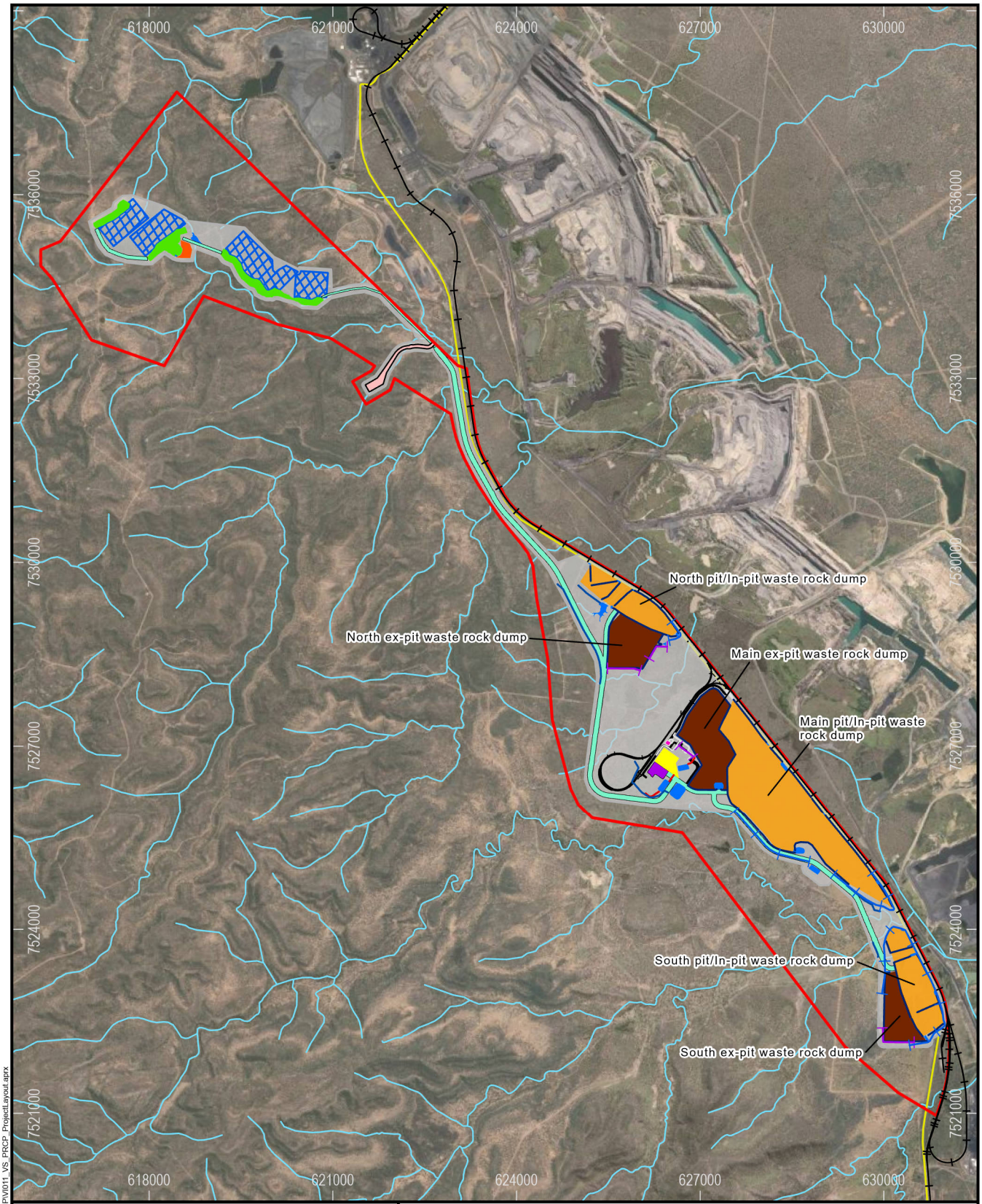
Waste rock removal and placement

Waste rock extracted during the early stages of each open pit will be placed in ex-pit dumps to the west of the open pits. Following this initial ex-pit placement and once sufficient pit space has developed, in-pit placement of waste rock will commence. This will continue for the life of each pit as it is developed. The in-pit dumps will have batters shaped up to a maximum slope of 15%. A central plateau will drain to the west to minimise the requirement for significant drainage infrastructure along the eastern toe of the dump (where space is limited, due to the presence of the existing road and rail).

An assessment of waste rock geochemistry has concluded that the waste rock does not pose a significant risk of generating saline or metalliferous drainage. Therefore, no selective handling and treatment measures are proposed. Furthermore, low-permeability capping over the dump surface is considered not to be required to create a geologically stable post-mining landform.

Coal extraction

Once waste rock has been removed to expose the coal seam, coal will be extracted via truck and shovel. The coal will be hauled to the CHPP. Crushing and screening will be completed as part of the CHPP raw coal handling circuit.



Legend

- Drainage Lines
- Railway
- Road
- Mine Access Road
- Rail Loop and Mine Roads
- Flood Levee
- Diversion Bund
- Diversion Drain
- Mine Water Drain
- Surface Water Drain
- Vulcan South Maximum Disturbance
- MLA Area
- CHPP
- Magazine
- MIA
- Dam
- Office
- Haul Road
- Ex-pit Waste Rock Dump
- Open Pit/In-pit Waste Rock Dump
- Highwall Mining Bench
- Highwall Rock Dump
- Highwall Plunge

Source: State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, WRM 2022, METServe 2022, Earthstar Geographics.

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Vulcan South

Site Layout

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

14/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 1-27

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Pit Geometry

The geometry of the northern, central and southern open-pit highwalls has been designed to produce stable slopes while considering the underlying geology (Blackrock Mining Solutions Pty Ltd 2019). Indicative cross-sections of the proposed pit highwalls in each of the resource areas of the Project are shown in **Figure 1-28** to **Figure 1-29,** as derived from Blackrock mining geotechnical wider pre-feasibility study which included the now separate Vulcan South project area.

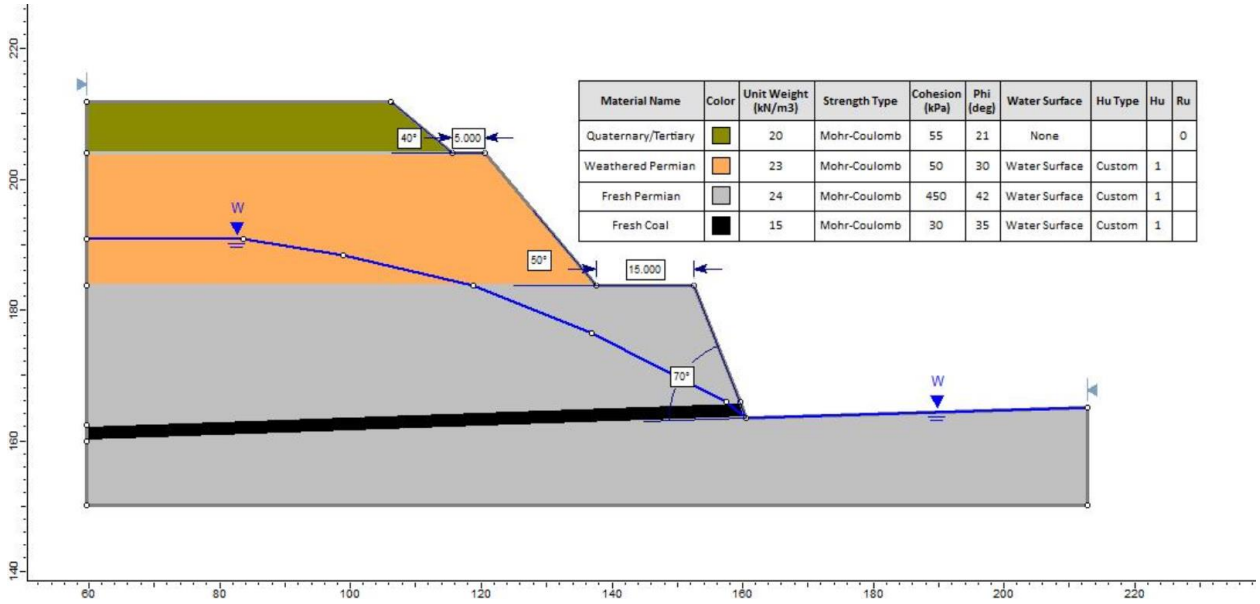


Figure 1-28 Geotechnical design of the Vulcan Central highwall (average thickness of Tertiary) (Blackrock Mining Solutions Pty Ltd 2019)

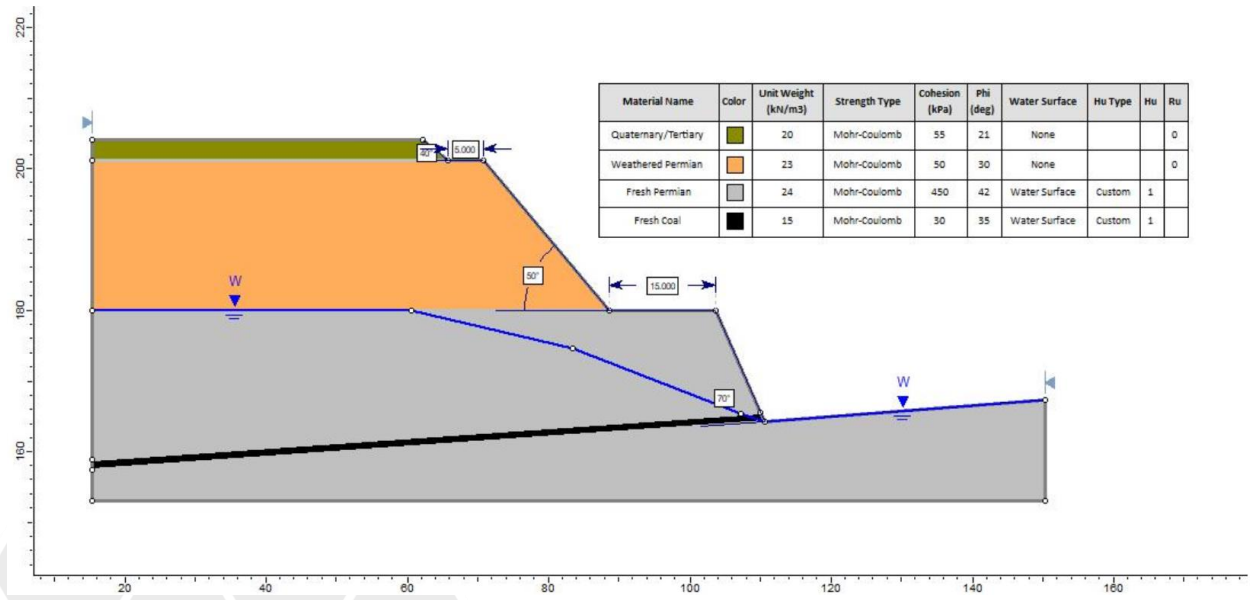


Figure 1-29 Geotechnical design of the Vulcan North/South highwalls (Blackrock Mining Solutions Pty Ltd 2019)

In-pit dumps

The most commonly used geotechnical classification of coal mine waste within the Bowen Basin is the BMA classification (Simmons and McManus 2004), as shown in **Figure 1-30**.

Most of the spoil to be generated for the Project comprises category 2. Taking into account the stability of this material, in-pit dumping will take place using benches with faces that have slopes as described in **Figure 1-31**.

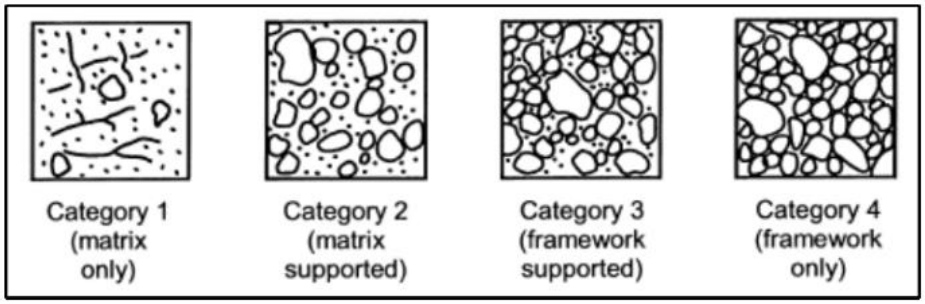


Figure 1-30 Spoil classification scheme (Simmons and McManus 2004)

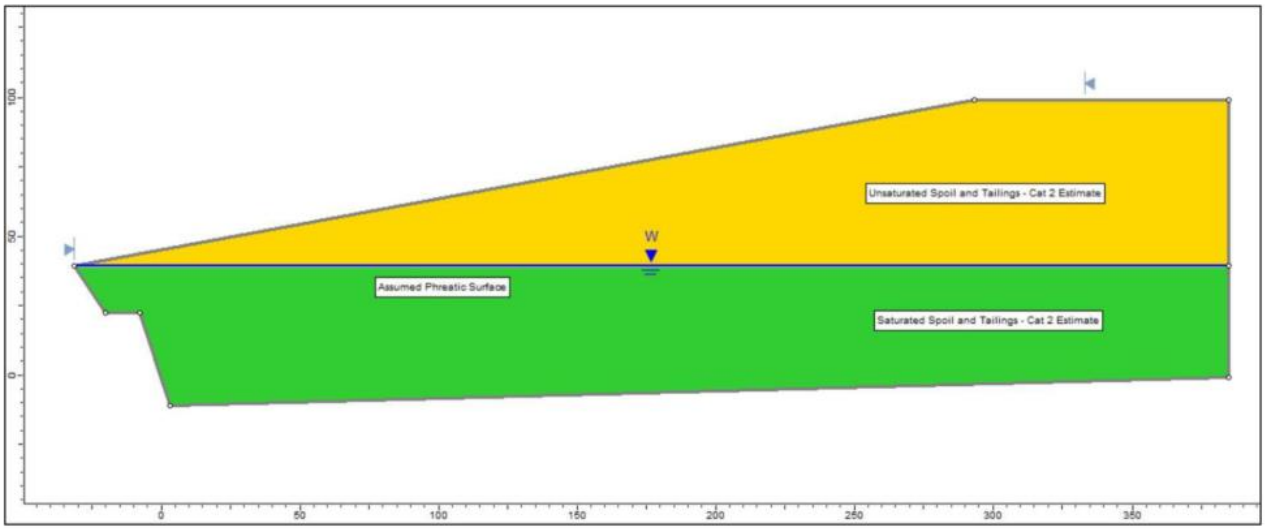


Figure 1-31 Geotechnical design of the in-pit spoil dumps of Vulcan South (Blackrock Mining Solutions Pty Ltd 2022)

Highwall Mining Trial

The Project includes a small-scale highwall mining trial program in the north of the MLA area. The trial will involve the establishment of four highwall mining benches across a series of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner. The highwall mining trial will target up to 750 kt of coal within the first year of mining operations. Mined coal will be loaded by front-end-loader and transported by truck to the Project CHPP via a dedicated haul road within the MLA. Whilst common in other coal mining regions, the trial will test the proposed highwall mining equipment in local conditions to assist Vitrinite's decision-making on the methodology's suitability for other assets held within the region.

The target areas for the trial present competent roof and floor materials and target seams that are relatively flat . The coal seams are of a thickness that is appropriate for highwall mining (0.9 to 1.5 m) and the coal itself is of reasonable strength whilst still being easily cut with a highwall continuous miner.

The depth of cover ranges between 12 and 50 m. This is considered optimal as the underground stress regime will be low to moderate, contributing to stable immediate roof conditions and reduced pillar loads. Reduced pillar loads allow for higher extraction ratios without impacting pillar stability, increasing coal recovery. Varying pillar parameters will be tested during the trial.

Based on local cover depth, coal strength, entry width and vertical stress conditions, the proposed panel design to be used for the Project's highwall trial are as follows:

- plunge width = 3.5 m;
- web width = 1.2 m;
- barrier pillar width = 5 m;
- number of entries per barrier = 10; and
- plunge height = 1.1 m.

The above design parameters are considered conservative and exceed the recommended stability factors for the overall panel layout, web width and barrier pillar width. This conservatism is considered warranted as a starting point; however, layout optimisation is expected to occur once the trial has commenced. The above layout results in an extraction ratio of approximately 70%, with up to 2,500 t per plunge and up to 25,000 t per panel.

Minimal infrastructure will be required to support the highwall mining trial. This will include mobile diesel fuel tanks, workshop containers and portable bathroom amenities. Earthmoving equipment will be required for the development of benches for the highwall miner to operate on, as well as equipment to build and maintain the haul road to the CHPP/ROM stockpile area. The benches will form part of the haul road and will be connected by sections of linking haul road. The highwall bench is proposed to be 100 m wide, including the highwall batter and haul road.

ROM coal will be loaded from the discharge conveyor of the highwall miner onto a stacker belt for stockpiling on the active bench. Loaders will manage the stockpile and load Moxy dump trucks for haulage to the Vulcan CHPP facilities. Waste rock from the benches will be temporarily stockpiled during highwall mining activities, prior to being back-filled into the bench areas during progressive rehabilitation. One of the benches will require establishment of a small waste rock dump that will be rehabilitated in situ.

During operations, mine-affected water will be controlled through the use of diversions, sumps, bunds and placement of mine affected water into completed down-dipping highwall plunges (voids) as proposed in the MAW management memo (**Appendix I**).

The key components of the mine water management strategy throughout the highwall mining stage of the Project include:

- clean water drains/contour banks and rock chutes/drop structures above the plunges will divert natural catchment runoff to the proposed surface water drains/sediment control structures and prevent contamination where active plunges are located;
- bunds along the bench will be built as required. These will direct MAW into the adjacent plunges. Bunds will also divert haul road runoff to the surface water drainage systems;
- direct mine water runoff (via gravity) either directly into a plunge or via a sump that dewaters to the plunge;
- as the highwall miner progresses, a mobile coal stockpile will keep pace within 100 m of the highwall miner before being trucked to the CHPP for processing. Disused coal stockpiles that are greater than 100 m from the highwall miner will be rehabilitated; and
- where plunges are no longer active, rehabilitation will commence to cover the voids at the surface. After covering the voids, surface runoff water would not be classified as MAW, and can be treated through the proposed sediment control structures (**Appendix I**).

Additional infrastructure

Explosive Magazine

An explosives magazine will be constructed between the highwall mining area and the Vulcan North pit, a safe distance from operational areas and critical infrastructure.

Administration buildings and warehouses

Onsite offices and administrative buildings are to be located just north of the MIA and adjacent to mine access roads for easy access.

Fuel storage and workshops

This will include mobile diesel fuel tanks, workshop containers and portable bathroom amenities. Earthmoving equipment will be required for the development of benches for the highwall miner to operate on as well as road construction and maintenance equipment to build and maintain the haul road to the CHPP/ ROM stockpile area.

ROM pad

ROM coal will be loaded from the discharge conveyor of the highwall miner onto a stacker belt for stockpiling on the active bench. Loaders will manage the stockpile and load B triple trucks for haulage to the CHPP. Waste rock from the benches will be temporarily stockpiled during highwall mining activities, prior to being back-filled into the bench areas during progressive rehabilitation. The ROM pad will be located within the MIA.

Coal handling and Processing plant (CHPP)

Coal will be processed by a modular coal CHPP. The proposed CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product for permanent storage within waste rock dumps. No wet tailings wastes or tailings dams are proposed.

The Project will include a modular CHPP to process ROM Coal into a number of marketable products (coking coal and thermal coal). In summary, the CHPP will include:

- A raw coal handling circuit to size ROM coal for further processing and remove incidental wastes;
- A raw coal bypass conveyor to provide the option to direct appropriate quality raw coal to the product stockpile;
- Three CHPP circuits (coarse, secondary coarse and mid-sized) for coal beneficiation, producing a single product stream;
- A tailings thickener to thicken ultrafine reject material; and
- Tailings dewatering technology to dewater tailings to a solid cake for disposal in active waste rock dumps.

The CHPP will produce dual products at any one time with different products produced in campaigns via control of different ROM feed materials. The CHPP will operate 24 hours a day, seven days per week and is anticipated to function for approximately 6 years (it may take 2 years to construct following the beginning of coal extraction until the completion of active mining). If there is an opportunity to commence the highwall trial during the VS construction period, ROM coal extracted from the trial may be handled through the adjacent VCM infrastructure before the construction of the Vulcan South CHPP has been completed.

The following chemicals and hydrocarbons will be required for processes in the CHPP, and will be stored on site:

- 215kL of diesel;
- Anionic flocculant (dry powder) 50m^3;
- Cationic flocculant (liquid) 50m^3; and
- Acrylate polymer 10m^3.

Rail Loop and TLO

Product coal will be railed from the Project rail loop onto the Goonyella Rail network. Export options include Dalrymple Bay to the north and RG Tanna, in Gladstone, to the south.

The train load out facility will link the product stockpiles with the proposed rail loop and will utilise a two-coal valve reclaim system to load at a rate of 3,500 tph. The train load out facility will be managed via an automated system, including overload protection and load veneering. The facility will be positioned over the rail line and will incorporate a suitable under rail spillage pit.

Water Management

To mitigate potentially adverse effects of mining and associated land disturbance, a water management system has been designed by WRM (**Appendix A**). The Project's water management system will include mine water drainage, mine water storages, sediment dams, pit water storages and flood protection works (i.e. levees).

The operational period of mining is expected to run for seven years from 2024 to 2031. **Figure 1-32** to **Figure 1-39** show indicative locations of the key features of the mine, including infrastructure related to the management of water on the Project site for three different stages of mining (Stages 1, 2 and 3). The main components of water-related infrastructure include:

- diverted water drains, bunds and drainage diversions to divert runoff from undisturbed catchments around areas disturbed by mining;
- flood protection levees along the southern side of the Vulcan North pit, along the western and south-eastern sides of the Vulcan Main pit, and around the Vulcan South pit;
- sediment dams and drains to collect and treat runoff from waste rock dumps; and
- mine-affected water drains and dams to store water pumped out of the open-cut pits and to collect runoff from the infrastructure areas.

The catchment areas of each of the water management types (surface water, mine affected water and diverted water) are also shown in **Figure 1-32** to **Figure 1-39**.

The water management system for the Project aims to protect the identified downstream environmental values and comprises the following key objectives:

- separate diverted water from mine-affected water to ensure that up-catchment water and mine-affected water do not mix wherever practicable;
- capture of mine-affected runoff (e.g. mine industrial area, haul road/ROM pad runoff), storage and priority reuse as mine water supply;
- divert up-catchment water runoff from upstream catchments around the active mining area;
- limit external catchment runoff draining into pits;
- manage sediment from disturbed catchment areas (e.g. ex-pit waste rock dumps, cleared/pre-strip areas) by using erosion and sediment control (ESC) measures prior to release offsite;
- reuse onsite water (e.g. mine-affected water) where possible to support mine operational water demands (and therefore limit mine-affected water inventories under normal operating conditions); and
- manage any mine-affected water releases to the receiving waters to meet environmental release conditions (not currently proposed).

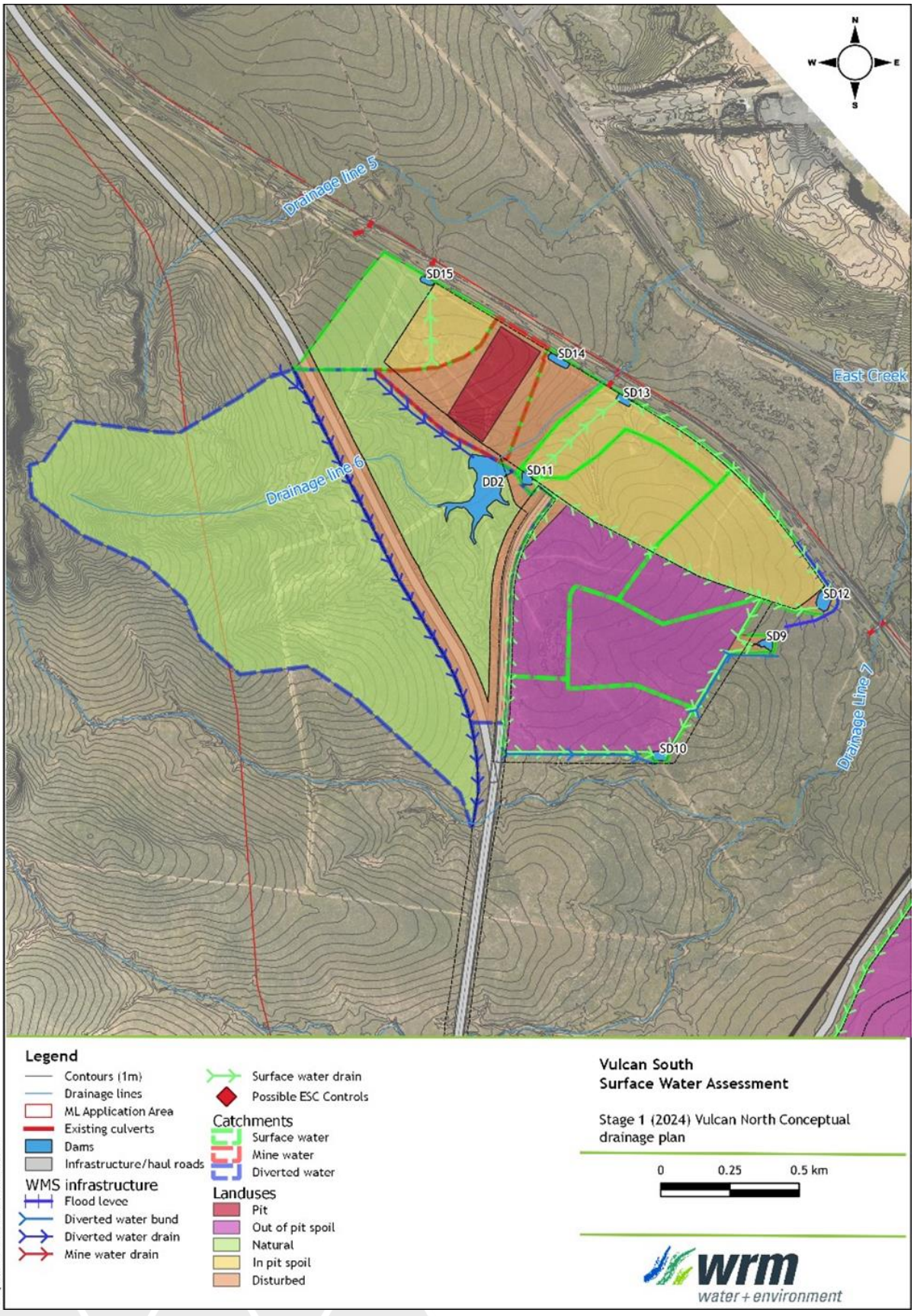


Figure 1-32 Stage 1 (Year 2024) Vulcan North mining area conceptual drainage plan

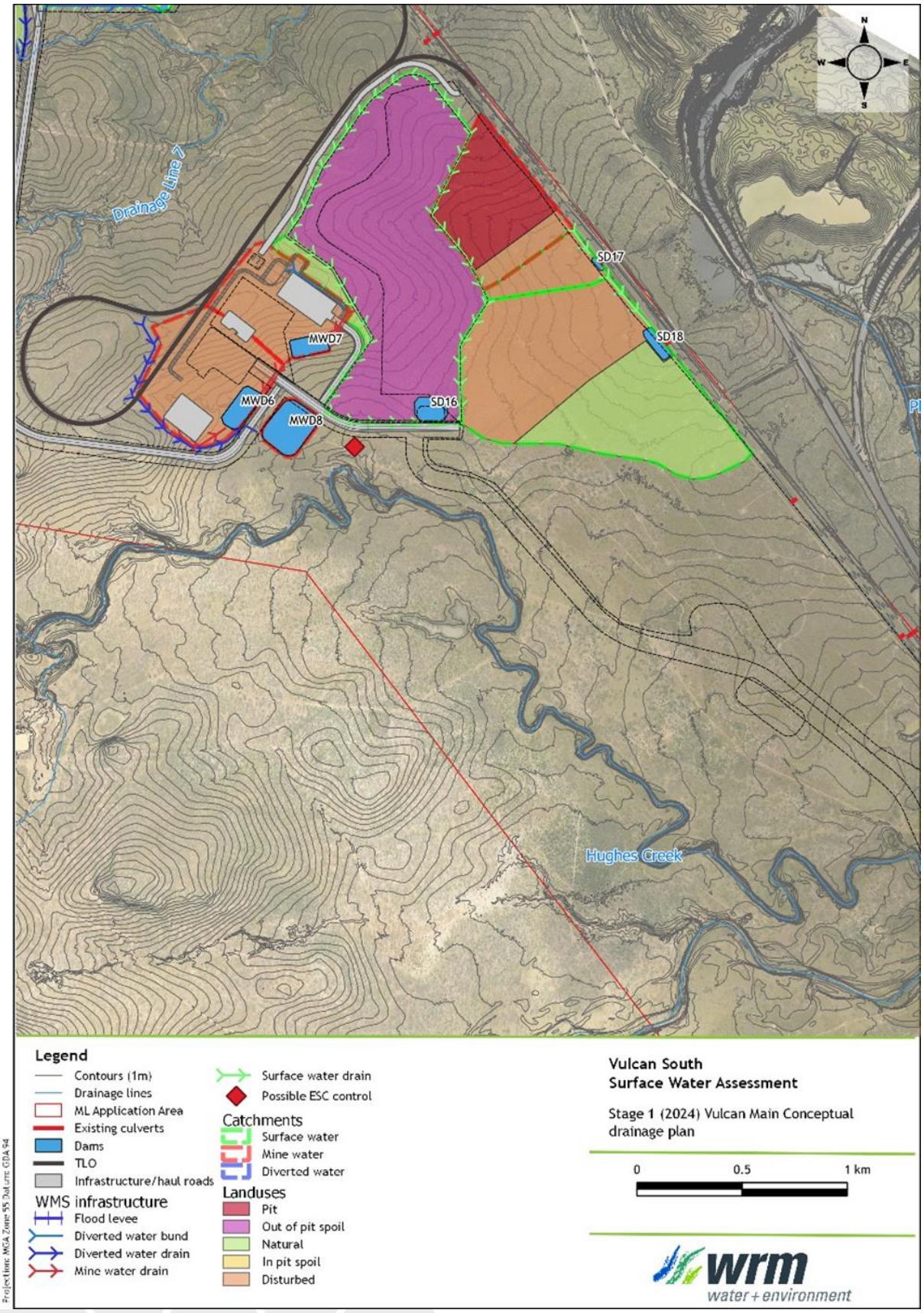


Figure 1-33 Stage 1 (Year 2024) Vulcan North mining area conceptual drainage plan

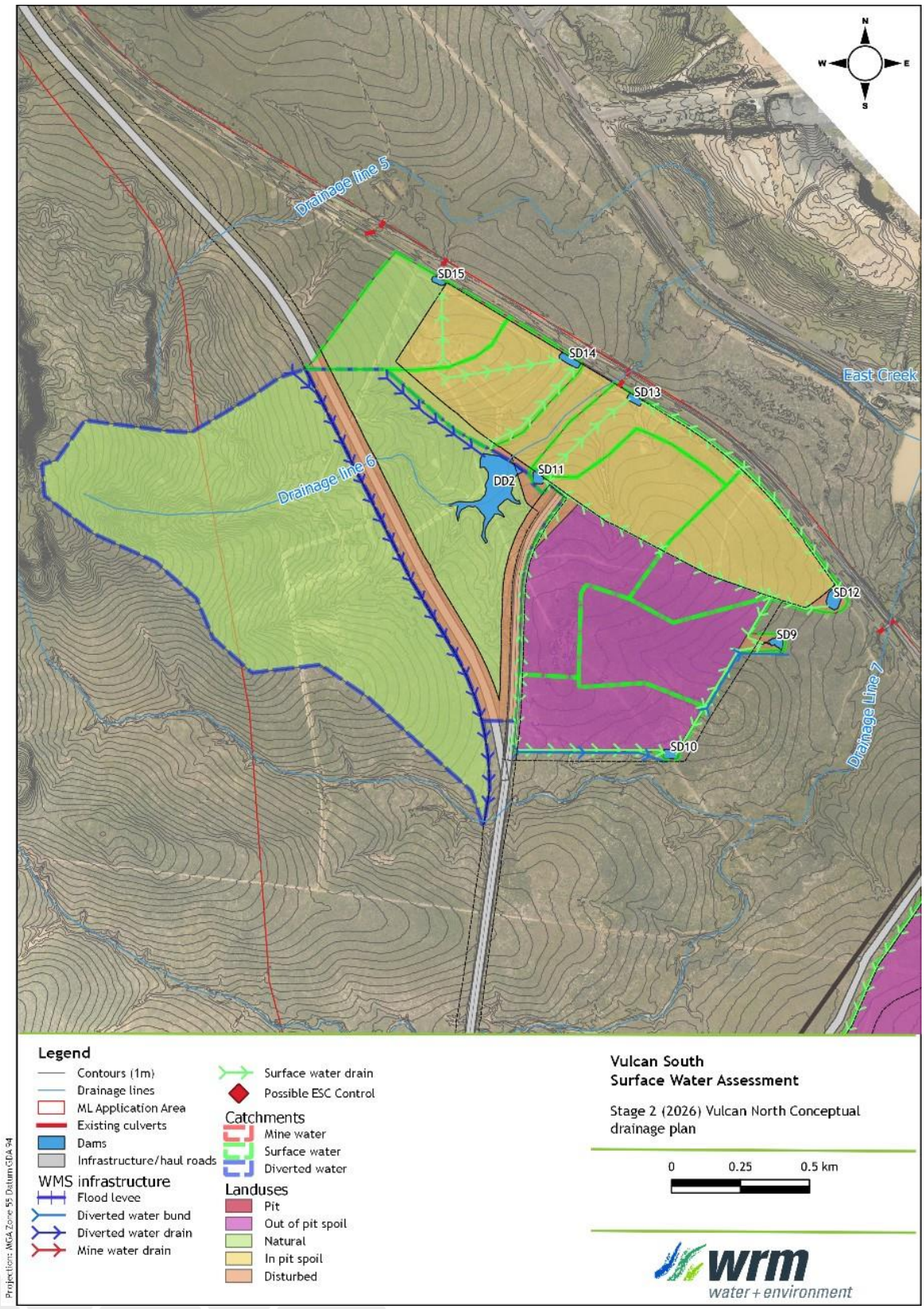


Figure 1-34 Stage 2 (year 2026) Vulcan North mining area conceptual drainage plan

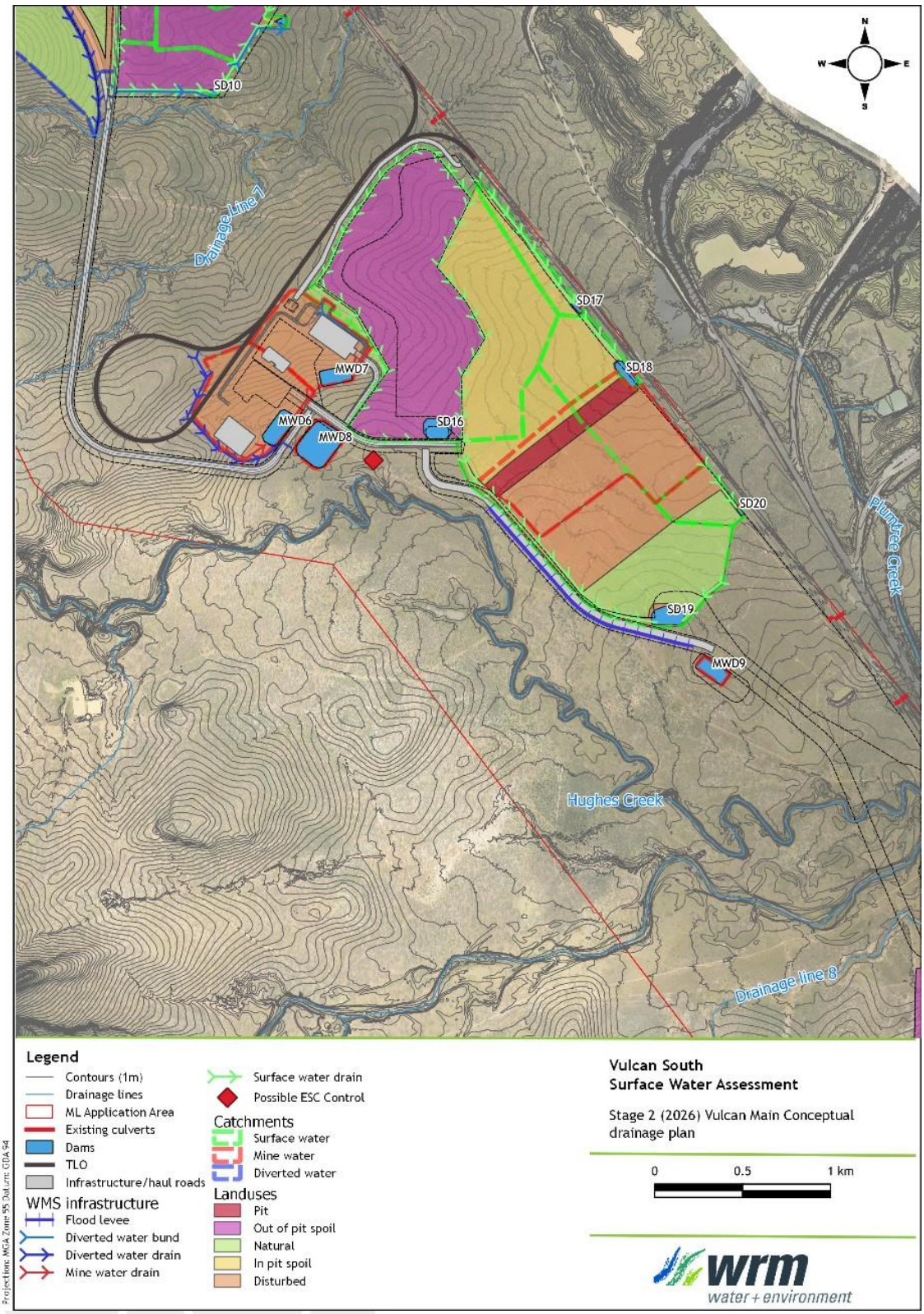


Figure 1-35 Stage 2 (year 2026) Vulcan Main mining area conceptual drainage plan

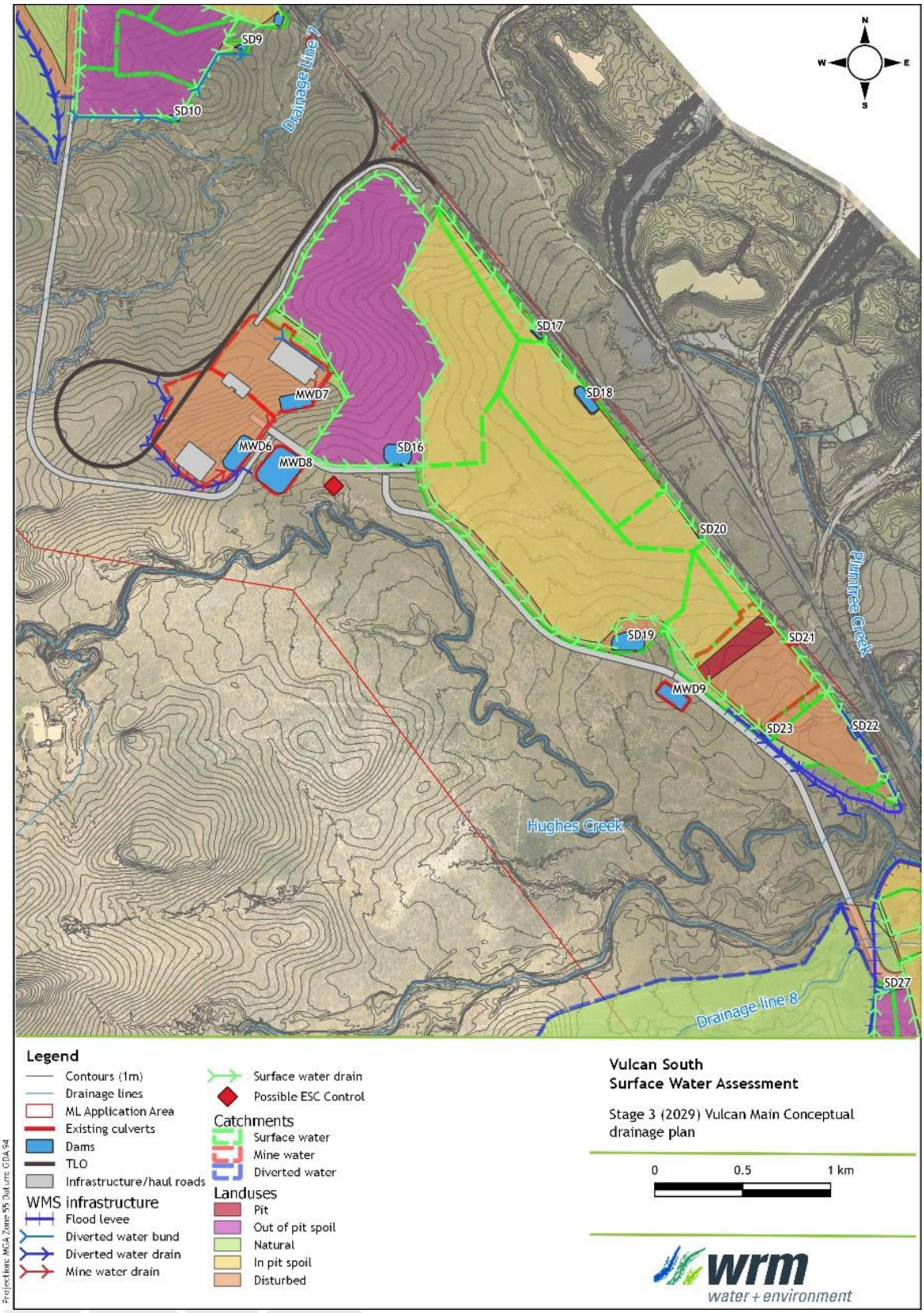


Figure 1-36 Stage 3 (Year 2029) Vulcan Main mining area conceptual drainage plan

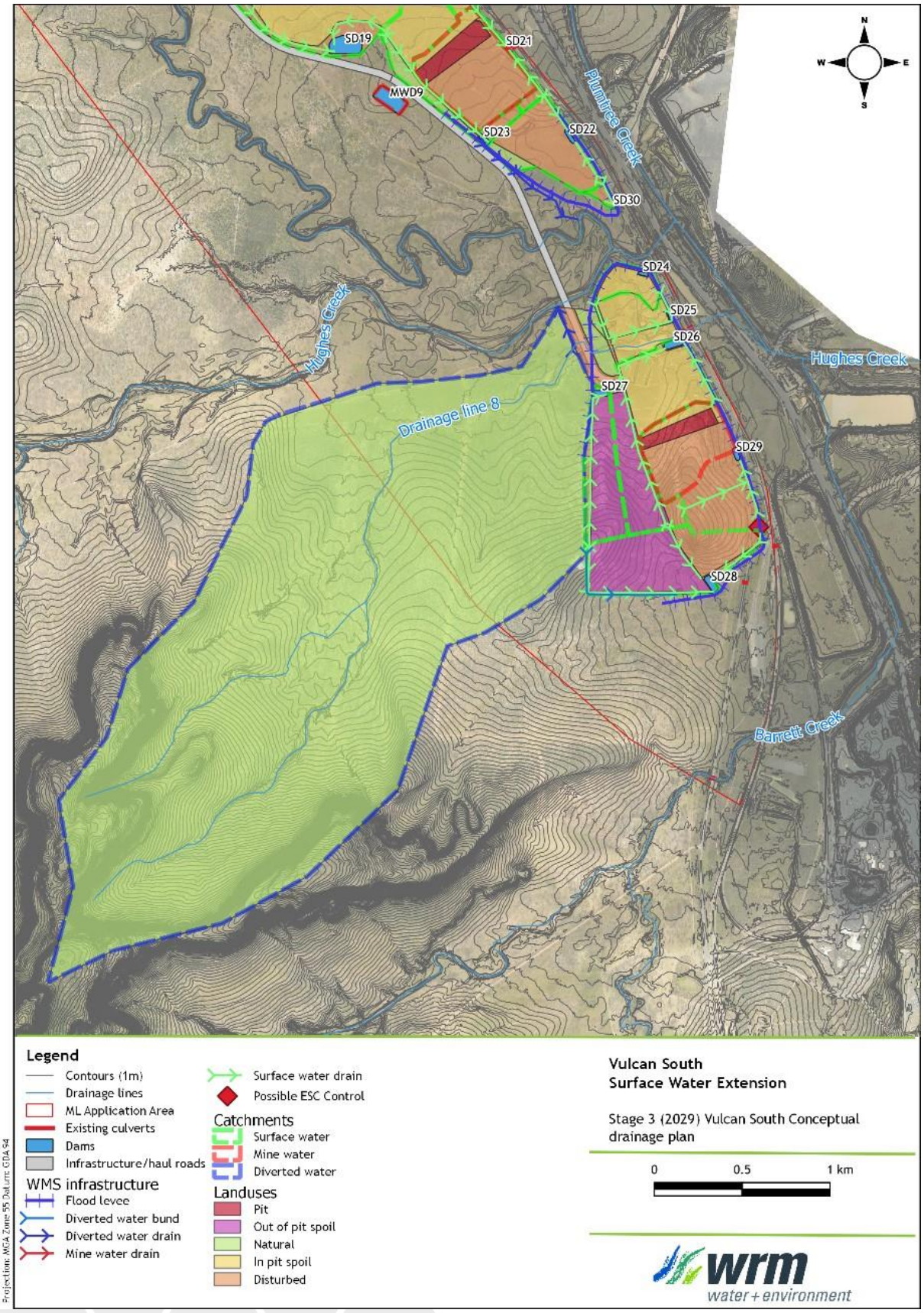


Figure 1-37 Stage 3 (Year 2029) Vulcan South mining area conceptual drainage plan

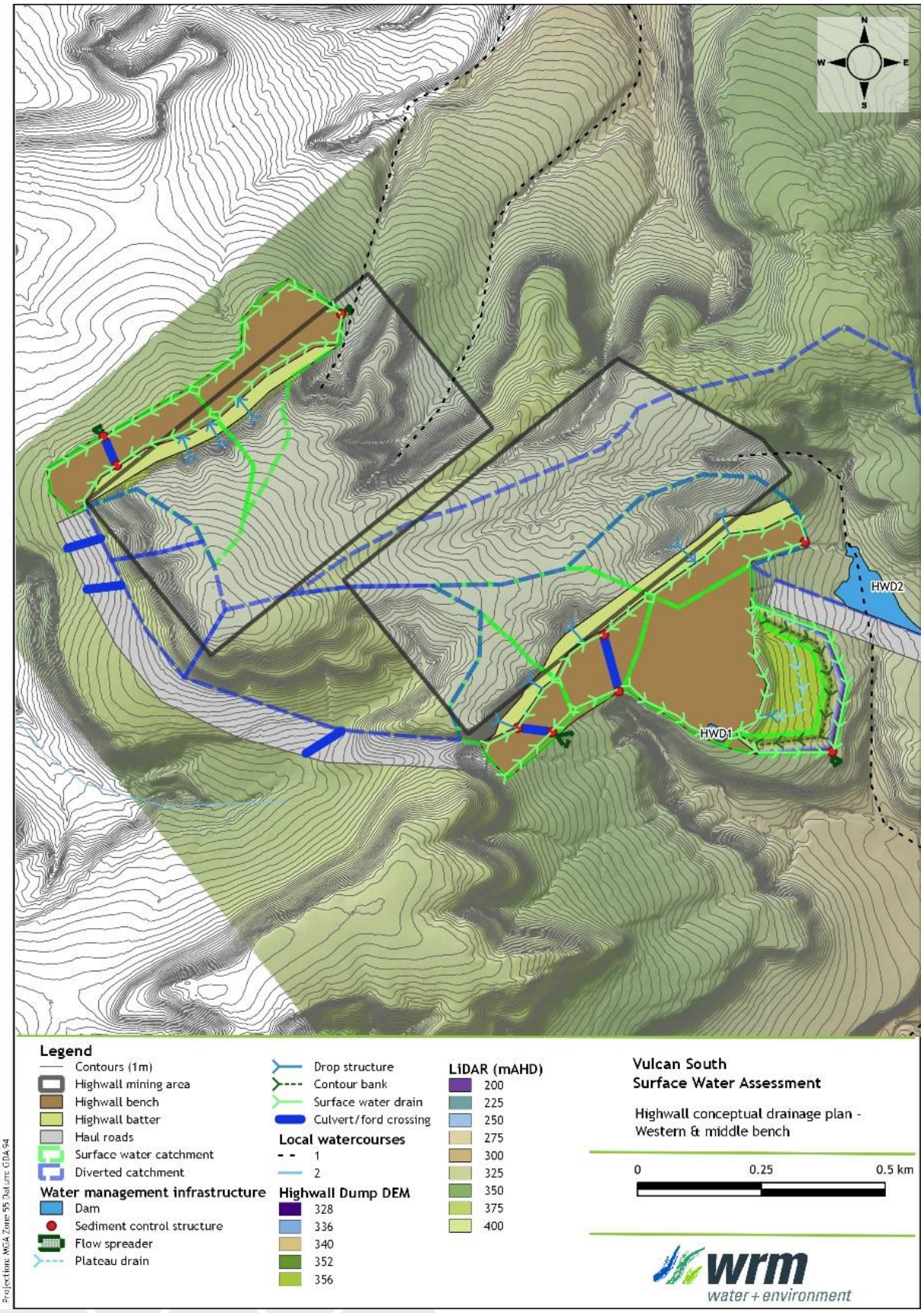


Figure 1-38 Highwall conceptual drainage plan – western & middle bench

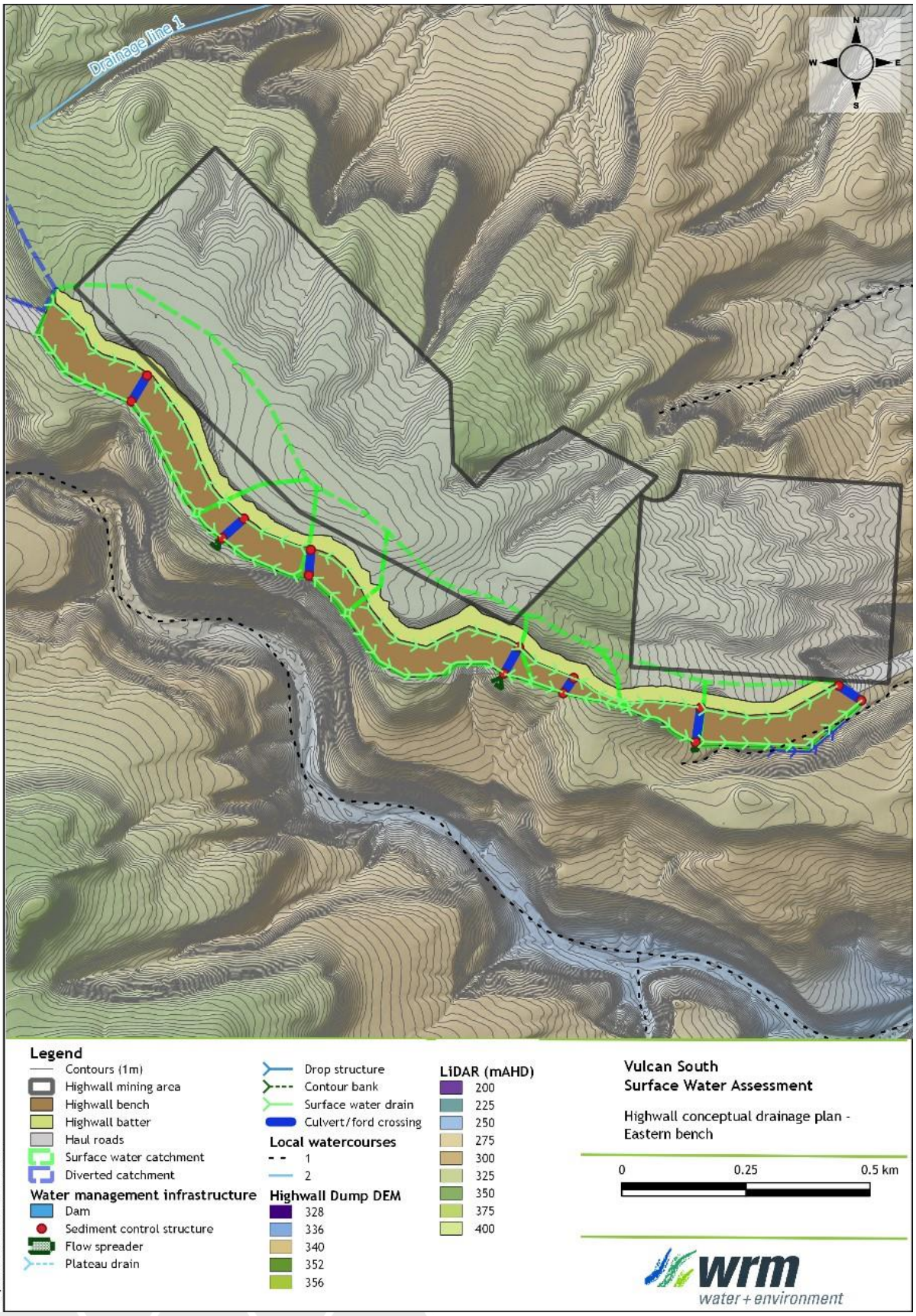


Figure 1-39 Highwall eastern bench mining area conceptual drainage plan

Diverted Runoff Water Management

A number of flood levees are proposed for the Project, including:

- Vulcan North levee on the southern edge of the Vulcan North pit to be constructed in Stage 1;
- Vulcan Main levee 2 on the western edge of the Vulcan Main pit to be constructed in Stage 2 and Vulcan Main levee 1 on the southern edge of the Vulcan Main pit to be constructed in Stage 3; and
- Vulcan South levee around the full extent of the Vulcan South pit to be constructed in Stage 3.

The flood levees will be regulated structures under the EP Act and will therefore be required to have a crest above the 0.1% AEP event.

The water management system has been designed to divert undisturbed catchments around mining operations wherever practicable. Three diverted water drains are proposed as part of the Project:

- drainage diversion 2 will be constructed in Stage 1 and will divert a catchment of approximately 105 ha away from the Vulcan North pit and dam DD2 (clean water storage dam as per Section 7.3.7.3 in **Appendix A**). This drainage diversion will collect an undisturbed catchment to the west of the Vulcan North pit and associated haul road. This drainage diversion will divert a portion of Drainage line 6 and discharge under a haul road to Drainage line 7 (which is a tributary of East Creek).
- drainage diversion 3 will be constructed in Stage 3 and will divert a portion of Drainage line 8 around the Vulcan South pit. This drainage diversion will collect an undisturbed catchment of approximately 570 ha and discharge to Hughes Creek.
- a minor drainage diversion diverts water southward around the Vulcan Main levee 1, to discharge into Hughes Creek.

A number of diverted water bunds are proposed in the vicinity of the three open cut pits. These bunds will collect runoff from minor catchments (i.e. smaller than 15 ha) where a drain is not deemed necessary and divert these catchments around mining operations.

2 LEGISLATIVE REQUIREMENTS

2.1 *Mineral Resources Act 1989*

Resource activities are regulated through a 'resource authority' under the *Mineral Resources Act 1989.* This provides resource companies with the right to enter land and undertake the approved activity. Under section 107(10) of this act, a mining claim can only be surrendered once improvement restoration (i.e., returning the tenement to substantially the same condition it was in before mining) has been carried out and the relevant environmental authority has been surrendered.

2.2 *Environmental Protection Act 1994*

The *Environmental Protection Act 1994* (EP Act) is the principal legislation for protecting environmental values potentially affected by the resource industry in Queensland. The EP Act grants the Queensland Government the power and means to assess, approve and prescribe conditions on proposed mining projects.

The EP Act requires that all areas of disturbed or undisturbed land within the relevant mining tenure be rehabilitated to a post-mining land use (PMLU), or managed as a non-use management area (NUMA). Section 125(1)(n) of the EP Act requires a proposed PRC plan to accompany site-specific applications for a mining activity. Sections 126C and 126D stipulate the requirements for PRC plans and PRCP schedules, respectively.

Under the EP Act, the Queensland Government is responsible for the issuing of an environmental authority (EA) to carry out a mining activity and approval of a PRCP schedule for a proposed PRC plan. Under section 172(4) of the act, if the PRCP schedule is refused, the EA application must also be refused. Under sections 426(1) and 431A of the act, an applicant is unable to undertake any relevant activities until an EA with a PRCP schedule is approved. The EA and PRCP schedule includes all conditions imposed on the authority and schedule.

The EP Act also prescribes the requirements for surrendering an EA, including the preparation of final rehabilitation reports and post-mining management reports.

2.3 *Mineral and Energy Resources (Financial Provisioning) Act 2018*

In Queensland, the *Mineral and Energy Resources (Financial Provisioning) Act 2018* regulates a financial provisioning scheme for reducing potential risks to the Government in the event a holder of an EA fails to meet their environmental and rehabilitation obligations. This act also amended the EP Act to require mining companies to develop PRC plans.

2.4 Progressive Rehabilitation and Closure Plans Guideline

This guideline, prepared by the Queensland Government Department of Environment and Science, contains information to assist applicants in developing a PRC plan as part of a site-specific application for a new mining activity. The administering authority must consider this guideline when making a decision about a PRCP schedule under section 176A of the EP Act.

2.5 Rehabilitation Requirements for Mining Resource Activities

This guideline has been prepared by the Queensland Government Department of Environment and Science to assist mining companies to propose acceptable rehabilitation outcomes and strategies. The administering authority must consider this guideline when making a decision about a PRCP schedule under section 176A of the EP Act.

2.6 *Environment Protection and Biodiversity Conservation Act 1999*

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's key piece of legislation protecting matters of national environmental significance.

Actions that will or are likely to impact matters of national environmental significance require approval from the Environment Minister under the EPBC Act. Any conditions attached to this approval that pertain to rehabilitation of the site after mining must be adhered to under the EPBC Act.

3 STAKEHOLDER ENGAGEMENT

3.1 Stakeholder Consultation Register

A Stakeholder Engagement Plan (SEP) that complies with section 126C(1)(c)(iv) of the EP Act was prepared to guide stakeholder engagement activities associated with project planning, the environmental approvals process and the development of the PRC Plan (**Appendix E**).

In accordance with section 126C(1)(c)(iv) of the EP Act, the SEP also discusses ongoing stakeholder engagement during progressive rehabilitation and closure.

Given that the proposed PMLUs seek to re-establish, for the most part, the current site land uses, the key stakeholders for rehabilitation of the site were deemed to be:

- the owners of the properties listed in **Table 1-9**;
- the Barada Barna People, as native title holders for the broader project area;
- neighbouring and downstream water users (BHP Billiton/Mitsubishi Alliance (BMA));
- Isaac Regional Council;

In addition to the above stakeholders, relevant stakeholders for the development of the Project also include:

- nearby businesses (BHP Billiton Mitsubishi Alliance (BMA) Pty Ltd; and Saraji Station);
- Queensland Department of Environment and Science (DES);
- Queensland Department of Resources (DoR);
- Queensland Department of Transport and Main Roads (DTMR); and
- Commonwealth Department Agriculture, Water and the Environment (DAWE)

Given the small scale and short duration of the Project and the proposal to return the land to its pre-mine land use, it is considered unlikely that stakeholder perspectives on PMLUs will change significantly during the course of progressive rehabilitation, particularly if the proposed rehabilitation activities are implemented successfully as anticipated.

Vitrinite will provide relevant stakeholders with copies of the annual rehabilitation progress return. These annual rehabilitation progress returns will be the principal mechanism for communicating any proposed changes to the PRC Plan, and to obtain feedback from stakeholders for consideration in ongoing planning and activities. Should significant amendments of the PRC Plan be proposed, stakeholders will be engaged as part of the amendment process.

Further detail regarding the PRC Plan annual reporting mechanism is outlined in **Section 9.1.10.**

3.2 Stakeholder Consultation Plan

A stakeholder consultation register that complies with section 126C(1)(c)(iii) of the EP Act is appended to the Project's SEP (**Appendix E**).

The stakeholder consultation register is a record of all consultation activities, describing the attendees, topics of discussion, outcomes and ongoing commitments for each consultation meeting.

During the consultation process outlined above, topics of discussion with stakeholders have included the proposed rehabilitation approach, the plan for the mine, PMLUs, areas of disturbance, rehabilitation and management methods, progressive rehabilitation and closure timeframes.

4 POST-MINING LAND USE

The MLA hosted five land uses prior to the mine. Most of these land uses are to be reinstated as post-mining land uses (PMLUs) once operations cease, except for rail corridor which will not qualify as a PMLU considering it will not be disturbed and therefore will not require a rehabilitation area:

- low-intensity cattle grazing
- low intensity cattle grazing with habitat for threatened fauna
- native ecosystems; and
- public road.

Most of the MLA area will have a PMLU of low-intensity grazing. Where supported by available soils, locally native plant species are to be incorporated into the planting mixes where grazing is the PMLU, to create pastoral land that partly restores habitat values for threatened fauna (namely, the Squatter Pigeon and Koala) impacted by the mine. In accordance with Part 3 of the *Environmental Protection (Rehabilitation Reform) Amendment Regulation 2019*, a PMLU of low-intensity grazing:

- is viable, having regard to the use of land in the surrounding region;
- is consistent with how the land was used before a mining activity was carried out on the land;
- is consistent with a use of the land permitted under the *Planning Act 2016*; and
- will deliver, or aim to deliver, a beneficial environmental outcome.

The locations of these PMLUs are described within the PRC Plan schedule (**Section 10.4**). Through in-pit dumping of waste rock, no voids will remain on site after mining. Consequently, no non-use management areas (NUMAs) are proposed.

Based on previous studies, grazing is an achievable PMLU in the Bowen Basin (Bisrat *et al.* 2004). To achieve the proposed PMLU, rehabilitated land should have a land suitability class of at least 4 (marginal land for grazing), which was the dominant land suitability class on site prior to mining. An exception is the sandstone escarpment areas of the Crocodile soil management unit, which are expected to retain a class of 5 (unsuitable for grazing). This soil management unit will be rehabilitated to a native plant community containing species typical of regional ecosystems 11.10.1, 11.10.7 and/or 11.10.3, the dominant communities present prior to mining.

Other PMLUs considered included "forestry" (hardwood *Eucalyptus* plantations) and "agriculture" (dryland cropping), but the limited topsoil materials and high cost of creating a productive growing medium with the materials available limit the feasibility of both options (see **Section 4.3** for an assessment of each option).

4.1 Accordance with Stakeholders' Requests

Through the consultation process undertaken for the development of this PRC Plan, all relevant stakeholders expressed support for the proposed PMLUs.

4.2 Regulatory Constraints

There are relatively few regulatory constraints on the post mining land use on the MLA. These are discussed below.

4.2.1 Isaac Regional Planning Scheme

Under the *Isaac Regional Planning Scheme*, the Project is located in a "Rural" zone. The Isaac Regional Planning Scheme defines uses suitable for "Rural" zones as cropping, intensive horticulture, aquaculture, grazing, intensive animal industries, renewable energy facilities and extractive industries. These defined uses are consistent with the PMLUs for the Mine.

4.2.2 Mackay, Isaac and Whitsunday Regional Plan

The Queensland Government, via their *Mackay, Isaac and Whitsunday Regional Plan*, maps the Project in a "regional landscape and rural production area", which includes land used for agriculture, water catchment, traditional uses, conservation areas and native forests. The PMLUs are consistent with these planned land uses.

The highwall trial area and land to the west of the proposed pits is mostly mapped as being of "high ecological significance" under the *Mackay, Isaac and Whitsunday Regional Plan*. This plan aims to minimise the impact of development on such areas of high ecological significance, and a PMLU that is compatible with restoring many of the original environmental values is consistent with this regional plan.

4.3 Assessment of Options

Four potential PMLUs were assessed as part of planning for the Project:

1) Low-intensity cattle grazing with low- to medium-density of native trees;
2) Native vegetation communities (native ecosystems);
3) Hardwood (e.g., *Corymbia citriodora*) plantation forestry; and
4) Dryland cropping.

These PMLUs were selected because they are land uses consistent with the *Isaac Regional Planning Scheme* and the *Mackay, Isaac and Whitsunday Regional Plan*.

In order to compare the relative merit of each PMLU option, a scoring system was applied across ten costs and benefits, in accordance with the *Progressive Rehabilitation and Closure Plans Guideline* (**Table 4-1**). This awarded a score of 1-5 for each consideration (cost/benefit), with the sum of all scores across considerations used to compare PMLU options. Even though different rehabilitation areas have slightly different rehabilitation methods and milestones, they are assessed together due to their similar constraints.

This assessment revealed that low-intensity grazing and native vegetation communities were the most appropriate PMLUs for the Project (**Table 4-1**). The overall scores were similar for both, with grazing being marginally favourable on flat terrain and native ecosystems being marginally favourable in steeper sandstone areas.

There are other reasons, not considered in **Table 4-1**, why forestry and cropping are considered risky options for the Project. In Queensland, plantation forestry is largely limited to coastal regions, and the performance of plantations is untested within the Isaac Regional Council area. Cropping is also a land use associated with high risk, given the highly dispersive subsoils across most of the Project area (see **Section 1.2.7**). Regular cultivation of the topsoil is likely to expose these subsoils to erosion, with irreversible outcomes.

According to the *Rehabilitation Requirements for Mining Resource Activities v2.01*, optimal PMLUs are those highest up in the following hierarchy:

1) avoid disturbance that will require rehabilitation
2) reinstate a "natural" ecosystem as similar as possible to the original ecosystem
3) develop an alternative outcome with a higher economic value than the previous land use
4) reinstate previous land use (e.g. grazing or cropping)
5) develop lower value land use
6) leave the site in an unusable condition or with a potential to generate future pollution or adversely affect environmental values.

The two favoured PMLUs, native ecosystems and low-intensity grazing, fall 2nd and 4th on this hierarchy, respectively. While cropping would fall 3rd, the physical and chemical constraints of the site, and the relative costs of ameliorating the topsoil to enable productive crop growth, preclude this as a viable option.

Table 4-1 Assessment of PMLU options

Considerations	PMLU Options*				Justification
	Low-intensity grazing	Native ecosystems	Forestry	Cropping	
Physical constraints	4	4	3	2	Shallow soil, sloping land and a hot/dry climate with limited access to irrigation mean that no land use achieves a score of "5". However, these are relatively minor constraints on re-establishing grazing or native ecosystems. Forestry is largely untested in such a dry climate, so this is awarded a neutral score of "3". Cropping is strongly limited (though not impossible) by the lack of access to irrigation and the thin, sandy soil and is awarded a score of "2".
Chemical constraints	4	4	2	1	Topsoil has poor nutrient-holding capacity, while subsoils are generally dispersive. These attributes largely preclude cropping as an option. They also pose substantial constraints on the performance of forestry, given that stressed trees are less likely to produce a desirable form for milling. While chemical constraints also affect the re-establishment of grazing and native ecosystems, this limitation is relatively minor.
Available materials	4	4	2	1	No land use has a score of "5" due to limited amounts of fresh topsoil that can be directly deposited onto disturbed areas (most soil requires some period of stockpiling, which reduces its quality as a growing medium). Nevertheless, this is expected to be a minor limitation for re-establishing grazing or native ecosystems as land uses. As forestry is an undeveloped industry in this climatic zone, strains of timber trees that perform well in local conditions would need to be investigated and mass-produced, something that is not likely to be achievable in the short timeframe of the Project. For cropping to be viable, existing soil would need to be overlaid with large quantities of suitable topsoil, to provide a favourable growing medium for crops and protect underlying soils from dispersion/erosion. Such material is unavailable.
Relative cost	4	3	2	1	The scores awarded reflect the costs of obtaining the materials required to instate each land use, and therefore generally reflect the scores awarded for material availability. The reason that grazing is slightly cheaper to instate than native ecosystems is due to the relatively simpler plant communities to be established on pastoral land. Restoring native ecosystems would require a more complex seed mix, which is more costly to collect/obtain.
Economic benefits for the community or landholder	4	1	3	5	Scores were based on the potential gross annual income generated from each land use once each has been instated. It is independent of the relative costs described above.
Environmental benefits	3	5	2	1	Scores were based on the biodiversity of native flora that are likely to coexist with the land use,

Considerations	PMLU Options*				Justification
	Low-intensity grazing	Native ecosystems	Forestry	Cropping	
					ranging from 5 = full diversity in native ecosystems, to 1 = no native species in crops. Forestry could vary from 2 to 4, depending on the dominance of weeds vs native species in the understorey. It is assumed that, as few native species are expected to regrow in stockpiled soils without active addition of seed, forestry would most likely create a monoculture of timber trees with few native species below. As a diversity of native grasses and trees will be planted in land used for grazing, biodiversity in this land use will be moderate (3).
Social value (recreation, public amenity, employment)	2	2	3	4	High scores were awarded for land uses dependent on a regular supply chain of materials, machinery or labour (maximising employment, for example cropping and, to a lesser extent, forestry). Moderate scores were also awarded for land uses that provide scenic amenity (forestry, native ecosystems), and/or those compatible with recreational activities such as bushwalking or hunting. Scores tended to be relatively similar across potential land uses, as the land uses providing maximum employment opportunities tended to have fewer recreational or public amenity benefits.
Compatibility with surrounding land uses	5	5	3	3	Grazing, native ecosystems and mining are the predominant surrounding land uses. Therefore, grazing and native ecosystems are fully compatible, while forestry and cropping are neutral. The latter two options will require application of water, fertiliser and/or pesticides, which may impact neighbouring land uses. However, this incompatibility is minor.
The land use before mining commenced	5	5	1	1	Land-uses in place on site prior to mining are awarded "5" and those not in place are awarded "1".
Compatibility with planning instruments under the *Planning Act 2016*	5	5	5	5	All options are fully compatible with the *Isaac Regional Council Planning Scheme* and the *Mackay, Isaac and Whitsunday Regional Plan.*
Total Score	**40**	**38**	**26**	**24**	

*For each consideration, each PMLU option is awarded a relative score (1-5), where 5 is feasible/desirable and 1 is prohibitive/undesirable. The sum of the scores across all considerations was used to compare the favourability of each option.

4.4 Statutory Constraints to be Imposed

Due to the absence of NUMAs or reactive waste rock material, and the fact that the final landform will generally resemble the surrounding landscape, few statutory constraints are expected to be imposed on future land managers of the Vulcan South area.

Any restrictions on the future stocking rates are to be described in the Post-mining Management Report (see **Section 9.6**) and imposed through a Site Management Plan, to be adopted by future land managers of the site. This is to be confirmed following pasture development and performance monitoring.

5 REHABILITATION GOALS

Under section 176A (3)(c)(i) of the EP Act, mined land must be rehabilitated to a stable condition. Land is in a stable condition, as defined in section 111A of the EP Act, if: (a) the land is safe and structurally stable, (b) there is no environmental harm being caused by anything on or in the land; and (c) the land can sustain a post-mining land use. These three components of stability are the general rehabilitation goals for all areas disturbed by mining in Queensland. They have been developed from the ecologically sustainable development (ESD) policy framework, especially in relation to intergenerational equity, polluter pays principle, protection of biodiversity, and maintenance of essential ecological processes.

5.1 Rehabilitation Objectives, Indicators and Completion Criteria

A clearly defined set of rehabilitation objectives has been developed for each PMLU proposed for the Project. For each objective, one or more rehabilitation indicators (measurements of progress towards the rehabilitation objectives) are proposed. These indicators are designed to be auditable against completion criteria, which act as targets for the rehabilitation process. Each completion criterion is applied to the PRCP Schedule as a milestone criterion for the later stages of rehabilitation. The full list of rehabilitation objectives, indicators and completion criteria is shown in **Table 5-2**. For details about how each indicator is to be measured, refer to **Section 9**.

The final PMLU's for the project are summarised in the table below, together with which RA they occur within.

Table 5-1 PMLU location within footprint

PMLU	Location within footprint	Explanation
A: Low-intensity cattle grazing	Located within the northern, central and southern ex-pit WRD's, as part of RA1.	The ex-pit WRDs will be lacking subsoil and therefore this environment will not be conducive to tree and shrub growth.
B: Low-intensity cattle grazing with habitat for threatened fauna	RA2, RA3 and RA4.	All areas except areas within the highwall mining area and the ex-pit WRDs are suitable for both cattle grazing and native vegetation establishment.
C: Native ecosystems	All areas within the highwall mining area (RA6 and RA7).	The highwall mining area is not suitable for cattle grazing, and native ecosystems will be re-established.
D: Saraji Road	Along the eastern ML boundary.	This PMLU is part of an agreement between Vitrinite and Isaac Regional Council (IRC). The realigned road's construction and commissioning will be in accordance with conditions specified in the agreement.

Refer to Figure 10-2 for rehabilitation areas.

Table 5-2 Rehabilitation objectives, indicators and completion criteria

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
PMLU A: Low-intensity cattle grazing					
A1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll *et al*. 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2021). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2020).
A2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal.	Prior to the commencement of topsoil placement.	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2 but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a hydrocarbon spill).
		Water quality at permanent monitoring locations downstream of the Project.	Annually, following rain events.	Surface water in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
		Groundwater quality within permanent monitoring bores.	Quarterly.	Groundwater in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.
A3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA area are incorporated into the completion criteria.
A4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
A5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
A6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).
PMLU B: Low-intensity cattle grazing with habitat for threatened fauna					
B1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies.	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll *et al.* 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2022). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2022).

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal	Prior to the commencement of topsoil placement	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2, but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a vehicle accident leading to hydrocarbon spills)
		Water quality at permanent monitoring locations downstream of the Project	Annually, following rain events	Surface water in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.	Site-specific surface water quality triggers will be established over time and present the most accurate measure of effect on water quality.
		Groundwater quality within permanent monitoring bores	Quarterly	Groundwater in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.	Site-specific groundwater quality triggers will be established over time and present the most accurate measure of effect on water quality.
B3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA area are incorporated into the completion criteria.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
B5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).
B6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B7	Koala food trees are to have a similar dominance within rehabilitated vegetation communities as they did in vegetation present on site prior to mining	Proportion of the total basal area of woody vegetation at the site that comprises *Eucalyptus crebra, Eucalyptus populnea* or *Eucalyptus camaldulensis*.	Sites are to be monitored six and ten years after planting.	*Eucalyptus crebra* and/or *Eucalyptus populnea* are to constitute 21% of the total basal area of woody vegetation on sand plains. **AND** *Eucalyptus camaldulensis* is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7.	Relative dominance of Koala food trees is based on secondary site data gathered from nine sand plain reference sites and three riparian reference sites (METServe, 2022).
B8	Trees are to be sufficiently tall to be used by Koalas and to escape browsing by cattle (except RA1).	Mean height of the tallest ten trees per hectare	Sites are to be monitored six and ten years after planting.	The mean height of the tallest ten trees per hectare is ≥4 m.	The Queensland Environmental Offsets Policy defines non-juvenile Koala habitat trees to be those with a height greater than 4 m (DES 2022). Such trees are also beyond the reach of cattle.
B9	Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons	The mean Normalised Difference Vegetation Index (NDVI) calculated using Landsat imagery captured following at least two months without rain (e.g., late dry season)	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	Rehabilitated areas are to have a mean NDVI between 0.1240 and 0.1778	Ecological surveys of the local region found that Squatter Pigeons are confined to vegetation with a density that falls within the range of NDVI values used as the completion criterion (METServe, 2022).
B10	Availability of food for the Glossy Black-cockatoo is restored to pre-mining levels	Basal area of the food tree *Casuarina cristata*	Sites are to be monitored six and ten years after planting.	Rehabilitated areas where the ground is level and soil management unit "Orange" has been used as topsoil are to have a minimum basal area of 0.5 m^2/ha stems of *Casuarina cristata* per ha.	*Casuarina cristata* was mostly restricted to Orange soil units pre-mining. Where present, *C. cristata* had a basal area of 0.5 to 5.83 m^2/ha (based on three reference sites).

ID	Rehabilitation Objective	Rehabilitation Indicator		Assessment Timing	Completion Criteria	Justification
B11	Diversity of food for the Greater Glider is restored to pre-mining levels	Species richness of *Eucalyptus* and *Corymbia* species in a 10 m × 50 m plot.	Sites are to be monitored six and ten years after planting.	Rehabilitated areas on the Zambezi soil management unit are to contain *Eucalyptus camaldulensis* and at least one other species of *Corymbia* or *Eucalyptus.*	Three secondary sites sampled in riparian reference sites all contained *E. camaldulensis* and one other *Eucalyptus* or *Corymbia* sp.	
PMLU C: Native ecosystems						
C1	Koala food trees are to have a similar dominance within rehabilitated vegetation communities as they did in vegetation present on site prior to mining	Proportion of the total basal area of woody vegetation at the site that comprises *Eucalyptus crebra, Eucalyptus populnea* or *Eucalyptus camaldulensis*.		Sites are to be monitored six and ten years after planting.	*Eucalyptus crebra* and/or *Eucalyptus populnea* are to constitute 21% of the total basal area of woody vegetation on sand plains. **AND** *Eucalyptus camaldulensis* is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7.	Relative dominance of Koala food trees is based on secondary site data gathered from nine sand plain reference sites and three riparian reference sites (METServe, 2022).
C2	Trees are to be sufficiently tall to be used by Koalas and to escape browsing by cattle (except RA1).	Mean height of the tallest ten trees per hectare		Sites are to be monitored six and ten years after planting.	The mean height of the tallest ten trees per hectare is ≥4 m.	The Queensland Environmental Offsets Policy defines non-juvenile Koala habitat trees to be those with a height greater than 4 m (DES 2022). Such trees are also beyond the reach of cattle.
C3	Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons	The mean Normalised Difference Vegetation Index (NDVI) calculated using Landsat imagery captured following at least two months without rain (e.g., late dry season)		Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	Rehabilitated areas are to have a mean NDVI between 0.1240 and 0.1778	Ecological surveys of the local region found that Squatter Pigeons are confined to vegetation with a density that falls within the range of NDVI values used as the completion criterion (METServe, 2022).

ID	Rehabilitation Objective	Rehabilitation Indicator		Assessment Timing	Completion Criteria	Justification
C4	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies.	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.		a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.		A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll *et al.* 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2022). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2022).
C5	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal	Prior to the commencement of topsoil placement	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.		This indicator requires assessment to achieve rehabilitation milestone 2, but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a vehicle accident leading to hydrocarbon spills)
		Water quality at permanent monitoring locations downstream of the Project	Annually, following rain events	Surface water in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.		Site-specific surface water quality triggers will be established over time and present the most accurate measure of effect on water quality.
		Groundwater quality within permanent monitoring bores	Quarterly	Groundwater in downstream monitoring locations is to remain within site-specific water quality monitoring limits, once established.		Site-specific groundwater quality triggers will be established over time and present the most accurate measure of effect on water quality.
PMLU D: Saraji Road						

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
D1	Design and construction in accordance with agreed conditions.	Isaac Regional Council (IRC) assessment.	At the completion of all works within the realigned road reserve.	Fulfilment of all conditions of an agreement with IRC for the construction and commissioning of Saraji Road.	The Saraji Road realignment will be undertaken during the operational phase of the Project, and comprises infrastructure to remain on site after the Project is completed. As such, there are no specific rehabilitation requirements other than to construct and commission the realigned road infrastructure in accordance with conditions specified in an agreement between Vitrinite and IRC.

6 REHABILITATION METHODOLOGY

6.1 infrastructure decommissioning and removal

6.1.1 Infrastructure to be decommissioned

Most infrastructure within the project area, including ancillary infrastructure (ROM pad, offices, fuel storage, haul roads and highwall benches), CHPP, Rail loop and TLO will be removed, de-contaminated, rehabilitated and decommissioned to comply with PMLU milestones.

All infrastructure related waste material, such as concrete, bitumen, tyres and fencing will be demolished/removed and disposed of offsite.

Services, such as water and electricity will also be disconnected and terminated prior to post-closure to comply with RM1.

As part of the final landform, no final voids are proposed and all open cut pits will be backfilled with overburden material and drainage structures will be implemented on and around the final landform to ensure that the landform is free draining. When sediment dam catchments and MAW dams are completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned.

In times when there is heavy rainfall, the plunges will accommodate the MAW runoff. When there is no runoff (or need for storage), then the plunges can be barricaded as the mining progresses along the bench.

In the highwall mining area, completed plunges will be either filled with MAW (as per **Appendix I**) and barricaded or just barricaded and rehabilitation will occur around this.

Diversions will be decommissioned and rehabilitated to comply with PMLU milestone requirements. Existing conditions natural topography will be reinstated within the Hughes Creek floodplain as well as Drainage line 6 and Drainage line 8 Post-closure to replicate the existing drainage line channels to minimise the impacts associated with the Post-closure Conditions landform. Drainage line 1 is proposed to be diverted and subsequently reinstated as part of the VCM. The Hughes Creek floodplain will be reinstated through the Vulcan Main and Vulcan South landforms (**Appendix A**).

6.1.2 Infrastructure to be retained

Infrastructure that is beneficial to the landholder, pending a written agreement between Vitrinite and the post-mining land holder, will be retained. This may include specific water infrastructure for stock watering purposes.

The railway line along the eastern edge of the ML existed prior to mining and will remain unaffected.

6.2 Landform Design

6.2.1 Overview

The final landform has been designed to limit the size of the Project's final footprint while maximising usage of areas already disturbed for the open-cut pits. No final voids are proposed as part of the final landform. The open-cut pits will be backfilled with waste rock material. Due to waste rock swell factors following blasting and handling, the Vulcan North, Main and South in-pit waste rock dumps will fill the void and extend approximately 5 m, 40 m and 20m, respectively, above the pit crests. These in-pit waste rock dumps take the shape of low plateaus. Outer batters will be shaped to 1(V):6(H) (15%) and will contain surface water management measures to drain water from the plateau to the surface water drainage features in the surrounding landscape. Contour banks will be constructed on batters to limit topsoil erosion until vegetation has been suitably established. Refer to the LEM – **Appendix F** for the Vulcan South in-pit WRD dimensions.

The ex-pit waste rock dumps will be approximately 40 metres high (Geotechnical assessment – Appendix G) and have batter slopes of up to 250 m for the Vulcan North ex-pit WRD, 220 m for the Vulcan Main ex-pit WRD and 210 m for the Vulcan South ex-pit WRD (**Appendix F**). Refer to **Appendix F** (LEM) for ex-pit WRD dimensions.

The pits will be backfilled progressively, utilising a combination of paddock dump and end-tipping techniques. Dump lifts are generally anticipated to be low, enhancing rapid material settlement. Placed waste shaping and profiling will be completed with bulldozers. Final landform geometry will be surveyed progressively to maintain adherence to the final landform and surface water management design. In-pit waste rock dumps will have a cover that facilitates plant establishment. Sub-soil, rock mulch and topsoil will be spread with bulldozers and will be the subject of depth and distribution survey and quality control monitoring, as detailed in **Section 9**. PAF materials will be placed in the central core of the WRD and encapsulated with at least 5 m of NAF waste rock material.

All other mining activities will result in limited change to the pre-mining topography and hence all areas excluding the in-pit dumps and the ex-pit dumps will resemble the pre-mining landform. To achieve this, minor shaping or reprofiling works will be undertaken once infrastructure has been removed and any contamination remediated, in order to smooth the ground surface and merge the landform into the surrounding natural contours.

The final landforms for Vulcan North, Vulcan Main and Vulcan South are depicted in **Figure 6-1**, **Figure 6-2**, and **Figure 6-3** respectively.

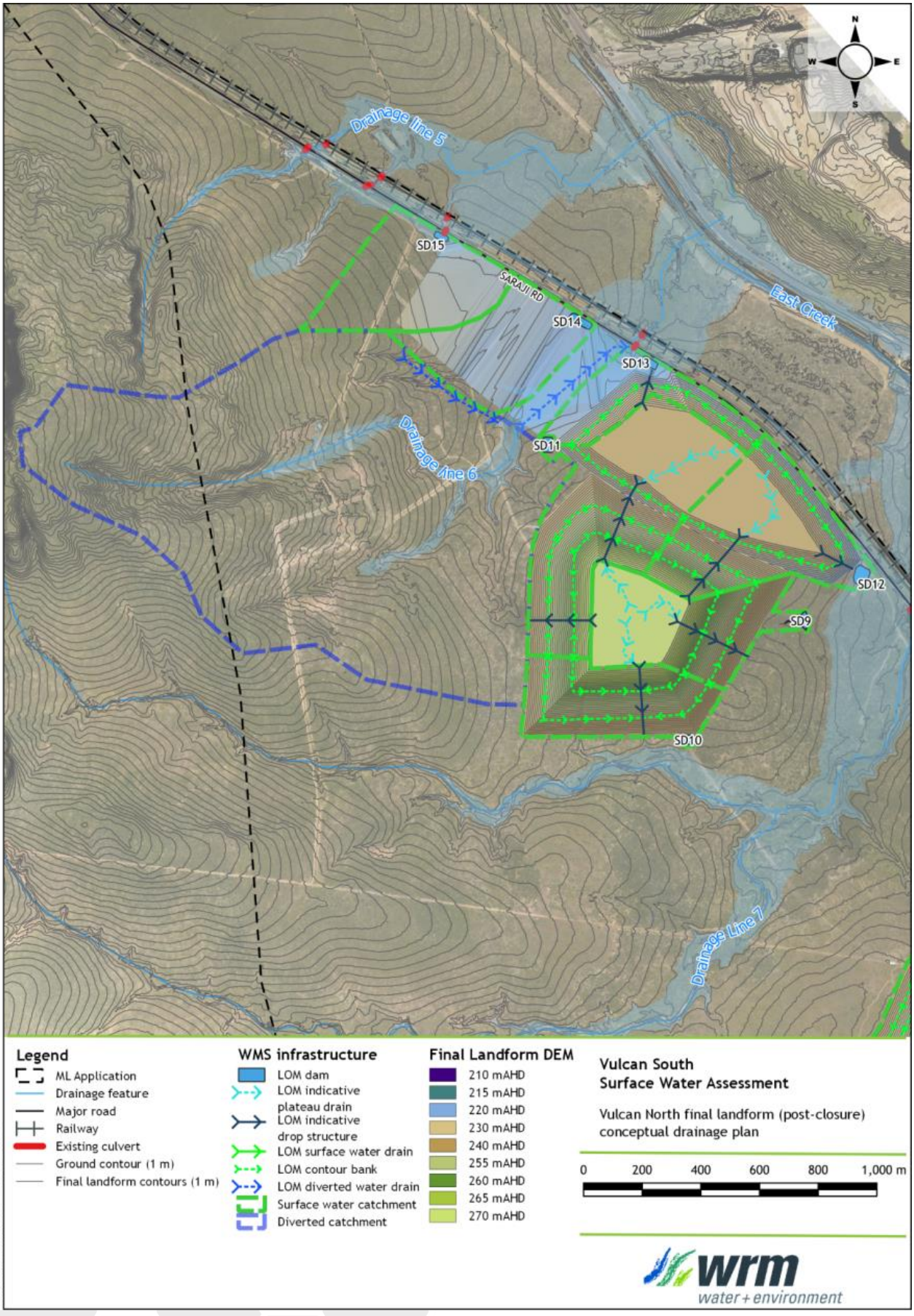


Figure 6-1 *Vulcan North Final Landform*

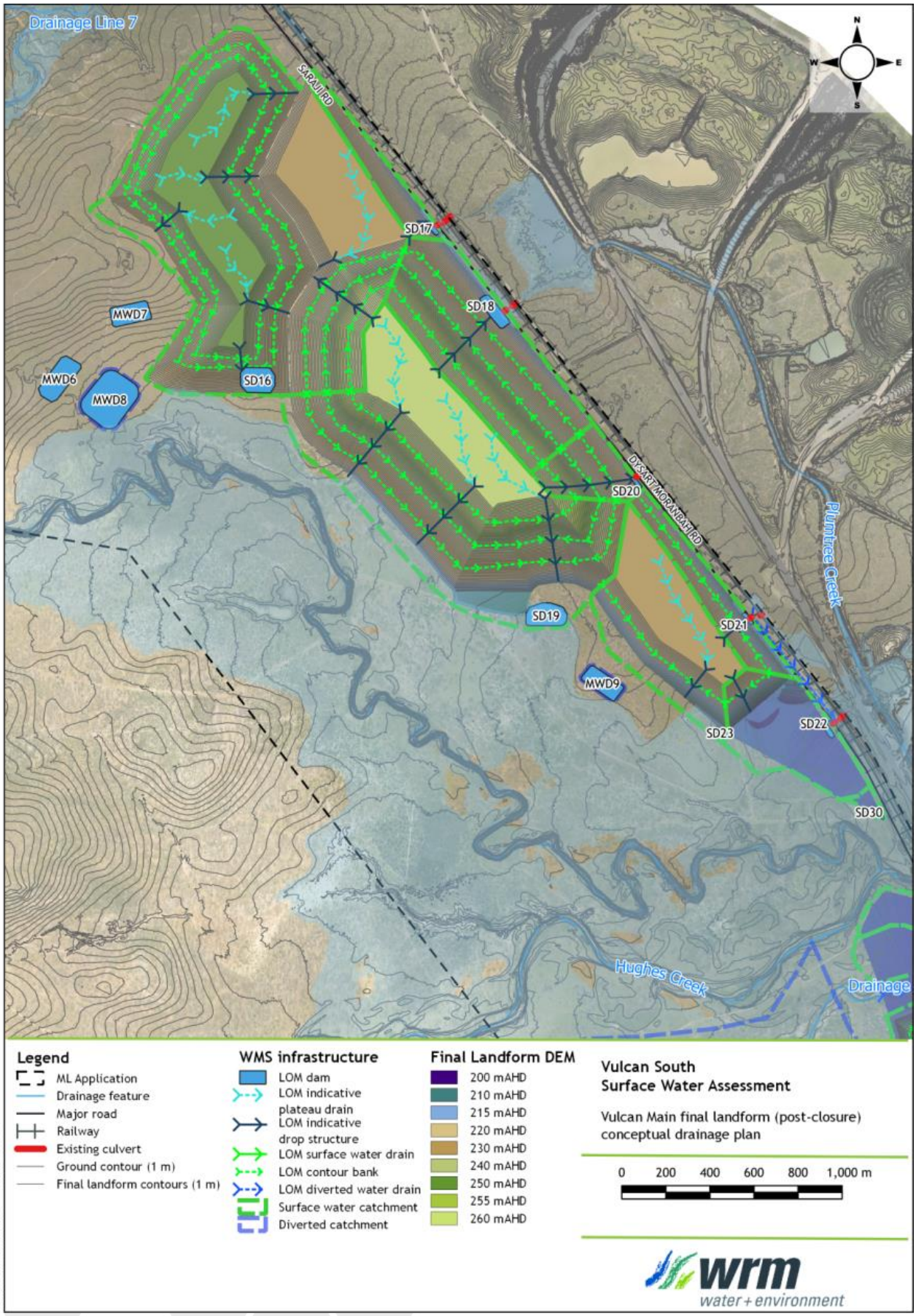


Figure 6-2 Vulcan Main Final Landform

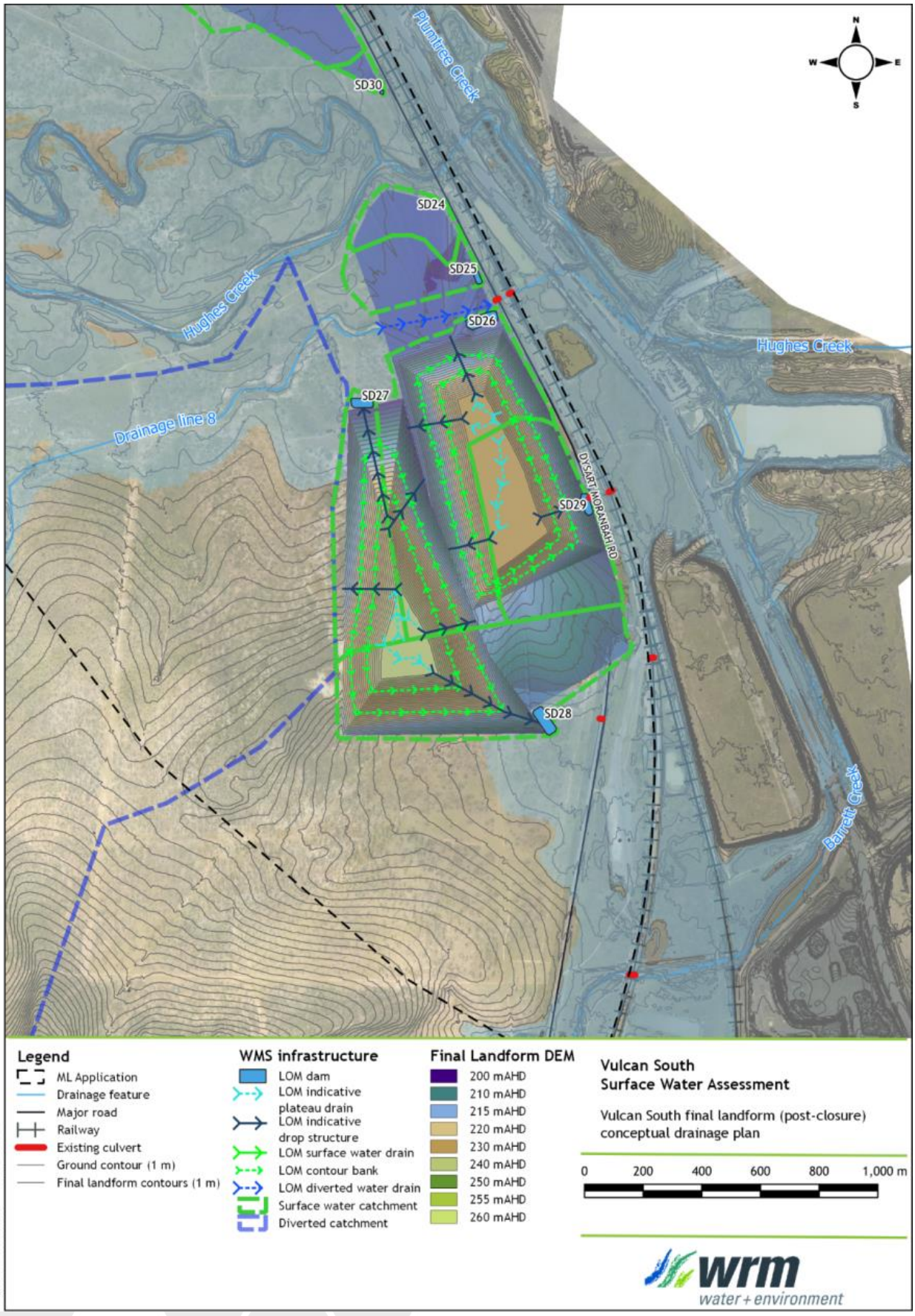


Figure 6-3 Vulcan South Final Landform

6.2.2 Design Assumptions and Limitations

The design of the final landform was based on the following limitations and assumptions:

- the footprints of the in-pit dumps are constrained by the boundaries of the pit, which is itself constrained by coal availability and the easement of Saraji Road along the eastern boundary of the MLA area. For logistic reasons, dumped waste rock will have steeper batters than 15%, which are later recontoured to a 15% slope, resulting in a final landform that extends slightly beyond the original boundaries of the pit;
- the footprints of the ex-pit dumps are constrained by surrounding flood plains, adjoining mine infrastructure and the MLA area boundary;
- batters shaped up to a maximum slope of 15 %.in order to produce a final landform, maximum elevations of 260 m, 250 m and 240 m (reduced level -RL) were selected for the Vulcan North, Main and South ex-pit dumps, respectively, to closely match the pre-mining and adjacent topography;
- the height of in-pit dumps is determined by the volume of waste rock to be removed during mining and the amount that can be stored in the ex-pit dumps given the above constraints in height and footprint;
- final landform designs for the in-pit dumps have considered the dump heights to closely match the hills in the nearby Harrow Range. The in-pit dumps will extend up to approximately 60 m above the surrounding ground level
- a swell factor of 25% has been assumed for waste rock material calculations of dump heights. This swell factor is typically what is observed elsewhere in the Bowen Basin;
- for stability reasons, a maximum slope of 15% was used on the final landforms (based on assessments by AARC 2022 and Blackrock Mining Solutions 2022: summarised in **Section 6.1.8** of this PRC plan) and, where possible, this was reduced further;
- drainage structures were incorporated into the design of the final landform to further improve long-term stability. Drainage designs were based on recommendations and assessments by WRM (2022) and have been engineered so that catchment boundaries and flows are as similar as practicable to the pre-mining state; and
- the plateau formed by the in-pit dumps have a 1% slope to the west, so that surface water is directed away from Saraji Road and into existing drainage systems.

6.2.3 Mine Waste Geochemistry

A geochemical assessment has been undertaken of the waste rock and coal rejects (RGS, 2022) (**Appendix H**). This found that waste rock at the Project had a universally low sulphide content and high acid-neutralising capacity due to high pH. Most of the coal reject materials represented by the samples tested have relatively low sulfide content, excess ANC, and are classified as NAF. All carbonaceous interburden samples within the MLA were classified as non-acid-forming and, as a mixed bulk material, carbonaceous interburden is considered to be non-acid-forming.

An analysis of the concentrations of 22 metals and metalloids (and four other trace elements) within waste rock revealed that no samples were relatively enriched, compared to the mean crustal abundance of each element (RGS, 2022). The potential solubility of any metals/metalloids in the materials was investigated further through water extract and kinetic leach column tests. Most metal/metalloid concentrations tested in the water extracts were below the applied water quality guideline criteria. The main exceptions were aluminium (four/10 samples) and copper (three/10 samples), which had a concentration in some of the water extracts above the applied freshwater aquatic ecosystem water quality guideline value for 95% species protection (ANZG 2018), but below the applied guideline values for livestock drinking water. Based on these results, the risk of potential impact on the quality of surface runoff and groundwater from bulk mining waste materials at the Project is low. The results of the kinetic leach column tests supported the results of the water extracts; namely, that the concentration of metals/metalloids in the leachate was low and typically below the laboratory limit of reporting. The concentrations of all metals/metalloids were below the applied water quality guideline criteria for aquatic freshwater ecosystems (95% species protection level) (ANZG 2018).

Like the waste rock material, the coal reject material had a mean acid-neutralising capacity that far exceeded (more than twice) the maximum potential acidity. However, there was variability between samples, such that one sample (out of 11) was classified as "potentially acid-forming", and a further three samples were classified as "uncertain". As a bulk mixed material, coal reject has a relatively low risk of generating acidic drainage. This risk can be further lessened by disposing reject materials within cells contained within waste rock dumps that have a very high acid-neutralising capacity. As for waste rock, leachate from coal reject samples did not have elevated metal concentrations during kinetic leach column tests. All processing wastes, including reject material and dry tailings, will be stored within waste rock dumps (primarily the in-pit dumps), removing the requirement for a tailings storage facility at the site. Priority will be given to disposing processing wastes within in-pit dumps at depth; however, scheduling constraints may necessitate storage of some material in out-of-pit waste rock dumps.

The in-pit disposal of mixed coarse and fine reject materials within waste rock cells is also a low risk strategy as the much larger volume of waste rock typically has very low sulphur content and excess acid-neutralising capacity. This mining waste management strategy is currently used at a number of coal mines in the Bowen Basin (RGS, 2022).

Overall, surface runoff and seepage from the waste rock material is expected to be pH neutral to slightly alkaline and have a low level of salinity. Dissolved metal and metalloid concentrations in surface runoff and leachate from bulk mining waste materials are expected to be low and unlikely to pose a significant risk to the quality of surface and groundwater resources.

6.2.4 Cover Design

Geochemical characterisation of waste rock has demonstrated that with a co-disposal strategy of rejects and waste rock at depth, there is a minimal potential for acid mine drainage, neutral metalliferous mine drainage or saline mine drainage (RGS, 2022) (**Appendix H**). Due to the benign nature of all waste rock material on site, low-permeability (air and water) cover systems are not required or proposed.

Rather than being designed to limit permeability, the proposed cover has been designed to facilitate vegetation re-establishment on waste rock. Following the return of waste rock to the mined pit, at least 300 mm of subsoil (removed from the pits prior to mining and stockpiled) will be spread over the waste rock (**Figure 6-4**). This will enhance the water-holding capacity of the soil and provide a more favourable growing environment for vegetation. Given the vulnerability of local subsoils to dispersion, some waste rock will be mixed with the subsoil (approximate ratio of rock to subsoil of 1:3), to provide protection from erosion, in the unexpected event that that rock mulch cover and developing grass cover doesn't provide adequate protection, and the overlying topsoil becomes eroded in places. Where required, 30% cover of rock mulch will be applied to 10-15% gradients will be more than adequate for maintaining stability until vegetation establishes.

Topsoil will be spread over the subsoil/rock mix to a depth of 0.25 m to provide a favourable medium for plant establishment. Note that this cover design varies slightly between rehabilitation areas due to rehabilitation requirements (**Table 6-1**).

In addition, a number of topsoil and subsoil ameliorative measures will be implemented, where required, to ameliorate poor soil structure, low moisture retention and low nutrient concentrations that may be encountered with the Limpopo SMU (**Section 1.2.7**). Such amelioration measures may include the application of organic matter, fertiliser, rapid establishing cover crops, and hydro mulching. More specific detail on the application of these measures is provided in **Section 6.3.4 to 6.3.7.**

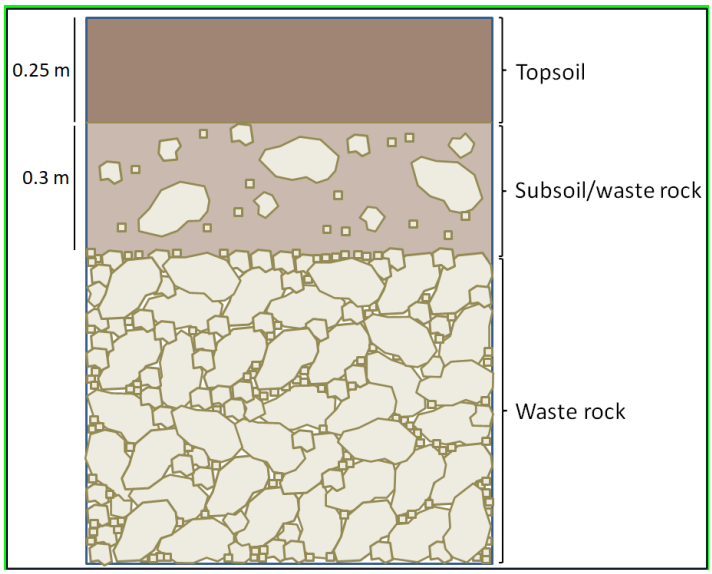


Figure 6-4 Cover design to optimise plant growth

There is strong evidence to support the suitability of the proposed cover design for plant establishment:

- Many independent studies across north-eastern Australia have found that 75-95% of total root biomass within open eucalypt forests and woodlands is contained in the upper 0.5 m of the soil profile (Eamus *et al.* 2002; Zerihun et al. 2006; Grant *et al.* 2012), so a soil depth of 55 cm is expected to be suitable for supporting tree growth.
- The cover design is similar to the natural soil profile on the Crocodile soil management unit, which has an average soil depth of 0.62 m above rock (see **Section 1.2.7**) and supports a dense cover of native vegetation.
- Trials undertaken at the adjacent Saraji Mine compared vegetation establishment on waste rock (spoil) that received 0 cm, 10 cm or 30 cm of topsoil prior to planting (Kopittke *et al.* 2004). Grass established at higher densities in the topsoil treatments than on the spoil; however, even on spoil, grass achieved 70% cover. Native trees and shrubs actually established better without topsoil, due to reduced competition with grass, but natural thinning over the first ten years resulted in a final stem density that was equivalent to the topsoil treatments. The spoil at Saraji is more saline (Kopittke *et al.* 2004) than that at Vulcan South, suggesting that local waste rock is unlikely to pose a barrier to root growth for local vegetation. Based on these trials, the cover proposed at the Project is expected to be ideal for establishing a productive pasture with a moderate density of native woody vegetation.

The highwall mining area cover design strategy will differ from areas in the central and southern portion of the lease due to the steep topography, rocky terrain and the nature of the SMU (Crocodile) unique to highwall mining area There is naturally little to no subsoil, especially on the sloped regions and a shallow layer of topsoil. For this reason, it will be very difficult to extract 0.3m of topsoil for use in rehabilitation. Instead, and more feasibly, 0.15 m of topsoil will be extracted from the highwall mining area and mixed with crushed rock (from the rocks located with the highwall mining area) to create a total depth of topsoil/crushed rock of 0.25 m, which is in line with the topsoil depth of areas outside of the highwall mining area (**Figure 6-5** below).

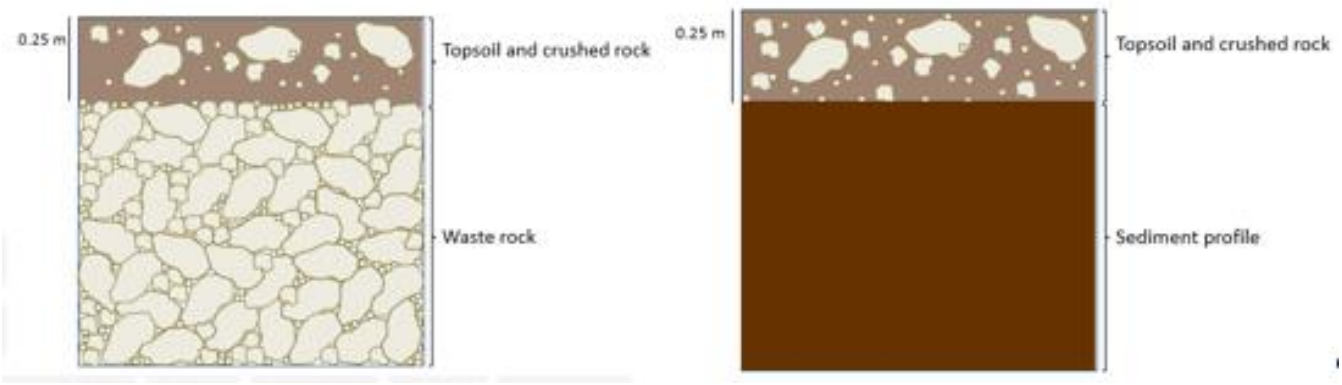


Figure 6-5 Highwall mining area cover design strategy for ex-pit WRD (left) and remaining areas (right)

Table 6-1 Cover variations in each rehabilitation area

Rehabilitation Area	Deviation from standard cover design	Justification
RA1: Ex-pit dump	Topsoil is to be placed directly on waste rock without an intermediate layer of subsoil.	Insufficient subsoil material is available at an appropriate stage of project development to apply this to the ex-pit Dump.
RA2: In-pit dump	None	N/A
RA3: Infrastructure	Topsoil is to be placed directly onto prepared disturbed surfaces.	Apart from the rail loop, where deeper incisions may be required for cuttings, no waste rock or subsoil is to be removed from infrastructure areas and therefore these remain intact. For the rail loop, subsoils will be replaced during the backfilling of any excavations, to resemble conditions prior to subsoil removal.
RA4: Dams and sediment ponds	Land is to be reformed prior to the deposition of topsoil. No waste rock or subsoil is added, beyond what is already contained within the dam walls.	There is to be minimal disturbance to the soil profile at dams once reforming has been conducted and topsoil returned.
RA5: Saraji Road	No cover is proposed.	RA5 is to remain an asphalt road in perpetuity.
RA6 Highwall Mining Area- ex-pit WRDs, dam, highwall bench and plunges	Ex-pit WRD: Topsoil/crushed rock is to be placed directly on waste rock without an intermediate layer of subsoil. Highwall plunges: the completed plunges will be barricaded or alternatively filled with MAW as a storage area and then barricaded.	Ex-pit WRD: Insufficient subsoil material is available at an appropriate stage of project development to apply this to the ex-pit Dump. The topsoil in this area is limited and therefore is to be mixed with crushed rock to allow for enough plant growth medium. Highwall plunges: This methodology will provide an option for the control of MAW
RA7 Highwall Mining Area- magazine and haul road	The topsoil in this area is limited and therefore is to be mixed with crushed rock to a level of 0.25 m to allow for enough plant growth medium.	The topsoil in this area is limited and therefore is to be mixed with crushed rock to a level of 0.25 m to allow for enough plant growth medium.

6.2.5 Material Availability

All materials (i.e., topsoils and subsoils) to be used for rehabilitating disturbed land will be sourced from the disturbance footprint and stockpiled during the mining process, until required for rehabilitation. Given that the post-mine landform will be similar but not identical to the pre-mine landform, discrepancies are likely between the quantities of materials obtained from each area and the quantities required to be returned.

As described in Section 6.2.3 and **Appendix C**, only 2/8 SMUs (Crocodile and Kei) contain viable subsoil to be used in rehabilitation without the need for additives. This means that subsoil collected from other SMUs will need to be mixed with materials such as gypsum before being used for rehabilitation. **Table 6-2** was calculated using the rehabilitation soil profile plan as described in **Section 6.1.3**, where 30 cm of the soil profile is removed prior to mining.

As can be seen by the materials balance shown in **Table 6-2**, any discrepancies caused by alterations to the landform are expected to be balanced by (a) replacing a slightly thinner layer of topsoil than removed and (b) mixing rock with subsoils. Ample remaining material is available as a contingency. Where additional topsoil or viable subsoil material is available, more will be placed as required. Assumptions for the material balance are that 30 cm of topsoil and subsoil will be stripped and 0.25 m will be placed back for rehabilitation in all areas except RA6 and RA7 (where 0.15m of topsoil will be stripped and 0.15 m will be returned and mixed with crushed rock).

Table 6-2 Materials balance for topsoils and subsoils to be used for rehabilitation

Material	Amount removed from disturbance footprint available for application (m^3)	Amount required for rehabilitation (m^3)	Balance (m^3)
Topsoil*	3,629,670	3,044,925	584,745
Subsoil†	1,293,600	970,200	323,400
Waste rock	282,248,294 tonnes	323,400 tonnes	281,924,894 tonnes

*The top 0.30 m of topsoil is removed from most disturbed areas prior to mining, while 0.25 m of topsoil is returned to all rehabilitated areas
"This calculation assumes that subsoil is only removed for RA2: In-pit dumps; and RA4: Dams, sediment ponds and water management infrastructure. RA3 and RA5 refer to infrastructure and rail construction areas which will not require subsoil layers rehabilitated.
*The top 0.30 m of topsoil is removed from most disturbed areas prior to mining, while 0.25 m is returned to all rehabilitated areas.
The exception to this is RA6 and RA7 of the highwall mining area, where there is naturally no subsoil and topsoil is limited. For this reason, 0.15m of topsoil will be stripped and combined with 0.10m of crushed rock to make up a 0.25 m depth.
†The top 0.30 m of subsoil is removed from some disturbed areas (RA2-in-pits and RA4-dams) prior to mining, and three parts of this is diluted with one part rock when returned to rehabilitated areas.
A 0.30 m layer of subsoil is required for rehabilitation, with the layer consisting of 0.075 m of waste rock and 0.225 m of subsoil – a 1:3 ratio of waste rock to subsoil.

Drilling conducted by Vitrinite has identified medium to high-strength sandstone resources both above and between coal seams that are likely to be suitable for use in rock mulching. Based on geological modelling, this resource is expected to be abundant far beyond the requirements for landform construction.

The geochemical and geophysical characteristics of waste rock will be assessed to identify the suitable strata for use in landform stabilisation. Once these strata are confirmed, mine scheduling and selective handling will be applied to ensure that suitable material is available for the progressive rehabilitation of landforms. Further information on waste rock testing is provided in **Section 6.3.8.**

6.2.6 Surface Water

A mine site water management system will be implemented throughout the operational and rehabilitation phases of the Project to mitigate the potential impacts on surface water resources. A surface water monitoring program will be implemented to monitor potential environmental impacts and ensure that the site water management system is meeting its objectives.

Final Landform Drainage

The conceptual final landform drainage is provided in **Appendix A**. This presents the proposed drainage principles to be implemented on the final landform. The drainage plan has been developed with the aim of retaining certain water infrastructure constructed during operations, for the management of surface waters in closure. Pending the requirements of the post-closure landholder and a formal written agreement between Vitrinite and the landholder some sediment dams may be retained for the purposes of stock watering. Otherwise, troughs or other water related infrastructure will be installed for the purposes of stock watering, as part of RM6.

The landform is intended to be free-draining and to discharge to the receiving environment water of a similar quality to surrounding background sites. **Figure 6-6** depicts the final landform and key drainage features of Vulcan North post-closure and the marked cross sections (XS-1 and XS-2) are illustrated in **Figure 6-7.** Figure 6-8 depicts the final landform and key drainage features of Vulcan Main and the marked cross sections (XS-3 and XS-4) are illustrated in **Figure 6-9, Figure 6-10** and **Figure 6-11**. **Figure 6-12** depicts the final landform and key drainage features of Vulcan South and the marked cross sections (XS-5, XS-6) are illustrated in **Figure 6-13.**

The following structures are proposed to comply with the site water management system:

- diverted water drains, bunds and drainage diversions to divert runoff from undisturbed catchments around areas disturbed by mining;
- flood protection levees along the southern side of the Vulcan North pit extent,
- along the western and southeastern sides of the Vulcan Main pit, and around the Vulcan South pit;
- sediment dams and drains to collect and treat runoff from waste rock emplacement areas; and
- mine-affected water drains and dams to store water pumped out of the open cut mining areas and to

The key features of the final landform are:

- no final voids are proposed. All open cut pits will be backfilled with waste rock material;
- drainage structures will be implemented on and around the final landform to ensure that the landform is free draining; and
- when sediment dam catchments are completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned.

The conceptual final landform is not considered likely to have a long-term significant impact on the receiving waters (WRM, 2022).

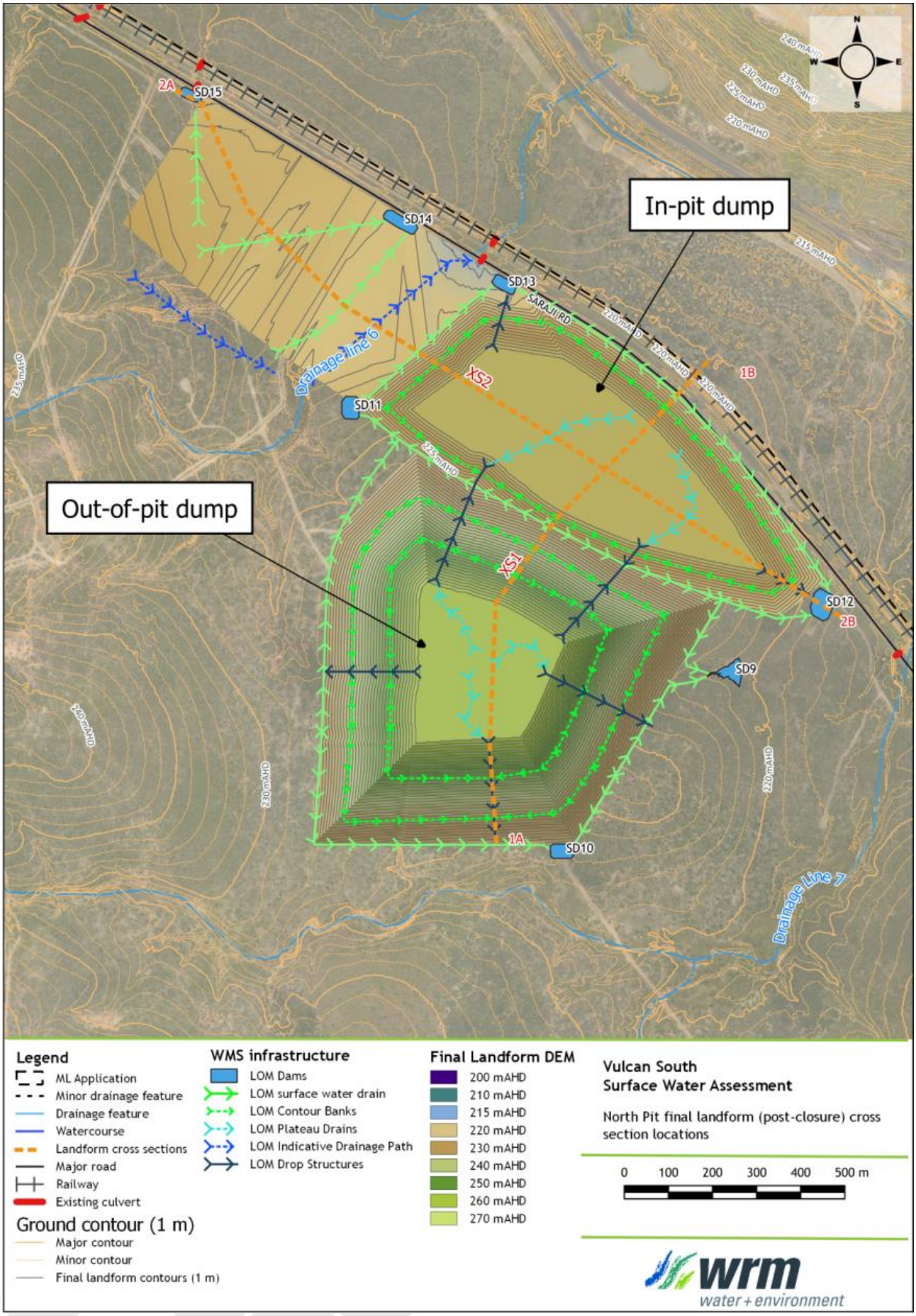


Figure 6-6 Vulcan North Final Landform cross section locations

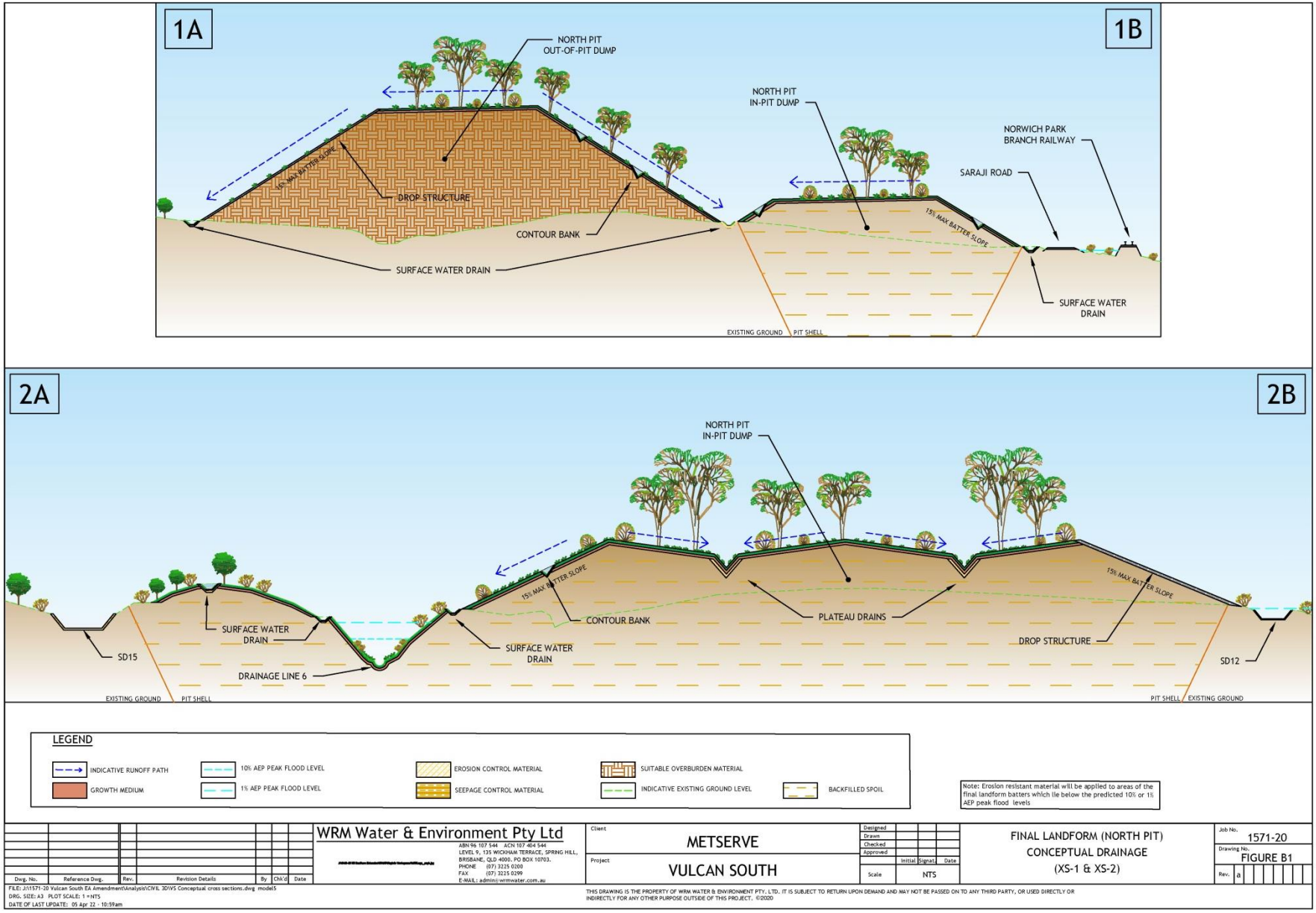


Figure 6-7 Vulcan North Final Landform Conceptual Design (XS-1, XS-2)

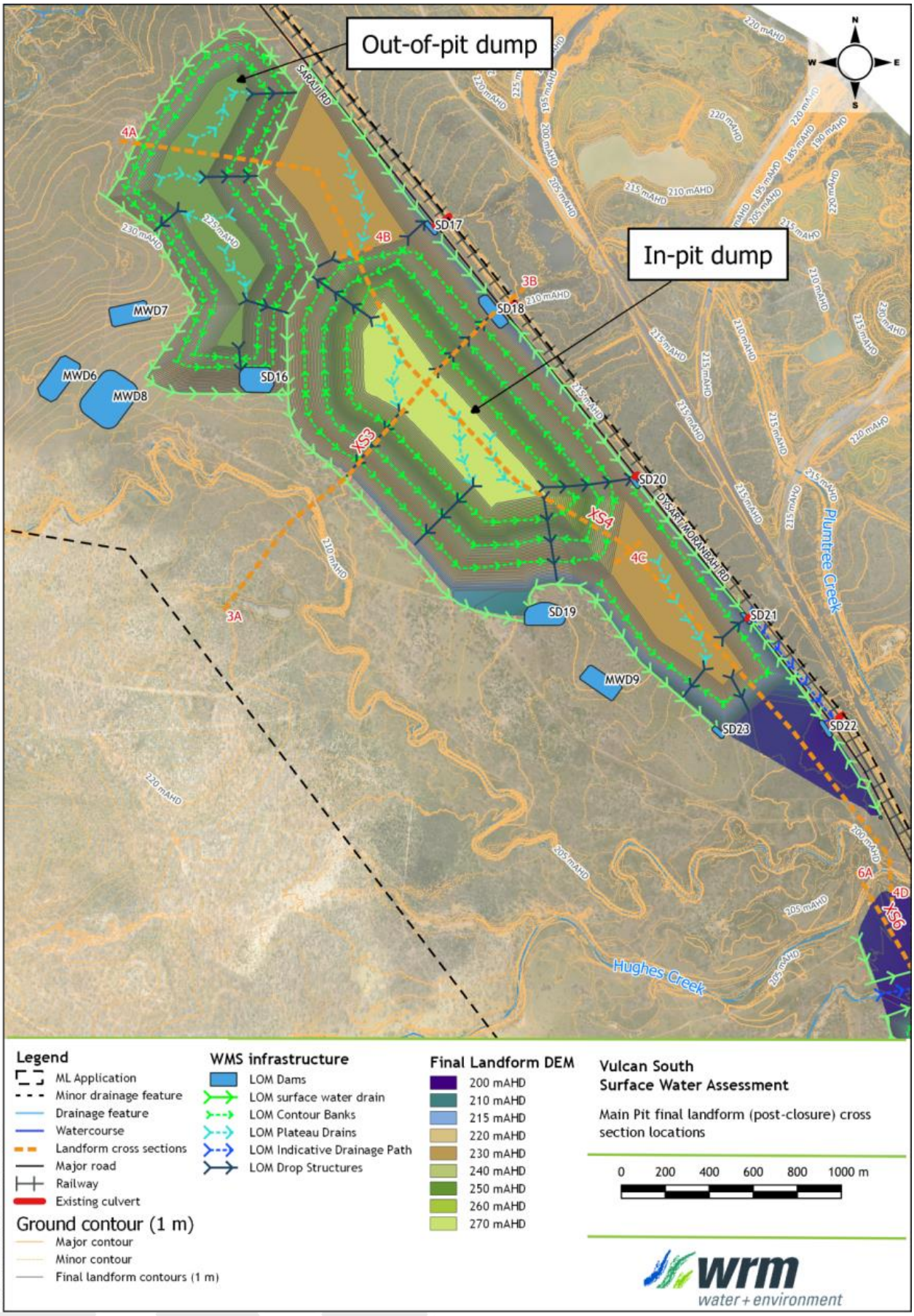


Figure 6-8 Vulcan Main Final Landform cross section locations

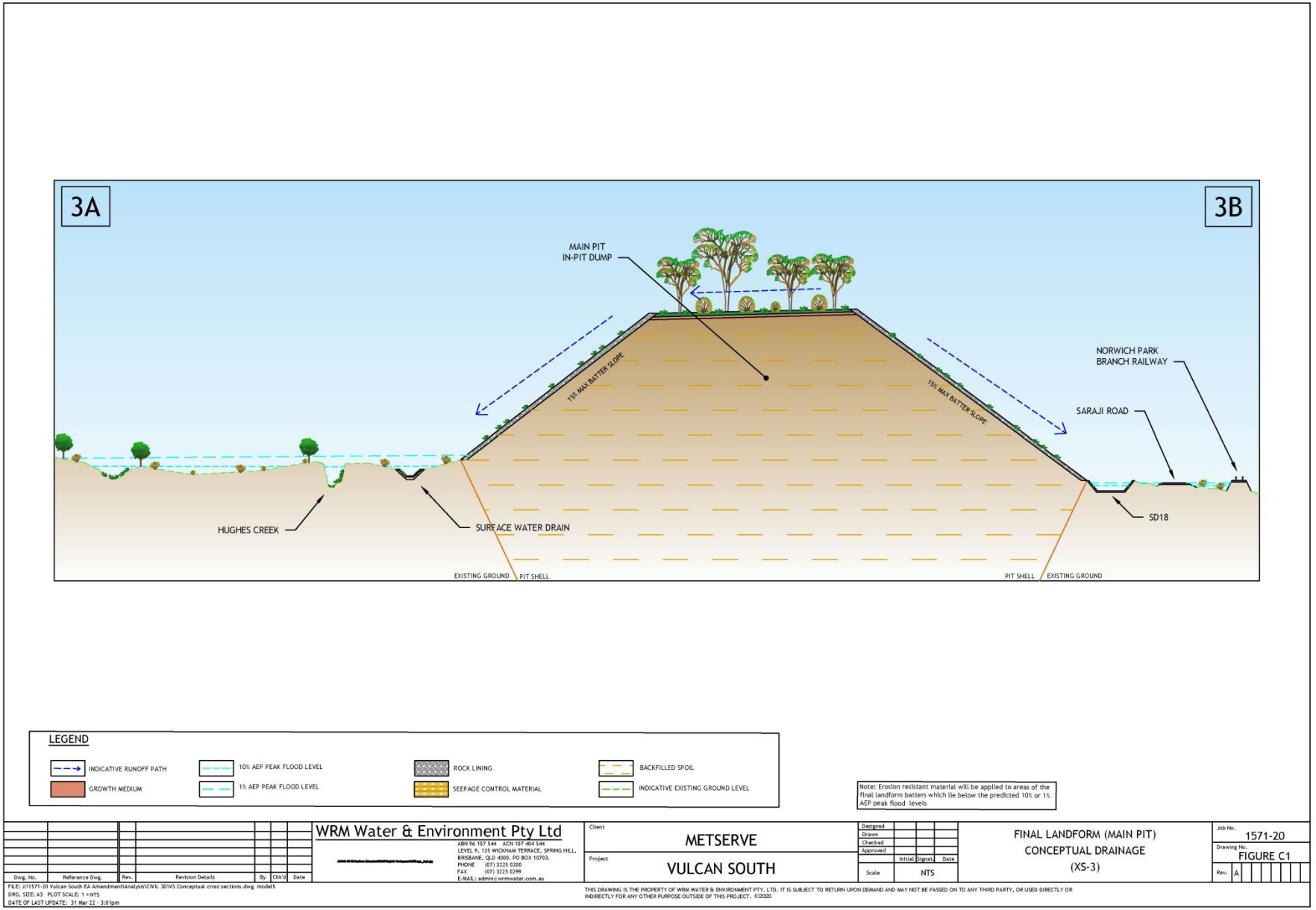


Figure 6-9 *Vulcan Main Final Landform Conceptual Design (XS-3)*

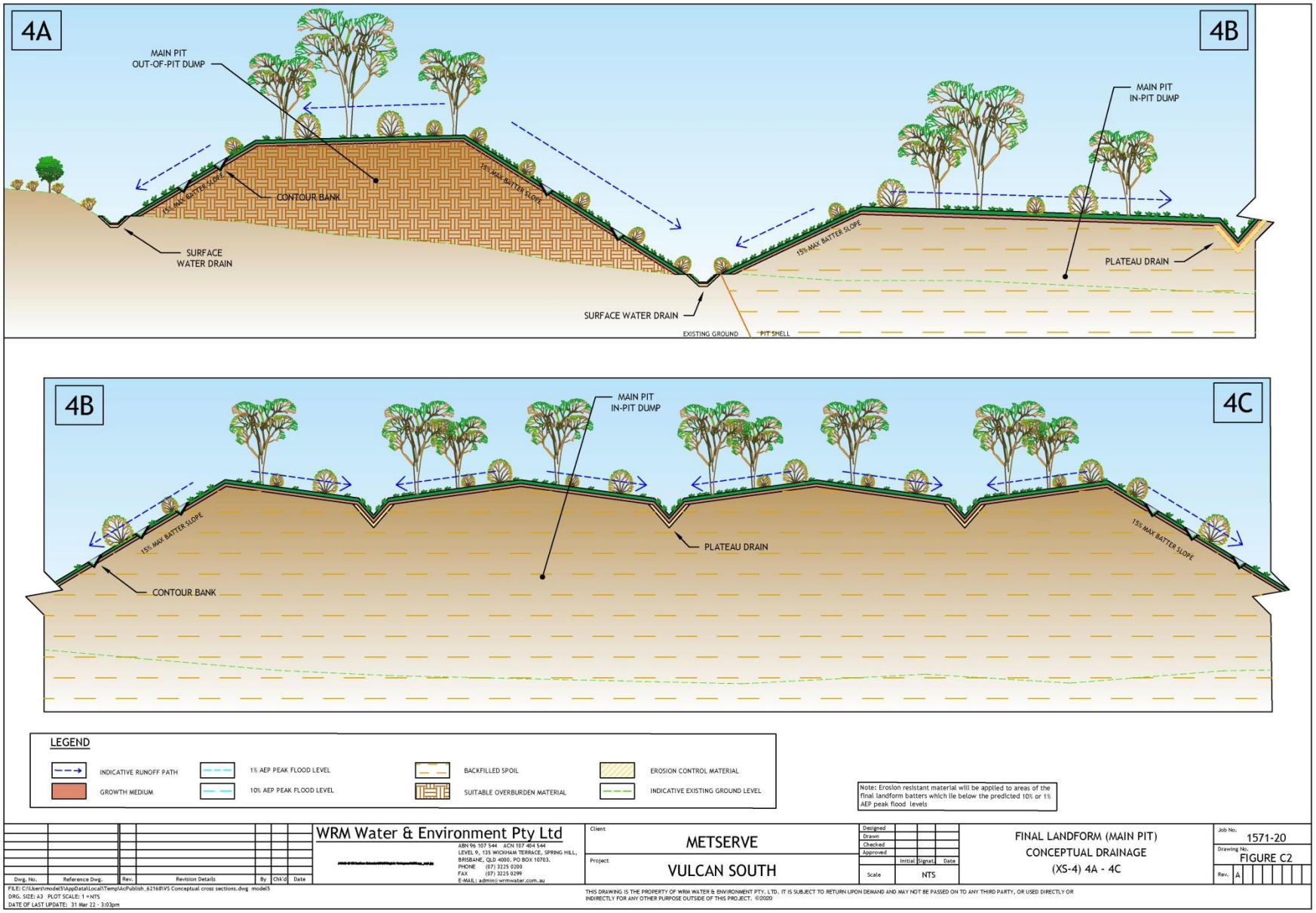


Figure 6-10 Vulcan Main Final Landform Conceptual Design (XS-4abc)

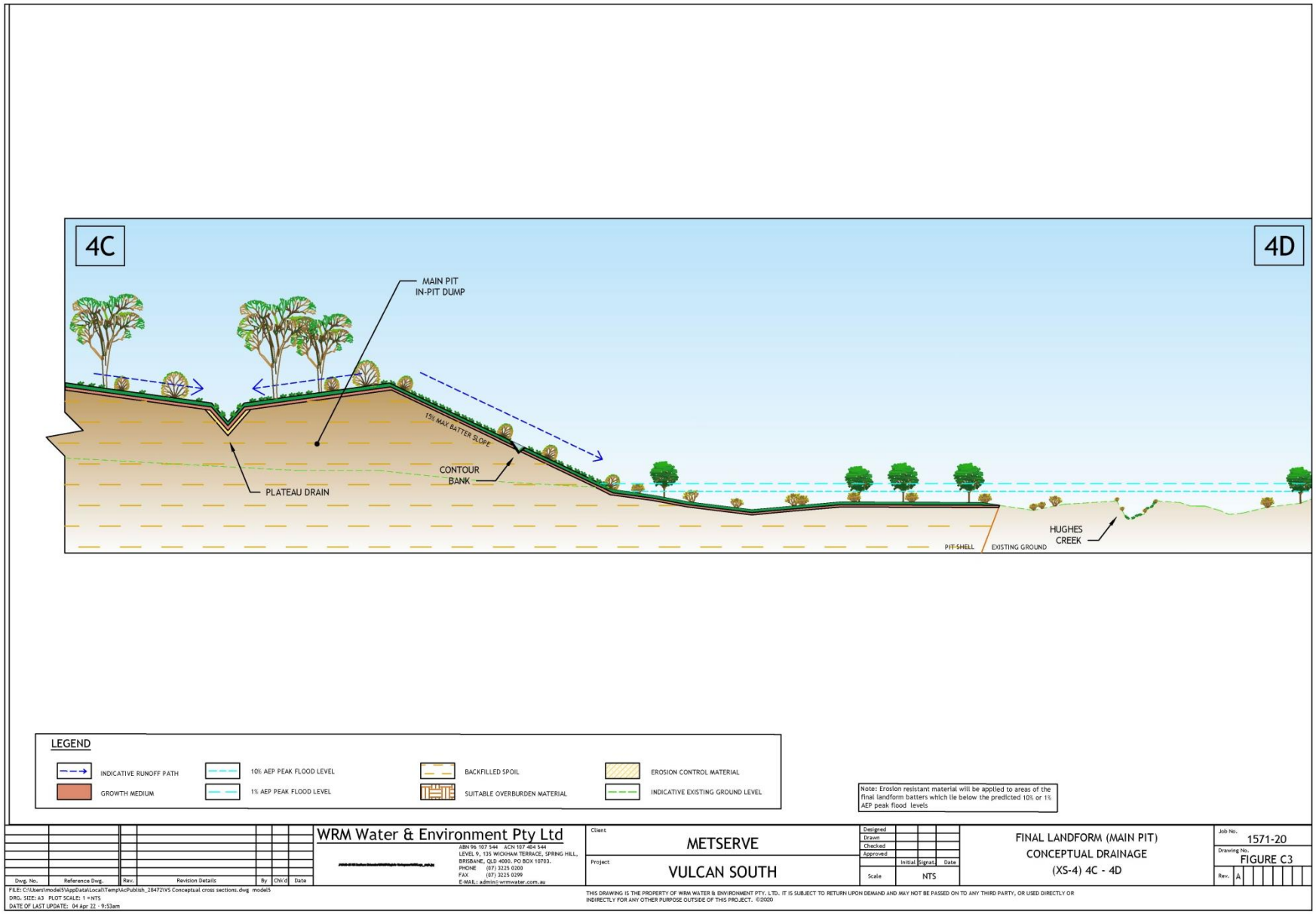


Figure 6-11 Vulcan Main Final Landform Conceptual Design (XS-4cd)

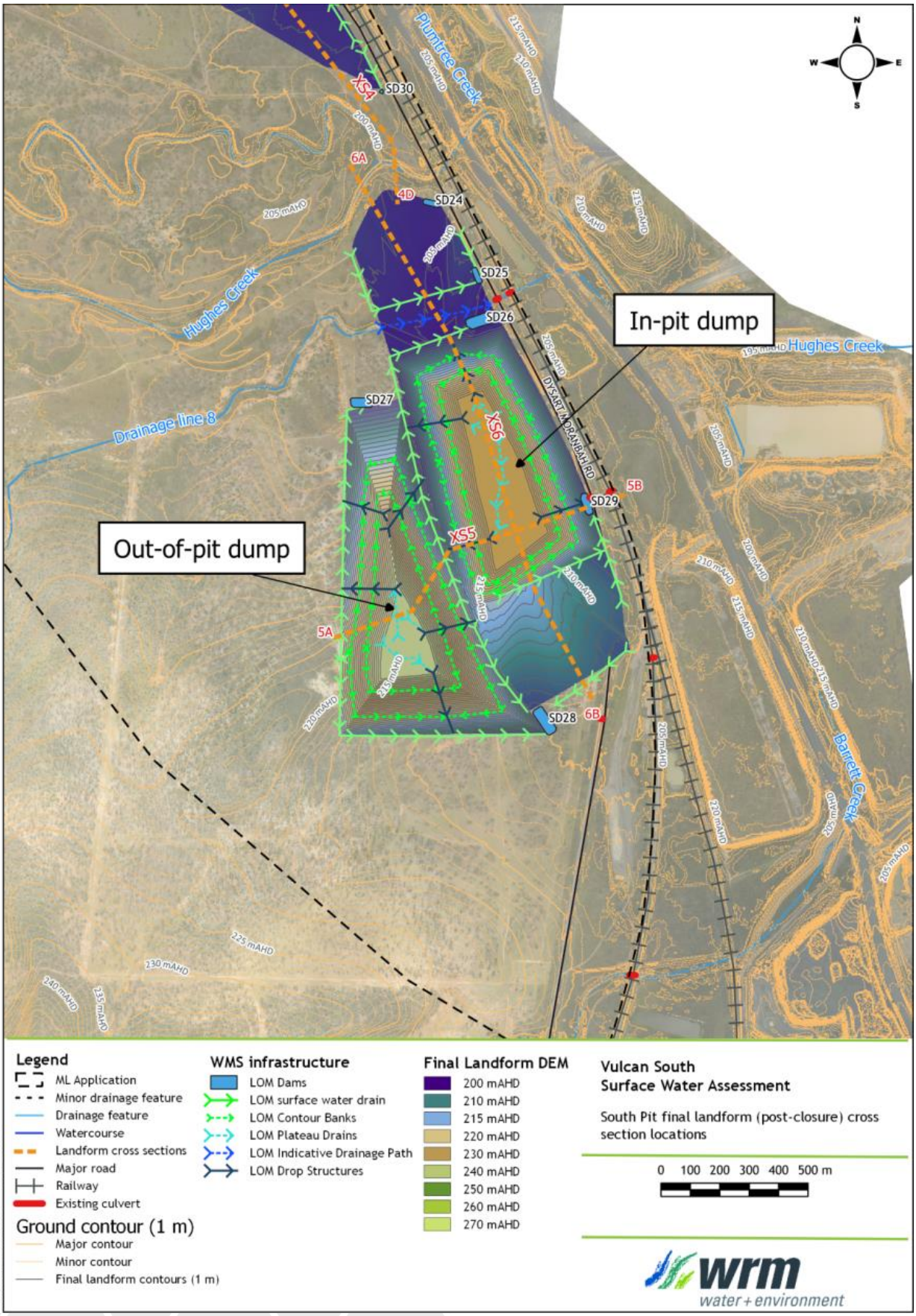


Figure 6-12 Vulcan South Final Landform cross section locations

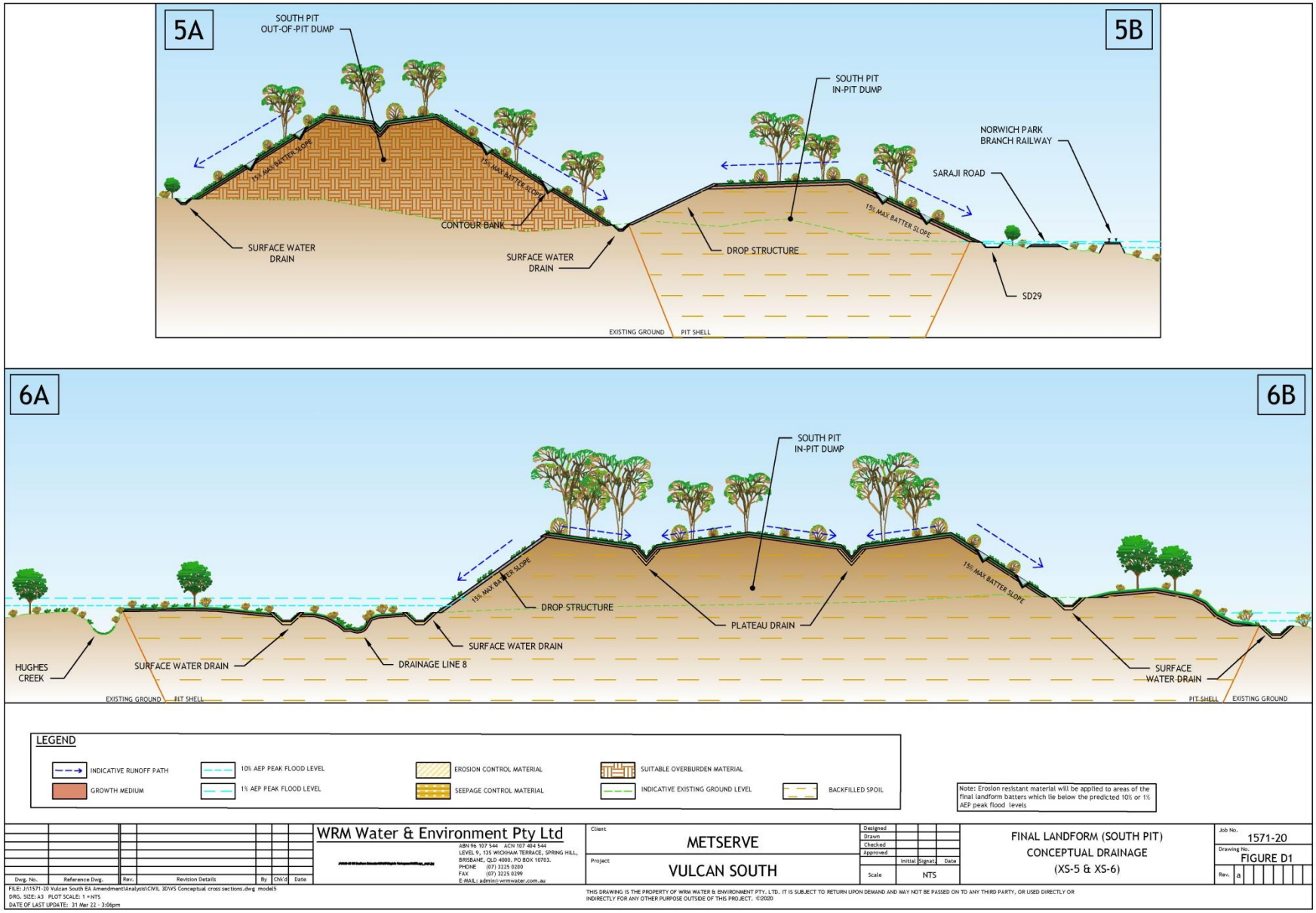


Figure 6-13 Vulcan South Final Landform Conceptual Design (XS-5, XS-6)

Water Management

The catchment areas of each of the mine water storages, as well as the assumed land use within each catchment are also shown in **Section 1.2.5**. The key water management features in the final landform include:

- no final voids are proposed as part of the final landform. The open cut pits will be backfilled with waste rock material;
- final landform batter slopes will be a maximum of 1(V):6(H) (approximately 15%);
- contour banks will be constructed on batters to limit topsoil erosion until vegetation has been suitably established;
- drainage structures will be constructed to direct runoff from disturbed areas to sediment dams;
- the plateaus include proposed drains and drop structures to drain the top of the landform to natural ground level;
- mine water dams will be decommissioned and rehabilitated to be in accordance with PMLU's ;
- Drainage line 6 and Drainage line 8 will be reinstated through the Vulcan North and Vulcan South final landforms respectively; and
- the Hughes Creek floodplain will be reinstated through the Vulcan Main and Vulcan South landforms.

When a sediment dam's catchment is completely rehabilitated, and water quality monitoring has established that the runoff is consistent with natural background conditions, the sediment dam will be decommissioned.

When Drainage Line 6 is rehabilitated, DD2 will be decommissioned. DD2 will remain until this time to allow in-stream vegetation to establish along Drainage Line 6 before receiving upstream catchment flows. Further details of proposed water storages, including indicative storage sizes and pumping rules are provided in **Appendix A.**

Impacts on downstream water quality

Preliminary baseline monitoring indicates that water in the surrounding environment is of poor quality. The water balance modelling indicates that no mine-affected spills are predicted from mine operations. Modelling (**Appendix A**) predicts that the EC for spills from the sediment dams will be below the water quality objective (720 µS/cm) for baseflows of the Project area. In consideration of the heavily disturbed nature of the surrounding catchment, it is unlikely that the Project will have a measurable impact on receiving water quality or environmental values.

As described in Section 6.2.9, the landform evolution model determined that there would be negligible sedimentation effects on downstream waterways (**Appendix F**).

Impacts on downstream water quality will be monitored throughout the duration of operations and rehabilitation, and specific milestone criteria have been developed to ensure no downstream impacts occur (Section 9). In summary, the conceptual final landform is not considered likely to have a long-term significant impact on the receiving waters (**Appendix A**).

Flood Modelling

WRM (2022) has modelled the extent of flood plains within the Project and surrounding areas based on the final landforms described in **Section 6.2.1** (**Appendix A**). Peak water levels and peak velocities were compared to pre-mining conditions for the 10%, 1% and 0.1% AEP events.

Models show only minor changes to flood plain configuration and function under the final landform. Most impacts do not extend beyond the Project area. The models highlighted that erosion and scour protection will be required along the reinstated drainage lines and existing channels to mitigate the risk of rapid geomorphic change. These impacts are generally confined within the Vulcan South MLA. Existing conditions natural topography will be reinstated within the Hughes Creek floodplain, as well as Drainage line 6 and Drainage line 8 post-closure to replicate the existing drainage line channels to minimise the impacts associated with the post-closure conditions landform.

Overall, the impact of the Project on the hydraulic characteristics of Boomerang Creek, Hughes Creek and their tributaries do not affect the existing conditions significantly.

It is expected that the channel and floodplain will undergo little, if any, adjustment to the altered hydraulic conditions upstream or downstream of Vulcan South as a result of the Project.

The full details of flood modelling are found in **Appendix A**, along with full mapping of flood extents under existing, operational and post-closure conditions presented in **Appendix A** of that appendix.

6.2.7 Hydrogeology

Hydrogeologist.com.au (2022) has developed a numerical hydrogeological model of all relevant aquifers within the MLA area and broader region to predict the effects of the Project, on local groundwater levels. This was based on a range of data sources, including an on-site groundwater monitoring network, groundwater assessments from nearby mines, and the Queensland Groundwater Database (DNRME, 2020).

An adaptive management strategy is proposed to assist with the management and mitigation of any potential drawdown and water quality impacts on the site. The overall framework for the adaptive management strategy includes ongoing monitoring programs of groundwater level and water quality, and the development of site-specific groundwater trigger levels and contaminant limits.

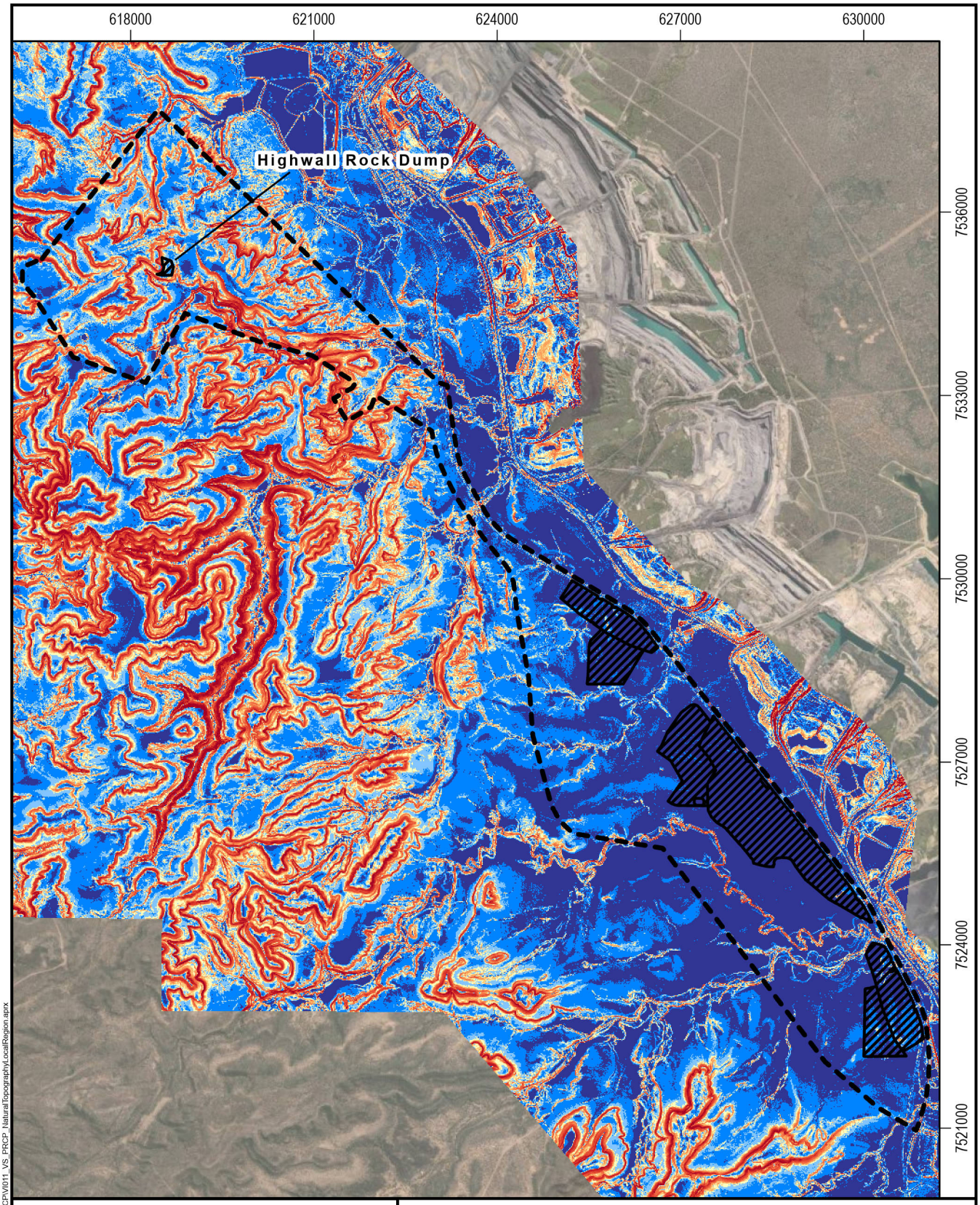
6.2.8 Predicted Stability

An extensive review of literature was undertaken to assess the local landscape, extent of protective cover of natural slopes, and slope stability in the region. Overall, that proposed final landform is expected to be stable under a post-mining land use of low-intensity cattle grazing. The following are the main lines of evidence for this:

- the final landform is similar to the topography of surrounding areas; the maximum slope proposed in the final landform is 15%, and 45% of the local landscape comprises grazed slopes that are naturally steeper than this;
- a 30% cover of rock mulch is applied to 10-15% gradients will be more than adequate for maintaining stability until vegetation establishes;
- studies conducted at other mines across the Bowen Basin have found that 15% gradients with only a moderate groundcover of 30-40% have very low erosion rates;
- other Bowen Basin mine sites regularly achieve vegetative cover of 30 to 100% on rehabilitated waste rock, which is more than adequate for maintaining the stability of 15% gradients; and
- even after considering the removal of vegetation expected from cattle grazing, a sufficient cover is expected to be maintained on rehabilitated sites in the long term.

Further discussion is provided in the subsection below.

The topography of the region is shown in **Figure 6-14.** The final landform has slopes comparable to the existing natural topography, which is stable under low-intensity grazing. A large percentage of the natural landscape surrounding the Mine is steeper than the maximum slope for the final landform.



Legend

- MLA Boundary
- Waste Rock Dump

Slope

- ≤5%
- 5-10%
- 10-15%
- 15-20%
- 20-25%
- 25-30%
- 30-35%
- 35-40%
- 40-45%
- 45-50%
- 50-55%
- 55-60%
- 60-65%
- 65-70%
- 70-75%
- 75-80%
- 80-85%
- 85-90%
- 90-95%
- ≥95%

Source: Vitrinite 2019-2022, METServe 2022, Earthstar Geographics.

Vulcan South

Natural Topography of the Local Region

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 6-14

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_NaturalTopographyLocalRegion.aprx

Extent of Protective Cover on Natural Slopes

Many naturally steep slopes in the local region maintain low erodibility via a high cover of rock, vegetation and leaf litter. Ecology surveys undertaken across the area surrounding and including the Project measured groundcover and slope. All sites were maintaining stability under low-intensity grazing. This data identified that when slopes were less than 20% there was no relationship between slope and percentage groundcover. These shallow slopes ranged widely in groundcover, from 40% to 95% (average = 70%). This implies that erosion is not an important force on these shallow slopes. Once slopes have a gradient exceeding 20%, increasing groundcover is required to maintain stability, and all natural sites with a slope greater than 40% had a groundcover exceeding 95%.

This data supports the notion that a final landform with slopes of 15% of less will not be at risk of erosion, provided a moderate cover of rock, vegetation and leaf litter can be established and maintained. Approximately 30% cover of rock mulch is to be applied to gradients of 10-15%. Rock is effective protection against erosion of waste slopes on newly rehabilitated mine sites (Williams 2001; Erskine & Fletcher 2013).

Rock will constitute approximately half of the protective cover required for maintaining long-term stability (based on the natural variation in cover observed in the region), while the remainder will be supplied by developing vegetation.

Previous Studies – slope stability

Other studies in central Queensland and elsewhere have investigated the stability of varying slopes on mine waste rock stockpiles and dumps. These are broadly consistent with the inferences about slope stability gained from investigating natural variation in slope and groundcover on the site.

Studies in Queensland demonstrated that any gradient exceeding 3.5%, if not protected by some sort of cover, will erode under average rainfall conditions, and extreme rainfall can erode bare slopes greater than 0.35% (Williams 2001). However, rock or vegetation cover drastically reduces erosion rates (**Figure 6-15**).

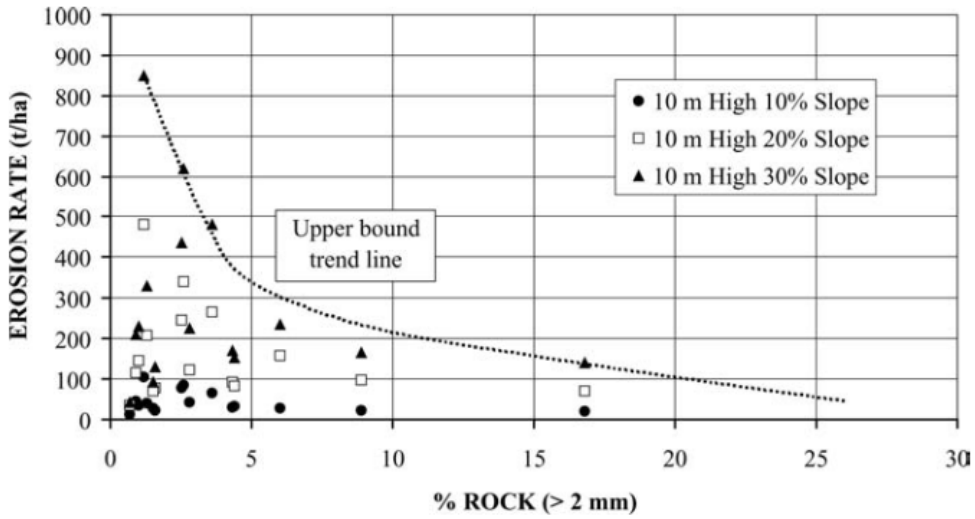


Figure 6-15 Erosion rate versus percentage rock for Bowen Basin soil materials (Williams, 2001)

The amount of cover required to protect slopes of various gradients from erosion has been investigated in numerous trials across Central Queensland. Carrol and Tucker (2000) found negligible differences in soil erosion for 10%, 20% and 30% slope gradients once vegetation established (**Figure 6-16**). Both Carroll *et al.* (2010) and Waters (2004) found that maintaining ground cover at 40-60% was sufficient in reducing erosion to negligible levels (<0.5 t/ha), regardless of slope. Likewise, a trial undertaken at Tarong, which simulated a heavy rainfall event on a 15% slope, found that 30-40% ground cover was sufficient to protect against erosion (Loch 2000: **Figure 6-17**).

In light of published data, the approximate 30% rock cover proposed for slope gradients of 10-15% will provide sufficient protection for these slopes during periods of low vegetation cover (e.g., initial phase of rehabilitation, or following fire or drought). An additional vegetation cover of 10-20% (total groundcover of 40-50%) is expected to provide a highly stable landform in the long-term.

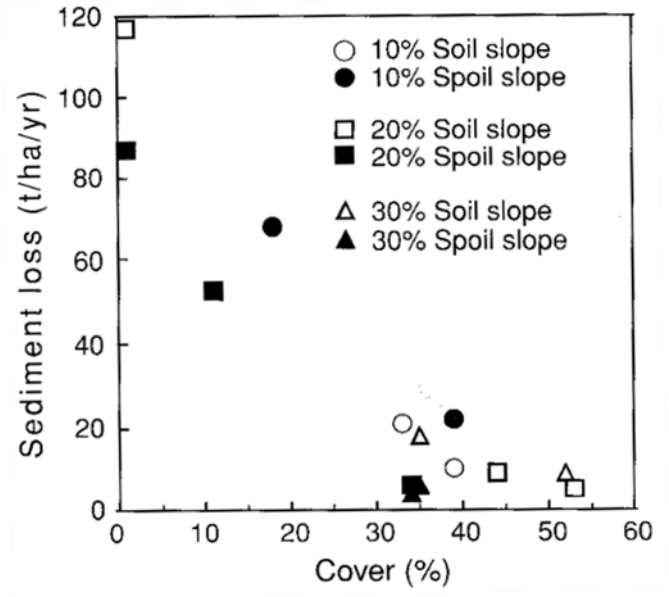


Figure 6-16 *Annual sediment loss versus pasture cover on soil and spoil stockpiles at Oaky Creek (Figure from Carrol and Tucker 2000)*

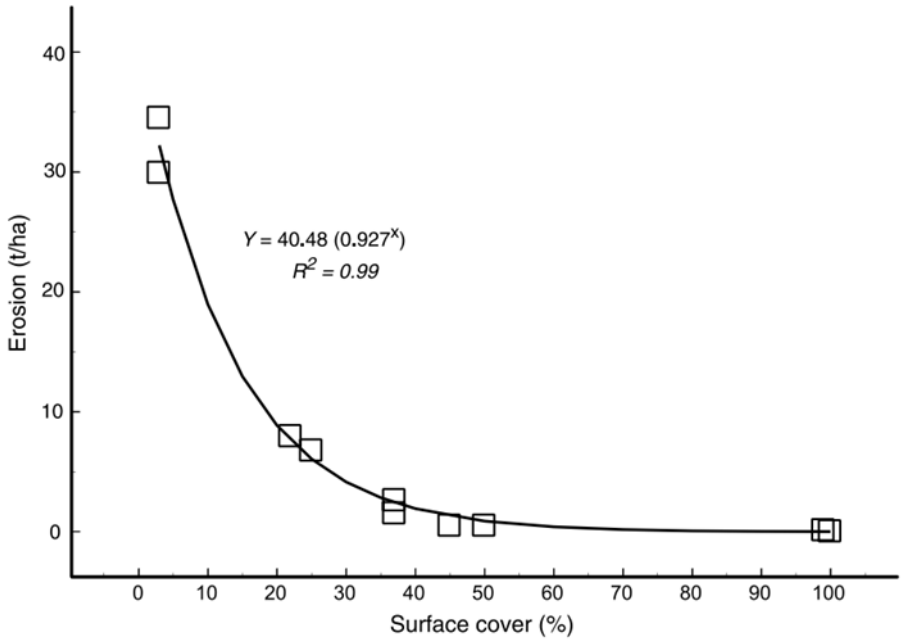


Figure 6-17 *Effects of surface cover on erosion from 12-m-long plots with 15% slope under simulated rain at Tarong (figure from Loch 2000).*

Previous Studies - Stability of Grazed Slopes

The above review of available data presents a coherent case for the proposed Project final landforms having low erodibility provided they have a moderate vegetation cover of 10-20%. However, in order for the landforms to have long-term stability, they must also support the prescribed post-mine land use of low-intensity grazing. Livestock affect landform stability by removing a portion of the vegetation cover and damaging soil surface structure via trampling (Blackburn 1983). For this reason, a review of published data concerning stability of slopes under grazing was undertaken.

Comparisons between adjacent grazed and ungrazed pastures at Charters Towers found that grazing regimes prevalent at the time reduced protective cover (vegetation and leaf litter) by 0–88% (mean of 41%), depending on seasonal conditions (Scanlan et al. 1996). Ludwig and Tongway (2002) found this reduction in cover to be less severe; grazing led to an 11% reduction in perennial grass cover and a 29% reduction in canopy cover of trees (correlated with leaf litter cover). Taken together, this data predicts that grazing in central Queensland removes, on average, approximately 1/3 of the vegetative groundcover. When this is taken into account, a target vegetative cover (grass, herbs and leaf litter) of 15-30%, in addition to the 30% rock cover proposed to be added to slopes, will be required in an ungrazed rehabilitated landscape to achieve a target cover of 40-50% once grazing is introduced. Given that other Bowen Basin mine sites regularly achieve vegetative cover of 30 to 100% (Carrol and Tucker 2000; Erskine and Fletcher 2013), a pre-grazing target of 15-30% vegetative cover is highly likely to be achieved at the Project.

Cattle currently graze natural slopes with gradients well in excess of 15% without compromising the stability of these slopes. However, the steepest slopes are somewhat protected from grazing because cattle prefer not to graze such areas (Mueggler 1965; Ganskopp & Vavra 1987). Nevertheless, gradients of 15% are well within the range of slopes utilised by cattle for grazing (Ganskopp & Vavra 1987), and the landform proposed for the Project is consistent with low-intensity grazing.

Geotechnical Assessment

A geotechnical assessment of Vulcan South's final landforms was undertaken by Blackrock Mining Solutions (**Appendix G**). The following considerations were used for the assessment:

- circular failure analyses using the auto-refine search algorithm and the general limit equilibrium method for spoil failures;
- a basal saturated spoil layer of approximately 5 m thickness was assumed for final landform slope stability assessment; and
- co-disposal of dry tailings in both the in-pit and ex-pit dumps.

Limit equilibrium analyses were assessed in terms of a circular failure mechanism acting through the unsaturated and saturated Category 2 spoil material, for in-pit and ex-pit dump final landforms, respectively (see Geotechnical assessment – **Appendix G**) .

Analyses returned critical Factor of Safety (FoS) values of 2.56 and 4.03 for the in-pit and ex-pit final landforms, respectively. The Vulcan North, Main and South in-pit WRD's returned a FoS of 3.01, 2.56 and 3.14, respectively. The Vulcan North, Main and South ex-pit WRD's returned a FoS of 3.48, 3.99 and 4.03, respectively. The FoS is a measure of driving forces versus resisting forces in a system. FoS values > 1 are indicative that a system is likely to be stable, while an FoS value of 1.5 is considered to be the generally accepted value for long-term slope design. The proposed final landform design exceeds the minimum FoS of 1.5 for all landform features, and is therefore acceptable from a geotechnical perspective.

6.2.9 Landform Evolution Modelling

Landform evolution modelling (LEM) was undertaken for the six proposed WRDs. These included the Vulcan North in-pit and ex-pit WRDs, Vulcan Main in-pit and ex-pit WRDs, and the Vulcan South in-pit and ex-pit WRDs. The LEM assessed the ability for the proposed WRD cover designs and embankment slopes to demonstrate that landform rehabilitation criteria are achievable and should result in long-term stability.

Erosion behaviour was simulated using SIBERIA software for the six proposed WRD landforms over a 10-year and 100-year timeframe. Slope angle, length of slope, dispersive characteristics of soil units, sediment transport information, and percentage of ground cover are important factors affecting erosion and are inputs to the model. The LEM analysed five proposed landform cover management scenarios to determine which is the most suitable for the longevity of a stable landform.

Erosion modelling predicted rilling, gully erosion and sedimentation for each of the potential cover design scenarios, which were compared to rehabilitation objectives.

An erosion risk rating was determined for each of the cover designs based on these rehabilitation objectives. The LEM predicted that once the proposed WRD landforms have fully established a cover of rock mulch with grass cover, rehabilitation objectives as outlined in the PRCP would be achieved. Erosion objectives achieved with this cover design in place include:

- Land is stable, with only minor active rills no deeper than 0.25 m;
- Erosion only affecting uppermost topsoil layer;
- Negligible sedimentation effects on downstream waterways; and
- Vegetative cover is effective, but may have reduced ability to recover following disturbance from mining in some areas.

Recommendations of the assessment include monitoring the proposed WRD rehabilitation areas until all milestone criteria have been met and the target vegetative cover is established.

More detailed information about the LEM is contained in the LEM Assessment Report (**Appendix F**).

6.3 Revegetation Plan

6.3.1 Revegetation Objectives

The following are the revegetation objectives for the site, consistent with the proposed PMLUs:

- to ensure rapid establishment of vegetation on exposed soil, to limit erosion over the early stages of rehabilitation;
- to establish a pasture with native and exotic grass species that is sufficiently dense in the long term to protect the soil surface from erosion and support low-intensity grazing;
- to establish a moderate density of locally native trees and shrubs that provide shade for livestock and sufficient cover for the vulnerable Squatter Pigeon;
- to establish a moderate density of Koala food trees;
- to establish a similar amount of food for the Glossy Black-cockatoo as present pre-mining;
- to establish a similar variety of Greater Glider food trees as present pre-mining; and
- to limit invasion by declared weed species to levels that are similar to those on site prior to mining or representative of adjacent areas.

6.3.2 Key Flora Species

The flora species to be planted in disturbed areas vary depending on the topsoil type used at each site. The flora species selected represent the dominant species in regional ecosystems that grow naturally on each soil management unit (**Table 6-3**). It is anticipated that many of these species may not be available from commercial seed providers. Therefore, it is expected that much of the seed used for rehabilitation efforts on site will require local collection by contractors.

Table 6-3 Key flora species on each soil management unit

Soil Type	Target RE	Dominant Trees	Dominant Midstorey	Dominant Grasses
Crocodile	11.10.1, 11.10.3, 11.10.1x1.	*Acacia shirleyi, Corymbia aureola, Corymbia citriodora, Corymbia trachyphloia, Eucalyptus crebra.*	*Acacia bancroftiorum, Acacia burdekensis, Acacia flavescens, Alphitonia excelsa, Dodonaea lanceolata, Erythroxylum australe.*	*Alloteropsis cimicina, Cleistochloa subjuncea, Cymbopogon refractus, Digitaria diminuta, Eriachne obtusa, Melinis repens*, Paspalidium caespitosum, Themeda triandra, Thyridolepis xerophila, Urochloa piligera.*
Fish	11.10.3	*Acacia rhodoxylon*	*Carissa ovata, Erythroxylum australe.*	*Alloteropsis cimicina, Cenchrus ciliaris*, Cleistochloa subjuncea, Eriachne obtusa, Melinis repens*, Paspalidium caespitosum.*
Kei	11.5.3	*Eucalyptus populnea, Corymbia dallachiana, Alphitonia excelsa, Ventilago viminalis,*	*Acacia burdekensis, Acacia excelsa, Carissa ovata, Cassia brewsteri, Eremophila mitchellii, Erythroxylum australe, Melaleuca nervosa, Vachellia bidwillii.*	*Alloteropsis cimicina, Aristida calycina* var. *calycina, Aristida gracilipes, Bothriochloa pertusa*, Cenchrus ciliaris*, Chrysopogon fallax, Eragrostis speciosa, Eriochloa crebra, Perotis rara, Urochloa piligera.*
Komati	11.9.2	*Eucalyptus orgadophila, Corymbia erythrophloia, Ventilago viminalis*	*Acacia excelsa, Atalaya hemiglauca, Bursaria incana, Carissa ovata, Cassia brewsteri, Denhamia cunninghamii, Erythroxylum australe, Vachellia bidwillii.*	*Bothriochloa pertusa*, Enneapogon* sp., *Cenchrus ciliaris*.*
Limpopo	11.5.9, 11.5.3	*Corymbia clarksoniana, Eucalyptus crebra, Eucalyptus melanophloia, Eucalyptus populnea,*	*Acacia burdekensis, Alphitonia excelsa, Cassia brewsteri, Erythroxylum australe, Grevillea parallela, Grevillea striata, Melaleuca nervosa, Petalostigma pubescens.*	*Alloteropsis cimicina, Aristida calycina* var. *calycina, Aristida gracilipes, Bothriochloa bladhii, Bothriochloa pertusa*, Cenchrus ciliaris*, Chrysopogon fallax, Eragrostis sororia, Eragrostis speciosa, Eriachne obtusa, Eriochloa crebra, Melinis repens*, Perotis rara, Setaria surgens, Urochloa piligera.*
Orange	11.4.8, 11.4.9	*Acacia harpophylla, Bauhinia hookeri, Casuarina cristata, Eucalyptus cambageana, Terminalia oblongata, Ventilago viminalis.*	*Carissa ovata, Eremophila mitchellii, Terminalia oblongata.*	*Ancistrachne uncinata, Cenchrus ciliaris*, Chloris divaricata, Chloris ventricosa, Eragrostis lacunaria, Paspalidium constrictum, Urochloa mosambicensis*.*

Soil Type	Target RE	Dominant Trees	Dominant Midstorey	Dominant Grasses
Sabie	11.10.3, 11.10.1x1, 11.10.7	*Acacia rhodoxylon, Acacia shirleyi Alphitonia excelsa, Corymbia aureola Corymbia citriodora, Corymbia clarksoniana, Eucalyptus crebra, Eucalyptus exserta, Eucalyptus melanophloia.*	*Acacia bancroftiorum Acacia burdekensis, Acacia curvinervia, Acacia flavescens, Alphitonia excelsa, Erythroxylum australe, Leptospermum lamellatum, Petalostigma pubescens.*	*Alloteropsis cimicina, Cleistochloa subjuncea, Cymbopogon refractus, Digitaria diminuta, Eriachne obtusa, Melinis repens*, Paspalidium caespitosum, Themeda triandra, Thyridolepis xerophila, Urochloa piligera.*
Zambezi	11.3.2, 11.3.7, 11.3.25	*Corymbia clarksoniana, Corymbia tessellaris, Eucalyptus camaldulensis, Eucalyptus crebra, Eucalyptus populnea, Melaleuca leucadendra.*	*Alphitonia excelsa, Bauhinia hookeri, Carissa ovata, Cassia brewsteri, Ficus opposita.*	*Bothriochloa ewartiana, Bothriochloa pertusa*, Cenchrus ciliaris*, Megathyrsus maximus*, Urochloa mosambicensis*.*

*Exotic pasture plants common on each soil prior to mining

6.3.3 Species of Conservation Significance

Where this is consistent with a proposed PMLU, habitat for threatened fauna inhabiting the Project area is to be incorporated into the landscape. The following subsections detail how this will be achieved for each species of conservation significance potentially impacted by the Project, as identified in **Section 1.2.10**.

Koala

Habitat for Koalas can be incorporated into PMLUs of "low-intensity cattle grazing" and "native ecosystems". This will be achieved by ensuring that trees established to provide shade for livestock are also food trees for Koalas. The tree species to be planted (via inclusion in the seed mix) vary by soil type, as shown in **Table 6-4**.

Table 6-4 List of Koala food trees suitable for planting on each soil management unit

Soil Management Unit	Suitable Food Trees
Crocodile	*Eucalyptus crebra*
Fish	None
Kei	*Eucalyptus populnea*
Komati	*Eucalyptus orgadophila*
Limpopo	*Eucalyptus populnea, Eucalyptus crebra*
Orange	None
Sabie	*Eucalyptus crebra*
Zambezi	*Eucalyptus camaldulensis* (on creek banks), *Eucalyptus populnea, Eucalyptus crebra,*

Greater Glider

Habitat for Greater Gliders can be incorporated into some PMLUs of "low-intensity cattle grazing" and "native ecosystems", primarily along the banks of drainage lines. The following food trees are to be included in seed mixes sown within 50 m of a watercourse or drainage line on the Zambezi soil unit: *Eucalyptus camaldulensis, Eucalyptus crebra, Eucalyptus populnea, Corymbia clarksoniana, Corymbia dallachiana* and *Corymbia tessellaris.*

Squatter Pigeon

Habitat for Squatter Pigeons can be incorporated into PMLUs of "low-intensity cattle grazing" and "native ecosystems" on all soil types contained within the Project, with the exception of the Crocodile and Sabie soil management units (rocky, sandstone-derived soils provide unfavourable foraging substrates).

Squatter Pigeons have two chief habitat needs that require restoration in rehabilitation sites: (1) a diversity of native and introduced pasture grasses and herbs (on which to feed) in the understorey; and (2) a minimum tree cover that generates a Normalised Differential Vegetation Index of at least 0.125 (measured across a 1-ha cell in the late dry season).

As these habitat features are generally co-located in productive pastures (related to understorey productivity and diversity) and sites with Koala habitat (a moderate tree cover), a PMLU of "low-intensity grazing", with a low-moderate tree cover for livestock shade and Koala habitat is likely to provide habitat for Squatter Pigeons with no additional management inputs.

Glossy Black-cockatoo

Glossy Black-cockatoo feed only on *Casuarina cristata* locally, and this canopy species is to be included in seed mixes applied to level ground with the "Orange" soil management unit. Areas where water pools are likely to be particularly favourable for this tree. Conversely, slopes that retain little water are unlikely to be suitable.

6.3.4 Topsoil Management

Topsoil is the most valuable soil horizon for post-mining rehabilitation. Topsoil contains a seed bank, micro-organisms and nutrients necessary for plant growth. In contrast, many of the subsoils on site are sodic and prone to dispersion (AARC, 2022). The soil characteristics of each soil management unit present on site (**Section 1.2.7**) were used to determine the maximum depth to which suitable topsoil material should be stripped for stockpiling and/or rehabilitation, in order to conserve an optimal growth medium for plants (**Table 6-5**).

Table 6-5 Maximum topsoil stripping depths for each soil management unit

Soil Management Unit	Stripping Depth (m)*	Qualities
Crocodile	0.1	Topsoil is strongly acidic, very rocky and not suitable for establishing improved pastures. It is most suited to a PMLU of native ecosystems similar than those naturally occurring on site.
Fish	0.1	Topsoil is suitable for all rehabilitation purposes to 0.1 m depth, though acidic (pH 5.5) is within the range for plant growth. Becomes sodic (potentially dispersive) below 0.1 m.
Kei	0.6	Topsoil is suitable for all rehabilitation purposes to depth of 0.6 m having low salinity, suitable pH and low exchangeable sodium percentage. Below 0.6 m this SMU is increasingly alkaline and may have a reduced availability of plant nutrients.
Komati	0.1	Topsoil is suitable for all rehabilitation purposes to 0.1 m depth. Below 0.1 m soil becomes increasingly alkaline and dispersive.
Limpopo	0.3	Topsoil is favourable for plant growth but has a low nutrient-holding capacity and should be improved with fertiliser when planting. These very sandy soils are prone to slumping and should not be used on slopes exceeding 3%. Subsoils are susceptible to dispersion.
Orange	0.1	Topsoil is suitable for all rehabilitation purposes to 0.1 m depth though moderate alkalinity may have an inhibiting effect on plan nutrient availability. Below 0.1 m there is a risk of dispersion and will be limited in its potential to be used as a topsoil /growth medium.
Sabie	0.1	Topsoil is suitable only for rehabilitation to a native ecosystem. Surface soil is acidic (pH 4.6) limiting plant nutrient availability and increasing risk of aluminium toxicity. Below a depth of 0.1 m sodicity increases and therefore so does dispersion risk.
Zambezi	0.3	Topsoil is favourable for plant growth but has a low nutrient-holding capacity and should be improved with fertiliser when planting. Below 0.3 m, soils are sodic and dispersive. The very sandy topsoil should not be used on slopes exceeding 3%.

*Recommendations from AARC (2022)

Topsoils and subsoils are to be stored separately. Likewise, soils from different soil management units are to be managed separately. Where possible, soils should be directly placed in prepared rehabilitation areas rather than stockpiled. This conserves a viable seedbank and promotes revegetation.

Topsoil Stockpiling

Where stockpiling of topsoil is required, the following actions are to be taken to reduce the risk of soil degradation and improve the chances of rehabilitation success:

- topsoil stockpiles should be less than 2 m high and be contoured and positioned in a manner that encourages water drainage and discourages erosion. Grass and herbaceous plants germinating from the soil seed bank are to be maintained as a protective cover for stockpiles;
- if stockpiles fail to develop a natural grass cover, they are to be seeded with a fast-growing, non-invasive, commercially available sterile grass species (recommended species are listed in the *Soil Conservation Guidelines for Queensland* (DSITI 2015));
- topsoil should be stockpiled for the minimum time practicable. Studies in the Hunter Valley have shown that the majority of deterioration occurs within the first year (Keipert *et al.* 2005);
- stockpiles are to be monitored annually for weeds and control measures implemented as appropriate;
- where soil must be stockpiled for extended periods (>2 years), soil will be tested before use for rehabilitation purposes; and
- topsoil stockpiles are to be located in areas fenced from livestock
- Storage of SMU's separately to prevent contamination.

Organic matter application

Sandy soils usually have poor soil structure, low moisture retention and low available nutrient concentrations.

The addition of organic matter to such soils helps to bind soil aggregates together and resist physical breakdown, improving soil structure. This in turn increases soil moisture retention and re-incorporates nutrients back into the soil. Where possible, topsoil should be stripped with its existing ground cover vegetation and, if subject to stockpiling, relocated with its cover crop vegetation.

Depending on availability, additional organic matter (such as mulches, manures, or compost), may be incorporated into the topsoil. Organic materials incorporated into the topsoil will increase organic carbon levels, providing more exchange sites for necessary cations, increase water holding capacity, and ensure less organic matter is oxidised into carbon dioxide and nitrous oxide or reduced into methane (**Appendix C**).

Application rates will vary depending on mulch type. Straw mulch should be applied at a rate of 5 t/ha. Note that fresh mulch should not be used in acidic soils. Manure should be incorporated at rates of 5-30 t/ha (depending on the type of manure). If available, compost can be applied at 70-150 t/ha (**Appendix C**).

Fertiliser Application

Fertilisers may be utilised to increase nutrient concentrations in soil. Presence of acidic soils within the Project area means that care must be taken, as some fertilisers (such as ammonium-based fertilisers) can have an acidifying effect on the soil. Were this to occur, lime applications would be required to mitigate the fertiliser's acidifying effects. Topsoil stockpiles from each of the soil units will be tested prior to use in rehabilitation to ascertain fertiliser requirements.

A calcium nitrate-based fertiliser such as calcium ammonium nitrate (15 to 27% N) is suitable for this application as it has near-neutral effect on soil pH and can be used to increase both nitrogen and calcium levels in the soil. An application rate of 25-50 kg N/ha should be sufficient for successful vegetation establishment (CRDC, 2020). This could be complemented with an application of sulphate of potash (41 % K) to increase potassium levels in the soil.

This fertiliser would also increase sulphur and can be drilled with seeds (unlike other potassium fertilisers such as muriate of potash which can damage seed germination). Typical application rates of potassium for pastures in light soils are of around 20 kg K/ha (**Appendix C**).

Alternatively, urea (46.7% N) may be applied as a nitrogen fertiliser (usually the most economical nitrogen fertiliser), but this would need to be applied in combination with lime (calcium carbonate), to overcome the acidifying effects of urea. A rate of 150 kg/ha of urea is recommended for soils in low rainfall areas where soil nitrate content is below 3 mg/kg. Limestone application rates should be around 1 t/ha of lime.

It is expected that 1 t/ha of lime (incorporated in the first 10 cm of soil) will increase the pH of sandy soils by 0.57 units (Department of Primary Industries n.d.). Follow up pH testing will be undertaken to evaluate the need to add more lime – lime would be added initially at small doses and then at gradually increasing application rates as necessary.

Phosphorus application rates would be carefully determined, as many Australian native species are adapted to low phosphorus concentrations in the soil. Application rates of 10-20 kg P/ha have been suggested for grazing pastures (Victoria Government 2013) and mine restoration (Daws *et al.* 2013). To achieve this, single superphosphate (8.8% P) could be applied, which would also supply sulphate. (Note this fertiliser should not be blended with urea).

After application, soil ameliorants will be incorporated into the soil to approximately 0.3 m (for example by using a scarifier or ripper tynes) so they are not lost by wind or washed away by rainfall. Ideally, after vegetation establishment (after 6 to 12 months since sowing) soils will be re-tested to determine if any follow-up application of ameliorants is required.

Besides using fertilisers, incorporating native leguminous forbs such as *Rhynchosia minima* (Rhynchosia) and tomentella (Hairy Glycine) to the seed mix is a natural method of increasing soil nitrogen levels due to the nitrogen fixing capabilities of legume species. This could establish natural nitrogen cycling within the topsoil resulting in long-term improvements in soil fertility and self-sustaining vegetation.

6.3.5 Subsoil Management

Many of the subsoils within the Project are dispersive and must be managed carefully to reduce the risk of erosion and sedimentation of downstream waterways. Most of these subsoils do not provide a favourable substrate for plant establishment. Instead, the following actions, where practicable, are to be taken to manage the storage of subsoils:

- subsoil to be directly placed into its final position rather than stockpiled as a priority;
- subsoil stockpiles to be contained, to ensure that any eroded material is retained within the pits and not released into waterways;
- subsoil stockpiles should not to be placed on slopes greater than 3%, and the stockpile surface should be levelled to reduce the speed of any run-off; and
- Sediment control infrastructure is to be constructed around all stockpile areas.

Where dispersive subsoil material is to be utilised in rehabilitation works, it will tested, and if required, treated with gypsum (calcium sulphate) prior to sowing/planting.

Dispersive soils generally have low porosity, low air movement and therefore low oxygen availability for plants. They also have slow water infiltration which can lead to waterlogging. Gypsum application rates for moderate to severe dispersive soils usually range from 2.5 to 5 t/ha depending on site-specific characteristics (DPIRD, 2020).

Given the high exchangeable sodium percentage in sodic subsoils, an application of 5 t/ha of gypsum is recommended (AARC, 2022). Gypsum will cause soil particles to flocculate, therefore improving soil structure, increasing water and plant root penetration into the soil. Irrigation will also be important where required.

These soils should be well irrigated so that sodium moves down the soil profile. In contrast, low amounts of water in the soil can result in sodium moving up the soil profile by evaporation.

The Crocodile and Kei SMUs represent an opportunity for use as a soil resource, given their non-sodic nature throughout the depth profile. If available as a soil resource, consideration will be given to incorporating ameliorants to address the pH limitations of these materials and improve their potential to support a rapid and successful rehabilitation outcome.

6.3.6 Revegetation Approach

Soil Spreading

A growing medium of 0.25 m of topsoil will be placed over the subsoil/waste-rock deposits described in **Section 6.1.3**. Organic material harvested from the mine footprint will be incorporated into the topsoil.

Following the spreading of topsoil, rehabilitated areas are to be ripped to a depth of 0.4 to 0.5 m. Ripping reduces compaction from heavy machinery, encourages the infiltration of water and reduces the risk of erosion. If engineered waterways are included in the landform, areas should be ripped on a grade (e.g. 0.5%). Otherwise, areas should be ripped on the contour.

Spread and ripped (at a grade of 0.5%) soil should have a rough surface with abundant troughs and banks, which help to resist erosion, improve infiltration and retain litter. In accordance with the results of trials elsewhere in the Bowen Basin (Williams 2001), a rock cover (sourced from waste rock) is to be placed upon topsoil on slopes greater than 10% (equivalent to 6°). This rock is to constitute approximately 30% of the soil cover, to convey optimal erosion protection during the initial stages of vegetation establishment (Williams 2001) (**Appendix C**).

Topsoil placement should occur in October-November, shortly before the commencement of the wet season. Soil operations are to be undertaken when the soil is dry or damp, but not saturated. Manual handling of wet soils is logistically difficult, damages the soil's structure and leads to compaction.

Contour banks on slopes will be constructed at a spacing of 80 m for slopes of 1V:6H (MCA 1998). Larger contour drains are generally more stable and longer lasting. Berms should be constructed of compacted material (IE Aust Erosion and Sediment Control Guidelines). Contour banks should convey water to engineered rock-lined spine drains on steep slopes. A competent basalt or alternative rock source is recommended. Geofabric in construction of rock-lined spine drains will be used where feasible (**Appendix C**).

Fertiliser and Soil Amelioration

Most of the topsoils within the Project area are nutrient-deficient, and the addition of an initial fertiliser application at the time of planting will facilitate plant establishment and growth. A controlled-release fertiliser with the following nutrient concentrations is to be applied at the time of seeding as required:

- Nitrogen: 15.0-27.0%;
- Phosphorus: 8.8%%; and
- Potassium: 41%

Application rates should follow the manufacturer's guidelines, but are expected to be 100-500 kg/ha, depending on nutrient concentrations. Further detail on specific application rates of fertilisers if required for amelioration of different anticipated conditions is also outlined above.

Seeding

Seeding operations shall not take place until the prepared area has been constructed in accordance with the specified requirements. Ideally, sowing should take place within one week of topsoil placement and ripping. Rainfall between cultivation and sowing results in the partial collapse of furrows and crusting of the soil surface. Sites may need to be re-ripped prior to sowing if rain occurs following the initial treatment. Seeding operations are not to be undertaken on days:

- when wind speeds exceed 15 km/h;
- where the surface is fully saturated;
- when temperatures exceed 37°C; and
- during heavy rain, or when heavy rain is imminent.

The seed mix to be applied varies by soil management unit (**Section 6.2.4**). However, all seed mixes are to include a combination of sterile grass varieties (e.g., Silk Sorghum *Sorghum* spp. and/or Japanese Millet *Echinochloa esculenta*)—which act as cover crops—native species and pasture species.

The seed mix is to be uniformly blended with a bulking agent such as dry sand or dry, fine sawdust at a rate of 1 part seed to 5 parts bulking agent by volume. This mix is then combined with fertiliser on the day of planting and distributed evenly across the planting area. Seed may be pre-mixed and stored with the bulking agent for several months; however, fertiliser should not be stored with seed for longer than necessary.

Hydromulching

Where deemed appropriate on the steepest banks or other areas that are more disposed to potential erosion, Hydromulching will be implemented. Hydromulching will be undertaken with a slurry of water, seed, fertiliser, mulch and a binder to contribute to ideal growing conditions and rapid vegetation through the stabilisation of the landform, incorporation of organic matter and nutrient addition.

Planting of Container Stock

Some species of trees and shrubs (especially those with fleshy fruits, such as *Erythroxylum australe* and *Carissa ovata*) recolonise poorly from directly sown seed, and are best reared in a nursery environment and planted as one-year-old tube stock. Monitoring of previous years' progressive rehabilitation on site (i.e., detecting the failure of certain species to germinate *in situ*) will inform which species should be prioritised for container stock in ongoing rehabilitation campaigns.

Container stock is to be hand-planted in clusters of 5-10 individuals, each seedling spaced approximately 2 m apart. The planting of container stock is to take place within five days of heavy rain (>40 mm over a 24 hr period), when soil moisture levels are high. The spacing between clusters will depend on the density of other species that successfully germinate, but planting densities of up to 100 trees per hectare may be required where seed germination is particularly poor.

All container stock is to be sun-hardened for at least one month prior to planting.

Planting holes are to be excavated to a minimum diameter equivalent to twice the diameter of the plant container and to a depth equivalent to the height of the plant container. The material at the bottom of the hole is to be broken up to a depth of 50 mm. The sides of the hole are to be roughened. The top of the plant's root ball is to be level with the surrounding ground. The topsoil is to be tamped down to create a slightly depressed basin surrounding the plant, without exposing the root system.

Fencing

Livestock-proof fencing is to be installed around all revegetated areas at or prior to the completion of seeding and planting. Rehabilitated areas are to be maintained free of livestock until these sites are sufficiently established for the commencement of grazing.

6.3.7 Seed Mix

Seed is to be sourced from a combination of local collections and commercial suppliers. Local seed collections will begin at least two years prior to the commencement of rehabilitation, to allow for the potential of unfavourable weather to cause the failure of seed production in any one year. Seed is to be stored for a maximum of five years prior to use, and regular collections/purchases will be required throughout the duration of the Project.

The preliminary seed mixes that are proposed for each soil management unit are shown in **Table 6-6**.

These have been developed based on the dominant species of trees, shrubs and grasses present within each soil management unit within the Project area prior to mining. Adjustments to these seed mixes will be made pending seed availability, the results of rehabilitation trials (**Section 6.3.8**) and the performance of the earliest rehabilitation efforts on site. It is expected that some of the species listed will display poor recruitment via direct seeding, and such species will be removed from the seed mixes and planted as container stock instead.

The value of Buffel Grass (*Cenchrus ciliaris*) for mine rehabilitation in Queensland is debated. This exotic pasture species is a rapid coloniser of disturbed ground and is effective for controlling erosion. Among earlier rehabilitation efforts in the Bowen Basin, Buffel Grass was the dominant pasture species planted (Grice *et al.* 2012). However, it is only moderately palatable to cattle and aggressively outcompetes other plant species, including more valuable pastures (Grice *et al.* 2012; Erskine and Fletcher 2013). Buffel Grass is considered the likely cause of a marked decline in species diversity over time at other mine rehabilitation areas within the Bowen Basin (Erskine and Fletcher 2013). This declining diversity jeopardises the stability and functionality of the rehabilitated landforms.

At the Project, Buffel Grass (*Cenchrus ciliaris*) is included within seed mixes on soil management units in which it was dominant pre-mining, but in much lower ratios than observed in reference sites. This approach is a compromise between replicating the pastures occurring on site prior to mining and establishing a diverse mix of native and exotic pasture species that have high pasture productivity and environmental value (i.e., can sustain the proposed PMLUs).

Table 6-6 Proposed seed mixes for each Soil Management Unit (SMU)

SMU	Trees and shrubs	Rate (kg/ha)	Pasture grasses	Rate (kg/ha)	Sterile cover crop	Rate (kg/ha)	Total Rate (kg/ha)
Crocodile	*Acacia bancroftiorum*	0.2	*Alloteropsis cimicina*	1	Japanese Millet - sterile hybrid	3	
	Acacia burdekensis	0.2	*Cleistochloa subjuncea*	2	Silk Sorghum	3	
	Acacia flavescens	0.15	*Cymbopogon refractus*	1			
	Acacia shirleyi	0.3	*Dichanthium sericeum*	2			
	Alphitonia excelsa	0.05	*Digitaria diminuta*	1			
	Corymbia aureola	0.2	*Eriachne obtusa*	1			
	Corymbia citriodora	0.3	*Paspalidium caespitosum*	1			
	Corymbia trachyphloia	0.05	*Themeda triandra*	1			
	Dodonaea lanceolata	0.05	*Urochloa piligera*	1			
	Eucalyptus crebra	0.2					
	Galactia tenuiflora	0.2					
	TOTAL	**1.9**		**11**		**6**	**16.7**
Fish	*Acacia rhodoxylon*	1.0	*Alloteropsis cimisina*	2	Japanese Millet - sterile hybrid	3	
	Cassia brewsteri	0.3	*Aristida calycina*	2	Silk Sorghum	3	
	Eucalyptus crebra	0.2	*Cenchrus ciliaris*	0.2			
	Eucalyptus populnea	0.2	*Eriachne obtusa*	1			
	Galactia tenuiflora	0.2	*Eriochloa crebra*	2			
	Glycine tomentella	0.2	*Paspalidium caespitosum*	2			
	TOTAL	**2.1**		**9.2**		**6**	**16.7**
Kei	*Eucalyptus populnea*	0.6	*Alloteropsis cimicina*	0.5	Japanese Millet - sterile hybrid	3	
	Cassia brewsteri	0.2	*Aristida calycina*	1	Silk Sorghum	3	
	Corymbia dallchiana	0.3	*Bothriochloa bladhii*	2			

SMU	Trees and shrubs	Rate (kg/ha)	Pasture grasses	Rate (kg/ha)	Sterile cover crop	Rate (kg/ha)	Total Rate (kg/ha)
	Alphitonia excelsa	0.1	*Cenchrus ciliaris*	0.2			
	Acacia excelsa	0.1	*Chrysopogon fallax*	1			
	Galactia tenuiflora	0.2	*Eragrostis sororia*	1			
	Glycine tomentella	0.2	*Eriochloa crebra*	1			
			Heteropogon contortus	2			
			Perotis rara	0.5			
	TOTAL	**1.7**		**9.2**		**6**	**16.9**
Komati	*Acacia excelsa*	0.2	*Bothriochloa ewartiana*	3	Japanese Millet - sterile hybrid	3	
	Atalaya hemiglauca	0.1	*Cenchrus ciliaris*	0.2	Silk Sorghum	3	
	Bursaria incana	0.1	*Dichanthium sericeum*	3			
	Cassia brewsteri	0.3	*Themeda triandra*	2			
	Corymbia erythrophloia	0.3	*Cymbopogon refractus*	1			
	Eucalyptus orgadophila	0.6					
	Galactia tenuiflora	0.2					
	Glycine tomentella	0.2					
	Rhynchosia minima	0.2					
	Vachellia bidwillii	0.1					
	TOTAL	**2.3**		**9.2**		**6**	**17.5**
Limpopo	*Acacia burdekensis*	0.2	*Alloteropsis cimicina*	1	Japanese Millet - sterile hybrid	3	
	Alphitonia excelsa	0.1	*Aristida calycina*	1	Silk Sorghum	3	
	Cassia brewsteri	0.05	*Bothriochloa bladhii*	1			
	Corymbia clarksoniana	0.3	*Chrysopogon fallax*	1			
	Eucalyptus crebra	0.3	*Eragrostis sororia*	0.5			
	Eucalyptus melanophloia	0.15	*Eriochloa crebra*	1.5			
	Eucalyptus populnea	0.3	*Heteropogon contortus*	1.5			
	Galactia tenuiflora	0.2	*Perotis rara*	0.5			
	Glycine tomentella	0.2	*Setaria surgens*	1			
	Grevillea parallela	0.05					
	Grevillea striata	0.05					
	Melaleuca nervosa	0.1					
	Petalostigma pubescens	0.1					
	TOTAL	**1.6**		**9**		**6**	**16.6**
Orange	*Acacia harpophylla*	0.6	*Ancistrachne uncinata*	1	Japanese Millet - sterile hybrid	3	
	Bauhinia hookeri	0.2	*Cenchrus ciliaris*	0.2	Silk Sorghum	3	
	Casuarina cristata	0.3	*Chloris divaricata*	2			
	Eremophila mitchelli	0.1	*Chloris ventricosa*	2			
	Eucalyptus cambageana	0.3	*Dichanthium sericeum*	3			
	Glycine tomentella	0.2	*Urochloa mosambicensis*	1			
	Terminalia oblongata	0.2					
	TOTAL	**1.9**		**9.2**		**6**	**17.1**

SMU	Trees and shrubs	Rate (kg/ha)	Pasture grasses	Rate (kg/ha)	Sterile cover crop	Rate (kg/ha)	Total Rate (kg/ha)
Sabie	*Acacia bancroftiorum*	0.1	*Alloteropsis cimicina*	1	Japanese Millet - sterile hybrid	3	
	Acacia burdekensis	0.05	*Aristida calycina*	1	Silk Sorghum	3	
	Acacia flavescens	0.05	*Cenchrus ciliaris*	0.2			
	Acacia shirleyi	0.4	*Cleistochloa subjuncea*	3			
	Alphitonia excelsa	0.1	*Chrysopogon fallax*	1			
	Corymbia aureola	0.3	*Cymbopogon refractus*	1			
	Corymbia clarksoniana	0.2	*Digitaria diminuta*	1			
	Eucalyptus crebra	0.3	*Eriachne obtusa*	1			
	Eucalyptus melanophloia	0.2					
	Galactia tenuiflora	0.2					
	TOTAL	**1.9**		**9.2**		**6**	**17.1**
Zambezi	*Alphitonia excelsa*	0.1	*Bothriochloa bladhii*	2	Japanese Millet - sterile hybrid	3	
	Bauhinia hookeri	0.2	*Bothriochloa ewartiana*	2	Silk Sorghum	3	
	Cassia brewsteri	0.1	*Cenchrus ciliaris*	0.2			
	Corymbia clarksoniana	0.3	*Heteropogon contortus*	2			
	Corymbia tessellaris	0.3	*Themeda triandra*	1.5			
	Eucalyptus camaldulensis	0.6	*Urochloa mosambicensis*	0.5			
	Eucalyptus crebra	0.4					
	Eucalyptus populnea	0.4					
	Ficus opposita	0.1					
	Galactia tenuiflora	0.2					
	Glycine tomentalla	0.2					
	Melaleuca leucadendra	0.2					
	TOTAL	**3.1**		**8.2**		**6**	**17.3**

6.3.8 Rehabilitation Trials

A rehabilitation trial will not be conducted for the project considering the small period of time between the completion of works at the highwall and when the area is available for rehabilitation. If a rehabilitation trial was conducted, it would delay the onset of actual rehabilitation. To be of value, trials need to occur on remediated landforms, this could not occur until 2027. Learnings from Vulcan Coal Mine are anticipated to be far more valuable than a trial at Vulcan South.

7 SURRENDER OF THE ENVIRONMENTAL AUTHORITY

A surrender application must comply with requirements contained in section 262 of the *Environmental Protection Act 1994*. This application must be accompanied by a final rehabilitation report, a post-mining management report and a compliance statement for the EA and PRCP schedule.

The final rehabilitation report is to contain an environmental risk assessment and information on any proposed costs related to residual risks remaining at the site. The environmental risk assessment must be done using a methodology agreed to by the administering authority. The risk assessment is a key step before the calculation of any residual risk costs for the site. The calculation of costs could include consideration of the present value of the future costs of likely repairs, necessary monitoring and maintenance costs and the ongoing management costs of rehabilitated land.

There is a payment as a pre-condition to the surrender of an EA in order to allow the government to address residual risks associated with a site at surrender. Residual risks may include the possibility that rehabilitation works and engineered structures may fail or the ongoing costs of monitoring and maintenance after surrender.

The residual risk requirements do not remove or change the obligations of an EA holder to complete rehabilitation to required standards. The residual risk framework enables companies to relinquish the tenure and surrender an EA whilst ensuring the State understands any remaining risks on site and is resourced to manage the risks, including possible financial consequences of future environment harm.

8 RISK ASSESSMENT

In accordance with section 126C(1)(f) of the EP Act, this section assesses the risks of a stable PMLU not being achieved, and how these risks will be managed or minimised. Risks are scored based on definitions in **Table 8-1** Risks specific to each rehabilitation milestone have been identified in identified in **Table 8-2**. Both inherent risks (in the absence of risk treatments) and residual risks (once controls are in place) are identified and assessed for each hazard.

Table 8-1 Scoring system used to assess risks

			Likelihood				
			1 Rare	**2 Unlikely**	**3 Possible**	**4 Likely**	**5 Almost Certain**
			Unlikely to occur in a lifetime; or very unlikely to occur; or no known occurrences in broader worldwide community.	Could occur about once during a lifetime; or more likely not to occur than to occur; or has occurred at least once in the broader worldwide industry.	Could occur more than once during a lifetime; or as likely to occur as not to occur; or has occurred at least once in the mining/commodities trading industry.	May occur about once per year; or more likely to occur than not occur; or has occurred at least once on a mine site in the Bowen Basin.	May occur several times per year; or expected to occur; or has occurred several times on a mine site in the Bowen Basin.
Consequence	**5 Catastrophic**	Unconfined and widespread environmental damage; impacts reaching into surrounding areas; major remediation measures required.	**15**	**19**	**22**	**24**	**25**
	4 Major	Long-term (2-10 years) impact; major remediation measures required.	**10**	**14**	**18**	**21**	**23**
	3 Moderate	Medium-term (<2 years) impact; requires moderate intervention.	**6**	**9**	**13**	**17**	**20**
	2 Minor	Short-term impact; requires minor remediation or intervention.	**3**	**5**	**8**	**12**	**16**
	1 Negligible	No lasting impact; requires minor or no remediation; minor management intervention mat be required.	**1**	**2**	**3**	**7**	**11**

Table 8-2 Risk assessment for rehabilitation of Vulcan South

Milestone	Hazard	Impact	Inherent Risk			Proposed actions	Justification of treatment option	Resource requirements	Performance measures	Reporting and monitoring	Residual Risk		
			Likelihood	Consequence	Risk Ranking						Likelihood	Consequence	Risk Rating
1: Infrastructure decommissioning and removal.	Schedule for infrastructure decommissioning and removal inadequately communicated among management and work teams.	• Failure to remove all infrastructure in accordance with the PRCP Schedule. • Achievement of milestone 1 delayed.	2	3	9	• Infrastructure decommission schedule to be incorporated into annual mine planning. • Monthly progress meetings are to take place between management (i.e., responsible personnel) and work crews regarding infrastructure decommissioning and removal. • A register of infrastructure is to track which structures exist in each rehabilitation area and which have been removed.	The proposed actions will allow the early identification of potential deviations from the PRCP Schedule, affording ample opportunity to adjust work rates to ensure that scheduled works are completed by the reporting date of 10 December.	Adequate time allocated for planning and progress meetings.	Refer to **Section 5.1**	Refer to **Section 9.1.1**	1	3	6
	Infrastructure decommissioning and removal takes longer than planned.	• Achievement of milestone 1 delayed.	2	2	5	• Monthly progress meetings are to take place between management (i.e., responsible personnel) and work crews regarding infrastructure decommissioning and removal. • Additional work team resourcing may be sought in the event that the completion of scheduled works is otherwise unlikely by the annual reporting date.	The proposed actions will allow the early identification of potential deviations from the PRCP Schedule, affording ample opportunity to adjust work rates to ensure that scheduled works are completed by the reporting date of 10 December.	Adequate time allocated for planning and progress meetings; funding for supplementary contractors, if required.			1	2	3
2: Remediation of Contaminated Land	Previously unidentified contamination source discovered.	• Achievement of milestone 2 delayed. • Financial cost of remediation.	2	3	9	• Records are to be kept of all spills, leaks and other incidents occurring at the Project that might result in contamination. These incidents are to be recorded in an Incident Register, and information about relevant incidents are to be provided to an approved auditor prior to their site visit/testing. • Employees and contractors are to be made aware of their reporting obligations through a Site Induction. • Initial consultation with an approved auditor to identify contamination targets for remediation or removal.	To be suitable for a PMLU of low-intensity grazing, contaminated land must be removed from the Contaminated Land Register or the Environmental Management Register, and declared suitable for any use. These works must be approved by a suitably qualified person and an approved auditor (under the *Environmental Protection Act 1999* Act).	Adequate time per shift for reporting; funding for audits.	Refer to **Section 5.1**	Refer to **Section 9.1.2**.	1	3	6
	Remediation work not completed to schedule.	• Achievement of milestone 2 delayed, stalling later phrases of rehabilitation.	2	3	9	• Decontamination works are to be incorporated into annual mine planning. • Monthly progress meetings are to take place between management (i.e., responsible personnel) and work crews regarding de-contamination works • Compliance with the PRCP schedule is to be overseen by responsible personnel.	Decontamination works must be completed to allow sufficient time for milestones 3 and 4 to be accomplished prior to the wet-season, or milestone 5 will be delayed by an additional year.	Adequate time allocated for planning and progress meetings.			1	3	6
	Waste rock is more reactive than anticipated.	• Potential for acid mine drainage, neutral metalliferous mine drainage or saline mine drainage to reduce water quality in groundwater and surface water. • High cost of remediation.	2	4	14	• Ongoing waste characterisation throughout operations. • Ongoing testing of mine-affected water throughout operations. • Should waste rock material with reactive chemistry be identified during operations: – Extraction is to cease until the situation can be resolved; and – Geochemical specialists are to be consulted to advise about appropriate handling and management of the material.	Ongoing testing of waste material and mine-affected water is a standard practice in QLD mining operations. It will provide an early detection system for mischaracterisation of rock. A response procedure will aim to prevent further removal of reactive material until appropriate infrastructure can be designed and constructed to manage the material.	Adequate budget for geochemical testing.			1	4	10
3: Landform Development and Reshaping/Reprofiling	Heavy rain prior to surface preparation and revegetation (milestones 4 and 5).	• Sedimentation of downstream waterways.	4	3	17	• Slope designed with shallow gradient. • Earthworks timed to coincide with dry-season. • Sediment management systems (drains and sediment dams) to be operational during construction of final landform.	The planned low slope gradient limits the capacity for water to carry material. Heavy downpours are unlikely between the months of June and October. Sediment management systems trap eroded material before it can enter local waterways. This system has been designed in accordance with the *Best Practice Erosion and Sediment Control* (IECA 2008) guidelines.	The sediment management system has been already designed for the planning and approval stages of the Project. Appropriate time and personnel are required for construction of this system.	Refer to **Section 5.1**	Refer to **Section 9.1.3**.	2	3	9
	Timing and design specifications for final landform not adequately implemented.	• Achievement of milestone 3 delayed. • Reduced safety and/or stability of final landform.	2	3	9	• Annual audits are to confirm agreement between as-constructed landforms and approved designs. • Monthly progress meetings are to take place between management (i.e., responsible personnel) and work crews regarding landform construction.	Early detection of inconsistencies between constructed landforms and approved designs will allow adequate opportunity for modifications to be completed by the reporting date of 10 December.	Adequate time allocated for planning and progress meetings; funding for auditors.			1	2	3
4: Surface preparation	Inappropriate topsoil and subsoil management whilst stockpiled.	• Reduced viability of topsoil, limiting plant establishment at rehabilitated sites. • Topsoil infested with weed propagules, which will invade rehabilitated sites.	4	4	21	• Spatial segregation of topsoil and subsoil, with signage installed at each stockpile to denote soil type. • Topsoil stockpiles to be managed in strict accordance with practices described in **Section 6.3.4.**	By minimising stockpile heights, preventing the mixing of subsoils and topsoil, maintaining a vegetative cover on stockpiles and controlling weed populations on stockpiles before they become dominant, soil health will be maintained.	Adequate signage, herbicides and personnel are required.	Refer to **Section 5.1**	Refer to **Section 9.1.4**.	2	3	9

Milestone	Hazard	Impact	Inherent Risk			Proposed actions	Justification of treatment option	Resource requirements	Performance measures	Reporting and monitoring	Residual Risk		
			Likelihood	Consequence	Risk Ranking						Likelihood	Consequence	Risk Rating
	Inadequate topsoil cover	• Exposure of dispersive subsoils to rain. • Gully erosion. • Cost of repeating landform reshaping and surface preparation.	3	4	18	• A minimum of 25 cm of topsoil is to be placed on all exposed subsoil. • 30% rock cover applied to topsoil on slopes. • Subsoils are to be mixed with 25% rock. • Rapidly establishing grasses to be included in seed-mixes. • Sediment management systems (drains and sediment dams) to be operational during surface preparation and revegetation.	Dispersive subsoils across the local region often naturally have a cover of only 10-20 cm of stable topsoil, and 25 cm is considered sufficient to protect the subsoil from exposure to erosional forces. A review of studies elsewhere in the Bowen Basin (refer **Section 6.2.8**) indicates that the measures in place at the Project will sufficiently limit the risk of erosion.	Adequate waste rock set aside for a protective cover; seed for pioneer grasses; appropriate time and personnel are required for construction of the sediment management system and final landform according to designs.			2	3	9
	Vehicles contaminated with weed seeds used for earthworks	• Weeds invading rehabilitated sites, inhibiting the establishment of desirable species and preventing achievement of milestones 6 and 7.	3	4	18	• Strict vehicle wash-down practices for vehicles entering the site from contaminated areas. • Annual weed monitoring program, to allow the early detection and treatment of new weed infestations.	Prevention of introduction and early treatment of new infestations are central to the successful and cost-effective management of weeds on site.	Adequate time and budget for wash-downs, monitoring and weed control.			2	3	9
	Heavy rainfall occurring prior to establishment of vegetative cover.	• Loss of topsoil from slopes. • Siltation of downstream waterways. • Failure of vegetation to establish on eroded surfaces. • Cost of reapplying topsoil to eroded surfaces.	4	3	17	• Low slope gradient in landform design to limit capacity for sediment loss. • Surface preparation immediately prior to seeding to limit time that bare slopes are exposed to rain events. • 30% rock cover applied to slopes. • Rapidly establishing grasses to be included in seed-mixes. • Sediment management systems (drains and sediment dams) to be operational during surface preparation and revegetation.	A review of studies elsewhere in the Bowen Basin (refer **Section 6.2.8**) indicates that the measures in place at the Project will sufficiently limit the risk of erosion.	Adequate waste rock set aside for a protective cover; seed for pioneer grasses; appropriate time and personnel are required for construction of the sediment management system and final landform according to designs.			2	3	9
5: Revegetation	Seed unavailable	• Lack of seed of certain species can lead to long-term effects on the composition of the eventual plant communities that establish.	4	3	17	• Seed collection and procurement is to commence at the start of the Project, so that supplies are available when revegetation begins. • A store of seed is to be maintained on site. • Woody species unavailable at the time of sowing are to be added to rehabilitated sites as tubestock in the following wet season.	Approximately half of the species to be used are not currently stocked by commercial seed suppliers and therefore require local collection. Collecting over two years prior to revegetation allows for certain species to seed poorly in any one year.	Funding for seed collection/purchase must be available from the start of the Project.	Refer to **Section 5.1**	Refer to **Section 9.1.5**.	2	2	5
	Heavy rain immediately after sowing	• Loss of topsoil from slopes. • Siltation of downstream waterways. • Failure of vegetation to establish on eroded surfaces. • Cost of reapplying topsoil to eroded surfaces.	4	3	17	• Low slope gradient in landform design to limit capacity for sediment loss. • Surface preparation and sowing is not to take place if heavy rain (>40 mm) is forecast over any one day within the next fortnight. • 30% rock cover applied to slopes during surface preparation. • Rapidly establishing grasses to be included in seed-mixes. • Sediment management systems (drains and sediment dams) to be operational during surface preparation and revegetation.	A review of studies elsewhere in the Bowen Basin (refer **Section 6.2.8**) indicates that the measures in place at the Project will sufficiently limit the risk of erosion.	Adequate waste rock set aside for a protective cover; seed for pioneer grasses; appropriate time and personnel are required for construction of the sediment management system and final landform according to designs.			2	3	9
	Inappropriate quantity of grass seed used in the seed mix	• Tree and shrub establishment inhibited by high grass cover. • Insufficient protective cover of grass increasing the risk of erosion.	3	3	13	• Seed mixes have been based on other mine sites across north-eastern Australia. • Grass seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • In sites with excessive grass densities, tubestock of trees and shrubs are to be planted within circles (1 m radius) of grass that have been killed using herbicide. • In sites with insufficient grass cover, there is to be supplementary sowing and/or fertilising in bare patches to encourage grass growth.	Studies elsewhere in the Bowen Basin indicate that dense grass can inhibit vegetation development (Erskine and Fletcher 2013). Early identification of issues and amendments of seed mixes will reduce overall costs associated with remediating over- or under-dense grass swards.	Adequate time for reviewing the revegetation methodology on an annual basis.			2	2	5

Milestone	Hazard	Impact	Inherent Risk			Proposed actions	Justification of treatment option	Resource requirements	Performance measures	Reporting and monitoring	Residual Risk		
			Likelihood	Consequence	Risk Ranking						Likelihood	Consequence	Risk Rating
	Inappropriate quantity of tree and shrub seed used in the seed mix	• Insufficient or excessive canopy cover can cause the eventual vegetative communities to fail to achieve milestones 6 and 7.	3	3	13	• Seed mixes have been based on other mine sites across north-eastern Australia. • Seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • Supplementary planting of tubestock or thinning of established seedlings may be required to correct for inappropriate tree densities.	A minimum tree and shrub density is required to achieve completion criteria pertaining to the Koala, Squatter Pigeon, Glossy Black-cockatoo and Greater Glider. However, excessive tree and shrub densities limit pasture development, jeopardising the achievement of the desired PMLU. Early identification of issues and amendments of seed mixes will reduce overall costs associated with remediating over- or under-dense grass swards.	Adequate time for reviewing the revegetation methodology on an annual basis.			2	2	5
	Topsoil quality being unsuitable for plant establishment.	• Poor seedling survival and establishment.	4	3	17	• Testing soil prior to use in rehabilitation • Amelioration strategies at the time of planting will facilitate plant establishment and growth.	Dispersity and nutrients deficiency is a potential problem with a portion of the project areas topsoil for use in rehabilitation. Nutrients levels naturally decline following extended periods of soil stockpiling. For these reasons, testing the soil prior to use in rehabilitation, especially if it was stockpiled for a period of time, is essential. In addition, soil amelioration strategies will be used prior to the use in rehabilitation.				2	2	5
	Drought over the first months after planting	• Poor seedling survival and establishment.	3	3	13	• Planting is to take place in the early wet season, when probability of further rain during seedling establishment is high. • Supplementary planting (seed or tubestock) may be required following exceptionally dry years.	Long dry periods soon after germination can result in widespread mortality of seedlings. The proposed actions reduce the risk of this occurring and propose remedial actions in the event it does occur.	Adequate time and budget allocated for planting in years following drought.			3	2	8
	Vehicles and/or footwear contaminated with weed seeds	• Weeds invading rehabilitated sites, inhibiting the establishment of desirable species and preventing achievement of milestones 6 and 7.	3	4	18	• Strict vehicle wash-down practices for vehicles entering the site from contaminated areas. • Annual weed monitoring program, to allow the early detection and treatment of new weed infestations.	Prevention of introduction and early treatment of new infestations are central to the successful and cost-effective management of weeds on site.	Adequate time and budget for wash-downs, monitoring and weed control.			2	3	9
	Intruding livestock	• Premature grazing could lead to poor seedling establishment.	4	3	17	• Cattle-proof fencing surrounding each rehabilitation area is to be installed prior to seeding. • Fences are to be inspected monthly, faults immediately repaired and livestock immediately removed.	Rehabilitated areas are to be maintained free of livestock until vegetation is adequately established (at least five years).	Fencing materials and personnel for construction and inspection.			1	1	1
6: Establishment of target vegetation type	Poor pasture development	• Insufficient pasture density to meet completion criteria. • Insufficient species richness of grasses to meet completion criteria. • Increased risk of erosion.	3	3	13	• Seed mixes have been based on other mine sites across north-eastern Australia. • Grass seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • In sites with insufficient grass cover, there is to be supplementary sowing and/or fertilising in bare patches to encourage grass growth.	Early identification of issues and amendments of seed mixes will reduce overall costs associated with remediating over- or under-dense grass swards.	Adequate time for reviewing the revegetation methodology on an annual basis; additional seed stocks and fertiliser, as required.	Refer to **Section 5.1**	Refer to **Section 9.1.6**	2	2	5
	Poor development of Koala, Glossy Black Cockatoo and greater Glider food trees	• Insufficient density of food trees to allow use of rehabilitated areas by the Koala, Glossy black cockatoo and Greater Glider. • Failure to achieve targets of completion criteria.	2	4	14	• Seed mixes have been based on other mine sites across north-eastern Australia. • Seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • Regular monitoring aims for the early detection of sites with inadequate seedling establishment. • Sites with insufficient density of food trees developing over the first two years will undergo supplementary planting of tubestock.	Early refinements of the seed mixes will reduce the need for later interventions. Tubestock is a superior method for adding trees to existing pastures, as tree seeds often fail to germinate/establish among competitive understorey species.	Adequate time for reviewing the revegetation methodology on an annual basis; a nursery facility to rear tubestock OR contracts with commercial nurseries to rear stock.			2	2	5
	Excessive density of trees and shrubs	• Pasture species become shaded out. • Habitat becomes unsuitable for the Squatter Pigeon. • Failure to achieve targets of rehabilitation completion criteria.	3	2	8	• Seed mixes have been based on other mine sites across north-eastern Australia. • Seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • Thinning of woody vegetation (using machinery or fire) may be required at sites with excessive shrub and tree densities.	Early refinements of the seed mixes will reduce the need for later interventions. Vegetation thinning is widely implemented in Queensland's pastoral landscapes to increase pasture production in densely forested situations.	Adequate time for reviewing the revegetation methodology on an annual basis; machinery to undertake thinning of trees and shrubs, if required.			1	2	3

Milestone	Hazard	Impact	Inherent Risk			Proposed actions	Justification of treatment option	Resource requirements	Performance measures	Reporting and monitoring	Residual Risk		
			Likelihood	Consequence	Risk Ranking						Likelihood	Consequence	Risk Rating
7: Achievement of stable PMLU	Insufficient density of trees and shrubs	• Habitat is unsuitable for the Koala and Squatter Pigeon. • Failure to achieve targets of rehabilitation completion criteria.	3	4	18	• Seed mixes have been based on other mine sites across north-eastern Australia. • Seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • Regular monitoring aims for the early detection of sites with inadequate seedling establishment. • Sites with insufficient density of trees and shrubs developing over the first two years will undergo supplementary planting of tubestock.	Early refinements of the seed mixes will reduce the need for later interventions. Tubestock is a superior method for adding trees to existing pastures, as tree seeds often fail to germinate/establish among competitive understorey species.	Adequate time for reviewing the revegetation methodology on an annual basis; a nursery facility to rear tubestock OR contracts with commercial nurseries to rear stock.			2	2	5
	Weeds	• Weeds could invade via wind, vehicles or footwear during vegetation development. • Weeds can inhibit the establishment of desirable species and preventing achievement of milestones 6 and 7.	2	4	14	• Strict vehicle wash-down practices for vehicles entering the site from contaminated areas. • Annual weed monitoring program, to allow the early detection and treatment of new weed infestations.	Prevention of introduction and early treatment of new infestations are central to the successful and cost-effective management of weeds on site. Weed risk is highest during topsoil stockpiling, surface preparation and planting, rather than during the development of the vegetation communities post-planting. However, weed management practices are to remain in place throughout the duration of rehabilitation.	Adequate time and budget for wash-downs, monitoring and weed control.			2	3	9
	Fire	• A fire during early stages of vegetation establishment could kill developing trees and shrubs prior to their establishment, leading to a failure to achieve rehabilitation completion criteria pertaining to tree cover.	2	3	9	• A fire break will be maintained along the western boundary of the Project, to minimise the risk of fires originating within bushland areas of the Harrow Range. • An Emergency Response Plan describes processes in place to control fires that originate on site.	Damaging fires are most likely to spread from the west, due to the large tracts of bushland present there and the hot, dry westerly winds typically associated with periods of high fire risk. Close proximity of the in-pit dump to Saraji Road precludes the installation of fire breaks along the eastern boundary of rehabilitated land (maintaining a strip of bare ground on the foot-slopes of the in-pit dump poses too high an erosion risk).	Personnel and machinery required to build and maintain fire breaks.			1	3	6
	Intruding livestock	• Premature grazing could damage developing trees and shrubs and impair pasture development.	4	3	17	• Fences are to be inspected monthly, faults immediately repaired and livestock immediately removed.	Rehabilitated areas are to be maintained free of livestock until vegetation is adequately established (at least five years).	Personnel for inspections and repairs; tools and equipment for fencing.			1	1	1
	Flooding	• Damage caused to water infrastructure	2	3	9	• Flood gates across waterways will also need to be inspected after runoff events to inspect for fence integrity.	Early identification of damage will prevent further deterioration of key water infrastructure	Personnel for inspections and repairs; tools and equipment			1	1	1
	Low pasture productivity	• Failure to support economically viable cattle grazing.	2	3	9	• Seed mixes have been based on other mine sites across north-eastern Australia. • Grass seed application rates are to be modified pending the outcome of the initial rounds of rehabilitation. • In sites with insufficient grass cover, there is to be supplementary sowing and/or fertilising in bare patches to encourage grass growth.	Early identification of issues and amendments of seed mixes will reduce overall costs associated with remediating inadequate grass cover.	Personnel/contractors required for regular monitoring; adequate time for reviewing the revegetation methodology on an annual basis; additional seed stocks and fertiliser, as required.	Refer to **Section 5.1**	Refer to **Section 9.1.8**	2	2	5
	Low pasture diversity	• Over-dominance of one or few pasture species increases the vulnerability of the pasture to extreme environmental events (flood, fire, drought, insect plagues). • Low pasture diversity is associated with reduced nutrient cycling and ecosystem stability. • Failure to sustain cattle grazing in the long-term.	4	4	23	• A multitude of local pasture species are to be included in seed-mixes. • Non-native grasses known to suppress other species (e.g., Buffel Grass) are to be sown at very low rates. • Regular monitoring (every two years) of rehabilitated sites will track pasture diversity and allow for an early modification of seed mixes and/or other interventions.	Over-dominance of Buffel Grass limits rehabilitation success and stability at other Bowen Basin mines (Erskine and Fletcher 2013). It is important to allow less aggressive grass species time to establish prior to Buffel Grass becoming too dense. A diversity of grasses improves ecosystem stability and protects against fluctuations in environmental conditions.				2	4	14

Milestone	Hazard	Impact	Inherent Risk			Proposed actions	Justification of treatment option	Resource requirements	Performance measures	Reporting and monitoring	Residual Risk		
			Likelihood	Consequence	Risk Ranking						Likelihood	Consequence	Risk Rating
	Poor landscape stability	• Failure of sites to develop adequate sediment and leaf litter capture by groundcover features. • Formation of a dysfunctional landscape that results in a loss of resources (nutrients, water, sediment) over the long term. • Failure to achieve rehabilitation completion criteria pertaining to land stability.	2	3	9	• Low slope gradient in landform design to limit capacity for sediment loss. • 30% rock cover applied to slopes during surface preparation. • Inclusion of a diversity of grass, trees and shrubs in seed mixes. • Topsoil storage and handling are to be in accordance with practices described in **Section 6.3.4.**	Landscape function analysis is a widely implemented framework for managing and monitoring landscape stability. A review of studies elsewhere in the Bowen Basin (refer **Section 6.2.8**) indicates that the measures in place at the Project will lead to a stable landform with low erodibility.				2	2	5

9 MONITORING

9.1 Milestone Monitoring

Nine rehabilitation milestones are described in the PRCP Schedule. A monitoring program has been developed to determine whether milestone criteria have been achieved. This program is described below, with respect to each of the rehabilitation milestones.

9.1.1 Rehabilitation Milestone 1: Infrastructure Decommissioning and Removal

Following the disconnection of services and removal of all buildings and mine infrastructure, an Infrastructure Decommissioning Checklist is to be completed. Failure of a site to meet all items on the checklist will trigger remedial works to remove outstanding infrastructure. This rehabilitation milestone monitoring is applicable to rehabilitation areas RA3 (Infrastructure, haul roads, offices, stockpiles, rail loadout, rail loop, CHPP and MIA) and RA7 (Highwall Mining Area- magazine and haul road). An example checklist is provided below in **Figure 9-1.** Further detail on the milestone criteria set for the decommissioning and removal of infrastructure is provided in **Section 0**. This includes a list identifying how infrastructure will be decommissioned.

Infrastructure Decommissioning Checklist

Name of Auditor:_____Date:_____

Rehabilitation Area:_____

Total Hectares Decommissioned:_____

Yes	No	N/A	
☐	☐	☐	Have all services been disconnected?
☐	☐	☐	Have all road materials (bitumen, gravel) been removed?
☐	☐	☐	Have all pipelines been drained and removed?
☐	☐	☐	Have all fences that do not form part of the post-mining land use been removed?
☐	☐	☐	Have all buildings been removed?
☐	☐	☐	Have all machinery and equipment been removed?
☐	☐	☐	Have all unnecessary surface water infrastructure and drainage been removed?
☐	☐	☐	Has all rubbish been removed?

If 'No' was selected for any of the above questions, provide a description of the works remaining to be undertaken:

_____

_____

_____

_____

_____

_____

Figure 9-1 Example Infrastructure Decommissioning Checklist

9.1.2 Rehabilitation Milestone 2: Remediation of Contaminated Land

A contaminated land investigation document is to be prepared by an approved auditor, which is to contain the following components:

- a site investigation report, scientifically assessing whether contamination exists;
- a validation report, describing works undertaken to remediate any contamination; and
- a site suitability statement, stating that land is not contaminated and is suitable for any use.

Rehabilitation areas for which this milestone may be relevant include RA1 (ex-pit Dumps), RA3 (Infrastructure, haul roads, offices, stockpiles, CHPP and MIA) and RA4 (dam and sediment ponds), RA6 (Highwall Mining Area- ex-pit WRD, dam, highwall bench) and RA7 (Highwall Mining Area- magazine and haul road).

9.1.3 Rehabilitation Milestone 3: Landform Development and Reshaping/Reprofiling

Following landform development and reprofiling, inspection and reporting is required to provide assurance that rehabilitation activities occurred in accordance with approved designs. Upon the completion of physical works, all landform works must have 'as-constructed' plans prepared. Deviations between design and construction are to be identified and highlighted. A database of design and 'as-constructed' plans for any engineering works associated with the mine rehabilitation is to be maintained.

Rehabilitation areas requiring landform development include RA1 (ex-pit Dumps), RA2 (in-pit dumps), RA4 (dams and sediment ponds), RA6 (Highwall Mining Area- ex-pit WRD, dam, highwall bench) and RA7 (Highwall Mining Area- magazine and haul road).

9.1.4 Rehabilitation Milestone 4: Surface Preparation

Soil assessments are to be undertaken of stockpiled topsoil within the six months prior to spreading. Soil is to be sampled at various depths of each stockpile. These tests are to be carried out by an appropriately qualified person to confirm that soil is suitable for target vegetation establishment.

As a record of milestone completion, GIS files should be kept that record:

- the boundaries of each area that had topsoil applied in each year (areas with different soil management units or topsoil spreading methodology are to be mapped separately);
- the date on which topsoil spreading occurred in each area;
- depth of topsoil applied in each area;
- the soil management unit of the topsoil applied in each area; and
- whether rock mulch was applied.

These records are to be kept wherever topsoil is spread, including in rehabilitation areas RA1 (ex-pit Dumps), RA2 (in-pit dumps), RA3 (Infrastructure, haul roads, offices, stockpiles, highwall benches and CHPP), RA4 (dams and sediment ponds) RA6 (Highwall Mining Area- ex-pit WRD, dam, highwall bench) and RA7 (Highwall Mining Area- magazine and haul road).

9.1.5 Rehabilitation Milestone 5: Revegetation

All areas in which seeding and planting have been carried out are to be entered into a GIS database that includes the following details:

- the boundaries of each area rehabilitated (areas with different soil management units, seed mixes or dates of planting are to be mapped separately);
- the soil management unit of the topsoil applied in each area;
- the seed mix applied to each area;

- the date the seed mix was applied to each area;
- the number and species of tubestock planted in each area; and
- the date tubestock was planted.

These records are to be kept wherever planting takes place, including in rehabilitation areas RA1 (ex-pit Dumps), RA2 (in-pit dumps), RA3 (Infrastructure, haul roads, offices, stockpiles, highwall benches and CHPP), RA4 (dams and sediment ponds), RA6 (Highwall Mining Area- ex-pit WRD, dam, highwall bench) and RA7 (Highwall Mining Area- magazine and haul road).

9.1.6 Rehabilitation Milestone 6: Land Suitable for the Commencement of Grazing

Monitoring of milestone RM6 involves a combination of field surveys and satellite imagery analysis. Methodologies for each are described below.

Erosion Monitoring

Erosion monitoring across the landform will be undertaken for the early detection of erosion, to allow for early intervention.

In-field erosion monitoring will be undertaken at permanent monitoring transects, (50 m in length) established across the landform in conjunction with the LFA monitoring sites. Visual observations will be taken whilst traversing transects on foot and recording the number and average depth of any erosion features, rill lines or gullies. Visual assessments should identify evidence of excessive sediment movement, including the formation of rills, removal of soil around the base of plants and accumulation of loose sediment at the base of slopes. In-field erosion monitoring will be accompanied by assessment of the water quality of run-off water released from the catchment of given rehabilitation areas.

Erosion monitoring methodology is further detailed in Section 9.6 of the **Vulcan South Soils and Land Suitability Assessment** (**Appendix C**).

Ground Cover

An accurate measurement is required to assess the rehabilitation completion criteria that "grazed land maintains a percentage ground cover of between 50% and 96%". While this criteria relates specifically to rehabilitation areas to which cattle have been introduced (at advanced stages of rehabilitation development), it is prudent to commence this monitoring prior to the introduction of cattle. This data can then be used to calculate the effect of grazing on percentage cover, and thereby predict the groundcover expected at ungrazed sites following cattle introduction. This in turn will be useful for adjusting stocking rates, if required.

Ground cover is to be calculated by running a 50 m measuring tape along the length of each vegetation monitoring transect. Observations of the type of cover (limited to the cover present below 1 m above ground level) are made at point intercepts along the centre line of the 50 m transect at 0.5 m intervals. Cover types include (a) vegetation (including all live vegetation and standing senescent vegetation that is still attached to the main plant and is not in intimate contact with the soil); (b) leaf litter and woody debris; (c) rock or (d) bare ground. The cover type that is intercepted directly below each point is recorded. The intercept point is to be assessed by viewing the ground through a small observation hole (in a piece of stiff card or plastic) or tube. Preferably, this should contain a cross hair, although this is not obligatory. A total of 100 observations are made per transect, and the sum of each cover type equates to its percentage cover.

Percentage cover is to be assessed at rehabilitation sites only (reference site data is not required). Monitoring is to be undertaken concurrently with assessments of landscape function and vegetation surveys in the late wet season.

Pasture Productivity

For PLMU of cattle grazing, pasture productivity within rehabilitated sites is to be equivalent to nearby unmined sites on the same soil types. Pasture productivity is to be assessed via one of two methods:

1) **Manual measurements of pasture mass at specific moments in time.** An electronic dry matter capacitance meter (e.g., Grassmaster Pro) can be used to estimate pasture dry mass (kg/ha) at points within rehabilitation areas. This technique is superior to traditional plate meters on stony ground, such as will be found on sloping rehabilitation areas. The exact number of replicate points required per rehabilitation area is dictated by the variation observed between points and the need to meet the conditions of the completion criteria, namely that pasture mass is not significantly different from unmined areas, with adequate sampling to detect ≥10% difference between groups. An appropriate sample size (n) is based on the following formula:

$$n = 15.68*\sigma^2 / d^2,$$

where σ^2 is the population variance, and d is the minimum difference required to be detected. This formula is based on a standard 95% confidence interval and 80% power. It is anticipated that several hundred point-readings are likely to be required per rehabilitation area and reference paddock. Data from the first 100 readings can be used to calculate n for a d value that represents 10% of the mean dry mass at the reference site. Reference and rehabilitation areas are to be assessed concurrently, at the end of the growing season (April-May).

2) **Satellite estimation of pasture growth rate.** The CSIRO is in the process of developing their "Pastures from Space" website, which uses satellite imagery to provide real-time data on pasture growth rates at fine spatial scales. This technique has been optimised for temperate Australian pastures, but its applicability to the tropics and subtropics remains unclear. With further development and optimisation, this tool could provide a highly efficient method for comparing pasture productivity between rehabilitation and reference areas, without the need to undertake labour-intensive field studies. It is expected that this tool may be available by the time pasture productivity monitoring is to commence at the Project (i.e., six years after the first planting).

9.1.7 Rehabilitation Milestone 7: Establishment of Target Vegetation Type

Field Surveys

Field surveys are to monitor the following attributes of rehabilitation areas:

- relative dominance of Koala food trees;
- height of Koala food trees;
- basal area of *Casuarina cristata*;
- species richness of Greater Glider food trees;
- percentage cover of declared weeds;
- species composition of the pasture;
- Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons; and
- Availability of food for the Glossy Black-cockatoo

These attributes are to be measured within a 10 m × 50 m belt transect installed within rehabilitation areas.

Tree height is measured with a range-finder or clinometer. The five tallest Koala trees present within the belt transect are to be measured.

Basal area of woody vegetation is to be measured using a Bitterlich gauge. Each species of tree/shrub is to be measured separately. Each site is to be assessed using two 360° sweeps of the gauge (one at each end of the transect, 50 m apart), and the basal area of each woody species is the average from the two sweeps. The proportion of the total basal area of all woody vegetation that comprises Koala food trees (*Eucalyptus crebra, Eucalyptus populnea* and *Eucalyptus camaldulensis*) is used to assess the milestone criterion pertaining to Koalas. The total basal area of *Casuarina cristata* is used to assess the milestone criterion pertaining to Glossy Black-cockatoos. The presence of different *Eucalyptus* and *Corymbia* species is used to the milestone criterion pertaining to the Greater Glider.

The entire belt transect is to be searched, and all species of forbs and grasses contained within it are to be recorded. Percentage ground cover of each species is to be estimated to the nearest 0.1%, with 0.1% cover being equivalent to 0.5 m^2 total cover within the transect. From this data, milestone completion criteria pertaining the grass species richness and weed cover can be assessed.

Field surveys are to be undertaken in the late wet season (February-May), to coincide with maximum growth of grasses and forbs. Permanent monitoring sites are to be installed within all rehabilitation areas, and each end of each transect is to be marked with a star picket. An average of one monitoring site is to be installed per 10 ha of rehabilitated land. Rehabilitation areas that are less than 10 ha in extent (i.e., RA4: dams and sediment ponds) are to have at least one monitoring site.

Reference sites are to be installed in nearby undisturbed land used for grazing. Reference sites are to be of a similar soil type and slope to rehabilitated sites, and must have a vegetation density appropriate for Squatter Pigeons.

Reference sites will be selected to (a) meet the requirements for soil, slope and vegetation density, (b) be evenly spaced, with at least 500 m between them, and (c) be preferentially located within the MLA area, and therefore not subject to any external access permissions. To avoid biases in the placement of these reference sites, their coordinates will be selected based on GIS information rather than through site visits. The baseline condition of reference sites must represent a random sample of analogous, nearby, unmined vegetation communities.

Reference sites are to be surveyed concurrently with every second rehabilitation area monitoring round. Reference sites must be monitored in the year rehabilitation success is expected. Vegetation development is to be assessed every two years until milestone criteria have been achieved.

After vegetation establishment (after 6 to 12 months since sowing) soils will be re-tested to determine if any follow-up application of ameliorants is required.

Normalised Difference Vegetation Index

Rehabilitation areas for which the PMLU includes habitat for the Squatter Pigeon, Greater Glider and Koala (i.e., RA2, RA3 and RA4) are to undergo monitoring of woody vegetation density six years and ten years after the revegetation milestone is achieved. It is important to note, RA6 and RA7 (Highwall mining area) contain rocky escarpments that won't provide suitable habitat for squatter pigeons, however; habitat will be provided for Greater Glider's and Koala's. Woody vegetation density is measured using the Normalised Difference Vegetation Index (NDVI). The following approach is to be adopted:

1) The entire rehabilitation area is divided into 1-ha cells.
2) Landsat satellite imagery is to be downloaded from an appropriately dry time of year:
    - following at least two months in which no more than 10 mm of rain fell in a single 24-hour period; and
    - following at least one week with no rain.

    By using imagery captured during dry periods, when grass is dry, the NDVI (an index of greenness) reflects the density of woody vegetation cover. The months of July-September are usually appropriate, but in unusually wet winters, other months may need to be considered.
3) Using mapping software, the mean NDVI value for each 1-ha cell is to be calculated.

By using imagery captured during dry periods, when grass is dry, the NDVI (an index of greenness) reflects the density of woody vegetation cover. The months of July-September are usually appropriate, but in unusually wet winters, other months may need to be considered.

All cells fully contained within the relevant rehabilitation area are to have NDVI values between 0.1240 and 0.1778 in order to satisfy the completion criteria for threatened fauna. One-hectare cells within parts the MLA area in which no disturbance has occurred and in which woody vegetation density is likely to have remained relatively stable over time (e.g., remnant vegetation) is to be used as reference points for NDVI.

NDVI values of reference cells within the focal year should closely resemble values of the same cells calculated from Landsat imagery collected in August 2018 (on which completion criteria were based). If this is not the case, imagery from a different time of year should be used or, if this is unavailable or yields a similar outcome, the completion criteria are to be adjusted to account for shifts in greenness that arise from measurement biases or the influence of pasture.

9.1.8 Rehabilitation Milestone 8: Achievement of a Stable PMLU

The achievement of a stable landscape that can support low-intensity cattle grazing is to be monitored through field survey programs, described below.

Landscape Function Analysis

Monitoring of the stability of rehabilitated land is to be based on the "stability index" of Landscape Function Analysis (LFA) (Tongway and Hindley 2004).

Methodology to be adopted is described in detail by Tongway and Hindley (2004). Permanent monitoring sites used for vegetation monitoring are also to be monitored for soil stability.

Monitoring is to take place in the late wet season (February-May), to coincide with maximum plant growth. Sites are to be monitored at the time of planting and then every two years for ten years after planting. This time series of six intervals will generate a sigmoidal curve for the stability index. A stable PMLU will be achieved when the landscape function analysis scores for soil stability have started to plateau, and the plateau values predicted from sigmoidal curve fitted to the data are equivalent to or exceed values at analogue sites (Tongway and Hindley 2004). If the curve does not plateau or exceed the target value within ten years, additional rounds of monitoring will take place every five years until the target is achieved.

Slope gradients, soil types and vegetation densities have all been considered when site locations were chosen. The Locations of proposed reference sites are listed in **Table 9-1.**

Table 9-1 Proposed reference sites for LFA monitoring

Site	Slope	Latitude	Longitude
R1	Flat[1]	-22.28313	148.16910
R2	Flat	-22.28582	148.17477
R3	Flat	-22.29014	148.18028
R4	Flat	-22.30203	148.19103
R5	Flat	-22.27888	148.17310
R6	Sloping[2]	-22.27799	148.16634
R7	Sloping	-22.28109	148.16087
R8	Sloping	-22.28729	148.17035
R9	Sloping	-22.29139	148.17512
R10	Sloping	-22.29853	148.19032

Reference sites are to be surveyed concurrently with every second round of rehabilitation area monitoring. Reference sites must be monitored in the year rehabilitation success is expected. Vegetation development is to be assessed every two years until milestone criteria have been achieved.

Ground Cover

Landscape Function Analysis, discussed above, involves an assessment of percentage ground cover as classes.

[1] Flat- reference sites located on slope gradients less than 6%.
[2] Sloping- reference sites located on slope gradients between 10-20%.

A more accurate measurement is required to specifically assess the rehabilitation completion criteria that "grazed land maintains a percentage ground cover of between 50% and 96%". While this criteria relates specifically to rehabilitation areas to which cattle have been introduced (at advanced stages of rehabilitation development), it is prudent to commence this monitoring prior to the introduction of cattle. This data can then be used to calculate the effect of grazing on percentage cover, and thereby predict the groundcover expected at ungrazed sites following cattle introduction. This in turn will be useful for adjusting stocking rates, if required.

Ground cover is to be calculated by running a 50 m measuring tape along the length of each vegetation monitoring transect. Observations of the type of cover (limited to the cover present below 1 m above ground level) are made at point intercepts along the centre line of the 50 m transect at 0.5 m intervals. Cover types include (a) vegetation (including all live vegetation and standing senescent vegetation that is still attached to the main plant and is not in intimate contact with the soil); (b) leaf litter and woody debris; (c) rock or (d) bare ground. The cover type that is intercepted directly below each point is recorded. The intercept point is to be assessed by viewing the ground through a small observation hole (in a piece of stiff card or plastic) or tube. Preferably, this should contain a cross hair, although this is not obligatory. A total of 100 observations are made per transect, and the sum of each cover type equates to its percentage cover.

Percentage cover is to be assessed at rehabilitation sites only (reference site data is not required). Monitoring is to be undertaken concurrently with assessments of landscape function and vegetation surveys in the late wet season.

Erosion Monitoring

Additional erosion monitoring across the landform will also be undertaken for the early detection of erosion, to allow for early intervention.

In-field erosion monitoring will be undertaken at permanent monitoring transects, (50 m in length) established across the landform in conjunction with the LFA monitoring sites, to provide a basis for temporal assessments.

Visual observations will be taken whilst traversing transects on foot and recording the number and average depth of any erosion features, rill lines or gullies. Visual assessments should identify any evidence of excessive sediment movement, including the formation of rills, removal of soil around the base of plants and accumulation of loose sediment at the base of slopes. In-field erosion monitoring will be accompanied by assessment of the water quality of run-off water released from the catchment of given rehabilitation areas.

Erosion monitoring methodology is further detailed in Section 9.6 of the **Vulcan South Soils and Land Suitability Assessment** (**Appendix C**).

For the PLMU of cattle grazing, pasture productivity within rehabilitated sites is to be equivalent to nearby unmined sites on the same soil types. Pasture productivity is to be assessed via one of two methods:

1) **Manual measurements of pasture mass at specific moments in time.** An electronic dry matter capacitance meter (e.g., Grassmaster Pro) can be used to estimate pasture dry mass (kg/ha) at points within rehabilitation areas. This technique is superior to traditional plate meters on stony ground, such as will be found on sloping rehabilitation areas. The exact number of replicate points required per rehabilitation area is dictated by the variation observed between points and the need to meet the conditions of the completion criteria, namely that pasture mass is not significantly different from unmined areas, with adequate sampling to detect ≥10% difference between groups. An appropriate sample size (n) is based on the following formula:

$$n = 15.68*\sigma^2 / d^2,$$

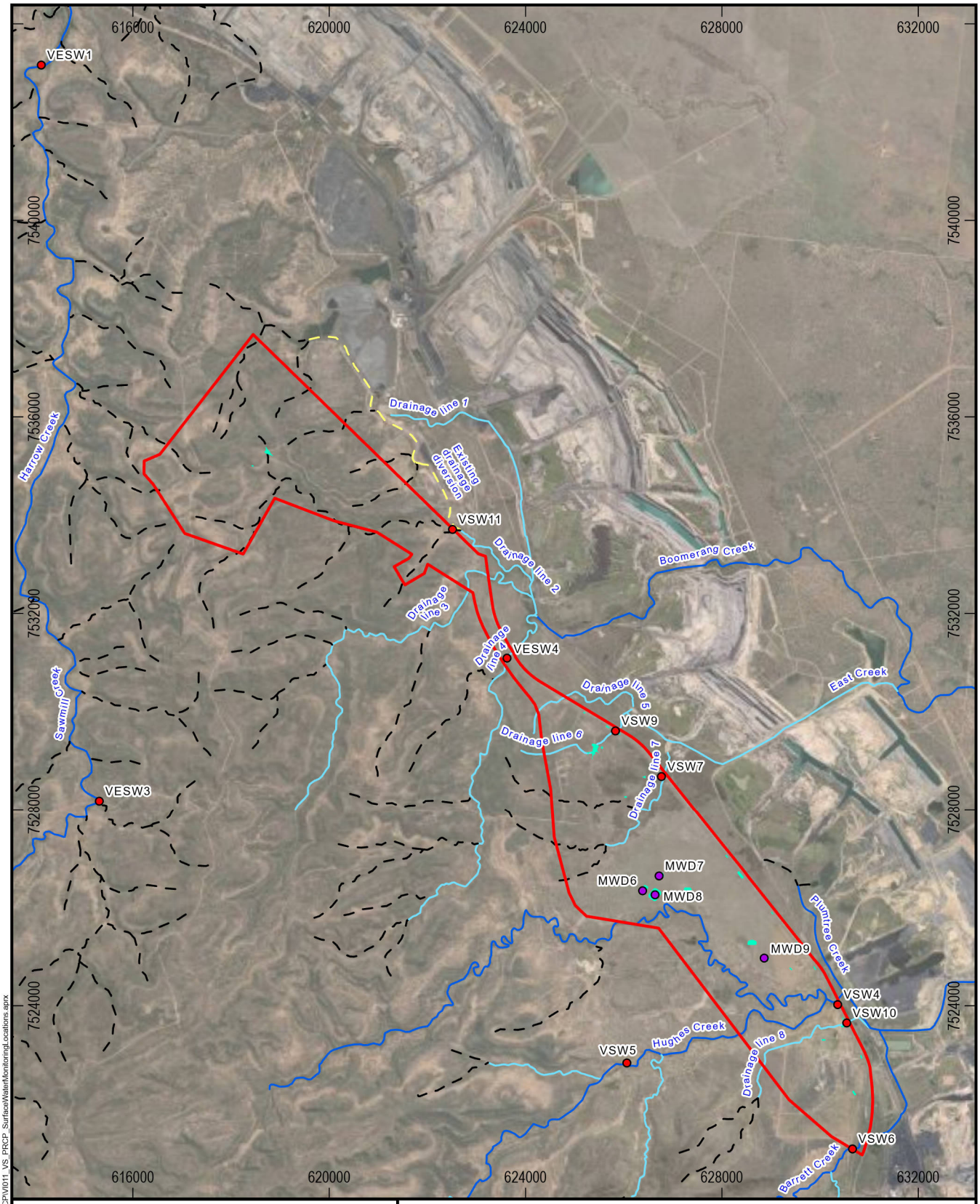
where σ^2 is the population variance, and d is the minimum difference required to be detected. This formula is based on a standard 95% confidence interval and 80% power. It is anticipated that several hundred point-readings are likely to be required per rehabilitation area and reference paddock. Data from the first 100 readings can be used to calculate n for a d value that represents 10% of the mean dry mass at the reference site. Reference and rehabilitation areas are to be assessed concurrently, at the end of the growing season (April-May).

2) **Satellite estimation of pasture growth rate.** The CSIRO is in the process of developing their "Pastures from Space" website, which uses satellite imagery to provide real-time data on pasture growth rates at fine spatial scales. This technique has been optimised for temperate Australian pastures, but its applicability to the tropics and subtropics remains unclear. With further development and optimisation, this tool could provide a highly efficient method for comparing pasture productivity between rehabilitation and reference areas, without the need to undertake labour-intensive field studies. It is expected that this tool may be available by the time pasture productivity monitoring is to commence at the Project (i.e., six years after the first planting).

Water Quality

The Project will have a groundwater and surface water monitoring program operating throughout all phases of the Project, including through rehabilitation and closure. The proposed surface water monitoring and groundwater locations that will be used to assess this milestone are shown in **Figure 9-2** and **Figure 9-3** respectively.

For a detailed description of the methodology to be adopted and the location of sampling sites, refer to the Receiving Environment Water Monitoring Program, which is to be completed prior to the commencement of the Project. A surface water monitoring schedule and proposed monitoring locations are presented in **Appendix A**. A Groundwater Impact Assessment has been developed with proposed monitoring locations presented in **Appendix B.**



Legend

- MLA Boundary
- Dams
- Proposed Water Monitoring Locations
  - Mine water dam monitoring location/ release point
  - Receiving water monitoring site
- Local Drainage Features
  - Minor Drainage Features
  - Drainage Features
  - Drainage Diversion
  - Watercourse

Source: WRM 2020-2022, State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_SurfaceWaterMonitoringLocations.aprx

Vulcan South

Surface Water Monitoring Locations

0 1 2 4

Kilometers

Scale: 1:112,000 (A4)

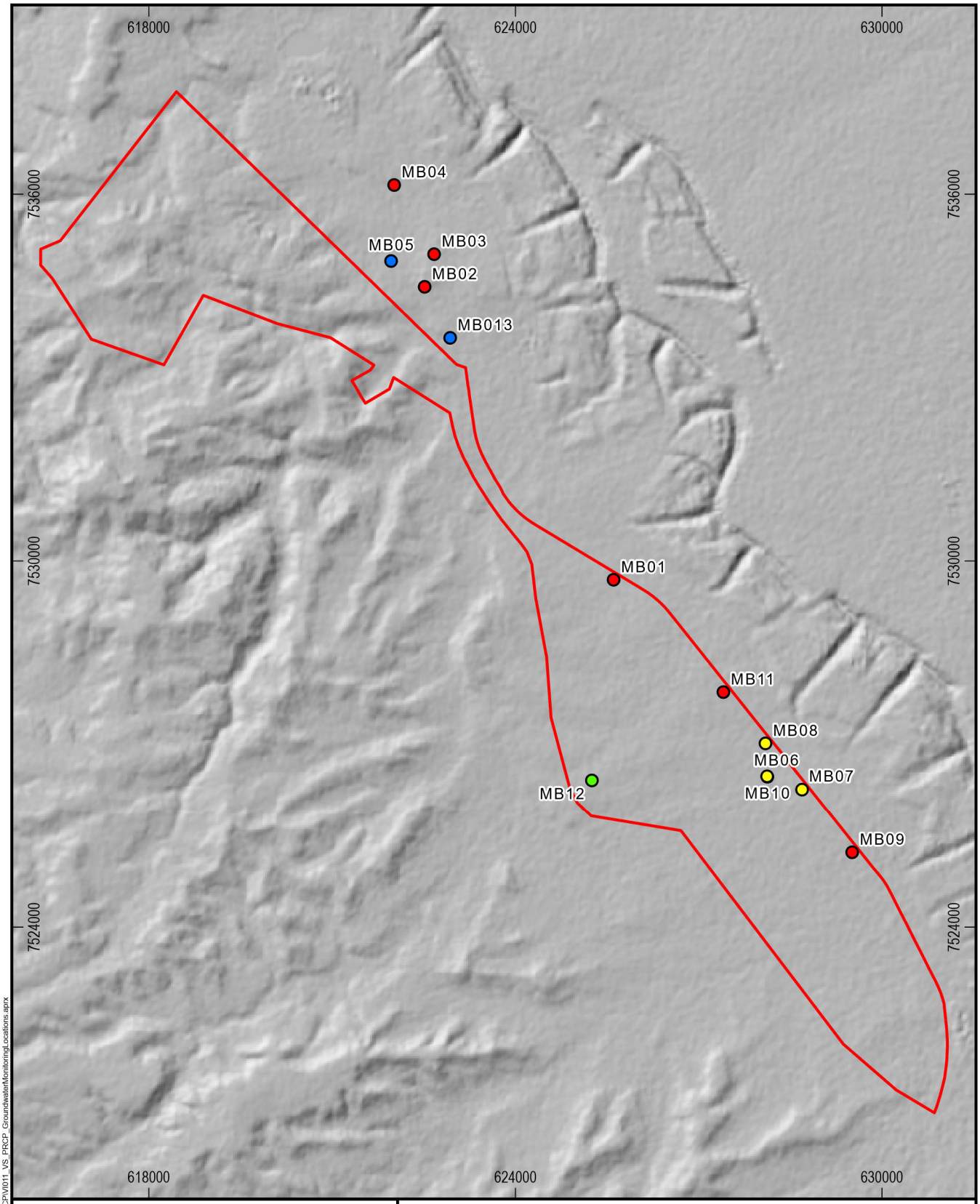
13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 9-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd



Legend

- MLA Boundary

Groundwater Monitoring Bores

- Back Creek Group
- DLL Coal Seam
- MAT Coal Seam
- Weathered Permian

Source: Geoscience Australia 2020, hydrogeologist.com.au 2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_GroundwaterMonitoringLocations.aprx

Vulcan South

Groundwater Monitoring Locations

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

13/03/2023

Datum: GDA2020
Projection: MGA55

FIGURE 9-3

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Receiving Environment Monitoring Program

A receiving environment monitoring program (REMP) document, describing in detail the proposed monitoring program for the local receiving waters, will be designed and implemented. The REMP will incorporate the current, historical and proposed monitoring as described in **Appendix A**.

Downstream monitoring points will be used to assess the water quality of the receiving waters in the context of rehabilitation establishment prior to removal of sediment dams and ultimately cessation of water monitoring. In addition to routine monitoring, these sites will be monitored directly after release events to assess the effect of releases.

Release contaminant trigger investigation levels

A set of initial proposed receiving water contaminant triggers levels have been developed, based on conditions at nearby operating coal mines, preliminary baseline results and the water quality objectives for the vicinity of the Project. These trigger levels are presented in **Appendix A** and are proposed to be measured against at the downstream water monitoring locations. Monitoring at these locations will allow for an accurate evaluation of the impact of any releases from the Project.

Drawdown monitoring

Ongoing monitoring of groundwater levels in the monitoring bore network will enable natural groundwater level fluctuations (such as responses to rainfall recharge) to be distinguished from potential groundwater level impacts (drawdown) due to dewatering/depressurisation resulting from proposed mining activities. Automatic data loggers are currently installed in the groundwater monitoring network, and they record daily measurements. These data loggers will be downloaded quarterly to coincide with groundwater quality sampling.

Drawdown due to the proposed Project is predicted to be limited to generally less than 2 km from the proposed pits (that is the lateral distance from the pit to the 1 m drawdown contour). This limited drawdown propagation is mainly due to the limited saturation of aquifers in the Project area, low hydraulic conductivities and low storage coefficients. The predicted drawdown extends east, toward Saraji Mine.

The groundwater monitoring network established by hydrogeologist.com.au (2022) will form the basis for ongoing drawdown monitoring and management through the life of the Project.

Areas not relevant for this milestone

In the event parts of the proposed disturbance footprint are not actually disturbed, undisturbed portions of "rehabilitation areas" will not be subject to the same set of milestone criteria as the disturbed portions. For example, the highwall mining area plunges are not expected to create surface disturbance, however; this area has still been considered within the disturbance footprint.

9.1.9 Rehabilitation Milestone 9: Acceptance of Saraji Road by Isaac Regional Council

Vitrinite is signatory to a formal compensation agreement with IRC for the realignment of Saraji Road. This agreement prescribes the terms and conditions for IRC's acceptance of responsibility for the management and maintenance of the realigned road.

Upon completion of the construction of the road realignment, Vitrinite is to provide IRC with a Certificate of Practical Completion. The receipt of this certificate denotes the start of a "Defects Period", during which Vitrinite will continue to be responsible for all maintenance costs associated with rectifying any identified defects in the realignment and must do so at the direction of IRC if required.

The Defects Period will end on the later of a 12-month period after Vitrinite provides IRC with a Certificate of Practical Completion or the date that IRC notifies Vitrinite that the new road alignment is accepted "off maintenance". Rehabilitation milestone 9 is considered complete following this acceptance by IRC.

Inspections of road condition will be the responsibility of IRC, but Vitrinite will be responsible for undertaking traffic monitoring in accordance with the compensation agreement.

9.1.10 Monitoring Report

Rehabilitation milestones RM6, RM7 and RM8 are expected to be assessed concurrently and, as they constitute the primary rehabilitation completion criteria for the Project, they will be monitored over an extended period of at least 10 years.

The results of each two-yearly monitoring event will be presented in a report that assesses progress of these three milestones. Each report will contain details about how the methodology used is consistent with this PRC Plan. Each report will also discuss how the results obtained indicate progression towards the fulfilment of milestone criteria.

This monitoring report is to be completed by 1 October in the calendar year in which surveys are undertaken, to allow adequate time to report on the findings by the state-wide reporting deadline of 10 December.

9.2 Audits

In accordance with section 285 of the *Environmental Protection Act 1994*, holders of a PRCP schedule must commission a rehabilitation auditor to undertake an audit of the PRCP schedule every three years. The first audit must be for the three-year period that commences from the day the schedule takes effect. Each subsequent audit period is for the three years commencing on the day after the previous audit period ended. Each audit report must be delivered to the administering authority within four months after the end of each audit period.

In accordance with section 286 of the *Environment Protection Act 1994*, each audit must include the following:

- a statement about whether the holder has complied with the schedule during the audit period;
- a description of actions the holder has taken with respect to rehabilitation milestones and management milestones;
- whether the holder has complied with conditions imposed on the schedule;
- a declaration stating the holder has not knowingly given false or misleading information;
- an assessment of whether the post-mining land use is likely to be achieved; and
- recommendations about actions the holder should take to ensure rehabilitation milestones and management milestones are achieved.

In addition to the mandatory three-yearly audits, the administering authority has the power (under section 322 of the *Environmental Protection Act 1994*) to issue an audit notice, which requires the holder of a PRCP schedule to commission an audit.

9.3 Annual Return

In addition to the annual return requirements that relate to EAs in accordance with section 316IA of the *Environmental Protection Act 1994*, the annual return must also include an evaluation of the effectiveness of the PRCP schedule, including the environmental management carried out under the schedule, for the year to which the annual return relates. This evaluation must include:

- whether any milestones to be completed under the PRCP schedule during the year have been met; and
- whether the conditions imposed on the PRCP schedule have been complied with.

9.4 Progressive Rehabilitation Report

In the event that a particular area within the tenure of the Project has been rehabilitated in accordance with all relevant requirements of the *Environmental Protection Act 1994*, the relevant environmental authority, the PRCP schedule and any relevant guidelines made under the *Environmental Protection Act 1994*, the holder of the EA can apply for progressive certification. In accordance with section 318ZD of the *Environmental Protection Act 1994*, the application for progressive certification must be accompanied by a progressive rehabilitation report. The

requirements for a progressive rehabilitation report are listed in section 318ZF of the *Environmental Protection Act 1994.*

9.5 Final Rehabilitation Report

A final rehabilitation report is to be prepared when applying to surrender the EA. The purpose of this final rehabilitation report is to demonstrate that the conditions of the EA have been complied with, and that rehabilitation of disturbed land has been carried out satisfactorily. The requirements of this final rehabilitation report are listed in section 262 of the *Environmental Protection Act 1994.*

9.6 Post-mining Management Report

A post-mining management report is to be submitted as part of the surrender application for the EA. This report states the requirements for ongoing management of the land and includes an environmental risk assessment. The requirements of this post-mining management report are listed in section 264A of the *Environmental Protection Act 1994.*

10 PRCP SCHEDULE

This section has been prepared in accordance with section 126D(1) of the *Environmental Protection Act 1994*. It contains a description of each rehabilitation area, a schedule of land availability for rehabilitation and a detailed description of the rehabilitation milestones that apply to each rehabilitation area. This information is used to develop a PRC Plan schedule that describes when each rehabilitation milestone is to be progressively achieved in each rehabilitation area.

10.1 Final Site Design

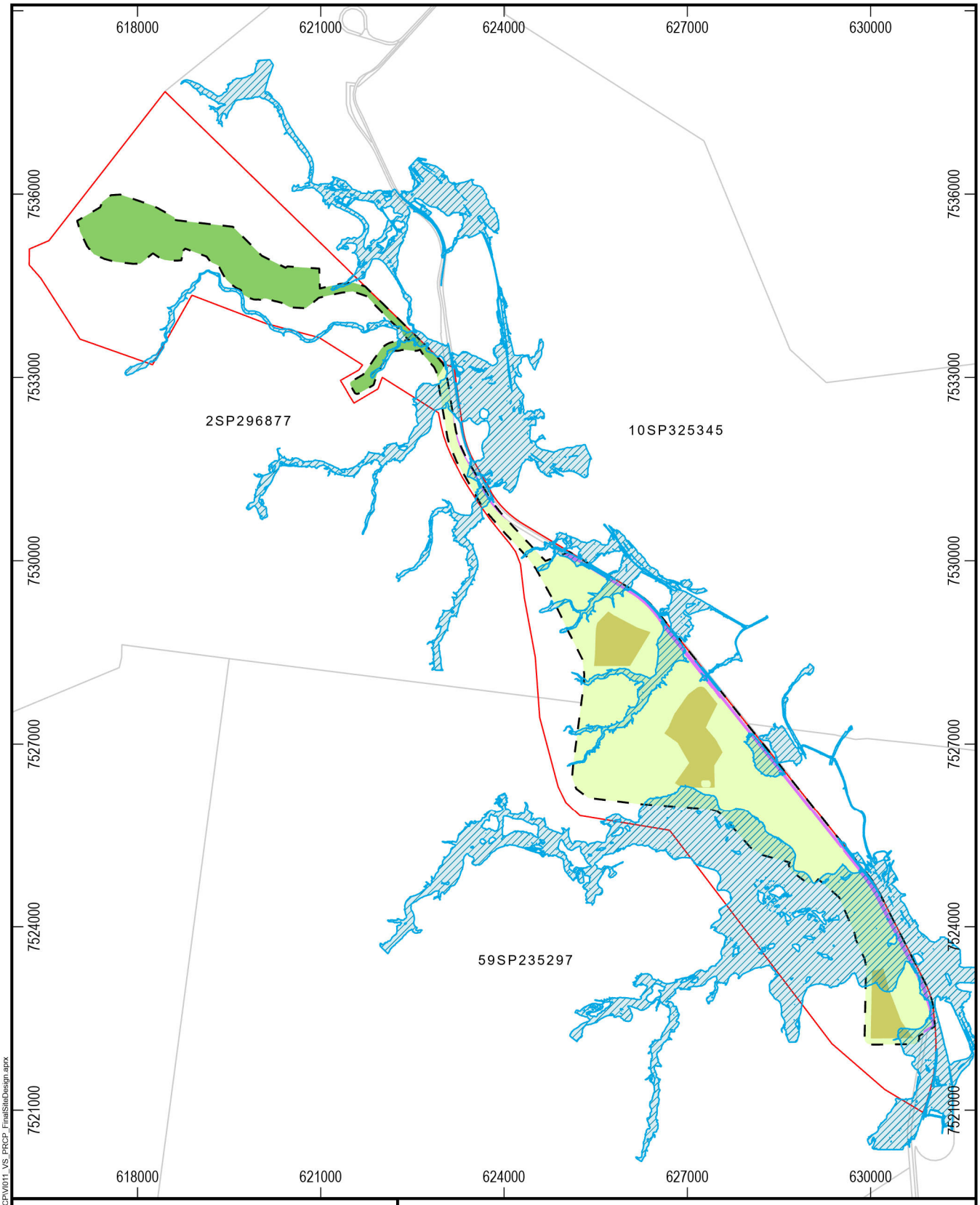
The final site design showing the maximum disturbance footprint, the mining lease boundaries, the PMLU for land within the mining lease, rehabilitation areas and flood plain extent is shown in **Figure 10-1**.

10.1.1 Rehabilitation Areas

The proposed disturbance footprint of the Project has been divided into the following five rehabilitation areas with a common PMLU and rehabilitation methodology:

- RA1: Ex-pit dumps;
- RA2: Open-cut mining pits; In-pit dumps;
- RA3: Infrastructure, Haul roads, internal tracks, offices, stockpiles, run-of-mine pad, train load-out, rail loop, and CHPP and MIA;
- RA4: Dams, sediment control drains and flood protection infrastructure; and
- RA5: Realigned Saraji Road;
- RA6: Highwall Mining Area- ex-pit WRD, dam, highwall bench; and
- RA7: Highwall Mining Area- magazine and haul road.

The division of the disturbance footprint into rehabilitation areas is shown in **Figure 10-2**.



Legend

- Cadastral Boundary
- Vulcan South Maximum Disturbance
- MLA Area
- Flood Plain Extent

PMLU

- Low Intensity Cattle Grazing
- Low Intensity Cattle Grazing with Habitat for Threatened Fauna
- Native Ecosystems
- Saraji Road

Source: State of Queensland (Department of Resources) 2022, Vitrinite 2020-2022, METServe 2020-2023.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_FinalSiteDesign.aprx

Vulcan South

Final Site Design

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

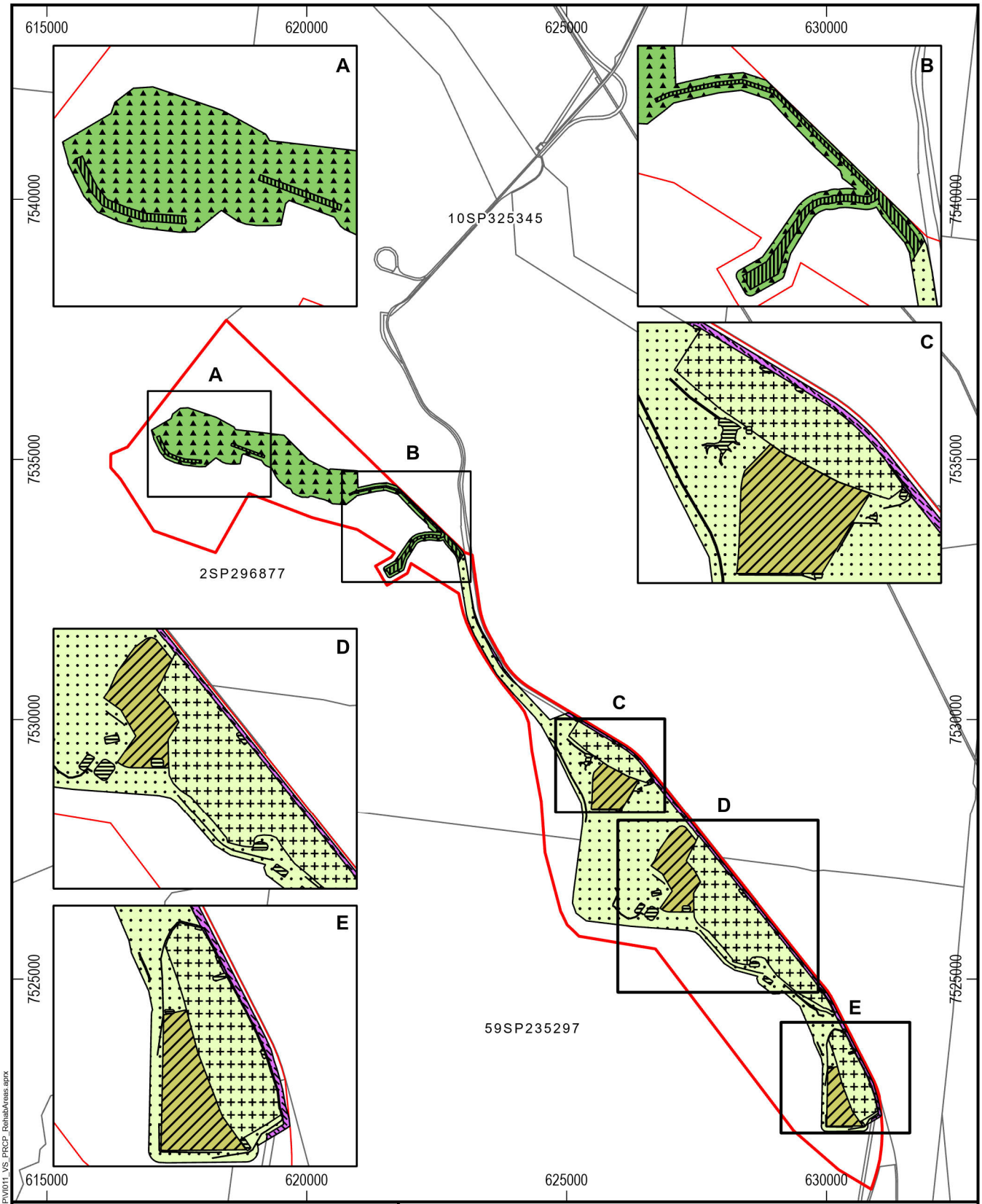
22/02/2023

Datum: GDA2020
Projection: MGA55

FIGURE 10-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd



Legend

- Cadastral Boundary
- MLA Area

Rehabilitation Areas

- RA1
- RA2
- RA3
- RA4
- RA5
- RA6
- RA7

PMLU

- Low Intensity Cattle Grazing
- Low Intensity Cattle Grazing with Habitat for Threatened Fauna
- Native Ecosystems
- Saraji Road

Source: State of Queensland (Department of Resources) 2022, Vitrinite 2020-2023, METServe 2020-2023. *Insets at different scales.*

Vulcan South

Rehabilitation Areas

0 1 2 4

Kilometers

Scale: 1:106,000 (A4)

22/02/2023

Datum: GDA2020
Projection: MGA55

FIGURE 10-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\PRCP\VI011_VS_PRCP_RehabAreas.aprx

10.2 Schedule of Land Availability

Land will become available for rehabilitation progressively through the life of the Project. Disturbed land is available for rehabilitation when:

- the land is no longer being mined;
- the land is no longer being used to dump further waste rock;
- the land is no longer being used for operating infrastructure or machinery for mining;
- the land is no longer being used for transport associated with operational or rehabilitation activities (in the case of haul roads particularly those associated with highwall mining); and
- the land does not support permanent infrastructure (e.g., Saraji Road).

10.2.1 Timing Considerations

Mine plans, which include the schedule of land available for rehabilitation, have been developed for each 12 months starting at the commencement of the Project. However, in accordance with the *Progressive Rehabilitation and Closure Plans Guideline*, annual reporting of rehabilitation works is to be based on the completion date of 10 December each calendar year. Consequently, the progression of the mine (and its rehabilitation) within any one calendar year is strongly dependent on the date the Project commences. All calculations and predictions of land availability within each calendar year are based on the current forecast Project commencement date of 31 March 2024. This date is subject to change, pending the government approval process.

One rehabilitation milestone (revegetation) is strongly season-dependent, and is only to take place following the start of wet season rain. It is assumed that any land available for rehabilitation later than July in any one calendar year is unlikely to have sufficient time to undergo infrastructure removal, decontamination and final landform shaping in preparation for revegetation at the start of the wet season (November-January, depending on the year). Consequently, deferring the commencement of rehabilitation of such land until the following year will not delay the revegetation stage.

Land that is available for rehabilitation before July will commence rehabilitation in the same calendar year. It is expected that rehabilitation milestones RM1, RM2 and RM3 (see **Section 10.3**) will be completed in the year that land becomes available for rehabilitation. Milestones RM4 and RM5 may also be completed the same year (relative to the reporting date of 10 December), but only if the wet season commences early (e.g., November). As the start of the wet season is unpredictable, for the purposes of the schedule, it is assumed that milestones RM4 and RM5 will be completed early in the following year, and hence are attributed to the following years' progress in the schedule. There is a ten year period scheduled between RM5 and RM6/RM7 to allow trees to establish.

Based on tree growth rates and pasture development at other mines in central Queensland (Mulligan *et al.* 2006), it is expected that the target vegetation community will be established ten years after planting, and the land will be suitable for the commencement of grazing at this time. This is a conservative estimate to allow for opportunities for remedial planting in the event of initial failures; grazing has been successfully introduced to central Queensland pastures with trees that are as young as four years old (Donaghy *et al.* 2010).

10.2.2 Schedule of Availability

The schedule of land availability for rehabilitation in each rehabilitation area is shown in Table 10-1.

.

Table 10-1 Schedule of land availability for rehabilitation

Rehabilitation Area		Land available for rehabilitation in each year (ha)*												
		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Total by RA
RA 1	Ex-pit dump	0	0	73.6	73.5	0	0	44.6	0	0	0	0	0	191.7
RA 2	In-pit dump	0	35.7	69.3	0	94.9	43.8	74.3	87.3	0	0	0	0	405.3
RA 3	Infrastructure, haul roads, offices, highwall benches, stockpiles, train load-out, rail loop CHPP and MIA	0	0	0	0	0	0	0	0	174.3	174.3	174.3	174.2	697.1
RA 4	Dam, sediment ponds and flood protection infrastructure†	0	0	0	0	0	0	0	0	25.9	0	0	0	25.9
RA 5	Saraji Road‡	0	0	0	0	0	0	0	0	0	55.2	0	0	55.2
RA 6	Highwall mining area: ex-pit dump, dam, highwall bench.	0	321.1	0	0	0	0	0	0	0	0	0	0	321.1
RA 7	Highwall mining area: magazine, and haul road	0	0	0	0	0	0	0	0	31.1	0	0	0	31.1
	Total by year	**0**	**356.8**	**142.9**	**73.5**	**94.9**	**43.8**	**118.9**	**87.3**	**231.3**	**229.5**	**174.3**	**174.2**	**1,727.4**

*Land areas represent hectares of land that becomes available for the first time in that year (i.e., is not cumulative across years).

†Erosion control infrastructure is to remain in place until sufficient vegetative cover has developed on rehabilitated land. This is conservatively estimated to be three years post-mining, but may be sooner.

‡The realigned Saraji Road corridor will be constructed and operational within year 1, however further rehabilitation works within the corridor fringes may be required following construction of the final in-pit dump landform. Hence rehabilitation works are schedule to occur after the landform is established. The RA5 area calculation is conservative as it assumes a potential realignment of the entirety of Saraji road intercepting the MLA rather than the likely realignment around the northern, central and southern open pits to allow for their slight extension outside of the MLA, in consultation with IRC. The exact area requiring rehabilitation was revisited following conditions when mining of the pits commence.

10.3 Rehabilitation Milestones

Rehabilitation milestones relevant to the Project area are listed in **Table 10-2**.

Table 10-2 Rehabilitation milestones

Code	Milestone	Description	Applicable Rehabilitation Areas
RM1	Infrastructure decommissioning and removal.	▪ Disconnect and terminate services such as water and electricity; ▪ Pipelines and drainage infrastructure drained and removed; ▪ Demolish and remove buildings and infrastructure(modular CHPP, TLO, administration, ablution block, workshops, magazine and warehouses, etc.); ▪ Bitumen, blue metal, aggregate, etc., have been removed; ▪ Fencing has been removed; ▪ Rail tracks and balast have been removed; and ▪ Boreholes have been decommissioned.	RA3 and RA7
RM2	Remediation of contaminated land.	▪ Contaminated land investigations have been carried out; ▪ Contaminated water (e.g. affected by hydrocarbons) has been treated on site or removed; ▪ Contaminated materials have been appropriately removed and disposed of; ▪ On-site remediation of hydrocarbon-contaminated soils has been completed; and ▪ Completion of validation testing to confirm that contaminated soils have been removed/remediated.	RA2, RA3, RA4, RA6 and RA7
RM3	Landform development and reshaping/re-profiling.	▪ Bulk earthworks to achieve required landform and slopes have been completed; ▪ Placement of subsoils over waste rock has been completed; ▪ General reshaping to achieve final landform is complete; and ▪ Installation of erosion and sediment control systems is complete.	RA1, RA2, RA3, RA4, RA6 and RA7
RM4	Surface preparation.	▪ Remediation any erosion or subsidence is complete; ▪ Growth media (topsoil) has been sourced, carted and spread; ▪ Ameliorants to improve or stabilise soils have been added; and ▪ Deep ripping has been undertaken.	RA1, RA2, RA3, RA4, RA6 and RA7
RM5	Revegetation.	▪ Direct seeding has been completed; ▪ Fertiliser has been applied; ▪ Tube stock (except RA1) has been planted; and ▪ Stock fencing to protect planting has been installed.	RA1, RA2, RA3, RA4, RA6 and RA7
RM6	Land is suitable for the commencement of grazing.	▪ Pasture is sufficiently productive to support grazing and (where relevant) trees are sufficiently tall to avoid damage by cattle; ▪ Internal stock fencing, to separate land ready for grazing from that not yet developed sufficiently, has been installed; and ▪ Water sources for cattle have been installed.	RA1, RA2, RA3, RA4
RM7	Establishment of target vegetation type.	▪ Monitoring has determined that vegetation meets the completion criteria. ▪ After vegetation establishment (after 6 to 12 months since sowing) soils will be re-tested to determine if any follow-up application of ameliorants is required.	RA1, RA2, RA3, RA4, RA6 and RA7
RM8	Achievement of post-mining land use to stable condition.	▪ Monitoring has determined that that the land is safe, structurally stable, does not cause environmental harm and is able to sustain the PMLU.	RA1, RA2, RA3, RA4, RA6 and RA7
RM9	Fulfilment of all conditions of the agreement with Isaac Regional Council for the	▪ The road has been constructed in accordance with all conditions agreed between Isaac Regional Council and Vitrinite Pty Ltd in the signed compensation agreement.	RA5

	construction and commissioning of Saraji Road.	▪ A "Defects Period" of at least 12 months has passed following the completion of construction. ▪ Isaac Regional Council has notified Vitrinite that the new road alignment is accepted "off maintenance".

10.3.1 Milestone Criteria

Milestone criteria pertaining to each of the rehabilitation milestones are listed in **Table 10-3**.

Table 10-3 Milestone Criteria

Code	Milestone	Milestone criteria
RM1	Infrastructure decommissioning and removal.	▪ All services disconnected; ▪ All road materials (bitumen, gravel) removed; ▪ All pipelines drained and removed; ▪ All fencing that is not part of the PMLU removed; ▪ All buildings demolished and removed; ▪ All machinery and equipment removed; ▪ All surface water drainage infrastructure that is not required in the PMLU is removed; ▪ All rubbish removed; and ▪ All waste is to be transported, disposed of and handled in accordance with relevant waste legislature.
RM2	Remediation of contaminated land.	▪ All contamination is remediated or removed from site; ▪ Any contamination removed from site is done so in accordance with relevant regulations; and ▪ A contaminated land investigation document is prepared by an approved auditor, which is to contain a site suitability statement stating that land is not contaminated and is suitable for any use.
RM3	Landform development and reshaping/reprofiling.	▪ All earthworks except topsoil are to be completed; ▪ Subsoil is to be applied and spread to RA2 (in-pit dumps); ▪ All erosion and sediment control systems are to be installed; ▪ The final landform is to be constructed as per the design plan; ▪ Batters are to have a maximum slope of 15%; ▪ All rehabilitation and associated works are to have 'as-constructed' plans prepared; and ▪ The back-filled pit is to be certified as geotechnically stable by a suitably qualified person.
RM4	Surface preparation.	▪ Any erosion or subsidence that occurs after the achievement of RM3 has been remediated prior to topsoil application; ▪ 250 mm of topsoil is to be placed over all surfaces; ▪ Slopes greater than 10% are to have a rock mulch cover of at least 30%; ▪ No areas are to have a rock mulch cover exceeding 50%, to facilitate the safe movement of cattle and production of pasture. ▪ An assessment of soil health and suitability has been completed by an appropriately qualified person to confirm soil is suitable for target vegetation establishment; and ▪ Any fertilisers/ameliorants recommended as a result of the soil assessment are to have been applied at the rate recommended by the appropriately qualified person. ▪ Contour ripping and/or ploughing (depth 0.4m -0.5m) has been undertaken after topsoil placement.

Code	Milestone	Milestone criteria
RM5	Revegetation.	▪ Completed seeding at a rate of 16.7 kg/ha; ▪ Any species not establishing after seeding (as identified 12 months after seeding) have been planted as tubestock in RA2, RA3 and RA4 at a density of 20-100 seedlings/ha; and Supplementary seeding and tubestock planting completed within one year of sites failing to achieve vegetation establishment on initial attempts.
RM6	Land is suitable for the commencement of grazing.	▪ Rehabilitated areas have a pasture biomass that is not >10% less than pasture biomass on unmined areas within the same soil management unit measured at the same time, as measured under both wet and dry conditions; ▪ All corrective actions recommended by suitably qualified persons in response to erosion or deficient vegetation cover have been implemented; ▪ Rehabilitated areas are to have a land suitability class for cattle grazing of 4 or lower; ▪ No active rill or gully erosion deeper than 15 cm present; ▪ Trees are, on average, at least 4 m tall; ▪ Water sources have been installed; and ▪ Stock fencing installation is complete.
RM7	Establishment of target vegetation type*.	▪ Rehabilitated areas are to have a mean NDVI between 0.1240 and 0.1778 AND/OR Squatter Pigeons are observed within rehabilitated areas; ▪ The species richness of grasses within 10 m ´ 50 m plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit; ▪ Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* AND rehabilitated areas are to have ≤0.1% cover of Harrisia martinii AND any other weeds listed under the Biosecurity Act are to be present in densities of <1 individual per hectare; ▪ Eucalyptus crebra and/or Eucalyptus populnea are to constitute 21% of the total basal area of woody vegetation on sand plains; ▪ Eucalyptus camaldulensis is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7; ▪ Rehabilitated areas where the ground is level and soil management unit “Orange” has been used as topsoil are to have a minimum basal area of 0.5 m2/ha stems of Casuarina cristata per ha. ▪ Rehabilitated areas on the Zambezi soil management unit are to contain Eucalyptus camaldulensis and at least one other species of Corymbia or Eucalyptus. ▪ Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons ▪ Availability of food for the Glossy Black-cockatoo is restored to pre-mining levels

Code	Milestone	Milestone criteria
RM8	Achievement of post-mining land use to stable condition*.	All corrective actions recommended by suitably qualified persons in response to erosion or deficient vegetation cover have been implemented; ▪ A suitably qualified person has certified that the final landform is geotechnically stable; ▪ The land suitability class of rehabilitated land is to be 4 or lower for cattle grazing; ▪ Rehabilitated areas have a pasture biomass that is not >10% less than pasture biomass on unmined areas with the same soil management unit measured at the same time, as measured under both wet and dry conditions; ▪ Eucalyptus crebra and/or Eucalyptus populnea are to constitute 21% of the total basal area of woody vegetation on sand plains. ▪ Eucalyptus camaldulensis is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7. ▪ Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites; ▪ Erosion monitoring has been completed; ▪ No active rill or gully erosion deeper than 25 cm present; ▪ Grazed land maintains a percentage ground cover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%; ▪ Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* AND rehabilitated areas are to have ≤0.1% cover of Harrisia martinii ▪ Any other weeds listed under the Biosecurity Act are present in densities of <1 individual per hectare; ▪ Surface water in downstream monitoring locations remains within site-specific water quality monitoring limits detailed in **Appendix A** – Surface Water Assessment: Interim contaminant trigger investigation levels; ▪ Groundwater in downstream monitoring locations remains within site-specific water quality monitoring limits detailed in **Appendix B** – Groundwater Assessment : Water Quality Objectives; ▪ At least 50% of established species show natural recruitment; and ▪ Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons ▪ Availability of food for the Glossy Black-cockatoo is restored to pre-mining levels ▪ Sites fulfil all other milestone criteria after having experienced at least one "drought" year (defined as having a total rainfall over a 12-month period that falls within the lowest decile recorded at the nearest weather station, Moranbah Airport).
RM9	Fulfilment of all requirements of an agreement with Isaac Regional Council for the construction and commissioning of Saraji Road.	▪ Isaac Regional Council (IRC) has notified Vitrinite that the new road alignment is accepted "off maintenance", in accordance with processes prescribed by a signed compensation agreement between Vitrinite and IRC.

*These milestone criteria preclude areas undisturbed by mining and still within the disturbance footprint.
^For Erosion Monitoring Classifications, see Section 9.6.1 of the **Vulcan South Soils and Land Suitability Assessment** (**Appendix C**).

10.4 PRCP Schedule

The PRC Plan Schedule is provided in **Table 10-4.**

Table 10-4 PRCP Schedule

Rehabilitation area		RA1							
Relevant activities		Ex-pit waste rock dump							
Total size of rehabilitation area (ha)		191.7							
Commencement of first milestone (RM1)		1-Aug-26							
PMLU		PMLU A: Low-intensity cattle grazing							
Date area is available	31/07/26	31/07/27		31/07/30					
Cumulative area available (ha)	73.6	147.1		191.7					
	Milestone completed by								
	10/12/26	10/12/27	10/12/28	10/12/30	10/12/31	10/12/37	10/12/38	10/12/41	
Milestone code	**Cumulative area achieved (ha)**								
RM3	73.6	147.1	147.1	191.7	191.7				
RM4		73.6	147.1	147.1	191.7				
RM5		73.6	147.1	147.1	191.7				
RM6						73.6	147.1	191.7	
RM7						73.6	147.1	191.7	
RM8						73.6	147.1	191.7	

Rehabilitation area	RA2													
Relevant activities	Open-cut mining pit; In-pit waste rock dump													
Total size of rehabilitation area (ha)	405.3													
Commencement of first milestone (RM1)	1-Aug-25													
PMLU	PMLU B: Low-intensity cattle grazing with habitat for threatened fauna													
Date area is available	31/07/25	31/07/26		31/07/28	31/07/29	31/07/30	31/07/31							
Cumulative area available (ha)	35.7	105.0		199.9	243.7	318.0	405.3							
	Milestone completed by													
	10/12/25	**10/12/26**	**10/12/27**	**10/12/28**	**10/12/29**	**10/12/30**	**10/12/31**	**10/12/32**	**10/12/36**	**10/12/37**	**10/12/39**	**10/12/40**	**10/12/41**	**10/12/42**
Milestone code	**Cumulative area achieved (ha)**													
RM2	35.7	105.0	105.0	199.9	243.7	318.0	405.3	405.3						
RM3	35.7	105.0	105.0	199.9	243.7	318.0	405.3	405.3						
RM4		35.7	105.0	105.0	199.9	243.7	318.0	405.3						
RM5		35.7	105.0	105.0	199.9	243.7	318.0	405.3						
RM6									35.7	105.0	199.9	243.7	318.0	405.3
RM7									35.7	105.0	199.9	243.7	318.0	405.3
RM8									35.7	105.0	199.9	243.7	318.0	405.3

Rehabilitation area		RA3								
Relevant activities		Haul roads, internal tracks, offices, soil stockpiles, run-of-mine pad, train load-out, rail loop, CHPP, MIA								
Total size of rehabilitation area (ha)		697.1								
Commencement of first milestone (RM1)		1-Aug-32								
PMLU		PMLU B: low intensity cattle grazing with habitat for threatened fauna								
Date area is available	31/07/32	31/07/33	31/07/34	31/07/35						
Cumulative area available (ha)	174.3	348.6	522.9	697.1						
	Milestone completed by									
	10/12/32	10/12/33	10/12/34	10/12/35	10/12/36	10/12/43	10/12/44	10/12/45	10/12/46	
Milestone code	**Cumulative area achieved (ha)**									
RM1	174.3	348.6	522.9	697.1	697.1					
RM2	174.3	348.6	522.9	697.1	697.1					
RM3	174.3	348.6	522.9	697.1	697.1					
RM4		174.3	348.6	522.9	697.1					
RM5		174.3	348.6	522.9	697.1					
RM6						174.3	348.6	522.9	697.1	
RM7						174.3	348.6	522.9	697.1	
RM8						174.3	348.6	522.9	697.1	

Rehabilitation area		RA4			
Relevant activities		Dam, sediment control drains and flood protection infrastructure			
Total size of rehabilitation area (ha)		25.9			
Commencement of first milestone (RM1)		1-Aug-32			
PMLU		PMLU B: Low intensity cattle grazing with habitat for threatened fauna			
Date area is available	31/07/32				
Cumulative area available (ha)	25.9				
	Milestone completed by				
	10/12/32	10/12/33	10/12/43		
Milestone code	Cumulative area achieved (ha)				
RM2	25.9				
RM3	25.9				
RM4		25.9			
RM5		25.9			
RM6			25.9		
RM7			25.9		
RM8			25.9		

Rehabilitation area		RA5
Relevant activities		Saraji Road
Total size of rehabilitation area (ha)		55.2
Commencement of first milestone (RM1)		1-Aug-33
PMLU		PMLU D: Saraji Road
Date area is available	31/07/33	
Cumulative area available (ha)	55.2	
	Milestone completed by	
	10/12/33	
Milestone code	**Cumulative area achieved (ha)**	
RM9	55.2	

Rehabilitation area				RA6
Relevant activities				Highwall Mining Area- ex-pit WRDs, dam, highwall bench
Total size of rehabilitation area (ha)				321.1
Commencement of first milestone (RM1)				1-Aug-25
PMLU				PMLU C: Native ecosystems
Date area is available	31/07/25			
Cumulative area available (ha)	321.1			
	Milestone completed by			
	10/12/25	10/12/26	10/12/36	
Milestone code	Cumulative area achieved (ha)			
RM2	321.1			
RM3	321.1			
RM4		321.1		
RM5		321.1		
RM7			321.1	
RM8			321.1	

Please note that of the 321.1 ha in RA6, the benches, dump and dams are 49.7 ha and the remainder (buffer areas and above plunge region) is 271.4 ha. This 271.4ha consists of the surface area above all the plunges and any buffer area around infrastructure, and therefore has only been included for conservative purposes. Most of this will likely not require rehabilitation.

Rehabilitation area				RA7
Relevant activities				Highwall Mining Area- magazine and haul road
Total size of rehabilitation area (ha)				31.1
Commencement of first milestone (RM1)				1-Aug-32
PMLU				PMLU C: Native ecosystems
Date area is available	31/07/32			
Cumulative area available (ha)	31.1			
	Milestone completed by			
	10/12/32	10/12/34	10/12/44	
Milestone code	**Cumulative area achieved (ha)**			
RM1	31.1			
RM2	31.1			
RM3	31.1			
RM4		31.1		
RM5		31.1		
RM7			31.1	
RM8			31.1	

11 REVISION OF THE PRC PLAN

The holder of a PRC plan may, at any time, apply to the administering authority to amend their PRCP schedule (an amendment application). An application may be made to amend only the PRCP schedule, or as part of an amendment application for an EA. An amendment application must be submitted in the approved form and be accompanied by the relevant fee and an amended rehabilitation planning part for the holder's PRC plan that complies with section 126C of the EP Act. Due to the dependencies between an EA and the PRCP schedule, an applicant should always consider whether a proposed amendment to the PRCP schedule requires a concurrent amendment to the EA in order to ensure consistency between both instruments.

Once a PRCP schedule has been amended, the rehabilitation planning part of the PRC plan must be reviewed and revised to make any necessary or appropriate changes. The administering authority is to be provided with a copy of the amended PRC plan within 10 business days of receiving a copy of the amended PRCP schedule (or receiving written notice under section 211 of the EP Act), unless the administering authority agrees to a longer period.

12 SPATIAL INFORMATION

Shapefiles detailing the following spatial information will be submitted in conjunction with this PRC plan:

- the location and maximum extent of the disturbance footprint for the mine life;
- the PMLU and NUMAs for the area within the resource tenures;
- the rehabilitation areas within the resource tenures; and
- the locations of sensitive receptors.

13 REFERENCES

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Appendix A – Surface Water Impact Assessment Report

Vulcan South

Surface water assessment

Vitrinite Pty Ltd

1571-20-B4, 16 May 2022

Report Title	Vulcan South Surface water assessment
Client	Vitrinite Pty Ltd
Report Number	1571-20-B4

Revision Number	Report Date	Report Author	Reviewer
0	6 July 2020	LZ/RN	JO
1	7 October 2020	LZ	JO
2 [DRAFT]	21 March 2022	RN	JO
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4	16 May 2022	RN	JO

For and on behalf of WRM Water & Environment Pty Ltd
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NOTE: This report has been prepared on the assumption that all information, data and reports provided to us by our client, on behalf of our client, or by third parties (e.g. government agencies) is complete and accurate and on the basis that such other assumptions we have identified (whether or not those assumptions have been identified in this advice) are correct. You must inform us if any of the assumptions are not complete or accurate. We retain ownership of all copyright in this report. Except where you obtain our prior written consent, this report may only be used by our client for the purpose for which it has been provided by us.

Executive Summary

Overview

The proposed Vulcan South (the Project) is a proposed open pit mining operation located to the southeast of Moranbah, in Central Queensland. The Project will operate for approximately nine years, including primary rehabilitation works, following a 2 year construction period and will extract approximately 13.5 million-tonnes (Mt) of ROM coal, consisting predominately of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 Mt per annum.

The Project will include three open pits, construction of a Coal Handling and Preparation Plant (CHPP) and train loadout facilities within the Mining Lease Application (MLA) area. The Project also includes a small-scale highwall mining trial program in the north of the MLA. No tailings dams are proposed as part of the Project.

The Project is located within the Isaac River catchment. The majority of the Project is located within the Harrow, Boomerang, East, Hughes, and Barrett creek catchments, which all drain to the Isaac River. These creeks have been altered due to existing mining operations downstream of the Project.

The Project surface water management system would be designed to accommodate the proposed production schedule and to mitigate potential natural surface water and flooding impacts. With appropriate mitigation measures in place, the potential impact of the proposed mining operations on surface flows and water quality in the receiving waters downstream of the Project will be insignificant.

Surface Water Management Strategy

The proposed Project surface water management strategy consists of a number of surface water management measures that will be implemented during construction and operational periods.

For surface water management purposes, the surface water that is generated and/or managed at the Project is divided into the following types based on water quality:

- **Mine affected water**: Mine affected water means the following water types:
    - pit water, tailings dam water, processing plant water;
    - rainfall runoff which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated, excluding rainfall runoff discharging through release points associated with erosion and sediment control structures that have been installed in accordance with the standards and requirements of an Erosion and Sediment Control Plan to manage such runoff, provided that this water has not been mixed with pit water, tailings dam water, processing plant water or workshop water;
    - groundwater which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated;
    - groundwater from the mine dewatering activities; and
    - a mix of mine affected water (under any of paragraphs i to v) and other water
- **Surface water**: Surface water runoff from areas that are disturbed by mining operations (including out-of-pit waste rock emplacements). This runoff does not come into contact with coal or other carbonaceous material and may contain high sediment loads but does not contain elevated levels of other water quality parameters (e.g. electrical conductivity, pH, metals, metalloids, non-metals). This runoff must be managed to ensure adequate sediment removal prior to release to receiving waters.

- **Diverted water**: Surface runoff from areas unaffected by mining operations. Diverted catchment water includes runoff from undisturbed areas and fully rehabilitated areas.
- **Raw water**: Untreated water that has not been contaminated by mining activities.
- **Potable water**: Treated water suitable for human consumption.
- **External water**: Water supplied from a source that is external to the Project area to make up water shortfalls for onsite water demands when site water sources cannot meet demand.

The water management system for the Project aims to protect the identified downstream Environmental Values and comprises the following key objectives:

- separate diverted water from mine affected water to ensure that up-catchment water and mine affected water do not mix wherever practicable;
- capture of mine affected runoff (e.g. mine industrial area, haul road/ROM pad runoff), storage and priority reuse as mine water supply;
- divert up-catchment water runoff from upstream catchments around the active mining area;
- limit external catchment runoff draining into pits;
- manage sediment from disturbed catchment areas (e.g. out-of-pit waste rock emplacements, cleared/pre-strip areas) by using erosion and sediment control (ESC) measures prior to release offsite;
- reuse onsite water (e.g. mine affected water) where possible to support mine operational water demands (and therefore limit mine affected water inventories under normal operating conditions); and
- manage any mine affected water releases to the receiving waters to meet environmental release conditions (not currently proposed).

The above objectives will be achieved by implementing the following water-related infrastructure:

- diverted water drains, bunds and drainage diversions to divert runoff from undisturbed catchments around areas disturbed by mining;
- flood protection levees along the southern side of the Vulcan North pit extent, along the western and southeastern sides of the Vulcan Main pit, and around the Vulcan South pit;
- sediment dams and drains to collect and treat runoff from waste rock emplacement areas; and
- mine-affected water drains and dams to store water pumped out of the open cut mining areas and to collect runoff from the infrastructure areas.

The above water management objectives, when implemented through appropriate management plans, will mitigate the effects of the Project operations on natural surface water quantity and quality and flooding downstream of the mine site during operations.

Water Balance

The Project will be a net importer of water due to the predicted water demands exceeding rainfall runoff and groundwater inflows into the mine site water management system.

The OPSIM model was used to assess varying rainfall and climatic conditions using a daily timestep to simulate all major components of the water management system. The water balance model results show that:

- there are no predicted mine water spills to the receiving environment during the life of mine from the mine water dams or open cut pits;
- under 'average' climatic conditions, the proposed water management system is in deficit, meaning external water will be required to meet site demands such as dust suppression, CHPP makeup demands, and TLO demands. During 50%ile climate conditions, the predicted external water required is up to 1,260 ML/yr and up to 1520 ML/yr during 1%ile (very dry) climate conditions; and
- the site water management system has been designed such that the risk of offsite release of mine affected water is very low (with no mine affected dam uncontrolled releases predicted under any modelled climatic conditions).

Flood assessment

A hydraulic (TUFLOW) model was developed for the Project to design the proposed flood protection infrastructure required to protect key mining infrastructure and to assess the potential flood impacts caused by the proposed infrastructure on downstream property. The TUFLOW model results show that:

- flood level impacts as a result of the Project are generally within the Project MLA area. Any impacts that extend into the Norwich Park Branch Railway corridor and downstream of the Project boundary may require mitigation measures. Where impacts cannot be fully mitigated, consent may be required from impacted neighbouring landowners/stakeholders (e.g., Aurizon, council, BMA); and
- there are only minor impacts under the final landform configuration. These impacts are generally confined within the Project MLA area. Existing conditions natural topography will be reinstated within the Hughes Creek floodplain as well as Drainage line 6 and Drainage line 8 Post-closure to replicate the existing drainage line channels to minimise the impacts associated with the Post-closure Conditions landform.

Final landform

A conceptual water management plan for proposed final landform of the Project was developed. As part of the final landform, no final voids are proposed and all open cut pits will be backfilled with overburden material and drainage structures will be implemented on and around the final landform to ensure that the landform is free draining. When sediment dam catchments are completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned.

Summary

Overall, the impact of the Project on the hydraulic characteristics of Boomerang Creek, Hughes Creek and their tributaries do not affect the existing conditions significantly. It is expected that the channel and floodplain will undergo little, if any, adjustment to the hydraulic conditions upstream or downstream of the Project as a result of the Project.

Mine affected water from the proposed Project will be managed through a mine water management system which is designed to operate in accordance with proposed EA conditions that are based on Model Mining Conditions, and incorporated into the release criteria used in modelling the mine water management system in this report.

In consideration of the already heavily disturbed nature of the surrounding catchment, it is unlikely that Project releases will have a measurable impact on receiving water quality or environmental values.

In summary, the conceptual final landform is not considered likely to have a long-term significant impact on the receiving waters.

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1 Introduction

1.1 BACKGROUND

The Vulcan South (the Project), which is managed by Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), is a proposed open pit and highwall mining operation located to the southeast of Moranbah, in Central Queensland. The Project is located immediately south and west of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM), located on ML700060. The Project mining lease application area abuts ML700060; however, proposed activities will be implemented separately. The VCM has been considered in a previous surface water assessment titled '*Vulcan Coal Mine EA Amendment Surface Water Assessment*' (WRM, 2021) and has not been considered further in this report.

The location of the EPCs and the proposed Project mining lease (ML) Application area are shown in Figure 1.1. Figure 1.2 shows an overview of the Project area including the Highwall mining area in the northwest, the Vulcan North mining area in the north, the Vulcan Main mining area in the Project centre and the Vulcan South mining area in the south.

The proposed mine stage layouts for the Project, including all major surface water infrastructure elements required during operations and post-mining, are shown in Figure 1.3 to Figure 1.13.

WRM Water & Environment Pty Ltd (WRM) was engaged by Mining and Energy Technical Services Pty Ltd (METServe), on behalf of Vitrinite, to undertake a surface water impact assessment for the Project. The surface water impact assessment will form part of an Environmental Authority application for the Project.

This report presents the following:

- An overview of the regulatory framework which applies to the Project (including aspects which do not directly relate to the surface water assessment) (Section 2);
- A description of the environmental values (EVs) of the receiving waters surrounding the Project (Section 3);
- A description of the existing surface water environment at the Project (Section 4);
- A description of the proposed water management strategy and details regarding water management infrastructure (Section 5);
- A detailed description of the configuration of the Project water balance model (Section 6);
- An assessment of the Project water management system performance (Section 7);
- An assessment of the potential flooding impacts of the Project (Section 8);
- A description of the surface water monitoring strategy proposed for the Project (Section 9);
- An assessment of the cumulative impacts of the Project (Section 10); and
- A summary of the Project findings (Section 11).

1.2 PROJECT DESCRIPTION

The Vulcan hard coking coal target has been defined and selected for open cut development via 3 separate open cut pits (known as Vulcan North, Vulcan Main and Vulcan South) that form the primary mining focus of the Project. The Project will operate

for approximately nine years, including primary rehabilitation works, following a 2 year construction period and will extract approximately 13.5 million-tonnes (Mt) of ROM coal, consisting predominately of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 Mt per annum. The Project will target the Alex and multiple Dysart Lower coal seams.

Truck and shovel mining operations will be employed to develop the pits. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO) at a location between the northern and central pits. The CHPP will include dry tailings technology to maximise water recycling and to produce a dry tailings waste product for permanent storage within active waste rock dumps. No wet tailings wastes are proposed and therefore no tailings dams are required.

Ex-pit waste rock dumps will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. Ancillary infrastructure, including a Run of Mine (ROM) pad, offices, roads and surface water management infrastructure will be established to support the operation.

A realignment of the existing Saraji Road and services infrastructure to the eastern boundary of the proposed Mining Lease Application (MLA) area, adjacent to the existing rail easement, is also proposed in a number of locations. The re-alignment will occur within the MLA area.

In-pit dumping will fill the majority of the pit volumes during operations with the remaining final voids to be backfilled upon cessation of mining, resulting in the establishment of low waste rock dump landforms over the former pit areas. Following backfill of the final voids, the remaining material stored in the initial out-of-pit waste rock dumps will be rehabilitated in-situ.

The Project includes a small-scale highwall mining trial program in the north of the MLA. The trial will involve the establishment of 4 highwall mining benches across a number of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner, or similar. The highwall mining trial will target up to 750 kilotonnes of coal, which will be transported by truck to the Project CHPP via a dedicated haul road within the MLA area. The trial is scheduled to be completed within the first year of mining operations.

The conceptual drainage plans for the open cut mining areas are shown in Figure 1.3 to Figure 1.8. The conceptual drainage plans of the Highwall mining area are shown in Figure 1.9 and Figure 1.10. The final landform plans are shown in Figure 1.11 to Figure 1.13.

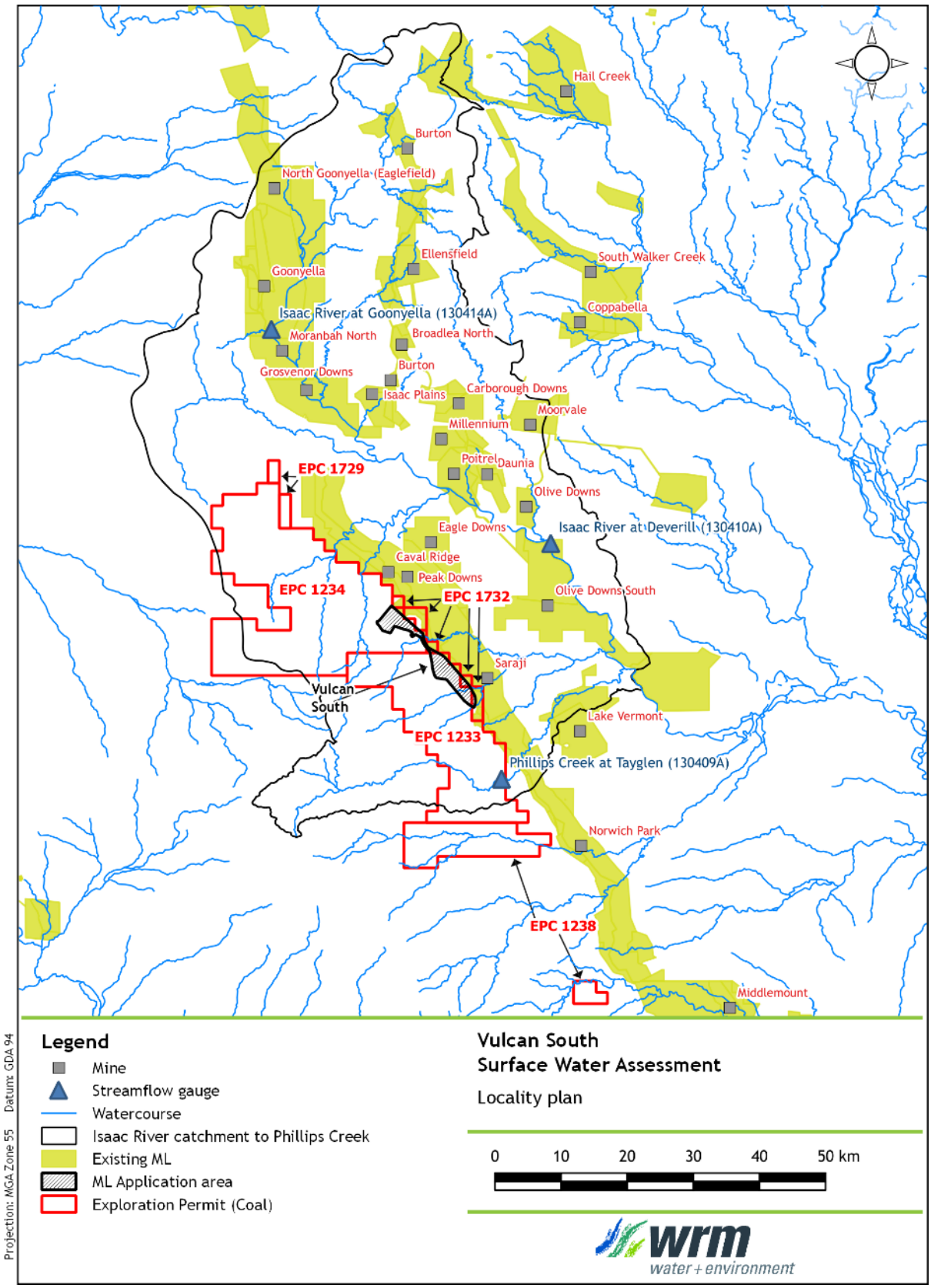


Figure 1.1 - Locality plan

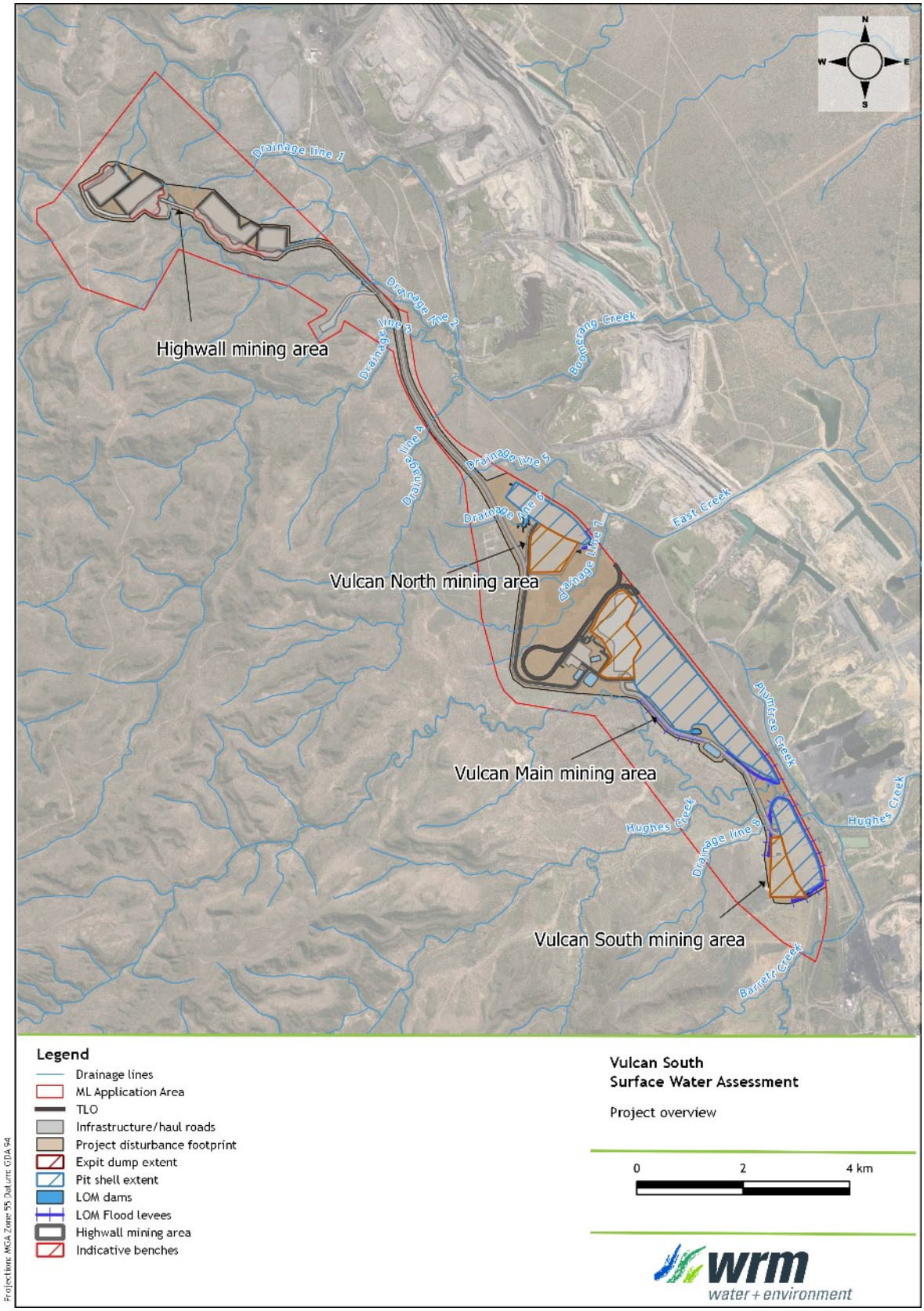


Figure 1.2 – Project overview

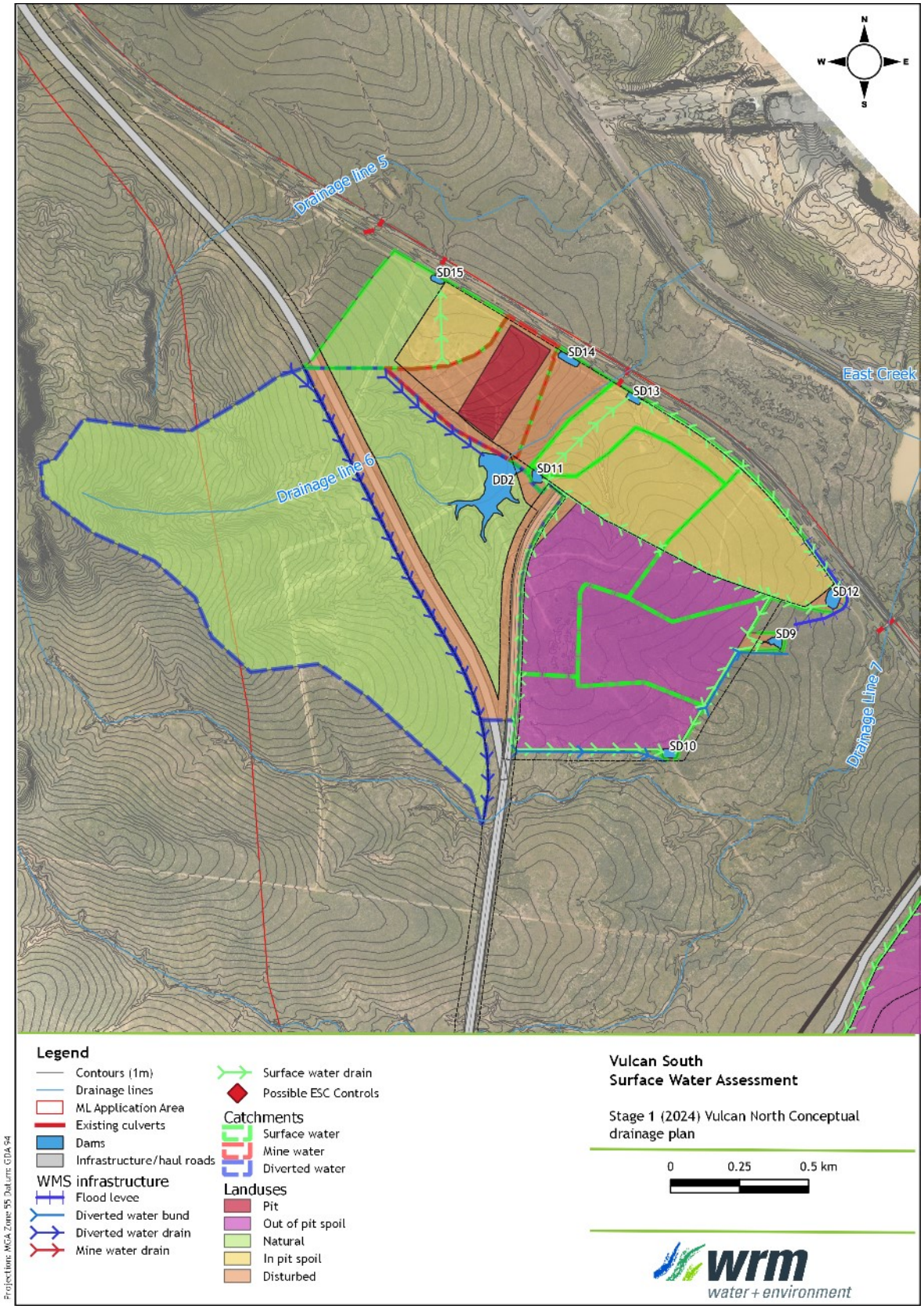


Figure 1.3 - Stage 1 (Year 2024) Vulcan North mining area conceptual drainage plan

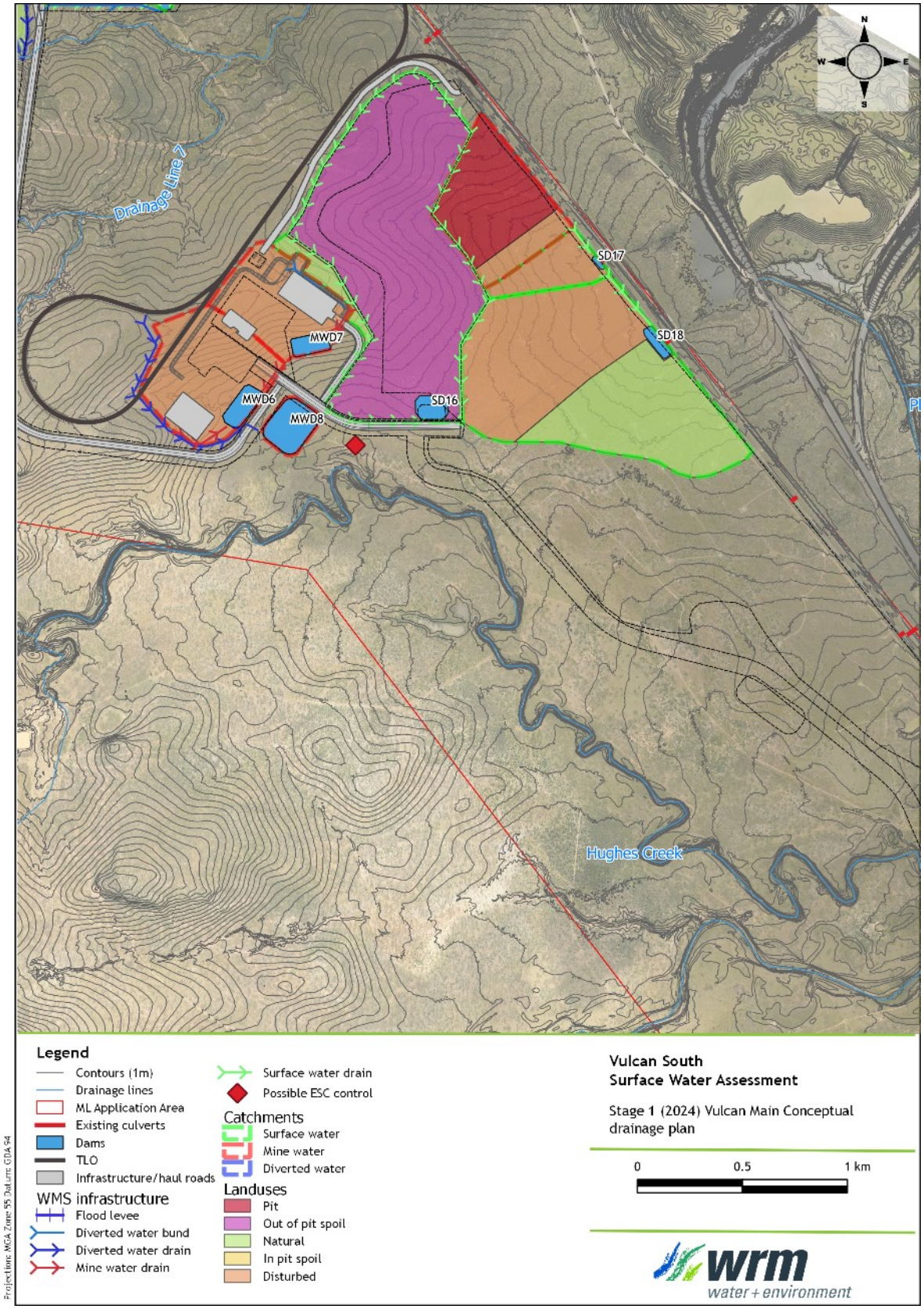


Figure 1.4 - Stage 1 (Year 2024) Vulcan Main mining area conceptual drainage plan

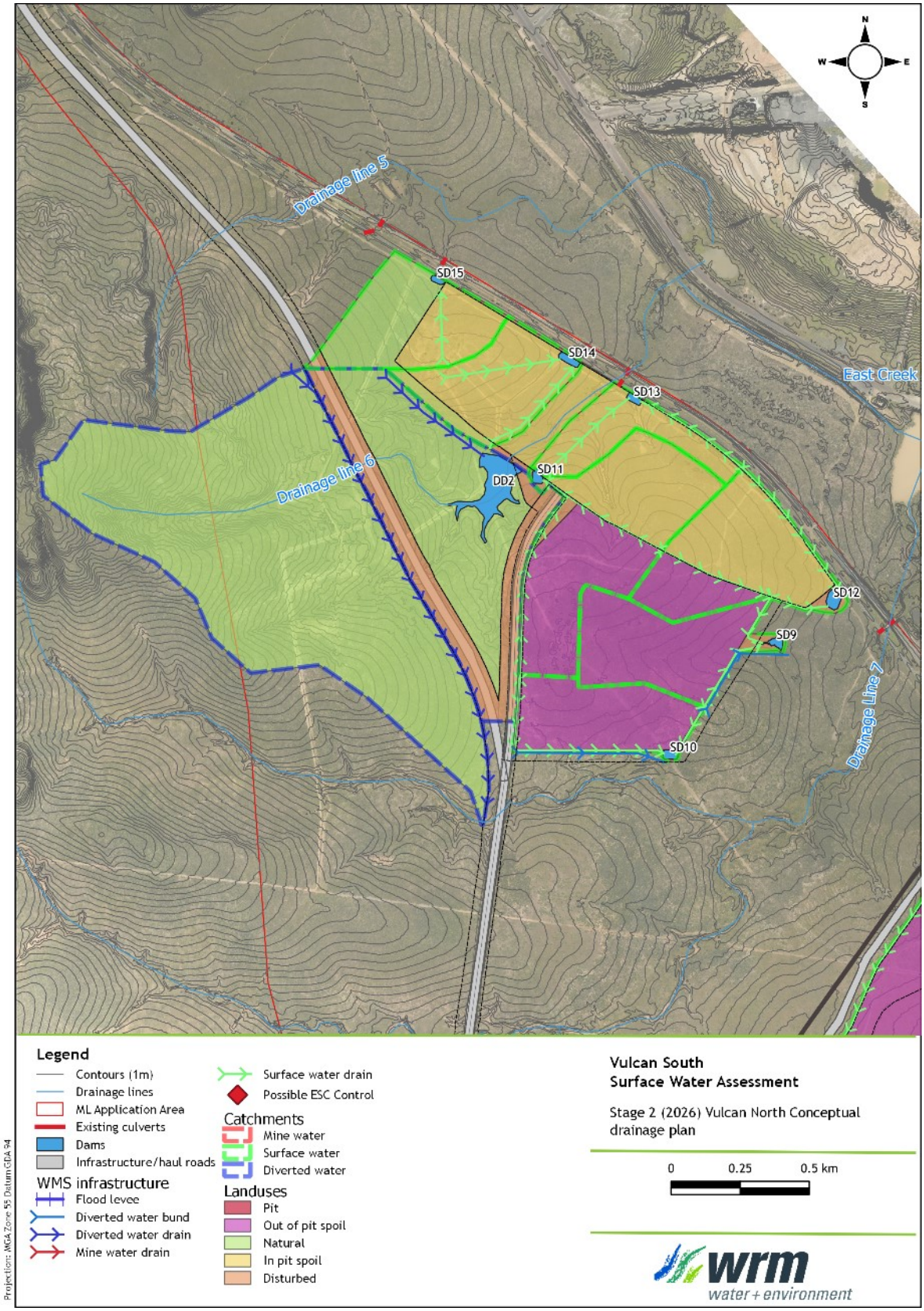


Figure 1.5 - Stage 2 (Year 2026) Vulcan North mining area conceptual drainage plan

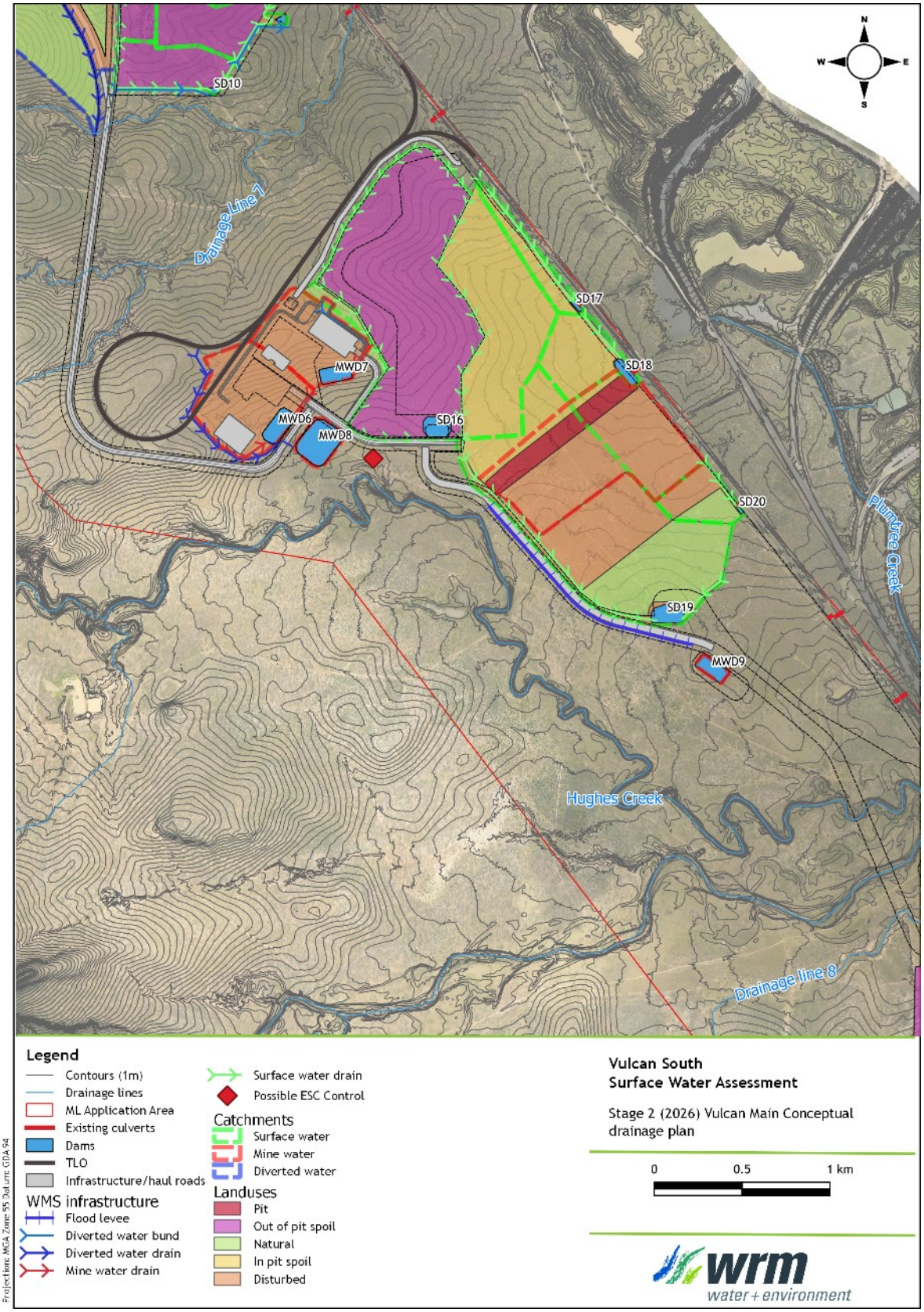


Figure 1.6 - Stage 2 (Year 2026) Vulcan Main mining area conceptual drainage plan

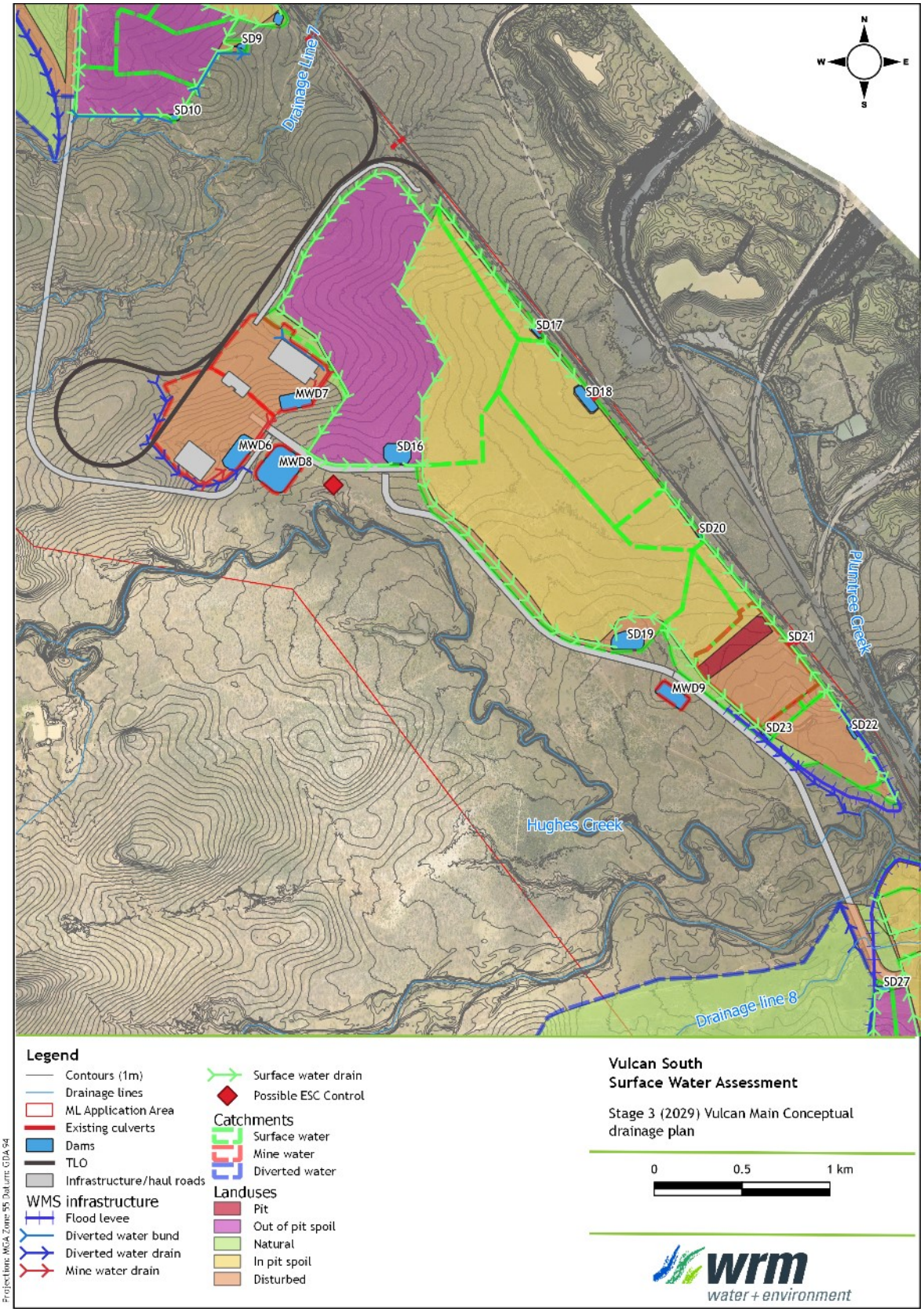


Figure 1.7 - Stage 3 (Year 2029) Vulcan Main mining area conceptual drainage plan

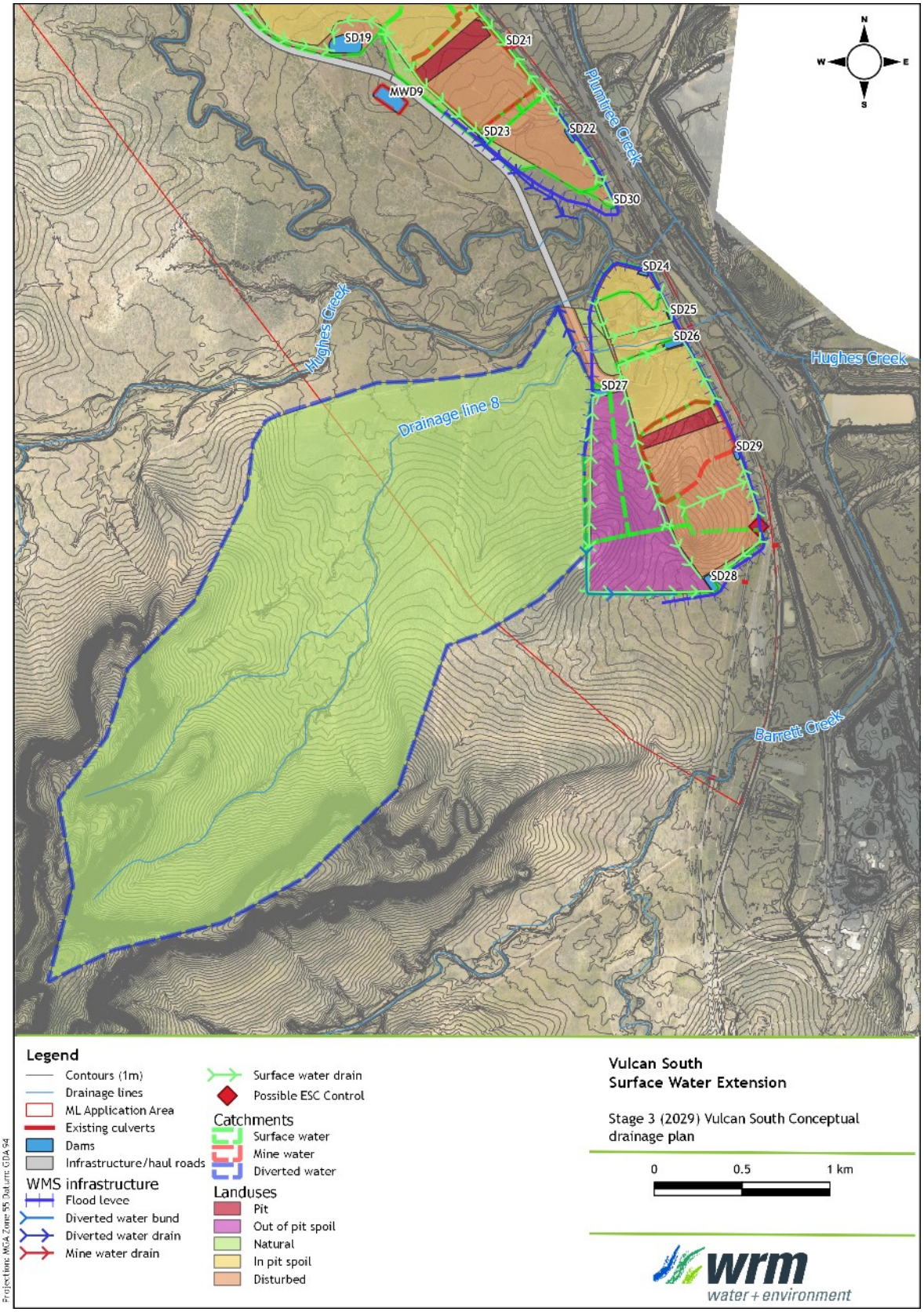


Figure 1.8 - Stage 3 (Year 2029) Vulcan South mining area conceptual drainage plan

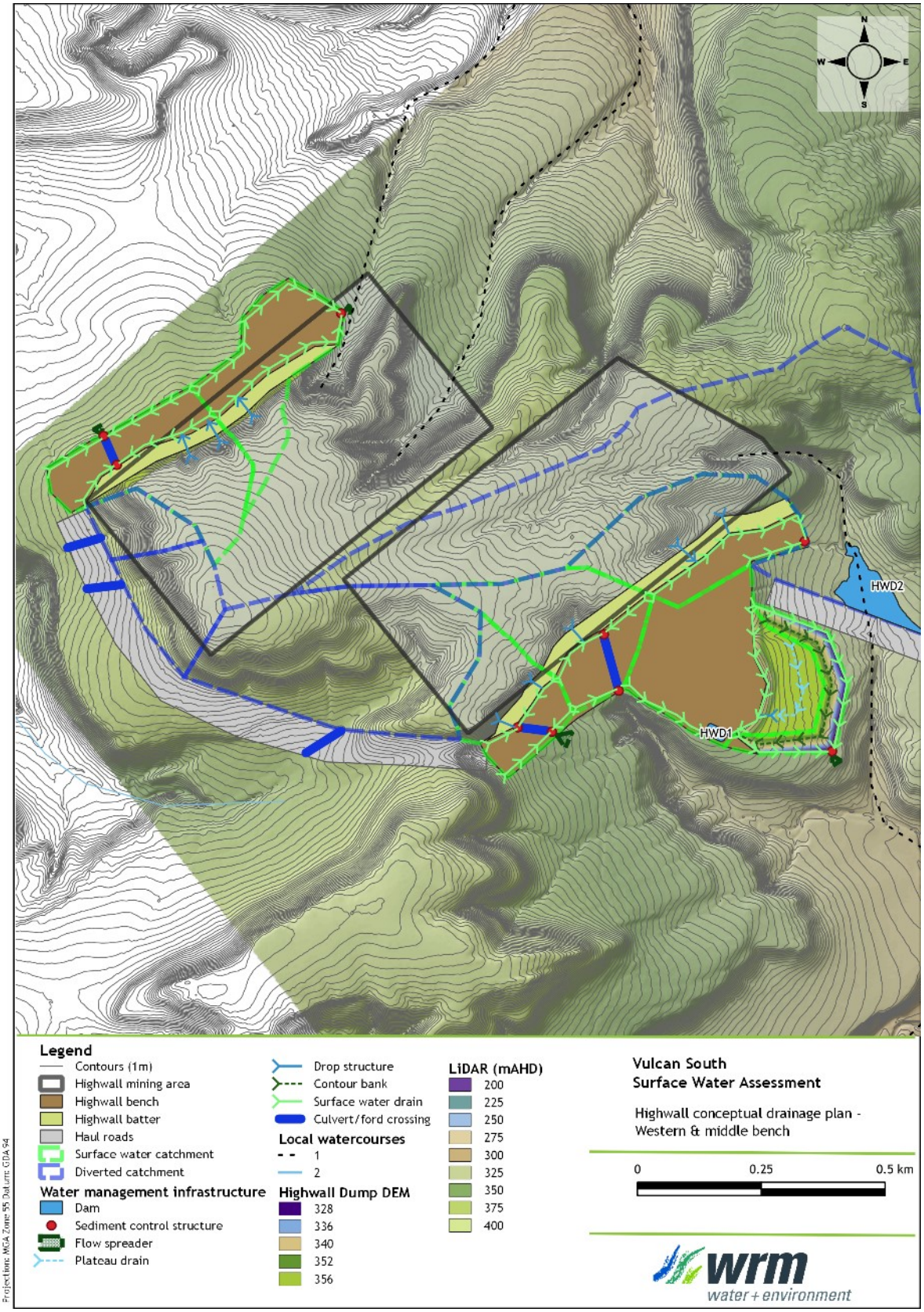


Figure 1.9 – Highwall western and middle bench mining area conceptual drainage plan (Year 2024)

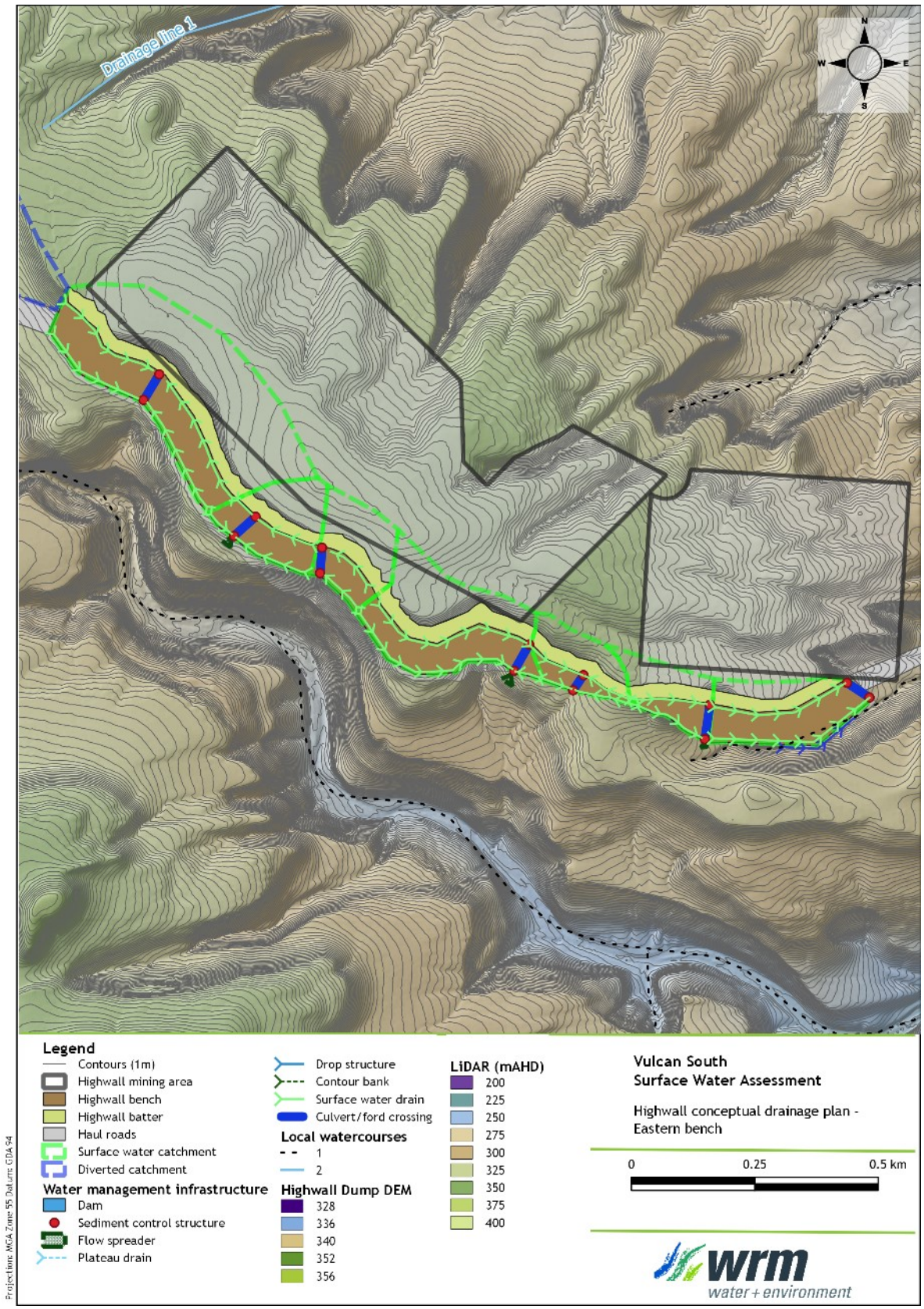


Figure 1.10 – Highwall eastern bench mining area conceptual drainage plan (Year 2024)

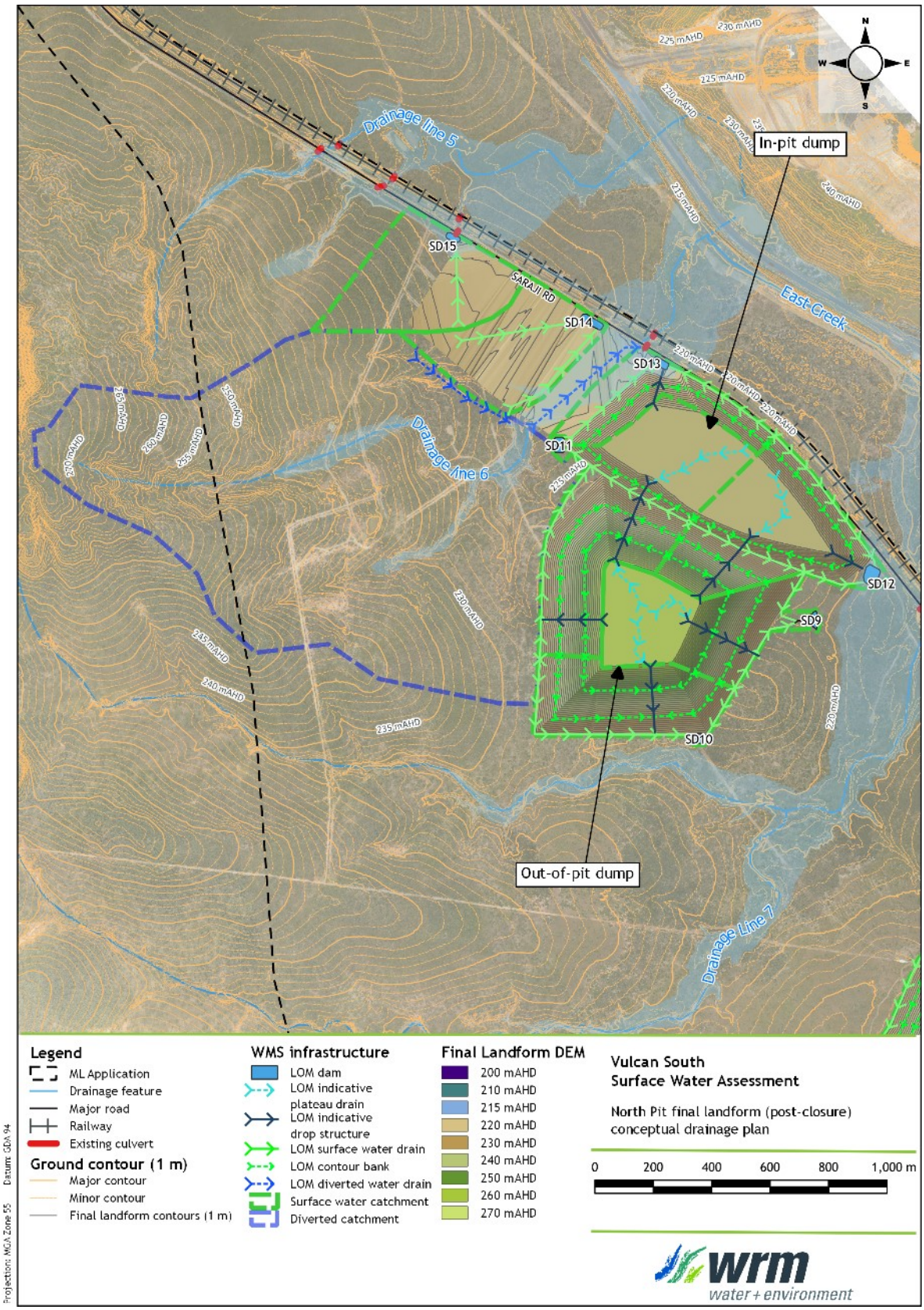


Figure 1.11 – Vulcan North final landform (post-closure) conceptual drainage plan

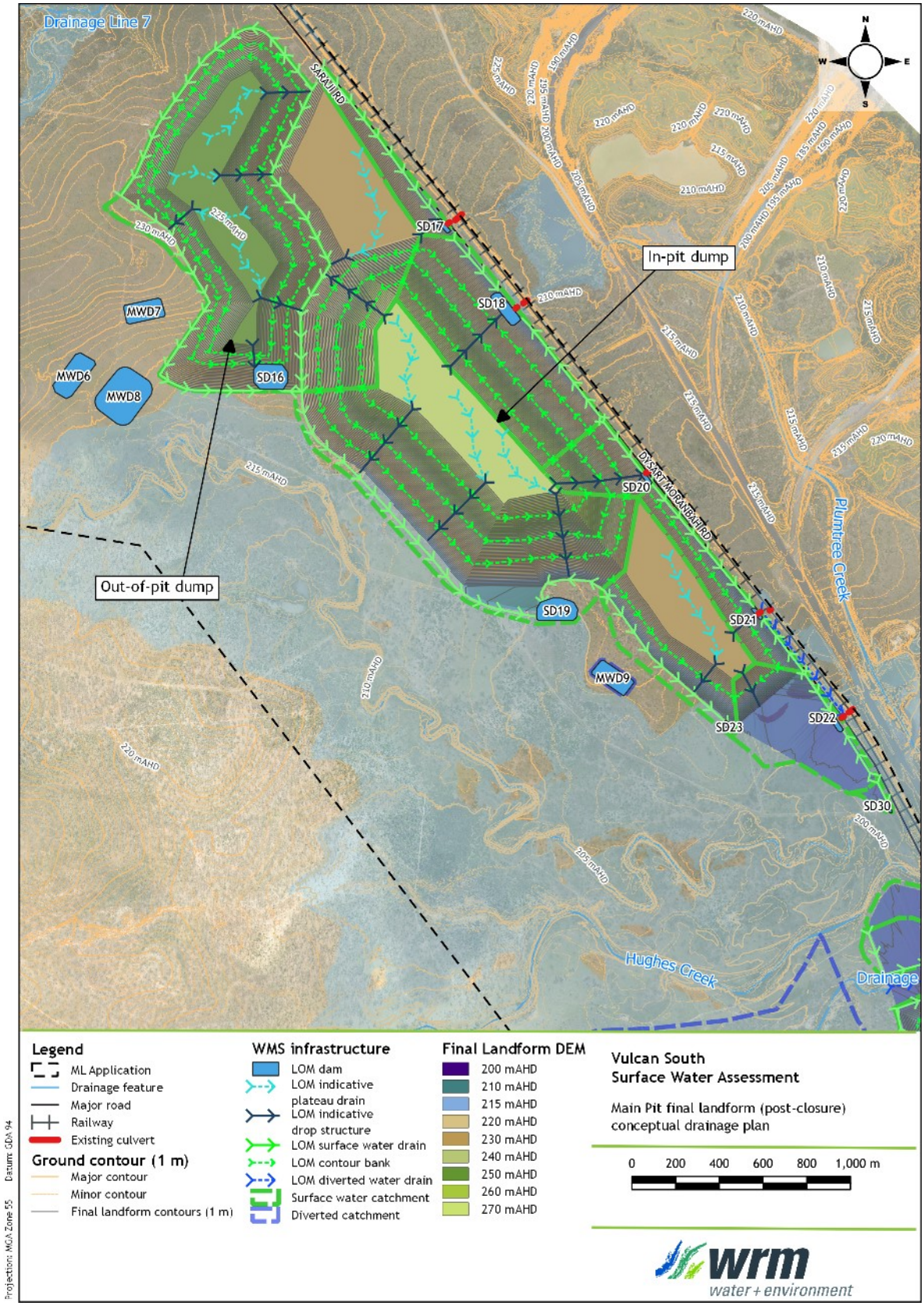


Figure 1.12 – Vulcan Main final landform (post-closure) conceptual drainage plan

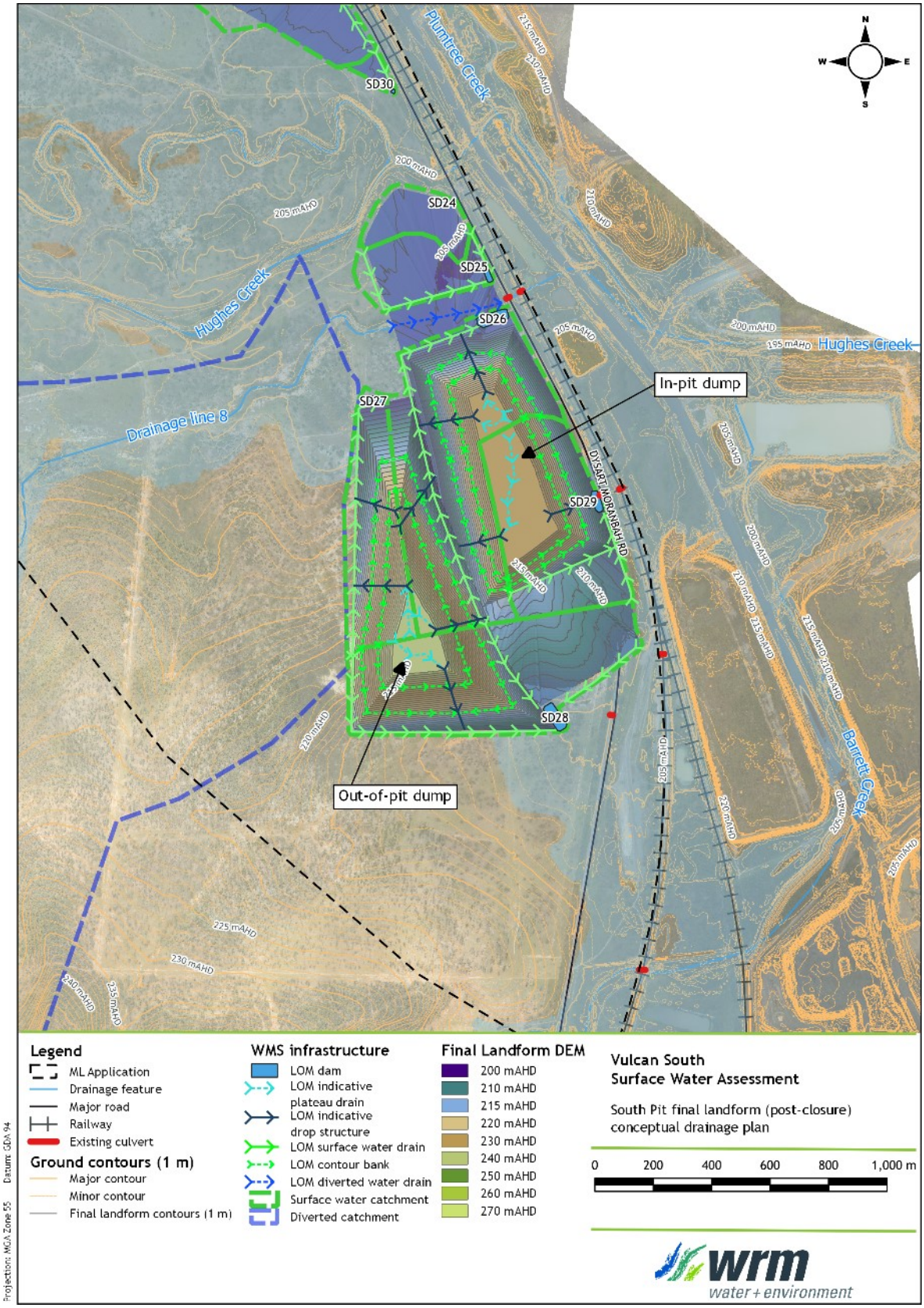


Figure 1.13 – Vulcan South final landform (post-closure) conceptual drainage plan

2 Regulatory framework

This section describes the regulatory framework (legislation, policies and standards) at Commonwealth and State level that would apply to surface water management for the Project.

2.1 COMMONWEALTH

The Project will be referred to the Department of the Environment and Energy for consideration under the *Environment Protection and Biodiversity Conservation Act 1999*.

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development has published information guidelines (IESC, 2018) for advice on coal seam gas and large coal mining development proposals. The report sections where the IESC information requirements have been addressed are outlined in Table 2.1.

Table 2.1 – IESC information requirements – surface water

Project information	Report section
Description of the proposal	
Provide a regional overview of the proposed project area including a description of the geological basin; coal resource; surface water catchments; groundwater systems; water-dependent assets; and past, current and reasonably foreseeable coal mining and CSG developments.	Section 1 and Main EA Report
Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Section 1 and Main EA Report
Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies.	Section 2 and Main EIS Report
Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Section 2
Surface water – context and conceptualisation	
Describe the hydrological regime of all watercourses, standing waters and springs across the site including:	
• geomorphology, including drainage patterns, sediment regime, and floodplain features;	Section 4
• spatial, temporal and seasonal trends in streamflow and/or standing water levels;	Section 4.4
• spatial, temporal and seasonal trends in water quality data (such as turbidity, acidity, salinity, relevant organic chemicals, metals, metalloids and radionuclides); and	Section 4.5
• current stressors on watercourses, including impacts from any currently approved projects.	Section 4 & 10
Describe the existing flood regime, including flood volume, depth, duration, extent and velocity for a range of annual exceedance probabilities. Provide flood hydrographs and maps identifying peak flood extent, depth and velocity. This assessment should be informed by topographic data that has been acquired using lidar or other reliable survey methods with accuracy stated.	Section 8

Project information	Report section
Provide an assessment of the frequency, volume, seasonal variability and direction of interactions between water resources, including surface water/groundwater connectivity and connectivity with sea water.	Refer to Groundwater report
Surface water – analytical and numerical modelling	
Provide conceptual models at an appropriate scale, including water quality, stores, flows and use of water by ecosystems.	Section 5, 6 & 7
Use methods in accordance with the most recent publication of *Australian Rainfall and Runoff* (Ball *et al*. 2016).	Section 8.3
Develop and describe a program for review and update of the models as more data and information becomes available.	Section 7.5 & 8.5
Describe and justify model assumptions and limitations and calibrate with appropriate surface water monitoring data.	Section 6 & 8
Provide an assessment of the risks and uncertainty inherent in the data used in the modelling, particularly with respect to predicted scenarios.	Section 7.4
Provide a detailed description of any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	N/A
Surface water – impacts to water resources and water-dependent assets	
Describe all potential impacts of the proposed project on surface waters. Include a clear description of the impact to the resource, the resultant impact to any assets dependent on the resource (including water-dependent ecosystems such as riparian zones and floodplains), and the consequence or significance of the impact. Consider:	
• Impacts on streamflow under the full range of flow conditions.	Section 8.7 & 8.8
• Impacts associated with surface water diversions.	Section 8.7
• Impacts to water quality, including consideration of mixing zones.	Section 7.3.9
• The quality, quantity and ecotoxicological effects of operational discharges of water (including saline water), including potential emergency discharges, and the likely impacts on water resources and water-dependent assets.	Section 7.3.9
• Landscape modifications such as subsidence, voids, post rehabilitation landform collapses, onsite earthworks (including disturbance of acid-forming or sodic soils, roadway and pipeline networks) and how these could affect surface water flow, surface water quality, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Sections 5, 7.3.9, 8.5 & 8.8
Discuss existing water quality guidelines, environmental flow objectives and requirements for the surface water catchment(s) within which the development proposal is based.	Section 2 & 3
Identify processes to determine surface water guidelines and quantity thresholds which incorporate seasonal variation but provide early indication of potential impacts to assets.	Section 9
Propose mitigation actions for each identified significant impact.	Section 6 & 8
Describe the adequacy of proposed measures to prevent or minimise impacts on water resources and water-dependent assets.	Section 6 & 8
Describe the cumulative impact of the proposal on surface water resources and water-dependent assets when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 10

Project information	Report section
Provide an assessment of the risks of flooding (including channel form and stability, water level, depth, extent, velocity, shear stress and stream power), and impacts to ecosystems, project infrastructure and the final project landform.	Section 8
Surface water – data and monitoring	
Identify monitoring sites representative of the diversity of potentially affected water-dependent assets and the nature and scale of potential impacts, and match with suitable replicated control and reference sites (BACI design) to enable detection and monitoring of potential impacts.	Section 4.5 & 9
Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 4.5 & 9
Identify data sources, including streamflow data, proximity to rainfall stations, data record duration and a describe of data methods, including whether missing data has been patched.	Sections 4.3 & 4.4
Develop and describe a surface water monitoring programme that will collect sufficient data to detect and identify the cause of any changes from established baseline conditions and assess the effectiveness of mitigation and management measures. The program will:	
• include baseline monitoring data for physico-chemical parameters, as well as contaminants (e.g. metals).	Section 4.5 & Appendix A
• comparison of physico-chemical data to national/regional guidelines or to site- specific guidelines derived from reference condition monitoring if available.	Section 4.5 & Appendix A
• identify baseline contaminant concentrations and compare these to national guidelines, allowing for local background correction if required.	Section 4.5 & Appendix A
Describe the rationale for selected monitoring parameters, duration, frequency and methods, including the use of satellite or aerial imagery to identify and monitor large-scale impacts.	Section 9
Identify dedicated sites to monitor hydrology, water quality, and channel and floodplain geomorphology throughout the life of the proposed project and beyond.	Section 9
Water-dependent assets – context and conceptualisation	
Identify water-dependent assets, including:	
• water-dependent fauna and flora and provide surveys of habitat, flora and fauna (including stygofauna) (see Doody *et al*. [in press]).	Refer to Main EA Report
• public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	
Identify GDEs in accordance with the method outlined by Eamus *et al*. (2006). Information from the GDE Toolbox15 (Richardson *et al*. 2011) and GDE Atlas (CoA 2017a) may assist in identification of GDEs (see Doody *et al*. [in press]).	Refer to Groundwater Report
Describe the conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015).	Refer to Groundwater Report
Estimate the ecological water requirements of identified GDEs and other water-dependent assets (see Doody *et al*. [in press]).	Refer to Groundwater Report

Project information	Report section
Identify the hydrogeological units on which any identified GDEs are dependent (see Doody *et al*. [in press]).	Refer to Groundwater Report
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 3 & 4
Describe the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).	Section 9
Water dependent assets – impacts, risk assessment and management of risk	
Provide an assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (see Doody *et al*. [in press]).	Refer to Groundwater Report
Describe the potential range of drawdown at each affected bore, and clearly articulate the scale of impacts to other water users.	Refer to Groundwater Report
Indicate the vulnerability to contamination (e.g. from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	Section 7.3.9
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	Section 5
Provide estimates of the volume, beneficial uses and impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	Section 7.3.9 & 7.3.10
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	Section 7 & 8
Identify the proposed acceptable level of impact for each water-dependent asset based on leading-practice science and site-specific data, and ideally developed in conjunction with stakeholders.	Section 7 & 8
Propose mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	Section 5, 8 & 9
Water-dependent assets – data and monitoring	
Identify an appropriate sampling frequency and spatial coverage of monitoring sites to establish pre-development (baseline) conditions, and test potential responses to impacts of the proposal (see Doody *et al*. [in press]).	Section 9
Consider concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design, see Doody *et al*. [in press]).	
Develop and describe a monitoring program that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change (see Doody *et al*. [in press]).	
Describe the process for regular reporting, review and revisions to the monitoring program.	

Project information	Report section
Ensure ecological monitoring complies with relevant state or national monitoring guidelines (e.g. the DSITI guideline for sampling stygofauna (QLD Government 2015)).	
Water and salt balance, and water management quality	
Provide a quantitative site water balance model describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc.), including all sources and uses.	Section 7
Describe the water requirements and on-site water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.	Section 7
Provide estimates of the quality and quantity of operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-dependent assets.	Section 7.3.7 & 7.3.10
Provide salt balance modelling that includes stores and the movement of salt between stores and takes into account seasonal and long-term variation.	Section 7.3.8
Cumulative impacts – context and conceptualisation	
Provide cumulative impact analysis with sufficient geographic and temporal boundaries to include all potentially significant water-related impacts.	Section 10
Consider all past, present, and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern in the cumulative impact analysis. Where a proposed project is located within the area of a bioregional assessment consider the results of the bioregional assessment.	Section 10
Cumulative impacts – impacts	
Provide an assessment of the condition of affected water resources which includes: • identification of all water resources likely to be cumulatively impacted by the proposed development; • a description of the current condition and quality of water resources and information on condition trends; • identification of ecological characteristics, processes, conditions, trends and values of water resources; • adequate water and salt balances; and • identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).	Section 4, 7 & 10
Assess the cumulative impacts to water resources considering: • the full extent of potential impacts from the proposed project, (including whether there are alternative options for infrastructure and mine configurations which could reduce impacts), and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally; • all stages of the development, including exploration, operations and post closure/decommissioning; • appropriately robust, repeatable and transparent methods;	Section 10

Project information	Report section
• the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts; and • opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.	
Cumulative impacts – mitigation, monitoring and management	
Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	Section 7.4, 7.5, 8, 9 & 10
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	
Identify cumulative impact environmental objectives.	
Describe appropriate reporting mechanisms.	
Propose adaptive management measures and management responses.	
Final landforms and voids – coal mines	
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Section 5 and Main EA report
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	
Provide an assessment of the long-term impacts to water resources and water-dependent assets posed by various options for the final landform design, including complete or partial backfilling of mining voids. Assessment of the final landform for which approval is being sought should considers: • groundwater behaviour – sink or lateral flow from void. • water level recovery – rate, depth, and stabilisation point (e.g. timeframe and level in relation to existing groundwater level, surface elevation). • seepage – geochemistry and potential impacts. • long-term water quality, including salinity, pH, metals and toxicity. • measures to prevent migration of void water off-site. For other final landform options considered sufficient detail of potential impacts should be provided to clearly justify the proposed option.	
Assess the probability of overtopping of final voids with variable climate extremes, and management mitigations.	N/A
Acid-forming materials and other contaminants of concern	
Identify the presence and potential exposure of acid-sulfate soils (including oxidation from groundwater drawdown).	Refer to Main EA Report, Geochemical Assessment Report and Section 6.8
Identify the presence and volume of potentially acid-forming waste rock, fine-grained amorphous sulphide minerals and coal reject/tailings material and exposure pathways.	
Identify other sources of contaminants, such as high metal concentrations in groundwater, leachate generation potential and seepage paths.	

Project information	Report section
Describe handling and storage plans for acid-forming material (co-disposal, tailings dam, encapsulation).	
Assess the potential impact to water-dependent assets, taking into account dilution factors, and including solute transport modelling where relevant, representative and statistically valid sampling, and appropriate analytical techniques.	
Describe proposed measures to prevent/minimise impacts on water resources, water users and water-dependent ecosystems and species.	

2.2 STATE

2.2.1 EP Act 1994

Resource activities are defined as environmentally relevant activities (ERAs) under the Queensland *Environmental Protection Act 1994* (EP Act) and as such, the development and operation of the Project are governed by the EP Act. The aim of the EP Act is to:

> *Protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ecologically sustainable development).*

2.2.1.1 Environmental Authority

An EA is granted in accordance with the EP Act and details the prescribed conditions that govern the ERA. In the context of surface water management, the EA sets out conditions that will be relevant to the Project, including:

- Management of contained water including release;
- Water management plan requirements;
- Regulation of water structures including dams and levees;
- Saline drainage management;
- Acid rock drainage management; and
- Storm water and sediment laden runoff management.

2.2.1.2 Model Mining Conditions

New mining project applications should apply the model mining conditions as outlined in *Model mining conditions* (DES, 2017). The purpose of the model mining conditions is to provide a set of model conditions to form the general environmental protection commitments given for EA's for mining activities administered under the EP Act. The model conditions may be used as a basis for proposing environmental protection commitments in application documents.

Model conditions can be modified to suit the specific circumstances of a mining project, subject to the assessment criteria outlined in the EP Act. It is unlikely that the administering authority will accept less rigorous environmental protection commitments or EA conditions without clear evidence that the risk of the environmental harm is addressed by environmental management practices, technologies or the nature of the EVs impacted by the project.

Schedule F - Water (Fitzroy model conditions) form the basis of the requirements for the Project water management system design.

2.2.1.3 Environmental Protection (Water and Wetland Biodiversity) Policy 2019

The *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* (EPP Water) is the primary instrument for surface water management under the EP Act. The EPP Water governs discharge to land, surface water and groundwater, aims to protect EVs and sets water quality guidelines and objectives.

The processes to identify EVs and to determine Water Quality Guidelines (WQGs) and Water Quality Objectives (WQOs) in Queensland waters is based on the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ guidelines).

The EVs for the Project location are outlined in Section 3.

2.2.1.4 Isaac River sub-basin Environmental Values and Water Quality Objectives 2011

The relevant document, pursuant to the EPP Water, for the Project is the *Isaac River Sub-basin Environmental Values and Water Quality Objectives Basin No. 130 (part)*, including all waters of the Isaac River Sub-basin (including Connors River, September 2011 [DEHP, 2011]). The document is made pursuant to the provisions of the EPP Water. It contains EVs and WQOs for waters in the Isaac River Sub-basin, and they are listed under Schedule 1 of EPP Water. Refer to Section 3 for further details.

2.2.1.5 Manual for Assessing Consequence Categories and Hydraulic Performance of Structures

The *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (the Manual) defines the methodology and assessment criteria to determine if a structure associated with an ERA should be regulated under the EP Act. The manual details the hydraulic design requirements for regulated structures and this document has been used as a reference in the preliminary design of the water management system and preliminary sizing of dams associated with the Project.

2.2.1.6 Guideline – Application Requirements for Activities with Impacts to Water

This guideline focuses on the types of impacts that environmentally relevant activities (ERAs) can have on water and outlines the information to be provided to the department as part of the ERA application process.

Section 4 of the guideline requires the applicant to provide details on a number of surface water-related issues, including:

- Discharges and releases;
- Unplanned and uncontrolled releases;
- Water infrastructure;
- Wetlands;
- Hydrology of receiving waters; and
- Mixing zones.

Table 2.2 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

The guideline also refers to the department's technical guideline "Wastewater releases to Queensland waters", which is discussed in Section 2.2.1.7.

Table 2.2 – Application requirements for activities with impact to Water – Guideline

Item	Report section
Discharges and releases	
Identify activities that could lead to indirect impacts and unplanned/uncontrolled release of contaminants to water, such as, spills and leaks or stream bed and/or bank disturbance and describe the magnitude of the disturbance	Section 7.3.7 & 7.3.10
Identify the location, depth and configuration (if relevant) of the areas where the unplanned/uncontrolled release could be discharged to waters	Section 5, 6, 7.3.7 & 7.3.10
Identify infrastructure (including containment devices) with the potential to release unplanned/uncontrolled contaminants to waters	Section 6.4
Identify the potential contaminant type and quantities that could be released from infrastructure	Section 6.8 & 7.3.7
Water infrastructure	
Provide detail on the location and storage capacity of water infrastructure on the site which may include regulated structures, tailings dams, waste rock dams, water storage dams, levees, heap leach pads and any other water management infrastructure	Section 6.4 & 8.5
Wetlands	
Applicants must describe how the existing environmental values of any wetlands on, or adjacent to, the site will be maintained, or enhanced	Section 3 & 9
Ecology and hydrology of receiving waters	
Describe, preferably through the use of water quality monitoring or modelling, how the proposed ERA will impact on hydrology of receiving waters, preferably through modelling	Section 7.3

2.2.1.7 Technical Guideline – Wastewater release to Queensland Waters

This guideline is provided to support a risk-based assessment approach to licensing releases of wastewater to surface water and applies the philosophy of the ANZECC & ARMCANZ (2000) Water Quality Guidelines and the intent of the EPP Water.

The information requirements identified in this guideline are as follows:

- Describe the proposed activity.
- Describe the receiving environment.
- Predict outcomes or impacts of the proposed wastewater release.
- Set circumstances, limits and monitoring conditions.

Table 2.3 lists the elements of the guideline relevant to this assessment and the sections of this report where those elements are addressed.

2.2.1.8 Reef discharge standards for industrial activities

New or expanded prescribed ERAs and resource activities are assessed against Section 41AA of the EP Regulation in relation to water quality. Since 1 June 2021, the administering authority must consider section 41AA of the EP Regulation when making an environmental management decision (EMD) for an ERA discharging dissolved inorganic nitrogen (DIN)/fine sediment in the Great Barrier Reef (GBR) catchment waters.

Table 2.3 – Wastewater release to Queensland waters – technical guideline

Item	Report section
Step 1 – Describe the proposed activity	
Define industry type and size (estimated production, current and ultimate)	Section 1.2
Identify the potential contaminants of concern in the proposed release	Section 6.8
Location and configuration of the proposed release	Section 6.4, 7.3.7 & 7.3.10
Step 2 – Describe the receiving environment	
Identify water bodies potentially affected by the proposed release	Section 4
Provide all relevant information on the receiving environment based on desktop and field studies (e.g. current, background water quality condition)	
Include special consideration for ephemeral streams	
Identify all relevant EV and WQOs	Section 3
Ensure all government planning requirements applying to the water bodies have been considered	Section 2
Step 3 - Predict outcomes or impacts of the proposed wastewater release	
Assess whether contaminants are potentially toxic	Section 6.8 and 7.3
Predict the assimilative capacity and sustainable load	Section 7.3
Consider other potential impacts	Section 7.3
Step 4 – Set circumstances, limits and monitoring conditions	
Specify any circumstances related to the approved wastewater release	Section 6.4
Include a receiving environment monitoring program (REMP) requirement	Section 9.6
Include reporting requirements for the approved activity	Section 9

2.2.2 Water Act 2000

In Queensland, the Water Act 2000 (Water Act) is the primary statutory document that establishes a framework for the planning, allocation and use of non-tidal water. The Water Act is primarily administered by the Department of Natural Resources, Mines and Energy (DNRME).

The main purpose of the Water Act is to provide a framework for the following:

- The sustainable management of Queensland's water resources by establishing a system for the planning, allocation and use of water and riverine protection.
- The sustainable and secure water supply for the south-east Queensland region and other designated regions;
- The management of impacts on underground water caused by the exercise of underground water rights by the resource sector; and
- The effective operation of water authorities.

A watercourse is defined by the Water Act as a river, creek or stream, including a stream in the form of an anabranch or a tributary, in which water flows permanently or intermittently. The DNRME have published a watercourse identification map of the state that shows: watercourses (other than their lateral limits); the downstream limit of watercourses; drainage features; lakes; and springs.

A watercourse determination for drainage features in the Project area has been undertaken by the DNRME. The watercourses and drainage features which intersect the Project are described in Section 4.

2.2.2.1 Water Plan (Fitzroy Basin) 2011

The Water Plan (Fitzroy Basin) 2011 is subordinate legislation to the Water Act. The plan is developed and administered by DNRME. The purpose of the plan is:

- To define the availability of water in the Fitzroy Basin;
- To provide a framework for sustainably managing water and the taking of water;
- To identify priorities and mechanisms for dealing with future water requirements;
- To provide a framework for establishing water allocations;
- To provide a framework for reversing, where practicable, degradation in natural ecosystems;
- To regulate the taking of overland flow water; and
- To regulate the taking of groundwater.

2.2.2.2 Water Regulation 2016

The Water Regulation 2016 is subordinate legislation to the Water Act and provides details, protocol and instruction for the following:

- Water rights and planning;
- Statutory authorisations to take or interfere with water;
- Matters relating to water licenses;
- Water allocations;
- Water supply and demand management;
- Declarations about watercourses.

2.2.3 Water Supply (Safety & Reliability) Act 2008

The Water Supply (Safety and Reliability) Act 2008 provides for the safety and reliability of water supply in Queensland. The purpose is achieved primarily by:

- Providing a regulatory framework for providing water and sewerage services in the State;
- Providing a regulatory framework for providing recycled water and drinking water quality, primarily for protecting public health;
- The regulation of referable dams; and
- Stating flood mitigation responsibilities.

3 Environmental Values

The Queensland Water Quality Guidelines and EPP Water guidelines establish EVs and WQOs for natural waters in Queensland. The Project is located within the 'Isaac western upland tributaries' area of the Isaac River sub-basin, shown in Figure 3.1. Under the EPP Water, the following EVs have been nominated for this area:

- Aquatic ecosystems
- Irrigation
- Farm supply/use
- Stock Water
- Aquaculture
- Human consumption
- Primary recreation
- Secondary recreation
- Visual recreation
- Drinking water
- Industrial use
- Cultural and spiritual values

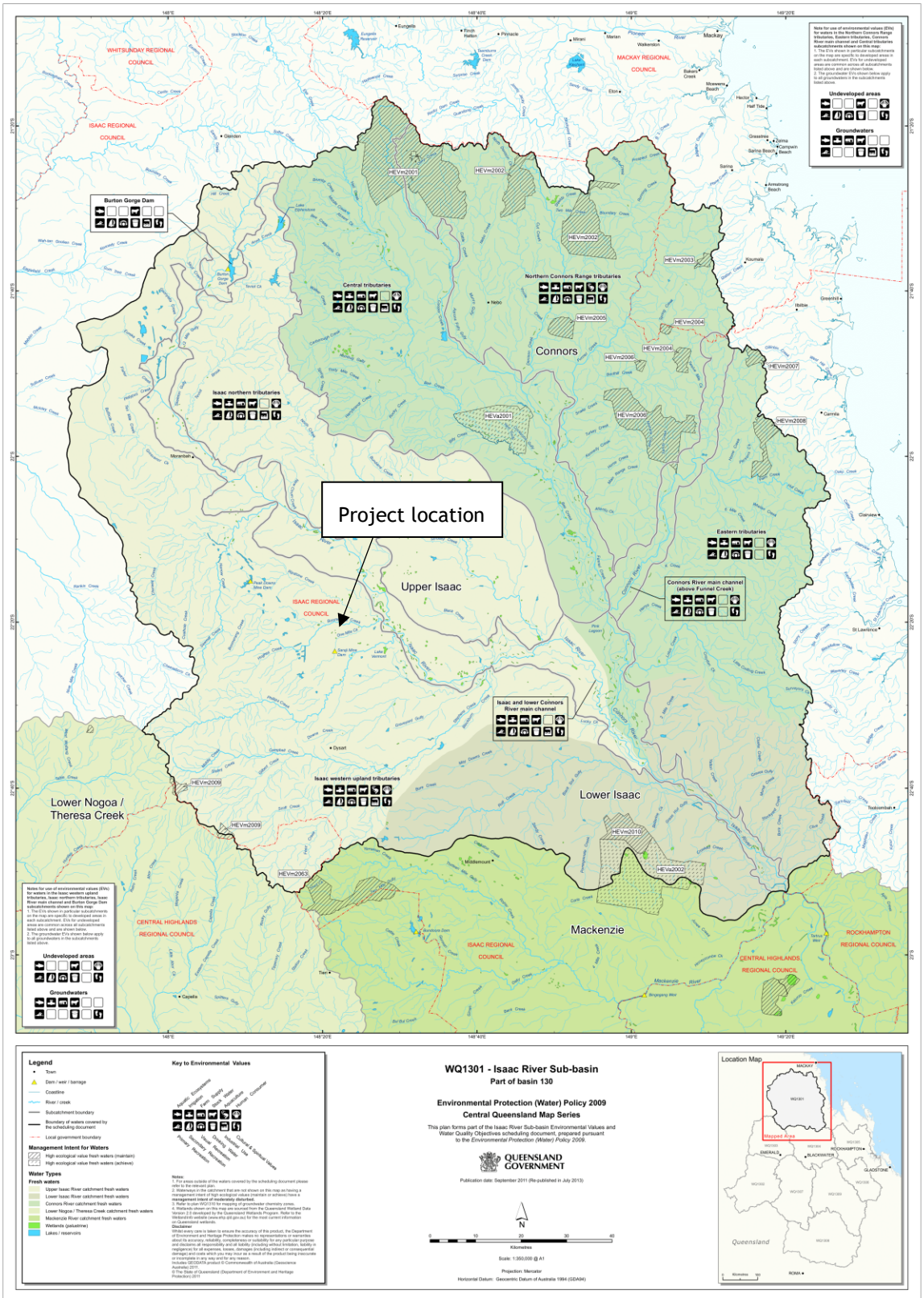


Figure 3.1 - Isaac River Sub-Basin EVs (source: DES, 2013)

The WQO default trigger values for the above EVs are provided in Table 3.1. The indicators and water quality guidelines relevant to the above surface water EVs are listed in the EPP Water (2011) and the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018).

Where different EVs have different WQOs, the Project has adopted the lowest concentration value for mine water and receiving waters trigger levels. WQO default trigger values are displayed for physio-chemical parameters only.

Table 3.1 – Water Quality Objectives default trigger values for the Project (from EPP Water [2009] for Isaac Western Upland Tributaries)

Parameter	WQO	Relevant EV
Ammonia N	< 20 µg/L	Aquatic ecosystem[a]
Oxidised N	< 60 µg/L	Aquatic ecosystem[a]
Organic N	< 420 µg/L	Aquatic ecosystem[a]
Total nitrogen	< 500 µg/L	Aquatic ecosystem[a]
Filterable Reactive Phosphorus (FRP)	< 20 µg/L	Aquatic ecosystem[a]
Total Phosphorus	< 50 µg/L	Aquatic ecosystem[a]
Chlorophyll a	< 5 µg/L	Aquatic ecosystem[a]
Dissolved oxygen	85-110% saturation > 4 mg/L at surface	Aquatic ecosystem[a] Drinking water[b]
Turbidity	< 50 NTU	Aquatic ecosystem[a]
Suspended solids	< 55 mg/L	Aquatic ecosystem[a]
pH	pH 6.5-8.5	Aquatic ecosystem[a]
Conductivity (EC) baseflow	720 µS/cm	Aquatic ecosystem[a]
Conductivity (EC) high flow	250 µS/cm	Aquatic ecosystem[a]
Sulfate	25 mg/L	Aquatic ecosystem[a]
Total Dissolved Solids	< 2000 mg/L	Stock watering[c]
Colour	50 Hazen Units	Drinking water[b]
Total Hardness	150 mg/L as CaCO3	Drinking water[b]
Sodium	< 30 mg/L	Drinking water[b]
Aluminium	< 5 mg/L < 0.055 mg/L	Stock watering[c] Aquatic ecosystem[d]
Arsenic	2.0 mg/L 0.5 mg/L up to 5 mg/L < 0.024 mg/L	Irrigation[b, e] Stock watering[f] Aquatic ecosystem[d]
Beryllium	< 0.5 mg/L	Irrigation[g]
Boron	< 5 mg/L < 0.37 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Cadmium	< 0.01 mg/L < 0.0002 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Chromium	< 1 mg/L < 0.001 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Cobalt	< 0.1 mg/L	Irrigation[g]
Copper	< 1 mg/L < 0.0014 mg/L	Stock watering (cattle)[f,e] Aquatic ecosystem[d]

Parameter	WQO	Relevant EV
Fluoride	< 2 mg/L	Irrigation[g]
Iron	< 10 mg/L	Irrigation[g]
Lead	< 0.1 mg/L < 0.0034 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Lithium	< 2.5 mg/L	Irrigation[g]
Manganese	< 10 mg/L < 1.9 mg/L	Irrigation[g] Aquatic ecosystem[d]
Mercury	< 0.002 mg/L < 0.00006 mg/L	Irrigation[g] Aquatic ecosystem[d]
Molybdenum	< 0.05 mg/L	Irrigation[g]
Nickel	< 1 mg/L < 0.011 mg/L	Stock watering[f, e] Aquatic ecosystem[d]
Selenium	< 0.02 mg/L < 0.005 mg/L	Stock watering[f,e] Aquatic ecosystem[d]
Uranium	< 0.1 mg/L	Irrigation[g]
Vanadium	< 0.5 mg/L	Irrigation[g]
Zinc	< 5 mg/L < 0.008 mg/L	Irrigation[g] Aquatic ecosystem[d]

[a] Table 2 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Aquatic ecosystem - moderately disturbed
[b] Table 4 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Drinking water EV
[c] Table 10 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Stock watering EV: salinity
[d] Table 3.4.1 of Australian and New Zealand Guidelines for Fresh and Marine Water Quality: trigger values for slightly-moderately disturbed systems (95% level of protection)
[e] short-term trigger value
[f] Table 11 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Stock watering EV: heavy metals and metalloids
[g] Table 9 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Irrigation EV: heavy metals and metalloids

The Queensland Globe service (Queensland Government, 2019) was used to identify any wetlands in the vicinity of the Project. There were no matters of state environmental significance (MSES) wetlands, wetland values or wetland protection areas identified in or adjacent the Project area.

4 Existing surface water environment

4.1 REGIONAL DRAINAGE CHARACTERISTICS

The Project is located within the Isaac River sub-basin of the greater Fitzroy Basin. Figure 4.1 shows the Upper Isaac River catchment to its confluence with Phillips Creek. The Isaac River commences approximately 100 km to the north of the Project site within the Denham Range. It drains in a south westerly direction through the Carborough and Kerlong Ranges before turning in a south easterly direction near the Goonyella Riverside Mine. It drains approximately 30 km to the east of the Project, and eventually flows to the Mackenzie River some 150 km to the southeast.

Three open water bodies are located in the Isaac upper catchment including Lake Elphinstone, Teviot Creek Dam and Burton Gorge Dam (Figure 4.1). Lake Elphinstone is a natural lake formed behind the Carborough Range whereas Teviot Creek Dam and Burton Gorge Dam are man-made structures that supply water to Burton and North Goonyella mines in the upper catchment.

Other than along the ranges, the majority of the Isaac River catchment has been cleared for agricultural use or for mining. There are several existing coal mines in the catchment, including Burton, North Goonyella, Goonyella Riverside, Broadmeadow, Broadlea North, Isaac Plains, Moranbah North, Millennium, Daunia, Poitrel, Grosvenor, Peak Downs, Saraji, Norwich Park and Lake Vermont mines.

Figure 4.2 shows the surrounding catchments of the Project area. The Project is located in the headwaters of the Boomerang, Hughes, Barret and Harrow creek catchments:

- Headwater drainage features of Boomerang Creek, which is a watercourse and tributary of the Isaac River, drains the northern portion of the Project area. Within the Project MLA boundary, Boomerang Creek and its tributaries are identified as drainage lines. Boomerang Creek is identified as a watercourse approximately 1 km downstream (east) of the Project MLA where Drainage lines 1, 2, 3 and 4 join. Boomerang Creek and its tributaries drain from Project MLA boundary via a series of culverts under the Norwich Park Branch Railway.
- Hughes Creek is a watercourse and tributary of Boomerang Creek and drains the majority of the southern Project area. Hughes Creek is identified as a watercourse within the Project MLA boundary. Hughes Creek drains from the Project MLA boundary via a rail bridge under the Norwich Park Branch Railway.
- Barrett Creek, which is identified as a watercourse within the Project MLA and is and tributary of Hughes Creek, drains a small portion of the southern Project area. Barrett Creek drains from the Project MLA boundary via a culvert under the Norwich Park Branch Railway.
- Headwater drainage features of Harrow Creek, which is a tributary of Cherwell Creek and the Isaac River, drains a small portion of the northern Project MLA area. Harrow Creek is identified as a watercourse approximately 2.2 km downstream (northwest) of the Project MLA.

The confluence of Boomerang and Hughes Creek occurs approximately 10 km to the east of the Project. Boomerang Creek drains into the Isaac River a further 10 km to the east of the Project. The catchment area of the Isaac River to Boomerang Creek is approximately 5,226 square kilometres (km^2). The catchment area of Boomerang Creek is 788 km^2, of which 177 km^2 makes up the Hughes Creek catchment.

The catchments of Boomerang Creek, Hughes Creek and Barrett Creek commence to the west of the Project area and drain in an easterly direction towards Saraji Road and the Norwich Park Branch Railway. The Ripstone Creek catchment lies to the north of the Project area and drains into Boomerang Creek approximately 30 km southeast of the Project. The headwater tributaries of Boomerang and Hughes Creek are ephemeral streams which experience flow only after sustained or intense rainfall.

The predominant catchment land uses of Boomerang Creek include undeveloped areas with some stock grazing to the west of Saraji Road and stock grazing and coal mining to the east. Boomerang Creek, Hughes Creek and Barrett Creek flow into the existing BHP Billiton Mitsubishi Alliance (BMA) operations (Peak Downs and Saraji). The existing BMA operations have diverted the original alignment of Boomerang Creek and its tributaries, as well as Harrow Creek to the north. Additional diversions of Boomerang Creek and its floodplain are also planned for approved operations further to the east.

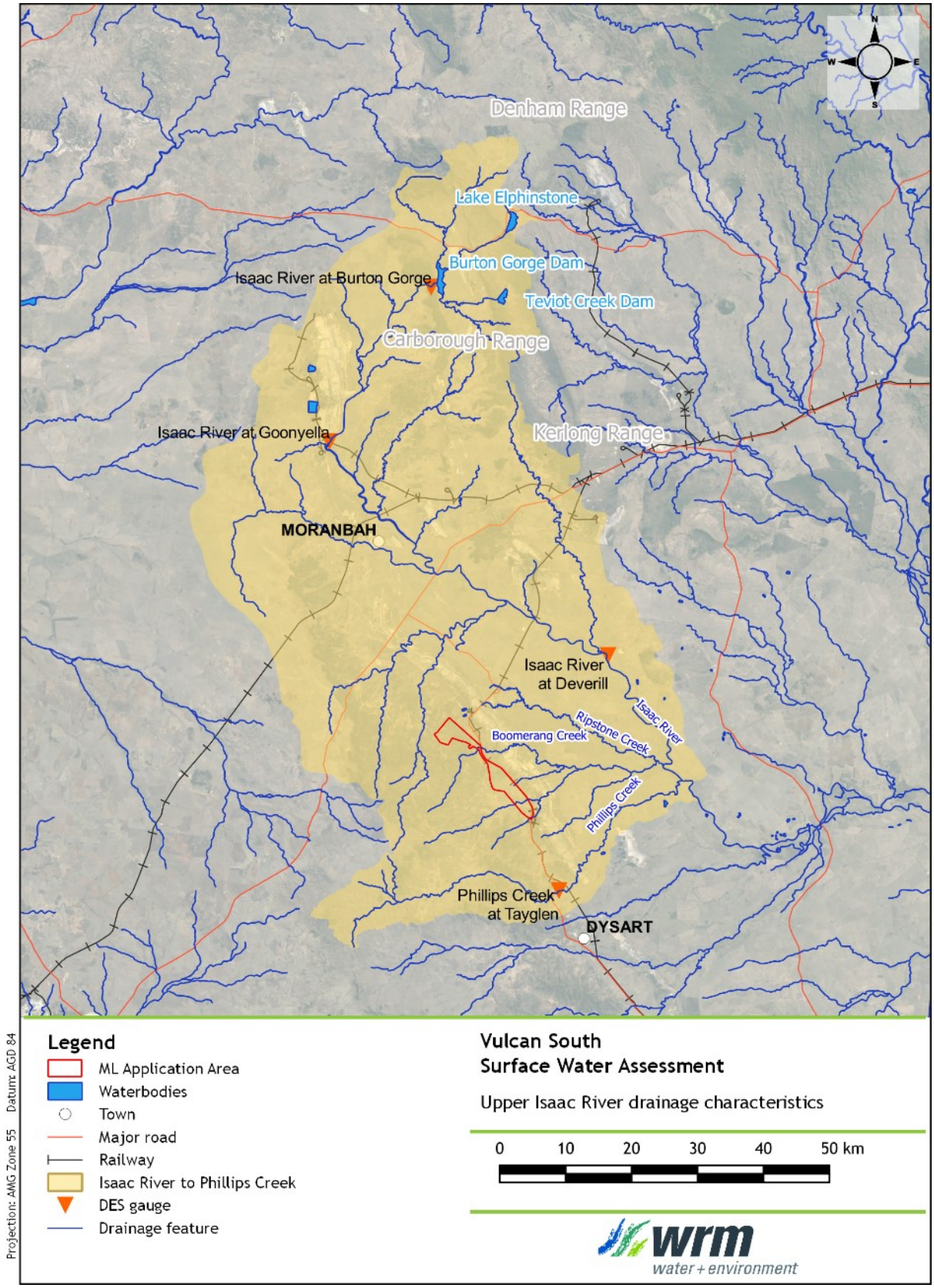


Figure 4.1 – Upper Isaac River drainage characteristics

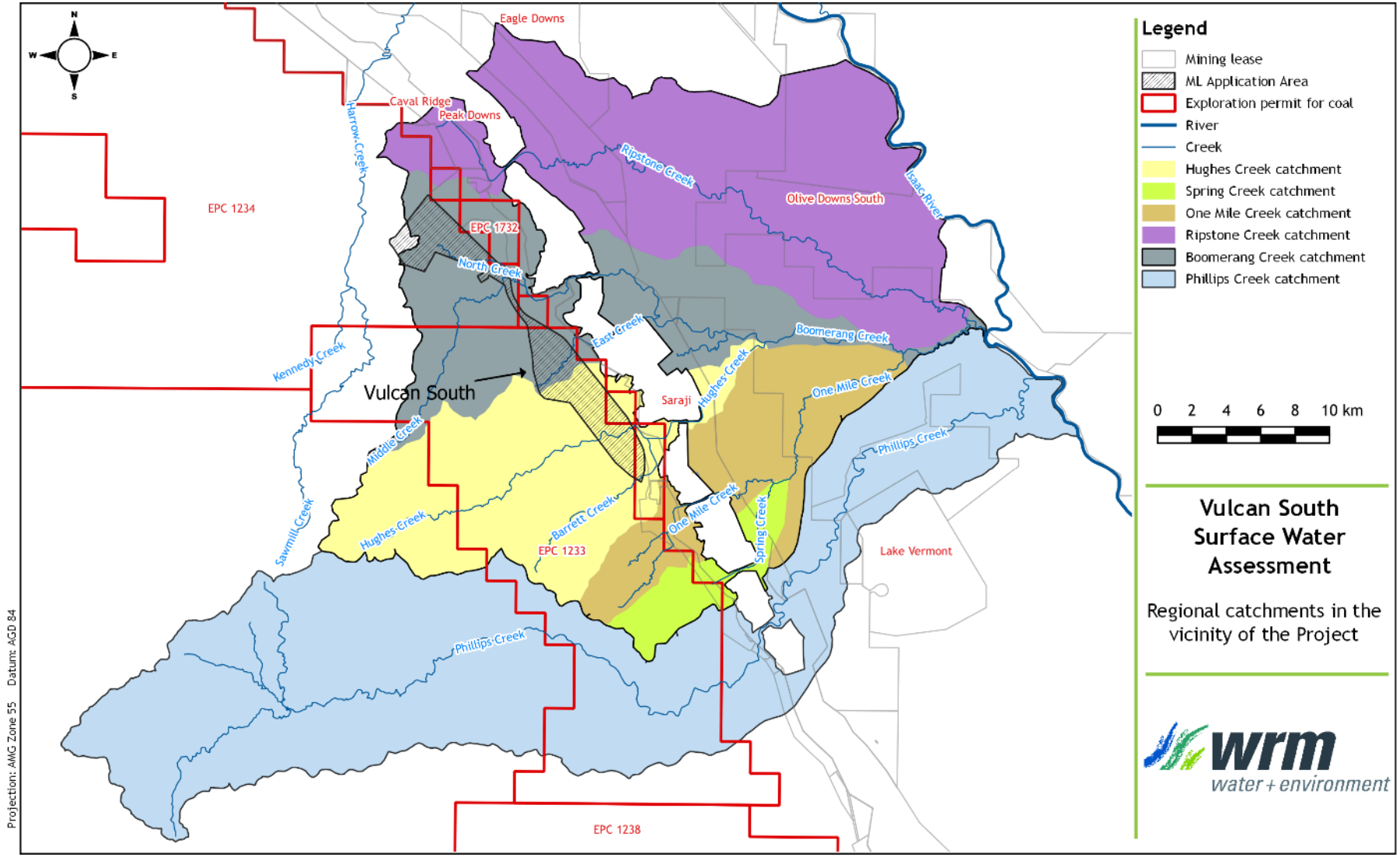


Figure 4.2 - Regional catchments in the vicinity of the Project

The northwest Project MLA area interacts with a small portion of the Harrow Creek catchment (Figure 4.2). Harrow Creek is a watercourse to the west of the Project that flows, which flows in a northerly direction. Sawmill Creek and Kennedy Creek are named tributaries of Harrow Creek. Harrow Creek flows into Cherwell Creek, which in turn discharges into the Isaac River to the north of the Project.

4.2 LOCAL DRAINAGE NETWORK

Figure 4.4 to Figure 4.5 shows the local drainage features within the northern, central and southern Project areas respectively. Drainage features in the north of the Project area (in the vicinity of the highwall mining test area) primarily drain to Boomerang Creek. Drainage features in the centre of the Project area (near the Vulcan North pit) primarily drain to Boomerang Creek. Drainage features in the central and southern areas of the Project area (near the Vulcan Main and Vulcan South pits) primarily drain to Hughes Creek and Barrett Creek. All drainage lines within the Project area eventually drain to the Isaac River.

The main drainage features which intersect the mining areas are (Figure 4.3 to Figure 4.5):

- Drainage line 1 (a tributary of Boomerang Creek);
- Drainage line 2 (a tributary of Boomerang Creek);
- Drainage line 6 (a tributary of Boomerang Creek);
- Drainage line 7 (a tributary of Boomerang Creek);
- Hughes Creek; and
- Drainage line 8 (a tributary of Hughes Creek).

Figure 4.6 shows typical cross sections along the three local drainage features through the Project area with corresponding 1% AEP flood levels at the locations shown in Figure 4.4 and Figure 4.5.

4.2.1 Drainage line 1 and 2

Drainage lines 1 and 2 are tributaries of Boomerang Creek which drain the northern extent of the Project area (Figure 4.3). Drainage lines 1 and 2 drain a significant portion of the VCM and have previously been described in detail (WRM, 2021).

Drainage line 1 drains the northeastern extent of the Project area, in particular the northern extent of the Highwall mining area. Drainage Line 1 crosses the Saraji Road and the Norwich Park branch railway to the northeast of the Project area before discharging into the Peak Downs Mine Lease (ML) downstream of the railway. Drainage Line 1 flows into an existing on-line water storage within the Peak Downs operations before eventually discharging into Drainage Line 2 to the east of the Project boundary. Drainage Line 1 has been diverted and significantly modified within the Peak Downs ML.

The typical dimensions of the Drainage Line 1 channel are (WRM, 2021):

- channel bed widths of 2 m to 5 m;
- channel top widths of 10 m to 25 m;
- channel depths 0.5 to 1 m; and
- overbank floodplain widths of 20 m to 50 m.

Drainage line 1 is proposed to be diverted and subsequently reinstated as part of the VCM (WRM,2021). No further works are proposed for Drainage line 1 as part of this Project.

A minor drainage feature which is a tributary of Drainage line 2 drains the southern extent of the Highwall mining area before discharging into Drainage line 2 at the eastern Project extent (Figure 4.3). Drainage line 2 has a catchment area of approximately 30 km^2. Drainage Line 2 crosses the Saraji Road and the Norwich Park branch railway to the east of the Project area before discharging into the Peak Downs ML downstream of the railway.

The typical dimensions of the Drainage Line 2 channel are (WRM, 2021):

- channel bed widths of 3 m to 5 m;
- channel top widths of 10 m to 30 m;
- channel depths 1 to 2 m; and
- overbank floodplain widths of 50 m to 150 m.

Drainage Line 2 will not be modified as part of the Project.

4.2.2 Drainage line 6

Drainage line 6 drains the majority of the Vulcan North mining area. The drainage line passes through a culvert under Saraji Road and the Norwich Park branch railway within the Project area (Figure 4.7). Drainage line 6 discharges into an existing drainage diversion within the Saraji Mine known as East Creek which in turn, passes through the Saraji Mine operation before draining into Boomerang Creek approximately 5 km to the east of the Project.

The typical dimensions of the Drainage Line 6 channel through the Project area are (Figure 4.6):

- channel bed widths of 1 m to 5 m;
- channel top widths of 5 m to 20 m;
- channel depths 0.5 to 1 m; and
- overbank floodplain widths of 15 m to 80 m.

Drainage line 6 will be diverted as part of the Project to avoid the Vulcan North mining area (Figure 1.3). The 1.8 km long drainage diversion will divert Drainage line 6 into Drainage line 7 during operations. Drainage Line 6 will be reinstated post-mining by constructing a drainage corridor through backfilled spoil. DD2 will collect runoff from the remaining Drainage line 6 catchment.

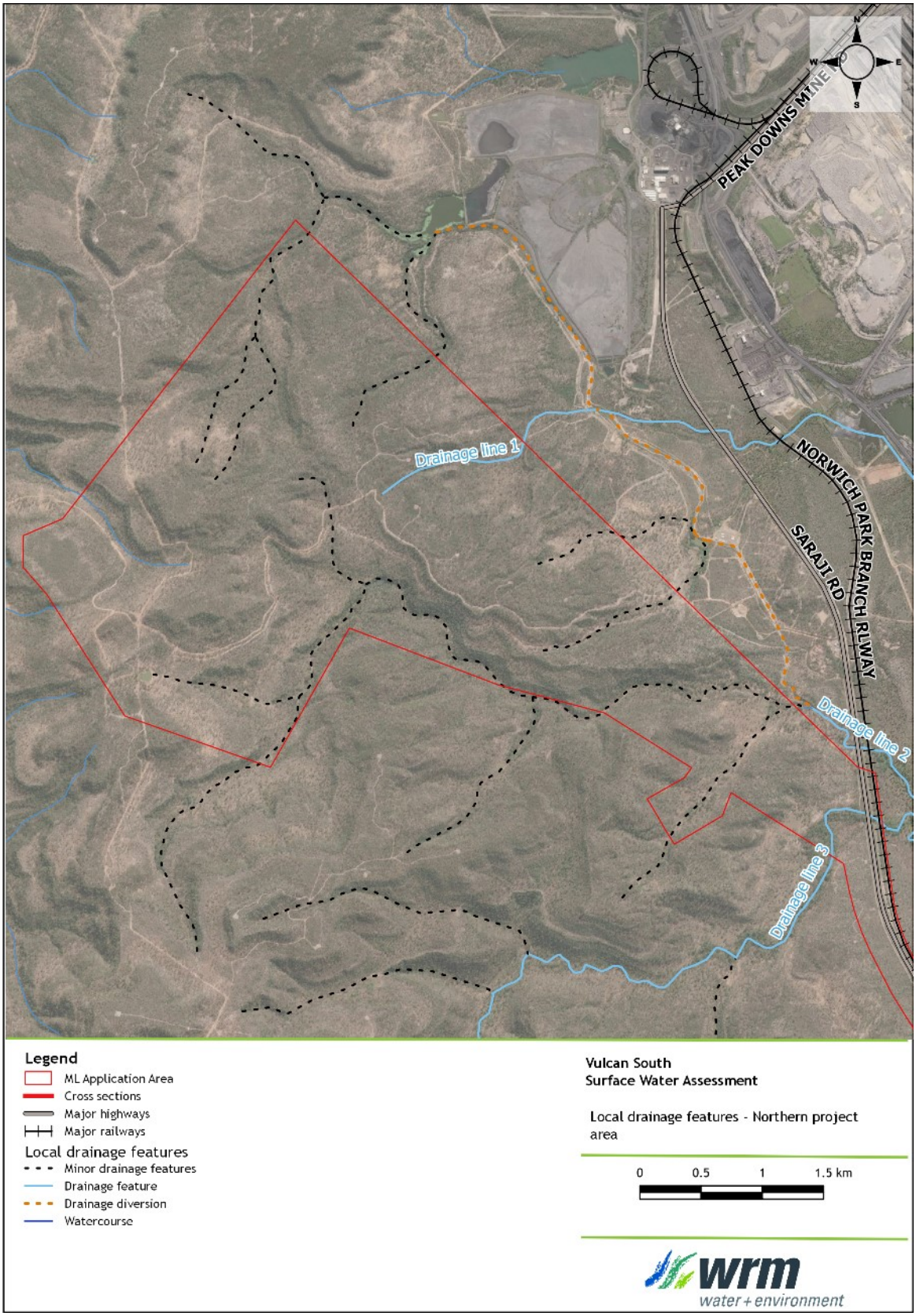


Figure 4.3 – Local drainage features – northern Project area

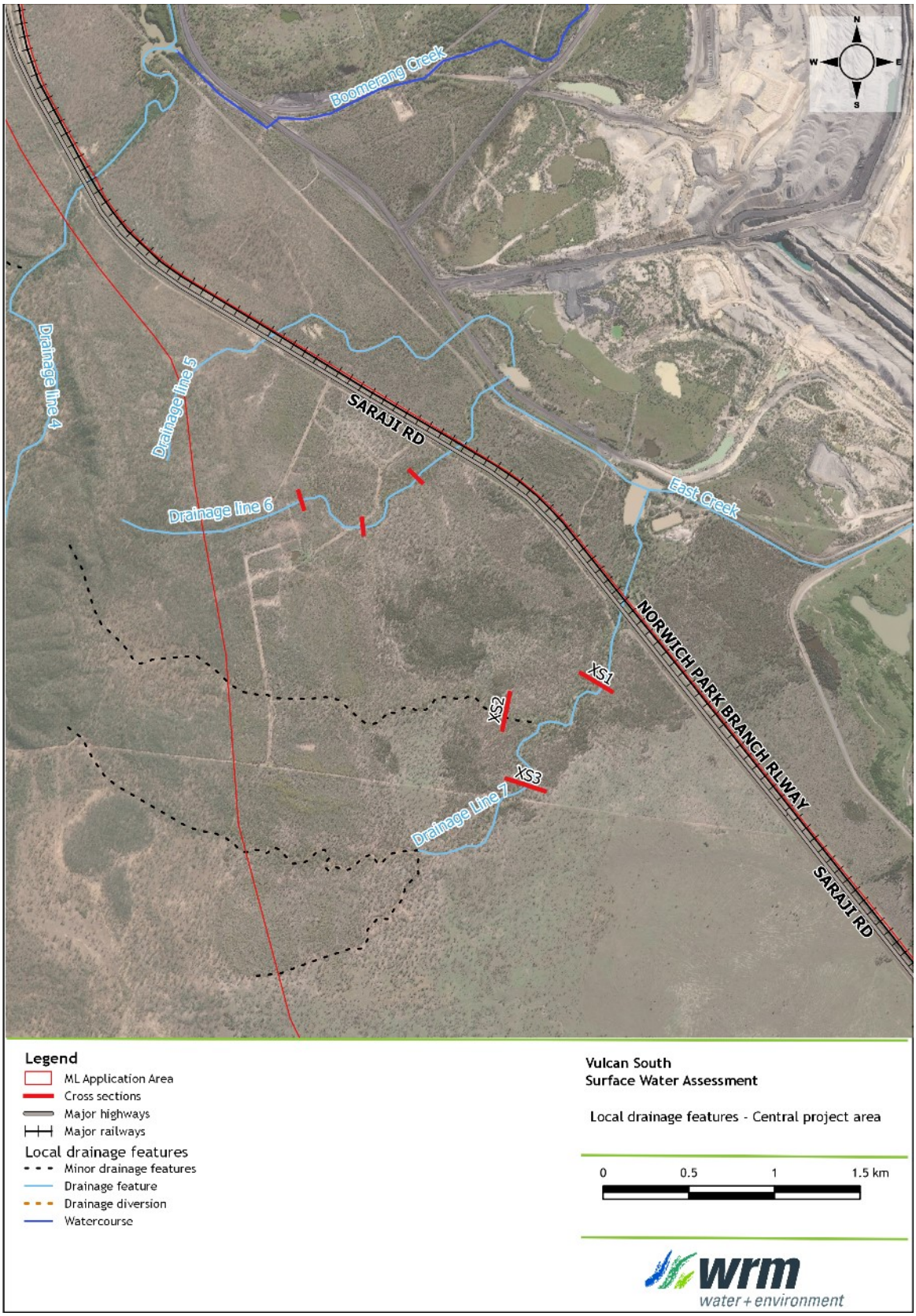


Figure 4.4 – Local drainage features – central Project area

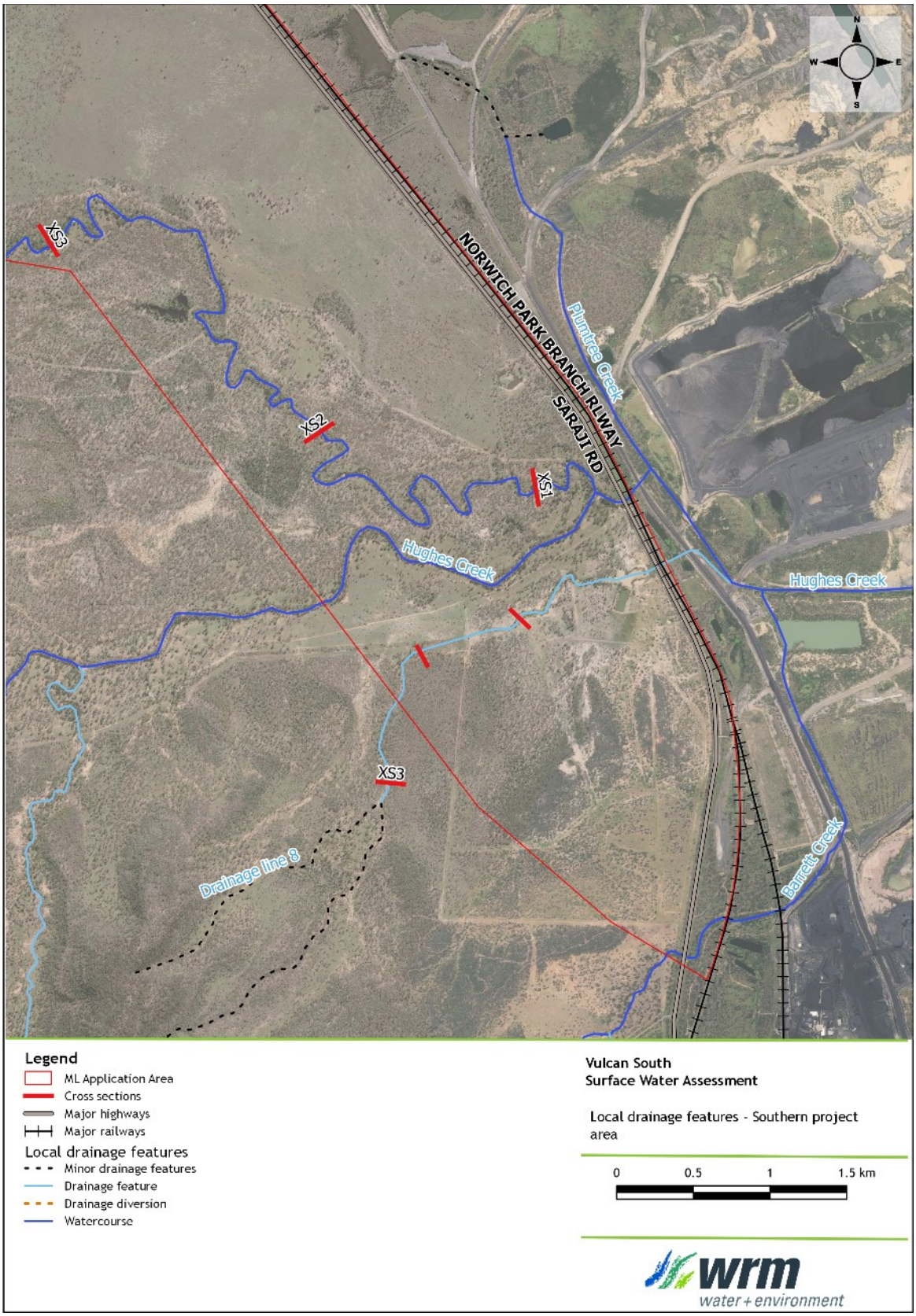


Figure 4.5 – Local drainage features – southern Project area

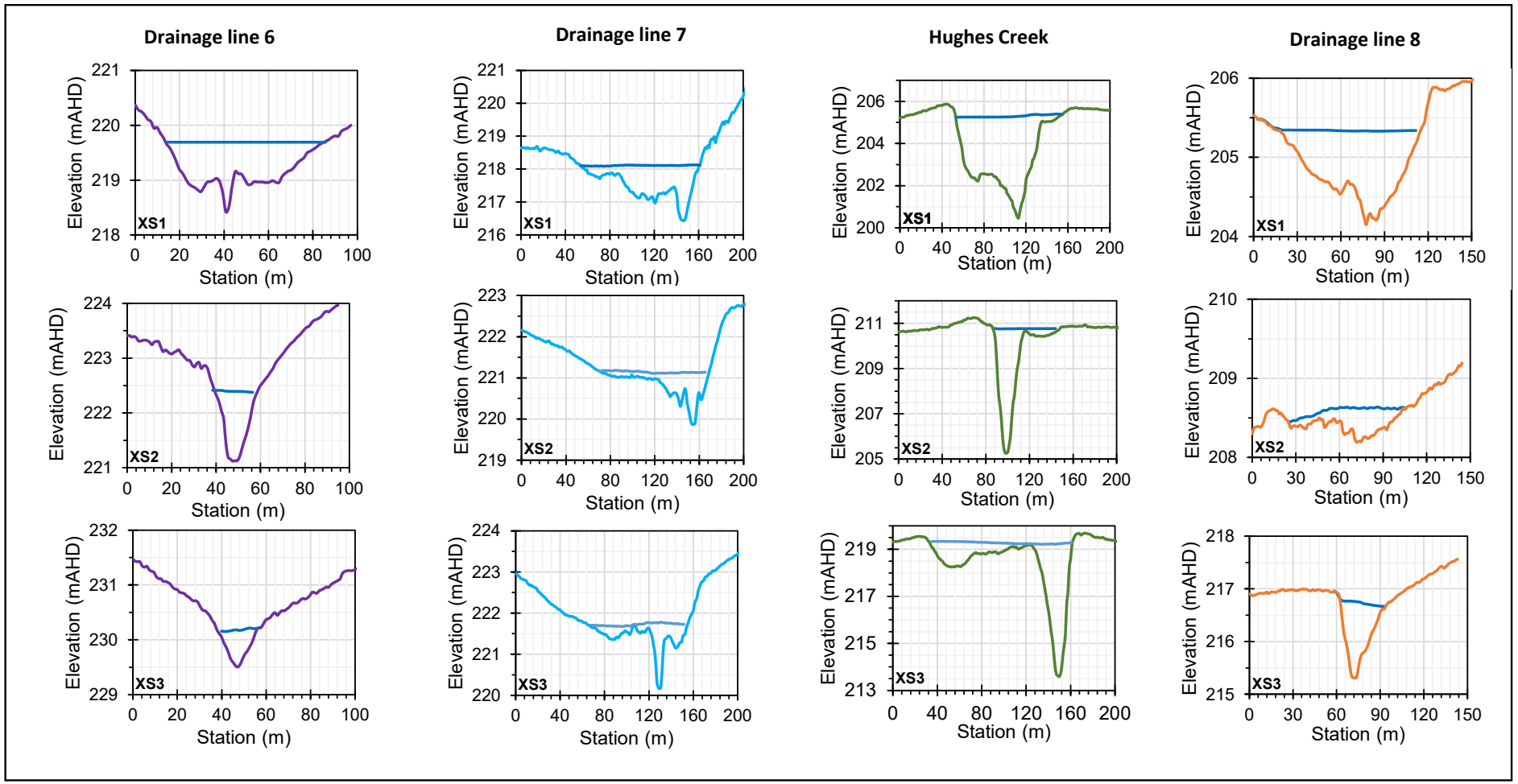


Figure 4.6 – Drainage line cross sections with 1% AEP flood levels



Figure 4.7 – Photograph of Drainage line 6 passing under the Norwich Park Branch railway

4.2.3 Drainage line 7

Drainage line 7 (Figure 4.8) lies between the proposed Vulcan North and Vulcan Main mining areas, and north of the TLO and CHPP area. Drainage line 7 will receive releases from sediment dams around the Vulcan North out of pit emplacement area and the diverted water catchment from Drainage line 6 during operations (Section 4.2.2).

Drainage line 7 collects a natural catchment to the west of the Project area and discharges through existing box culverts under Saraji Road and the Norwich Park Branch railway (Figure 4.9). The Drainage line 7 flows into a dam 400 m east of the Project area, which forms part of the drainage diversion known herein as East Creek within the Saraji Mine.

The typical dimensions of the Drainage Line 7 channel through the Project area are (Figure 4.6):

- channel bed widths of 3 m to 5 m;
- channel top widths of 10 m to 15 m;
- channel depths 1.0 to 2.0 m; and
- overbank floodplain widths of 50 m to 100 m.



Figure 4.8 – Photograph of Drainage line 7 south of the Vulcan North mining area



Figure 4.9 – Photograph of Drainage line 7 passing through box culverts under Saraji Road

4.2.4 Hughes Creek

Hughes Creek is a watercourse which collects a significant natural catchment to the west of the Project area. The creek flows west-east between the Vulcan Main and Vulcan South areas, passing under two bridges crossings of Saraji Road and the Norwich Park branch railway (Figure 4.10). A number of drainage features discharge into Hughes Creek to the east of the Project Area, including Barrett Creek and Drainage line 8. Hughes Creek passes through the Saraji Mine operation before discharging to Boomerang Creek, approximately 10 km to the east of the Project area. Hughes Creek has been diverted and significantly modified within the Saraji ML.

A tributary of Hughes Creek flows on the southern edge of the Vulcan Main mining area and will receive releases from sediment dams around the southern side of the Vulcan Main in pit and out of pit emplacement areas and the northern side of the Vulcan South in pit emplacement areas. Hughes Creek will also receive the diverted water catchment from Drainage line 8 during operations (Section 4.2.5).

The typical dimensions of the Hughes Creek channel within the Project area are (Figure 4.6):

- channel bed widths of 3 m to 10 m;
- channel top widths of 30 m to 50 m;
- channel depths 2 to 5 m; and
- overbank floodplain widths of 50 m to 150 m.



Figure 4.10 – Photograph of Hughes Creek passing under Saraji Road

4.2.5 Drainage line 8

Drainage line 8 is a tributary of Hughes Creek which flows through the proposed Vulcan South mining area. Drainage line 8 currently passes through box culverts under Saraji Road and the Norwich Park branch Railway before discharging into Hughes Creek to the east of the Project area. Drainage line 8 is proposed to be diverted during operations around the Vulcan South mining area into Hughes Creek (Figure 1.8) to the north. Drainage Line 8 will be reinstated postmining by constructing a drainage corridor through backfilled spoil.

The typical dimensions of the Drainage Line 8 channel through/upstream of the Project area are (Figure 4.6):

- channel bed widths of 1 m to 3 m;
- channel top widths of 10 m to 20 m;
- channel depths 0.5 to 1.0 m; and
- overbank floodplain widths of 50 m to 150 m.

Drainage line 8 is not well defined in its lower reaches (i.e. closer to the proposed Vulcan South mining area) and an existing farm is located on the section of Drainage Line 8 that is to be diverted.

4.3 RAINFALL AND EVAPORATION

Long term rainfall and evaporation data at the Project was not available. As such, long term daily evaporation and rainfall data was sourced from the DES SILO climate data service at the approximate Project coordinates (Latitude: -22.35, Longitude: 148.2) from January 1889 to January 2020 (i.e. 131 years of data).

Table 4.1 shows statistics for Morton's lake evaporation and Table 4.2 shows statistics for rainfall (as mm/month and mm/year) over the historical dataset.

Figure 4.11 shows a comparison between the evaporation and rainfall. Evaporation rates are generally higher than rainfall throughout the year.

Table 4.1 – Evaporation (Morton's lake) statistics over the historical period (mm)

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max	240	204	201	152	118	94	103	142	171	215	222	239	1,967
90th %ile	224	190	186	144	109	88	97	125	160	199	214	229	1,891
Median	201	168	167	132	102	80	91	118	152	189	201	213	1,804
10th %ile	171	143	150	121	93	75	83	110	141	174	182	188	1,726
Min	120	122	127	94	76	59	77	97	121	160	121	145	1,506

Table 4.2 – Rainfall statistics over the historical period (mm)

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max	502	471	324	267	208	168	132	273	134	143	191	351	1,254
90th %ile	208	221	162	70	66	74	61	61	47	88	100	149	881
Median	98	85	45	19	15	21	7	6	6	20	39	71	567
10th %ile	20	14	2	0	0	0	0	0	0	0	7	23	362
Min	0	0	0	0	0	0	0	0	0	0	0	2	221

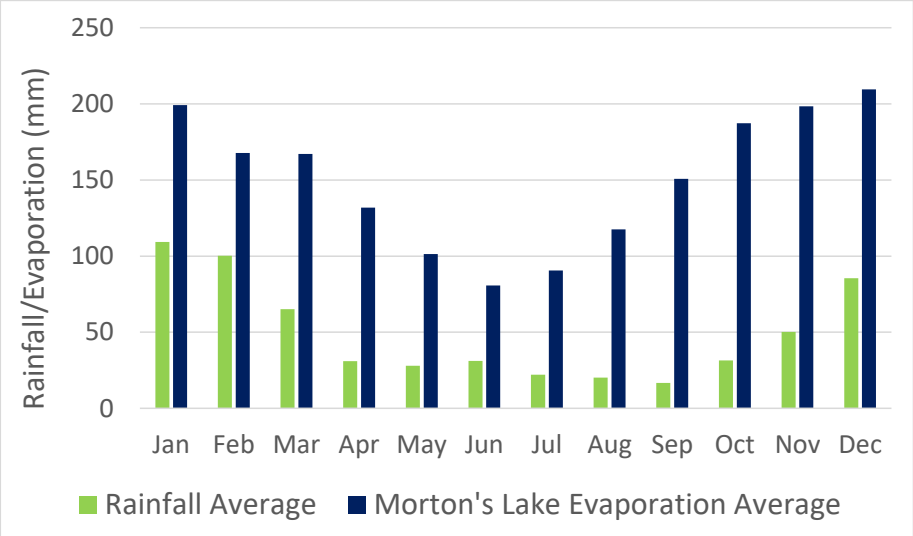


Figure 4.11 – Long term SILO mean monthly rainfall and evaporation at the Project

4.4 STREAMFLOW

There are no stream flow data available for East Creek or Hughes Creek at the time of preparing this report. There are two streamflow gauges operated by the Department of Natural Resources, Mines and Energy (DNRME) in the vicinity of the Project including (see Figure 1.1):

- Isaac River at Deverill (approximately 25 km northeast of the Project); and
- Phillips Creek at Tayglen (approximately 15 km southeast of the Project).

The stream gauge on the Isaac River at Deverill (Station ID: 130410A) is located approximately 20 km upstream of where Boomerang Creek meets the Isaac River.

Historical flow and river height monitoring data (1968 to 2018) for the Isaac River at Deverill, provides an indication of the flow regime (refer Figure 4.12). Surveyed cross section data for this gauging station collected in September 2014 (DNRME, 2017) indicates that sediment covers the bottom one metre of the gauge range. The mean river height data shown in Figure 4.12 suggests that surface flow above the sand is more likely to occur only in the wetter months from November to April, reducing to shallow subsurface flows from about May to October in an average year.

The Phillips Creek at Tayglen Creek streamflow gauge (Station ID: 130409A) is located on Phillips Creek. Phillips Creek is an easterly draining tributary of the Isaac River, south of Hughes Creek. DNRME maintains data for the gauge between 1968 and 1988. The catchment area to the gauge location is 344 km^2.

A typical sequence of recorded flows from this station is shown in Figure 4.13. The creek is characterised by brief periods of flow interspersed by long periods of no flow. This ephemeral behaviour is typical for streams in this part of the Fitzroy Basin.

The median annual flow over the period of record was approximately 12,730 ML/a (52 mm of runoff), most of which occurred in the summer months (as shown in Figure 4.14). Figure 4.15 compares flow frequency curves for a number of gauged catchments in the Isaac River catchment which are located in the vicinity of the Project. Figure 4.15 shows that for Phillips Creek at Tayglen, flow only occurred approximately 22% of the time, which would be similar to other creeks in the vicinity of the Project.

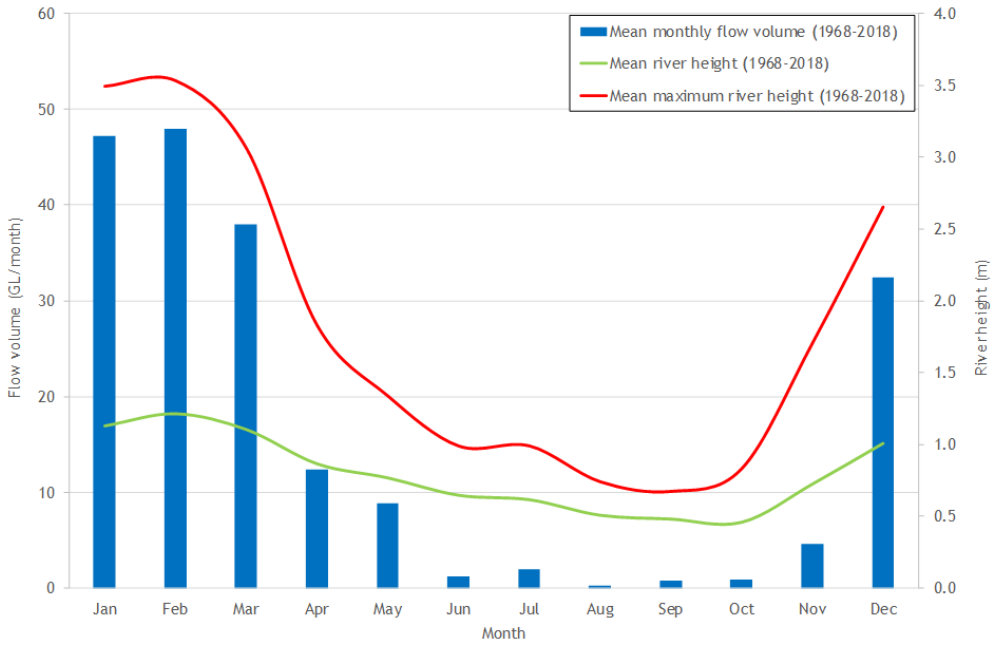


Figure 4.12 - Flow volume and river height in the Isaac River at Deverill

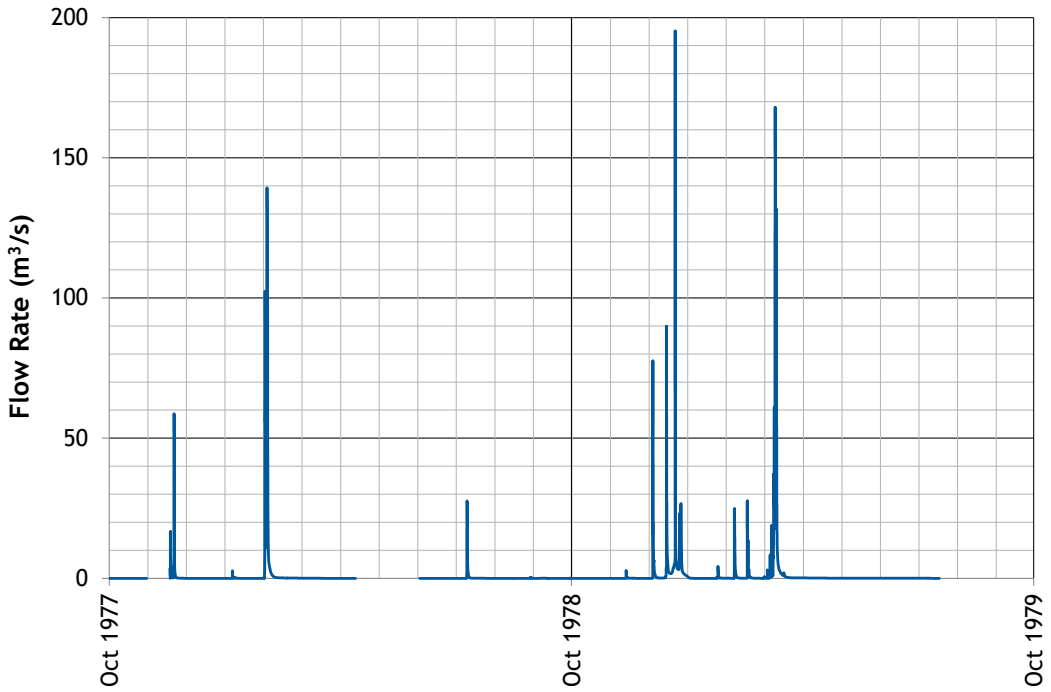


Figure 4.13 - Sample flow sequence - Phillips Creek at Tayglen 1977 - 1979

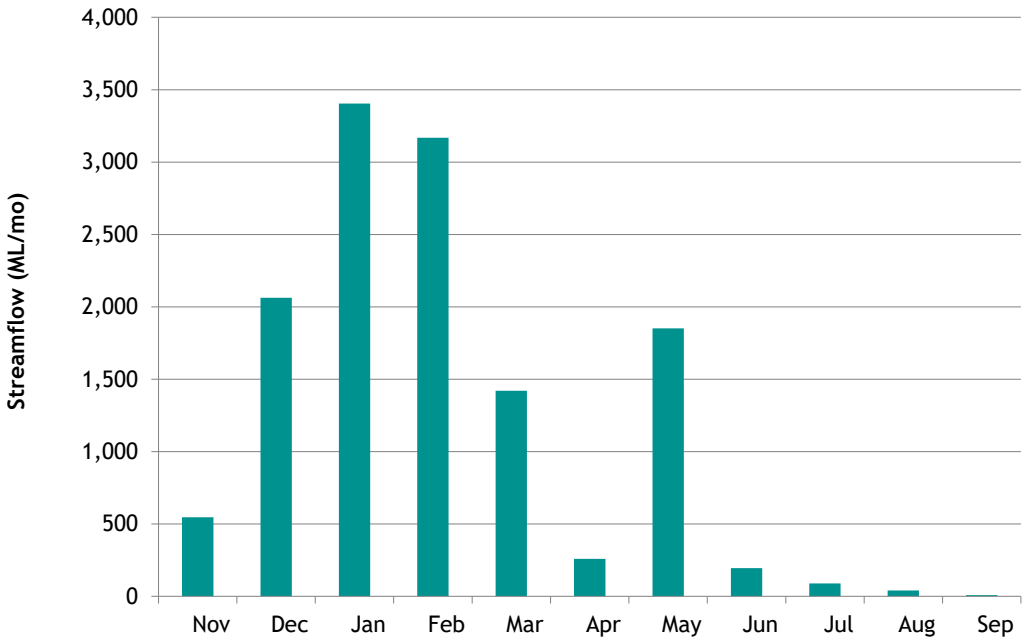


Figure 4.14 - Measured mean monthly streamflow - Phillips Creek at Tayglen 1968-1988

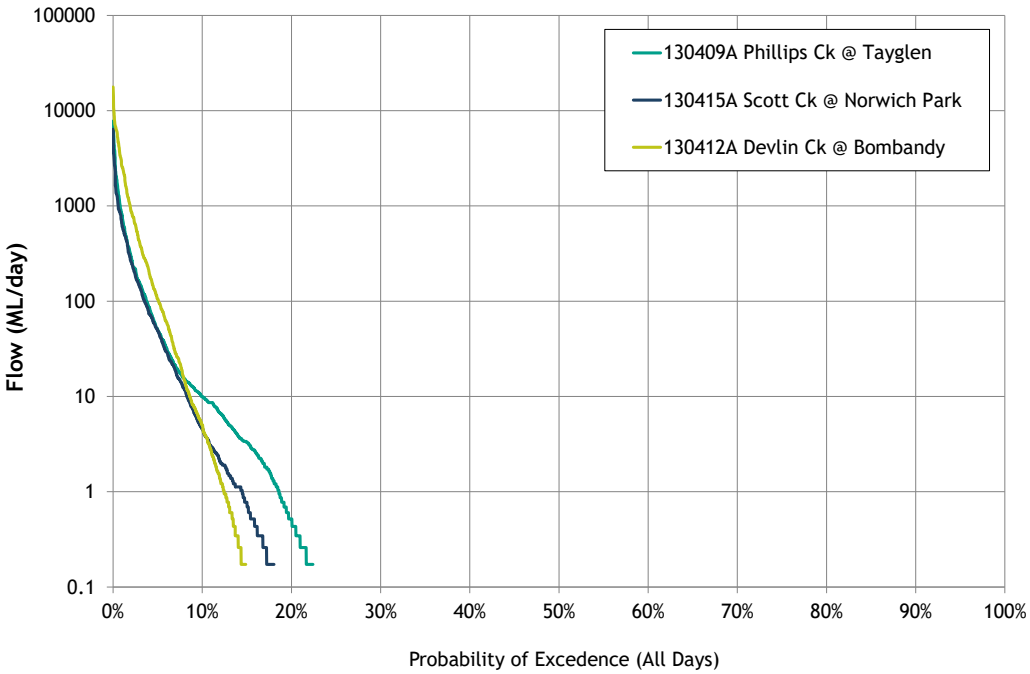


Figure 4.15 - Recorded frequency curves at nearby DNRME gauges (no flow days included)

4.5 WATER QUALITY

4.5.1 Regional Isaac River water quality

Publicly available regional water quality data for the Isaac River at the Deverill Gauging Station has been analysed for median results and are displayed in Table 4.3. This site was selected as complete datasets (i.e. individual sample analysis results) are publicly available, as opposed to summary data only.

DNRME has collected daily electrical conductivity (EC) data at the Isaac River at Deverill gauge. The Deverill gauge is located upstream of the point where Boomerang Creek drains into the Isaac River. The gauge would therefore be representative of water quality in the receiving waters of the Isaac River from the Project.

Figure 4.16 presents a time history of recorded instantaneous EC and stream flow for the Isaac River at Deverill gauging station. Figure 4.17 details the relationship between instantaneous flow and EC at the Isaac River at Deverill gauging station. The data collected by DNRME at the Deverill gauging station spans the period from 2011 to 2018 and indicates:

- The EC values for high flows greater than 200 m^3/s are generally below the high flow WQO EC of 250 µs/cm.
- The EC of instantaneous flows below 100 m^3/s vary significantly from 50 µS/cm to 1,870 µS/cm with many recorded values exceeding the low flow WQO EC of 720 µS/cm but are below the Peak Downs EA receiving waters trigger value of 2,000 µS/cm.
- The mean daily EC has exceeded the low flow WQO on a total of 23 days over this period and all of these days experienced some flow (not stagnant flow).
- The stream flows are highly ephemeral with baseflows ceasing within a few days or weeks of a runoff event, or at least flowing below the top of the sandy bed.

Table 4.3 - Water quality median data in the Isaac River at Deverill

Parameter	Unit	Isaac River at Deverill	WQO default guideline value (refer Table 3.1)
Aluminium - Total	mg/L	-	< 5 (stock)
Aluminium - Dissolved	mg/L	0.05	< 0.055 (aquatic)
Boron - Total	mg/L	0.06	< 5 (stock)
Calcium - Dissolved	mg/L	16	-
Chloride - Total	mg/L	32	-
Copper - Dissolved	mg/L	0.03	< 0.0014 (aquatic)
EC	µS/cm	261	< 720 (baseflow) < 250 (high flow)
Filterable Reactive Phosphorus	µg/L	0.35	< 20 (aquatic)
Fluoride - Total	mg/L	0.14	< 2 (irrigation)
Iron - Dissolved	mg/L	0.06	-
Manganese - Dissolved	mg/L	0.01	< 1.9 (aquatic)
Nitrate - Total	mg/L	1.4	-
Nitrogen – Total	µg/L	0.76	< 500 (aquatic)
pH	-	7.6	6.5–8.5 (aquatic)
Phosphorus - Total	µg/L	0.35	< 50 (aquatic)
Potassium - Total	mg/L	4.55	-
Sodium - Total	mg/L	22	< 30 (drinking water)

Parameter	Unit	Isaac River at Deverill	WQO default guideline value (refer Table 3.1)
Sulfate - Total	mg/L	10.9	< 25 (aquatic)
Total Alkalinity	mg/L	78	-
Total Dissolved Solids	mg/L	155	< 2,000 (stock)
Total Suspended Solids	mg/L	135	< 55 (aquatic)
Turbidity	NTU	247	< 50 (aquatic)
Zinc - Dissolved	mg/L	0.01	< 0.008 (aquatic)

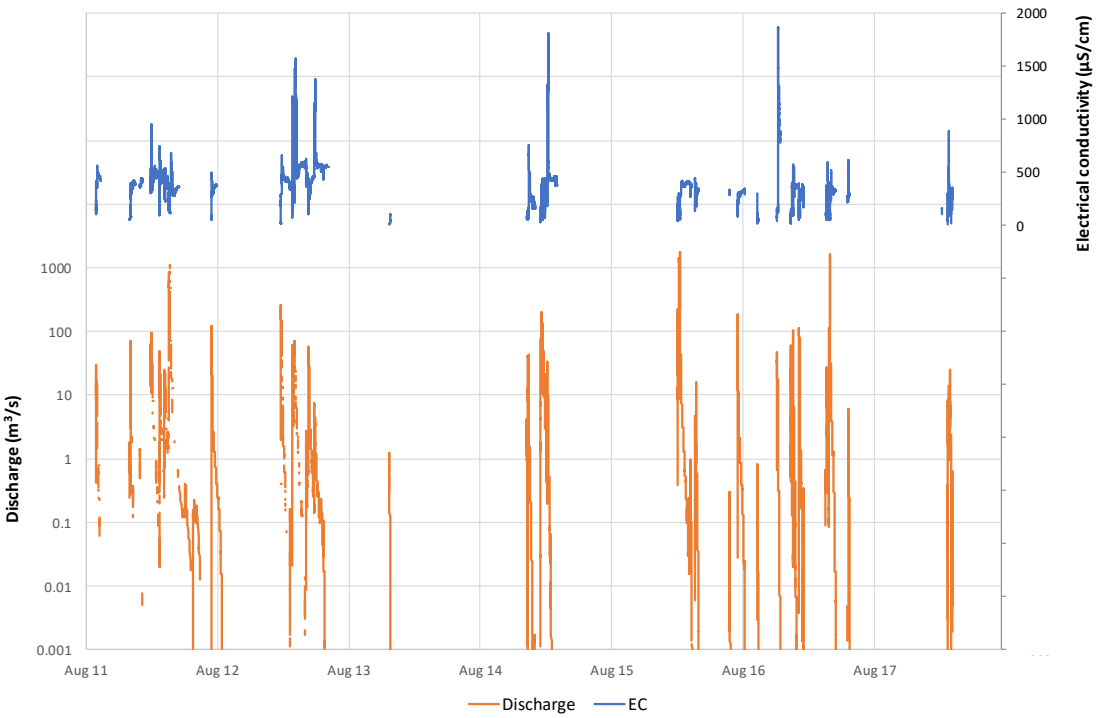


Figure 4.16 - Electrical Conductivity and Flow (Isaac River at Deverill Gauge)

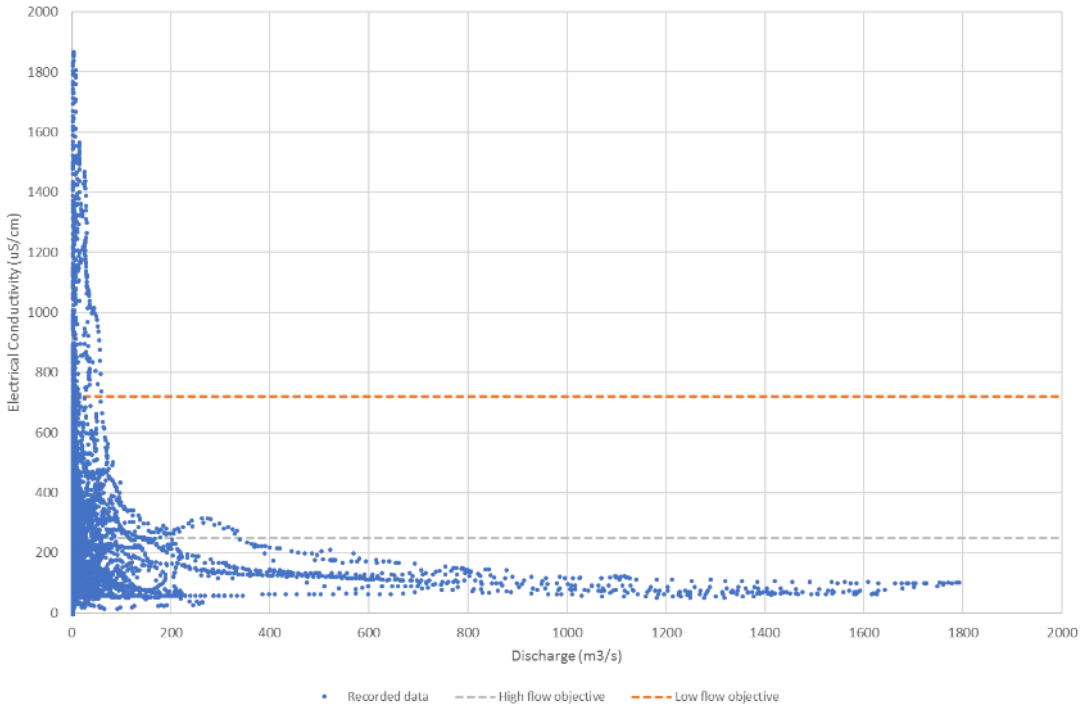


Figure 4.17 - Flow vs Electrical Conductivity (Isaac River at Deverill Gauge)

4.5.2 Local water quality

Water quality sampling has been undertaken as a component of the baseline surface water quality sampling in early 2020. Analyses for a comprehensive range of physio-chemical parameters were completed at the monitoring sites.

The baseline monitoring locations are shown in Figure 4.18 and the full suite of baseline monitoring undertaken for the broader Project area is presented in Appendix A. Monitoring results from the sites most relevant to the Project are outlined in Table 4.4.

Review of Table 4.4 shows that certain baseline water quality values surrounding the Project do not meet the WQO for the region, these include:

- Suspended solids;
- Turbidity;
- Sulfate as SO_4;
- Aluminium (filtered);
- Copper (filtered);
- Aluminium (total);
- Iron (total);
- Ammonia as N;
- Total Nitrogen as N;
- Total Phosphorous as P;
- Reactive Phosphorous as P; and
- Dissolved Oxygen.

To establish local water quality objectives, the Queensland Water Quality Guidelines require that with 3 or more reference sites, 12 samples are collected over at least 12, but preferably 24 months. Vitrinite has established more than 3 reference sites, which will continue to be either upstream reference sites or reference sites until mining commences. However, data collection is limited to periods of flow in an ephemeral system. Therefore, reliance is placed on regional water quality data to establish WQOs until there is sufficient data to develop local water quality objectives.

Table 4.4 - Baseline water quality monitoring

Parameter	Unit	VSW-4 4/03/2020	VSW-6 4/03/2020	VSW-7 4/03/2020	VSW-5 18/03/2020	VSW-4 19/03/2020	VSW-6 19/03/2020	VSW-7 19/03/2020	VESW-4 19/03/2020	WQO (see Table 3.1)
pH Value	-	7.16	7.12	7.57	6.78	7.11	6.89	7.57	7.13	6.5 - 8.5
Sodium Adsorption Ratio	-	0.61	0.26	0.34	0.68	0.37	0.77	0.42	0.51	-
Electrical Conductivity	µS/cm	81	46	106	44	74	80	124	129	> 720 (baseflow) > 250 (high flow)
Total Dissolved Solids (Calc.)	mg/L	53	30	69	29	48	52	81	84	> 2,000
Suspended Solids (SS)	mg/L	296	379	1200	77	2050	386	51	168	> 55
Turbidity	NTU	1590	503	1240	339	850	701	346	419	> 50
Total Hardness as CaCO3	mg/L	18	12	40	7	22	16	51	18	> 150
Hydroxide Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	-
Carbonate Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	-
Bicarbonate Alkalinity as CaCO3	mg/L	33	6	49	11	26	21	65	45	-
Total Alkalinity as CaCO3	mg/L	33	6	49	11	26	21	65	45	-
Sulfate as SO4 - Turbidimetric	mg/L	4	2	<1	2	6	4	1	2	> 25
Chloride	mg/L	6	3	6	5	5	9	6	7	-
Calcium	mg/L	4	3	8	1	4	3	9	4	-
Magnesium	mg/L	2	1	5	1	3	2	7	2	-
Sodium	mg/L	6	2	5	4	4	7	7	5	> 30
Potassium	mg/L	3	3	2	3	4	4	2	5	-
Dissolved Metals										
Aluminium	mg/L	0.26	0.2	0.07	1.11	0.35	0.22	0.02	0.09	> 0.055
Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.004	> 0.024
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.0002
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.001

Cobalt	mg/L	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.006	-
Copper	mg/L	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	> 0.0014
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.0034
Manganese	mg/L	0.125	0.04	0.066	0.011	0.192	0.026	0.002	0.295	> 1.9
Molybdenum	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Nickel	mg/L	0.001	<0.001	0.001	<0.001	0.002	0.001	0.001	0.003	> 0.011
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.005
Silver	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Uranium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.1
Vanadium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.5
Zinc	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	> 0.008
Boron	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	> 0.37
Iron	mg/L	0.18	0.13	0.15	0.63	0.33	0.21	0.11	3.02	-
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.00006
Total Metals										
Aluminium	mg/L	22.8	6.62	21.8	7.97	16.5	10.3	9.22	6.36	> 5
Arsenic	mg/L	0.005	0.003	0.003	0.002	0.005	0.005	0.002	0.005	> 0.5
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.01
Chromium	mg/L	0.02	0.006	0.026	0.005	0.017	0.008	0.011	0.004	> 1
Cobalt	mg/L	0.014	0.003	0.013	0.003	0.018	0.005	0.004	0.01	> 0.1
Copper	mg/L	0.023	0.008	0.016	0.006	0.02	0.009	0.005	0.012	> 1
Lead	mg/L	0.032	0.009	0.022	0.007	0.028	0.011	0.006	0.01	> 0.1
Manganese	mg/L	0.477	0.112	0.334	0.077	0.804	0.13	0.108	0.383	> 10
Molybdenum	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.05
Nickel	mg/L	0.028	0.006	0.022	0.006	0.025	0.012	0.008	0.009	> 1
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.02
Silver	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Uranium	mg/L	0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	-
Vanadium	mg/L	0.03	<0.01	0.03	<0.01	0.02	0.01	0.01	<0.01	-

Zinc	mg/L	0.058	0.022	0.037	0.024	0.059	0.031	0.022	0.031	> 5
Boron	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	> 5
Iron	mg/L	27.7	8.42	25.7	7.88	21.8	12.9	7.86	12.5	> 10
Mercury	mg/L	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.002
Fluoride	mg/L	0.2	<0.1	0.2	<0.1	0.1	0.1	0.2	0.1	< 2
Ammonia as N	mg/L	0.11	0.07	0.11	0.1	0.09	0.21	0.12	6.95	> 0.02
Nitrite as N	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.04	0.21	-
Nitrate as N	mg/L	0.02	0.02	0.04	0.14	<0.01	0.08	0.03	0.1	-
Nitrite + Nitrate as N	mg/L	0.02	0.02	0.04	0.14	<0.01	0.09	0.07	0.31	-
Total Kjeldahl Nitrogen as N	mg/L	1.8	0.8	0.6	1.3	2.6	2	1.1	9.9	-
Total Nitrogen as N	mg/L	1.8	0.8	0.6	1.4	2.6	2.1	1.2	10.2	> 0.5
Total Phosphorus as P	mg/L	0.43	0.19	0.18	0.12	0.58	0.37	0.1	0.41	> 0.05
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.02
Total Anions	meq/L	0.91	0.25	1.15	0.4	0.78	0.76	1.49	1.14	-
Total Cations	meq/L	0.7	0.4	1.08	0.38	0.72	0.72	1.38	1.33	-
Chlorophyll a	mg/m^3	<12	<4	<10	-	-	<8	<3	-	-
Dissolved Oxygen	mg/L	6.4	6.8	7.6	7.5	7.1	5.9	6.7	4.9	< 4

Note: Recorded exceedances of the WQOs have been shaded in grey.

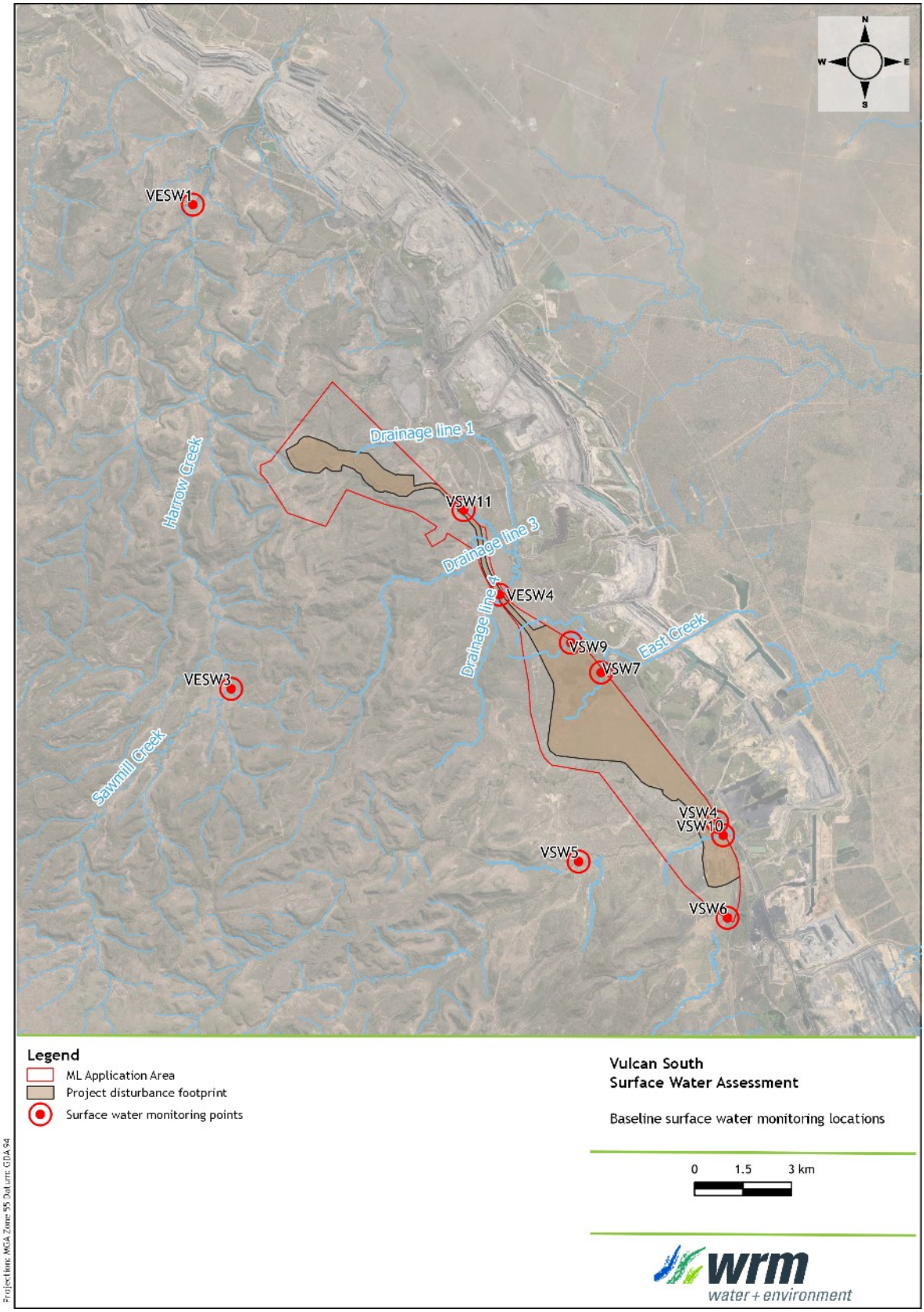


Figure 4.18 - Baseline surface water monitoring locations

4.6 SOIL CHARACTERISTICS

AARC Environmental Solutions Pty Ltd (2022) completed a *Soil and Land Suitability Assessment* (SLSA) for the Project and surrounds. To characterise the soils at the site, AARC collected 42 detailed soil profiles and analysed 12 laboratory samples from the site vicinity.

The area surrounding the Project is dominated by clastic sedimentary rocks of marine and lacustrine origin, including sandstones, mudstones, siltstones and coal. Surface geology at the site includes Quaternary clay, silt, sand, gravel and soil with colluvial and residual deposits, as well as late Tertiary to Quaternary poorly consolidated sand, silt, clay, minor gravel and high-level alluvial deposits (AARC, 2022).

4.6.1 Soil management units

AARC mapped the Soil Management Units (SMUs) across the site using the methodologies specified in the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al*, 2008) based on soil morphology, parent material and land attributes.

A description of each SMU found within the Project area is outlined in Table 4.5. The majority of the site consists of the Limpopo SMU, the Orange SMU and the Zambezi SMU.

Table 4.5 - Soil Management Units surveyed on site (AARC, 2022)

Soil Management Unit	Description
Crocodile	A shallow rocky soil unit associated with hill slopes and plateaus. Soil textures grade from loam at the surface, to loamy sands with depth; often containing rock material with little to no pedologic development throughout the solum.
Limpopo	The Limpopo unit is a brown texture-contrast soil. Soil textures predominantly grade from sands to clay sands in the surface soils to light clays in deeper horizons.
Zambezi	A predominantly grey coloured texture contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display diffuse orange to yellow mottles.
Orange	A dark cracking clay associated with the flat grassy plains in the middle of the Project area. The predominant textures of soils within this unit range from light clays in surface soils to light medium clays in deeper horizons.
Sabie	A dark-coloured texture contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display red to orange mottles.
Komati	A dark brown coloured soil unit displaying vertic properties. Soil textures predominantly grade from light to medium clays with calcareous segregations occurring within the deeper horizons.
Fish	A predominantly sandy soil unit occurring on the flats of the southeastern end of the Project area. Soil textures grade from loamy sand at the surface, to clay and silty sands with depth.
Kei	A brown coloured soil unit occurring on the flats of the southeastern end of the Project area. Soil textures grade from clayey to loamy sands at the surface, to medium clay with depth and orange to yellow mottles present in the deeper horizons.

4.6.2 Sodic and dispersive soils

Sodic soils contain large concentrations of Sodium relative to other cations. These soils have a degree of dispersivity and can accelerate erosion.

AARC (2022) identified areas of high sodicity on site through the measurement of the Exchangeable sodium percentage and Emerson Class of surveyed soils. The Crocodile and Kei SMU were identified as having a low risk of dispersion and were not identified as being sodic.

For the remaining SMUs, AARC (2019) identified the depth horizons with sodic properties as follows:

- Fish SMU: Sodic below a depth of 0.2 m;
- Komati SMU: Sodic below a depth of 0.2 m;
- Limpopo SMU: Sodic below a depth of 0.5 m;
- Orange SMU: Sodic below a depth of 0.2 m;
- Sabie SMU: Sodic below a depth of 0.2 m; and
- Zambezi SMU: Sodic below a depth of 0.5 m.

To control erosion from sodic dispersive soils, soils will be selectively handled and managed where required, as per the ameliorative measures outlined by AARC (2019), and further detailed in the *Vulcan South Progressive Rehabilitation and Closure Plan* (METServe, 2022).

5 Proposed surface water management strategy and infrastructure

5.1 TYPES OF WATER GENERATED ONSITE

Land disturbance associated with mining has the potential to adversely affect the quality of surface runoff in downstream receiving waters through increased sediment loads. In addition, runoff from active mining areas (including coal stockpiles, etc.) may have increased concentrations of salts and other pollutants when compared to natural runoff. The proposed strategy for the management of surface water at the Project is based on the separation of water from different sources based on anticipated water quality.

Definitions of the types of water generated within the Project are shown in Table 5.1.

5.2 PROPOSED WATER MANAGEMENT INFRASTRUCTURE

The operational period of mining is expected to run for eight years from 2023 to 2031.

Figure 1.3 to Figure 1.10 show indicative locations of the key features of the mine, including infrastructure related to the management of water on the Project site for three different stages of mining (Stages 1, 2 and 3). The main components of water-related infrastructure include:

- diverted water drains, bunds and drainage diversions to divert runoff from undisturbed catchments around areas disturbed by mining;
- flood protection levees along the southern side of the Vulcan North pit extent, along the western and southeastern sides of the Vulcan Main pit, and around the Vulcan South pit;
- sediment dams and drains to collect and treat runoff from waste rock emplacement areas; and
- mine-affected water drains and dams to store water pumped out of the open cut mining areas and to collect runoff from the infrastructure areas.

The catchment areas of each of the mine water storages, as well as the assumed landuse contributing to each catchment are also shown in Figure 1.3 to Figure 1.10.

Details of proposed water storages, including indicative storage sizes and pumping rules are provided in Section 6.4.

5.3 WATER MANAGEMENT STRATEGY OVERVIEW

The water management system for the Project aims to protect the identified downstream EVs and comprises the following key objectives:

- separate diverted water from mine affected water to ensure that up-catchment water and mine affected water do not mix wherever practicable;
- capture of mine affected runoff (e.g. mine industrial area, haul road/ROM pad runoff), storage and priority reuse as mine water supply;
- divert up-catchment water runoff from upstream catchments around the active mining area;
- limit external catchment runoff draining into pits;

- manage sediment from disturbed catchment areas (e.g. out-of-pit waste rock emplacements, cleared/pre-strip areas) by using erosion and sediment control (ESC) measures prior to release offsite;
- reuse onsite water (e.g. mine affected water) where possible to support mine operational water demands (and therefore limit mine affected water inventories under normal operating conditions); and
- manage any mine affected water releases to the receiving waters to meet environmental release conditions (not currently proposed).

The Project water management system will include mine water drainage, mine water storages, sediment dams, pit water storages and flood protection works (i.e. levees). Further details of the mine water management system are provided in Section 6.4.

Table 5.1 – Types of water managed within the Project

Water type	Definition
Mine affected water	In accordance with the DES *Guideline Model Mining Conditions* (2017), mine affected water means the following types of water: i) pit water, tailings dam water, processing plant water ii) water contaminated by a mining activity which would have been an environmentally relevant activity under Schedule 2 of the *Environmental Protection Regulation 2008* if it had not formed part of the mining activity iii) rainfall runoff which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated, excluding rainfall runoff discharging through release points associated with erosion and sediment control structures that have been installed in accordance with the standards and requirements of an Erosion and Sediment Control Plan to manage such runoff, provided that this water has not been mixed with pit water, tailings dam water, processing plant water or workshop water iv) groundwater which has been in contact with any areas disturbed by mining activities which have not yet been rehabilitated v) groundwater from the mine dewatering activities vi) a mix of mine affected water (under any of paragraphs i to v) and other water
Surface water	Surface water runoff from areas that are disturbed by mining operations (including out-of-pit waste rock emplacements). This runoff does not come into contact with coal or other carbonaceous material and may contain high sediment loads but does not contain elevated levels of other water quality parameters (e.g. electrical conductivity, pH, metals, metalloids, non-metals). This runoff must be managed to ensure adequate sediment removal prior to release to receiving waters.
Diverted water	Surface runoff from areas unaffected by mining operations. Diverted catchment water includes runoff from undisturbed areas and fully rehabilitated areas.
Raw water	Untreated water that has not been contaminated by mining activities.
Potable water	Treated water suitable for human consumption.
External water	Water supplied from a source that is external to Project area to make up water shortfalls for onsite water demands when site water sources cannot meet demand.

5.4 DIVERTED RUNOFF WATER MANAGEMENT

5.4.1 Flood levees

A number of flood levees are proposed for the Project, as shown on Figure 1.3 to Figure 1.10 including:

- Vulcan North levee on the southern edge of the Vulcan North pit to be constructed in Stage 1;
- Vulcan Main levee 2 on the western edge of the Vulcan Main pit to be constructed in Stage 2 and Vulcan Main levee 1 on the southern edge of the Vulcan Main pit to be constructed in Stage 3; and
- Vulcan South levee around the full extent of the Vulcan South pit to be constructed in Stage 3.

The flood levees will be regulated structures under the EP Act and will therefore be required to have a crest above the 0.1% AEP event. An assessment of the levees against the requirements of the EP Act is given in Section 8.5.4.

5.4.2 Diverted water drains, bunds and dams

The water management system has been designed to divert undisturbed catchments around mining operations wherever practicable.

Three diverted water drains are proposed as part of the Project (Figure 1.3 to Figure 1.10):

- Drainage diversion 2 will be constructed in Stage 1 and will divert a catchment of approximately 105 ha away from the Vulcan North pit and dam DD2. This drainage diversion will collect an undisturbed catchment to the west of the Vulcan North pit and associated haul road. This drainage diversion will divert a portion of Drainage line 6 and discharge under a haul road to Drainage line 7 (which is a tributary of East Creek).
- Drainage diversion 3 will be constructed in Stage 3 and will divert a portion of Drainage line 8 around the Vulcan South pit. This drainage diversion will collect an undisturbed catchment of approximately 570 ha and discharge to Hughes Creek.
- A minor drainage diversion diverts water southward around the Vulcan Main levee 1, to discharge into Hughes Creek.

A number of diverted water bunds are proposed in the vicinity of the three open cut pits, as shown on Figure 1.3 to Figure 1.10. These bunds will collect runoff from minor catchments (i.e. smaller than 15 ha) where a drain is not deemed necessary and divert these catchments around mining operations.

Dam DD2 will be constructed in Stage 1 to collect water from an undisturbed catchment (catchment area of approx. 46.5 ha) to the west of the Vulcan North pit, between the pit and the haul road. In addition, DD2 may potentially provide some level of flood protection for the Vulcan North pit.

Dam HWD2 will be constructed during highwall operations north of the highwall central haul road (Figure 1.9) to collect an undisturbed catchment north of the highwall central bench. The dam will collect an undisturbed catchment of approximately 34 ha.

Additional temporary drainage management measures including bunds, drains and re-contouring adjacent pit progression may be constructed as required to prevent runoff and flood waters from flowing into the open pits. These drainage management measures will be mined through as the pits progress. It is expected that temporary drainage measures will be designed to convey at least a 5% AEP (1 in 20-year ARI) flow event.

5.5 SURFACE WATER MANAGEMENT

Sediment water containment (runoff from spoil and incomplete rehabilitated areas) will be managed in accordance with the site Erosion and Sediment Control Plan (ESCP). The ESCP will adopt the three cornerstones of ESC:

- Drainage control – prevention or reduction of soil erosion caused by concentrated flows and appropriate management and separation of the movement of diverted and surface water through the area of concern.
- Erosion control – prevention or minimisation of soil erosion (from dispersive, nondispersive or competent material) caused by rain drop impact and exacerbated overland flow on disturbed surfaces.
- Sediment control – trapping or retention of sediment either moving along the land surface, contained within runoff (i.e. from up-slope erosion) or from windborne particles.

The Project will require a combination of the three control measures to effectively manage sediment and erosion at the site.

5.5.1 Sediment dam locations and sizing

Catchment runoff from both active and newly rehabilitated overburden dumps at the Project will be managed in accordance with an ESCP. The sediment dams have been sized in accordance with the IECA method (IECA, 2008), and have been based on the following design standards and methodology:

- 'Type D' sediment basins with a depth of 3m;
- total sediment basin volume = settling zone + sediment storage volume. The sediment storage volume is the portion of the basin storage volume that progressively fills with sediment until the basin is de-silted. The settling zone is the minimum required free storage capacity that must be restored within 5 days after a runoff event;
- sediment basin settling volume based on 85th percentile 5-day duration rainfall with an adopted volumetric event runoff coefficient for disturbed catchments of 0.45 (Group C soils – loamy clay); and
- solids storage volume = 50% of settling zone volume.

The adopted design standard does not provide 100% containment for runoff from disturbed areas. Hence, it is possible that overflows will occur from sediment dams several times during a wet season if rainfall exceeds the design standard.

A summary of the conceptual sediment dam capacities and surface areas (based on a depth of 3 m) is provided in Table 5.2.

Table 5.2 - Proposed sediment dams

Storage name	Indicative commissioning year	Max. catchment area (ha)	Total volume required (ML)	Dam surface area (ha)	5-day dewatering rate (ML/d)	Overflows to
East Creek Out of pit spoil						
SD9	2023	19.0	4.2	0.19	0.56	Drainage line 7
SD10	2023	15.8	3.5	0.15	0.46	
SD15	2023	18.1	4.0	0.18	0.53	Drainage line 5
East Creek In pit spoil						
SD11	2023	32.6	7.1	0.32	0.95	Drainage line 6
SD12	2023	23.3	5.1	0.23	0.68	Drainage line 7
SD13	2023	10.5	2.3	0.10	0.31	Drainage line 6
SD14	2023	15.9	3.5	0.16	0.47	
Hughes Creek In pit spoil						
SD17	2023	9.4	2.1	0.09	0.27	Hughes Creek
SD18	2023	43.7	9.6	0.43	1.28	
SD19	2025	105.0	23.0	1.02	3.07	Hughes Creek
SD20	2028	10.3	2.3	0.10	0.30	Hughes Creek
SD21	2028	12.7	2.8	0.12	0.37	
SD22	2028	22.6	5.0	0.22	0.66	
SD23	2028	34.5	7.6	0.34	1.01	Hughes Creek
SD24	2028	5.8	1.3	0.06	0.17	
SD25	2028	8.5	1.9	0.08	0.25	
SD26	2028	39.5	8.7	0.38	1.15	
SD29	2028	15.5	3.4	0.15	0.45	
SD30	2028	1.1	0.2	0.01	0.03	
Hughes Creek Out of pit spoil						
SD16	2023	148.8	32.6	1.45	4.35	Hughes Creek
SD27*	2028	15.5	3.4	0.15	0.45	
SD28	2028	32.4	7.1	0.32	0.95	Barrett Creek
Highwall dams						
HWD1	2023	10.0	2.2	0.1	0.29	Drainage line 2

For modelling purposes, the sediment dams have been grouped into four discrete nodes based upon the type of sediment they primarily collect and the waterway which they overflow to, as follows:

1. East Creek In pit spoil
2. East Creek Out of pit spoil
3. Hughes Creek In pit spoil

4. Hughes Creek Out of pit spoil

The sediment dams have been grouped into the above nodes in Table 5.2 and Figure 6.1.

Runoff from haul roads and access roads will be managed through the sites ESCP, which will be developed prior to the commencement of construction activities.

Management of runoff from these roads will be a combination of drainage control, erosion control and sediment control measures. The design of the measures will be undertaken during detailed design, but will likely include some of the following measures:

- Catch drains;
- Check dams;
- Grass swales;
- Rock lining/protection;
- Road surface gravelling;
- Sediment traps; and
- Sediment basins.

The sizing of haul/access road sediment basins will be undertaken in accordance with the Best Practice Erosion and Sediment Control Guidelines (IECA, 2008). Any runoff captured within the sediment basins will be released to the downstream environment in accordance with the site ESCP or pumped back into the mine water system.

5.6 MINE AFFECTED WATER MANAGEMENT

5.6.1 Mine affected water dams

Table 5.3 shows the capacities of the proposed mine affected water dams at the Project. The dam sizes have been determined based on the water balance model (see Section 7) to ensure that the open cut pits can be adequately dewatered and limit the spill risk to the receiving waters.

The adopted full storage volumes (FSVs), surface areas, operating volumes (OVs) and max operating volumes (MOVs) were refined using the water balance model and available space from site mapping. MWD8 and MWD9 have been designed to keep the pit dewatered for as long as practical. The CHPP mine water dams (MWD6 & MWD7) have been sized to limit the risk of spills to the receiving waters.

Vitrinite are not currently planning any controlled mine affected water releases to the environment from the mine water dams. Therefore, under normal operating conditions any releases from mine affected water dams to the receiving waters would be uncontrolled releases. As outlined above, the water management system has been optimised to reduce the risk of this occurrence and this risk has been assessed in Section 7.3.7.

Notwithstanding the above, during future operations and depending upon future climate conditions, controlled mine affected water releases may be required to manage mine water inventories stored within the mine water system. If required, these discharges would be performed in accordance with the mine affected water release conditions within a future Project EA.

To limit the risk of uncontrolled discharges from the mine water storages, OVs have been set for these water storages (as shown in Table 5.3) as follows:

- MWD8 and MWD9 have a maximum operating volume (MOV) of 131.6 ML and 25.0 ML respectively. When the water inventory in these dams exceeds its MOV, all transfers to these dams (i.e. pit dewatering and mine water transfers) cease.
- MWD6 and MWD7 have OVs. When the water inventory in these dams exceeds their respective OVs, these storages commence dewatering to MWD9.

Table 5.3 - Proposed mine affected water dams

Storage	FSV (ML)	OV (ML)	MOV (ML)	FSV surface area (ha)	FSV water depth (m)	Adopted dewatering rate (ML/d)
MWD6	73.9	64.3	-	1.97	5	2.15
MWD7	56.1	48.8	-	1.50	5	2.15
MWD8	159.8	-	131.6	2.92	7	-
MWD9	30.0	-	25.0	1.33	3	4.32

5.6.2 Preliminary consequence assessment

A preliminary consequence assessment of the mine affected water dams using the *Manual for assessing consequence categories and hydraulic performance of structures* (DES, 2016) suggests that the consequence category of mine water dams will be low. This is based on the following:

- The expected harm to humans consequence category is low. MWD6, MWD7 and MWD9 are small dams and do not have a significant constructed wall (less than 3 m) that could fail. Although MWD8 has a significant volume it is not located adjacent to or upstream of any planned buildings, other places of occupation or public infrastructure (e.g., roads or rail) that would lie within the failure impact zone. MWD8 and MWD9 would fail away from populated areas towards Hughes Creek. The CHPP Dams (MWD6 and MWD7), although located adjacent the CHPP area, are located at a lower elevation than the workshop area and would not impact the CHPP area in the event of a dam break. The downstream drainage structures (Figure 4.10) under Saraji Road and the Norwich Park branch railway are designed to service a significant undisturbed catchment associated with Hughes Creek (i.e. greater than 10,000 ha) and would therefore be suited to withstand any failure from the Project mine water dams. The downstream receiving waters are unlikely to be used for water supply.
- The expected harm to general environment consequence category is low. The downstream receiving waters are heavily modified and have been diverted through the Peak Downs and Saraji operations. Controlled releases of mine water are not proposed. Further, groundwater assessments predict there will negligible groundwater to manage in the mine water management system and dump runoff quality is expected to be of a suitable quality to release to the receiving waters (following sediment removal). Hence any potential releases of contaminants to the receiving waters from mine water dams are unlikely to have an adverse effect.
- The expected general economic loss or property damage consequence category is low. This is for similar reasons given for the expected harm to humans consequence category and remedial costs would likely be less than $1 million.

5.6.3 Pit dewatering rates

The timeframes required to dewater the pits will be governed by the available pumping capacity. For this assessment, the pit dewatering rates within the model have been nominated as follows:

- Vulcan North pit dewaters to MWD8 at 100 L/s during Stage 1;
- Vulcan Main pit dewaters to MWD8 at 100 L/s during Stage 1, to MWD8 and MWD9 at 100 L/s during Stage 2 - 3; and

- Vulcan South pit dewaters to MWD8 and MWD9 at 100 L/s during Stage 3.

Alternative pumping capacities based upon the required duration to dewater the pits following a 1% AEP 24 hour storm event (assuming a volumetric rainfall/runoff coefficient of 1.0) are outlined in Table 5.4.

Table 5.4: 1% AEP 24 hour pit dewatering rates

Stage	Dewatering duration (days)	Pit dewatering rate (L/s)		
		Vulcan North	Vulcan Main	Vulcan South
1	5	81	150	-
	10	41	75	-
	30	14	25	-
2	5	-	306	-
	10	-	153	-
	30	-	51	-
3	5	-	140	97
	10	-	70	48
	30	-	23	16

The alternative dewatering pump rates shown above may be adopted by site depending upon available pumping infrastructure.

5.7 RELEASE OF WATERS TO THE RECEIVING WATERS

There are four key mechanisms through which water from the Project can enter the receiving waters:

- dewatering overflows from sediment dams;
- overflows from mine affected water dams and the open cut pits;
- runoff from diverted water catchments; and
- runoff from rehabilitated catchments.

Sediment dam/mine affected overflows are a point source. Model predictions of volumes from sediment dam and mine affected dam overflows are provided in Section 7.3.7. Runoff from rehabilitated catchments is likely to be both a point and diffuse source of water to the receiving environment. When a sediment dam catchment is completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned. Surface runoff and seepage from the rehabilitated catchment will be allowed to shed directly to the receiving environment.

5.8 SEWAGE AND EFFLUENT DISPOSAL

Sewage will be trucked offsite by registered waste transport contractors.

5.9 POST-CLOSURE CONDITIONS WATER MANAGEMENT

Figure 1.11, Figure 1.12 and Figure 1.13 show the conceptual final landform drainage plan for the Vulcan North, Vulcan Main and Vulcan South mining areas respectively under post-closure conditions. The final landform plan has been developed with an aim to use water infrastructure constructed during operations. The post-closure layout shown are conceptual only and may be updated should the mine plan and final landform plans change over the mine life.

The key features of the final landform include the following:

- No final voids are proposed as part of the final landform. The open cut pits will be backfilled with overburden material;
- Final landform batter slopes will be 1(V):6(H);
- Contour banks will be constructed on batters to limit topsoil erosion until vegetation has been suitably established;
- Drainage structures will be constructed to direct runoff from disturbed areas to sediment dams;
- The plateaus include proposed drains and drop structures to drain the top of the landform to natural ground level;
- Mine water dams will be decommissioned following rehabilitation of infrastructure areas;
- Drainage line 6 and Drainage line 8 will be reinstated through the Vulcan North and Vulcan South final landforms respectively; and
- The Hughes Creek floodplain will be reinstated through the Vulcan Main and Vulcan South landforms.

When a sediment dam catchment is completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with EA release conditions, the sediment dam and associated drainage infrastructure will be decommissioned. Surface runoff and seepage from the rehabilitated catchment will be allowed to shed directly to the receiving waters.

When Drainage line 6 is rehabilitated, DD2 will be decommissioned. DD2 will remain until this time to allow in-stream vegetation to establish before receiving upstream catchment flows.

6 Water balance model configuration

6.1 OVERVIEW

A computer-based operational simulation model (OPSIM) was used to assess the dynamics of the mine water balance under conditions of varying rainfall and catchment conditions throughout the development of the Project. The OPSIM model dynamically simulates the operation of the water management system and keeps complete account of all site water volumes and representative water quality on a daily time step.

The model has been configured to simulate the operations of all major components of the water management system. The simulated inflows and outflows included in the model are given in Table 6.1.

Table 6.1 - Simulated inflows and outflows to the water management system

Inflows	Outflows
Direct rainfall on water surface of storages	Evaporation from water surface of storages
Catchment runoff	Haul road dust suppression demand
Moisture stored within the ROM coal	Potable water demand
Groundwater inflows to the open cut pit	Moisture stored within product coal and rejects
External water pipeline	TLO demand
Trucked potable water	Dam overflows

6.2 SIMULATION METHODOLOGY

The Project water management system will change over the eight year mine life, including changes in catchment areas, production profile and site water demands. To represent the evolution of the mine layout over time, the Project was modelled in three discrete stages. Three representative years of the mine plan have been selected to reflect the average conditions over the mine stage.

The modelled mining stages are summarised in Table 6.2.

Table 6.2 - Representative mine stages adopted for assessment and modelling purposes

Mine stage	Representative year	Applied range of mine life	Stage duration
Stage 1	2024	1/1/2023 - 1/1/2025	2 years
Stage 2	2027	1/1/2025 - 1/1/2028	3 years
Stage 3	2031	1/1/2028 - 1/1/2031	3 years

Over the mine stages, the three mine pits progress their active status within the water balance model as follows:

- Inactive: Mining in the pit has either not yet commenced in the mine plan or has been completed and backfilled. For modelling purposes, the pit does not receive rainfall runoff, is not dewatered and does not spill.
- Active: The pit is actively being mined. For modelling purposes, the pit has a storage curve which varies per Stage, receives runoff and is actively dewatered.

The mining status for each pit during each mine stage is outlined in Table 6.3.

Table 6.3 - Pit status progression over mine stages

Stage	Mine pit		
	Vulcan North	Vulcan Main	Vulcan South
1	Active	Active	Inactive
2	Inactive	Active	Inactive
3	Inactive	Active	Active

6.3 CATCHMENT YIELD PARAMETERS

The OPSIM model uses the Australian Water Balance Model (AWBM) (Boughton, 2003) to estimate runoff from rainfall. The AWBM is a saturated overland flow model which allows for variable source areas of surface runoff. The AWBM uses a group of connected conceptual storages (three surface water storages and one ground water storage) to represent a catchment. Water in the conceptual storages is replenished by rainfall and is reduced by evaporation (surface stores only). Simulated surface runoff occurs when the conceptual storages fill and overflow.

The model uses daily rainfalls and estimates of catchment evapotranspiration to calculate values of runoff using a daily water balance of soil moisture. The model has a baseflow component which simulates the recharge and discharge of a shallow subsurface store. Runoff depth calculated by the AWBM is converted into a runoff volume by multiplying the contributing catchment area.

The model parameters define the storage depths (C1, C2 and C3), the proportion of the catchment draining to each of the storages (A1, A2 and A3), and the rate of flux between them (K_{base}, K_{surf} and BFI). Catchments across the site have been characterised into the following land use types:

- Natural, representing areas in their undisturbed state;
- Open cut mining pit;
- In pit spoil, representing uncompacted dumped overburden material within the pit shell;
- Out of pit spoil, representing dumped overburden material outside of the pit shell; and
- Disturbed/industrial, representing roads, hardstands and stripped areas.

The adopted AWBM parameters are shown in Table 6.4. These parameters have been based on parameters typical for coal mines in this part of the Bowen Basin. The landuse configurations for the mining areas over the three modelled stages are shown in Figure 1.3 to Figure 1.8 and are outlined in Table 6.6, Table 6.7, and Table 6.8.

Table 6.4 – Adopted AWBM parameters

Parameter	Natural	Disturbed/Industrial	Pit	In pit spoil/Out of pit spoil
A1	0.134	0.1	0.134	0.07
A2	0.433	0.9	0.433	0.10
A3	0.433	-	0.433	0.83
C1	5.7	4	2.6	5
C2	57.8	16	26.7	10
C3	115.7	-	53.3	200
C_{avg}	75.9	14.8	35.0	167.4
BFI	0	0	0	0.5
k_{base}	0	0	0	0.9
k_{surf}	0.1	0	0	0.1
C_{v*}	18.7%	37.6%	28.3%	12.0%

* Long term volumetric runoff coefficient.

6.4 CONCEPTUAL WATER MANAGEMENT SYSTEM CONFIGURATION AND SCHEMATIC

Figure 1.3 – Figure 1.8 show the conceptual Project water management system layout as well as catchment areas and land uses for the three mine stages. Figure 6.1 shows the schematised plan of the proposed water management system configuration. The modelled water management system configuration is outlined in Table 6.5.

Table 5.2 and Table 5.3 shows the sediment dam and mine water dam sizes respectively that were adopted for the water balance assessment.

Table 6.5 – Water management system operating rules for the Project

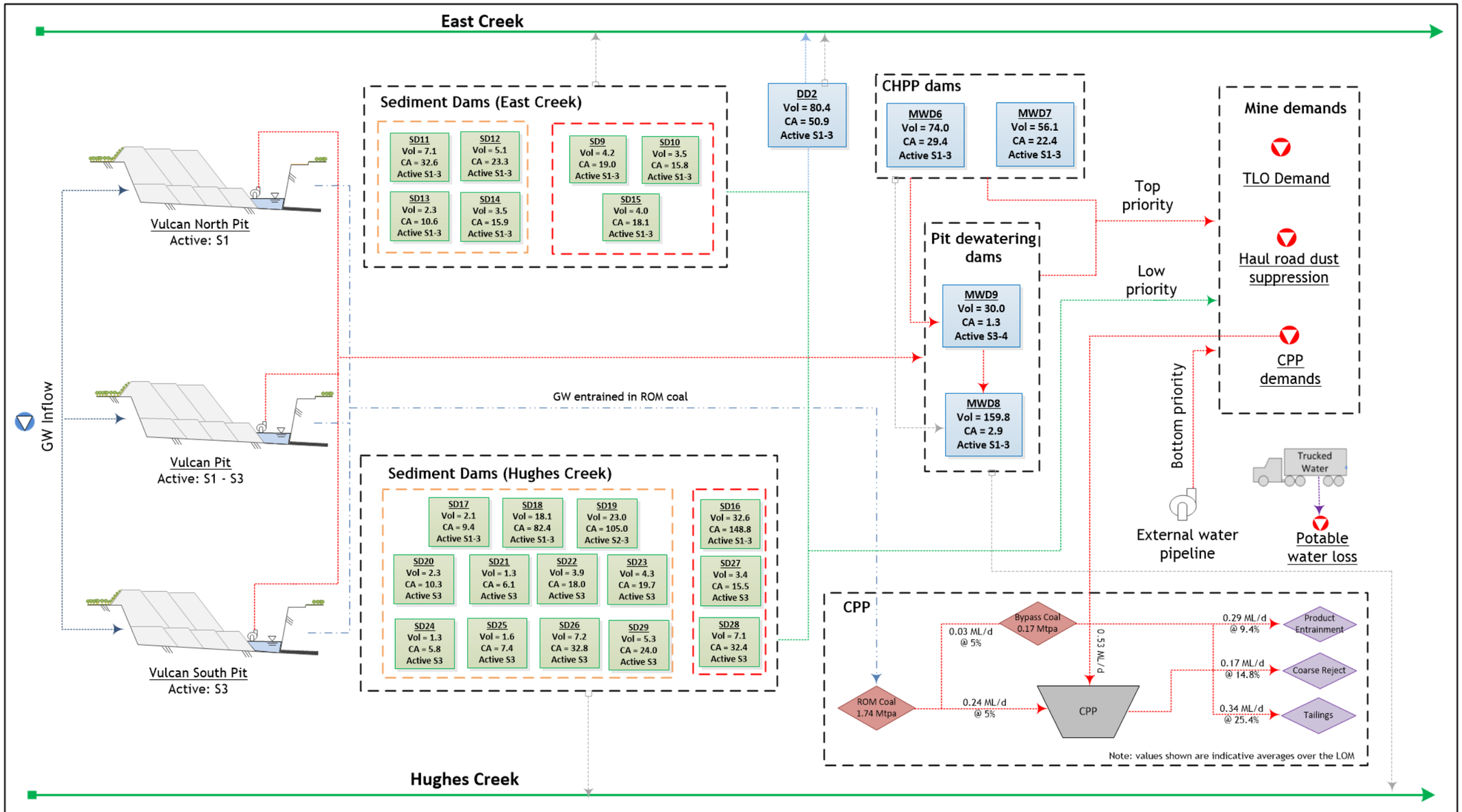
Item	Node Name	Operating Rules
1	***External water supply***	
1.1	External water pipeline	• Mine affected water can be imported to supplement mine water demands • Supplies mine demands (3rd priority)
1.2	Trucked water	• Supplies the potable water demand
2	***Supply to demands***	
2.1	Haul road dust suppression/TLO Demand	• Supplied from the following sources: ○ 1st priority: Mine affected water dams; ○ 2nd priority: Sediment/diverted water dams; and ○ 3rd priority: External water pipeline. • 100% loss assumed • Haul road dust suppression values vary depending on haul road length, as outlined in Section 6.5.1

		• TLO demand assumed as constant 0.2 ML/d as outlined in Section 6.5.3

2.2	CHPP demand	• Supplied by the following sources:
		  ○ 1st priority: Mine affected dams;
		  ○ 2nd priority: Sediment/clean water dams; and
		  ○ 3rd priority: External water pipeline.
		• Varies depending upon production schedule, as outlined in Section 6.5.2

2.3	Potable water demand	• Sourced from trucked water delivered to site • 100% loss assumed • Assumed constant rate of 50 ML/yr (as outlined in Section 6.5.4)
3	***Pit water***	
3.1	All pits	• Pit status progression outlined in Table 6.3 • Active pits dewater to the pit dewatering dams (MWD8 and MWD9) at 100 L/s (8.64 ML/d) • Receive groundwater inflows as outlined in Section 6.6
4	***Operation of mine affected water dams***	
4.1	MWD6 & MWD7 (CHPP dams)	• Mine affected water storages that capture runoff from the CHPP/ROM pad • Supply water to the mine demands as outlined in Item 2 above • In Stages 2 and 3 when above their OV, transfer water to MWD9 at 4.32 ML/d • Overflows to MWD8
4.2	MWD8	• Turkeys nest dams, receiving no external catchment • Main pit dewatering dam, pits dewater to this storage at 100 L/s (8.64 ML/d) • Supplies water to the mine demands as outlined in Item 2 above
4.3	MWD9	• Turkeys nest dams, receiving no external catchment • Secondary pit dewatering dam, dewatering the pits at 100 L/s (8.64 ML/d) and transferring the water to MWD8 when MWD8 is below its MOV • When MWD8 is above its MOV, MWD9 stores water • Receives transfers from the CHPP dams when they are above their OV
5	***Operation of sediment dams***	
5.1	Sediment dams (SD9 – SD29)	• Up to 20 sediment dams active over the mine life • Assumed to be dewatered to 33% of capacity every 5 days following sediment removal (not modelled) • Supplies water to the mine demands as outlined in Item 2 above

		• Overflows to the receiving waters (i.e. to East Creek or Hughes Creek)
6	***Clean water storages***	
6.1	DD2	• Diverted water dam that receives inflows from the rural catchment to the southwest of Vulcan North pit • Transfers water from empty to the diversion drain to the southwest of Vulcan North pit at 100 L/s (8.64 ML/d), which flows to East Creek, from empty



Vulcan South	
Figure	Proposed integrated water management system schematic
Job	1571-20
Date	18/03/2022

Legend

- Surface water
- Mine affected water
- Raw water
- Groundwater
- External/diverted water
- Pumped flow
- Coal moisture
- Spillway/overflow
- Receiving waterway
- In pit runoff
- Out of pit runoff

Notes

Spill Flow Directions:
Good engineering practice is to include a stabilised spillway as a contingency for dam safety. This arrow does not indicate that these discharges (spills/overflows) are a part of the water management system or that spills will occur. The arrow is to show the direction of water flow (by gravity) should the dam water level exceed the dam spillway level.

Volumes (Vol.) recorded in ML, catchment areas (CA) in hectares, coal amounts in dry tonnage.

wrm water + environment

Figure 6.1 - Water management system schematic for the Project

Table 6.6 - Storage catchment areas (Stage 1)

Storage	Landuse area (ha)					
	Natural	Disturbed	In pit spoil	Out of pit spoil	Pit	Total Area
Sediment dams						
	0.0	1.2	0.0	17.8	0.0	19.0
SD10	0.0	0.8	0.0	15.0	0.0	15.8
SD11	0.0	1.4	14.2	16.9	0.0	32.6
SD12	0.0	1.4	15.4	6.4	0.0	23.2
SD13	0.0	0.4	10.1	0.0	0.0	10.5
SD14	0.0	6.0	0.0	0.0	0.0	6.0
SD15	10.4	0.5	7.1	0.0	0.0	18.1
SD16	3.0	2.1	0.0	92.9	0.0	98.0
SD17	0.0	9.4	0.0	0.0	0.0	9.4
SD18	36.9	45.5	0.0	0.0	0.0	82.4
Other dams						
DD2	32.5	18.4	0.0	0.0	0.0	50.9
Mine affected water dams						
MWD6	0.0	29.5	0.0	0.0	0.0	29.5
MWD7	0.0	22.4	0.0	0.0	0.0	22.4
MWD8	0.0	4.8	0.0	0.0	0.0	4.8
Mine pits						
Vulcan North	3.8	2.5	2.6	0.0	6.2	15.1
Vulcan Main	0.0	5.7	0.0	0.0	22.1	27.8

Table 6.7 - Storage catchment areas (Stage 2)

Storage	Landuse area (ha)					
	Natural	Disturbed	In pit spoil	Out of pit spoil	Pit	Total Area
Sediment dams						
SD9	0.0	1.2	0.0	17.8	0.0	19.0
SD10	0.0	0.8	0.0	15.0	0.0	15.8
SD11	0.0	1.4	14.2	16.9	0.0	32.6
SD12	0.0	1.4	15.4	6.4	0.0	23.2
SD13	0.0	0.4	10.1	0.0	0.0	10.5
SD14	0.0	2.2	13.7	0.0	0.0	15.9
SD15	10.4	0.5	7.1	0.0	0.0	18.1
SD16	2.3	4.5	51.2	92.9	0.0	150.9
SD17	0.0	2.0	6.7	0.0	0.0	8.7
SD18	0.0	1.2	14.4	0.0	0.0	15.6
SD19	28.5	34.5	11.2	0.0	0.0	74.1
SD20	4.1	6.2	0.0	0.0	0.0	10.3
Other dams						
DD2	32.5	18.4	0.0	0.0	0.0	50.9
Mine affected water dams						
MWD6	0.0	29.5	0.0	0.0	0.0	29.5
MWD7	0.0	22.4	0.0	0.0	0.0	22.4
MWD8	0.0	4.8	0.0	0.0	0.0	4.8
Mine pits						
Vulcan Main	0.0	40.9	4.7	0.0	11.4	57.0

Table 6.8 - Storage catchment areas (Stage 3)

Storage	Landuse area (ha)					
	Natural	Disturbed	In pit spoil	Out of pit spoil	Pit	Total Area
Sediment dams						
SD9	0.0	1.2	0.0	17.8	0.0	19.0
SD10	0.0	0.8	0.0	15.0	0.0	15.8
SD11	0.0	1.4	14.2	16.9	0.0	32.6
SD12	0.0	1.4	15.4	6.4	0.0	23.2
SD13	0.0	0.4	10.1	0.0	0.0	10.5
SD14	0.0	2.2	13.7	0.0	0.0	15.9
SD15	10.4	0.5	7.1	0.0	0.0	18.1
SD16	2.3	4.5	51.2	92.8	0.0	150.8
SD17	0.0	4.0	6.7	0.0	0.0	10.7
SD18	0.0	4.0	40.9	0.0	0.0	44.9
SD19	0.0	12.6	92.4	0.0	0.0	105.0
SD20	0.0	0.6	9.6	0.0	0.0	10.3
SD21	0.0	2.2	3.9	0.0	0.0	6.1
SD22	1.8	16.2	0.0	0.0	0.0	18.0
SD23	3.9	3.1	12.7	0.0	0.0	19.7
SD24	0.0	1.1	4.7	0.0	0.0	5.8
SD25	0.0	0.3	7.0	0.0	0.0	7.4
SD26	0.0	3.0	16.4	13.4	0.0	32.8
SD27	0.0	3.1	0.0	12.5	0.0	15.5
SD28	0.0	13.6	0.0	18.8	0.0	32.3
SD29	0.0	12.0	0.0	0.0	0.0	12.0
SD30	0.0	1.1	0.0	0.0	0.0	1.1
Other dams						
DD2	32.5	18.4	0.0	0.0	0.0	50.9
Mine affected water dams						
MWD6	0.0	29.5	0.0	0.0	0.0	29.5
MWD7	0.0	22.4	0.0	0.0	0.0	22.4
MWD8	0.0	4.8	0.0	0.0	0.0	4.8
MWD9	0.0	5.0	0.0	0.0	0.0	5.0
Mine pits						
Vulcan Main	0.0	18.4	2.6	0.0	5.1	26.1
Vulcan South	0.0	12.2	2.1	0.0	3.7	17.9

6.5 SITE WATER DEMANDS

6.5.1 Haul road dust suppression

Water for haul road dust suppression is primarily sourced from the mine dams (with the priorities outlined in Table 6.5). Haul road designs were provided by Vitrinite.

Haul road dust suppression demands are estimated using supplied haul road design plans and historical climate data as follows:

- Daily pan evaporation and rainfall rates are sourced from the SILO database;
- For a dry day (zero rainfall), the haul road watering rate is equal to the daily evaporation rate;
- For a rainy day when rainfall is less than the daily evaporation rate, the watering rate is reduced and is only required to make up the remaining depth to the daily evaporation rate; and
- For a rainy day when rainfall exceeds the daily evaporation rate, no haul road watering is required.

Assuming a haul road width of 30 m, an in-pit haul road length of 3 km for Vulcan North/South pits and 5 km for Vulcan Main pit, the estimated demand rates averaged over each month are summarised in Table 6.9.

Table 6.9 - Forecast Haul Road Dust Suppression usage

Month	Haul road demand (kL/d)		
	Stage 1	Stage 2	Stage 3
January	4073	1412	2310
February	3583	1242	2033
March	3752	1300	2128
April	3234	1121	1835
May	2463	854	1397
June	2006	695	1138
July	2216	768	1257
August	2867	994	1626
September	3934	1364	2232
October	4569	1584	2592
November	4652	1613	2639
December	4486	1555	2545
Annual	3486	1208	1977

6.5.2 CHPP demand

The projected annual coal production schedule for the Project (provided by Vitrinite), is summarised in Table 6.10. The amount of washed coal for each stage was derived from the average value over the stage period. In addition, Vitrinite indicated that all coking coal would be processed and an initial estimate of 20% of thermal coal would bypass the CHPP. The assumed volumes of washed coal and bypass coal per stage are also provided in Table 6.10.

Table 6.10: Forecast annual production data

Stage	Year	Coking Coal	Thermal Coal	Bypass Coal	Washed coal	Bypass coal
		Dry coal tonnes/annum				
	2023*	-	-	-	1,738,694	188,956
1	**2024**	956,733	944,780	188,956		
	2025	802,743	1,006,624	201,325		
	2026	954,886	886,235	177,247	1,630,963	162,177
2	**2027**	1,189,133	539,799	107,960		
	2028	1,080,609	729,842	145,968		
	2029	926,571	1,025,096	205,019	1,576,083	170,768
3	**2030**	671,848	806,589	161,318		

* Note that coking and thermal coal breakdowns of ROM coal were not provided for 2023.

Key parameters regarding the CHPP process (provided by DRA Global and also derived from coal physicals) are outlined in Table 6.11.

Table 6.11: Key CHPP parameters

Parameter	Value
ROM coal moisture	5%
Product coal moisture	9.4%
Coarse reject moisture	14.8%
Tailings moisture	25.4%
Plant efficiency (ROM:Product)	56.5%
Feed rejects (ROM:Coarse reject)	21.5%
Plant tailings (ROM:Tailings)	22.0%

The key CHPP parameters (Table 6.11) and stage washed coal values (Table 6.10) were input to the model to produce water makeup requirements over the mine life. The makeup requirements are supplied by the dams as outlined in Table 6.5.

The average CHPP water makeup requirement over each stage are provided in Table 6.12.

Table 6.12: Estimated CHPP makeup requirements

Stage	CHPP makeup requirement (ML/d)
1	0.56
2	0.53
3	0.51

6.5.3 TLO demand

Water for the TLO demand is sourced from the mine dams (with the priorities outlined in Table 6.5). A nominal TLO demand of 0.2 ML/d (200 kL/d) was assumed.

6.5.4 Potable water demand

Potable water demand is supplied by trucked water delivered onsite. Potable water demand was assumed at 50 ML/annum (137 kL/d).

6.6 WATER SOURCES

6.6.1 Groundwater inflows to the open cut pits

Groundwater inflow estimates to the open cut pits were provided by Hydrogeologist.com.au (2020) and have been provided as daily rates for six-monthly periods over the mine life. A summary of the predicted groundwater inflows (grouped by pit area) are provided in Table 6.13.

Table 6.13: Estimated groundwater inflows

Period	Groundwater inflow (m^3/day)		
	Vulcan North	Vulcan Main	Vulcan South
1/01/2023	0	0	0
1/07/2023	0.88	0	0
1/01/2024	1.86	0.21	0
1/07/2024	1.45	2.6	0
1/01/2025	4.71	6.41	0
1/07/2025	3.09	35.93	0
1/01/2026	1.15	37.14	0
1/07/2026	0	33.72	0
1/01/2027	0	35.09	0
1/07/2027	0	42.42	0
1/01/2028	0	32.2	0
1/07/2028	0	29	0
1/01/2029	0	21.9	0.15
1/07/2029	0	9.05	0.77
1/01/2030	0	2.62	2.34
1/07/2030	0	10.72	2.05
1/01/2031	0	6.28	0.89

The low magnitude of the predicted groundwater inflows means that the inflows will likely have a negligible impact on the Project water balance. Notwithstanding, groundwater inflows for each stage have been averaged and were input into the model as per Table 6.14.

Table 6.14: Modelled groundwater inflows

	Groundwater inflow (kL/d)		
	Vulcan North	Vulcan Main	Vulcan South
Stage 1	1.05	0.7	0
Stage 2	0	31.79	0
Stage 3	0	13.97	0.91

6.6.2 External water

A key objective of the mine site water management system is to reuse surface water runoff captured within the mine affected water system. Recycling mine water will reduce the volume of water from external sources that is required to satisfy site demands. However, the volume of water captured onsite is highly variable and dependent upon climatic conditions. Hence, there is a requirement to source water from reliable external sources.

For the purposes of the assessment, it has been assumed that Vitrinite will source external mine water from neighbouring operations to provide water as required via a pipeline for the life of the Project. The pipeline will transfer mine affected water to be stored in MWD8 when mine affected water inventories are low.

6.7 WATERCOURSE FLOW MODELLING

As outlined in Section 4.4 and 4.5, Hughes Creek and East Creek streamflow and water quality data was not available for this assessment.

Flows in the surrounding natural watercourses have therefore been simulated using the calibrated AWBM parameter set previously derived for Phillips Creek (WRM, 2012) (as shown in Table 6.15). Phillips Creek is a tributary of the Isaac River and is located approximately 12 km south of the Project area. Phillips Creek drains primarily undisturbed land to the west of the Norwich Park Branch Railway through Saraji Mine to the Isaac River. Phillips Creek drains into the Isaac River approximately 4 km downstream of Hughes Creek. The undisturbed catchment which drains to Phillips Creek is similar in nature to the undisturbed catchment to the west of the Project which drains to East and Hughes Creek.

The catchment area of East Creek directly downstream of the Project (i.e. approximately where Drainage Line 7 meets East Creek) is approximately 1,550 ha. The catchment area of Hughes Creek directly downstream of the Project (i.e. approximately where Hughes Creek meets Barrett Creek) is 16,600 ha. These catchment areas have been adopted for assessing the potential mixing within the downstream receiving waters.

Table 6.15 - Phillips Creek AWBM parameters

Parameter	Phillips Creek Value
A1	0.013
A2	0.444
A3	0.543
BFI	0.21
C1	15.0
C2	100.0
C3	651.0
C_{av}	398.1
Kbase	0.914
Ksurf	0.502
Average annual runoff co-efficient (C_v)	4.5%

6.8 WATER QUALITY MODELLING

RGS Environmental (2022) have undertaken an assessment of the overburden and potential coal reject materials at Vulcan South. RGS (2022) presented initial results from the Jupiter Pit area. A series of geochemical tests were completed on samples from the Jupiter pit to assess the risk of potential oxidation of sulphides, acid and metalliferous drainage, potential presence and potential leaching of soluble metals/metalloids and other salinity/erosion issues. RGS (2022) made the following findings regarding the geochemical characterisation of the potential spoil:

- all samples tested had a high factor of safety and negligible risk of generating acid mine drainage;
- assay of the multi-element concentration present in selected representative samples indicates that there are no elements (metals/metalloids) enriched in the sample materials compared to median crustal abundance in unmineralised soils;
- the initial static and kinetic test results indicate that surface runoff and seepage from the sample materials are likely to be pH neutral with moderate excess alkalinity, and low levels of salinity;
- the initial geochemistry results are consistent with the larger data set of results obtained from geochemical characterisation of 139 samples from 21 drill holes across the broader Jupiter and Vulcan areas in the VCM and Vulcan South; and
- the results represent an 'assumed worst case' scenario as the samples are pulverised (to minus 75 micrometres) prior to testing. Therefore, samples have a very high surface area compared to materials in the field. This process provides a greater potential for dissolution and reaction and represents an assumed initial 'worst case' scenario for geochemical testing of these materials.

In consideration of the RGS (2022) findings from the preliminary geochemical characterisation, salinity is considered the key contaminant for assessment purposes. Assessment of other contaminants has not been undertaken as part of this surface water assessment. If subsequent monitoring data indicates that there are other contaminants of concern, the assessment can be updated to include additional water quality parameters.

6.8.1 Adopted salinity parameters

The water balance model is configured to use salinity as an indicator of water quality using electrical conductivity (EC) values runoff for each landuse type and other sources of water.

The proposed EC values are shown in Table 6.16. EC values have been sourced from previous water balance models for mines in similar areas of the Bowen Basin.

Table 6.16 - Adopted salinity concentrations

Water source/land use	EC (µS/cm)	Comment
Natural/ undisturbed	300	Value adopted for Olive Downs SWA and Lake Vermont Northern Extension SWA
Disturbed	500	Runoff value typical for cleared/stripped areas
Mining pit	4,500	Value adopted for Lake Vermont Northern Extension SWA
In pit spoil/out of pit spoil	350	Value adopted for Olive Downs SWA
External water (pipelines from BMA Peak Downs)	10,000	Salinity of mine water unknown, conservatively high value adopted
Industrial area	900	Salinity of ROM coal unknown, conservatively high value adopted
Groundwater	9,520	Average groundwater salinity reading from historical groundwater monitoring undertaken at site (Hydrogeologist.com.au, 2020)

7 Water management system assessment

7.1 OVERVIEW

The Project OPSIM model was used to assess the performance of the water management system, using the following key performance indicators:

- overall water balance – the average inflows and outflows of the water management system based on all model realisations (Section 7.3.1);
- mine water inventory – the risk of accumulation (or reduction) of the overall mine water inventory (Section 7.3.2);
- in-pit storage – the risk of accumulation of water in the mining pits, and the associated water volumes (Section 7.3.3, 7.3.4 and 7.3.5);
- external water demand – the volumes of imported external water (via the external pipeline) required to supplement site mine water supplies (Section 7.3.6);
- uncontrolled spillway discharges – the risk and associated volumes of uncontrolled discharge from the mine affected water storages and sediment dams to the receiving waters (Section 7.3.7);
- overall salt balance – the average salt loads in and out of the water management system based on all model realisations (Section 7.3.8);
- potential receiving water impacts - predicted water quality in the receiving waters during predicted 'worst case' release scenarios (Section 7.3.9 and 7.3.10); and
- sensitivity analysis - varying the assumed haul road dust suppression over the mine life and the potential impacts of climate change (Section 7.4).

The use of a large number of climate sequences reflecting the full range of historical climatic conditions provides an indication of the system performance under very wet, very dry and average climatic conditions. It is important to note that the results of the water balance modelling are dependent on the accuracy of input assumptions. There is inherent uncertainty with respect to some key site characteristics (e.g. catchment yield/runoff, groundwater inflows etc.).

7.2 INTERPRETATION OF MODEL RESULTS

In interpreting the results of the water balance assessment, it should be noted that the results provide a statistical analysis of the water management system's performance over the 8 years of mine life, based on 122 stochastically generated climatic rainfall sequences and historical average monthly evaporation. The model results are presented as a probability of exceedance. For example, the 10%ile represents 10% probability of exceedance and the 90%ile represents 90% probability of exceedance. There is an 80% chance that the result will lie between the 10%ile and 90%ile traces.

Whether a percentile trace corresponds to wet or dry conditions depends upon the parameter being considered. For site water storage, where the risk is that available storage capacity will be exceeded, the lower percentiles correspond to wet conditions. For example, there is only a small chance that the 1%ile storage volume will be exceeded, which would correspond to very wet climatic conditions. For off-site site water supply volumes (for example), where the risk is that insufficient water will be available, there is only a small chance that more than the 1%ile water supply volume would be required. This would correspond to very dry climatic conditions.

It is important to note that a percentile trace shows the likelihood of a particular value on each day and does not represent continuous results from a single model realisation. For example, the 50%ile trace does not represent the model time series for median climatic conditions.

7.3 WATER BALANCE MODEL RESULTS

7.3.1 Overall water balance

Average water balance results based on all of the 122 model realisations are presented in Table 7.1. The results presented in Table 7.1 are the average of all realisations and will include wet and dry periods distributed throughout the mine life. Rainfall yield and evaporation for each stage is affected by the variation in climatic conditions within the adopted climate sequence.

Table 7.1 provides an indication of the long-term average annual inflows and outflows. Key outcomes from the overall water balance are as follows:

- Average annual inflows from rainfall runoff for surface water dams increases from Stage 1 to Stage 3, as the pit progresses, and more catchment runoff is collected in these dams.
- Average inflow volumes to mine storages are greatest in Stage 2, when the Vulcan Main pit catchment area is greatest.
- The proposed water management system is in negative balance under 'average' climate conditions. This indicates that the Project will require significant volumes of external water to meet mine water demands every year.
- External water requirements are greatest in Stage 1 due to the significantly larger haul road length during this Stage to the Highwall mining area.

It should be recognised that the following items are subject to climatic variability:

- Rainfall runoff;
- Evaporation;
- External water requirement;
- Dust suppression demand; and
- Dam overflows.

Whilst it provides an indication of the long-term average annual inflows and outflows, application of the nominated values for other purposes should only be undertaken with due consideration of the suitability of the nominated value and any potential implications.

In particular, the "average" sediment dam overflows do not necessarily mean that discharges occur under median climatic conditions. It means that there was a discharge in at least one of the 122 model realisations. A more detailed analysis of the performance of the various components of the water management system is provided in the following sections.

Table 7.1 - Average annual water balance - all realisations

Description	Stage 1	Stage 2	Stage 3
	Inflows (ML/year)		
Rainfall Runoff			
Mine affected water	188	240	214
Surface water	297	347	524
Diverted water	70	71	71
Groundwater inflow	1	12	5
ROM Coal Moisture	91	86	83
External Pipeline	1,222	332	526
Trucked potable water	50	50	50
Total Inflows	1,920	1,138	1,474
	Outflows (ML/year)		
Evaporation	23	56	57
Dam overflows			
Mine affected water	0	0	0
Surface water	125	160	231
Diverted water	70	70	71
CHPP			
Product moisture	102	96	92
Coarse rejects moisture	65	61	59
Fine rejects moisture	130	122	118
Haul road dust suppression	1,273	441	722
TLO demand	73	73	73
Potable water demand	50	50	50
Total Outflows	1,911	1,129	1,474
	Change in volume (ML/year)		
Change in stored volume	9	8	-1

7.3.2 Mine affected water inventory

7.3.2.1 MWD8 inventory

Figure 7.1 shows the forecast inventory for MWD8 which is the key out-of-pit mine affected water storage, controlling the dewatering of the pit. Figure 7.2 shows the annual maximum forecast inventory for MWD8 over the mine life.

These results show the 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile traces.

As outlined in Section 5.6.1, to prevent uncontrolled discharges from MWD8 a MOV is required. If the MOV is exceeded, all transfers to the storage cease (i.e. pit dewatering and mine water dam dewatering). The MWD8 MOV, in addition to the FSV are shown in Figure 7.1 and Figure 7.2.

The model results show the following:

- The MWD8 inventory is maintained below the FSV for all climatic conditions assessed and therefore is not predicted to spill under any modelled climate sequence.
- The MWD8 inventory is maintained below its MOV for 5%ile and drier conditions in Stage 1 and 25%ile & drier conditions in Stages 2 & 3. This means pit and mine dam dewatering is restricted under 1%ile in Stage 1 and 10%ile and wetter conditions in Stages 2 and 3.
- Under the 50%ile trace, the MWD8 inventory is maintained below 55 ML for the entire mine life.
- Under very wet (1%ile) conditions, MWD8 has an inventory of up to 153 ML during Stage 2.
- Under wet (10%ile conditions), MWD8 has a maximum inventory of approximately:
    - up to 90 ML during Stage 1; and
    - up to 135 ML during Stage 2 and 3.

7.3.2.2 MWD9 inventory

Figure 7.3 shows the annual maximum forecast inventory for MWD9. MWD9 acts as a transfer dam for Vulcan Main pit and Vulcan South pit. MWD9 is not active in Stage 1. The results show the 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile traces.

The model results show the following:

- The MWD9 inventory is maintained below the FSV for all climatic conditions assessed and therefore is not predicted to spill under any modelled climate sequence.
- Under wet (10%ile conditions), MWD9 has a maximum inventory of approximately up to 25 ML during both Stage 1 & 2.

7.3.2.3 MWD6 and MWD7 inventories

Mine water dams MWD6 and MWD7 collect mine water draining from the CHPP area and the TLO area. They have been grouped together for the purpose of this assessment as they are operated in a similar way. Figure 7.4 shows the annual maximum forecast combined inventory for MWD6 and MWD7.

The model results show that:

- The combined water inventories in MWD6 and MWD7 remain below the combined FSV under the 1%ile and drier climate sequence. Model results indicate that the mine dams spill into MWD8 very infrequently (i.e. less than 1% of the time).
- Under the 50%ile trace, the maximum mine water inventory is maintained well below the MOV for all years.
- The maximum water inventory only rises above the MOV under conditions wetter than the 5%ile during all stages.

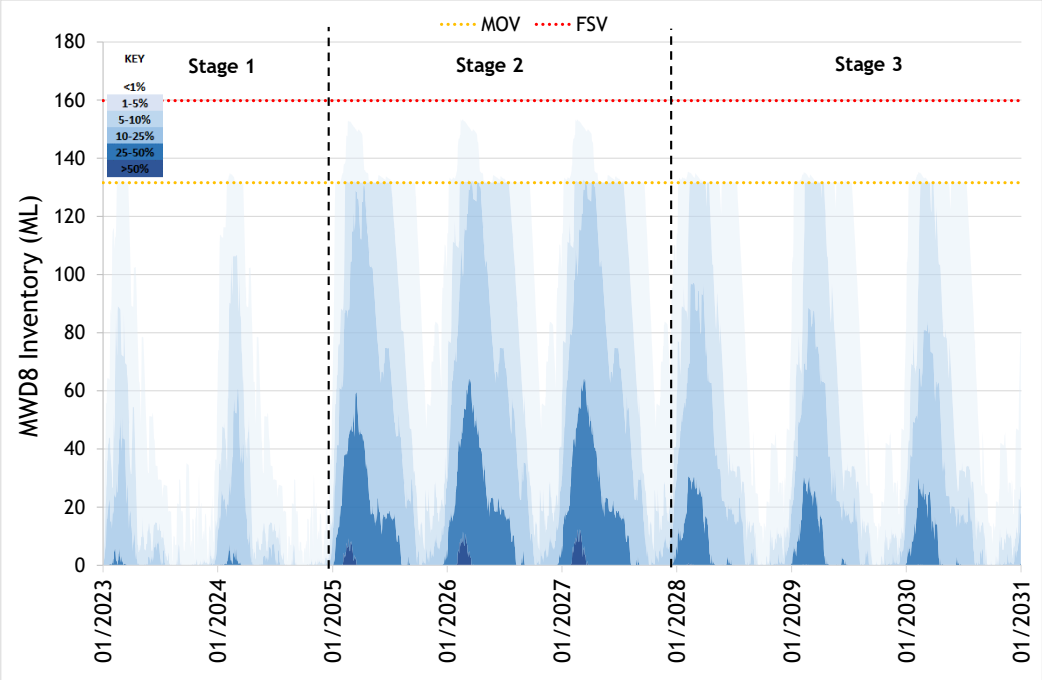


Figure 7.1 - Forecast MWD8 inventory

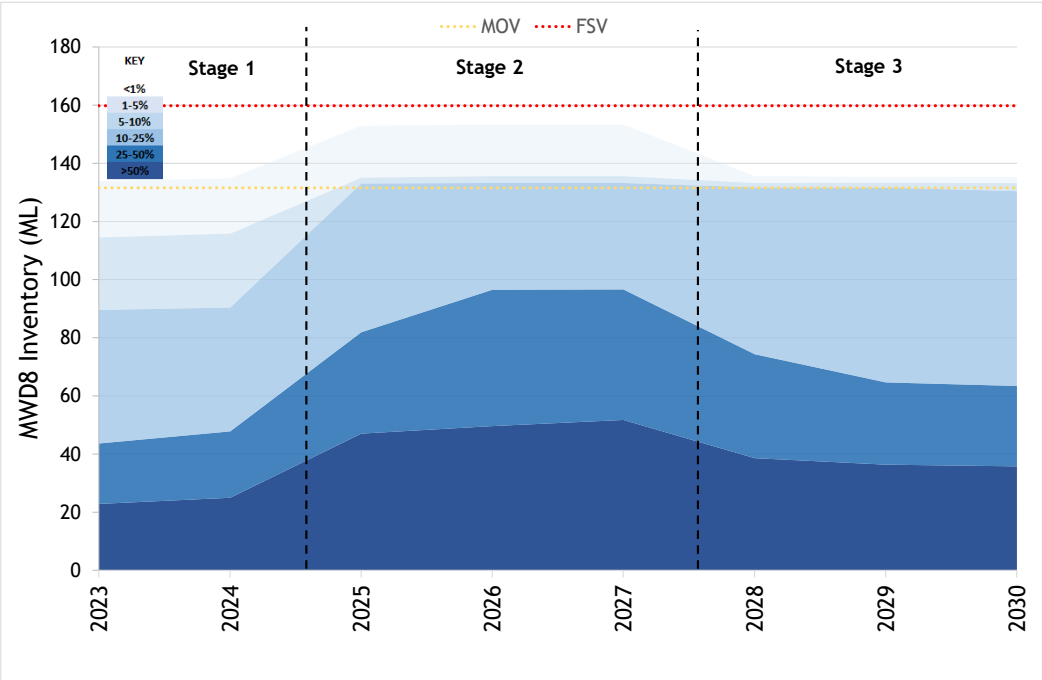


Figure 7.2 - Forecast annual maximum MWD8 inventory

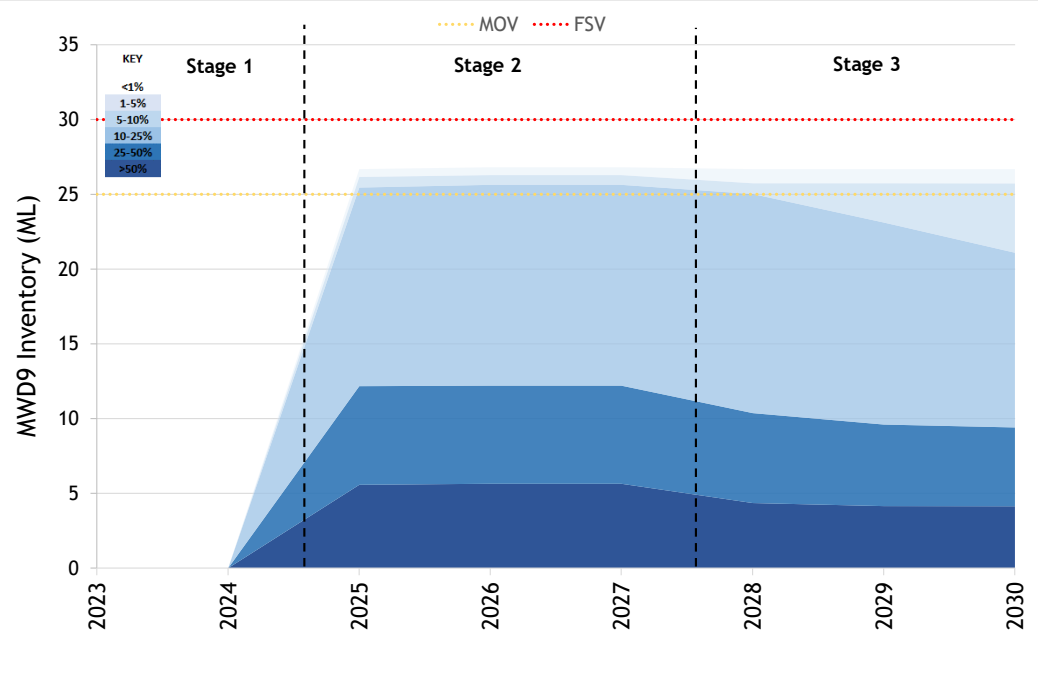


Figure 7.3 - Forecast annual maximum MWD9 inventory

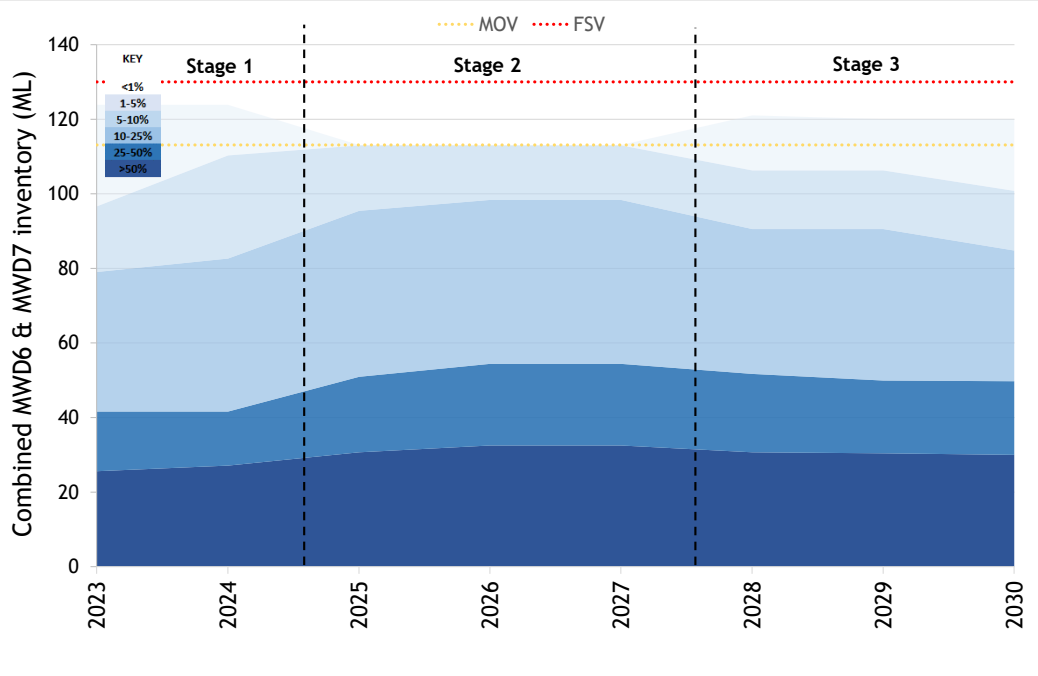


Figure 7.4 - Forecast annual combined maximum water inventory in MWD6 and MWD7

7.3.3 Vulcan North pit water inventory

Figure 7.5 shows the forecast annual maximum Vulcan North pit inventory during Stage 1. The pit is inactive and therefore empty during Stages 2 and 3.

The 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile percentile traces are shown. As outlined in Section 5.6.1, the pit is continuously dewatered into MWD8 as long as MWD8 is maintained below its MOV.

The model results show the following:

- The pit is empty for the majority of the mine life.
- The Vulcan North pit will have a forecast inventory of approximately:
  - up to 20 ML under very wet (1%ile conditions); and
  - up to 2 ML under wet (10%ile conditions).

The results suggest that MWD8 has sufficient capacity to dewater the Vulcan North pit for the entirety of its active mine life.

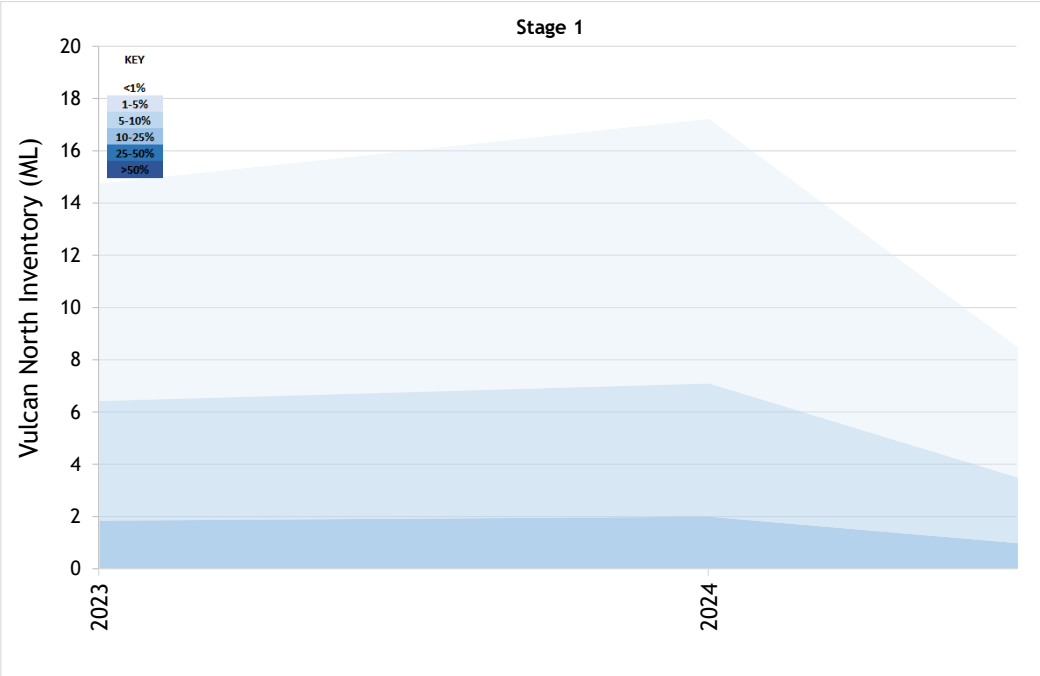


Figure 7.5 – Vulcan North forecast annual maximum pit inventory

7.3.4 Vulcan Main pit water inventory

Figure 7.6 shows the forecast pit inventory for Vulcan Main pit. Figure 7.7 shows the forecast annual maximum inventory in Vulcan Main pit.

The 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile percentile traces are shown. As outlined in Section 5.6.1, the pit is continuously dewatered into MWD8 and MWD9.

The model results show the following:

- Under very wet (1%ile) conditions, the Vulcan Main pit will have a forecast inventory of approximately:
  - up to 50 ML during Stage 1;
  - up to 130 ML during Stage 2; and
  - up to 65 ML during Stage 3.
- Under wet (10%ile conditions), the Vulcan pit will have an inventory of approximately:
  - up to 20 ML during Stage 1;
  - up to 60 ML during Stage 2; and
  - up to 10 ML during Stage 3.
- Under 50%ile conditions, the maximum pit inventory is less than 1 ML for Stages 1 and 3, and less than 5 ML during Stage 2.

The results suggest that the Vulcan Main pit may begin to accumulate water during Stage 2 during very wet climate conditions due to capacity being reached in MWD8 and MWD9. If there is a 5%ile or wetter climatic condition then the on-site water storages would be filled to capacity and the Vulcan Main pit would be required to store excess water potentially disrupting mining activities.

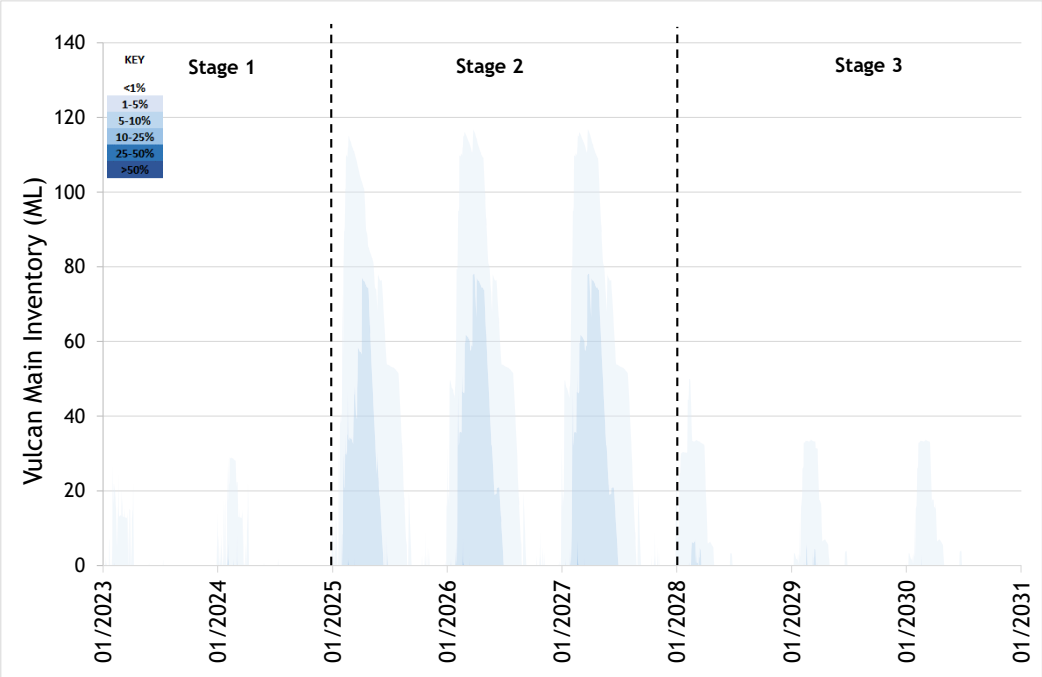


Figure 7.6 – Vulcan Main pit forecast mine pit inventory

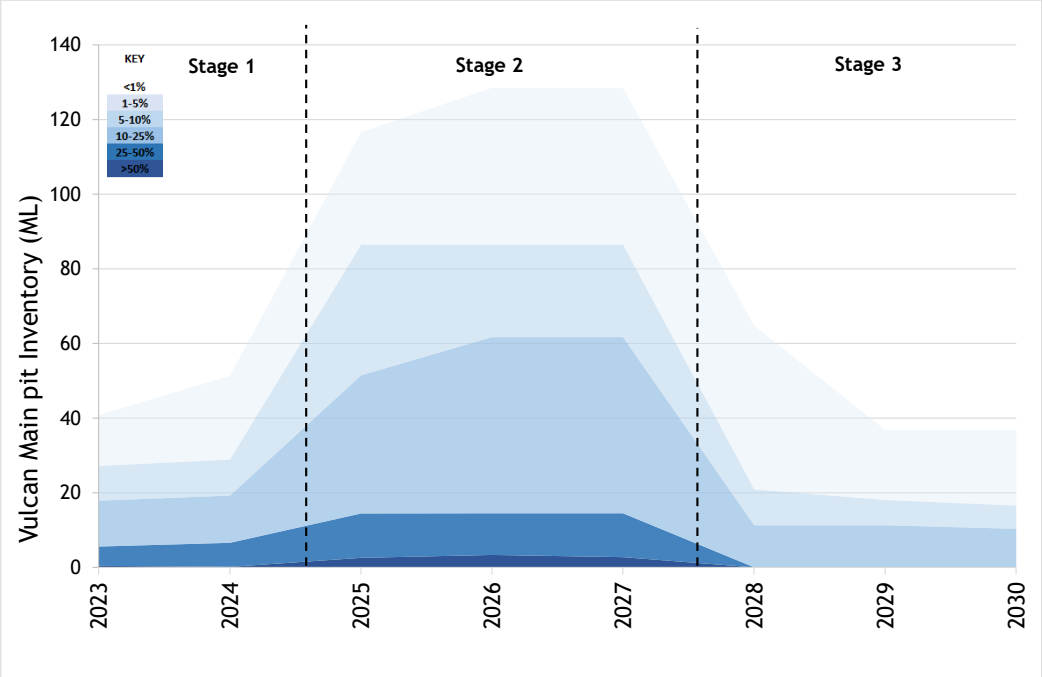


Figure 7.7 – Vulcan Main pit forecast annual maximum pit inventory

7.3.5 Vulcan South pit water inventory

Figure 7.8 shows the forecast annual maximum inventory in Vulcan South pit. The Vulcan South pit is only active in Stage 3.

The 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile percentile traces are shown. As outlined in Section 5.6.1, the pit is continuously dewatered into MWD8 and MWD9.

The model results show the following:

- The Vulcan South pit will have a forecast inventory of approximately:
  - up to 25 ML during very wet (1%ile) climate conditions; and
  - up to 5 ML during wet (10%ile) climate conditions.
- Under 25%ile and drier conditions the pit is kept dewatered for the entirety of its mine life.

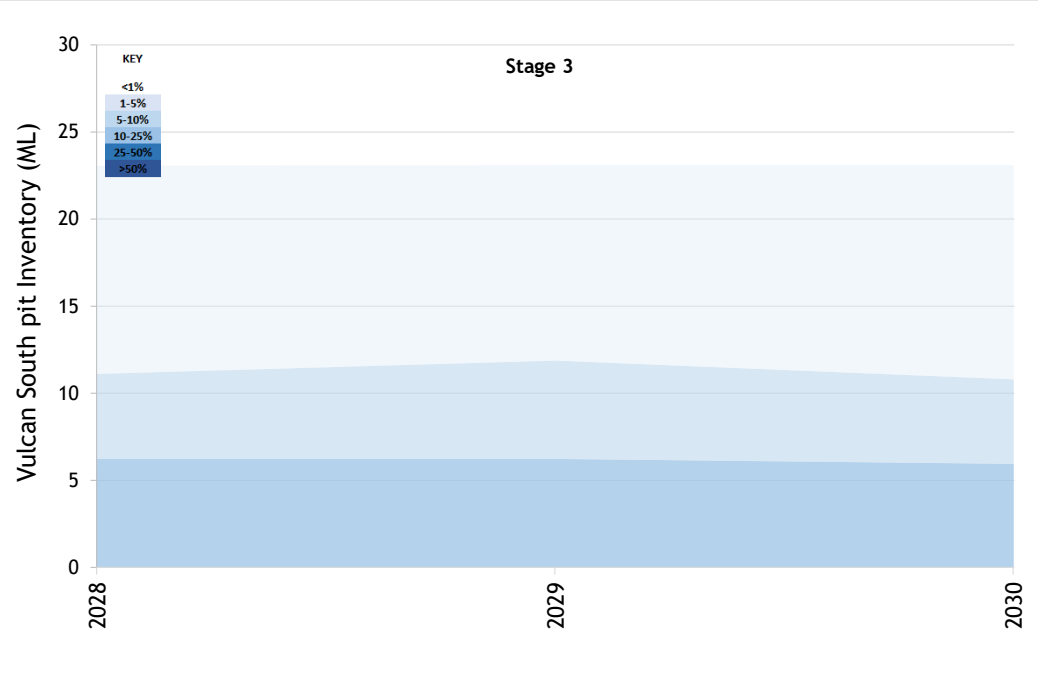


Figure 7.8 – Vulcan South pit forecast annual maximum pit inventory

7.3.6 External makeup requirements

Figure 7.9 shows the total annual modelled external water required to meet predicted mine demands. The 1%ile (driest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile percentile traces are shown. As outlined in Section 6.4, the external pipeline is used to satisfy mine demands as lowest priority when all other sources are empty.

The modelling results show the following:

- Stage 1 requires significantly more external water than Stages 2 and 3 because Stage 1 has the largest haul road dust suppression requirements and therefore the highest mine water demands.
- During the driest (1%ile) climatic conditions, the external water requirement is:
  - up to approximately 1,520 ML/annum during Stage 1;
  - up to 655 ML/annum during Stage 2; and
  - up to 930 ML/annum during Stage 3.
- During 50%ile conditions, the predicted external water requirements is:
  - up to approximately 1,260 ML/annum during Stage 1;
  - up to approximately 355 ML/annum during Stage 2; and
  - up to approximately 540 ML/annum during Stage 3.

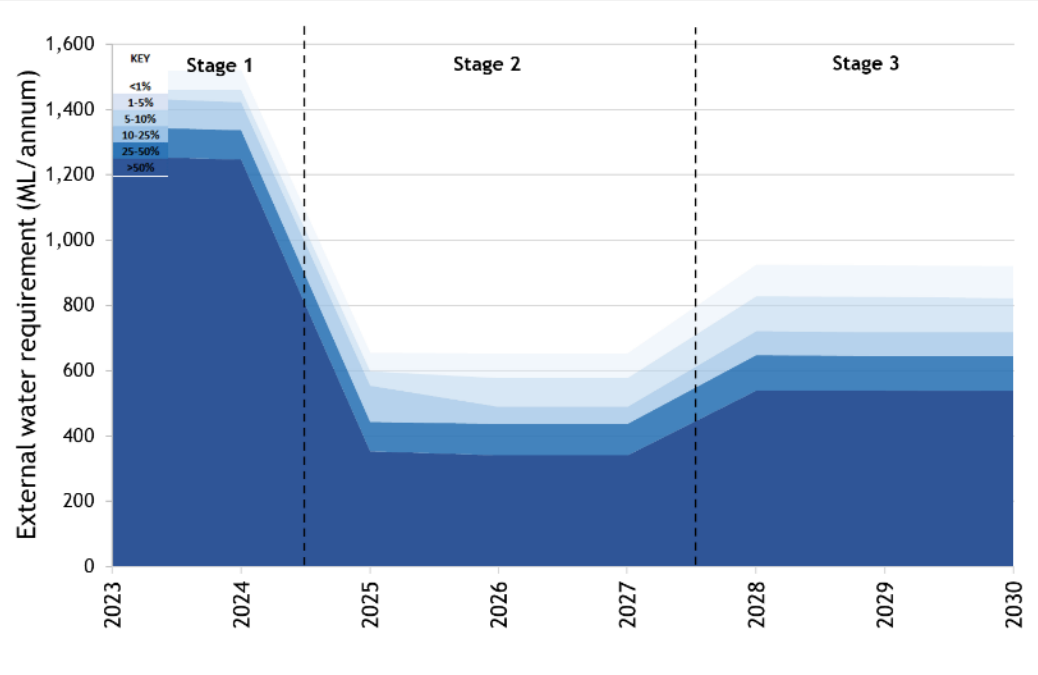


Figure 7.9 – Forecast external water requirement for dust suppression

7.3.7 Releases/overflows to the receiving waters

7.3.7.1 Mine Affected Water Dams

As outlined in Section 7.3.2, no spills are predicted from any of the mine affected water dams (i.e. MWD6, MWD7, MWD8 and MWD9) to the extenral environment under any of the climate sequences modelled.

Under very rare circumstances (i.e. <1%ile) MWD6 and MWD7 are predicted to spill to MWD8. This does not cause MWD8 to spill to Hughes Creek.

7.3.7.2 Sediment Dams

Consistent with the IECA guidelines (2008), sediment dams do not provide 100% containment for captured runoff. Hence overflows will occur from sediment dams when rainfall exceeds the design standard.

The potential for releases from the proposed sediment dam has been modelled using a passive overflow rather than active release (to regain storage capacity within 5 days).

Figure 7.10 shows the forecast annual sediment dam releases to Hughes Creek. Figure 7.11 shows the forecast annual sediment dam releases to East Creek.

The model results indicate that:

- The predicted sediment dam releases to Hughes Creek progressively increases over the mine life. This is due to sediment dams which release to Hughes Creek progressively being constructed over the mine life as the dump areas associated with the Vulcan Main and Vulcan South pits increases.
- The predicted sediment dam releases to East Creek increase in Stage 2 compared to Stage 1 before decreasing again in Stage 3. This is due to no new sediment dams draining to this creek being constructed at the commencement of Stage 3. The surface water catchment areas do not change between Stages 2 and 3, however mine demands for the sediment dam water increase in Stage 3.

- Under wet (10%ile) conditions, the annual volume of sediment dam releases to Hughes Creek is approximately:
  - up to 308 ML/yr during Stage 1;
  - up to 376 ML/yr during Stage 2; and
  - up to 574 ML/yr during Stage 3.
- Under wet (10%ile) conditions, the annual volume of sediment dam releases to East Creek is approximately:
  - up to 105 ML/yr during Stage 1;
  - up to 157 ML/yr during Stage 2; and
  - up to 159 ML/yr during Stage 3.
- Under 50%ile conditions, the annual volume of sediment dam releases to Hughes Creek is approximately:
  - up to 43 ML/yr during Stage 1;
  - up to 31 ML/yr during Stage 2; and
  - up to 66 ML/yr during Stage 3.
- Under 50%ile conditions, the annual volume of sediment dam releases to East Creek is approximately:
  - 0 ML/yr during Stage 1;
  - up to 10 ML/yr during Stage 2; and
  - up to 11 ML/yr during Stage 3.
- Overall, the results indicate that under average or drier conditions low spill volumes are expected to the receiving waters, while wet conditions result in more significant spill volumes.

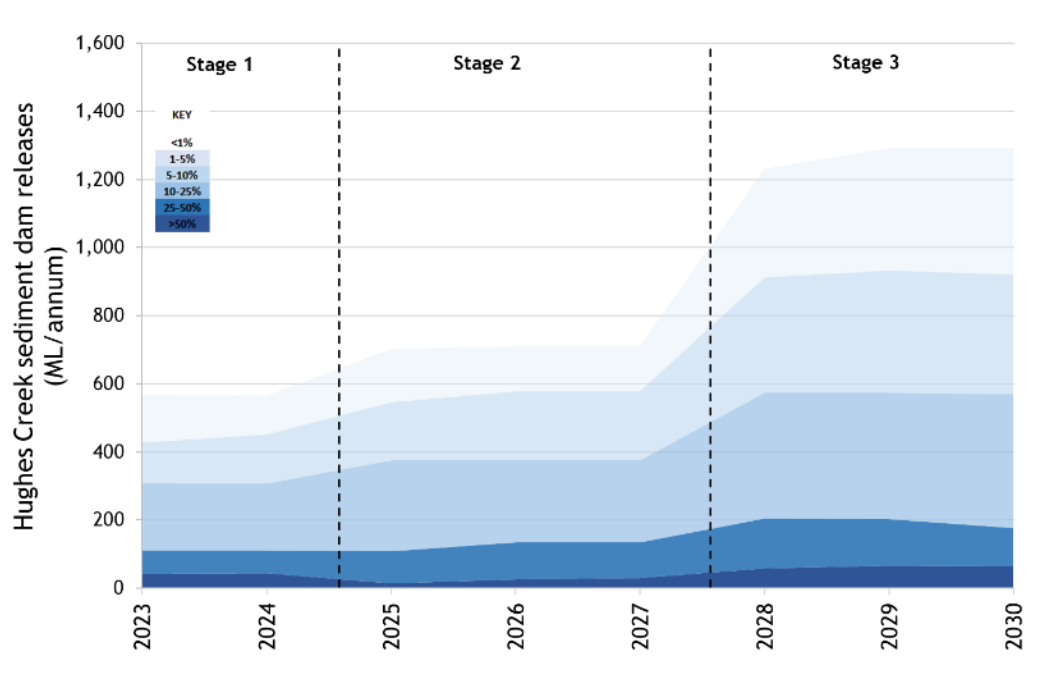


Figure 7.10 - Forecast annual sediment dam releases to Hughes Creek

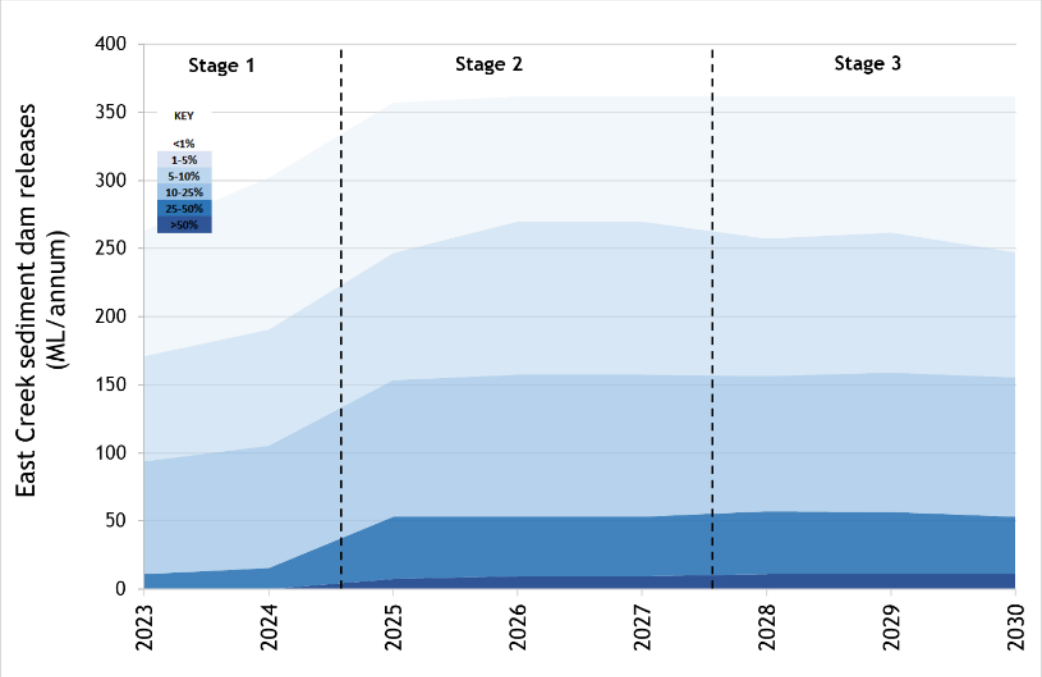


Figure 7.11 – Forecast annual sediment dam releases to East Creek

7.3.7.3 DD2

DD2 collects water from a primarily undisturbed catchment to the southwest of the Vulcan North pit, with a small area of haul road. Water stored in DD2 is dewatered to the existing drainage diversion at 100 L/s. If the capacity of DD2 is exceeded, water would spill to the Vulcan North pit in Stage 1 and East Creek in Stages 2 and 3.

Figure 7.12 shows the combined annual total pumped flows from DD2 to the existing drainage diversion, as well as any overflows. The 1%ile (wettest climatic conditions), 5%ile, 10%ile, 25%ile and 50%ile percentile traces are shown.

The model results predict the following:

- DD2 does not spill either to the pit or to the receiving waters under any climate sequence. Therefore, the results in Figure 7.12 represent only pumps to the drainage diversion from DD2.
- Under wet (10%ile) conditions DD2 dewaters up to approximately 120 ML/year to the receiving waters in all stages.
- Under very wet (1%ile climatic conditions) DD2 dewaters up to approximately 170 ML/year to the receiving waters in all stages.

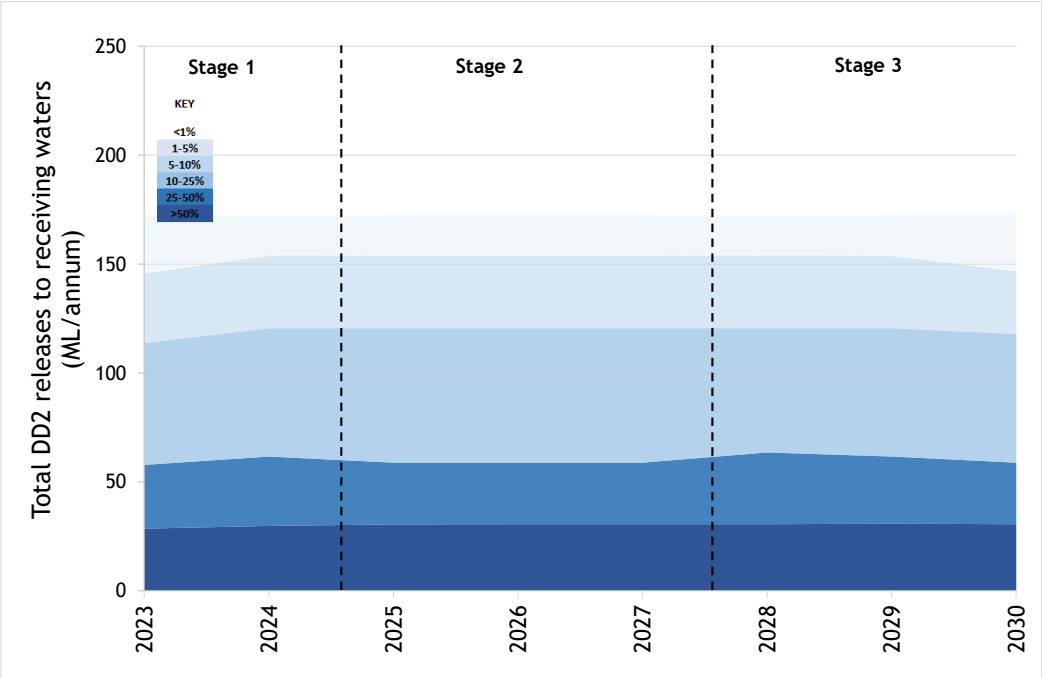


Figure 7.12 – Forecast total annual releases from DD2 to the existing waters

7.3.8 Overall salt balance

Table 7.2 shows the average annual salt balance for the Project for each stage.

Salt inputs to the Project include salts in the groundwater inflow, catchment runoff, salt store din ROM coal and external water. Salt inputs from direct rainfall was assumed to be zero.

Salt outputs from the Project include site demands and offsite (spillway) discharges from the water management system.

The results indicate the following:

- The largest contributor to the Project salt load is due to external water assuming it is sourced from BMA. This is due to the high assumed salinity of the BMA water (Section 6.8.1).
- The largest outflow in the salt balance from the Project is haul road dust suppression demands.
- The change in stored salt load is generally low in comparison to the total inputs and outputs, which suggests that salt will not accumulate within the site water management system.

Note that the salt balance is reported in annual tonnes of total dissolved solids (TDS) based on an EC to TDS conversion factor of 0.7.

Table 7.2 - Average annual salt balance (based on TDS)

Description	Stage 1	Stage 2	Stage 3
Inflows (t/year)			
Rainfall Runoff			
Mine affected water	214	156	139
Surface water	83	92	143
Diverted water	20	31	20
Groundwater inflow	4	77	36
ROM Coal Moisture	640	602	581
External Pipeline	8,552	2,326	3,681
Trucked potable water	0	0	0
Total Input	9,515	3,285	4,601
Outflows (t/year)			
Evaporation	0	0	0
Dam overflows			
Mine affected water	0	0	0
Surface water	36	43	64
Diverted water	20	31	20
CHPP			
Product moisture	576	380	390
Coarse rejects moisture	455	427	412
Fine rejects moisture	736	486	498
Haul road dust suppression	7,266	1,651	2,929
TLO demand	419	264	289
Potable water demand	0	0	0
Total Output	9,508	3,283	4,602
Change in salt (t/year)			
Change in stored volume	7	2	-1

7.3.9 Receiving waters water quality

The three potential sources of receiving waters contamination from the water management system are releases from the sediment dams, releases from the mine affected dams and pumped releases from DD2. As outlined in Section 7.3.7, the mine affected dams are not predicted to spill under any of the modelled climate sequences. Releases from DD2 are expected to be of a water quality that is similar to the receiving waters as it primarily collects water from an undisturbed rural catchment.

Potential impacts to EC in the receiving waters were assessed at points directly downstream of the Project. The reporting location for East Creek is downstream of the Project, where Drainage line 7 joins East Creek. The reporting location for Hughes Creek is downstream of the Project, where Barrett Creek joins Hughes Creek. The default WQO trigger levels for EC outlined in Section 3 have been used for this assessment.

Figure 7.13 shows the predicted annual maximum EC in East Creek over the mine life. Figure 7.14 shows the predicted annual maximum EC in Hughes Creek over the mine life. The 1%ile, 5%ile, 10%ile, 25%ile and 50%ile (median climatic conditions) traces are shown. The results predict that:

- For East Creek:
  - Under 1%ile conditions the maximum EC is approximately 460 µS/cm in Stage 1, 470 µS/cm in Stage 2 and 440 µS/cm in Stage 3; and
  - Under 50%ile conditions the maximum EC is approximately 420 µS/cm in Stage 1, 430 µS/cm in Stage 2 and 420 µS/cm in Stage 3.
- For Hughes Creek:
  - Under 1%ile conditions the maximum EC is approximately 370 µS/cm in Stage 1, 400 µS/cm in Stage 2 and 410 µS/cm in Stage 3; and
  - Under 50%ile conditions the maximum EC is approximately 350 µS/cm in Stage 1, 330 µS/cm in Stage 2 and 350 µS/cm in Stage 3.

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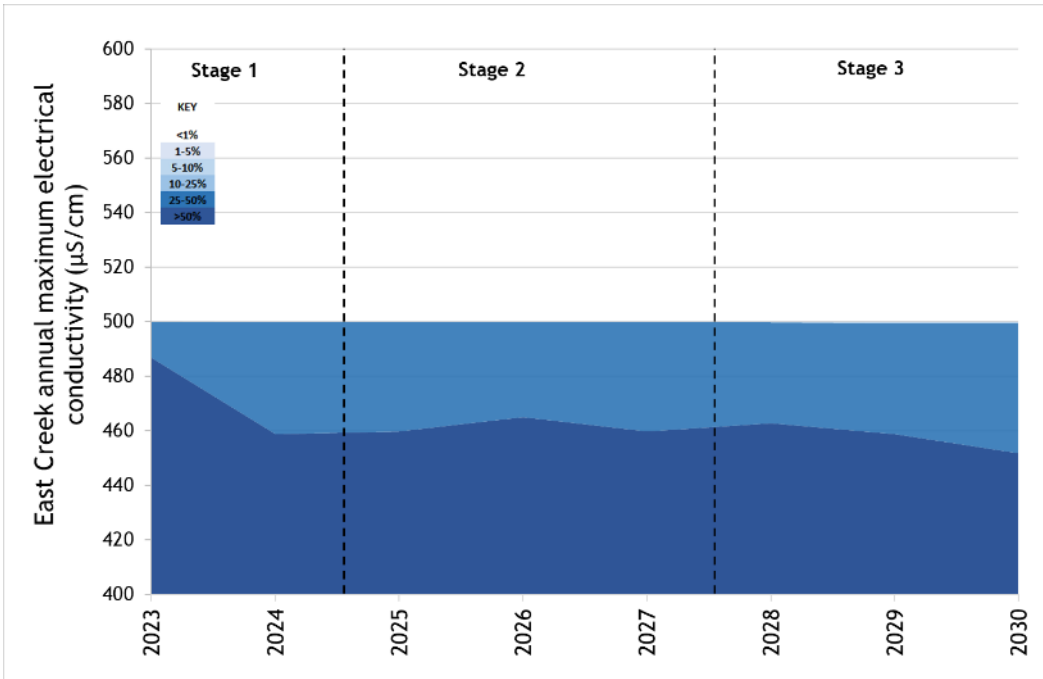

Figure 7.13 - Predicted East Creek annual maximum EC variation downstream of the Project

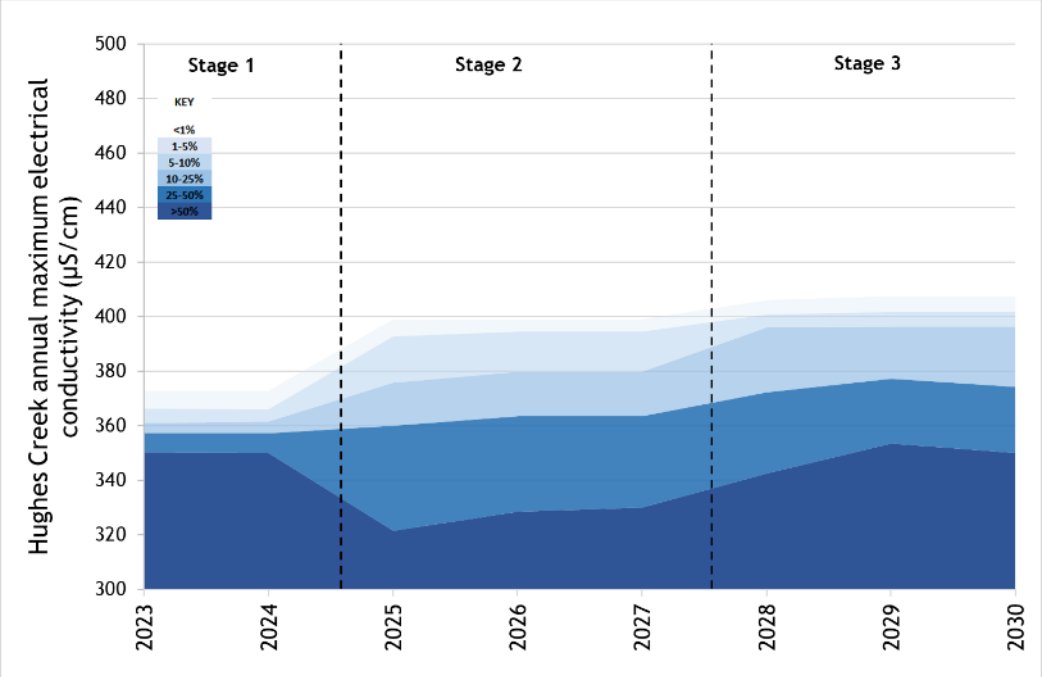

Figure 7.14 – Predicted Hughes Creek annual maximum EC variation downstream of the Project

7.3.10 Release scenarios

The OPSIM model was used to assess the release (spill or transfer) from sediment dams and DD2. No other dams or storages are predicted to release to the receiving waters. The release scenarios that were investigated include:

- Scenario 1 – The highest EC release from the sediment dams; and
- Scenario 2 – The highest flow rate release from the sediment dams.

The release events were compared to the WQO levels outlined in Section 3.

7.3.10.1 Scenario 1 – Sediment dams highest EC release

The cumulative release with the highest EC from the Project occurs during Stage 2 to East Creek at approximately 480 µS/cm with a flow rate of approximately 0.7 ML/d. Figure 7.15 and Figure 7.16 shows the release rate and EC compared to the rates in the receiving waters. The WQO levels outlined in Section 3 are also shown.

The OPSIM model predicts that during the Scenario 1 release, the release causes a minor increase to EC levels in the receiving waters. This is due to the low flow rate of the release in comparison to the high flows already present within the receiving waters. The model predicts that during the event both the EC levels of the release, and within the receiving waters remain above the high flow WQO but below the baseflow WQO. It is noted that for this assessment, the assumed receiving waters EC level (300 µS/cm) is greater than the high flow WQO of 250 µS/cm.

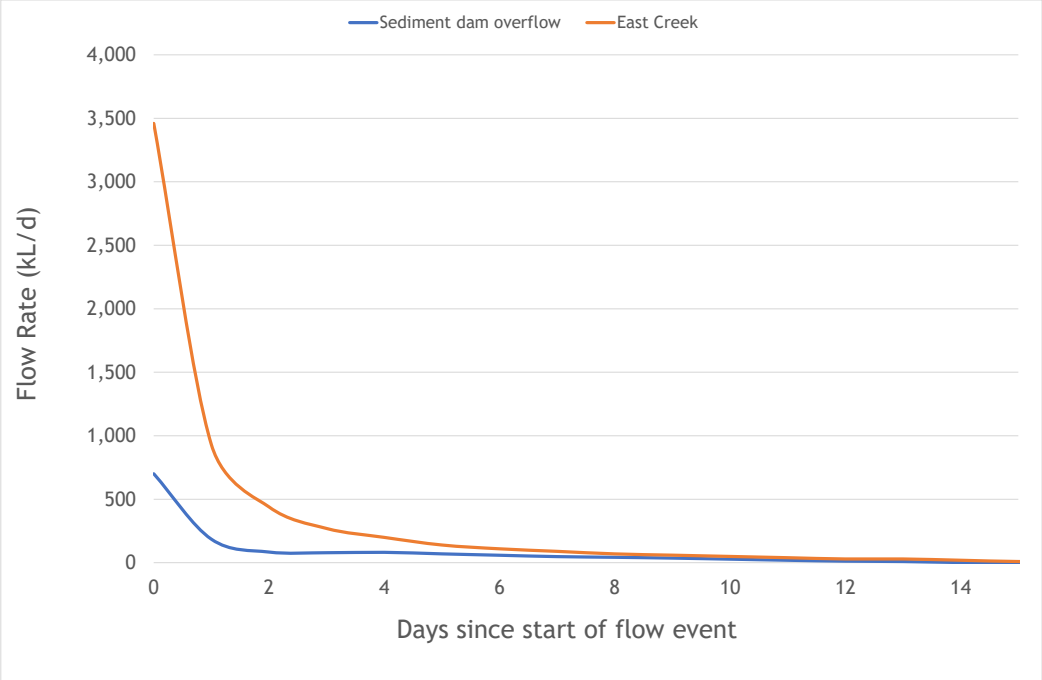

Figure 7.15 - Project release rate compared to flow rate in the receiving waters - Scenario 1

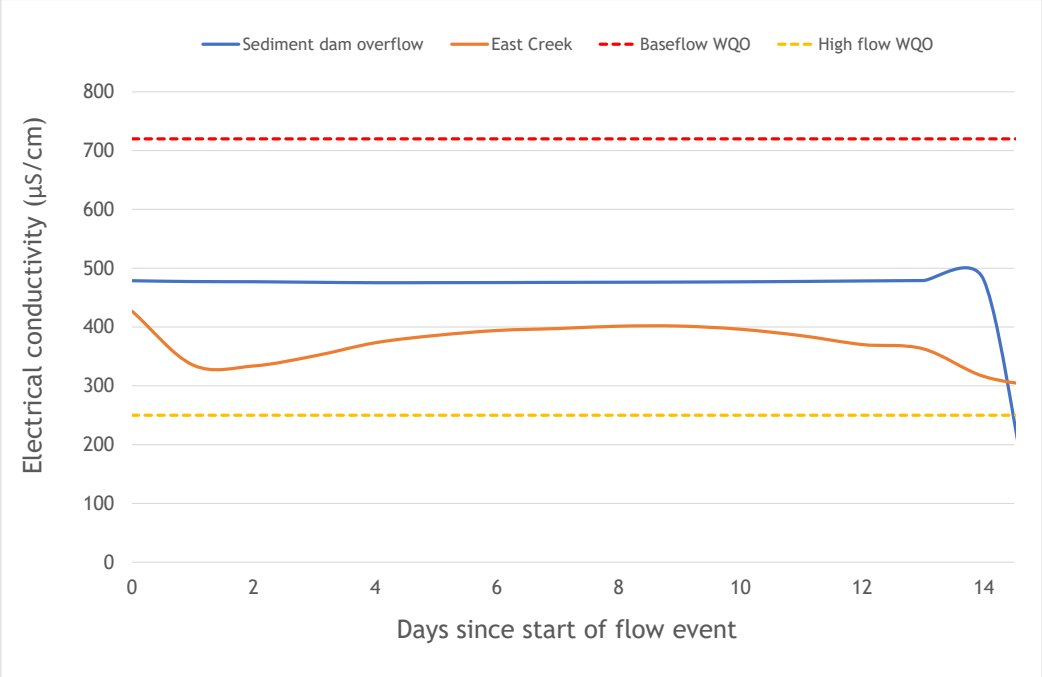

Figure 7.16 - Project release EC levels compared to EC levels in the receiving waters and corresponding water quality criteria - Scenario 1

7.3.10.2 Scenario 2 – Sediment dam highest flow rate

The Scenario 2 highest release rate occurs during Stage 3 with a cumulative release of approximately 306 ML/d to Hughes Creek. Figure 7.17 and Figure 7.18 shows the Scenario 2 release rate and EC from the cumulative release compared to the flow rate and EC in Hughes Creek during and following the release event.

The OPSIM model predicts that during the Scenario 2 release, Hughes Creek will already have a very large flow. The cumulative release has a negligible effect on the Hughes Creek EC levels due to the already high flows present. The model predicts that during the event both the EC levels of the release, and within Hughes Creek remain above the high flow WQO but below the baseflow WQO. It is noted that for this assessment, the assumed Hughes Creek EC is greater than the high flow WQO of 250 µS/cm.

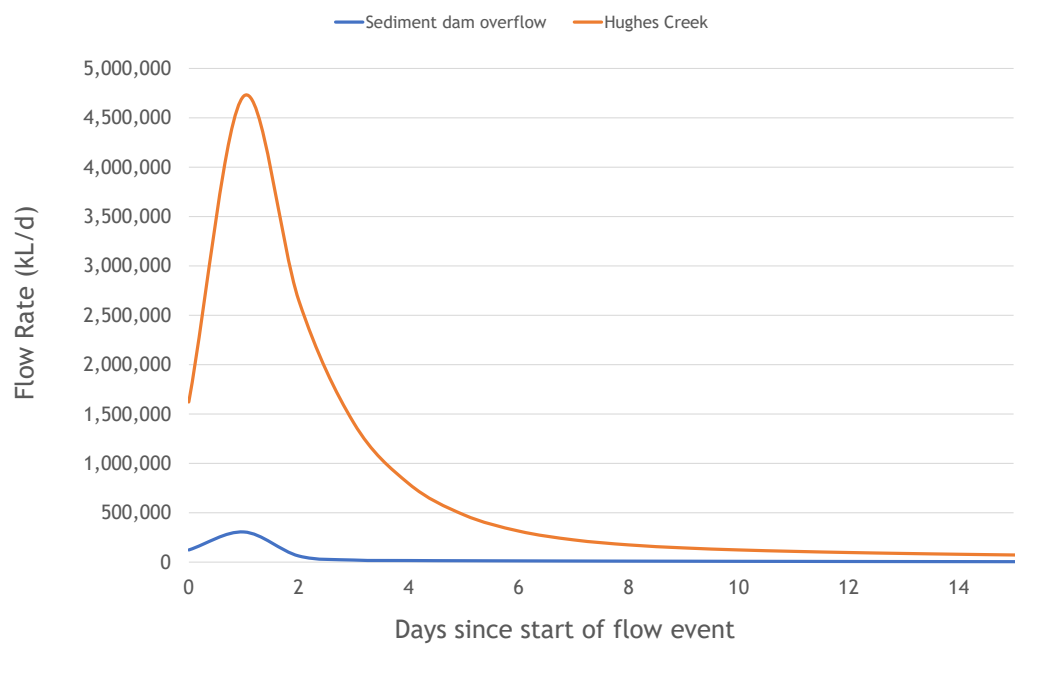

Figure 7.17 – Project release rates compared to flow rates in the receiving waters- Scenario 2

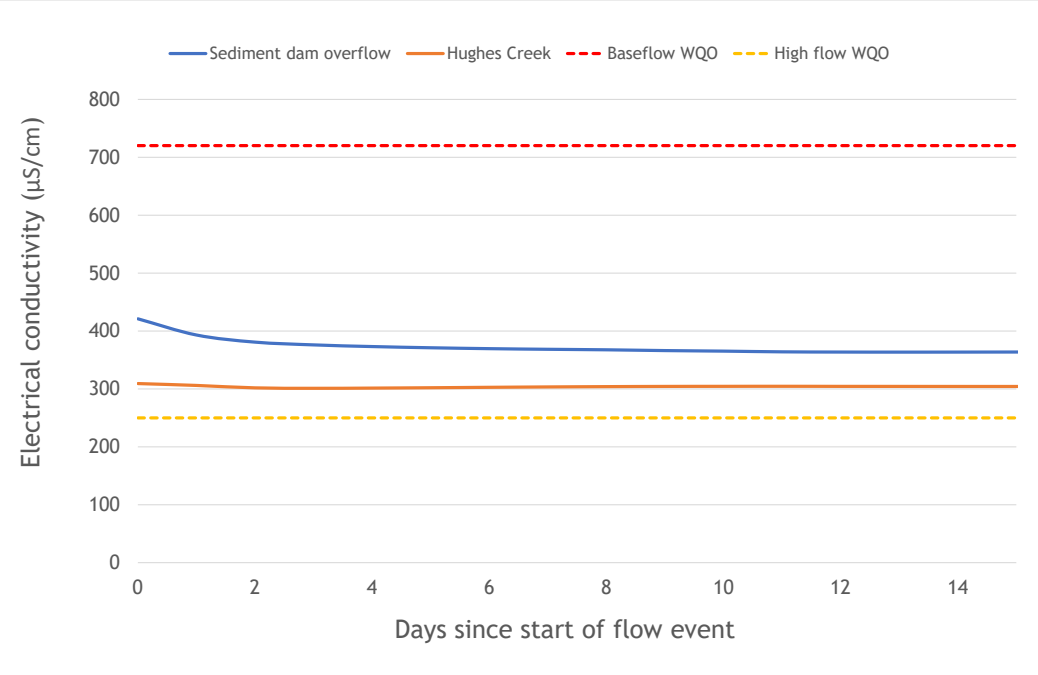

Figure 7.18 - Project release EC levels compared to EC levels in the receiving waters as well as the corresponding water quality criteria - Scenario 2

7.4 SENSITIVITY ANALYSIS

7.4.1 Haul road dust suppression

A sensitivity analysis was undertaken by varying the haul road dust suppression demand to assess the potential impacts on the overall water balance and MWD spill risk.

As outlined in Section 7.3, haul road dust suppression has the biggest influence on the Project water and salt balance. The haul road dust suppression demand has been estimated using the methodology outlined in Section 6.5.1. It is likely that the dust suppression demand will vary over the mine life as operations progress, as well as climatic and seasonal conditions. The haul road dust suppression is therefore likely the largest uncertainty for the water balance model and will have the greatest effect on the overall water balance.

7.4.1.1 Higher haul road dust suppression

It is noted that the highest haul road demand occurs in Stage 1, when the haul road to the Highwall mining area is active. To assess the impact of retaining a high haul road dust suppression across the entire mine life, this scenario has been run retaining the haul road dust suppression from Stage 1 across Stages 2 and 3.

Figure 7.19 shows the annual maximum MWD8 inventory, Figure 7.20 shows the annual maximum Vulcan Main pit inventory and Figure 7.21 shows the forecast annual total external water requirement.

The results of the sensitivity analysis indicate that:

- Slightly less water would accumulate in onsite water storages and the Vulcan Main pit when compared to the base case:
  - Under 10%ile conditions, MWD8 would store up to 131 ML in Stage 2 and 99 ML in Stage 3 when compared with 133 and 131 ML respectively in the base case.
  - During Stage 2, MWD8 would not significantly rise above its MOV under wettest (1%ile) conditions, unlike under the base case.
  - During Stage 2, under 1%ile conditions the Vulcan Main pit would store up to approximately 100 ML compared to 130 ML in the base case.
- Significantly more external water would be required to meet site water demands in Stages 2 and 3. During the driest climatic conditions (1%ile), external water demand would be up to 1480 ML/annum in Stage 2 and 3. This is in comparison to the base case external pipeline demand which is up to 650 ML/annum and 920 ML/annum respectively under 1%ile conditions.
- No mine affected water dam spills to the environment occur for this sensitivity assessment or the base case.

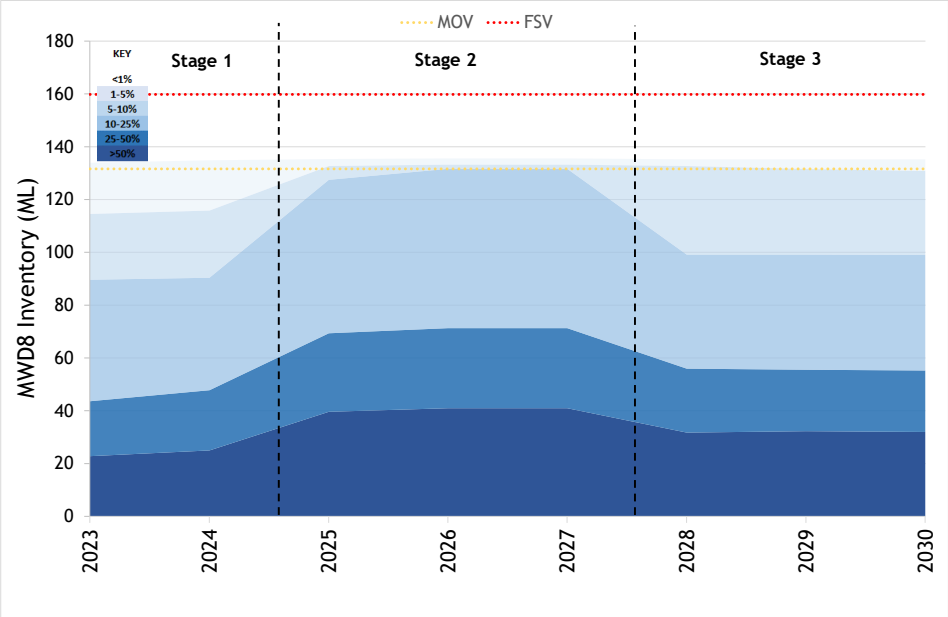

Figure 7.19 - Forecast annual maximum MWD8 inventory - high dust suppression sensitivity analysis

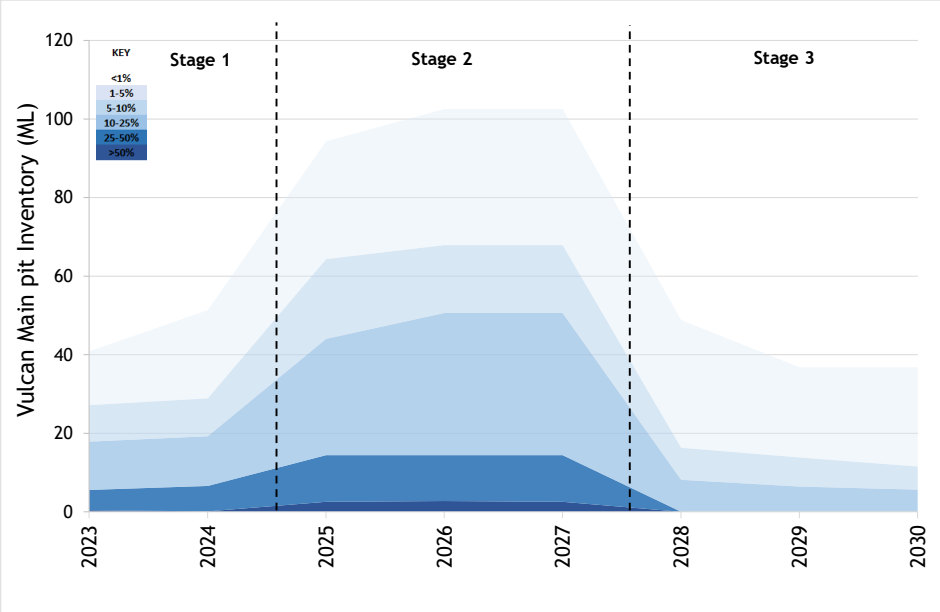

Figure 7.20 - Vulcan Main pit forecast annual maximum mine pit inventory - high dust suppression sensitivity analysis

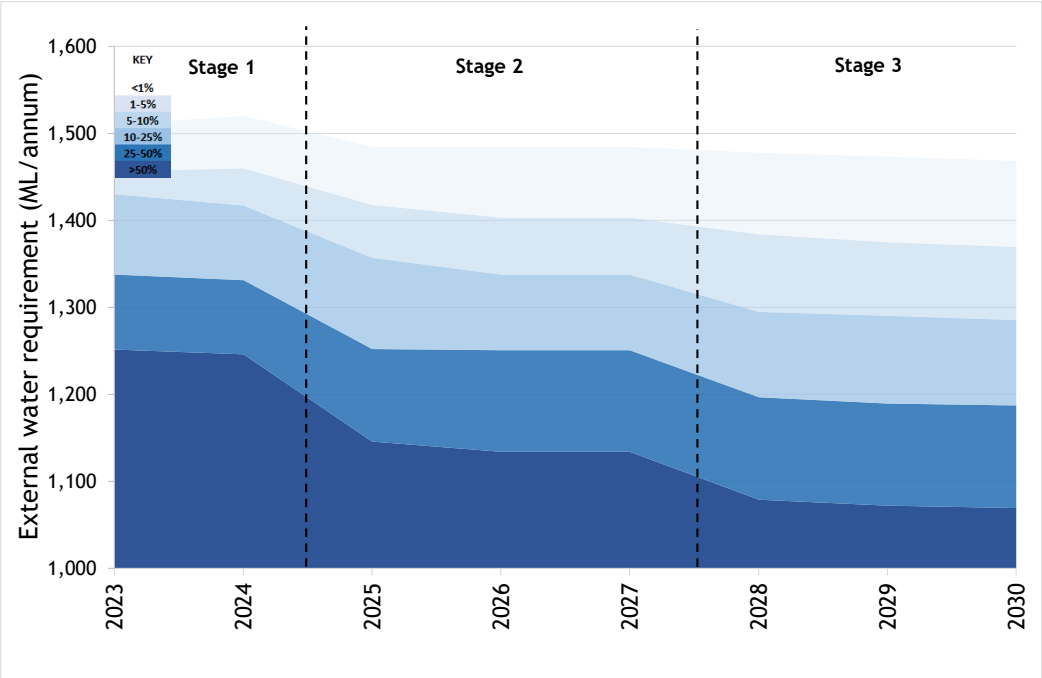

Figure 7.21 - Forecast annual total external water requirement - high dust suppression sensitivity analysis

7.4.1.2 Lower haul road dust suppression

To assess the impact of retaining a low haul road dust suppression across the entire mine life, this scenario has been run retaining the haul road dust suppression from Stage 2 across Stages 1 and 3. It is noted that the lowest haul road demand occurs in Stage 2.

Figure 7.22 shows the annual maximum MWD8 inventory, Figure 7.23 shows the annual maximum Vulcan Main pit inventory and Figure 7.24 shows the forecast annual total external water requirement.

The results of the sensitivity analysis indicate that:

- Slightly more water would accumulate in onsite water storages and the Vulcan Main pit when compared to the base case:
  - Under 10%ile conditions, MWD8 would store up to 120 ML in Stage 1 and 132 ML in Stage 3 when compared with 90 and 131 ML respectively in the base case.
  - During Stage 1, MWD8 would rise above its MOV under wettest (1%ile) conditions, unlike under the base case.
  - During Stage 1 & 3, under 1%ile conditions the Vulcan Main pit would store up to approximately 50 ML and 55 ML, compared to 51 and 64 ML in the base case respectively.
- Far less external water would be required to meet site water demands in Stages 1 and 3. During the driest climatic conditions (1%ile), external water demand would be up to 680 ML/annum and 640 ML/annum in Stage 1 and 3 respectively. This is in comparison to the base case external pipeline demand which is up to 1,520 ML/annum and 925 ML/annum respectively under 1%ile conditions.
- Under this scenario, MWD6, MWD7, MWD8 and the pits would not spill. However MWD9, would spill in Stage 3 under 2% of modelled simulations, with an annual spill volume of up to 12 ML.

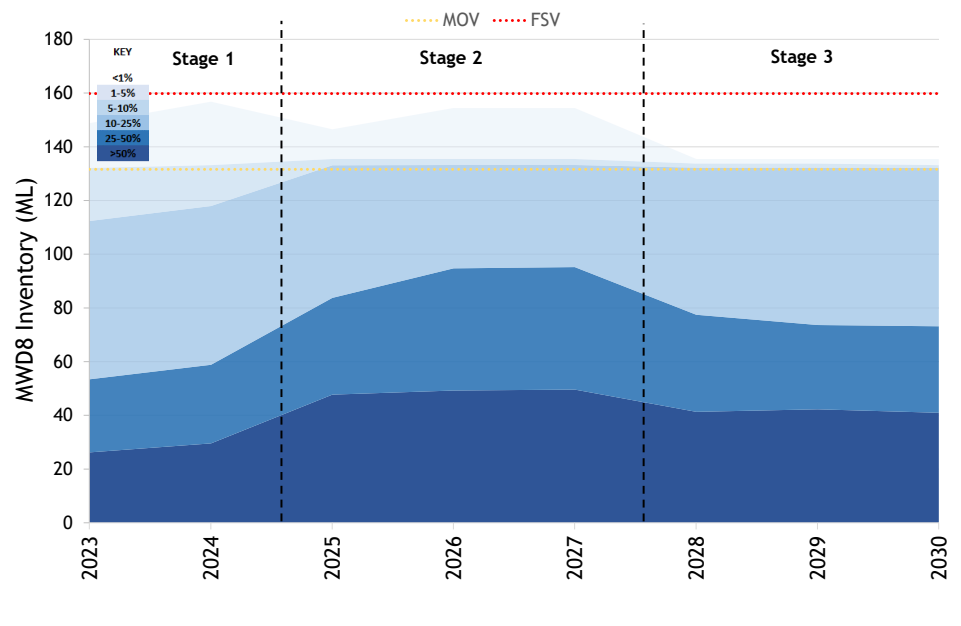

Figure 7.22 – Forecast annual maximum MWD8 inventory – low dust suppression sensitivity analysis

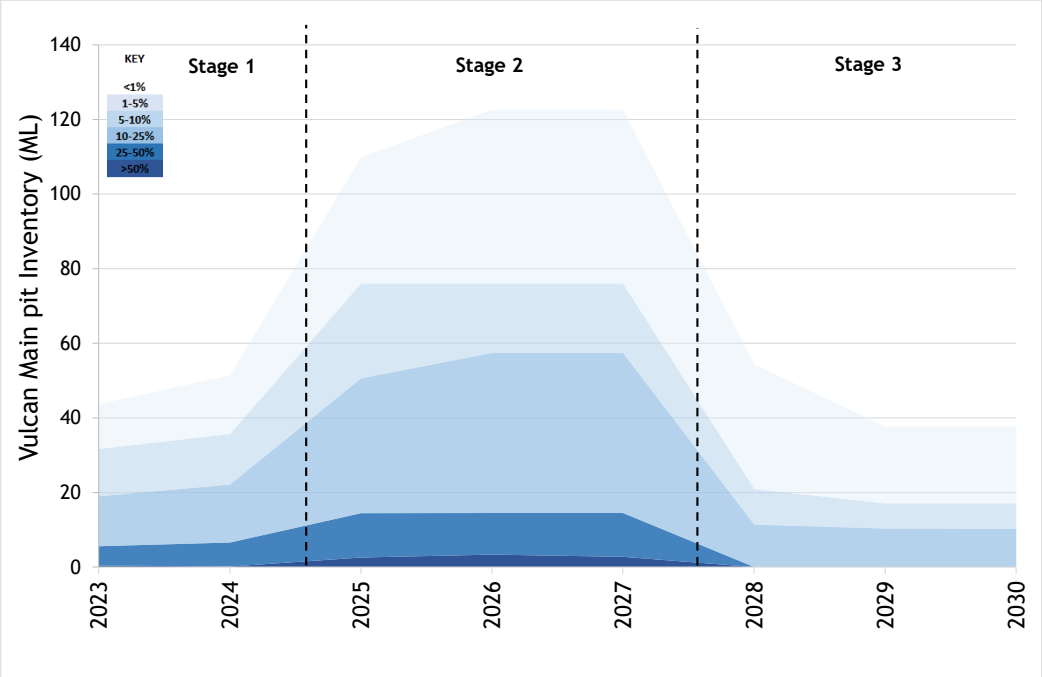

Figure 7.23 - Vulcan Main pit forecast annual maximum mine pit inventory - low dust suppression sensitivity analysis

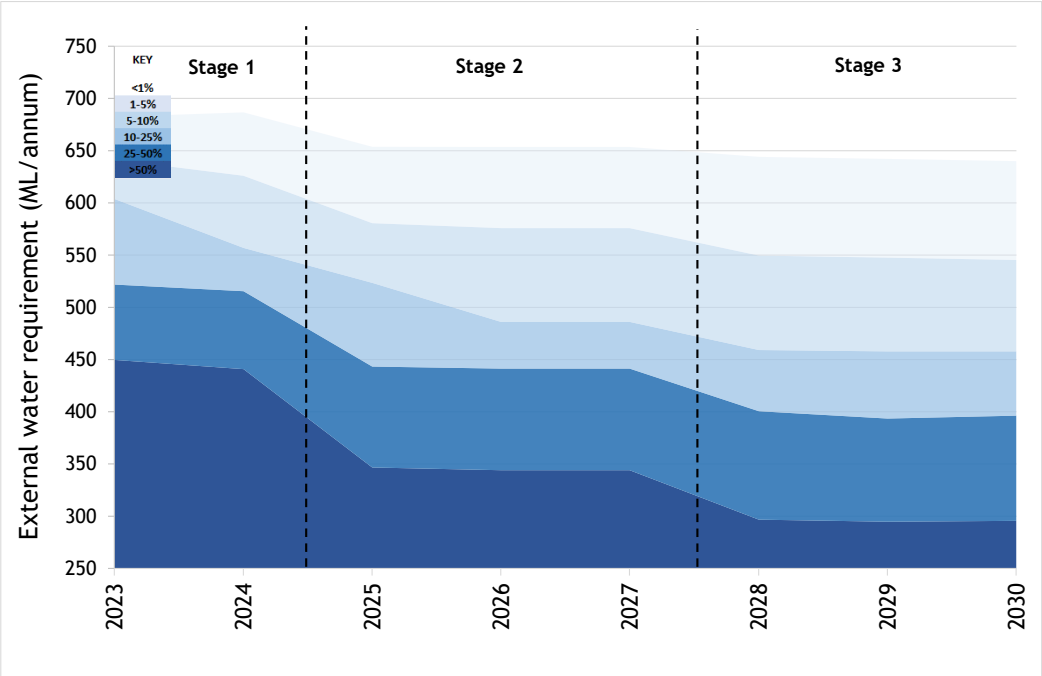

Figure 7.24 - Forecast annual total external water requirement - low dust suppression sensitivity analysis

7.4.2 Climate change

The potential changes to climate within the operational life of the Project were assessed using the projections and methodologies given in the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Commonwealth Bureau of Meteorology (BoM) report entitled "Climate Change in Australia Technical Report" (CSIRO, 2015). This report provides guidance on the possible projections of future climate for the Australian East Coast based on a current understanding of the climate system, historical trends and model simulations of the climate response to changing greenhouse gas and decreasing aerosol emissions.

Projections are given for a number of climatic variables including (but not limited to) temperature, rainfall, wind speed and potential evapotranspiration. CSIRO (2015) presents a number of possible approaches to quantify risks associated with climate change impacts.

For this assessment, the Representative Concentration Pathway 4.5 (RCP4.5) emissions scenario has been adopted. Potential changes in climate have been obtained using the projection builder tool provided in the Climate Change Australia website. Climate variable inputs for the 'best case', 'maximum consensus' case 'and 'worst case' RCP4.5 climate change scenarios are provided in Table 7.3.

Temperatures are expected to increase by approximately 1°C, rainfall is expected to decline by between 3% and 10% and evapotranspiration is expected to increase by between 3% and 4%.

The climate variable inputs (rainfall and evaporation) to the Project water balance model were adjusted to undertake the climate change impact assessment. Table 7.3 shows the adopted climate projections for the 'best case' and 'worst case' RCP4.5 climate change scenarios. The 'maximum consensus' scenario has not been run as it falls between 'best case' and 'worst case' scenarios.

Table 7.3 – Projections of changes to climate

Scenario	Climate model	Mean surface temperature	Rainfall	Evapotranspiration
		Annual change	Annual change	Annual change
Best case	MIROC5	1.02°C	-3.1%	3.2%
Maximum consensus	MIROC5	1.02°C	-3.1%	3.2%
Worst case	GFDL-ESM2M	1.07°C	-10.4%	3.9%

Figure 7.25 and Figure 7.26 show the forecast annual modelled demand for water from external sources for the 'best' and 'worst' case climate scenarios respectively.

The model results are summarised as follows:

- 'Best' case climate scenario (Figure 7.25):
  - For the 1%ile results (very dry climatic conditions), the 'best' case modelled annual external water demands are up to approximately 15 ML/a higher than the base case results.
  - For the 50%ile results the 'best' case modelled annual external water requirement be up to 10 ML/a higher than the base case results.
- 'Worst' case climate scenario (Figure 7.26):
  - For the 1%ile results (very dry climatic conditions), the 'worst' case modelled annual external water demands are up to approximately 30 ML/a higher than the base case results.

- For the 50%ile conditions, the ‘worst’ case modelled annual external water requirements are up to 80 ML/a higher than the base case.

There is an increase in external water demand requirements under both the ‘best’ and ‘worst’ climate scenarios, when compared with the base case results. This is due to the increase in evaporation and decrease in rainfall under both scenarios.

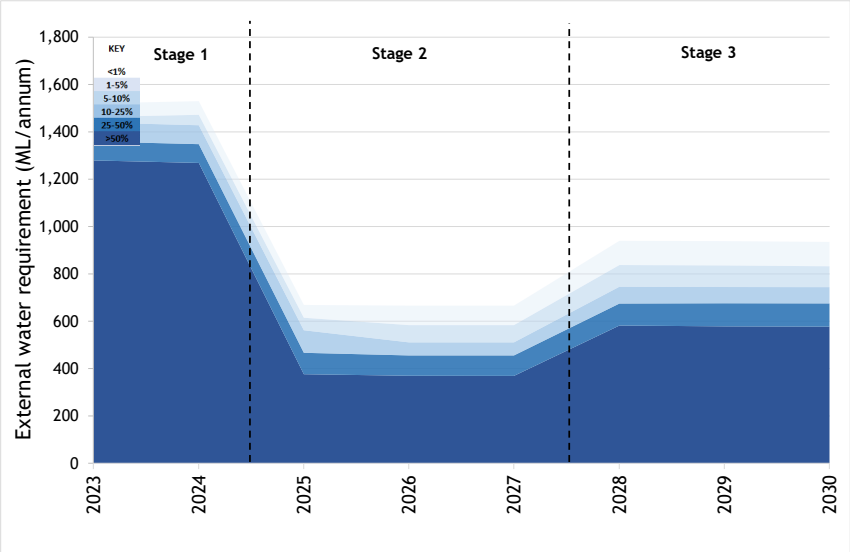

Figure 7.25 – Forecast annual total external water requirement – climate change ‘best case’ sensitivity analysis

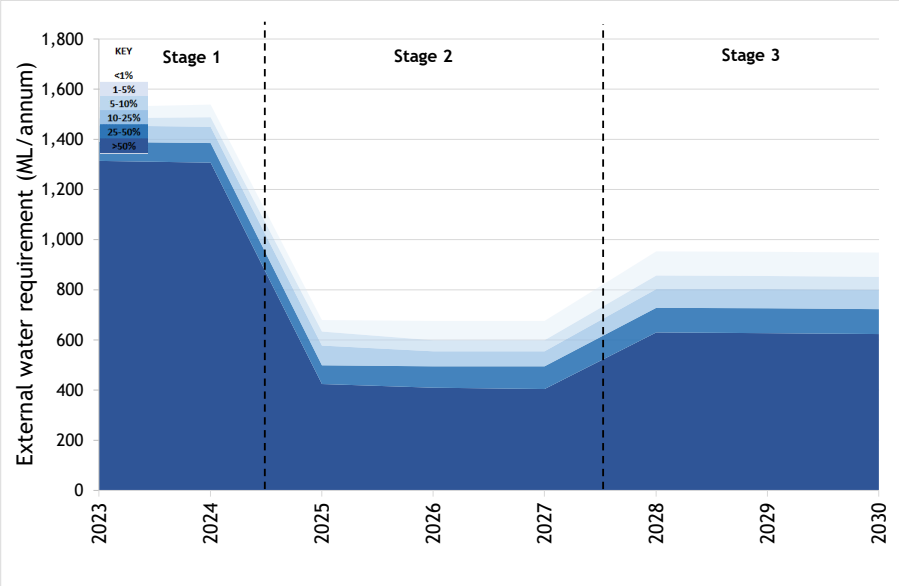

Figure 7.26 – Forecast annual total external water requirement – climate change ‘worst case’ sensitivity analysis

7.5 ADAPTIVE MANAGEMENT OF THE WATER MANAGEMENT SYSTEM

The model results presented above represent the application of the proposed water management system rules over the mine life, regardless of climatic conditions. There are

numerous options for adaptive management of the mine water system to respond to climatic conditions and the current site water inventory in a way that will reduce the risks of impacts to surface water resources.

A site water balance model will be developed once the mine is operational and will be updated regularly (annually or biennially) using site monitoring data.

8 Flood modelling and impact assessment

8.1 OVERVIEW

The drainage features that cross the Project have been assessed to determine the potential impact of the Project on flood behaviour including:

- The potential to impact on flood levels;
- The potential to increase the extent of flooding;
- The potential to increase erosion and/or sedimentation of the impacted waterways;
- The potential to impact on the morphology of the adjacent floodplains; and
- The potential loss of flow from the catchment.

8.2 ADOPTED METHODOLOGY

8.2.1 Hydrological model

A hydrological model was developed for the Boomerang Creek and Hughes Creek catchments, including the features that cross the Project area, using the XP-RAFTS runoff-routing software (Innovyze, 2019). Section 8.3 describes the development, configuration and calibration of the hydrological model.

There was no publicly available recorded streamflow data in the drainage lines that cross the proposed Project area to calibrate the model. As a result, the XP-RAFTS design discharges estimated for Boomerang Creek and Hughes Creek catchments were validated against the Rational Method for the 10% and 1% AEP design flood event.

The Phillips Creek catchment was also included in the hydrologic model because of the availability of recorded water levels and flows. The peak 10% and 1% AEP design discharges estimated for Phillips Creek by the XP-RAFTS model were validated against a Flood Frequency Analysis (FFA) of the annual series peak discharges recorded at the (now closed) Phillips Creek at Tayglen streamflow gauge.

Design flood hydrographs estimated using the calibrated XP-RAFTS model were adopted as inflows in the hydraulic model.

8.2.2 Hydraulic model

The TUFLOW model was used to estimate design flood levels, velocities and extents in Boomerang Creek, Hughes Creek and their tributaries across the Project area for the 10% (1 in 10) AEP, 1% (1 in 100) AEP and 0.1% (1 in 1000) AEP design flood events for the Existing Conditions, Life of Mine (Operational) Conditions and the proposed Final Landform Conditions. The model results were used to assess the potential impacts on flood levels, velocities and extents along Boomerang Creek, Hughes Creek and their tributaries for the Operational and Post-closure conditions. Section 8.4 and Section 8.5 describes the development and configuration of the hydraulic model and Section 8.6 to Section 8.9 provide the flood modelling results and impact assessment.

The potential flood impacts of the Project were assessed for the following three conditions:

- Existing Conditions;
- Life of Mine (Operational) Conditions; and
- Post-closure Conditions.

8.3 EXISTING CONDITIONS HYDROLOGIC MODEL CONFIGURATION

8.3.1 General

Figure 8.1 shows the configuration of the XP-RAFTS model of the Boomerang, Hughes and Phillips Creek catchments. The model consists of a total of 93 sub-catchments, ranging in size from 0.1 km^2 to 59.8 km^2. This includes 49 sub-catchments for Boomerang Creek, 30 sub-catchments for Hughes Creek, 3 sub-catchments for Barrett Creek and 11 sub-catchments for Phillips Creek.

The XP-RAFTS model uses a single sub-catchment approach to determine runoff hydrographs, based on the overall sub-catchment parameters (fraction impervious, slope and roughness). All sub-catchments were assigned a fraction impervious of 0%, catchment slope based on the available topographic data and a Manning's n (roughness) of 0.04. Channel routing was modelled using the Muskingum-Cunge method, based on the channel length and average channel slope for each "link" between catchment nodes.

8.3.2 Design rainfall depths, intensities and temporal patterns

Design rainfall depths and intensities for the design events were derived using intensity-frequency duration (IFD) data obtained from the Bureau of Meteorology's (BOM's) 2019 Rainfall IFD Data System.

The East Coast North temporal patterns were adopted for events up to the 1% AEP as per recommendations in Australian Rainfall and Runoff (AR&R) Data Hub (Geoscience Australia, 2019). For the 0.1% AEP event, one temporal pattern was applied to each storm duration. The 0.1% AEP temporal patterns were adopted from the Generalised Short Duration Method (GSDM) (BOM, 2003) for storm durations of 6 hours and less.

8.3.3 Design rainfall losses

The initial (IL) and continuing loss (CL) method of accounting for rainfall losses was adopted for this assessment. The recommended regional IL and CL values for the Boomerang Creek and Hughes Creek catchments from the AR&R Data Hub (Geoscience Australia, 2019), were 45 mm (prior to adjustment for preburst rainfall) and 1.9 mm/hr respectively. The IL and CL adopted for the 0.1% AEP was 0.0 mm and 1.9 mm/h respectively.

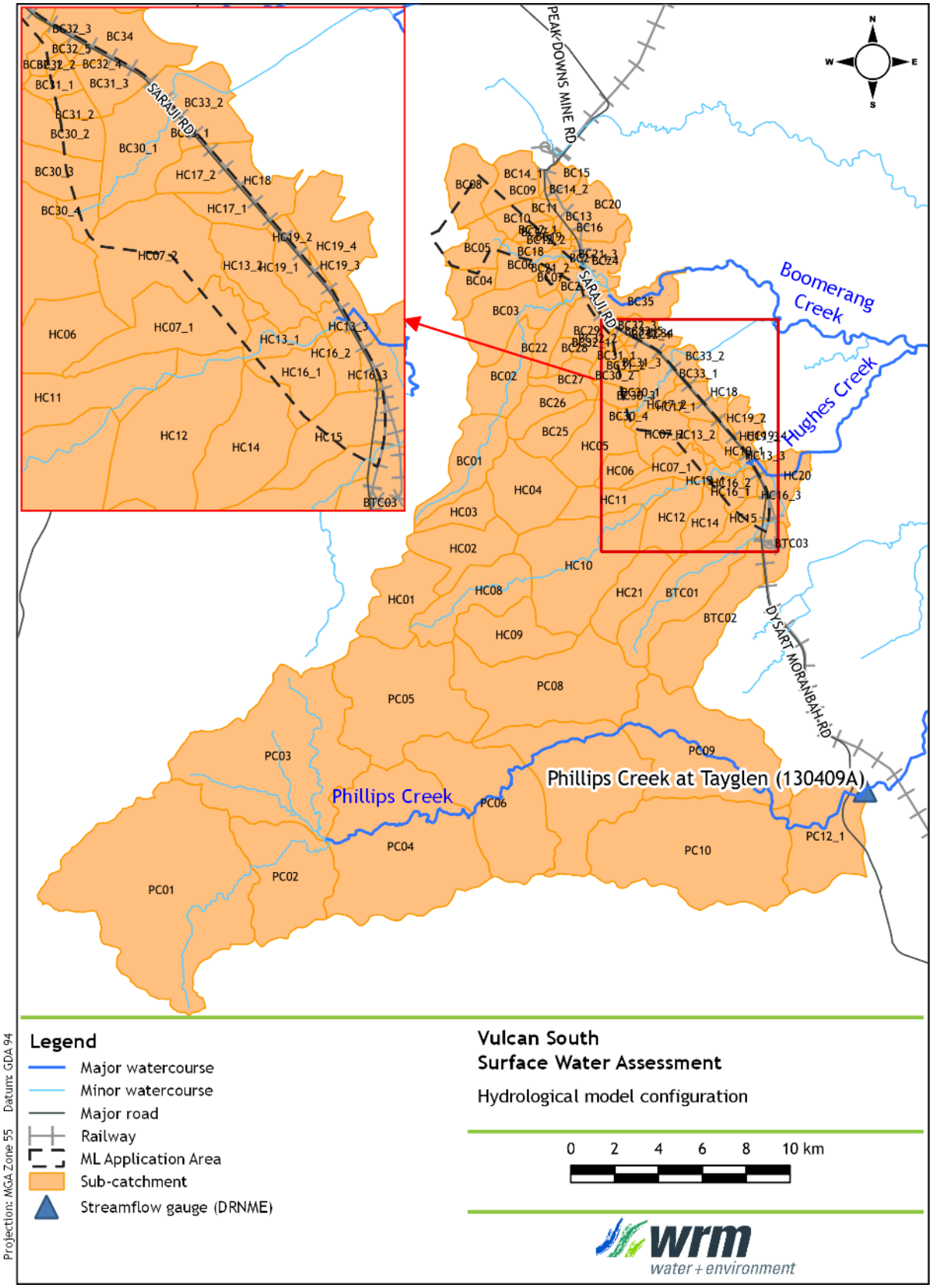

Figure 8.1 - XP-RAFTS model configuration

8.3.4 Peak flow validation

8.3.4.1 Boomerang Creek and Hughes Creek catchments

The Rational Method was used to validate the 10% and 1% AEP design flood discharges in Boomerang Creek and Hughes Creek estimated by XP-RAFTS. Table 8.1 compares the XP-RAFTS design discharge estimates for Boomerang Creek at BC11 and BC17 and for Hughes Creek at HC14 against the Rational Method estimates. The table shows that the design discharges derived by the XP-RAFTS model are generally within 15% of the Rational Method estimates.

Table 8.1 - Peak design discharge comparison between XP-RAFTS and Rational Method

Sub-catchment ID (see Figure 8.1)	Sub-catchment area (ha)	AEP event (%)	Design Discharge (m^3/s)		
			Rational Method	XP-RAFTS	Difference
BC11	61	10%	3.8	3.3	-0.5
		1%	6.7	7.2	0.5
BC17	107	10%	8.1	7.2	-0.9
		1%	14.0	15.5	1.5
HC15	225	10%	11.7	9.9	-1.8
		1%	21.0	21.5	0.5

8.3.4.2 Phillips Creek catchment

The results of the XP-RAFTS model for Phillips Creek were validated by comparing the peak design discharges from XP-RAFTS to the results of a FFA undertaken to the annual flood peak series from DNRME's Tayglen gauge (gauge no. 130409A), which operated between 1968 and 1988. The catchment to the gauge is approximately 344 km^2.

The results compared in Table 8.2 show that the XP-RAFTS 1% AEP peak discharge compares reasonably well with the FFA expected result. The 10% AEP XP-RAFTS peak discharge overestimates the FFA peak discharge, however it is within the 90th percentile confidence limits.

Table 8.2 - FFA at Tayglen gauge compared to XP-RAFTS peak discharge

Design event	XP-RAFTS design peak discharge (m^3/s)	FFA design peak discharges (m^3/s)			% Difference
		Expected result	Lower confidence limit	Upper confidence limit	
10%	490	376	227	622	23%
1%	1,109	1,083	402	2,922	2%

8.3.4.3 Summary

Overall, the XP-RAFTS hydrological model is considered satisfactorily validated and acceptable for estimating design hydrographs for input into the hydraulic model.

8.3.5 Adopted design discharges

The hydrologic model was run for the 1 hr to 24 hr storm durations. Table 8.3 shows the adopted peak design discharges estimated by the XP-RAFTS model at key locations in the vicinity of the Project area for the 10%, 1% and 0.1% AEP design flood events. Table 8.3 also shows the critical storm durations and representative temporal patterns producing the peak discharge at each location.

Table 8.3 - Adopted design discharges, critical storm durations and temporal pattern

Key location	AEP event (%)	XP-RAFTS Ensemble mean peak discharge (m^3/s)	XP-RAFTS adopted design peak discharge (m^3/s)[1]	Critical storm duration (hours)	Temporal pattern number
Drainage Line 2 upstream of Saraji Road (BC06)	10%	50.9	51.5	3	4*
	1%	102.4	102.8	2	8*
	0.1%	NA	233.4	2	NA
Drainage Line 3 at Saraji Road (BC23)	10%	69.4	71.0	6	7
	1%	164.7	166.8	6	2*
	0.1%	NA	323.9	3	NA
Drainage Line 4 at Saraji Road (BC29)	10%	68.5	70.2	6	4
	1%	143.1	145.2	4.5	2
	0.1%	NA	342.4	2	NA
Drainage Line 6 at Saraji Road (BC31_3)	10%	10.9	11.0	3	4
	1%	22.3	23.1	2	1
	0.1%	NA	51.6	1	NA
Drainage Line 7 at Saraji Road (BC30_1)	10%	23.5	23.9	6	4
	1%	52.3	53.5	6	8
	0.1%	NA	115.4	2	NA
Hughes Creek at Norwich Park Branch Railway (HC13_3)	10%	237.3	240.5	6	7*
	1%	554.1	558.7	6	10
	0.1%	NA	1095.4	6	NA
Drainage Line 8 at Norwich Park Branch Railway (HC16_2)	10%	23.5	23.9	6	4
	1%	50.6	50.9	4.5	3
	0.1%	NA	117.8	2	NA
Barrett Creek at Saraji Road (BTC01)	10%	74.8	76.0	6	8
	1%	177.7	182.0	6	3
	0.1%	NA	383.9	3	NA

NA – not applicable; Note that the 1 hour to 6 hour storm durations were all run in the hydraulic model for the 0.1% AEP event.
[1]Adopted design peak discharge calculated from the temporal pattern which generated a peak discharge closest to, but higher than, the ensemble mean.
*Indicates the selected temporal pattern run in the hydraulic model.

8.4 HYDRAULIC MODEL DEVELOPMENT

The two-dimensional TUFLOW hydraulic model (BMT, 2018a) was used to simulate the flow behaviour of Boomerang Creek, Hughes Creek and their tributaries in the vicinity of (and through) the proposed Project area. Separate TUFLOW hydraulic models were developed for Boomerang Creek and Hughes Creek. Figure 8.2 shows the extent of the Existing Conditions TUFLOW model

TUFLOW represents hydraulic behaviour on a fixed grid by solving the full two-dimensional depth averaged momentum and continuity equations for free surface flow (BMT, 2018b). The model automatically calculates breakout points and flow directions within the study area. A 2 m grid cell size was adopted for both TUFLOW models to obtain the best representation of flow distributions between the drainage channels, drainage diversions, hydraulic structures (e.g. culverts) and floodplains.

8.4.1 Topographic data

The TUFLOW model used topographic aerial survey data (LiDAR) supplied by Aerometrex Pty Ltd via Vitrinite. The ground surface data was obtained by LiDAR capture on 7, 8 and 27 May 2019. Aerometrex Pty Ltd quote that the LiDAR data has a vertical root mean squared error of 0.0755 m.

8.4.2 Inflow and outflow boundaries

Figure 8.2 to Figure 8.4 shows the locations of the 2D inflow and outflow boundaries used in the TUFLOW model. The discharge hydrographs estimated using the XP-RAFTS runoff-routing model were adopted as inflows to the TUFLOW model.

Normal depth outflow boundaries were adopted at Peak Downs's Boomerang Creek diversion and East Creek diversion as well as Saraji's Hughes Creek diversion, all located at least 1.6 km downstream of the Project area to ensure that the boundary assumptions have no material impact on peak flood levels in the study area. The adopted tailwater slopes are as follows:

- Boomerang Creek diversion: 0.0025 m/m;
- East Creek diversion: 0.0045 m/m; and
- Hughes Creek diversion: 0.0020 m/m.

8.4.3 Manning's 'n' values

The TUFLOW model uses Manning's 'n' values to represent hydraulic resistance. Manning's 'n' values were adopted based on typical published values (e.g. Chow (1959)) and consistent with Manning's 'n' value adopted in nearby flood studies. Manning's 'n' values were mapped within the study area based on aerial photography taken on 27 May 2019. The following Manning's 'n' values were adopted:

- Vegetated channels: 'n' = 0.060;
- Rocky channels: 'n' = 0.045;
- Light vegetation: 'n' = 0.050;
- Dense vegetation: 'n' = 0.080;
- Exposed soil / unsealed roads: 'n' = 0.025;
- Water bodies / dams: 'n' = 0.015;
- Sealed roads: 'n' = 0.020; and
- Buildings: 'n' = 0.300.

8.4.4 Hydraulic structures

There are 43 culvert structures modelled as 1d structures in the 2d domain (22 in the Boomerang Creek model and 21 in the Hughes Creek model). The culvert locations are shown in Figure 8.2 to Figure 8.4 and include the culverts beneath Saraji Road and the Norwich Park Branch Railway.

The culvert structures within the Peak Downs and Saraji mining leases were modelled as gaps or openings to represent the culverts as information on these structures were not available for this study.

The Hughes Creek bridge was modelled as a layered flow constriction.

8.5 CHANGES TO EXISTING CONDITIONS

8.5.1 Operational Conditions model changes

The Existing Conditions TUFLOW models developed for Boomerang Creek and Hughes Creek were updated to include mine water infrastructure required during operations. The model

updates representing the Operational Conditions configuration is shown in Figure 8.3 and include:

- Proposed life-of-mine landforms and open cut pits;
- Modified inflow boundary locations to represent Operational Conditions catchment areas;
- Proposed culverts along the proposed haul roads, levees, and diversions;
- Proposed levees and diversions; and
- Proposed haul roads.

8.5.2 Post-closure Conditions model changes

The Existing Conditions TUFLOW models developed for the Project was updated to reflect the Post-closure Conditions configuration. The model updates shown in Figure 8.4 include:

- Proposed final landforms drainage corridors;
- Modified inflow boundary locations to represent Post-closure Conditions catchment areas; and
- Proposed culverts.

8.5.3 Proposed culverts

The proposed culvert configurations shown in Figure 8.3 and Figure 8.4 are summarised in Table 8.4 below. The proposed culvert configurations were sized based on the following:

- Proposed culverts along the proposed haul road in the Operational Conditions model were provided by Vitrinite; and
- Proposed culverts along Saraji Road in the Operational and Post-closure conditions models were based on existing culverts.

Table 8.4 – Proposed culvert configurations, Operational and Post-closure conditions

Culvert ID	Type	Diameter / width (m)	Height (m)	No. of barrels	US Invert level (mAHD)	DS Invert level (mAHD)
CulvHR1.3[1]	CSP	1.2	-	4	224.98	224.02
CulvHR1.4[1]	CSP	1.2	-	4	226.19	225.9
CulvHR1.5[1]	CSP	1.05	-	2	231.0	230.12
CulvHR2.3[1]	CSP	1.2	-	6	204.93	204.75
CulvHR2.2[1]	CSP	1.2	-	10	200.9	200.45
CulvHR2.1[1]	CSP	1.2	-	10	200.16	200.09
C0023393*	RCP	0.75	-	4	209.39	208.51
C0023391*	RCP	0.9	-	1	202.85	202.7
C0023390*	RCBC	2.0	1.5	2	201.20	201.20
C0023389*	RCP	0.75	-	2	203.6	203.5

CSP = Corrugated steel pipe
RCP = Reinforced concrete pipe
RCBC = Reinforced concrete box culvert
[1] = Provided by Vitrinite
* = Based on existing culverts

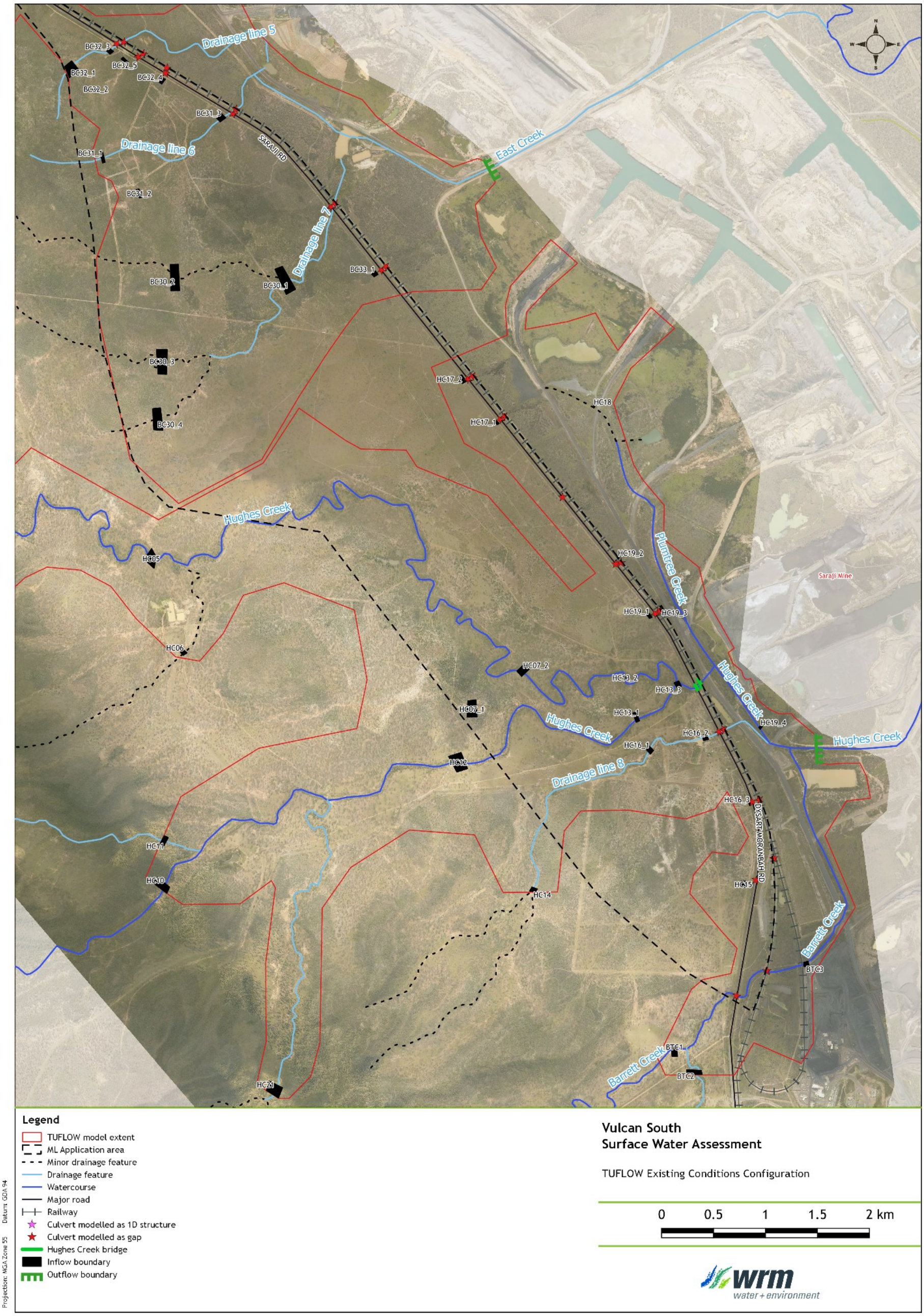

Figure 8.2 – Existing Conditions hydraulic model configuration

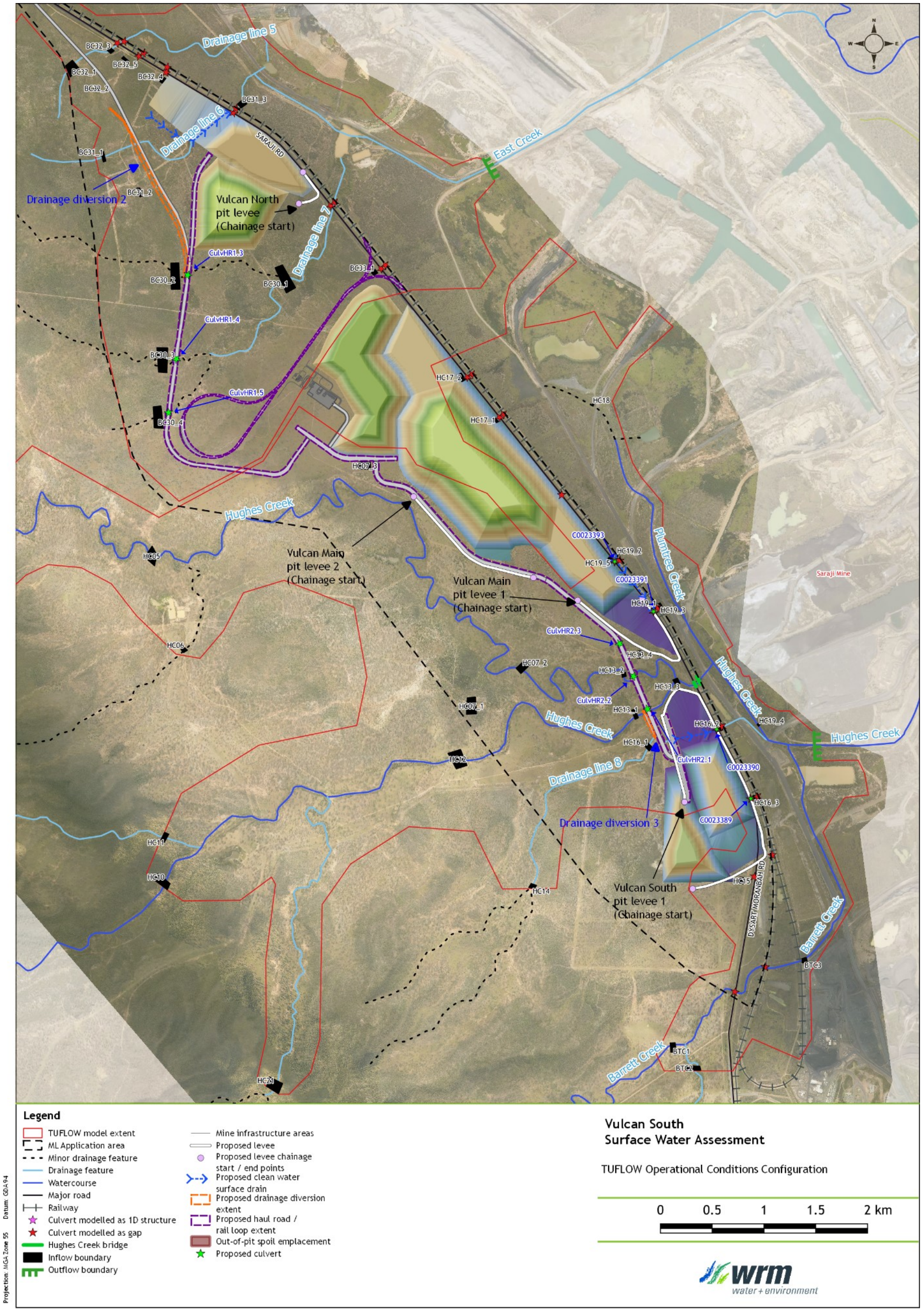

Figure 8.3 – Life of mine (Operational) Conditions hydraulic model configuration

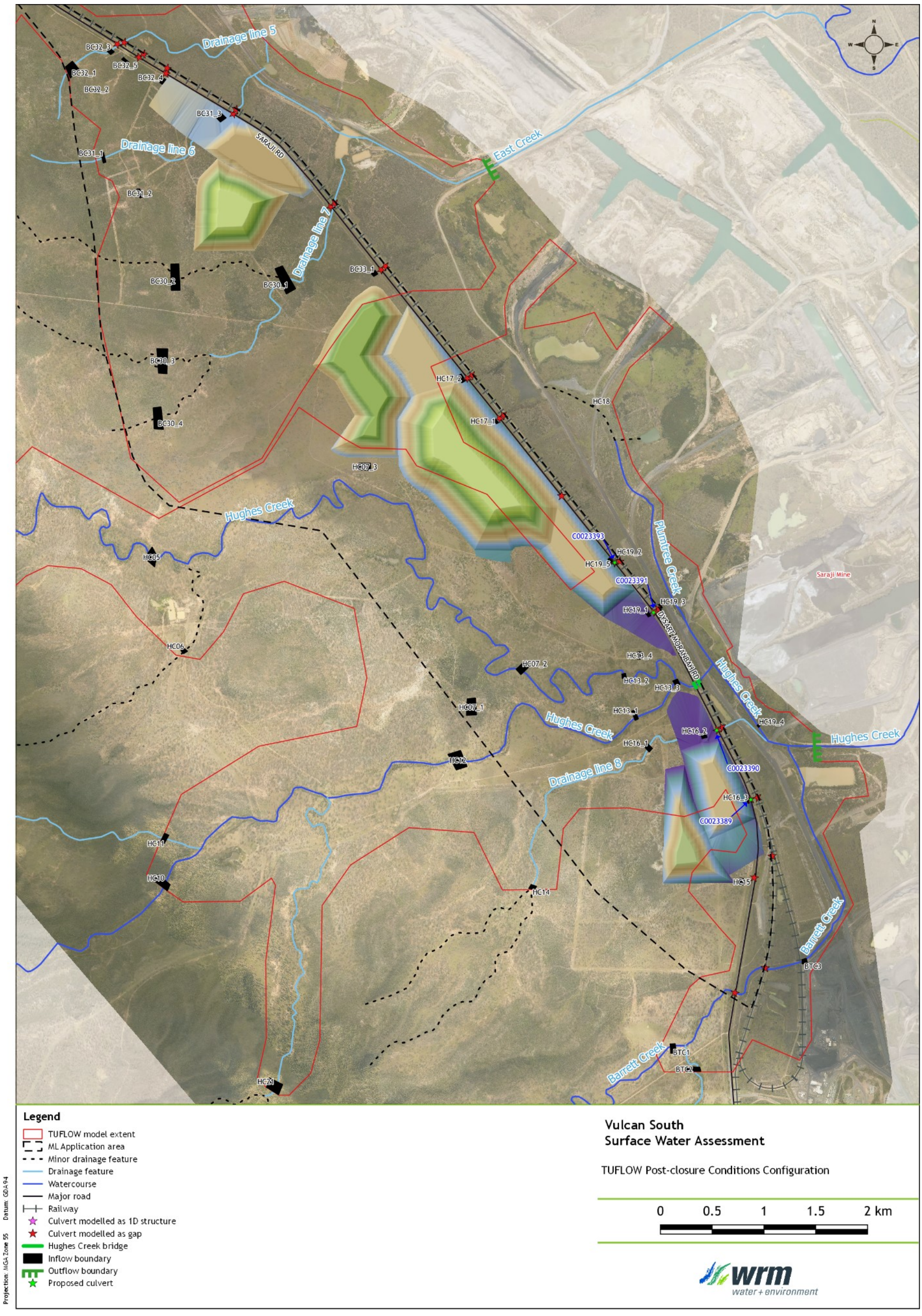

Figure 8.4 – Post-closure Conditions hydraulic model configuration

8.5.4 Proposed flood protection levees

Table 8.5 shows the required minimum crest levee levels during Operational Conditions along the proposed pit flood protection levees (see Figure 8.3). The proposed flood protection levees will be required during operations to protect the mining pit from ingress of clean water. Figure 8.3 shows the reported chainage start (0 m) locations along the proposed flood protection levees.

It is recommended that peak 0.1% AEP peak flood levels are adopted for the basis of the flood levee requirements during operations and the freeboard for determining the required levee crest level is 1 m above the flood level. The results show that the proposed flood protection levees will range between 1 m and 5 m high.

The proposed flood protection levee configurations are preliminary only. The final horizontal and vertical alignment will be confirmed in conjunction with the proposed haul road and final landform requirements during the design phase.

Table 8.5 – 0.1% AEP flood levels plus 1 m freboard height adjacent to the proposed flood protection levees required for operations

Chainage (m)	Required minimum crest levee level with 1 m freeboard requirement included (mAHD)			
	Vulcan North pit levee	Vulcan Main pit levee 1	Vulcan Main pit levee 2	Vulcan South pit levee
0	-	-	-	-
200	221.1	208.6	217.3	208.0
400	221.1	208.3	216.0	208.0
600	-	207.4	215.0	208.0
800	-	207.4	214.5	207.8
1000	-	207.4	212.6	207.5
1200	-	207.1	211.3	207.1
1400	-	206.9	211.0	206.7
1600	-	206.9	211.0	206.4
1800	-	206.9	211.0	206.4
2000	-	-	-	206.4
2200	-	-	-	206.2
2400	-	-	-	206.2
2600	-	-	-	206.1
2800	-	-	-	206.9
3000	-	-	-	208.2
3200	-	-	-	208.6
3400	-	-	-	208.7
3600	-	-	-	208.7

8.5.5 Proposed drainage diversions

The proposed drainage diversions were designed to divert runoff from undisturbed catchments around the proposed Vulcan North, Vulcan Main and Vulcan South pits to adjacent existing drainage lines. Figure 8.3 shows the location of the proposed drainage diversion.

The preliminary sizing of the proposed drainage diversions was based on attaining sufficient capacity to ensure that the proposed pits are protected against floodwater during the 0.1% AEP event.

Drainage diversion 2 was designed with the following characteristics:

- a 10 m base width
- a 1(V):3(H) batter slope to existing ground levels; and
- a 2 m high bund along the western side of the drain.

The preliminary Drainage diversion 3 configuration was designed for local 10% AEP flows as the results of the modelled events show that the Hughes Creek floodplain is inundated during larger events. Drainage diversion 3 was designed with a 10 m base width and with 1(V):3(H) batter slopes that grade up to existing ground levels.

The results show that the drainage diversions have sufficient capacity to convey flood events up to the 0.1% AEP. Refinements to the design will be required to be undertaken in conjunction with confirmation of the proposed haul road and final landform configurations. Also, careful consideration of scour protection will be required at the upstream and downstream ends of the drainage diversions as well as at tributary inflow locations.

8.6 EXISTING CONDITIONS DESIGN FLOOD LEVELS AND EXTENTS

8.6.1 General

The TUFLOW model was used to determine the Existing Conditions 10%, 1% and 0.1% AEP design flood levels, depth, extents and velocities in the vicinity of the Project. Figure B.1 to Figure B.6 in Appendix B show the predicted flood depth and flood velocity profiles under Existing Conditions for the 10%, 1% and 0.1% AEP events.

8.6.2 East Creek

Key findings on flooding within the East Creek catchment and its tributaries are summarised below:

- For the 10% AEP event (see Figure B.1 and Figure B.4):
  - floodwaters through the Project area are generally conveyed within the channel banks of natural drainage lines. Saraji Road is overtopped at some crossing locations. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey the 10% AEP event;
  - peak flood velocities along natural drainage channels in the vicinity of the Project area are up to 2.0 m/s in localised areas; and
  - overbank flood depths adjacent to natural drainage lines are generally shallow (less than 0.5 m).
- For the 1% AEP event (see Figure B.2 and Figure B.5):
  - floodwaters through the Project area are generally conveyed within the channel banks of natural drainage lines with limited overbank flooding. Saraji Road is overtopped at most crossing locations. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey the 1% AEP event;
  - peak flood velocities in natural drainage channels are typically elevated (greater than 2.0 m/s in localised areas). Overbank velocities are generally up to 1 m/s; and
  - flood widths and depths adjacent to natural drainage lines are greatest upstream of Saraji Road and Norwich Park Branch Railway where floodwaters are impounded behind the constructed embankments.

- For the 0.1% AEP event (see Figure B.3 and Figure B.6):
  - floodwaters through the Project area are generally conveyed within the channel banks of natural drainage lines with confined overbank flooding;
  - flood velocities along natural drainage channels are typically elevated (greater than 2.5 m/s in localised areas). Overbank velocities are generally up to 1 m/s; and
  - peak flood widths and depths along the eastern side of the Project area increase as natural drainage lines drain towards Saraji Road and Norwich Park Branch Railway where floodwaters are impounded behind the constructed embankments. Flood depths impounded behind the railway embankment at the eastern boundary of the Project are up to 5 m.

8.6.3 Hughes Creek

Key findings on flooding within the Hughes Creek catchment and its tributaries are summarised below:

- For the 10% AEP event (see Figure B.1 and Figure B.4):
  - floodwaters through the Project area are generally conveyed within the Hughes Creek channel. Minor breakouts occur along the Drainage line 8 and Barrett Creek channels upstream of Saraji Road. The Norwich Park Branch Railway culverts have sufficient flow capacity to convey the 10% AEP event;
  - peak flood velocities along natural drainage channels are typically elevated in the vicinity of the Project area (greater than 2.0 m/s in localised areas). Overbank velocities are generally up to 1 m/s; and
  - overbank flood depths adjacent to natural drainage lines are generally shallow (less than 0.5 m). Notwithstanding this, Hughes Creek flood depths are up to 3 m upstream of the railway.
- For the 1% AEP event (see Figure B.2 and Figure B.5):
  - overbank flooding occurs at several locations within the Project area along Hughes Creek, with flood widths of up to 1.6 km just upstream of the railway;
  - overbank flood depths are up to 4.5 m adjacent to Hughes Creek upstream of the railway. The railway embankment is overtopped during this event; and
  - peak flood velocities along natural drainage channels are typically elevated (up to 3.2 m/s in localised areas). Overbank velocities are generally up to 1.5 m/s.
- For the 0.1% AEP event (see Figure B.3 and Figure B.6):
  - significant overbank flooding occurs along Hughes Creek within the Project area along Hughes Creek and Barrett Creek, with flood widths of up to 2 km;
  - overbank flood depths are up to 5 m adjacent to Hughes Creek, with some localised areas that exceed 5 m; and
  - peak flood velocities along natural drainage channels are typically elevated (up to 4 m/s in localised areas). Overbank velocities are generally up to 2.0 m/s.

8.7 OPERATIONAL CONDITIONS POTENTIAL FLOOD IMPACTS

8.7.1 General

Figure 8.3 shows the proposed Life of Mine (Operational) Conditions configuration used in the TUFLOW model. The TUFLOW model results show that the proposed Operational Conditions configuration may cause potential flow constraints and flood impacts as a result of the life of mine infrastructure. These include:

- Changed flow conditions between the Norwich Park Branch Railway and proposed Saraji Road realignment and operational flood protection levees;

- Changed catchment areas due to the Operational Conditions configuration;
- Constriction of the overbank flooding areas at locations where the permanent out-of-pit spoil emplacement are proposed;
- Constriction of the overbank flooding at proposed levee locations to protect pits from inundation; and
- Diversion of floodwaters around proposed pit locations into adjacent drainage lines.

Figure C.1 to Figure C.6 in Appendix C show the change in peak water levels and the change in peak velocities for Operational Conditions compared to Existing Conditions across the Project.

Table 8.6 summarises the changes in peak water levels and peak velocities for the 10%, 1% and 0.1% AEP events at the reporting location points shown in Figure C.1 to Figure C.6. Figure 8.5 and Figure 8.6 provide a comparison of peak water levels along East Creek and along Hughes Creek, respectively.

A range of measures would be required to mitigate the potential impacts. These mitigation measures may include erosion protection in locations of increased flood velocities, staged flood protection levee construction (acknowledging this may impact on mine plan scheduling), limit the timeframe that the proposed infrastructure is in place, additional road/rail culverts, etc. Where impacts cannot be fully mitigated, consent may be required from impacted neighbouring landowners/stakeholders (e.g., Aurizon, council, BMA).

Table 8.6 – Changes in peak water levels (m) and peak velocities (m/s) under Operational Conditions at reporting locations in the vicinity of the Project

Location ID	Modelled change in peak water level (m)			Modelled change in peak velocities (m/s)		
	10%	1%	0.1%	10%	1%	0.1%
RP1	-0.04	-0.02	-0.04	-0.11	-0.06	-0.18
RP2	0.01	0.02	-0.06	0.01	0.01	-0.03
RP3	0.29	0.21	0.28	-0.06	-0.09	-0.02
RP4	0.18	0.28	0.45	0.06	0.06	0.04
RP5	0.04	0.04	-0.05	0.02	0.01	0.02
RP6	0.73	0.67	0.83	-0.57	-0.60	-0.61
RP7	-0.01	0.20	0.32	0.04	-0.03	0.16
RP8	-0.13	0.05	0.04	-0.01	-0.03	-0.03
RP9	0.53	0.77	1.07	-0.07	-0.03	-0.09
RP10	-0.01	0.17	0.24	-0.01	-0.01	0.04
RP11	-0.01	0.15	0.24	0.01	0.02	0.09

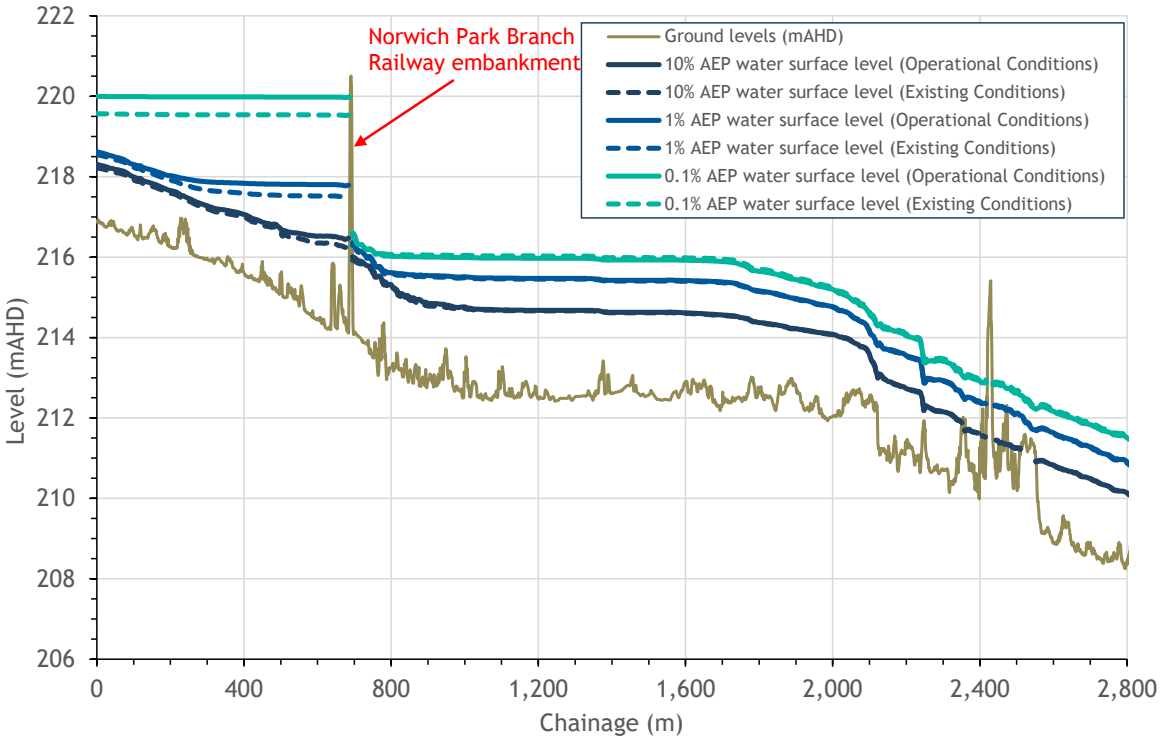

Figure 8.5 – Comparison of Operational and Existing conditions water surface levels along East Creek for the 10%, 1% and 0.1% AEP events

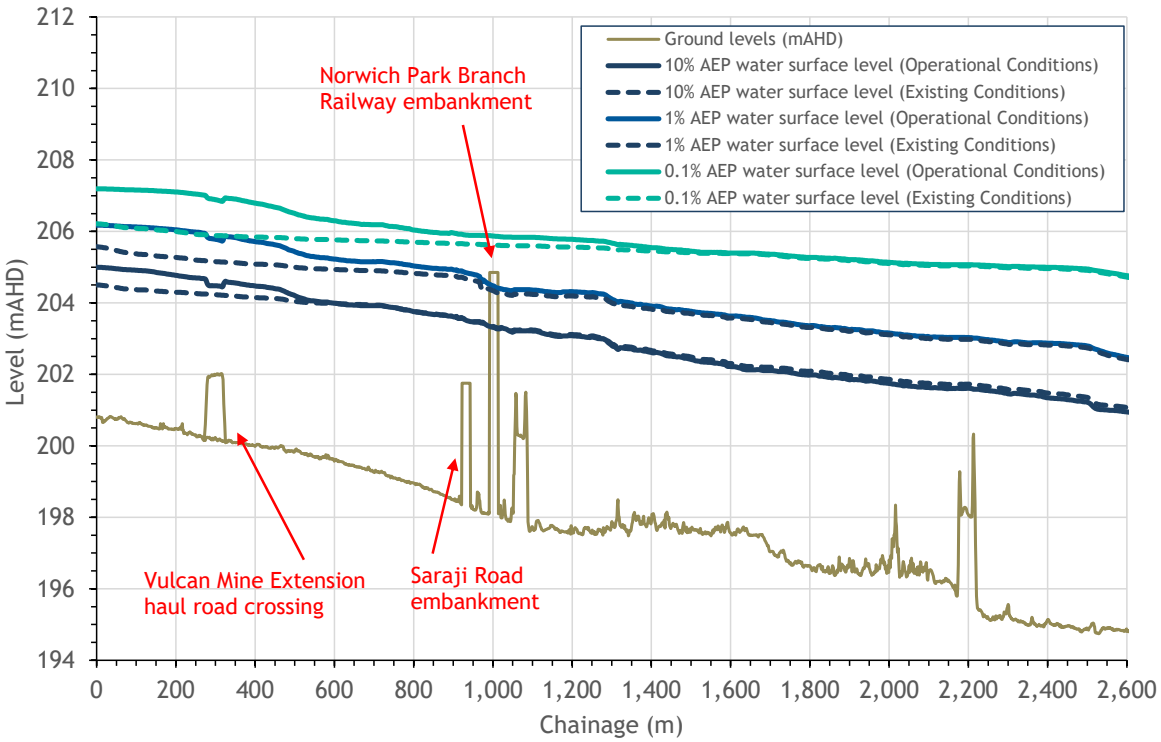

Figure 8.6 – Comparison of Operational and Existing conditions water surface levels along Hughes Creek for the 10%, 1% and 0.1% AEP events

8.7.2 East Creek

Key findings on potential Operational Conditions flooding impacts along East Creek in the vicinity of the project include:

- For the 10% AEP event (see Figure C.1 and Figure C.4):
  - within the Project MLA area, there are increases in peak water levels and peak velocities along Drainage line 7 due to Drainage Diversion 2 diverting flows from Drainage line 6 around the proposed Vulcan Main pit;
  - within the railway corridor, there are increases in peak water levels of up to 0.2 m and increases in peak velocities of up to 0.23 m/s; and
  - at the TUFLOW model downstream boundary (Location ID RP2) there are negligible impacts.
- For the 1% AEP event (see Figure C.2 and Figure C.5):
  - impacts are generally confined within the Project MLA area, upstream of the Norwich Park Branch Railway corridor; and
  - at the railway culvert upstream invert along Drainage line 7, there are increases in peak water levels and peak velocities of up to 0.3 m and 0.12 m/s, respectively;
  - the Norwich Park Branch Railway culverts along Drainage line 7 have sufficient flow capacity to drain the additional catchment flows without overtopping the railway finished formation level; and
  - at the TUFLOW model downstream boundary (Location ID RP2) there are negligible impacts.
- For the 0.1% AEP event (see Figure C.3 and Figure C.6):
  - floodwaters are impounded behind the constructed embankment of the Norwich Park Branch Railway;
  - impacts are generally confined within the Project MLA area, upstream of the Norwich Park Branch Railway corridor;
  - at the railway culvert upstream invert along Drainage line 7, there are increases in peak water levels and peak velocities of up to 0.45 m and 0.2 m/s, respectively;
  - the Norwich Park Branch Railway culverts along Drainage line 7 have sufficient flow capacity to drain the additional catchment flows without overtopping the top of ballast level; and
  - at the TUFLOW model downstream boundary (Location ID RP2) there are negligible impacts.

8.7.3 Hughes Creek

Key findings on potential Operational Conditions flooding impacts along Hughes Creek in the vicinity of the project include:

- For the 10% AEP event (see Figure C.1 and Figure C.4):
  - within the Project MLA area, there are increases in peak water levels and peak velocities along Hughes Creek upstream of the proposed haul road; and
  - within the railway corridor and downstream of the railway, there are no increases in peak water levels and localised area of increases in peak velocities of up to 0.5 m/s.
- For the 1% AEP event (see Figure C.2 and Figure C.5):
  - within the Project MLA area, there are impacts due to the overbank constriction created between the proposed Vulcan South and Vulcan Main pit levees;

- downstream of the railway, at the model boundary (Location ID RP8), there are negligible increases in peak velocities and increases in peak water levels of 0.05 m; and
- The railway embankment is not overtopped due to increases in peak water levels during Operational Conditions and therefore has a 1% AEP flood immunity.

- For the 0.1% AEP event (see Figure C.3 and Figure C.6):
  - floodwaters overtop the Norwich Park Branch Railway under both Existing and Operational conditions;
  - within the Project MLA area, there are impacts due to the overbank constriction created between the proposed Vulcan South and Vulcan Main pit levees. Peak water levels increase by up to 1.4 m and peak velocities increase by up to 3.4 m/s along the haul road. Erosion and scour protection measures will be required to mitigate these impacts;
  - at the Hughes Creek bridge, there are increases in peak water levels and peak velocities of up to 0.32 m and 1.1 m/s, respectively; and
  - at the TUFLOW model downstream boundary (Location ID RP8) there are negligible impacts.

8.8 POST-CLOSURE CONDITIONS POTENTIAL FLOOD IMPACTS

8.8.1 General

Figure 8.4 shows the proposed Post-closure Conditions configuration used in the TUFLOW model. The TUFLOW model results show that the proposed Post-closure Conditions configuration may cause potential flow constraints and flood impacts within the Project area. These include:

- Changed flow conditions between the Norwich Park Branch Railway and proposed final landform locations;
- Changed catchment areas due to the final landform configuration; and
- Constriction of the overbank flooding areas at locations where the permanent out-of-pit spoil emplacement is proposed.

Figure D.1 to Figure D.6 in Appendix D show the change in peak water levels and the change in peak velocities for the 10%, 1% and 0.1% AEP events for Post-closure Conditions compared to Existing Conditions across the Project.

Table 8.7 summarises the changes in peak water levels and peak velocities for the 10%, 1% and 0.1% AEP events at the reporting location points shown in Figure D.1 to Figure D.6.

In general, the Post-closure Conditions configuration will not impact on peak water levels or velocities along Drainage line 5, Drainage line 6, Drainage line 7 and East Creek for events up to and including the 0.1% AEP event. The results also show that there are negligible impacts along Drainage line 8 and Hughes Creek for the 10% and 1% AEP events and small impacts for the 0.1% AEP event.

There will be some areas that will require erosion control measures such as where existing natural drainage paths enter constructed drains and at the upstream and downstream ends of constructed drains. Hence, the proposed surface water drainage infrastructure for the Project will result in a very low risk of changes to the existing erosion and sedimentation process in the receiving waters.

Table 8.7 – Changes in peak water levels (m) and peak velocities (m/s) under Post-closure Conditions at reporting locations in the vicinity of the Project

Location ID	Modelled change in peak water level (m)			Modelled change in peak velocities (m/s)		
	10%	1%	0.1%	10%	1%	0.1%
RP1	0.00	0.00	0.01	0.00	0.00	0.01
RP2	0.00	0.00	0.00	0.00	0.00	0.00
RP3	0.00	0.00	0.00	0.00	0.00	0.00
RP4	0.00	0.00	0.00	0.00	0.00	0.00
RP5	0.00	0.00	0.00	0.00	0.00	0.00
RP6	0.01	0.02	0.02	0.00	0.00	-0.01
RP7	0.00	0.04	0.05	0.01	0.00	0.03
RP8	-0.01	0.04	0.04	0.00	0.01	0.01
RP9	0.01	0.03	0.05	0.00	0.00	-0.01
RP10	-0.01	0.02	0.04	-0.04	-0.04	0.00
RP11	0.00	0.03	0.04	0.01	0.01	0.01

8.8.2 East Creek

Key findings on potential Post-closure Conditions flooding impacts along East Creek in the vicinity of the project include:

- For the 10% AEP event (see Figure D.1 and Figure D.4) and 1% AEP event (see Figure D.2 and Figure D.5):
  - there are no increases in peak water levels and peak velocities within the Norwich Park Branch Railway corridor;
  - downstream of the railway corridor, there are no modelled increases in peak water levels and peak velocities; and
  - within the Project MLA area, there are no increases in peak water levels and peak velocities.
- For the 0.1% AEP event (see Figure D.3 and Figure D.6):
  - there are no increases in peak water levels within the Norwich Park Branch Railway corridor. There are minor increases in peak velocities of up to 0.1 m/s within the railway corridor;
  - downstream of the railway corridor, there are no modelled increases in peak water levels and peak velocities; and
  - within the Project MLA area, there are no increases in peak water levels. There are generally no increases in peak velocities, except along the toe of the proposed Vulcan Main pit final landform at Drainage line 6 where maximum velocities are up to 0.9 m/s.

8.8.3 Hughes Creek

Key findings on potential Post-closure Conditions flooding impacts along Hughes Creek in the vicinity of the project include:

- For the 10% AEP event (see Figure D.1 and Figure D.4):
  - there are no increases in peak water levels and peak velocities within the Norwich Park Branch Railway corridor;

- downstream of the railway corridor, there are no modelled increases in peak water levels and peak velocities; and
- within the Project MLA area, there are generally no increases in peak water levels and peak velocities except for at the proposed Vulcan South pit final landform along Drainage line 8. Localised impacts occur where the Post-closure Conditions reinstates the natural topography. Rehabilitation of Post-closure Conditions topography in this area will be undertaken to replicate a Drainage line 8 channel and mitigate these impacts.

- For the 1% AEP event (see Figure D.2 and Figure D.5):
  - there are no increases in peak water levels and generally only localised areas of increase in peak velocities within the Norwich Park Branch Railway corridor;
  - downstream of the railway corridor, there are minor increases in peak water levels and peak velocities along Hughes Creek and at the downstream boundary of generally up to 0.1 m and 0.1 m/s, respectively; and
  - within the Project MLA area, there are generally no increases in peak water levels and peak velocities, except for along the toe of the proposed Vulcan Main and Vulcan South pit final landforms where it is recommended for erosion and scour protection to be implemented.
- For the 0.1% AEP event (see Figure D.3 and Figure D.6):
  - there are no increases in peak water levels and generally only localised areas of increase in peak velocities within the Norwich Park Branch Railway corridor;
  - downstream of the railway corridor, there no increases in peak water levels and minor increases in peak velocities along Hughes Creek and at the downstream boundary of generally up to and 0.2 m/s; and
  - within the Project MLA area, there are generally no increases in peak water levels and peak velocities, except for along the toe of the proposed Vulcan Main and Vulcan South pit final landforms where it is recommended for erosion and scour protection to be implemented.

8.9 SUMMARY

The hydrologic (XP-RAFTS) model design discharge hydrographs for the Boomerang Creek and Hughes Creek catchments were input to hydraulic (TUFLOW) model. Peak water levels and peak velocities were compared to assess the potential flood impacts in the vicinity of the Project for the 10%, 1% and 0.1% AEP events. The three scenarios assessed were:

- Existing Conditions;
- Life of mine (Operational) Conditions; and
- Post-closure Conditions.

The results of the comparison between Operational Conditions peak flood levels and Existing Conditions peak flood levels show that flood impacts as a result of the proposed mine water infrastructure are generally within the Project MLA area. The impacts that extend into the Norwich Park Branch Railway corridor and downstream of the Project boundary may require mitigation measures. These could include erosion protection in locations of increased flood velocities, staged flood protection levee construction (acknowledging this may impact on mine plan scheduling), limit the timeframe that the proposed infrastructure is in place, and additional road/rail culverts, etc. Where impacts cannot be fully mitigated, consent may be required from impacted neighbouring landowners/stakeholders (e.g., Aurizon, council, BMA).

The results of the comparison between Post-closure Conditions peak flood levels and Existing Conditions peak flood levels show that generally there are only minor impacts under the final landform configuration. These impacts are generally confined within the Project MLA area. Existing conditions natural topography will be reinstated within the Hughes Creek floodplain as well as Drainage line 6 and Drainage line 8 Post-closure to

replicate the existing drainage line channels to minimise the impacts associated with the Post-closure Conditions landform.

9 Surface water monitoring

9.1 OVERVIEW

Monitoring of surface water quality both within and external to the mine site will form a key component of the surface water management system. Monitoring of upstream, onsite and downstream water quality will assist in demonstrating that the site water management system is effective in meeting its objective of minimal impact on receiving water quality and will allow for early detection of any impacts and appropriate corrective action.

The surface water monitoring protocols will:

- provide valuable information on the performance of the water management system;
- ensure compliance with the Project EA; and
- facilitate adaptive management of water resources on the site.

Details of the receiving water quality monitoring, mine affected water quality monitoring and sediment dam water monitoring program are outlined in Sections 9.2, 9.4 and 9.5 respectively. Locations of the proposed surface water monitoring locations and mine affected dam monitoring locations are shown in Figure 9.1 and Figure 9.2 and summarised in Table 9.1. Note that the mine water release points are the same as the mine water monitoring locations (i.e. at the spillway).

Table 9.1 – Proposed surface water and mine water dam quality monitoring locations

Station ID	Catchment Area	Easting*	Northing*	Description
Receiving water monitoring sites				
Upstream sites				
VESW3	Harrow Creek	615,316	7,528,175	Harrow Creek upstream of the Project
VESW4	Boomerang Creek	623,621	7,531,088	Drainage line 4 upstream of Saraji Road
VSW5	Hughes Creek	626,062	7,522,834	Hughes Creek approximately 5.0 km upstream of Saraji Road
VSW6	Hughes Creek	630,659	7,521,084	Barrett Creek upstream of Saraji Road
Downstream sites				
VESW1[1]	Harrow Creek	614,134	7,543,160	Harrow Creek downstream of Highwall mining area
VSW4[1]	Hughes Creek	630,357	7,524,021	Hughes Creek upstream of Saraji Road
VSW7[1]	East Creek	626,767	7,528,677	Drainage line 7 upstream of Saraji Road
VSW9	East Creek	625,830	7,529,606	Drainage line 6, upstream of Saraji Road
VSW10	Hughes Creek	630,541	7,523,648	Drainage line 8, upstream of Saraji Road
VSW11	Boomerang Creek	622,511	7,533,708	Minor drainage line, upstream of confluence of Drainage line 2
Mine water dam monitoring locations/release points				
MWD6	-	626,383	7,526,338	MWD6 spillway to MWD8
MWD7	-	626,719	7,526,640	MWD7 spillway to MWD8
MWD8	-	626,637	7,526,256	MWD8 spillway to Hughes Creek
MWD9	-	628,860	7,524,968	MWD9 spillway to Hughes Creek

* Projection – MGA94 (Zone 55)
[1] Remote logger location

9.2 REEF DISCHARGE STANDARDS

Section 3.2.3 of DES (2021) states that "triggers for assessment under section 41AA do not include diffuse sources of contaminated stormwater that contains sediment only. This will allow for an exclusion for stormwater proposed to be managed through erosion and sediment control measures."

Erosion and Sediment Control measures have been outlined in this EA (Section 5) using the Best Practice Erosion and Sediment Control document (IECA, 2008) and addresses:

- the fullest separation possible of diverted, surface and mine-affected water runoff;
- the diversion of upstream runoff from disturbed areas;
- the stabilisation of soils in disturbed areas; and
- the installation and maintenance of control measures such as sediment and erosion control devices (e.g., silt fences, swales, settling basins, energy dissipaters and vegetated buffers).

A detailed ESCP can be prepared for the Project, however, as outlined in this EA, surface water and diverted water releases from the Project do not trigger the need for an assessment under Section 41AA of EPR 2019.

9.3 RECEIVING WATER QUALITY MONITORING

The proponent has undertaken a round of baseline monitoring at a number of surface water locations in the Project vicinity (as detailed in Section 4.5.2). Vitrinite will monitor the receiving water locations at a number of these sites for surface water flows and water quality upstream and downstream of the Project, as well as the addition of a number of sites. Locations of the proposed surface water monitoring locations are shown in Figure 9.1 and summarised in Table 9.1.

Sampling for the surface water monitoring locations will be undertaken monthly and following any rainfall event greater than 50 mm in a 24-hour period. Monitoring will be also be undertaken downstream of any spill following a release event. Field and laboratory sampling will be undertaken. Note that sampling may only be possible during brief periods of runoff immediately following rainfall due to the ephemeral nature of the natural surface water system.

The surface water quality monitoring points have been designated as upstream and downstream monitoring points in Table 9.1. Upstream monitoring points, which are not influenced by releases from the Project, will be used to analyse the background surface water quality in the vicinity of the Project. This information can be used to develop site specific trigger levels for contaminant releases when sufficient data is available.

Downstream monitoring points will be used to assess the water quality of the receiving waters in the context of the Project. In addition to routine monitoring, these sites will be monitored directly after release events to assess the effect of Project releases.

Electrical Conductivity and pH can vary between the time of sampling and analysis in the laboratory. Therefore, field testing of samples will be undertaken for the following parameters:

- Electrical Conductivity;
- pH;
- Dissolved Oxygen; and
- Temperature.

In lieu of field testing of turbidity, the laboratory result for total suspended sediment should be used to inform on turbidity. In addition, the suite of laboratory analyses shown in Table 9.2 will be collected for the water quality monitoring locations.

The receiving water locations will be monitored against the WQOs for the Project (outlined in Table 3.1). In addition, preliminary release contaminant trigger investigation levels have been proposed for downstream monitoring sites.

9.3.1 Release contaminant trigger investigation levels

A set of initial proposed receiving water contaminant triggers levels have been developed, based on conditions at nearby operating coal mines, preliminary baseline results and the WQOs for the Project vicinity. These trigger levels are presented in Table 9.3 and are proposed to be measured against at the downstream water monitoring locations (i.e. VESW1, VSW4, VSW7, VSW9, VSW10 and VSW11). Monitoring at these locations will allow for an accurate evaluation of the impact of any releases from the Project.

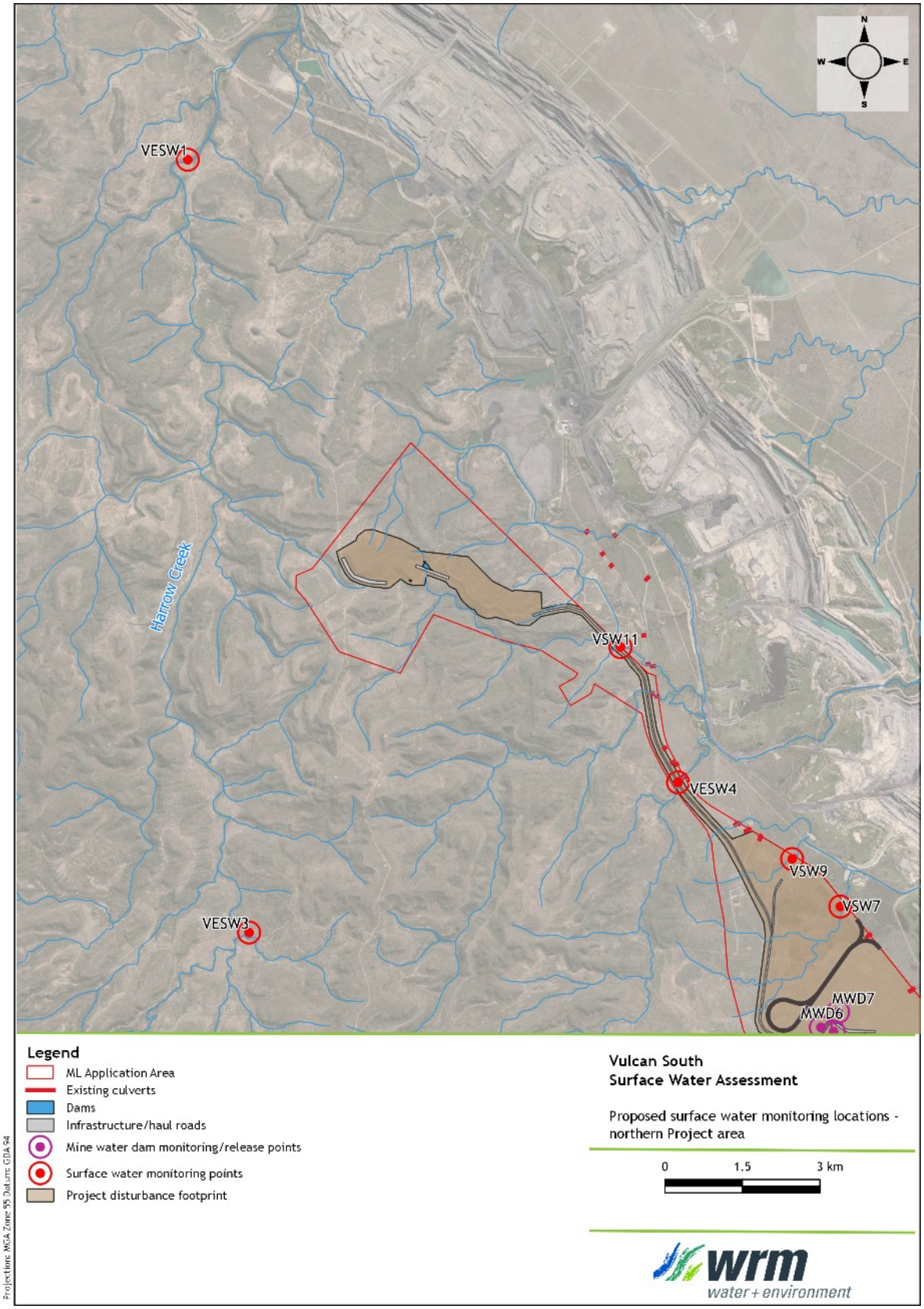

Figure 9.1 - Proposed surface water monitoring locations - northern Project area

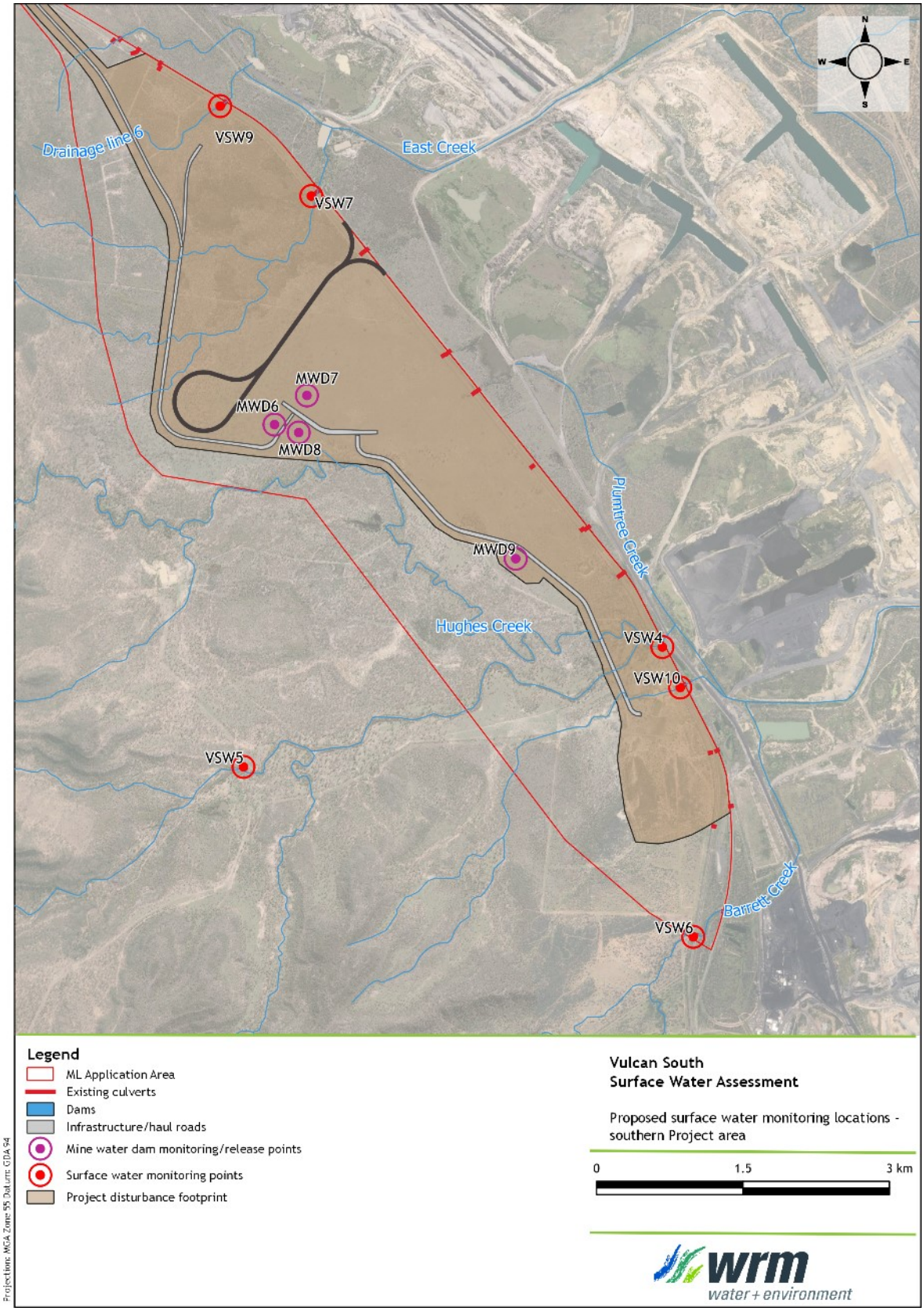

Figure 9.2 - Proposed surface water monitoring locations - southern Project area

It is noted that only limited baseline water monitoring has been undertaken and therefore the receiving water contamination water levels may need to be refined following further monitoring. Total suspended solids (TSS) levels will be updated once sufficient baseline monitoring has been collected. These levels will be update progressively as part of the Water Management Plan for the Project.

Table 9.2 – Receiving waters water quality laboratory analysis parameters

Analyte		Analyte	
Physico-chemical		*Metals and metalloids (total and filtered)*	
1	Electrical conductivity	17	Aluminium
2	pH	18	Arsenic
3	Turbidity	19	Cadmium
4	Total Suspended Solids	20	Chromium
5	Dissolved Oxygen	21	Copper
Major cations and anions		22	Iron
6	Sulfate	23	Lead
7	Calcium	24	Mercury
8	Fluoride	25	Nickel
9	Chloride	26	Zinc
10	Sodium	27	Boron
Nutrients		28	Cobalt
11	Total Phosphorus	29	Manganese
12	Filterable Reactive Phosphorus	30	Molybdenum
13	Total Nitrogen	31	Selenium
14	Oxidised Nitrogen	32	Silver
15	Total Kjeldahl Nitrogen	33	Uranium
16	Ammonium	34	Vanadium
		Hydrocarbons	
		35	Total Petroleum Hydrocarbon (C6-C36)
		Biological	
		36	Chlorophyll-a

Table 9.3 – Receiving water contaminant trigger levels

Quality characteristic	Units	Trigger level	Monitoring locations	Monitoring frequency
pH	-	6.5 – 8.0	VESW4, VSW4, VSW5, VSW6 & VSW7	Monthly, following any rainfall event greater than 50 mm in a 24-hour period and following a release event
Electrical conductivity	(µS/cm)	1,500		
TSS or TDS	(mg/L)	*TBC*		
Sulfate (SO_4^{2-})	(mg/L)	1,000		

9.4 MINE AFFECTED WATER QUALITY MONITORING

The water quality monitoring program will also include monitoring at all dams which contain mine affected water with the potential to discharge to the receiving waters. This includes the following dams:

- MWD6;
- MWD7;
- MWD8; and
- MWD9.

Locations of the proposed mine water monitoring locations are shown in Figure 9.1 and Figure 9.2 and summarised in Table 9.1.

Sampling for the mine water dam monitoring locations will be undertaken quarterly, as well as daily during a release event.

As outlined in Section 5.6.1, Vitrinite are not currently planning any mine affected controlled releases to the environment. Therefore, any releases from the mine water system would be uncontrolled from the dam spillways. The release locations for mine affected water would therefore be located on the spillway on the mine water dams, as outlined in Table 9.1.

Water quality parameters which will be collected for the mine water dams are outlined in Table 9.4. Note that the metals listed in Table 9.4 will be analysed for both total and dissolved concentrations.

Table 9.4 – Dam laboratory analysis parameters

Location	Parameter	Monitoring frequency
MWD6, MWD7, MWD8 & MWD9	pH, EC, sulfate, fluoride, aluminium, arsenic, cadmium, cobalt, copper, lead, nickel and zinc	Quarterly and daily during a release event

Preliminary mine affected water release limits have been proposed based upon similar surrounding mines for the mine affected water releases, as outlined in Table 9.5. Note that maximum EC, TSS and Sulphate water release limits will be outlined once sufficient baseline monitoring data has been collected. These release limits will be generated progressively as part of the Water Management Plan for the Project. Mine affected water releases would occur only during times of sufficient natural flow in the receiving waters to provide adequate dilution so that the receiving waters triggers given in Table 9.3 are not exceeded.

Table 9.5 – Mine affected water release limits

Quality Characteristic	Units	Minimum	Maximum
Electrical Conductivity (EC)	µs/cm	n/a	TBC
pH	pH units	6.5	9.0
Total Suspended Solids (TSS)	mg/L	n/a	TBC
Sulphate (SO_4^{2-})	mg/L	n/a	TBC

9.5 SEDIMENT DAM MONITORING

Surface runoff and seepage from spoil piles, including any rehabilitated areas, would be monitored for 'standard' water quality parameters including, but not limited to pH, EC, major anions (sulfate, chloride and alkalinity), major cations (sodium, calcium, magnesium and potassium), TDS and a broad suite of soluble metals/metalloids. This monitoring would be undertaken at all Project sediment dams (as listed in Table 5.2 and shown in Figure 1.3 - Figure 1.10).

The sediment dam monitoring would be used to validate the anticipated quality of water runoff reporting to sediment dams and haul road runoff dams. Initially, the sediment dam monitoring would occur on a regular (e.g. monthly) basis to demonstrate the water quality of stored waters is consistent with the relevant operating parameters to allow releases from sediment dams to occur when required. Subject to demonstrating the water quality objectives can be met, the frequency of monitoring and suite of parameters for the sediment dam monitoring would be reviewed and updated accordingly (e.g. to occur only when releases occur).

9.6 RECEIVING ENVIRONMENT MONITORING PROGRAM (REMP)

A REMP document will be developed which describes in detail the proposed monitoring program for the local receiving waters. The REMP will incorporate the historical and proposed monitoring as described in Section 4.5.2 and in the sections above.

The main objective of the REMP will be to report against WQOs for local waterways potentially affected by discharge from the Project and will assist in assessing general aquatic ecosystem health.

10 Cumulative impacts

10.1 OVERVIEW

The objective of this assessment is to identify the potential for impacts from the Project to have compounding interactions with similar impacts from other projects, including activities proposed, under development or already in operation within a suitable region of influence of the Project.

There are two levels at which cumulative impacts have been assessed:

- Localised cumulative impacts – These are the impacts that may result from multiple existing or proposed mining operations in the immediate vicinity of the Project. Localised cumulative impacts include the effect from concurrent operations that are close enough to potentially cause additive effect on the receiving waters. For the purposes of this assessment, all existing and proposed projects located within the Isaac River catchment have been included.
- Regional cumulative impacts – These include the Project's contribution to impacts that are caused by mining operations throughout the Bowen Basin region or at a catchment level. Each coal mining operation in itself may not represent a substantial impact at a regional level; however, the cumulative effect on the receiving waters may warrant consideration.

10.2 EXISTING PROJECTS

Projects which are currently operating within the Isaac River catchment upstream of the Deverill gauging station and have been included in the cumulative impacts assessment for the project are listed in Table 10.1.

10.3 NEW OR DEVELOPING PROJECTS

Relevant projects that have been considered include:

- Projects within the predicted sphere of influence of the Project, as listed on the Department of State Development, Manufacturing, Infrastructure and Planning (DSDMIP) website that are undergoing assessment under the State Development and Public Works Organisation Act 1971 (SDPWO Act) for which an Initial Advice Statement (IAS) or an EIS are available.
- Projects within the predicted sphere of influence of the Project, which are listed on the website of the Department of Environment and Science (DES) that are undergoing assessment under the Environmental Protection Act 1994 (EP Act) for which an IAS or an EIS are available.
- Projects within the predicted sphere of influence of the Project, which are listed on the website of +-the Department of Infrastructure, Local Government and Planning (DILGP) that are undergoing assessment under the Regional Planning Interests Act 2014 (RPI Act) for which an Assessment Application is available.

Projects currently undergoing assessment or having recently completed assessment under these processes and included in the cumulative impact assessment for the Project are listed in Table 10.2.

10.4 CUMULATIVE IMPACTS – SURFACE WATER RESOURCES

10.4.1 Water quality

The Project is located in the Isaac River catchment, which is a major tributary within the Fitzroy basin. The Fitzroy basin is the largest catchment in Queensland draining into the Pacific Ocean and also the largest catchment that drains to the Great Barrier Reef, although it does not contribute significant freshwater flows to the coastal environment when compared to river systems further north.

In 2008, the Queensland Government undertook an investigation into the cumulative effects of coal mining in the Fitzroy River basin on water quality (EPA, 2009). The investigation found that:

- There were inconsistencies in discharge quality limits and operating requirements for coal mine water discharges as imposed through environmental authorities.
- In some cases, discharge limits and operating conditions of coal mines were not adequately protecting downstream environmental values.

These conclusions led to a number of inter-related actions by Queensland Government and other stakeholders:

- Water quality objectives were developed for the Fitzroy Basin and added to Schedule 1 of the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP (Water)) in October 2011.
- Model water conditions were developed for coal mines in the Fitzroy basin (DERM February 2012). These model water conditions are designed to manage water discharges to meet the water quality objectives set out in the EPP (Water) and to provide consistency between mining operations in the Fitzroy basin.
- Environmental authorities for a number of mining operations were amended to introduce conditions consistent with the model water conditions.
- A number of mining operations entered into Transitional Environmental Programs (TEP) under the EP Act. These TEPs were focussed on actions that would allow mines to achieve compliance with new environmental authority conditions and upgrade operating conditions.

With these measures in place, a strong strategic and policy framework is now in place for management of cumulative water quality impacts from mining activities. This framework allows for management of individual mining activities in such a way that overarching water quality objectives can be achieved.

Mine affected water from the proposed Project will be managed through a mine water management system which is designed to operate in accordance with proposed EA conditions that are based on Model Mining Conditions, and incorporated into the release criteria used in modelling the mine water management system in this report.

It is noted that the Project is located within the Boomerang Creek catchment, which has already been significantly disturbed by existing mining operations in the Project vicinity.

In addition, given that the proposed project water releases will be managed within an existing overarching strategic framework for management of cumulative impacts of mining activities, the proposed management approach for mine water from the project is expected to have negligible cumulative impact on surface water quality and associated environmental values.

Table 10.1 – Existing projects considered in the cumulative impact assessment

Project - Proponent	Description	Operational status	Relationship to the Project Mining Lease	
			Timing	Location
Burton Mine – Peabody Energy Australia	Open cut coal mine	Ceased production indefinitely	May have overlapping operational phases with the construction and operations of the project, although unlikely given the current operational status.	Located 75 km to the north of the Project area. Located within the Isaac River catchment (upstream).
Eaglefield Mine - Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 75 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
North Goonyella Mine - Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 75 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
Goonyella Riverside Mine - BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 60 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
Moranbah North Mine – Anglo American	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 50 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
Grosvenor Mine – Anglo American	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 40 km to the north of the Project area. Located within the Isaac River catchment (upstream).
Broadlea Mine – Fitzroy Australia Resources	Open cut coal mine	Care and maintenance	May have overlapping operational phases with the construction and operations of the project.	Located 40 km to the north of the Project area. Located within the headwaters of Smoky Creek, within the Isaac River catchment.
Carborough Downs Mine – Fitzroy Australia Resources	Underground coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 35 km to the northeast of the Project area. Located within the headwaters of Billy's Gully, within the Isaac River catchment.
Isaac Plains Mine - Stanmore Coal	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 35 km to the north of the Project area. Located within the headwaters of Billy's Gully, within the Isaac River catchment.

Millennium Mine – Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 30 km to the northeast of the Project area. Located within the headwaters of Southern Gully, within the Isaac River catchment.
Daunia Mine - BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 25 km to the northeast of the Project area. Located within the Isaac River catchment (upstream).
Poitrel Mine - BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 20 km to the northeast of the Project area. Located within the Isaac River catchment (upstream).
Caval Ridge Mine - BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 10 km to the north of the Project area. Located within the Isaac River catchment (upstream).
Peak Downs Mine - BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located directly adjacent (i.e. less than 1 km to the north and east of the Project area. Located within the Isaac River catchment.
Moorvale Mine – Peabody Energy Australia	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 35 km to the northeast of the Project area. Located within the headwaters of North Creek, within the Isaac River catchment.
Saraji Mine – BMA	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 10 km to the southeast of the Project area. Located within the Isaac River catchment.
Norwich Park Mine – BMA	Open cut coal mine	Ceased production indefinitely	May have overlapping operational phases with the construction and operations of the project, although unlikely given the current operational status.	Located 45 km to the southeast of the Project area. Located within the Isaac River catchment (downstream).
Lake Vermont Mine – Jellinbah Group	Open cut coal mine	Operating	May have overlapping operational phases with the construction and operations of the project.	Located 30 km to the southeast of the Project area. Located within the Isaac River catchment (downstream).

Table 10.2 - Proposed projects considered in the cumulative impact assessment

Project - Proponent	Description	Project status	Relationship to the Project Mining Lease	
			Timing	Location
Moranbah South Project – Anglo American	Underground coal mine	Approved project	May have overlapping operational phases with the construction and operations of the project.	Located 30 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
Moorvale South Project – Peabody Energy Australia	Open cut coal mine	Approved project	May have overlapping operational phases with the construction and operations of the project.	Located 25 km to the northeast of the Project area. Located within the Isaac River catchment (upstream).
Eagle Downs Mine – Bowen Central Coal Joint Venture	Underground coal mine	Construction on hold – site on care and maintenance	May have overlapping operational phases with the construction and operations of the project.	Located 10 km to the north of the Project area. Located within the Isaac River catchment upstream).
Winchester South Project – Whitehaven Coal	Open cut coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	Located 15 km to the northwest of the Project area. Located within the Isaac River catchment (upstream).
Olive Downs Coking Coal Project – Pembroke Olive Downs Pty Ltd	Open cut coal mine	Approved with conditions	May have overlapping operational phases with the construction and operations of the project.	Located 10 km to the west of the Project area. Located within the Isaac River catchment (downstream).
Saraji East Mine - BMA	Open cut coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	Located 15 km to the southwest of the Project area. Located within the Isaac River catchment (downstream).
Dysart East Coal Mine – Bengal Coal	Underground coal mine	ML granted	May have overlapping operational phases with the construction and operations of the project.	Located 35 km to the southwest of the Project area. Located within the Isaac River catchment (downstream).
Red Hill - BMA	Underground coal mine	Approved with conditions	May have overlapping operational phases with the construction and operations of the project.	Located 60 km to the northeast of the Project area. Located within the Isaac River catchment (upstream).
Isaac Downs Project	Open cut coal mine	EIS active	May have overlapping operational phases with the construction and operations of the project.	Located 30 km to the north of the Project area. Located within the Isaac River catchment (upstream).

10.4.2 Loss of Catchment and Stream Flows in the Isaac River

The Project will result in a loss of catchment to the Isaac River during operations and post-mining. The surface runoff volume lost from the catchment will generally be in proportion to the loss of catchment area. The Project area is less than 0.2% of the catchment area of the Isaac River to the confluence of Phillips Creek. Of this, around 40% of this area is managed through the ESCP and then released to the downstream environment. An additional 50% would be collected and diverted around the Project through diversion drains or dam DD2.

There are approximately 18 existing coal mines in the vicinity of the Project that also capture runoff from the Isaac River catchment, as shown in Figure 10.1. The total estimated captured area of all these projects (including the Project) combined represents around 7.3% of the Isaac River catchment to the Phillips Creek confluence.

A comparison of the captured catchment areas of the existing mining projects considered in the cumulative impact assessment with the Isaac River catchment to the Phillips Creek confluence is provided in Table 10.3, which indicates the following:

- The combined total catchment area of the existing mines (including the Project) represents around 7.3% of the total catchment area of the Isaac River to the Phillips Creek confluence.
- The combined mine affected catchment area (estimated) represents less than 2.5% of the total Isaac River catchment area to the Phillips Creek confluence.

When taking into account potential discharges from the operating mines in accordance with their current approved release rules, the overall loss of catchment area and associated stream flow is relatively small. In practical terms, impacts on the volume of water flow in the Isaac River would be negligible.

Table 10.3 – Catchment area of existing projects considered in the cumulative impact assessment

Catchment	Total catchment area (km^2)	Estimated mine affected catchment area (km^2)
Vulcan South (the Project)	15.3	4.8
Other mines	551	182
Combined	566	187
Isaac River (to the Phillips Creek confluence)	7,731	-

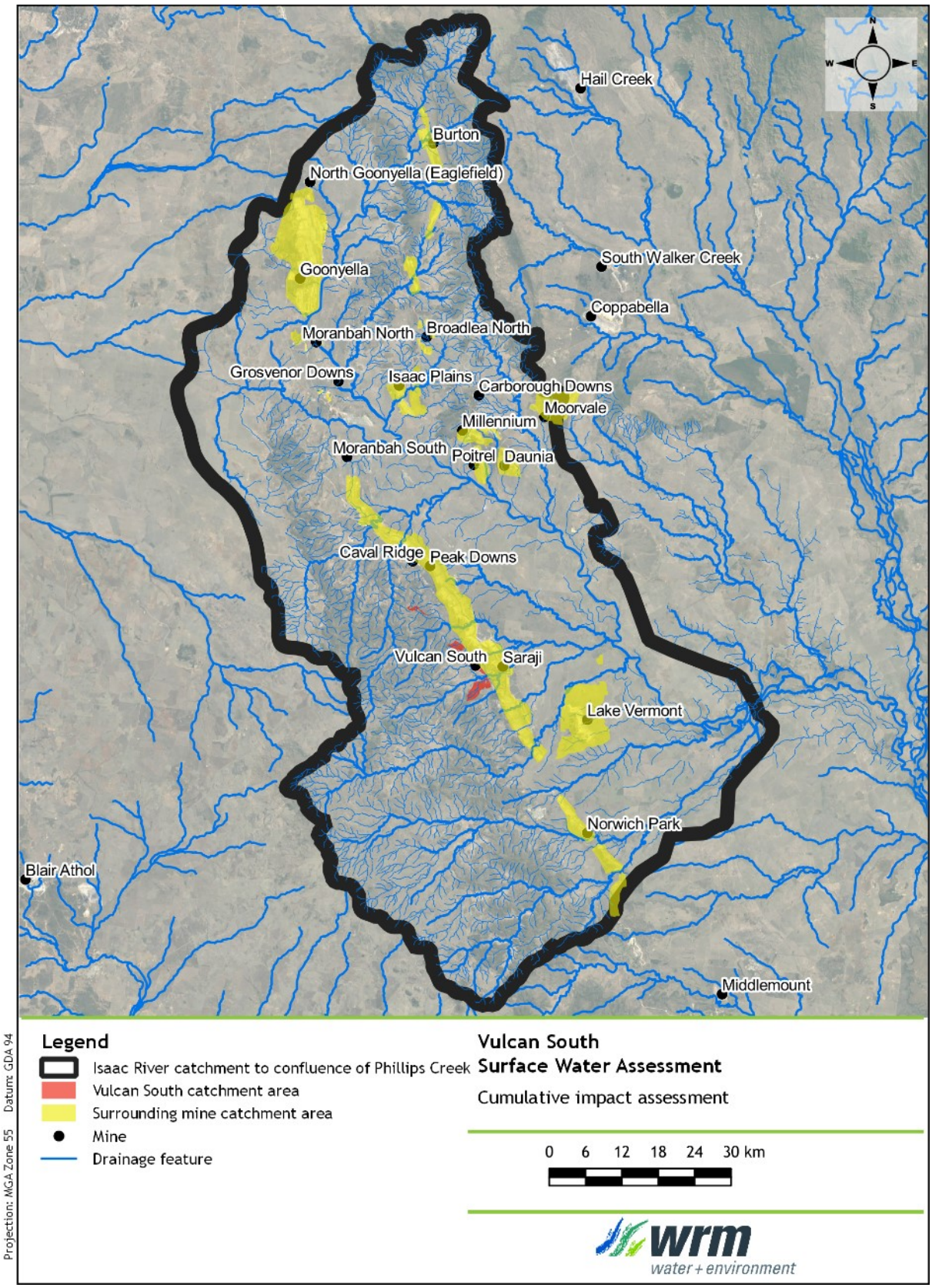

Figure 10.1 – Cumulative impact assessment

11 Summary of findings

11.1 OVERVIEW

The potential impacts of the Project on surface water resources will be mitigated through the implementation of a mine site water management system to control the flow and storage of water of different qualities across the site. A surface water monitoring program will be implemented to monitor potential environmental impacts and ensure that the site water management system is meeting its objectives.

11.2 WATER MANAGEMENT SYSTEM PERFORMANCE

The performance of the mine water management system has been investigated using a detailed site water balance model. The model simulated water inflows and outflows through the various stages of mine development, based on 122 realisations with different climatic sequences.

Water collected on the site will be used as first priority to satisfy site demands. Mine affected water from the infrastructure areas and open cut pit will be collected in MWD6, MWD7, MWD8 and MWD9 and reused to meet operational needs.

External water will be supplied to MWD8 when the site water inventory is at a low level, in order to meet site water demands.

The water balance results show that although water collected onsite will be used as a first priority to meet mine demands, the Project will frequently require external water to operate. Under 50%ile conditions, the Project is predicted to require up to 1,250 ML/annum in external water.

The water balance model was used to assess the risk of uncontrolled offsite spills from the mine affected water dams that can potentially overflow directly to the receiving waters (MWD6, MWD7, MWD8 and MWD9). There were no modelled overflows from the mine affected water dams to the receiving waters during any of the model realisations over the life of the Project.

11.3 FLOODING

The hydrologic (XP-RAFTS) model design discharge hydrographs for the Boomerang Creek and Hughes Creek catchments were input to hydraulic (TUFLOW) model. Peak water levels and peak velocities were compared to assess the potential flood impacts in the vicinity of the Project for the 10%, 1% and 0.1% AEP events. The three scenarios assessed were:

- Existing Conditions;
- Life of mine (Operational) Conditions; and
- Post-closure Conditions.

The results of the comparison between Operational Conditions peak flood levels and Existing Conditions peak flood levels show that flood impacts as a result of the proposed mine water infrastructure are generally within the Project MLA area. The impacts that extend into the Norwich Park Branch Railway embankment and downstream of the Project boundary may require mitigation measures. These could include erosion protection in locations of increased flood velocities, staged flood protection levee construction (acknowledging this may impact on mine plan scheduling), limit the timeframe that the proposed infrastructure is in place, additional road/rail culverts, etc. Where impacts cannot be fully mitigated, consent may be required from impacted neighbouring landowners/stakeholders (e.g., Aurizon, council, BMA).

The results of the comparison between Post-closure Conditions peak flood levels and Existing Conditions peak flood levels show that generally there are only minor impacts under the final landform configuration. These impacts are generally confined within the Project MLA area. It is recommended that erosion and scour protection options are considered along the proposed drainage corridor and existing channels where these increases occur as required to mitigate the risk of rapid geomorphic change.

Overall, the impact of the Project on the hydraulic characteristics of Boomerang Creek, Hughes Creek and their tributaries do not affect the existing conditions significantly. It is expected that the channel and floodplain will undergo little, if any, adjustment to the altered hydraulic conditions upstream or downstream of the Project as a result of the Project.

11.4 IMPACTS ON DOWNSTREAM WATER QUALITY

Preliminary baseline monitoring indicates that water quality in the surrounding environment is of poor quality. Notwithstanding, the water balance modelling indicates that no mine affected spills are predicted from mine operations. In addition, modelling predicts that spills from the sediment dams will be below the 720 µS/cm WQO for baseflows of the Project area.

In consideration of the already heavily disturbed nature of the surrounding catchment, it is unlikely that Project releases will have a measurable impact on receiving water quality or environmental values.

11.5 CUMULATIVE IMPACTS

The Project will reduce the catchment area draining to receiving waters due to capture of runoff from disturbed catchment areas within the water management system. The Project catchment area represents approximately 0.2% of the total catchment area of the Isaac River to its confluence with Phillips Creek. Of this, approximately 40% will be managed through the Project ESC and released back to receiving waters. The combined total catchment area of the existing mines (including the Project) represents around 7.3% of the total catchment area of the Isaac River to the Phillips Creek confluence.

The site water management system has been designed such that the risk of offsite release of mine affected water is very low (with no mine affected dam uncontrolled releases predicted under any modelled climatic conditions).

11.6 FINAL LANDFORM

A conceptual final landform water management plan for the Project under post-closure conditions has been developed. The key features of the final landform are:

- No final voids are proposed. All open cut pits will be backfilled with overburden material.
- Drainage structures will be implemented on and around the final landform to ensure that the landform is free draining.
- When sediment dam catchments are completely rehabilitated, and water quality monitoring of the runoff has established that it is consistent with natural background conditions, the sediment dam and associated drainage infrastructure will be decommissioned.

In summary, the conceptual final landform is not considered likely to have a long-term significant impact on the receiving waters.

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Appendix A - **Baseline surface water monitoring results**

Parameter	Unit	VSW-1 1/02/20	VSW-2 1/02/20	VSW-3 1/02/20	VSW-2 5/03/20	VSW-3 5/03/20	VSW-4 4/03/20	VSW-6 4/03/20	VSW-7 4/03/20	VESW-1 5/03/20	VESW-2 5/03/20	VSW-5 18/03/20	VSW-1 19/03/20	VSW-2 19/03/20	VSW-3 19/03/20	VSW-4 19/03/20	VSW-6 19/03/20	VSW-7 19/03/20	VESW-1 19/03/20	VESW-2 19/03/20	VESW-3 19/03/20	VESW-4 19/03/20	WQO (see Table 3.1)
pH Value	-	7.42	6.74	6.54	7.38	6.92	7.16	7.12	7.57	7.79	8.41	6.78	7.53	7.04	6.57	7.11	6.89	7.57	7.89	7.74	7.00	7.13	6.5 - 8.5
Sodium Adsorption Ratio	-	6.64	2.92	1.69	3.86	0.55	0.61	0.26	0.34	0.82	0.93	0.68	9.17	1.86	1.10	0.37	0.77	0.42	0.87	0.58	0.37	0.51	-
Electrical Conductivity	µS/cm	1400	310	184	442	66	81	46	106	219	395	44	2440	346	104	74	80	124	306	280	70	129	> 720 (baseflow) > 250 (high flow)
Total Dissolved Solids (Calc.)	mg/L	910	202	120	287	43	53	30	69	142	257	29	1590	225	68	48	52	81	199	182	46	84	> 2,000
Suspended Solids (SS)	mg/L	10	55	20	100	293	296	379	1200	62	33	77	168	10	92	2050	386	51	<5	33	155	168	> 55
Turbidity	NTU	43	221	91	116	751	1590	503	1240	320	41	339	221	37	209	850	701	346	9	143	324	419	> 50
Total Hardness as CaCO3	mg/L	191	37	26	50	16	18	12	40	64	125	7	362	78	16	22	16	51	99	108	22	18	> 150
Hydroxide Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Carbonate Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	8.00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
Bicarbonate Alkalinity as CaCO3	mg/L	63	12	4	27	9	33	6	49	62	120	11	174	70	15	26	21	65	94	103	29	45	-
Total Alkalinity as CaCO3	mg/L	63	12	4	27	9	33	6	49	62	129	11	174	70	15	26	21	65	94	103	29	45	-
Sulfate as SO4 - Turbidimetric	mg/L	212	40	19	58	2	4	2	<1	7	13	2	340	33	6	6	4	1	11	6	3	2	> 25
Chloride	mg/L	275	54	34	80	10	6	3	6	25	40	5	528	40	17	5	9	6	30	19	6	7	-
Calcium	mg/L	27	5	4	7	3	4	3	8	14	32	1	46	10	3	4	3	9	20	27	4	4	-
Magnesium	mg/L	30	6	4	8	2	2	1	5	7	11	1	60	13	2	3	2	7	12	10	3	2	-
Sodium	mg/L	211	41	20	63	5	6	2	5	15	24	4	401	38	10	4	7	7	20	14	4	5	> 30
Potassium	mg/L	8	7	7	7	4	3	3	2	6	6	3	11	7	5	4	4	2	8	6	4	5	-
Dissolved Metals																							
Aluminium	mg/L	0.11	0.45	0.39	<0.01	0.28	0.26	0.2	0.07	<0.01	<0.01	1.11	0.01	<0.01	0.07	0.35	0.22	0.02	<0.01	<0.01	0.09	0.09	> 0.055
Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.001	0.002	0.004	> 0.024
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.0002
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.001
Cobalt	mg/L	<0.001	<0.001	<0.001	0.002	0.004	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.002	<0.001	0.001	<0.001	<0.001	<0.001	0.001	0.005	0.006	-
Copper	mg/L	0.003	0.001	0.002	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	> 0.0014
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.0034
Manganese	mg/L	0.039	0.019	0.015	0.141	0.278	0.125	0.04	0.066	0.089	0.102	0.011	0.443	0.201	0.028	0.192	0.026	0.002	0.012	0.362	0.309	0.295	> 1.9
Molybdenum	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Nickel	mg/L	0.002	0.002	0.002	0.003	0.003	0.001	<0.001	0.001	0.002	0.002	<0.001	0.003	0.003	0.002	0.002	0.001	0.001	0.003	0.002	0.003	0.003	> 0.011
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.005
Silver	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Uranium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.1
Vanadium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.5
Zinc	mg/L	0.024	<0.005	0.024	<0.005	0.014	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	> 0.008
Boron	mg/L	0.09	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	> 0.37
Iron	mg/L	0.2	0.35	0.35	<0.05	0.38	0.18	0.13	0.15	<0.05	<0.05	0.63	1.83	<0.05	0.24	0.33	0.21	0.11	<0.05	<0.05	1.6	3.02	-

Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.00006
Total Metals																						
Aluminium	mg/L	0.89	3.38	1.56	1.71	12.8	22.8	6.62	21.8	5.42	0.72	7.97	3.61	0.94	3.76	16.5	10.3	9.22	0.38	3.94	6.56	6.36	> 5
Arsenic	mg/L	0.001	0.002	0.001	0.001	0.003	0.005	0.003	0.003	0.002	0.001	0.002	0.002	0.001	0.003	0.005	0.005	0.002	<0.001	0.002	0.003	0.005	> 0.5
Cadmium	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.01
Chromium	mg/L	<0.001	0.002	0.001	0.001	0.008	0.02	0.006	0.026	0.004	<0.001	0.005	0.003	<0.001	0.002	0.017	0.008	0.011	<0.001	0.004	0.006	0.004	> 1
Cobalt	mg/L	<0.001	0.001	<0.001	0.003	0.013	0.014	0.003	0.013	0.003	0.001	0.003	0.006	0.003	0.003	0.018	0.005	0.004	<0.001	0.003	0.008	0.01	> 0.1
Copper	mg/L	0.004	0.004	0.002	0.004	0.014	0.023	0.008	0.016	0.004	<0.001	0.006	0.003	0.002	0.003	0.02	0.009	0.005	0.001	0.003	0.006	0.012	> 1
Lead	mg/L	<0.001	0.004	0.002	0.003	0.016	0.032	0.009	0.022	0.007	<0.001	0.007	0.005	<0.001	0.004	0.028	0.011	0.006	<0.001	0.003	0.007	0.01	> 0.1
Manganese	mg/L	0.042	0.034	0.024	0.195	0.586	0.477	0.112	0.334	0.174	0.156	0.077	0.431	0.214	0.106	0.804	0.13	0.108	0.046	0.444	0.389	0.383	> 10
Molybdenum	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	> 0.05
Nickel	mg/L	0.002	0.004	0.003	0.006	0.016	0.028	0.006	0.022	0.008	0.004	0.006	0.005	0.004	0.004	0.025	0.012	0.008	0.003	0.007	0.009	0.009	> 1
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.02
Silver	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Uranium	mg/L	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Vanadium	mg/L	<0.01	<0.01	<0.01	<0.01	0.01	0.03	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	0.01	<0.01	<0.01	<0.01	<0.01	-
Zinc	mg/L	0.031	0.017	0.029	0.014	0.1	0.058	0.022	0.037	0.018	<0.005	0.024	0.021	0.015	0.018	0.059	0.031	0.022	<0.005	0.01	0.019	0.031	> 5
Boron	mg/L	0.06	<0.05	<0.05	0.05	0.38	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	> 5
Iron	mg/L	0.79	3.26	1.62	2.35	11.7	27.7	8.42	25.7	7.15	0.83	7.88	5.57	1.62	6.96	21.8	12.9	7.86	0.66	4.26	8.88	12.5	> 10
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	> 0.002
Fluoride	mg/L	<1.0	0.1	<0.1	0.1	<0.1	0.2	<0.1	0.2	0.1	0.2	<0.1	0.2	<0.1	<0.1	0.1	0.1	0.2	0.1	0.2	<0.1	0.1	< 2
Ammonia as N	mg/L	0.05	0.1	<0.01	0.1	0.99	0.11	0.07	0.11	0.1	0.02	0.1	0.17	0.13	0.21	0.09	0.21	0.12	0.16	0.55	0.22	6.95	> 0.02
Nitrite as N	mg/L	0.03	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	0.04	<0.01	0.62	<0.01	0.21	-
Nitrate as N	mg/L	1.7	1.57	1.19	0.08	<0.01	0.02	0.02	0.04	0.14	<0.01	0.14	0.07	0.05	<0.01	<0.01	0.08	0.03	<0.01	0.16	<0.01	0.1	-
Nitrite + Nitrate as N	mg/L	1.73	1.58	1.19	0.09	<0.01	0.02	0.02	0.04	0.17	<0.01	0.14	0.09	0.05	<0.01	<0.01	0.09	0.07	<0.01	0.78	<0.01	0.31	-
Total Kjeldahl Nitrogen as N	mg/L	1.6	1.3	0.9	2.7	1	1.8	0.8	0.6	0.7	0.9	1.3	2.1	0.7	0.9	2.6	2	1.1	0.7	1.3	1.2	9.9	-
Total Nitrogen as N	mg/L	3.3	2.9	2.1	2.8	1	1.8	0.8	0.6	0.9	0.9	1.4	2.2	0.8	0.9	2.6	2.1	1.2	0.7	2.1	1.2	10.2	> 0.5
Total Phosphorus as P	mg/L	0.04	0.09	0.05	0.18	0.2	0.43	0.19	0.18	0.17	0.21	0.12	0.09	0.02	0.08	0.58	0.37	0.1	0.02	0.09	0.12	0.41	> 0.05
Reactive Phosphorus as P	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	> 0.02
Total Anions	meq/L	13.4	2.6	1.43	4	0.5	0.91	0.25	1.15	2.09	3.98	0.4	25.4	3.21	0.9	0.78	0.76	1.49	2.95	2.72	0.81	1.14	-
Total Cations	meq/L	13.2	2.7	1.58	3.93	0.63	0.7	0.4	1.08	2.08	3.7	0.38	25	3.4	0.88	0.72	0.72	1.38	3.06	2.92	0.72	1.33	-
Ionic Balance	%	0.87	-	-	0.97	-	-	-	-	-	3.61	-	0.98	2.82	-	-	-	-	-	-	-	-	-
Chlorophyll a	mg/m³	<4	<4	<4	<2	-	<12	<4	<10	4	<2	-	<3	<1	<4	-	<8	<3	2	<2	<4	-	-
Dissolved Oxygen	mg/L	6.7	7.3	7.3	7	6.8	6.4	6.8	7.6	6.7	7.5	7.5	6.2	6.8	5.6	7.1	5.9	6.7	7.3	5.5	6.3	4.9	> 4

Note: Recorded exceedances of the WQOs have been shaded in grey.

Appendix B – **Existing Conditions flood maps and results**

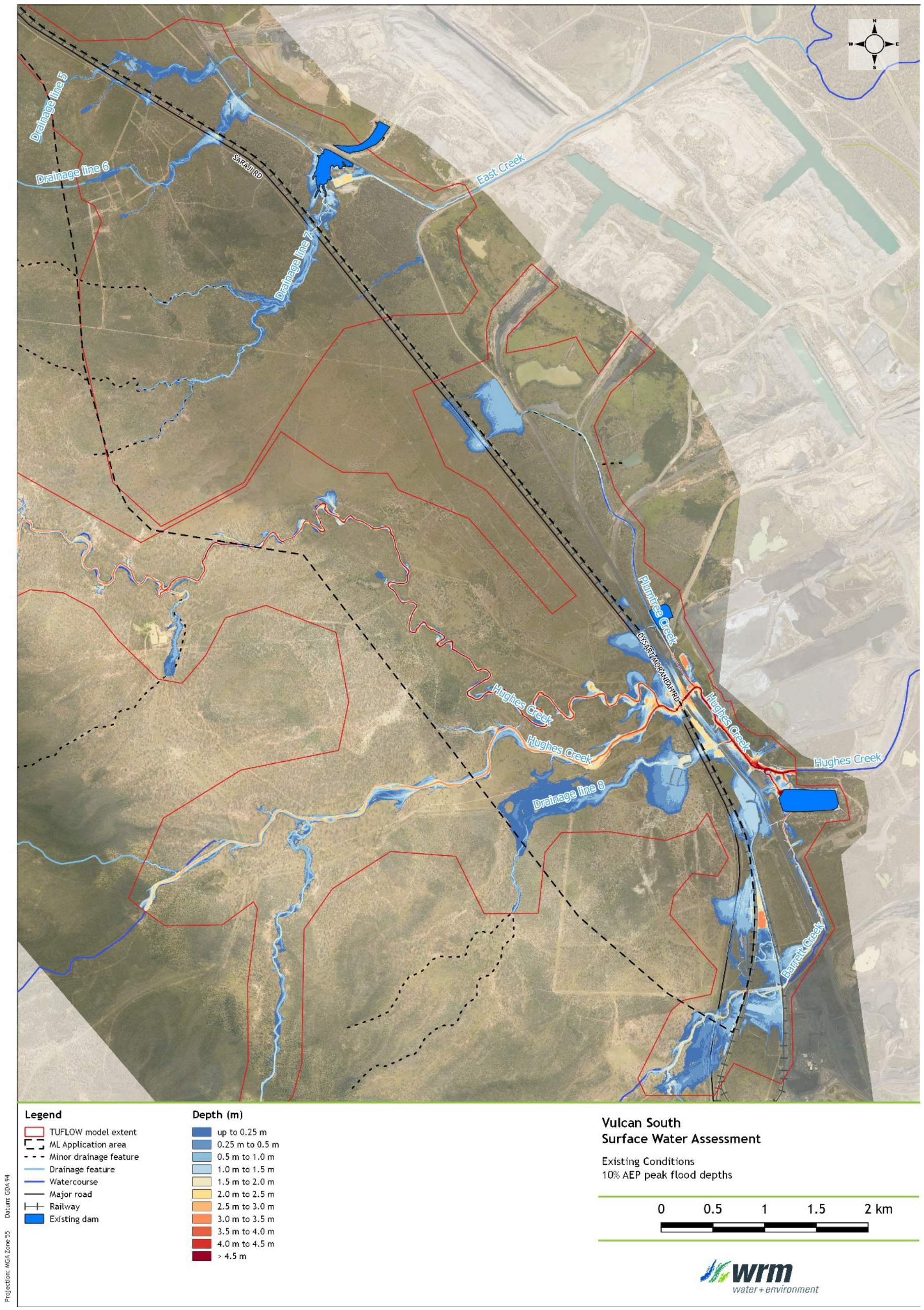

Figure B.1 – 10% AEP peak flood depths – Existing Conditions

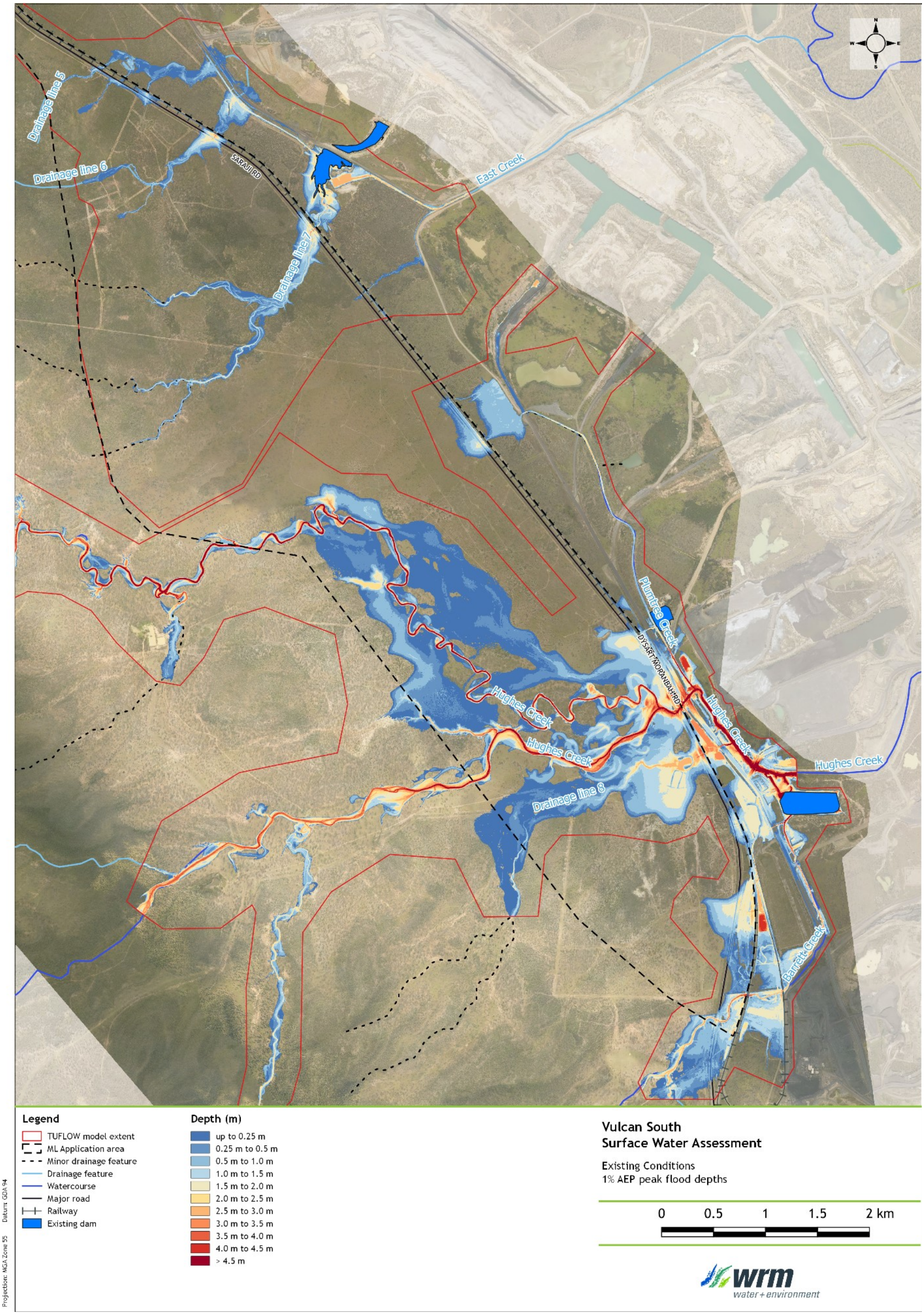

Figure B.2 – 1% AEP peak flood depths – Existing Conditions

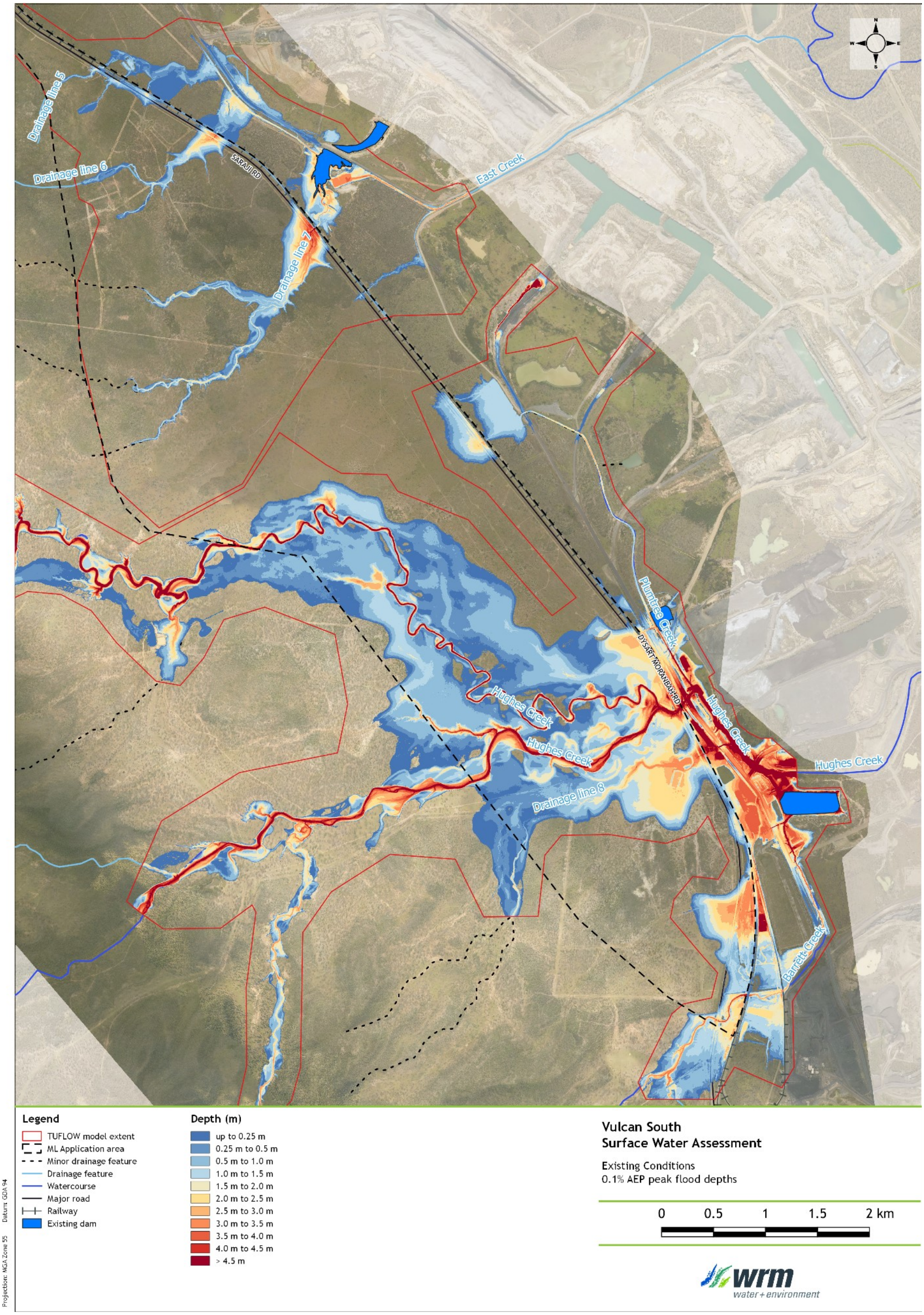

Figure B.3 – 0.1% AEP peak flood depths – Existing Conditions

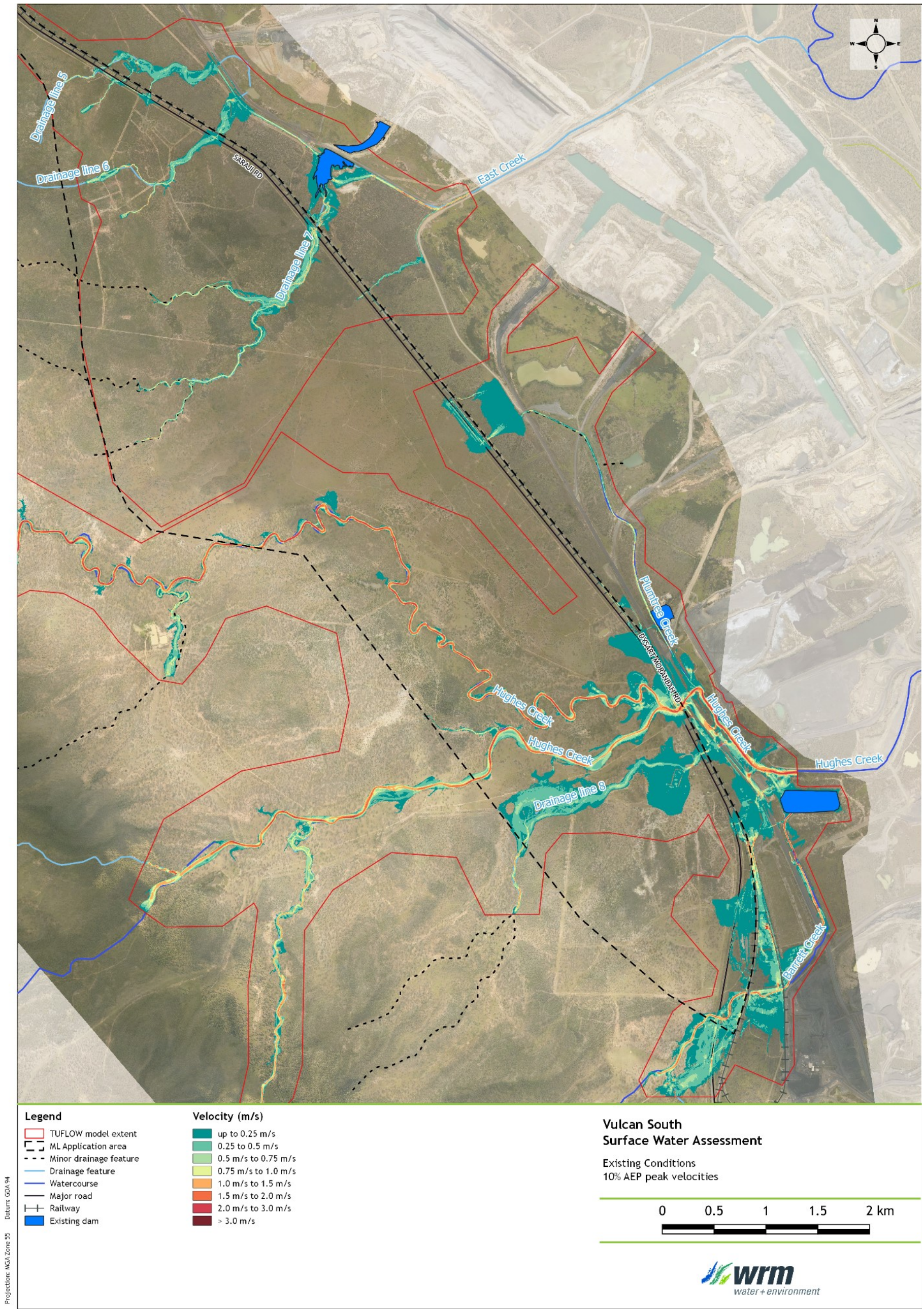

Figure B.4 – 10% AEP peak velocities – Existing Conditions

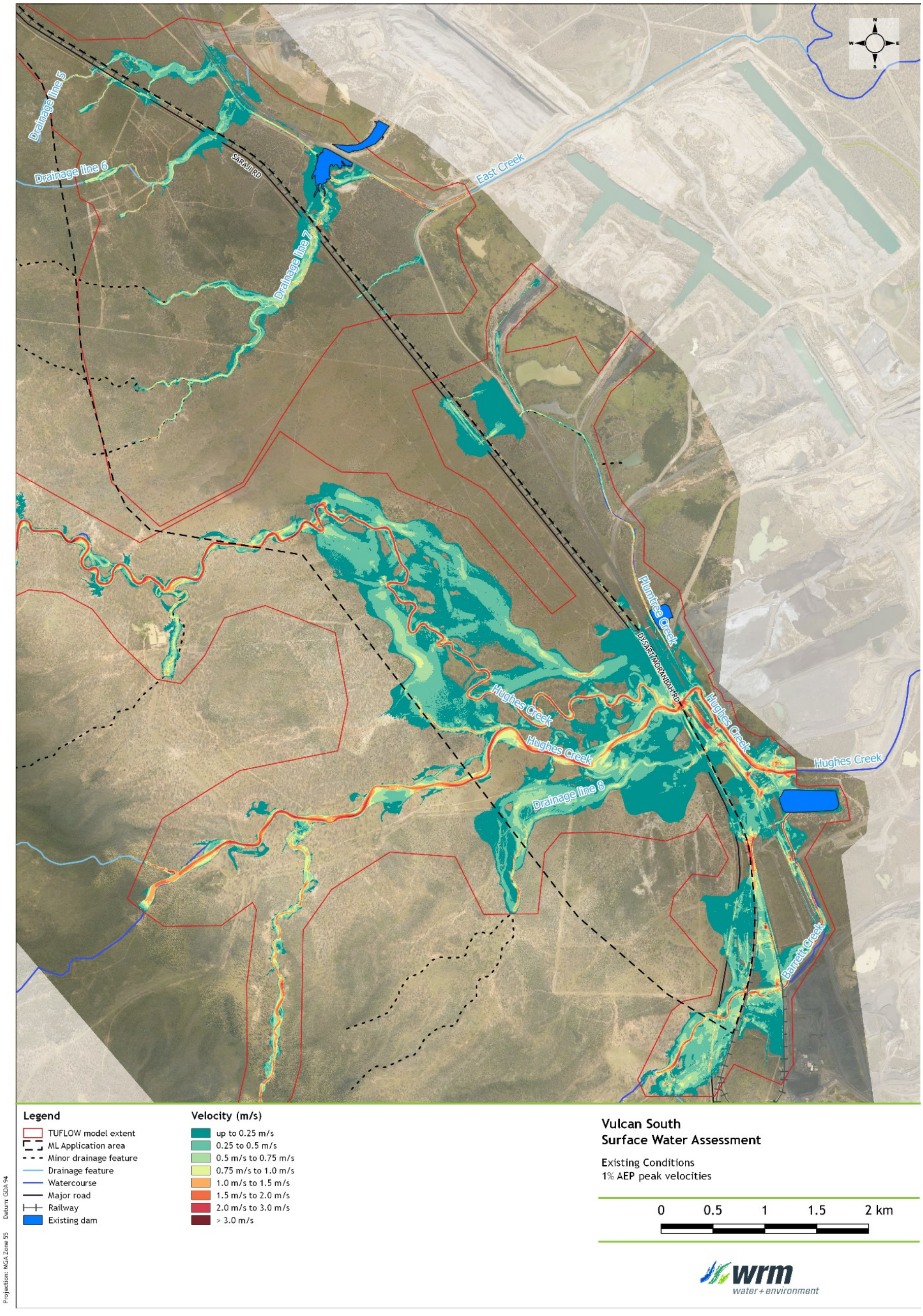

Figure B.5 – 1% AEP peak velocities – Existing Conditions

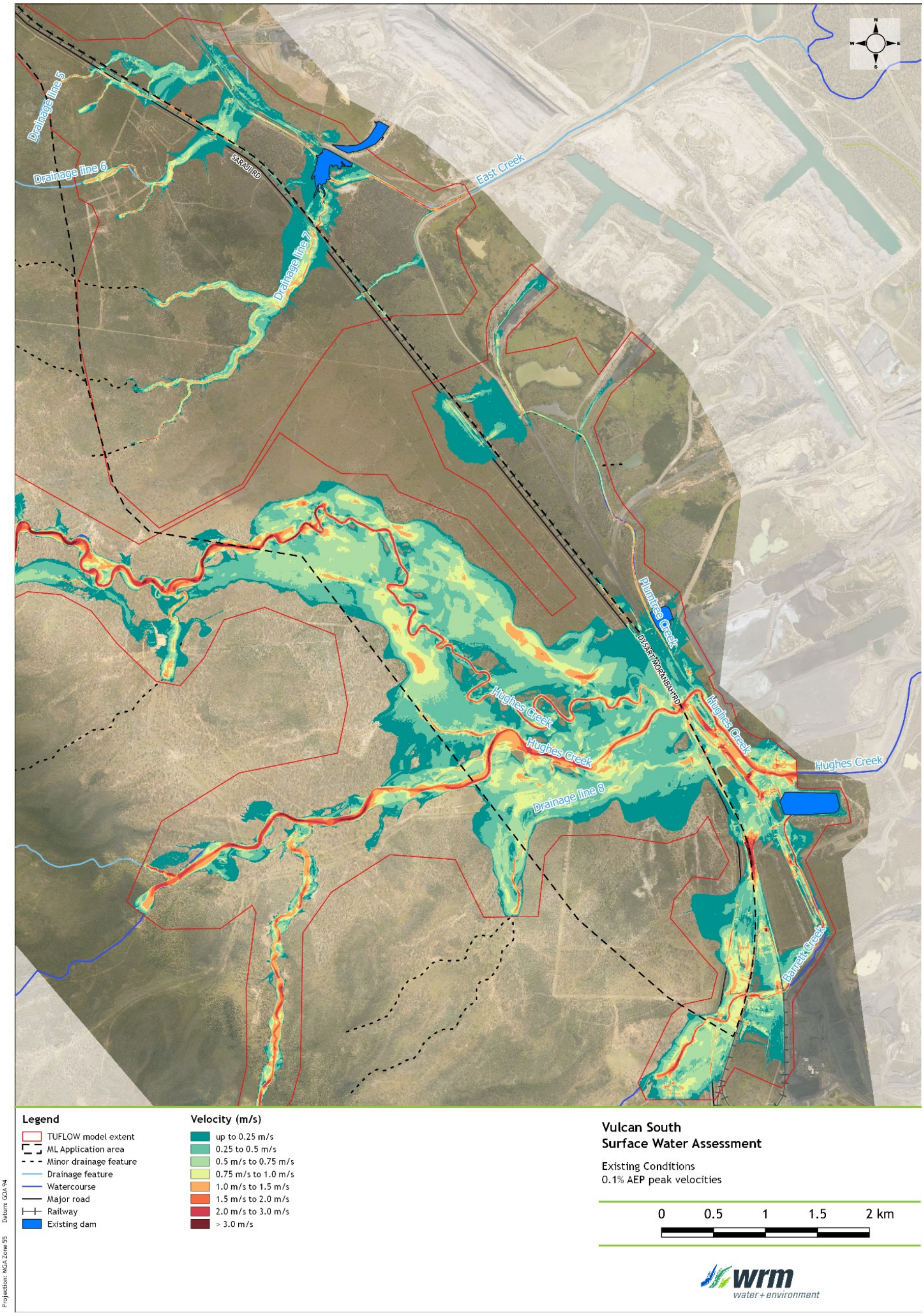

Figure B.6 – 0.1% AEP peak velocities – Existing Conditions

Appendix C – **Operational Conditions flood impact maps**

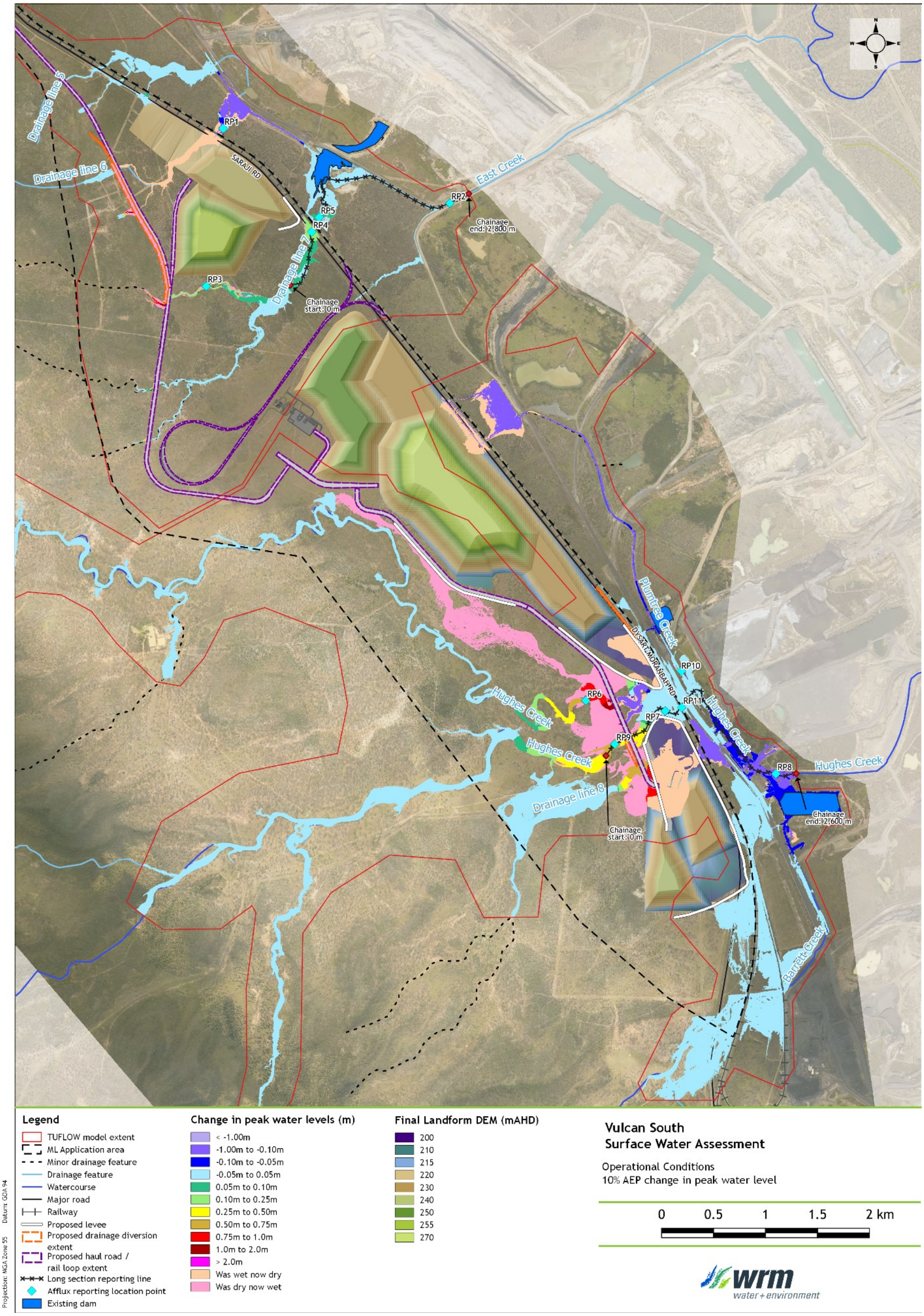

Figure C.1 - 10% AEP change in peak water levels - Operational Conditions impacts

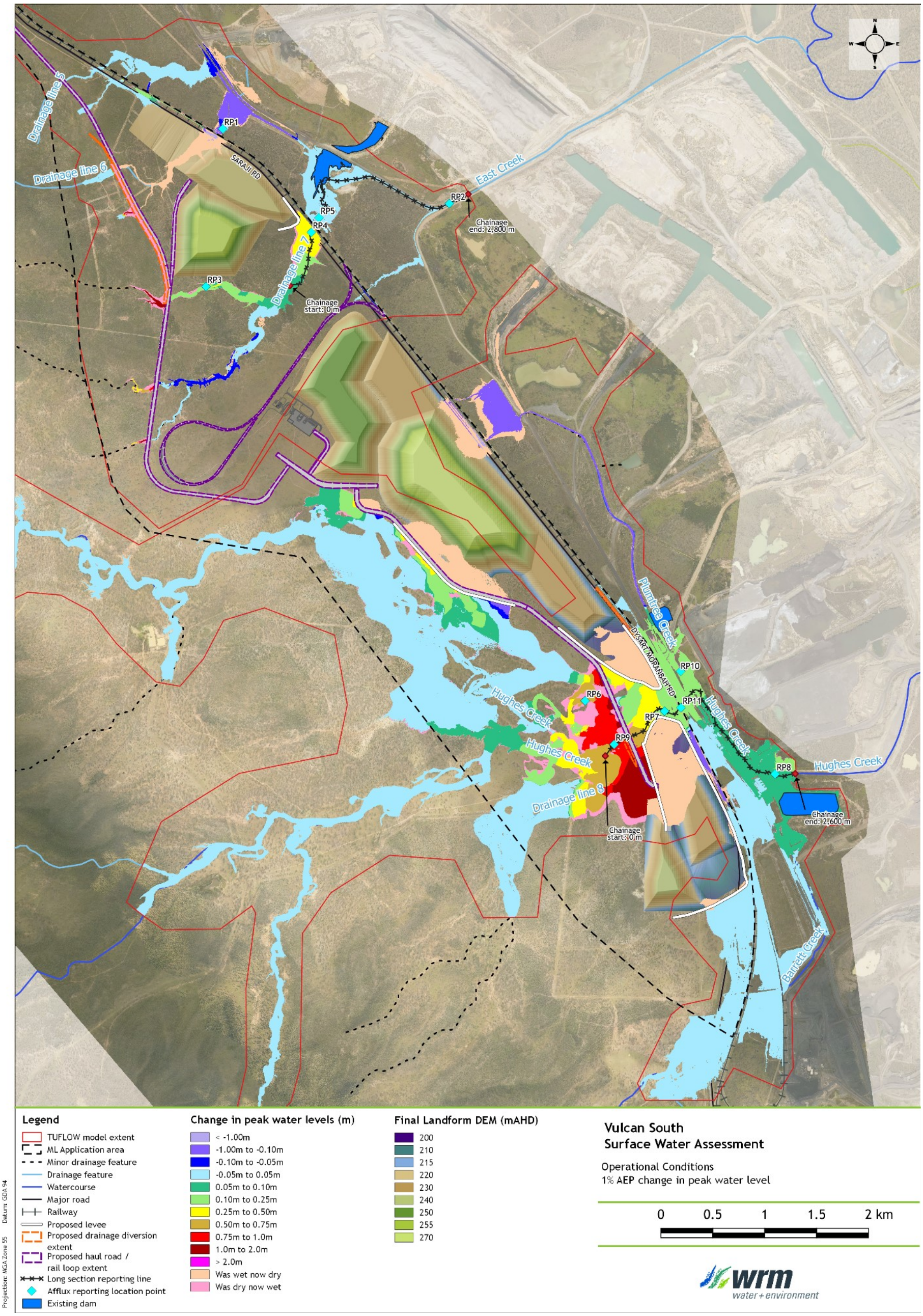

Figure C.2 - 1% AEP change in peak water levels - Operational Conditions impacts

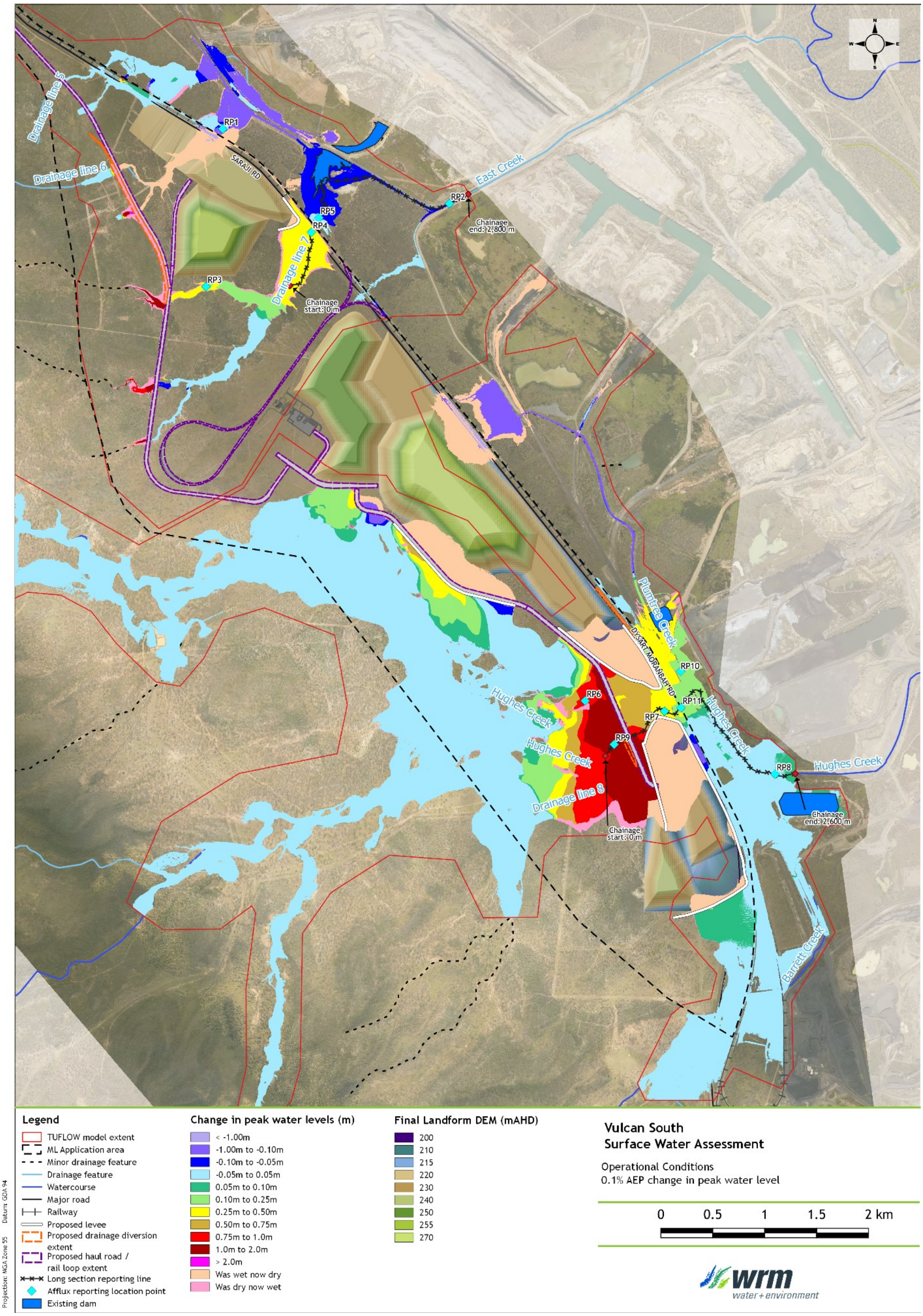

Figure C.3 - 0.1% AEP change in peak water levels - Operational Conditions impacts

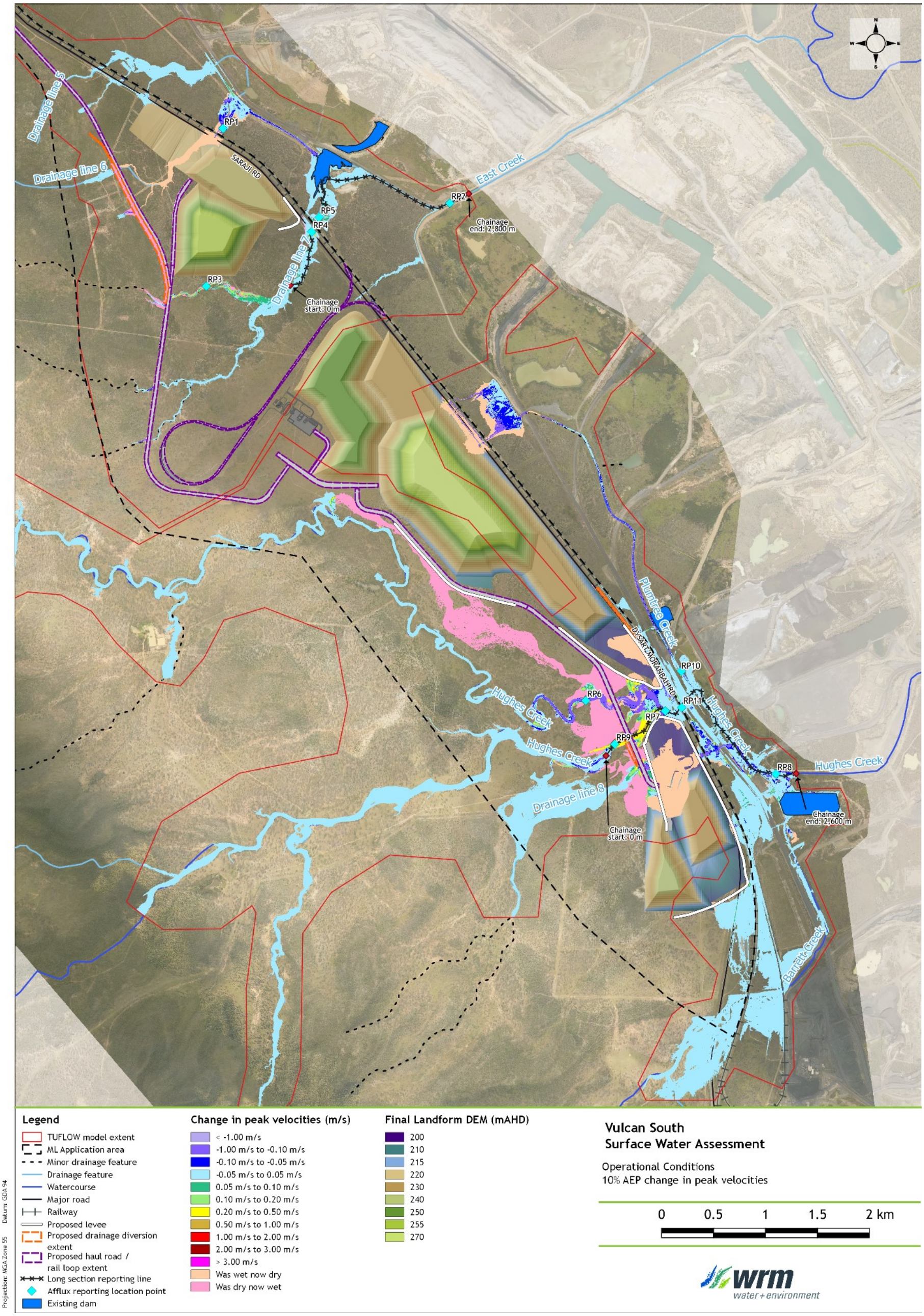

Figure C.4 - 10% AEP change in peak velocities - Operational Conditions impacts

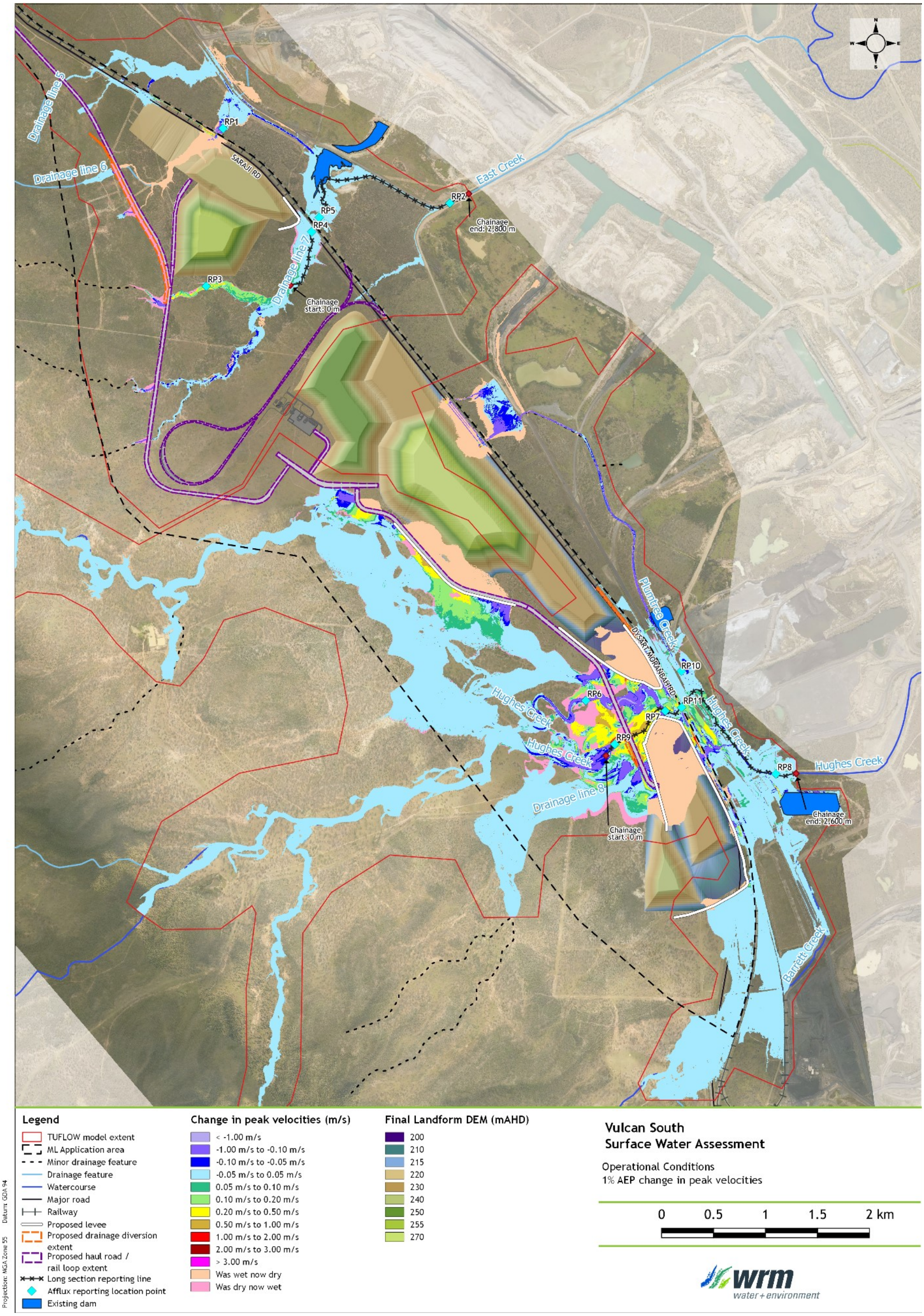

Figure C.5 - 1% AEP change in peak velocities - Operational Conditions impacts

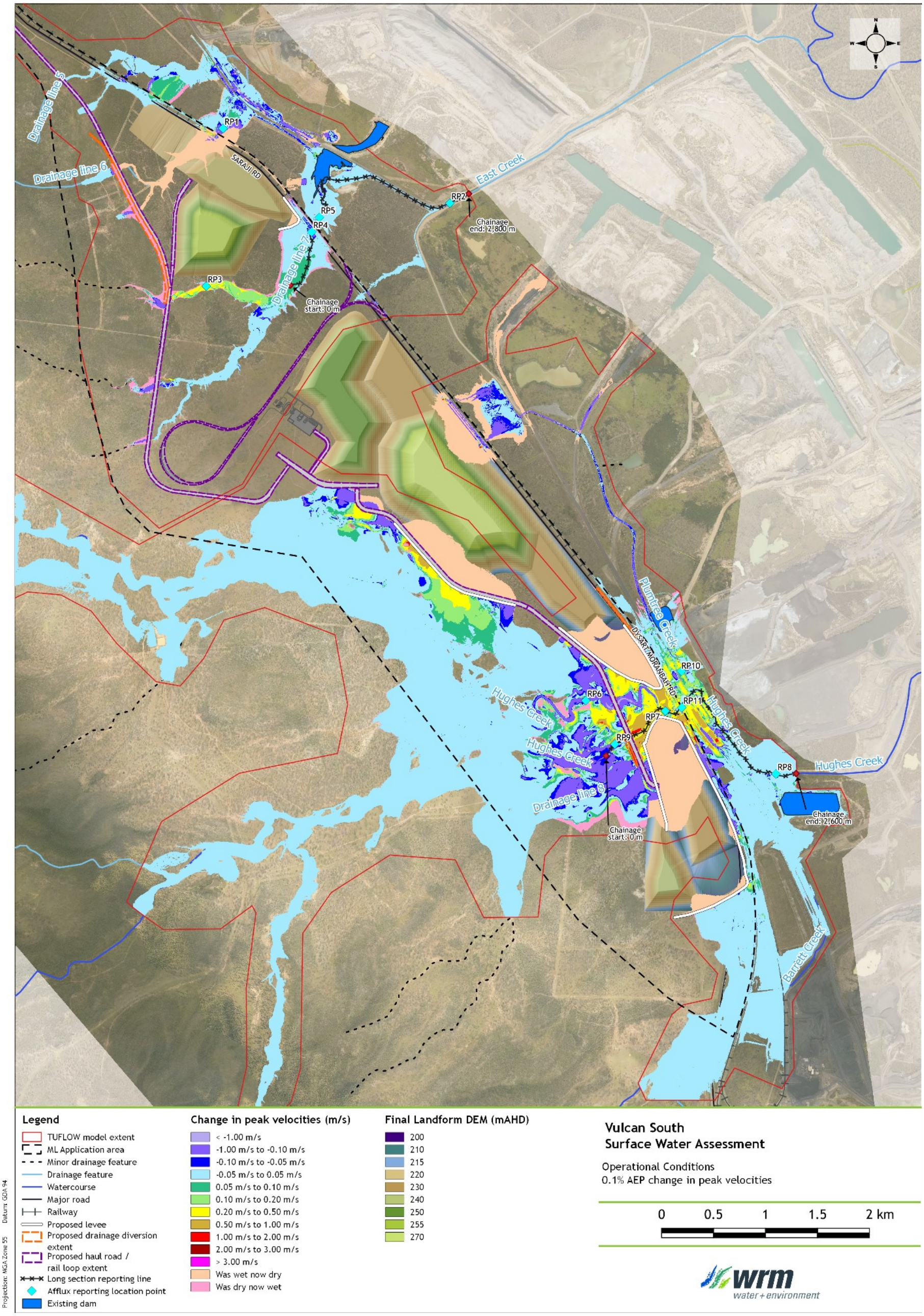

Figure C.6 - 0.1% AEP change in peak velocities - Operational Conditions impacts

Appendix D – **Post-closure Conditions flood impact maps**

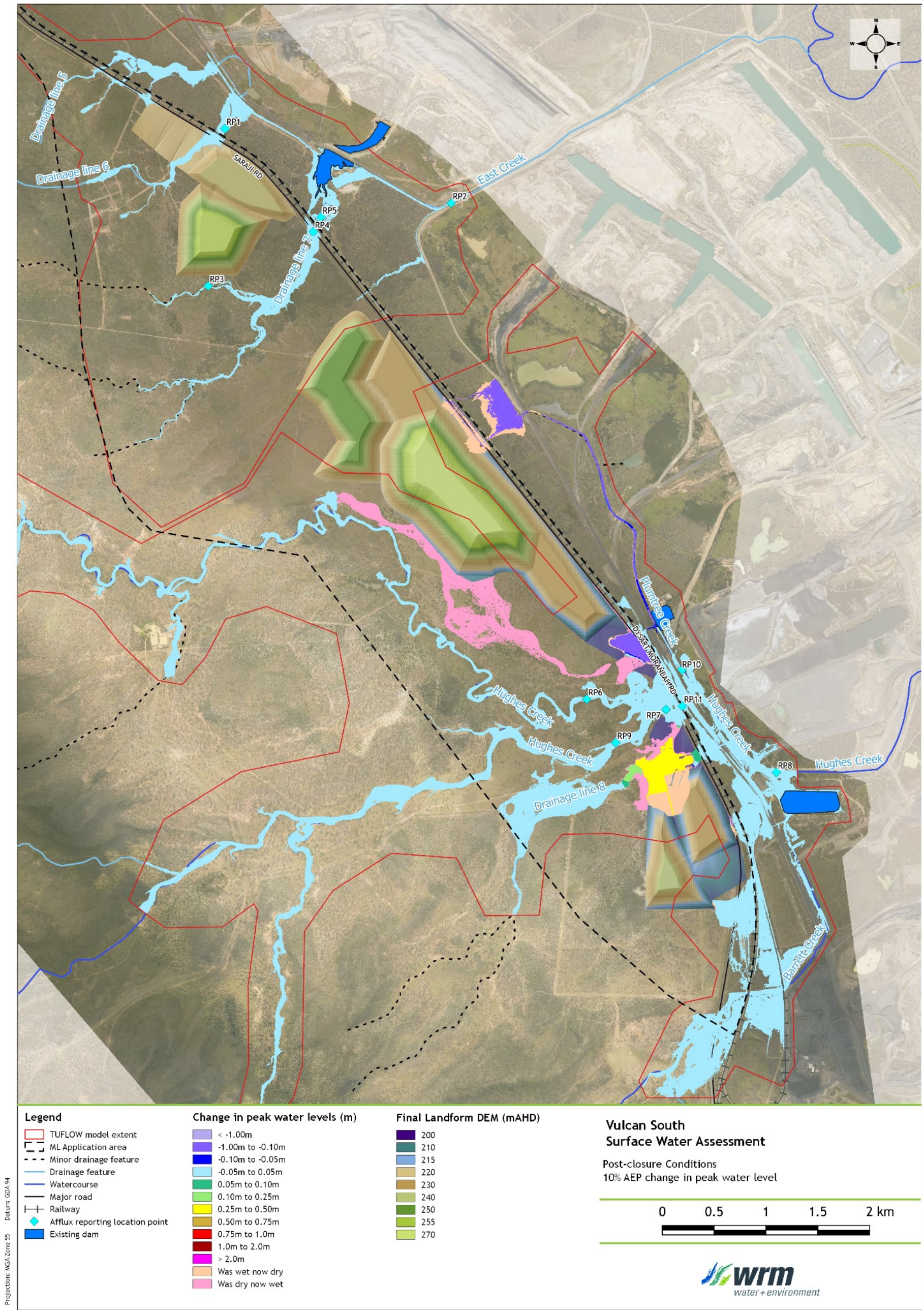

Figure D.1 – 10% AEP change in peak water levels - Post-closure Conditions impacts

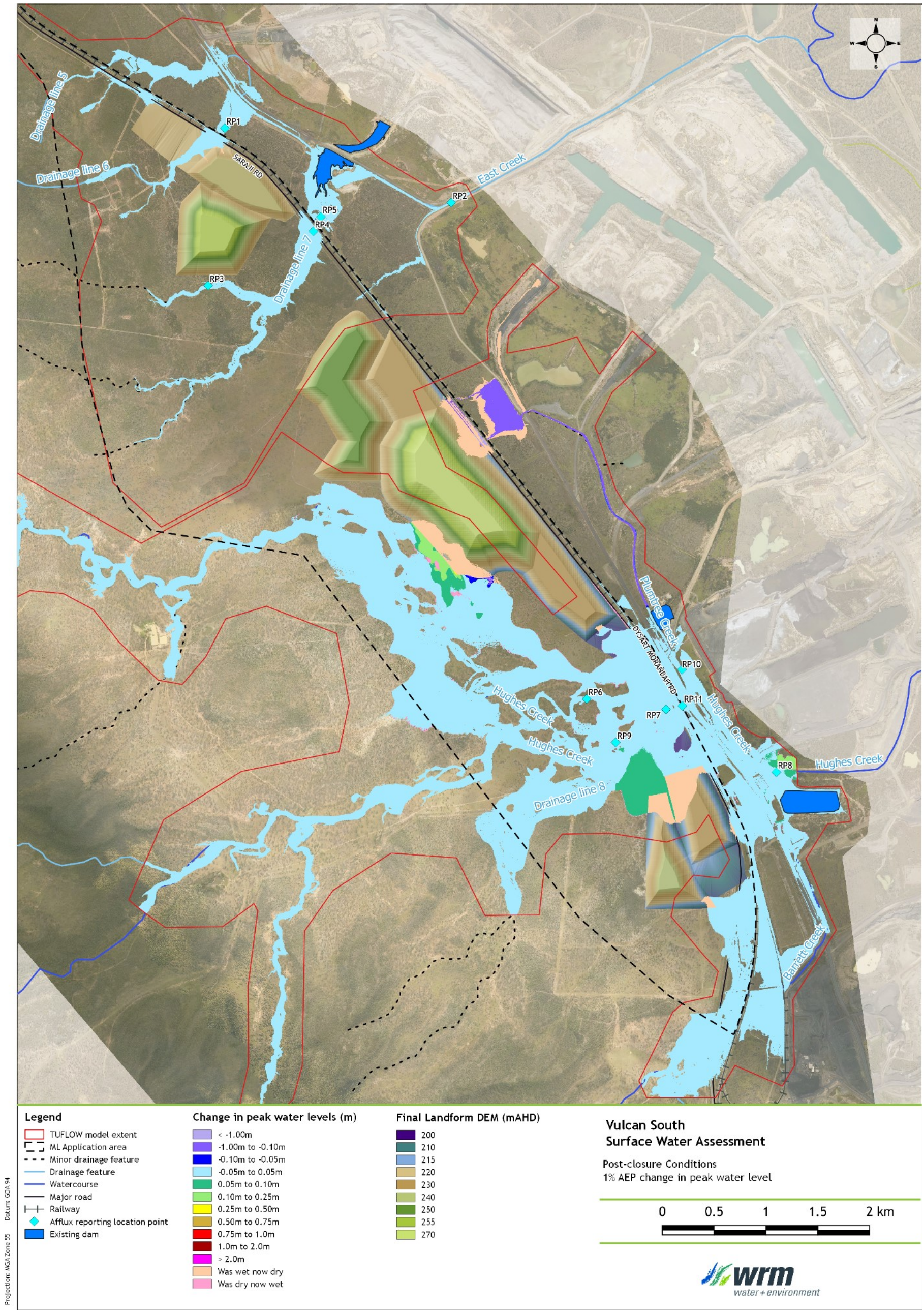

Figure D.2 - 1% AEP change in peak water levels - Post-closure Conditions impacts

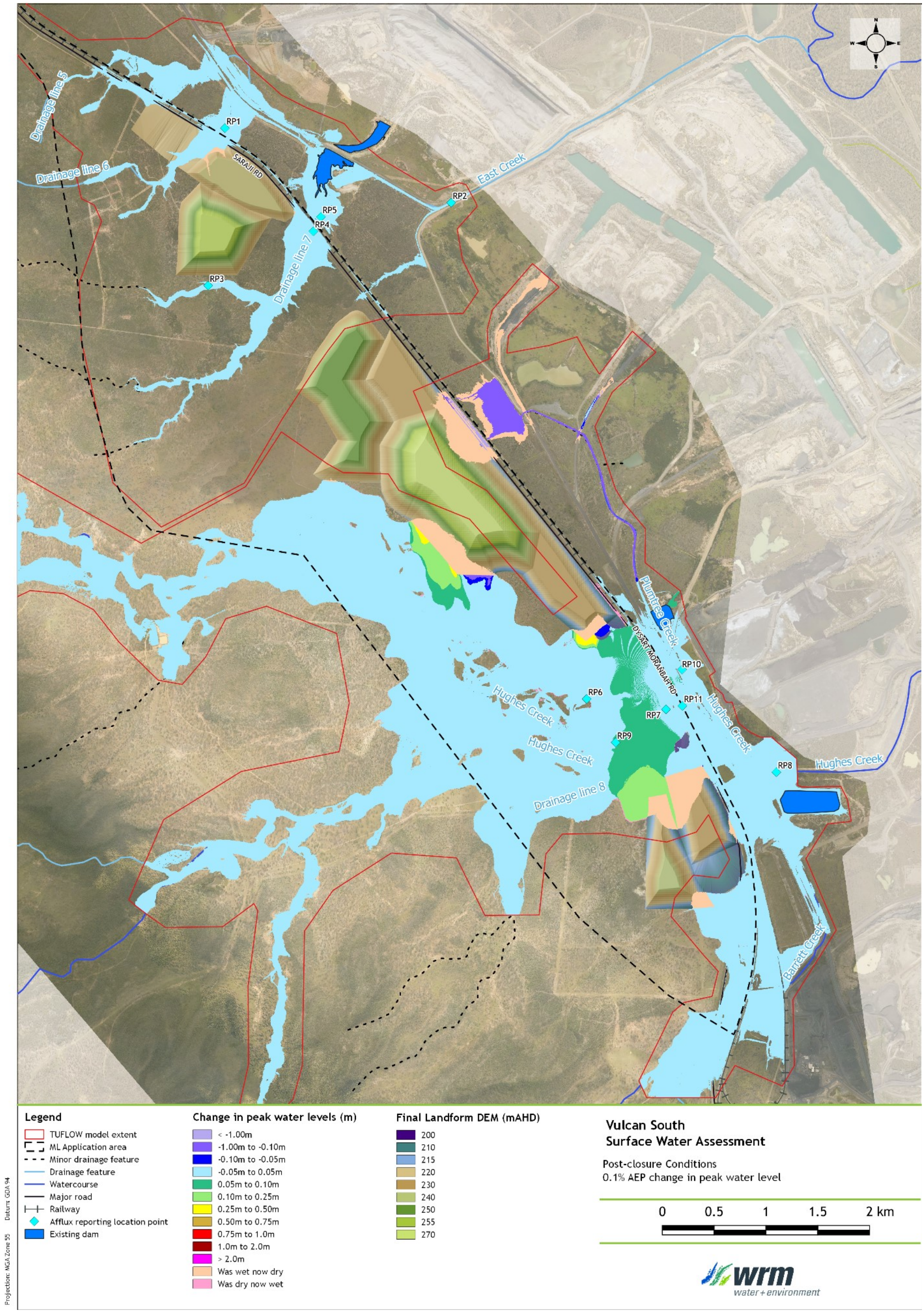

Figure D.3 - 0.1% AEP change in peak water levels - Post-closure Conditions impacts

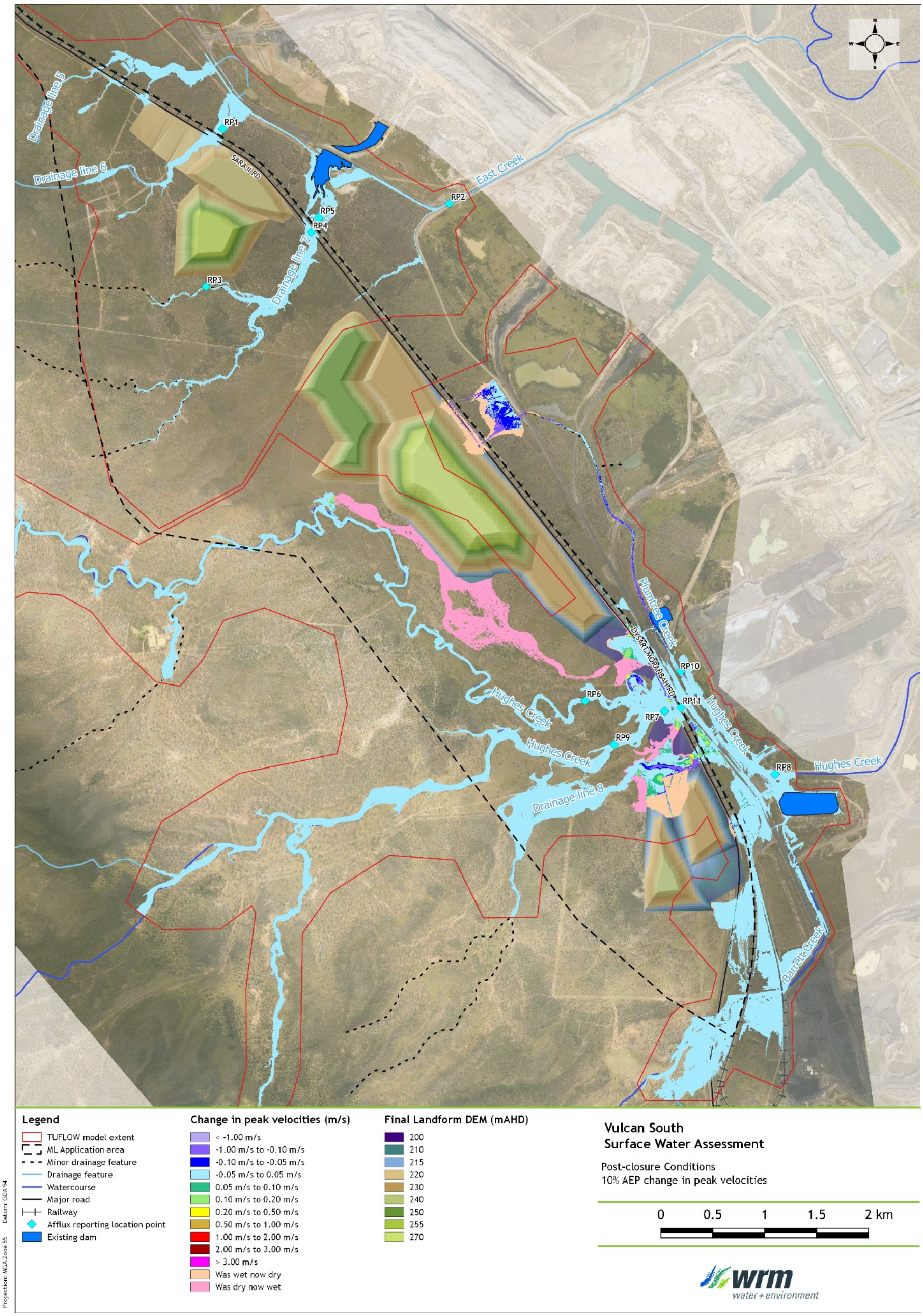

Figure D.4 - 10% AEP change in peak velocities - Post-closure Conditions impacts

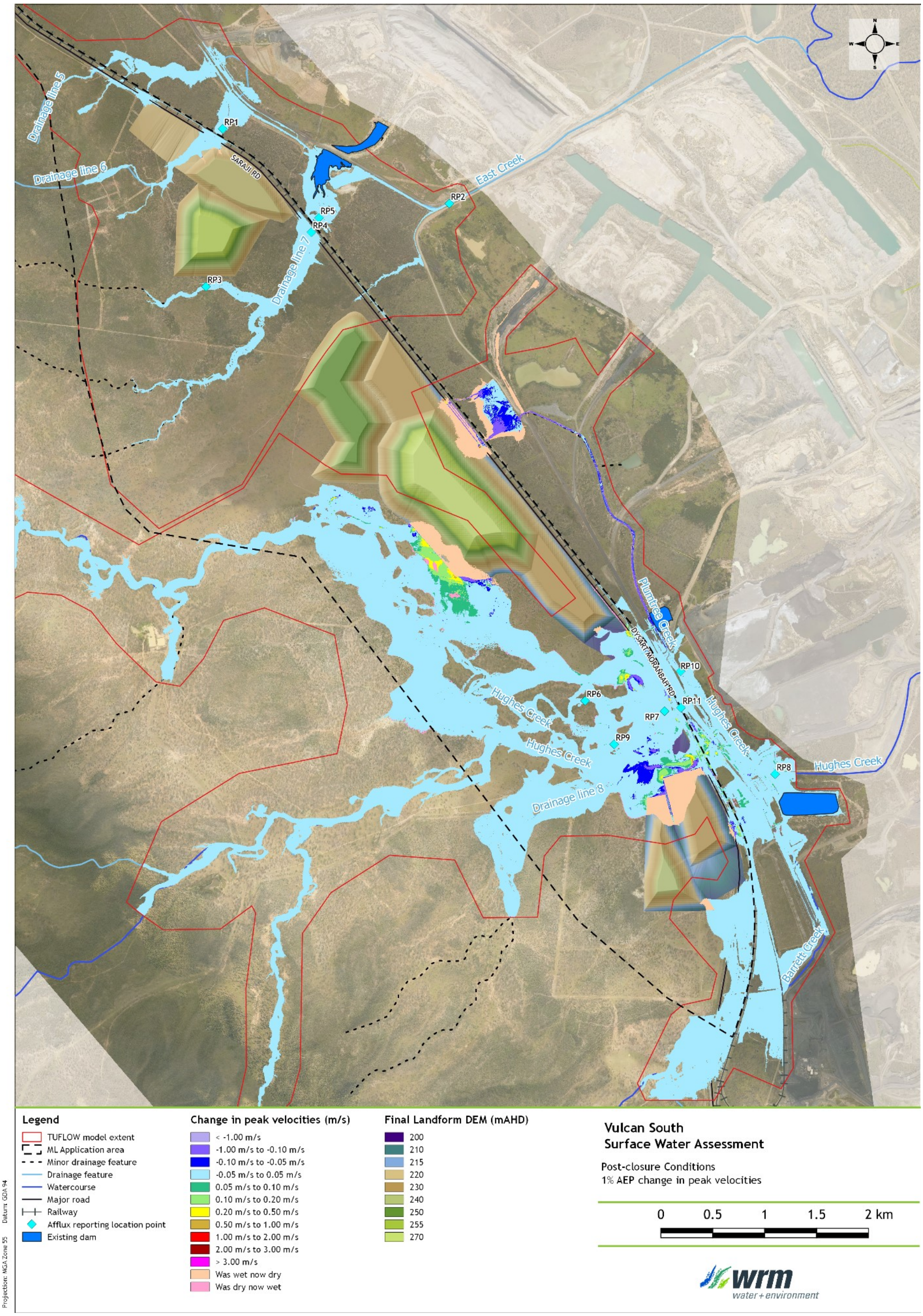

Figure D.5 - 1% AEP change in peak velocities - Post-closure Conditions impacts

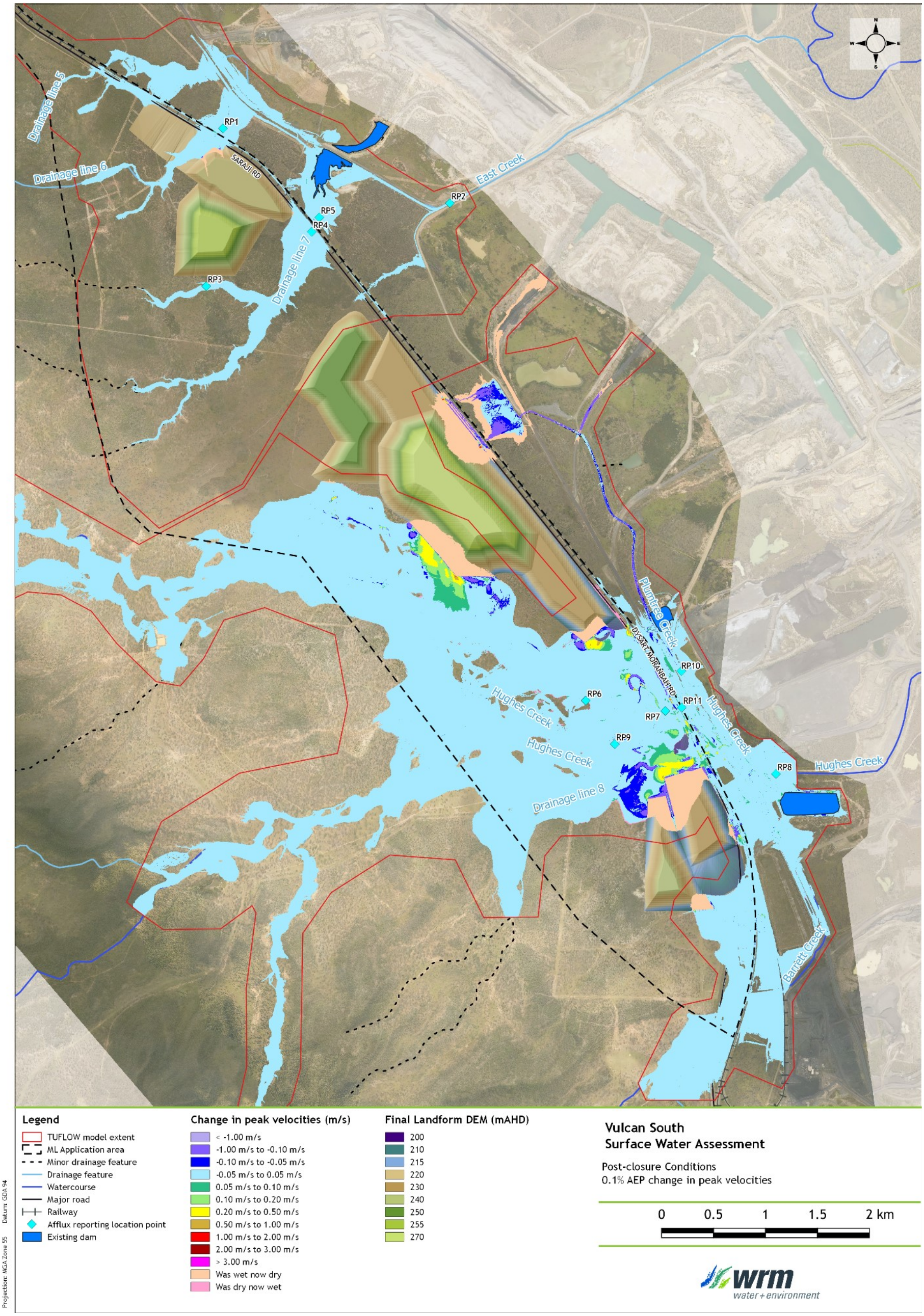

Figure D.6 - 0.1% AEP change in peak velocities – Post-closure Conditions impacts

Appendix B – Groundwater Impact Assessment Report

REPORT ON

VULCAN SOUTH

GROUNDWATER IMPACT ASSESSMENT

For: Vitrinite Pty Ltd

Project number: 4027

Date: 14/03/2022

ABN: 50 627 068 866 www.hydrogeologist.com.au info@hydrogeologist.com.au

1/149 Boundary Road, Bardon. QLD. 4065 P.O. Box 108, The Gap. QLD. 4061

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Appendix B Hydraulic testing results
Appendix C Groundwater modelling

Vulcan South – Groundwater Impact Assessment

Prepared for

Vitrinite Pty Ltd

1. Introduction

hydrogeologist.com.au has been engaged by Mining & Energy Technical Services Pty Ltd (METServe) to prepare a groundwater impact assessment to support an Environmental Authority (EA) application for Vulcan South (VS) (the Project). The Project is proposed to be developed by Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), and is located:

- north of Dysart and approximately 35 km south of Moranbah in Queensland's Bowen Basin; and
- to the immediate west of the BHP Billiton Mitsubishi Alliance (BMA) Saraji Mine and Peak Downs Mine.

The Project location is presented in Figure 1.1.

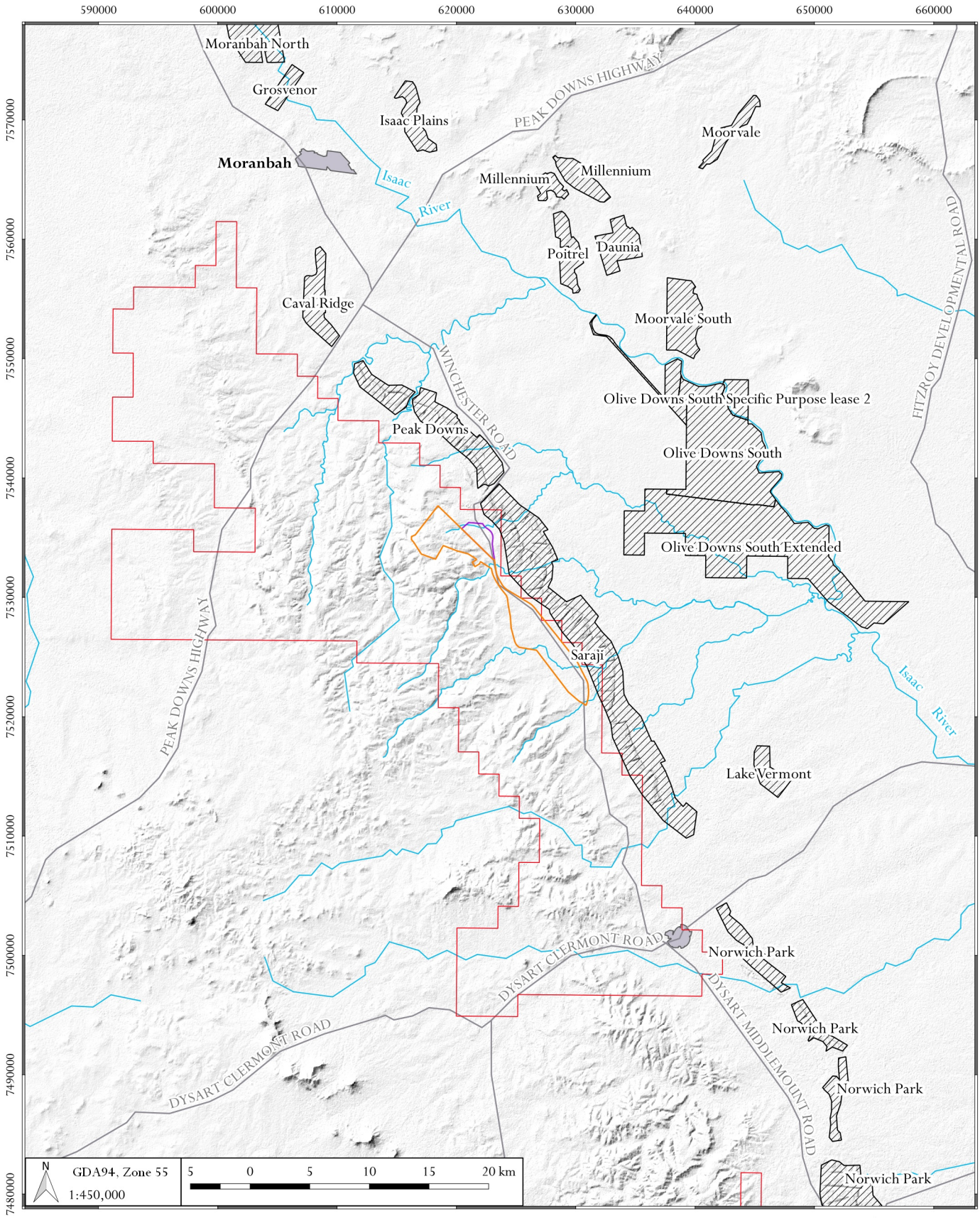
METServe has been engaged by Vitrinite to manage the environmental approval process for the Project. Vitrinite has commissioned environmental assessment work for the purposes of preparing a mining lease application (MLA) and EA application. The groundwater impact assessment will also support the likely referral of the Project to the Commonwealth Department of the Environment and Energy (DoEE) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

1.1. Background

The Project is located immediately to the south of Vitrinite's coal mine, the Vulcan Coal Mine (VCM), which is located on ML700060 (Figure 1.1). The proposed MLA boundary (the Project area) abuts ML700060, however proposed activities for VS and VCM will be implemented separately.

The Vulcan hard coking coal target has been defined and selected for open cut development via three separate open cut pits that form the primary mining focus of the Project (i.e. Vulcan North pit, Vulcan Main pit, and Vulcan South pit). The Project will operate for approximately nine years, including primary rehabilitation works, following a two year construction period and will extract approximately 13.5 million tonnes (Mt) of ROM coal consisting predominantly of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 million tonnes per annum (Mtpa). The Project will target the Alex and multiple Dysart Lower coal seams. Truck and shovel mining operations will be employed to develop the pits.

Ex-pit waste rock dumps will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. Ancillary infrastructure, including a Run of Mine (ROM) pad, modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO), Mine Infrastructure Area (MIA), offices, roads and surface water management infrastructure will be established to support the operation. In-pit dumping will fill the majority of the pit volumes during operations with the remaining final voids to be backfilled upon cessation of mining, resulting in the establishment of low waste rock dump landforms over the former pit areas. The initial Ex-pit waste rock dump will be rehabilitated in-situ.



LEGEND

- Combined exploration permits coal
- Established mining operation
- Mining lease application area
- VCP - ML 700060
- Watercourse
- Major road

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Vulcan South - Groundwater Impact Assessment (4027)

Project location and surrounding mines

FIGURE No.
1.1

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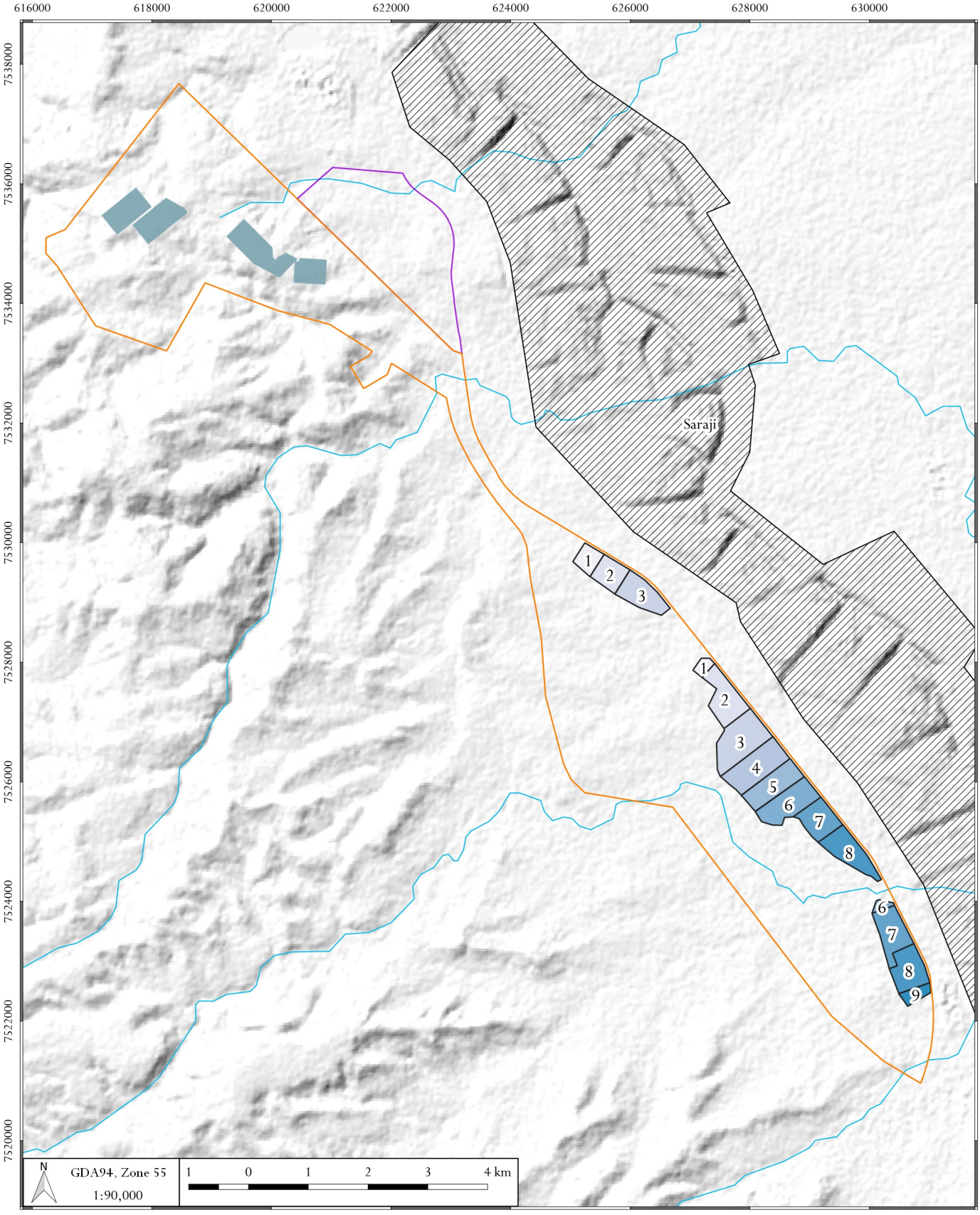
The Project includes a small-scale highwall mining trial program in the north of the Project area. The trial will involve the establishment of four highwall mining benches across a number of hillsides to facilitate extraction of coal utilising a highwall miner. The highwall mining trial will target up to 750 kt of coal which will be transported by truck to the CHPP via a dedicated haul road. The highwall mining trial is scheduled to be completed within the first year of mining operations.

The open cut mining footprint will cover a total area of approximately 477 hectares (ha). The annual mine progression for the Project is shown in Figure 1.2 along with the proposed MLA area, which for the purpose of this assessment is referred to as the Project area.

hydrogeologist.com.au (2019) established a groundwater monitoring network across the Project area in June 2019 to support the Project (Appendix A). The groundwater monitoring network was equipped with data loggers to enable high frequency (daily) groundwater level measurements to be captured. On-going monitoring and sampling of the groundwater monitoring network is being carried out to further supplement the groundwater level and quality data included in this groundwater impact assessment. The monitoring and sampling of the groundwater monitoring network is planned for and carried out in consideration of the Queensland Monitoring and Sampling Manual (Department of Environment and Science, 2018a).



LEGEND

Vulcan South mine progression (Year):

1	4	7
2	5	8
3	6	9

- Established mining operation
- Mining lease application area
- Highwall mining area
- VCP - ML 700060

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Vulcan South - Groundwater Impact Assessment (4027)

Vulcan South - mine progression

FIGURE No.
1.2

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Based on or contains data provided by the State of Queensland [2019]
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1.2. Objectives and scope

The objective of the assessment is to identify and assess the Project groundwater impacts in a robust manner that meets the expectations of multiple stakeholders. These stakeholders include the Queensland Government, the Commonwealth Government, surrounding landholders, and mining companies. The scope of work defines the following distinct activities which have been compiled into the groundwater impact assessment to support Project approval:

- Review existing geological and hydrogeological information in the public domain and from private investigations.
- Describe the following components of the groundwater regime:
    - geology and stratigraphy, locally and regionally, including faulting;
    - aquifer types (confined / unconfined), hydraulic characteristics and connectivity;
    - depth to, and thickness of aquifers and their transmissivity;
    - relationship between local and regional groundwater flows;
    - groundwater flow directions and discharge;
    - groundwater quality and chemistry;
    - sources of recharge and recharge rates for each aquifer; and
    - surface water interactions and potential groundwater dependent ecosystems (GDEs).
- Determine the local environmental values and water quality objectives of the groundwater resource in accordance with the Environmental Protection (Water) Policy 2009 (EPP Water) (Department of Environment and Heritage Protection, 2011), the Queensland Water Quality Guidelines (Department of Environment and Heritage Protection, 2009), and the ANZECC Water Quality Guidelines (AWQG, 2018).
- Develop a calibrated numerical groundwater model to predict potential drawdown of all relevant aquifers. The groundwater impact assessment should:
    - present the conceptualisation of the hydrogeological system, including assumptions and limitations;
    - define each hydrogeological or hydrostratigraphic unit including storage, flow, connectivity, recharge / discharge pathways and the predicted changes likely to occur as a result of the Project;
    - simulate the Project and predict groundwater level drawdown or depressurisation in each hydrostratigraphic unit during the Project and post closure;
    - predict the volumes of groundwater reporting to each pit as seepage or inflow including proportions from each hydrostratigraphic unit;
    - predict residual groundwater levels and recovery rates in each hydrostratigraphic unit during post closure; and
    - include an assessment of the quality of, and risks inherent in, the data used and modelling, which may require sensitivity analysis.
- Predict and present impacts on environmental values, including identified third party landholder bores and potential GDEs.
- Predict and present impacts on potential interactions and connectivity between surface waters and groundwaters.
- Predict and present drawdown impacts during operations and post mining resulting from the Project.
- Predict and present cumulative drawdown impacts with other existing, known or reasonably foreseeable projects in the region during and post mining.
- Propose an ongoing groundwater management strategy including monitoring of the established bore monitoring network, any measures to manage or mitigate potential impacts and a program for the review and update of the numerical model.
- Describe potential impacts on groundwater quality from the Project (e.g. spills, contaminants).

1.3. Data and information sources

Data and information used for the purposes of this assessment has been obtained from the following sources:

- proponent provided information from METServe and Vitrinite;
- reports and publications as listed in Section 9 of this report;
- groundwater assessments from nearby mines including:
    - Caval Ridge Mine (URS, 2009);
    - Saraji Mine (AECOM, 2016); and
    - Olive Downs Coal Project (HydroSimulations, 2018).
- relevant Bowen Basin publications including:
    - CSIRO (2002);
    - Arrow Energy (2012);
    - URS (2012); and
    - Arrow Energy (2016).
- publicly available datasets including:
    - Australian Bureau of Meteorology (BoM) weather and climate data (Bureau of Meteorology, 2016);
    - Scientific Information for Land Owners (SILO) rainfall and evaporation (https://www.longpaddock.qld.gov.au/silo/);
    - Groundwater Dependent Ecosystems Atlas (GDE Atlas, BOM, 2018) (http://www.bom.gov.au/water/groundwater/gde/);
    - QLD globe (https://qldglobe.information.qld.gov.au/); and
    - Queensland Springs Database (https://data.qld.gov.au/dataset/springs/resource/4cdc89ef-b583-446e-a5c7-0836a91a3767).
- spatial mapping data from the Queensland spatial catalogue (QSpatial) (http://qldspatial.information.qld.gov.au/catalogue/custom/index.page).

2. Regulatory framework

hydrogeologist.com.au have considered the Project description and activities proposed against the various legislation and guidelines produced by the Queensland and Commonwealth Governments. Relevant legislation is described below.

2.1. Queensland

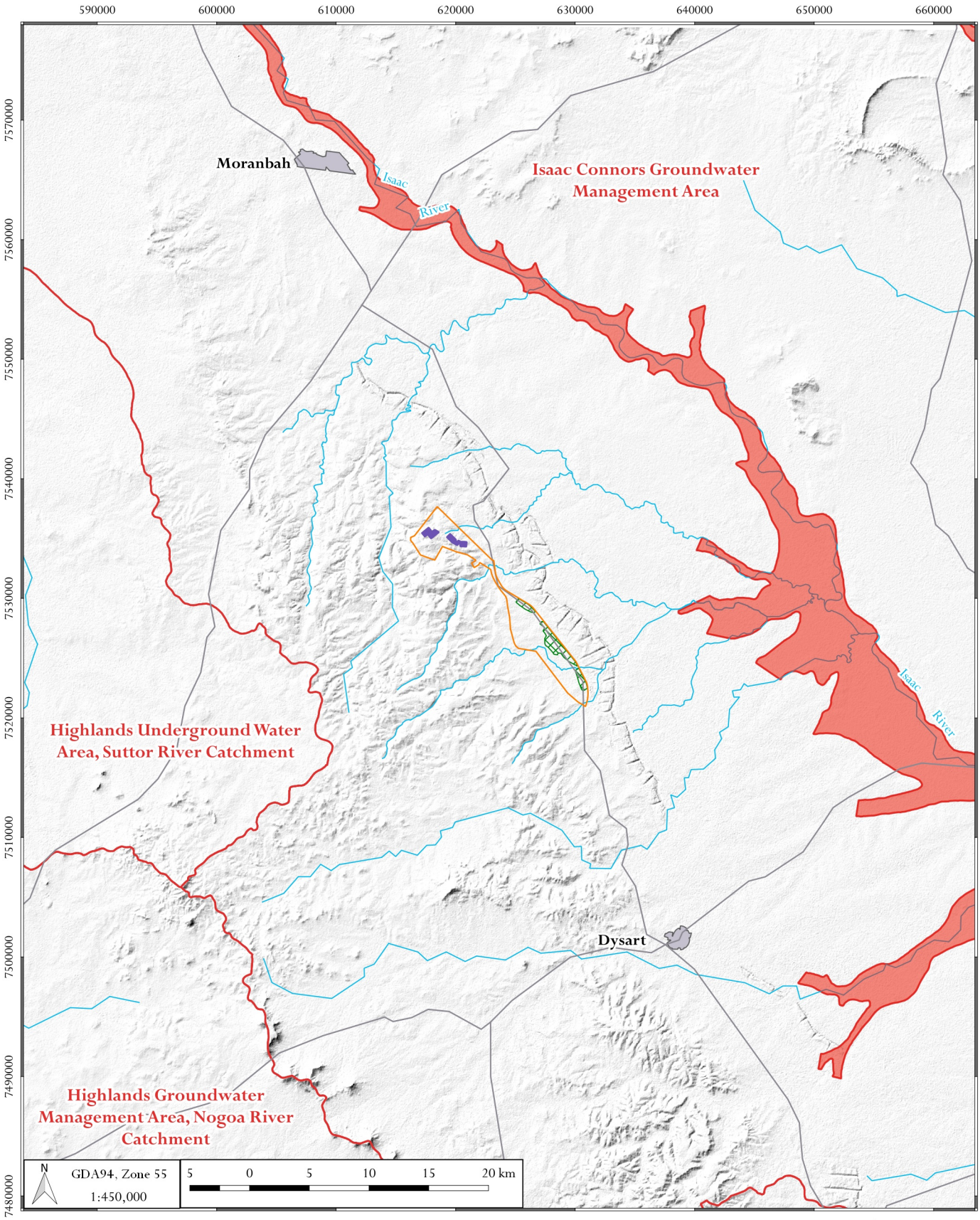
2.1.1. Water Act 2000

The *Water Act 2000* (Water Act), supported by the subordinate Water Regulation 2016, is the primary legislation regulating groundwater resources in Queensland. The purpose of the Water Act is to advance sustainable management and efficient use of water resources by establishing a system for planning, allocation and use of water. The Water Act is enacted under a framework of catchment specific Water Plans.

Water resources within the Project area are covered by the Water Plan (Fitzroy Basin) 2011 (Queensland Government, 2014) (Water Plan). The Water Plan covers surface waters (zone WQ1301) associated with the Isaac River, and groundwaters (zone WQ1310) of the Fitzroy Basin. Section 7 of the Water Plan defines the groundwater units and groundwater sub-areas areas, including the Isaac Connors groundwater management area, as follows:

> *(3) The Isaac Connors groundwater management area consists of the following (also each a groundwater unit)—*
>
> *(a) Isaac Connors Groundwater Unit 1, containing the aquifers of the Quaternary alluvium;*
>
> *(b) Isaac Connors Groundwater Unit 2, containing all subartesian aquifers within the Isaac Connors groundwater management area other than the aquifers included in Isaac Connors Groundwater Unit 1.*
>
> *(4) The area of Isaac Connors Groundwater Unit 1 shown on map E in schedule 4 is the Isaac Connors Alluvium groundwater sub-area for this plan.*

Map E, in Schedule 4, is reproduced as Figure 2.1 in this report. Figure 2.1 indicates that the Isaac Connors Alluvium groundwater sub-area is limited to the Isaac River and those parts of its tributaries that are adjacent to the confluence with the Isaac River. The Project area is approximately 20 km to the west of the Isaac River (Figure 2.1) and is well outside the Isaac Connors Groundwater Unit 1. It is assessed by **hydrogeologist.com.au** that the proposed open pits would drain groundwater from the Isaac Connors Groundwater Unit 2, that is the sub-artesian aquifers within the Isaac Connors groundwater management area. This interpretation is confirmed by the general absence of Quaternary alluvium near the proposed open pits and more broadly within the Project area, as discussed in Sections 4 and 5 of this report.



LEGEND

- Isaac Connors Alluvium Groundwater Sub-Area
- Groundwater management area
- Proposed pit
- Highwall mining area
- Mining lease application area
- Watercourse
- Major road

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22/02/2022

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Vulcan South - Groundwater Impact Assessment (4027)

Groundwater management areas and units

FIGURE No.
2.1

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2.1.2. Environmental Protection Act 1994

The quality of Queensland waters is protected under the Environmental Protection (Water) Policy 2009 (EPP Water) (Department of Environment and Heritage Protection, 2011).The EPP Water achieves the objective of the *Environmental Protection Act 1994* (EP Act) to protect Queensland waters whilst supporting ecologically sustainable development. Queensland waters include waters in rivers, streams, wetlands, lakes, aquifers, estuaries, and coastal areas.

The Isaac River Sub-basin Environmental Values and Water Quality Objectives (2011) is made pursuant to the provisions of the EPP Water, which is subordinate legislation under the EP Act. The EPP Water provides a framework for identifying environmental values (EVs) for Queensland waters, and deciding the water quality objectives (WQOs) to protect or enhance the EV. The Isaac River Sub-basin Environmental Values and Water Quality Objectives (2011) contains EV (Section 2, Table 1) and WQO for waters (including groundwaters) in the Isaac River Sub-basin.

For Isaac River groundwaters, the EVs selected for protection are as follows:

- aquatic ecosystems;
- irrigation;
- farm supply/use;
- stock water;
- primary recreation;
- drinking water; and
- cultural and spiritual.

The draft water quality guidelines (Department of Environment and Science, 2018b) inform the development of water quality guidelines to enhance or protect the 'aquatic ecosystem' EV for Queensland waters, in accordance with the provisions of the EPP Water. The draft guidelines (Department of Environment and Science, 2018b) outline protocols for comparing test site water quality against relevant WQO recognised under the EPP Water.

Section 2.7 of the Queensland Water Quality Guidelines (Department of Environment and Heritage Protection, 2009) provides guidance on the approach taken to identify EV, water quality indicators and guidelines (as a basis for WQO) in groundwaters. Where local EV and WQO have been scheduled under the EPP Water for groundwaters, these are the applicable reference source for decision making.

In the absence of scheduled data, the EPP Water identifies applicable EV and potential sources for water quality guidelines to inform decision making. The EP Act identifies that groundwater quality is an EV to be protected and therefore the groundwater quality should be maintained within the range of natural quality variations. Natural quality variations should be established through baseline characterisation.

In the absence of scheduled data, the default management intent is that there should be 'no change' to the natural variation in groundwater quality. From the Queensland Water Quality Guidelines (Department of Environment and Heritage Protection, 2009), no change in the natural variation in groundwater quality is deemed to have occurred if there are no detectable changes to the 20th, 50th and 80th percentiles of the natural distribution of values. Where review of local data indicates that some groundwater systems are clearly impacted, then in these cases, the management intent would be to improve quality, and more stringent percentiles may be used to derive guideline values.

Generally, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (AWQG, 2018) should apply to the quality of both surface waters and groundwaters since the EVs which they protect relate to above-ground uses (e.g. irrigation, drinking water, farm animal or fish production and maintenance of aquatic ecosystems). Hence groundwater should be managed in such a way that when there is a surface expression of groundwater, whether from natural seepages or from bores, it will not cause the established WQO for these waters to be exceeded, nor compromise their designated EV (an important exception is stygofauna).

The Department of Regional Development, Manufacturing and Water (DRDMW) Groundwater Database (GWDB) contains groundwater quality data from registered groundwater bores. Where sufficient data exist, water quality guidelines are developed at aquifer/sub-aquifer level based on existing conditions, using groundwater quality data sourced from the DRDMW GWDB or from local monitoring data. Following the definition and mapping of chemistry zones, the groundwater quality data are used to calculate a range of percentiles for available indicators for each chemistry zone.

Where there is potential for groundwater to be impacted by activities such as mining, it is important to acquire localised reference (or baseline) data prior to commencement of the activity. In this situation, the local pre-development data would be used as reference data. Where the groundwater quality is slightly disturbed due to anthropogenic contamination or from naturally occurring groundwater chemistry, the slightly disturbed waters guideline applies. Where groundwater is moderately or highly disturbed, more stringent percentiles may be applied as follows:

- high ecological value (HEV) groundwaters guideline: 20/50/80th percentiles of the waters in the sub-aquifer chemistry zones;
- slightly disturbed (SD) groundwaters guideline: 20/40/70th percentiles of the waters in the sub-aquifer chemistry zones; and
- waters potentially impacted by human activities – guideline: no change to the 20/50/80th percentiles of local pre-development data.

2.1.3. Environmental authority

The Queensland guideline (Department of Environment and Science, 2016) provides information to those preparing a site-specific application for a new EA (site-specific application) or an application to amend an EA (amendment application) for resource projects or activities that are carried out on one or more resource tenures (e.g. mineral development licence or mining lease); and involve the exercise of underground water rights (or a change to the exercise of underground water rights).

Section 126A of the EP Act (State of Queensland 2019, n.d.) outlines the mandatory information that must be included within a groundwater assessment. It requires that groundwater assessments must state the following:

- *any proposed exercise of underground water rights during the period in which resource activities will be carried out under the relevant tenure;*
- *the areas in which underground water rights are proposed to be exercised;*
- *for each aquifer affected, or likely to be affected by the exercise of underground water rights, include:*
    - *a description of the aquifer;*
    - *an analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers and surface water;*
    - *a description of the area of the aquifer where the water level is predicted to decline because of the exercise of underground water rights; and*
    - *the predicted quantities of water to be taken or interfered with because of the exercise of underground water rights during the period in which resource activities are carried out.*
- *the environmental values that will, or may, be affected by the exercise of underground water rights and the nature and extent of the impacts on the environmental values;*
- *any impacts on the quality of groundwater that will, or may, happen because of the exercise of underground water rights during or after the period in which resource activities are carried out; and*
- *strategies for avoiding, mitigating or managing the predicted impacts on the environmental values or predicted impacts on the quality of groundwater.*

EAs are administered by a range of Queensland Government and local government agencies. The agency that administers an EA is called the administering authority and for this Project it is the Department of Environment and Science (DES).

2.2. Commonwealth

The EPBC Act is administered by the DoEE and is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES). Under the 2013 amendment to the EPBC Act, impacts on groundwater resources, in relation to coal seam gas (CSG) development and large coal mining development were included, and are known as the 'water trigger'.

A project may be declared a controlled action by the DoEE, with water resources being one of the controlling provisions. The Independent Expert Scientific Committee (IESC) is a statutory body under the EPBC Act that provides scientific advice to the DoEE and relevant state ministers on CSG or large coal mining development proposals. Guidelines have been developed in order to assist the IESC in reviewing these proposals. Whilst the Project is not considered to be a large coal mining development, the IESC information requirements checklist is presented in Table 2-1, with details on where aspects have been addressed and documented within the report.

Table 2-1 IESC information requirements checklist

Information requirements	Section addressed
Description of the proposal	
Provide a regional overview of the proposed project area including a description of the: ▪ *geological basin;* ▪ *coal resource;* ▪ *surface water catchments;* ▪ *groundwater systems;* ▪ *water-dependent assets; and* ▪ *past, present and reasonably foreseeable coal mining and CSG developments.*	Sections 3, 4, 5, 5.7.2
Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies or regulations.	Section 2
Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Sections 1, 5.9, 6.2, 7
Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Section 2
Risk assessment	
Identify and assess all potential environmental risks to water resources and water-related assets, and their possible impacts. In selecting a risk assessment approach consideration should be given to the complexity of the project, and the probability and potential consequences of risks.	Section 6
Assess risks following the implementation of any proposed mitigation and management options to determine if these will reduce risks to an acceptable level based on the identified environmental objectives.	Section 7
Incorporate causal mechanisms and pathways identified in the risk assessment in conceptual and numerical modelling. Use the results of these models to update the risk assessment.	Section 6
The risk assessment should include an assessment of: ▪ *all potential cumulative impacts which could affect water resources and water-related assets; and* ▪ *mitigation and management options which the proponent could implement to reduce these impacts.*	Section 6
Groundwater – Context and Conceptualisation	
Describe and map geology at an appropriate level of horizontal and vertical resolution including: ▪ *definition of the geological sequence(s) in the area, with names and descriptions of the formations and accompanying surface geology, cross-sections and any relevant field data; and.* ▪ *geological maps appropriately annotated with symbols that denote fault type, throw and the parts of sequences the faults intersect or displace.*	Section 4

Information requirements	Section addressed
Define and describe or characterise significant geological structures (e.g. faults, folds, intrusives) and associated fracturing in the area and their influence on groundwater – particularly groundwater flow, discharge or recharge. ▪ *Site-specific studies (e.g. geophysical, coring / wireline logging etc.) should give consideration to characterising and detailing the local stress regime and fault structure (e.g. damage zone size, open/closed along fault plane, presence of clay/shale smear, fault jogs or splays).* ▪ *Discussion on how this fits into the fault's potential influence on regional-scale groundwater conditions should also be included.*	Sections 4, 5, 5.9.1
Provide site-specific values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and specific yield or specific storage characteristics including the data from which these parameters were derived) for each relevant hydrogeological unit. In situ observations of these parameters should be sufficient to characterise the heterogeneity of these properties for modelling.	Sections 5, 5.4
Provide time series level and water quality data representative of seasonal and climatic cycles	Sections 5.3, 5.8
Provide data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, and hydrographs. All boreholes used to provide this data should have been surveyed.	Section 5.5.5
Provide hydrochemical (e.g. acidity/alkalinity, electrical conductivity, metals, and major ions) and environmental tracer (e.g. stable isotopes of water, tritium, helium, strontium isotopes, etc.) characterisation to identify sources of water, recharge rates, transit times in aquifers, connectivity between geological units and groundwater discharge locations.	Section 5.8
Describe the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Section 5.5.4
Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	Sections 5.5 and 5.6
Groundwater – Analytical and Numerical Modelling	
Provide a detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 6.1, Appendix C
Undertake groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), including independent peer review.	Section 6.1, Appendix C
Calibrate models with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	Section 0, Appendix C
Describe each hydrogeological unit as incorporated in the groundwater model, including the thickness, storage and hydraulic characteristics, and linkages between units, if any.	Appendix C
Describe the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the proposed project.	Sections 5.5.4, 6, Appendix C
Describe the various stages of the proposed project (construction, operation and rehabilitation) and their incorporation into the groundwater model. Provide predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps for all hydrogeological units.	Sections 1, Appendix C
Identify the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	Section 6.2.1, Appendix C
Undertake model verification with past and/or existing site monitoring data.	Appendix C
Provide an explanation of the model conceptualisation of the hydrogeological system or systems, including multiple conceptual models if appropriate. Key assumptions and model limitations and any consequences should also be described.	Section 5.9
Consider a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.	Appendix C
Undertake sensitivity analysis and uncertainty analysis of boundary conditions and hydraulic and storage parameters, and justify the conditions applied in the final groundwater model (see Middlemis and Peeters [in press]).	Section 6.2.4, Appendix C
Provide an assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.	Appendix C

Information requirements	Section addressed
Undertake an uncertainty analysis of model construction, data, conceptualisation and predictions (see Middlemis and Peeters [in press]).	Appendix C
Provide a program for review and update of models as more data and information become available, including reporting requirements.	Section 7
Provide information on the magnitude and time for maximum drawdown and post-development drawdown equilibrium to be reached.	Section 6.2.3
Groundwater – Impacts to Water Resources and Water-dependent Assets	
Provide an assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts. Consider and describe: ▪ *any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, interaquifer connectivity and connectivity with sea water;* ▪ *the effects of dewatering and depressurisation (including lateral effects) on water resources, water-dependent assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance;* ▪ *the potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units;* ▪ *the possible fracturing of and other damage to confining layers; and* ▪ *for each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the proposed project, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.*	Section 6
Describe the water resources and water-dependent assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.	Sections 5, 5.7.2, 6
For each potentially impacted water resource, provide a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.	Section 6
Describe existing water quality guidelines, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	Sections 2 5.8.3, 5.8.4
Provide an assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 6
Describe proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.	Section 7
Provide a description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.	Section 7
Groundwater – Data and Monitoring	
Provide sufficient data on physical aquifer parameters and hydrogeochemistry to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.	Section 5
Develop and describe a robust groundwater monitoring program using dedicated groundwater monitoring wells – including nested arrays where there may be connectivity between hydrogeological units – and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time.	Section 5
Develop and describe proposed targeted field programs to address key areas of uncertainty, such as the hydraulic connectivity between geological formations, the sources of groundwater sustaining GDEs, the hydraulic properties of significant faults, fracture networks and aquitards in the impacted system, etc., where appropriate.	Section 7
Provide long-term groundwater monitoring data, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	Section 5.8
Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 5.8

Information requirements	Section addressed
Cumulative Impacts – Context and Conceptualisation	
Provide cumulative impact analysis with sufficient geographic and temporal boundaries to include all potentially significant water-related impacts.	Section 6, Appendix C
Consider all past, present and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern in the cumulative impact analysis. Where a proposed project is located within the area of a bioregional assessment consider the results of the bioregional assessment.	Section 6, Appendix C
Cumulative Impacts – Impact	
Provide an assessment of the condition of affected water resources which includes: ▪ *identification of all water resources likely to be cumulatively impacted by the proposed development;* ▪ *a description of the current condition and quality of water resources and information on condition trends;* ▪ *identification of ecological characteristics, processes, conditions, trends and values of water resources;* ▪ *adequate water and salt balances; and,* ▪ *identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).*	Section 6, Appendix C
Assess the cumulative impacts to water resources considering: ▪ *the full extent of potential impacts from the proposed project, (including whether there are alternative options for infrastructure and mine configurations which could reduce impacts), and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally;* ▪ *all stages of the development, including exploration, operations and post closure/decommissioning;* ▪ *appropriately robust, repeatable and transparent methods;* ▪ *the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts; and* ▪ *opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.*	Section 6, Appendix C
Cumulative Impacts – Mitigation, Monitoring and Management	
Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	Section 7
Identify cumulative impact environmental objectives.	Section 7
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	Section 7
Describe appropriate reporting mechanisms.	Section 7
Propose adaptive management measures and management responses.	Section 7

3. Baseline conditions

3.1. Climate

Climate plays a major role in defining two characteristics of groundwater systems; recharge and evapotranspiration. The BoM (2016) classifies the climate of a particular area using multiple criteria – temperature and humidity, amount of seasonal rainfall and type of vegetation. Based on these criteria, the Project area can be characterised as subtropical, with mostly hot dry summers and mild winters. In terms of rainfall, the Project area is classified as summer rainfall dominant with the majority of the rain falling between November and March.

In order to establish the long-term rainfall and evapotranspiration trend, the following data were used:

- data from BoM Station 035019, located at Clermont Post Office (approximately 70 km southwest of the Project area), the closest site suitable for long-term monthly statistics with rainfall data available from 1870 and evaporation from 1979; and
- data from synthetic (interpolated) SILO data (Jeffrey *et al.*, 2001).

At the Clermont Post Office (BoM Station 035019), mean annual potential evaporation (2,080 mm, evaporation if unlimited water is available) greatly exceeds mean rainfall (658 mm). Further, mean potential evaporation exceeds mean rainfall for every month and may limit groundwater recharge from rainfall (Figure 3.1). Hence, on a monthly basis, it is likely that only episodic, or large and persistent rainfall has the potential to generate groundwater recharge. Approximately 70% of the average annual rainfall occurs between November and March, with January and February traditionally the wettest month, and August and September the driest months (Figure 3.1).

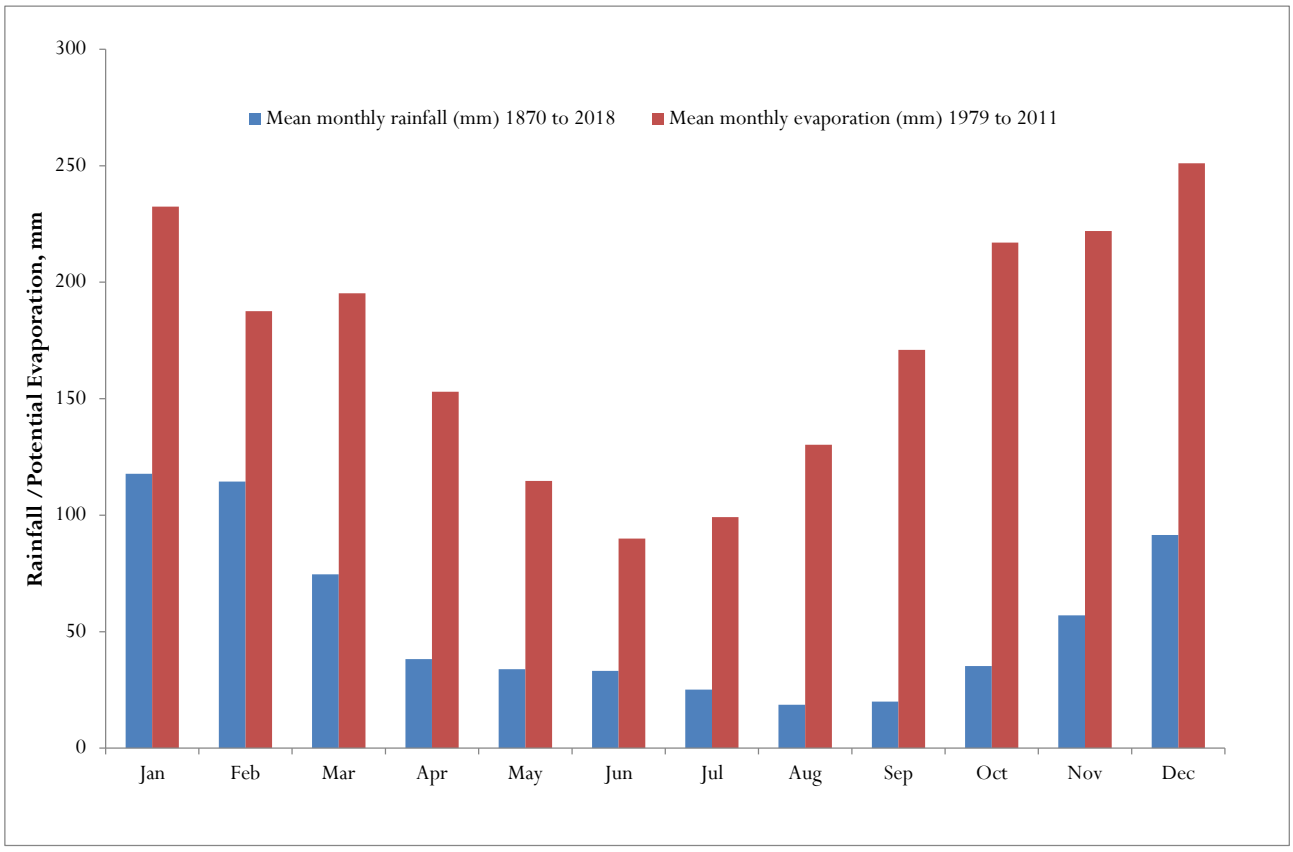


Figure 3.1 Rainfall and evaporation at Clermont Post Office (Station 035019)

Monthly patched point SILO rainfall data, adjacent to the Project area, were obtained from the Long Paddock website (https://www.longpaddock.qld.gov.au/silo/) in August 2019. SILO is a database of Australian climate data from 1889 to the present. It provides continuous daily meteorological datasets for a range of climate variables in ready-to-use formats suitable for biophysical modelling, research, and climate applications. The datasets are constructed from observational data obtained from BoM. SILO interpolates rainfall and evaporation records from available stations to a selected point. Consistent with data from Clermont Post Office (BoM Station 035019), mean annual potential evaporation for the SILO data (2,013 mm) greatly exceeds mean rainfall (582 mm). Further, mean potential evaporation exceeds mean rainfall for every month for the SILO data.

The cumulative rainfall departure (CRD) from monthly mean is another useful qualitative tool to show periods of rainfall that are wetter or dryer than average conditions. Figure 3.2 shows both total monthly rainfall (blue bars on the left axis) and the CRD (red curve) on the right axis for data between January 1901 to July 2019. Wetter than average periods are shown by an increasing trend in CRD; conversely, drier than average periods are shown by a decreasing trend. Notable observations from Figure 3.2 include the following:

- drier than average conditions between 1918-1950, 1960-73 and 2001-2007;
- above average rainfall between 1953-1960, 1973-1979, 2007-2012; and
- a relatively average rainfall period since 2012.

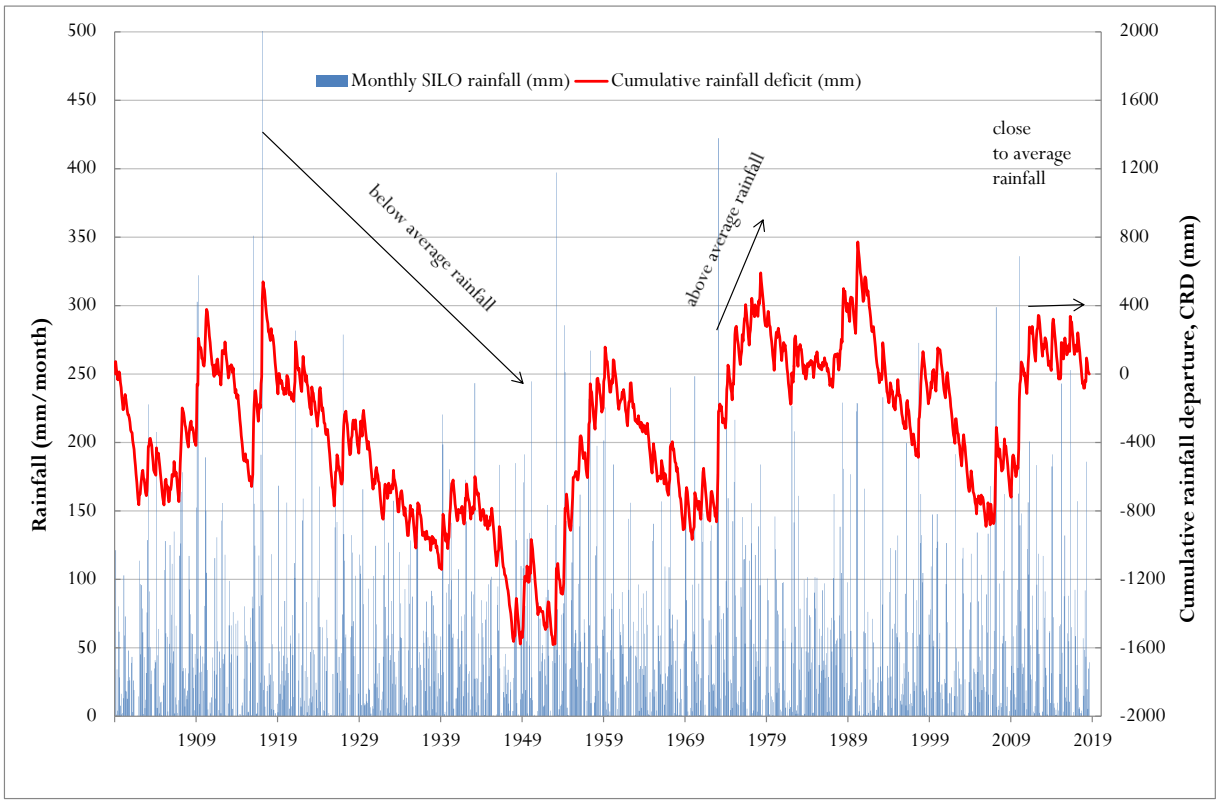


Figure 3.2 Monthly SILO rainfall and CRD

3.2. Topography and drainage

The Project area slopes from the Harrow Range in the west to the Isaac River east of the Project area (Figure 3.3). Surface elevations reach approximately 500 mAHD approximately 25 km to the west of the Project area. The surface elevation within the Project area is generally between 380 mAHD in the north, and 200 mAHD in the south.

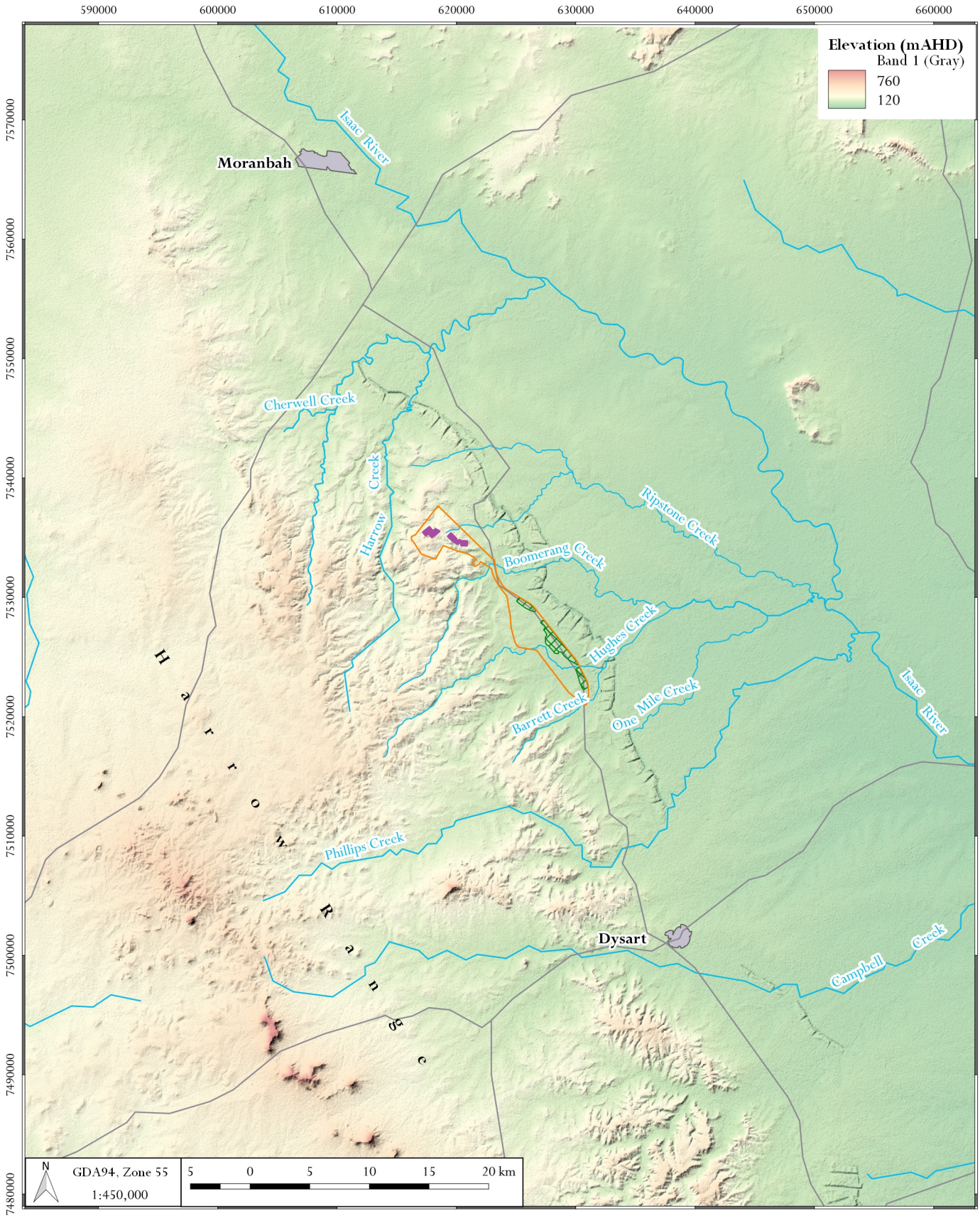
The Project area is surrounded by a number of ephemeral catchments (Figure 3.3) which drain from west to east, including the following creeks:

- Harrow Creek;
- Boomerang Creek;
- Hughes Creek;
- Barrett Creek;
- Phillips Creek; and
- Campbell Creek.

A tributary of Ripstone Creek flows through the Project area to the north-east, extending through the neighbouring BMA Saraji Mine. Boomerang Creek and a tributary of Hughes Creek flow through the central and southern parts of the Project area from west to east. Barrett Creek flows through the southernmost extent of the Project area.

A number of surface water diversions have been constructed in association with the existing coal mines to the east of the Project area. These include diversions on Ripstone Creek, Harrow Creek, Boomerang Creek and Hughes Creek. These diversions are all located downstream of the Project area and have been constructed by BMA. Surface water flow data captured and maintained by BMA indicates these creeks are all ephemeral.

The ephemeral creeks surrounding the Project area have limited flow, and typically only discharge after heavy rainfall events. The largest local surface water catchment near the Project area is Phillips Creek (10 kms to the south of the Project area), which flows into the Isaac River. The confluence of these two surface water systems is located approximately 20 km to the east of the Project area.



LEGEND

- Proposed pit
- Highwall mining area
- Mining lease application area
- Watercourse
- Major road

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Topography and drainage

FIGURE No.
3.3

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Whilst Hughes Creek and Boomerang Creek are much closer to the proposed pits, Phillips Creek (some 10 kms to the south) is the only watercourse with publicly available stream flow data. Figure 3.4 and Figure 3.5 are from the DRDMW Water Monitoring Information Portal (WMIP) (https://water-monitoring.information.qld.gov.au/), visited on 10 September 2019).

Figure 3.4 shows discharge and water level data for the historic gauging station (130409a) on Phillips Creek at Tayglen. Figure 3.4 shows that flows within Phillips Creek are ephemeral, with short-duration flows generally occurring over the summer months. Based on daily flow data between 1968 and 1988, Figure 3.5 shows that Phillips Creek flows less than 25 % of the time, with less than 10% probability of flows exceeding 0.1 m^3/s (8.64 ML/day) and less than 2% probability of flows exceeding 10 m^3/s (864 ML/day).

The reader is directed to the Vulcan South– Surface Water Assessment (WRM, 2022) report for further information analysis and impact assessment regarding surface water systems in the Project area.

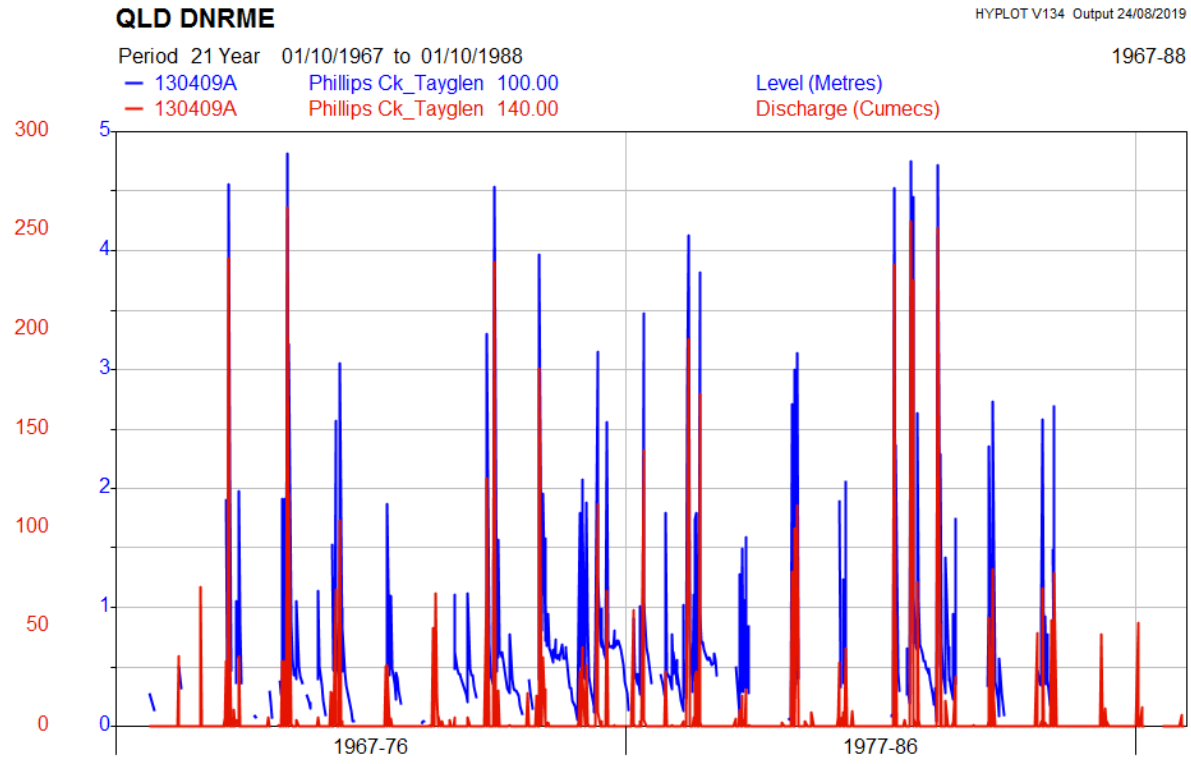


Figure 3.4 Discharge and water level, Phillips Creek at Tayglen (from DRDMW Water Monitoring Information Portal)

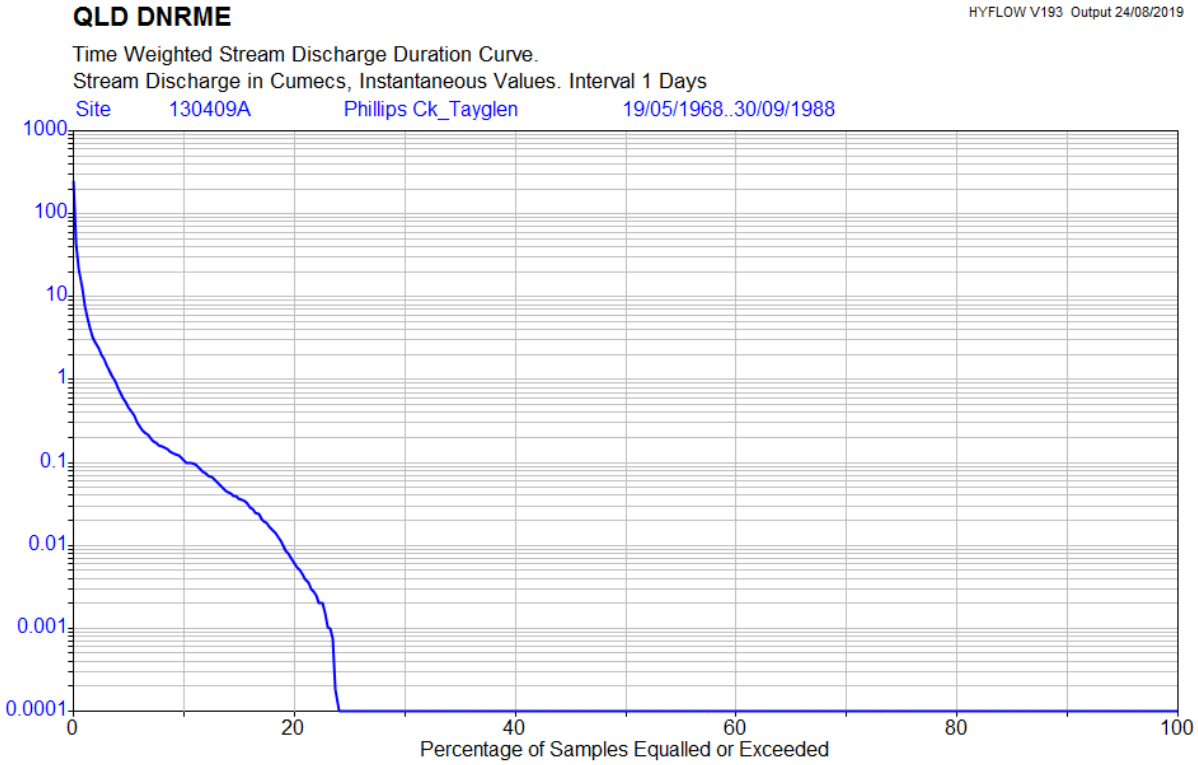


Figure 3.5 Daily flow duration, Phillips Creek at Tayglen (from DRDMW Water Monitoring Information Portal)

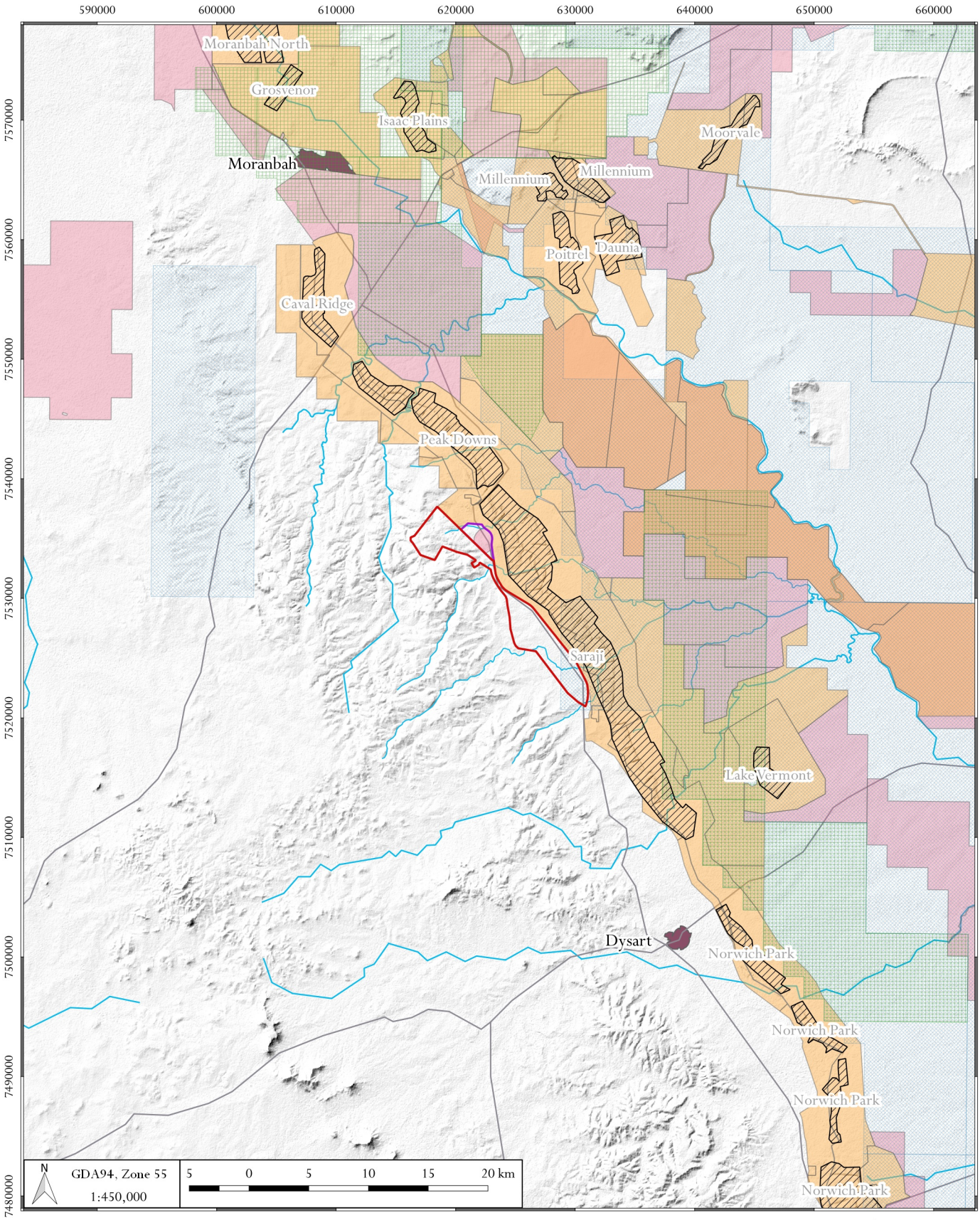
3.3. Land use

Land use is dominated by coal exploration and mining, beef cattle grazing, and CSG exploration and operations. Figure 3.6 shows the distribution of mineral development licences (MDLs) and mining leases (MLs) in the region. Figure 3.6 also shows the petroleum leases and exploration permits for petroleum in the region relating to CSG.

The individual coal mines in close proximity to the Project area are the BMA Saraji Mine and BMA Peak Downs Mine. Caval Ridge Mine is located to the north of Peak Downs Mine and Norwich Park Mine is located to the south of Saraji Mine. These series of coal mines are owned by BMA, however Norwich Park Mine is currently in care and maintenance.

Peak Downs Mine and Saraji Mine commenced coal production in the early 1970s with mining extending some 50 km in length and 2 km to 5 km in width. The mines generally follow the strike of the coal seams within the Moranbah Coal Measures and the mines extract coal seams that are stratigraphically higher than the coal seams to be mined as part of the Project.

Lake Vermont Mine is located to the south-east of Saraji Mine and is owned by the Jellinbah Group. Lake Vermont Mine currently has a production capacity of 8 Mtpa and was last expanded in 2012/2013.



LEGEND

- Mining lease
- Mineral development licence
- Established mining operation
- Mining lease application area
- VCP - ML 700060
- Exploration permits for petroleum
- Petroleum leases
- Watercourse
- Major road

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Mining tenure

FIGURE No.
3.6

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4. Geology

4.1. Regional geology

The Bowen Basin is an elongated, north-south trending structure that extends from central Queensland to the south beneath the Surat Basin, and into New South Wales where it connects with the Gunnedah Basin and Sydney Basin. The Bowen Basin covers an area of approximately 200,000 km^2, from Collinsville in the north to Rolleston in the south (AECOM, 2016; Arrow Energy, 2016; URS, 2012) and contains Permian to Triassic age sediments with a maximum thickness of about 9,000 m (OGIA, 2016). The Bowen Basin evolved above a basement of Early Palaeozoic metamorphic and sedimentary rocks of the Drummond Basin and Anakie Block (CSIRO, 2002).

The Bowen Basin is divided into a number of structural elements which comprise north north-west to south south-east trending platforms / shelves, separated by sedimentary troughs. The Project area is located on the western limb of the northern Bowen Basin, a northerly plunging syncline, and at the southern end of the Collinsville Shelf (AECOM, 2016). The major basin elements and structure are shown in Figure 4.1. The general Project area is represented by the red rectangle in Figure 4.1.

The depositional history of the Bowen Basin is complex and individual formations are not always laterally extensive or easy to correlate across the basin. Deposition in the basin began during the Early Permian, with river and lake sediments and volcanics being deposited in the east, and a thick succession of coals and non-marine sedimentary rocks in the west (Geoscience Australia, 2019; AECOM, 2016). These sediments were then overlain by mostly fine-grained sediments such as mudstone and siltstone of marine origin (OGIA, 2016).

The Back Creek Group is regionally developed and consists of generally fine grained clastic sediments; but is lithologically variable and comprises four formations: the Tiverton, Gebbie, Blenheim and Exmoor, in ascending stratigraphic order (AECOM, 2016). A sag phase (post-extension thermal subsidence) during the mid-Permian resulted in basin-wide marine transgression and regression cycles for the remainder of the Middle Permian and much of the Late Permian (AECOM, 2016).

The Late Permian resulted in reactivation of the volcanic arc (uplift of the New England Orogeny) and westward thrusting in the New England Orogeny, which altered the Bowen Basin into a foreland basin. The resultant infill allowed for widespread, coal-forming alluvial and delta plain depositional environments, preserved as the equivalents of the Blackwater Group. The northern half of the basin saw eastward prograding deltas combined with major axial fluvial systems which resulted in the deposition of the upper delta plain Moranbah Coal Measures and equivalents (lower delta plain German Creek Formation and the MacMillan Formation), (AECOM, 2016). The non-marine deposition of the Fort Cooper Coal Measures and equivalents (Burngrove and Fairhill Formations) then followed.

Subsequent subdued volcanic activity in the east may have produced the basin-wide peat forming environments of the prograding alluvial and delta depositional systems that resulted in the Rangal Coal Measures (AECOM, 2016).

Compressive deformation of the Bowen Basin units occurred during the Middle to Late Triassic period, resulting in regional uplift and erosion, folding of sediments and strike-slip movement along faults to accommodate contraction. This led to a series of north-south trending faults with (generally) westward directed thrusts, which bound the eastern margin of the Bowen Basin.

Sedimentation in the basin was terminated by the Middle to Late Triassic (AECOM, 2016). Cainozoic post-basin faulting and subsequent Tertiary basin development (i.e. the Duaringa Basin) occurred concordantly with the emplacement of post-Triassic-aged intrusions (Main Range Volcanics) as the entire basin was subjected to a long period of deep weathering where lateritic profiles were strongly developed. Terrestrial Tertiary deposits are widespread, where basalt and associated intermediate and acid rocks are found over large areas across the Bowen Basin (AECOM, 2016). The Permian and Triassic sediments are thus covered by a thin veneer of unconsolidated to semi-consolidated Cainozoic sediments (Tertiary to Quaternary alluvium and colluvium); (HydroSimulations, 2018). The alluvial sediments are localised along rivers and creeks. Volcanic intrusions and extrusions (i.e. basalt) are also present within the region, but not in the Project area.

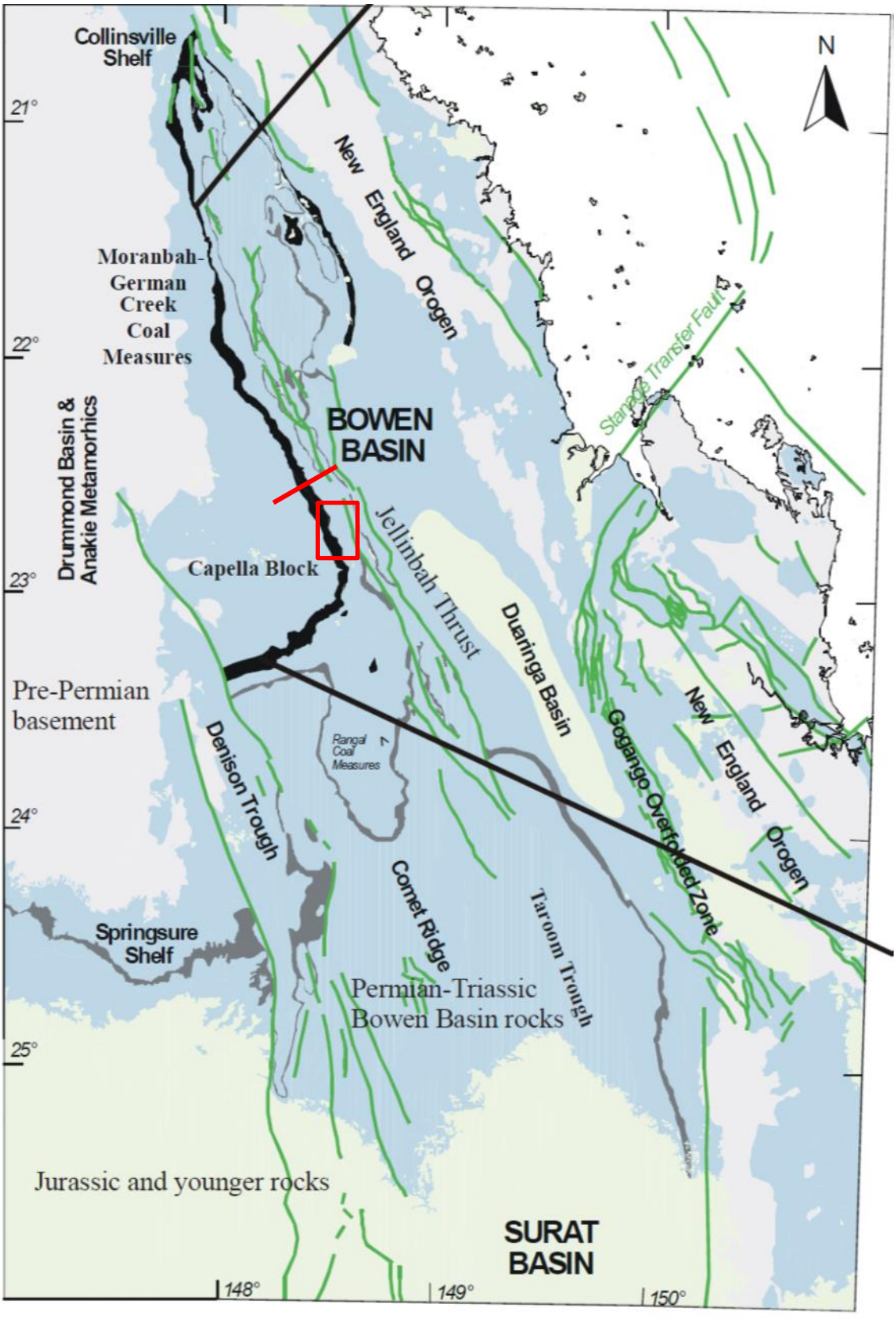


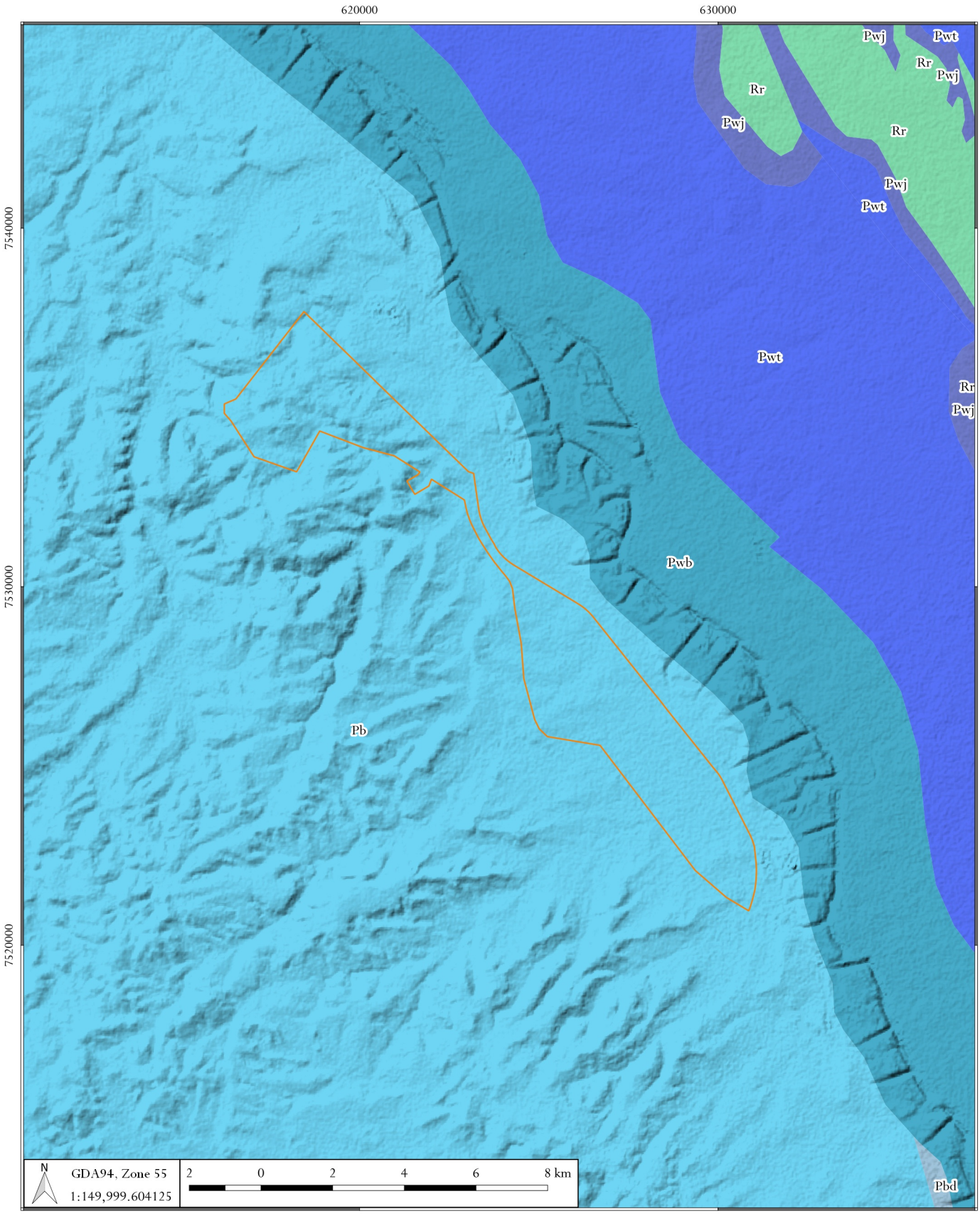
Figure 4.1 Major basin elements and regional faults (green lines) after CSIRO, 2002

Note: Figure 4.2 inset area is shown in red

A detailed description of the Bowen Basin development and stratigraphy is provided by CSIRO (2002); in particular a detailed account is given on the Moranbah Coal Measures / German Creek Coal Measures within the western limb of the central Bowen Basin.

Regionally, the stratigraphic sequence is summarised by URS (2012) as follows: *the Permo-Triassic sediments of the Bowen Basin are overlain by a thin covering of unconsolidated Quaternary alluvium and colluvium, poorly consolidated Tertiary aged sediments of the Suttor and Duaringa Formations and, in places, remnants of Tertiary basalt flows. The Triassic Rewan Group underlies the Tertiary sediments and, in places, a number of outcrops of the Moolayember Formation and Clematis Sandstone can be found. The Permian Blackwater Group, coal measures and associated overburden and interburden are located below the Triassic strata and overly the Back Creek Group.* Figure 4.2 shows the Bowen Basin solid geology in and around the Project area. Near the Project area, because of the easterly dip, the Permian Black Creek Group, Moranbah Coal Measures, Fort Cooper Coal Measures and Rangal Coal Measures sub-crop from west to east.

The Permian coal measures occur as stratified sequences of interbedded and consolidated sandstone, siltstone, mudstone, and coal with the coal measures outcropping to the east and west of the Isaac River.



LEGEND

Geology solid

- Pb - Back Creek Group
- Pbd - German Creek Formation
- Pwb - Moranbah Coal Measures
- Pwj - Rangal Coal Measures, Bandanna Fmt.
- Pwt - Fair Hill Fmt., Fort Cooper Coal Measures
- Rr - Rewan Group

Mining lease application area

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Regional Bowen Basin solid geology

FIGURE No.
4.2

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4.2. Local geology

Cross-section D-D' of URS (2012) extends near the Project area and is reproduced as Figure 4.3. The section extends from the west/south-west to the east/north-east and the approximate location of the section is shown as a red line in Figure 4.1. The Project area would plot between ~140,000 m and ~142,000 m on the section, characterised by sub-cropping Moranbah Coal Measures beneath the Tertiary and Quaternary sediments. Beneath the Moranbah Coal Measures, the Back Creek Group forms the Permian basement and outcrops to the west of the site. The Triassic units (notably the Rewan Group) are absent locally and occur further to the east. The local surface geology is shown in Figure 4.4.

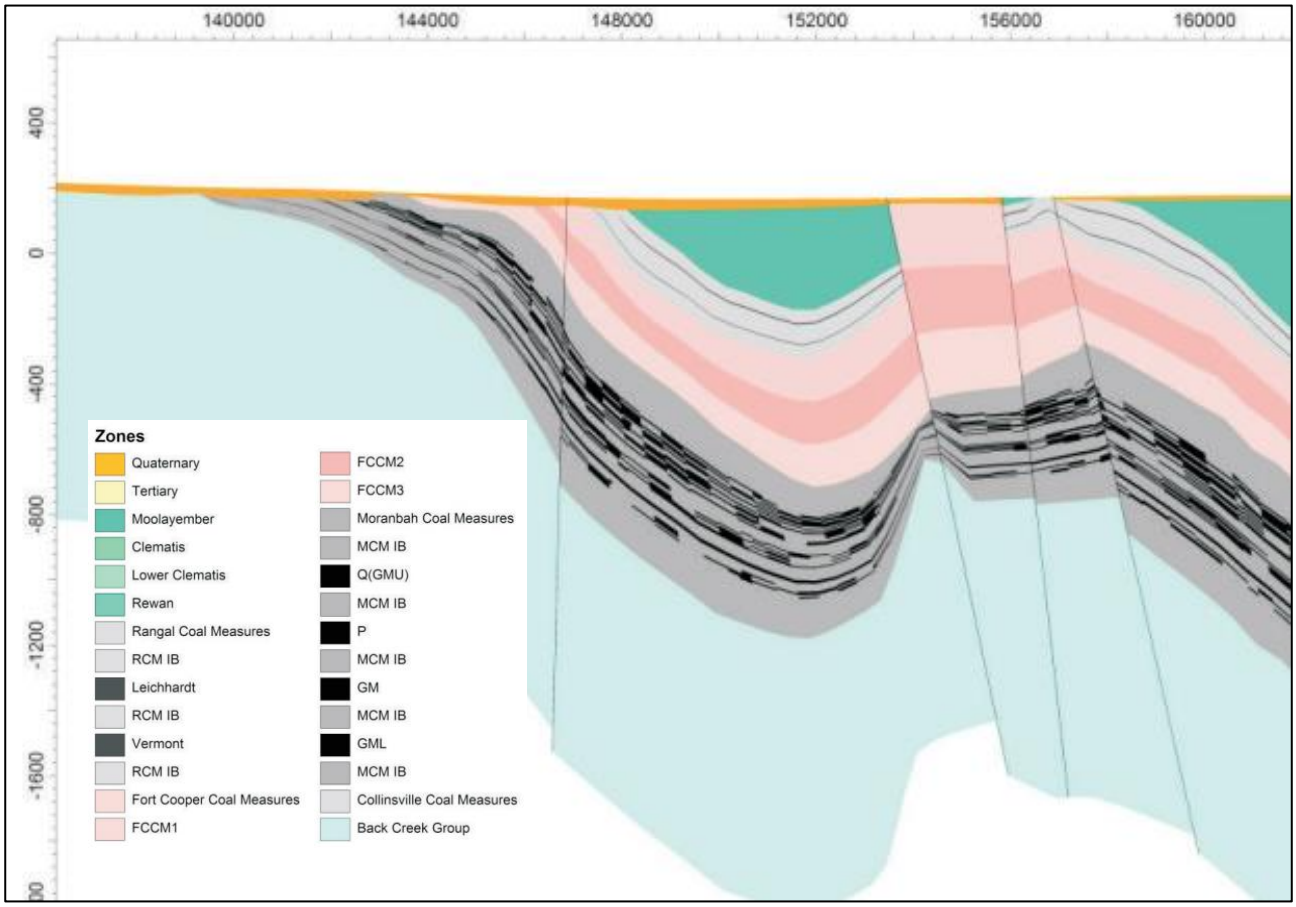
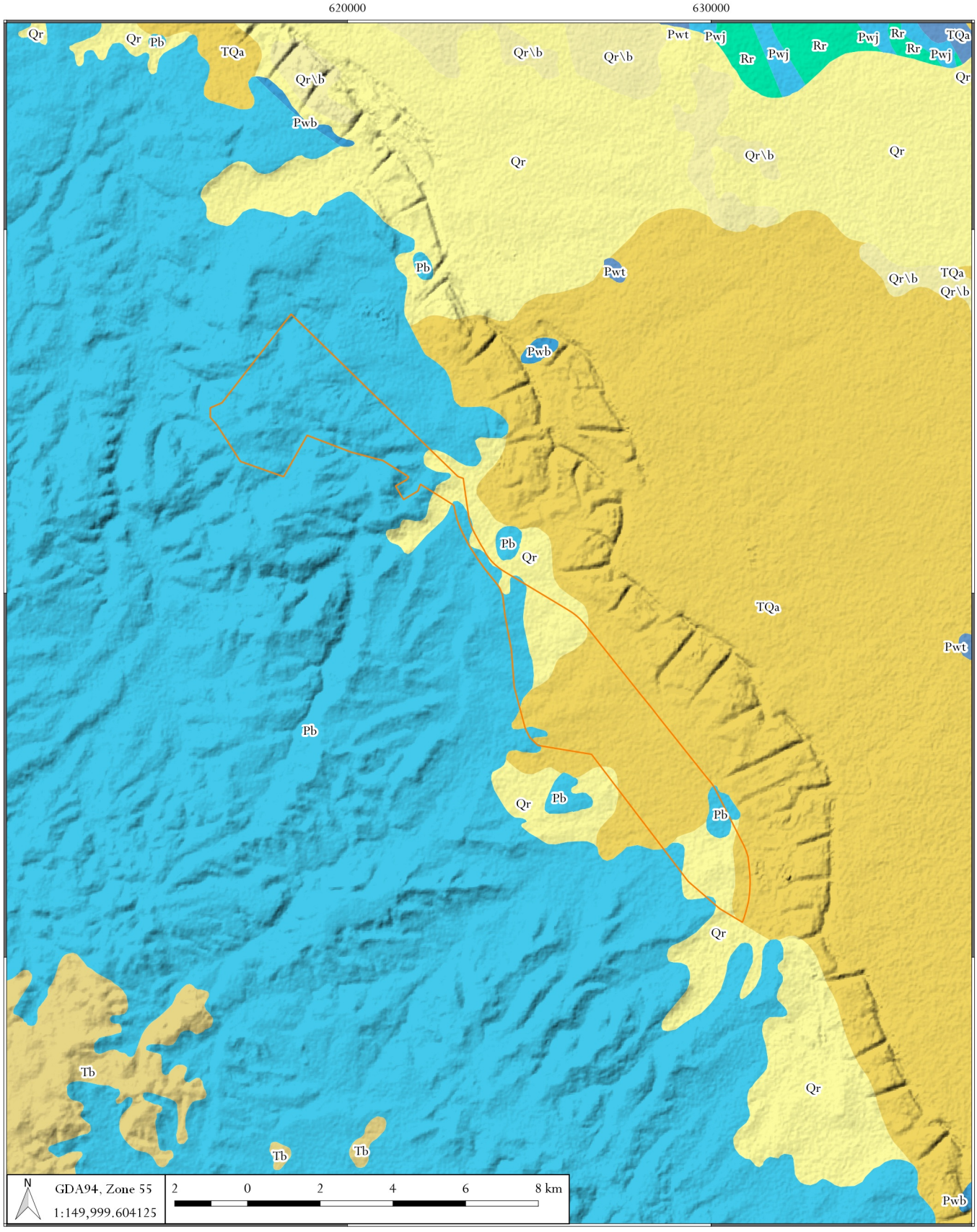


Figure 4.3 Cross-section D-D' from URS (2012)



LEGEND

Geology - surface

- Pb - Back Creek Group
- Pwt - Fort Cooper Coal Measures
- Pwb - Moranbah Coal Measures
- Qr\b - Colluvium
- Qr - Colluvium
- Pwj - Rangal Coal Measures
- Rr - Rewan Group
- Tb - Basalt
- TQa - Alluvium
- Mining lease application area

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Local surface geology

FIGURE No.
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4.2.1. Quaternary alluvium

Quaternary alluvium is mapped in excess of 10 kms to the north and south of the Project area associated with Cherwell Creek and Phillips Creek, respectively. None of these mapped Quaternary alluvium deposits are, however, recognised in Figure 2.1 nor shown in Figure 4.4. Figure 2.1 indicates that the Isaac Connors Alluvium groundwater sub-area is limited to the Isaac River and those parts of its tributaries that are adjacent to the confluence with the Isaac River. In general, the Quaternary alluvium, where present, is associated with the larger ephemeral surface drainage features in the catchment, such as the Isaac River.

The alluvium comprises irregular sequences of unconsolidated clay, silt, sand, and gravel. The Quaternary alluvium sediments are variable in thickness, elongated, irregular, and lensoidal (URS, 2012). This is due to the meandering and braided nature of the depositional environment that includes cross-cutting and reworking of older alluvial deposits. The alluvium is also considered to be heterogeneous due to the irregular nature of the bedrock and clayey composition (Arrow Energy, 2016).

The Quaternary alluvial sediments (in excess of 10 kms) to the south-east of the Project area are reported to have a maximum thickness of 25 m at Phillips Creek (AGE, 2007 in AECOM, 2016) as a result of infilling a paleo-channel carved through Tertiary sediments and into the underlying Permian coal measures. Similar thicknesses of alluvial sediments are understood to occur along the Isaac River, east of the Project area.

4.2.2. Tertiary sediments

The Tertiary aged sediments are mapped as present in the southern portion of the Project area (see TQa in Figure 4.4). These are generally described as clay, silt, sand, gravel and colluvial and residual deposits with a predominantly clay matrix. AECOM (2016) refer to the Tertiary aged sediments as heterogeneously distributed lensoidal sand deposits separated by a low permeability clay-rich matrix. Tertiary sediments comprise unconsolidated to consolidated fluvial sediments which include clay, silty clay, sandy clay, clayey sand, sand and gravel with clay predominant (AECOM, 2016). Typically, these sediments are less than 15 m thick although the Tertiary sediments have been reported up to 57 m thick at Saraji Mine. The presence of paleo-channels and lensing of units within the Tertiary sediments prevent correlation of discrete units; individual units are laterally discontinuous with varied thickness (AECOM, 2016).

The Duaringa Formation is mapped 10 km to the south-east of Saraji Mine and contains mudstone and siltstone (i.e. low permeability strata). The Duaringa Formation is more of a laterally extensive Tertiary stratigraphic unit that is mappable and correlatable over a larger area of the Bowen Basin to the east.

Weathering of the Tertiary sediments is evident (AGE, 2011 in AECOM, (2016)) and the lithologies can vary from heavily leached, mottled white and maroon clays to sandy clays.

A basal sand and gravel sequence has been identified beneath the clay rich matrix in the western limb of the Bowen Basin. Comprising medium to coarse grained sands and fine gravels, the basal sand and gravel sequence has a maximum thickness of approximately 3 m and is considered to be locally continuous. The basal Tertiary sequence indicates the presence of a laterally discontinuous paleo-channel system assumed to be related to a proto-Phillips Creek system (AECOM, 2016).

At the Olive Downs Coal Project located approximately 20 km to the north-east, lithological logs indicate that the Cainozoic (Quaternary to Tertiary aged) alluvium comprises heterogeneous, fine to coarse grained sands interspersed with lenses of clays and gravels. These sediments, while spatially variable, generally comprise four main lithologic sequences including:

- upper soil and clay layer (up to 10 m thick);
- sand and sandy clay unit (3 m to 15 m thick);
- sand and gravel unit (up to 8 m thick); and
- basal clay unit (> 1 m thick).

At the Olive Downs Coal Project, the heterogeneity of the Cainozoic sediments was observed in surface geophysics (transient electromagnetics) with discrete areas of the alluvium, correlating to clayey / less permeable zones (HydroSimulations, 2018). HydroSimulations (2018) also found that Cainozoic aged sediments comprise much of the surficial regolith material at the site, including alluvium and colluvium.

The Tertiary sediments are defined by an unconformable boundary with the underlying Permian coal measures which characterises the Permian topography prior to deposition of the Tertiary sediments (AECOM, 2016).

hydrogeologist.com.au (2019) drilled and constructed several groundwater monitoring bores within the Project area. **hydrogeologist.com.au** (2019) used the term "*weathered Permian*" to describe the lithology intersected above the fresh Permian coal measures and those rocks considered equivalent to the regolith described by (HydroSimulations, 2018). It is assessed by **hydrogeologist.com.au** that within the Project area, the lithology intersected above the fresh Permian coal measures does not constitute Tertiary aged sediments, rather a weathering profile that had developed during the Tertiary on the Permian strata. There was no evidence of an unconformable horizon in the drill hole observations and the material intersected, graded from highly weathered, generally clay bound material at the surface through to the unweathered Permian coal measures that typically occurred between 1 m to 20 m below ground level.

4.2.3. Permian coal measures

Blackwater Group

Coal seams within the Permian coal measures of the Blackwater Group form the main economic resource of the numerous mines in the region (HydroSimulations, 2018). In increasing depth (age) order, the major coal measures of the Blackwater Group include the:

- Rangal Coal Measures;
- Fort Cooper Coal Measures; and
- Moranbah Coal Measures.

The Permian coal measures occur as stratified sequences of interbedded and consolidated sandstone, siltstone, mudstone, and coal. Four major coal "superseams", that occur for more than 200 km along the western limb of the Bowen Basin, were recognised by CSIRO (2002). The superseams (Figure 4.5) in stratigraphic order from oldest to youngest are:

- Lower Superseam (Goonyella Lower – Dysart - German Creek Seams);
- Middle Superseam (Goonyella Middle - Harrow Creek – Aquila Seams);
- P-Superseam (P Seams – Pleiades Seam) and 'P-tuff' a regional tuffaceous unit; and
- Upper Superseam (Goonyella Upper Seams).

The Project area is in the "middle tile" of CSIRO (2002) where the lower seams of the Moranbah Coal Measures are mined. Here, the lowest Dysart seams are the stratigraphic equivalents of the Goonyella Lower seam to the north and the German Creek seam to the south (Figure 4.5).

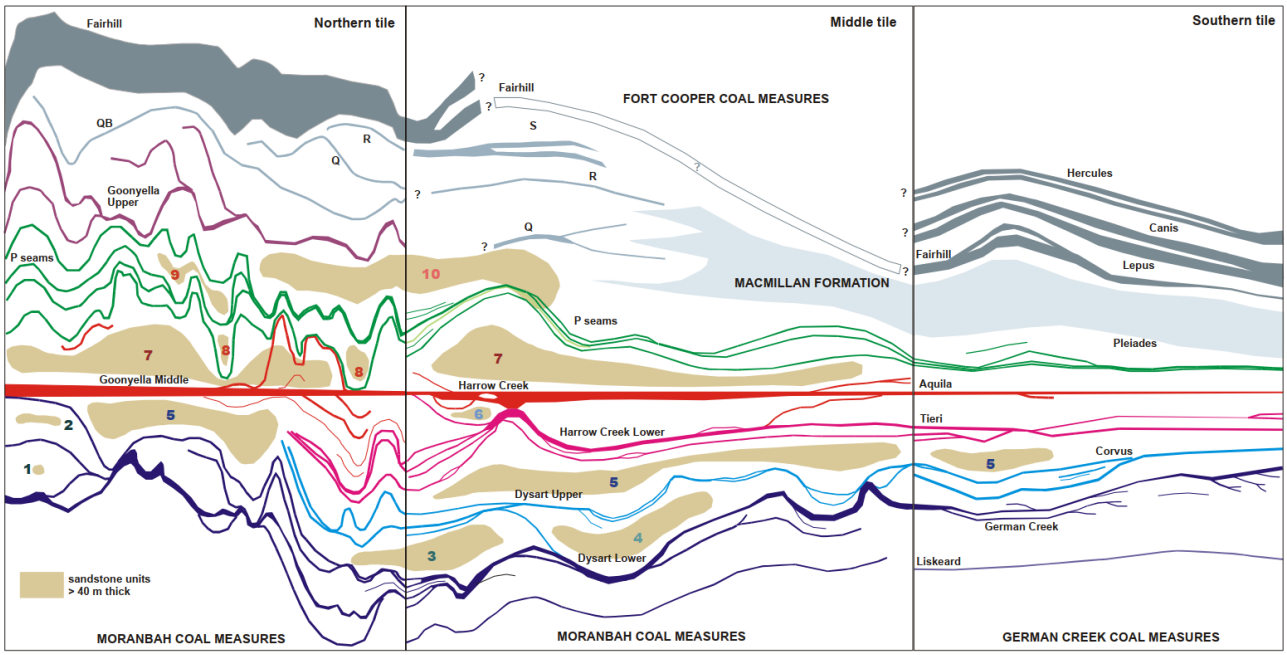


Figure 4.5 Regional correlation sections showing the "superseams", after CSIRO, 2002

The sequence of coal seams in the Moranbah Coal Measures have a cumulative coal thickness of 20 m to 30 m in the north, progressively thinning to the south. Near the Project area the cumulative thickness of coal appears to be between 5 m and 15 m (CSIRO, 2002).

The three open cut pits are targeting the ALEX and Dysart Lower-Lower (DLL) coal seam of the Moranbah Coal Measures. Outcropping at surface to the west of the Project is the basal section of the Moranbah Coal Measures, locally mapped by Vitrinite as a sequence of sandstones and siltstones. This sequence is capped in a resistant, quartzose medium to coarse grained sandstone, locally referred to as the Mesa Sandstone due to the characteristic mesa plateaus that have formed in the region. The base unit of the Moranbah Coal Measures is locally referred to as the Mesa Siltstone (Tom O'Malley, Vitrinite, per.comm., 2019).

The ALEX coal seam is about 1 m thick of high quality and low ash content, overlying approximately 2 m of siltstone and a very thickly bedded medium sandstone locally referred to as the Mesa Sandstone which grades into the Mesa Siltstone. The DLL consists of a 2.5 m thick seam with four plies; and a separate basal ply, with high ash and good quality coal. An additional 1 m thick coal seam makes the entire sequence to be mined approximately 3.5 m thick. The regional sediments dip approximately eastward at about 4° in the Project area (Tom O'Malley, Vitrinite, per.comm., 2019).

East of the Project area, at the Saraji Mine, the Permian coal measures are generally undisturbed and have a gentle regional dip of 2° to 5° towards the east (AECOM, 2016). Minor faults are mapped within the existing Saraji Mine which locally steepen the coal seams to approximately 9° to 10°. The Saraji South Fault is located south of the Saraji Mine, near Phillips Creek. The Saraji South Fault is a high angle, north north-west trending normal fault, with throws mapped between 10 m and 50 m (AGE, 2011 in AECOM, (2016)). The Downs Creek Fault is a north north-west trending normal fault with a maximum throw of 60 m and is located south of the Project area, near Lotus Creek Road.

At Saraji Mine, the Permian coal measures comprise overburden of sandstone, siltstone, claystone, mudstone, coal, coal parting materials and sub-coal (underburden) strata. The Moranbah Coal Measures include the Dysart series, Harrow Creek group, P, Q and R coal seams. Of these, the Harrow Creek Upper (H16) and Dysart Lower (D24 and D14) coal seams are mined at Saraji Mine (AECOM, 2016). The H16 seam is the uppermost of the two targeted coal seams and sub-crops to the west of the Saraji Mine with an easterly dip.

Near the Caval Ridge Mine, the Permian coal measures generally dip from west to east, at between 3° and 6°. The sequence within the northern extension of the Peak Downs Mine (located to the south of the Caval Ridge Mine and to the north of Saraji Mine) shows considerable deformation with strata dipping to 30° and along strike flexures in excess of 10°. Faulting and seam splitting is common, producing local steepening of the coal seams (over 10°). Minor faulting occurs in the seams in the Caval Ridge Mine area. Vertical displacement along faults ranges from less than 1 m to 36 m along the regional Harrow Creek Fault in the Peak Downs Mine (URS, 2009). Near the Olive Downs Coal Project, the coal measures dip around 7° to the east, which steepens in the south to 15° (HydroSimulations, 2018).

Back Creek Group

The Back Creek Group outcrops within and to the west of the Project area (Figure 4.4). The local interpretation of the Back Creek Group is on-going (Tom O'Malley Vitrinite, per.comm., 2019). The Exmoor and Blenheim Formations of the Back Creek Group are currently interpreted to be conformably underlying the Moranbah Coal Measures. The top of the Exmoor Formation is characterised by prominent coarse-grained siliceous boulder sandstone in outcrop, whilst the top of the Blenheim Formation is easily identifiable by the stratigraphic marker of the fossiliferous and worm burrowed sandstone, locally termed the Worm Burrow Sandstone.

Coal seams within the Back Creek Group include the MAY coal seam that has been interpreted to be within the Dingo Siltstone of the Exmoor Formation, and the Matilda (MAT) coal seam within the MAT Siltstone of the Blenheim Formation. The MAT coal seam is the target coal seam in the Highwall Mining area. The stratigraphic interpretation of these coal seams and the Back Creek Group has not been fully assessed; interpretations are ongoing as more information is gathered (Tom O'Malley Vitrinite, per.comm., 2019).

5. Hydrogeology

An aquifer is generally defined as a geological unit that can transmit and store significant quantities of groundwater. Within the region, the Quaternary alluvium, Tertiary sediments, and Permian coal measures yield low volumes of groundwater and hence they would not typically be classified as aquifers in most hydrogeological settings. In reality, they would be called either poor aquifers or aquitards. However, there may be individual lithological units within these formations that have higher hydraulic conductivities than the intervening units, and as groundwater in these formations are to be assessed for the determination of impact, they are referred to as aquifers for the purposes of this report. This approach is consistent with URS (2009) and URS (2012), AECOM (2016) and HydroSimulations (2018).

5.1. Regional hydro-stratigraphy

The regional and local geology are described in Sections 4.1 and 4.2, respectively. Near the Project area, the Tertiary Suttor Formation, Duaringa Formation, Tertiary basalt, Triassic Rewan Group, Moolayember Formation and Clematis Sandstone are all absent. In addition, the Permian Rangal Coal Measures and Fort Cooper Coal Measures are also absent locally (Table 5-1).

Hence the interpretation of **hydrogeologist.com.au** of the local hydrostratigraphy, consistent with HydroSimulations (2018), URS (2012) and AECOM (2016), includes isolated Quaternary alluvium, older Tertiary sediments, colluvial sediments and weathered Permian coal measures; and unweathered or fresh Permian coal measures.

Table 5-1 Interpreted regional and local hydro-stratigraphy

Period	Group	Unit	Regional	Local
Quaternary		alluvium	✔	✘ only at isolated places
Tertiary		regolith*	✔	✔
		Suttor & Duaringa Formations	✔	✘
		basalts	✔	✘
Triassic		Moolayember Formation	✔	✘
		Clematis Sandstone	✔	✘
		Rewan Group	✔	✘
Permian	Blackwater Group	Rangal Coal Measures	✔	✘
		Fort Cooper Coal Measures	✔	✘
		Moranbah Coal Measures and	✔	✔
	Back Creek Group	German Creek Formation	✔	✘
	Back Creek Group Exmoor Formation	Dingo Sandstone	✔	✔
		Dingo Siltstone	✔	✔
		Wallaby Hill Sandstone	✔	✔

Note: The regolith concept of HydroSimulations (2018) is adopted for the weathered Permian coal measures.

5.2. Local hydrogeology

The following section defines the hydro-stratigraphic units for the Project. AECOM's (2016) hydro-stratigraphy of the Saraji Mine is reproduced as Table 5-2. The Project area is to the west of, and at a higher elevation than Saraji Mine and other mines to the east. Occupying a higher position in the landscape significantly affects the local hydrogeology, as several units listed by AECOM (2016) are absent, while others may, in places, be unsaturated. This is because under topographically higher elevations, the groundwater table is generally deeper than that observed at Saraji Mine, and the Permian coal measures are at shallower depths due to their dip to the east.

Table 5-2 Hydro-stratigraphy of the Saraji Mine, after AECOM (2016)

Age	Stratigraphic unit	Lithology	Aquifer type
Quaternary	Alluvium	Clay, silts, sand, gravel, floodplain alluvium	Unconfined (aquifer)
Tertiary	Sediments	Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, conglomerate, claystone	Aquitard
	Duaringa Formation	Mudstone, sandstone, conglomerate, siltstone, oil, shale, lignite, and basalt	Aquitard
Unconformity			
Late Permian	Fort Cooper Coal Measures	Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff	Confined aquifer (coal) and confining unit (interburden)
	Moranbah Coal Measures	Coal, sandstone, siltstone, mudstone, carbonaceous mudstone	Confined aquifer (coal) and confining unit (interburden)
Middle Permian	Back Creek Group	Sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite	Confining unit

The following sections define the hydrogeology of the various hydro-stratigraphic units for the Project and further discuss groundwater flow, quality, and the hydraulic characteristics. The local hydro-stratigraphic units are listed as follows:

- Quaternary alluvium;
- Tertiary sediments; and
- Permian coal measures.

5.2.1. Quaternary alluvium

Although Quaternary alluvium was not observed during the drilling of local monitoring bores (Section 5.3), nor mapped in close proximity to the open pits proposed by the Project, it is important as a regional hydro-stratigraphic unit and is described here following the observations made by URS (2009) and URS (2012), AECOM (2016) and HydroSimulations (2018). Quaternary alluvium is mapped (Figure 4.4) near both the northern and southern boundaries of the Project area associated with Cherwell Creek and Phillips Creek, respectively.

The Quaternary alluvium is recognised to occur as discrete channels associated with the present day, larger surface water systems such as the Isaac River and some of its tributaries. Where it exists, the Quaternary alluvium forms an unconfined aquifer of limited lateral extent. Due to the semi-arid climate, the ephemeral nature of the stream flow, and spatial discontinuity of the more permeable sand and gravel layers, the groundwater resource in the Quaternary alluvium is not abundant and groundwater only occurs in isolated areas (URS, 2012). The alluvial sediments are often unsaturated and, where they are saturated, are generally disconnected laterally.

HydroSimulations (2018), (Figure 4-4, not reproduced in this report) shows interpreted alluvium near the Olive Downs Coal Project, based on a geophysical (transient electromagnetic, TEM) survey. The results indicate that all Quaternary alluvium is associated with the Isaac River, and near its confluence with Phillips Creek and Ripstone Creek. No Quaternary alluvium is shown near, or to the west of Saraji Mine. These observations are also confirmed by Figure 4.4 which indicates a general absence of Quaternary alluvium near the Project area. In addition, a review of bore data by AECOM (2016) indicated several bores were drilled in close proximity to Phillips Creek but only a few of these bores intersected the Quaternary alluvium; and some of these were reported to be drilled dry. The other bores drilled along the creek were constructed in the Tertiary sediments below and adjacent to the alluvial sediments.

5.2.2. Tertiary sediments

Tertiary sediments have been mapped in the southern portion of the Project area and at Saraji Mine. These sediments consist of lenses of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays (URS, 2009) with thicknesses near the Caval Ridge Mine up to 30 m. The silts and clays are densely compacted, hard, and generally dry. Potential for groundwater, however, exists within sandy and gravely sections, and represents an unconfined to confined aquifer depending on location. Most of the clean sand and gravel lenses are permeable but are of limited lateral and vertical extent (URS, 2009). Historically, mining issues associated with Tertiary sediment derived groundwater at the Peak Downs Mine appear limited to pit wall stability rather than ongoing problems with groundwater inflow. This generally indicates low hydraulic conductivity and limited lateral extent of the more permeable areas (URS, 2009).

HydroSimulations (2018) found that near the Olive Downs Coal Project, the surficial regolith material covering much of the site comprises Cainozoic (Quaternary to Tertiary) aged sediments, including alluvium and colluvium. Older alluvial (TQa in geological maps and Figure 4.4) sediments are distributed extensively across the region, and colluvium and residual deposits (Qr and Qr\b) occur within isolated patches to the north. No Quaternary alluvium is shown near or to the west of Saraji Mine. Site drilling logs indicate the sequences exhibit similar geological characteristics and have therefore been grouped as 'regolith' by (HydroSimulations, 2018).

HydroSimulations (2018) summarised regolith as:

"*Based on site geological logs, the regolith comprises a heterogeneous distribution of fine to coarse grained sand, clay, sandstone and claystone. The regolith material is generally 15 m to 45 m thick. The units are all recorded as being highly weathered, with the depth of weathering extending to around 50 m below ground level (mbgl), into the underlying coal measures*".

As described in Section 4.2.2, **hydrogeologist.com.au** use the term "*weathered Permian*" to describe the lithology intersected above the fresh Permian coal measures and those rocks are considered equivalent to the regolith of (HydroSimulations, 2018). There was no evidence of an unconformable horizon in the drill holes and the material intersected was highly weathered, generally clay bound material down to the top of the unweathered Permian coal measures. It was assessed by **hydrogeologist.com.au** that the lithology intersected above the fresh Permian coal measures in the Project area did not constitute Tertiary aged sediments, rather a weathering profile that had developed during the Tertiary on the Permian strata. Within the monitoring bores drilled for the Project, the depth of weathering typically occurred between 1 m to 20 m below ground level and the weathered profile was generally unsaturated.

Hence, whether the strata are Tertiary sediments or weathered Permian regolith is not of significance in the saturated groundwater flow context as much of the strata are unsaturated beneath the Project area and nearby at Saraji Mine (AECOM, 2016). To this end, it is recognised that locally there are no Tertiary sediments in the vicinity of the proposed open pits, however the weathered profile or regolith intersected is highly likely to have similar hydraulic properties to the majority of the Tertiary sediments described and documented at other sites within the region, that is clayey in nature, of low permeability and of limited saturation. The term Tertiary sediments from here on refers to a mix of specific Tertiary aged sediments and the weathered zone or regolith material that has formed on top the Permian coal measures.

The Tertiary sediments outcrop beneath most of the Project area and to the east (Figure 4.4). The Tertiary sediments, where saturated, form an unconfined unit, although confinement (due to the generally low hydraulic conductivity) is possible deep into the regolith.

5.2.3. Permian coal measures

Throughout the Bowen Basin, the coal seams are considered to be poor aquifers within the Permian coal measures, and the adjacent overburden and interburden sediments generally considered as aquitards. Accordingly, AECOM (2016) hydrogeologically divided the Permian coal measures into non-coal-bearing over- and inter-burden units and coal seams. URS (2009) noted, in the context of overall low yields and therefore low hydraulic conductivity, that historical mining issues with groundwater in the Permian coal measures at Peak Downs Mine appear to have been limited to pit wall stability rather than ongoing problems with groundwater inflow, indicating the generally low hydraulic conductivities of the Permian coal measures on site.

The coal seams generally are considered dual-porosity strata where primary-porosity is provided by the matrix and a secondary porosity is the result of the presence of fractures (joints and cleats). Natural cleats within the coal seams are likely the dominant space for groundwater storage; the main pathway for groundwater movement is dependent on fracture interconnectivity (URS, (2009) and AECOM, (2016)). The coal seam aquifers are generally confined above and below by the low permeability inter- and overburden (AECOM, 2016).

The non-coal-bearing overburden and interburden units comprise claystone, mudstone, sandstone, siltstone, and shale. These low permeability rock types are not recognised for their high groundwater potential. They can, however, provide localised supplies of variable, generally low yielding and poor quality groundwater (AECOM, 2016). The overburden and interburden rocks in several mines in the northern Bowen Basin (e.g. Broadlea Coal Mine, Burton Mine and Ellensfield Coal Mine) have been described as essentially impervious to groundwater movement (AGE, 2007 in AECOM, 2016).

The target coal seams at the Saraji Mine are the Harrow Creek Upper seam and the Dysart Lower seams of the Moranbah Coal Measures and these seams form confined aquifers. These seams are laterally extensive along the western and eastern margins of the Bowen Basin and within the Project area but with varying thickness.

Within the Project area, the targeted ALEX and DLL coal seams of the Moranbah Coal Measures are regarded as poor aquifers (because of their limited thickness) and the interburden (including over- and under-burden) as aquitards. Groundwater in the ALEX and DLL coal seams are expected to be confined from above by overburden and the regolith and from underneath by the interburden.

The Back Creek Group comprises sandstone, siltstone, shale and minor coal; and is considered a semi-pervious lower boundary for groundwater flow to the overlying Blackwater Group (URS, 2012). The Back Creek Group is normally considered as the base layer for numerical models (the base of a model, by definition is impervious). The Exmoor Formation of the Back Creek Group is locally mapped by Vitrinite as the Dingo Sandstone, Dingo Siltstone and Wallaby Hill Sandstone (from top down), but contains recognised and laterally extensive coal seams (MAY and MAT seams) that, together with the sandstones, can potentially form poor aquifers similar to those interpreted in the Blackwater Group.

The German Creek Coal Measures are considered to be part of the Back Creek Group according to the Australian Stratigraphic Units Database (https://asud.ga.gov.au/search-stratigraphic-units/results/7142, visited on 14 August 2019). The stratigraphic relationships are shown in Table 5-2.

5.3. Groundwater monitoring network

In June 2019, eight monitoring bores were drilled in the Project area (see Section 1.1) with four bores drilled to the east in nearby ML700060 (as part of the VCM). Monitoring bore MB13 was drilled in early 2021 for the VCM. Table 5-3 summarises the location, target unit and construction details for each monitoring bore (**hydrogeologist.com.au**, 2019) which forms the groundwater monitoring network. The bores are shown in Figure 5.1 along with the registered groundwater bores associated with the DRDMW GWDB. MB06 and MB10 are nested monitoring bores drilled on the same site.

Table 5-3 Vulcan South monitoring bores – construction details from hydrogeologist.com.au (2019)

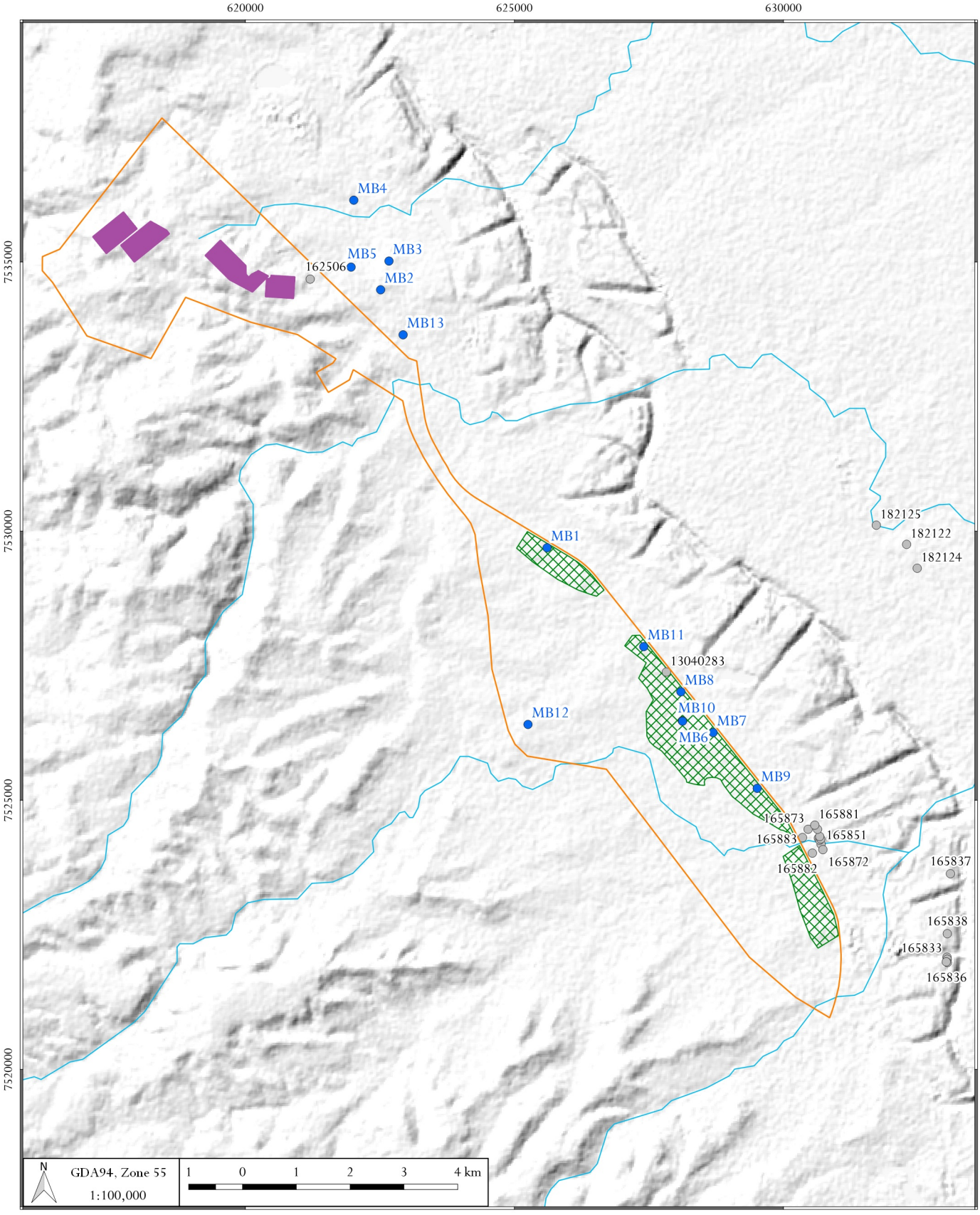
ID	Area	Easting	Northing	Target unit	Casing height (maGL)	Hole depth (mbGL)	Screen interval (mbGL)	Airlift yield (L/min)	Casing elevation (mAHD)
MB01	Project	625606	7529691	DLL coal seam	0.70	24.9	21.9 – 24.9	Dry	222.91
MB02	VCM	622513	7534483	DLL coal seam	0.71	12.0	9.0 – 12.0	Dry	254.69
MB03	VCM	622668	7535017	DLL coal seam	0.70	33.8	30.8 – 33.8	<0.1	257.68
MB04	VCM	622014	7536148	DLL coal seam	0.71	21.5	18.5 – 21.5	1	243.28
MB05	VCM	621964	7534905	MAT coal seam	0.77	40.9	37.9 – 40.9	0.5	252.70
MB06	Project	628119	7526476	Weathered Permian	0.70	24.6	21.6 – 24.6	Dry	214.61
MB07	Project	628691	7526258	Weathered Permian	0.67	43.0	40.0 – 43.0	0.1	215.99
MB08	Project	628092	7527015	Weathered Permian	0.70	24.0	21.0 – 24.0	Dry	212.24
MB09	Project	629511	7525222	DLL coal seam	0.65	34.4	31.4 – 34.4	0.1	208.98
MB10	Project	628123	7526469	DLL coal seam	0.70	40.3	37.3 – 40.3	<0.1	214.60
MB11	Project	627403	7527854	DLL coal seam	0.70	29.9	26.9 – 29.9	Dry	225.66
MB12	Project	625251	7526409	Back Creek Group	0.66	38.2	32.2 – 38.2	1	241.43
MB13	VCM	622931	7533648	MAT coal seam	0.63	36.92	33.5 – 36.5	Unknown	223.13

Notes: *Easting and northing coordinates are in GDA94, Zone 55*

maGL – metres above ground level

mbGL – metres below ground level

The DLL coal seam (Dysart Lower Lower) is in the Mesa Siltstone (Lower Moranbah Coal measures); the MAT seam is in the Dingo Siltstone of the Exmoor Formation (Back Creek Group).



LEGEND

- Monitoring bore
- Registered bore
- Proposed pit
- Highwall mining area
- Mining lease application area

DATE
23/02/2022

hydrogeologist .com.au

Vulcan South - Groundwater Impact Assessment (4027)

Groundwater monitoring bore network

FIGURE No.
5.1

©2022 Oasis Hydrogeology Pty Ltd - trading as hydrogeologist.com.au
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
Based on or contains data provided by the State of Queensland [2019]
Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\05_01_4027_Vulcan South_Groundwater monitoring bore network.qgz

5.3.1. Rationale

The groundwater monitoring network was established based on available information relating to the general understanding of groundwater flow conditions (west to east), the coal resource and general geology of the region and the available mining and exploration tenure. The rationale for locating the monitoring bores was to have an upstream and downstream bore plus an understanding of groundwater conditions within the Project area and to the north and south. The groundwater within the Permian coal measures is often brackish to saline which restricts the environmental value of the groundwater (Section 5.8.3) which is typically limited livestock watering and industrial use.

The Project area monitoring bores were designed to target the Permian coal measures and the Tertiary sediments as there is no mapped Quaternary alluvium within or in close proximity to the Project area. A number of the Project area monitoring bores targeting the Permian coal measures and the Tertiary sediments were dry.

The target coal seams of the Moranbah Coal Measures (Section 4.2.3) generally strike in a north north-west to south south-east orientation and dip to the east. This local orientation of geology spatially constrains the groundwater monitoring network to the west of proposed Vulcan pits. As a result, monitoring bore MB12 has been constructed within the Back Creek Group (see Section 4.2.3 and Section 5.2.3). The Back Creek Group underlies the Moranbah Coal Measures. The general groundwater flow conditions are from west to east and a suitable upstream monitoring site in the target coal seam(s) was not able to be practically established. However, it is assessed that MB12 will be able to provide an appropriate site for the monitoring of drawdown that may propagate through the Back Creek Group extending to the west of the Vulcan pits. There is no mining development upstream of the Vulcan pits.

The Project area is adjacent to existing mining leases which are operated by BMA. The establishment of Project specific groundwater monitoring bores on the BMA mining leases to the east (Figure 3.6) is not practical or achievable therefore mining tenure has spatially constrained the groundwater monitoring network to the east of proposed Vulcan pits. Monitoring bores MB01, and MB06 through to MB11 were all located and designed on existing cleared drill pads (to minimise land and vegetation clearances). The monitoring bores were spatially distributed so far as was reasonably practical to do so to provide an adequate spatial spread of the data. At the time of monitoring bore installation, the mine plan was not available for consideration.

The VCM groundwater monitoring bores were located in association with ML700060 to the north and to the immediate east of the Project area. The spatial constraints associated with local geology and mining tenure also affected the location of the VCM groundwater monitoring bores.

Subsequent to installing the monitoring bores, the mine plan was provided, and it is clear that a significant number of the Project area monitoring bores will be disturbed by mining operations. Prior to this disturbance occurring, replacement monitoring bores will be established in locations which provide an adequate spatial distribution in the target formation and will enable long term monitoring. Any replacement monitoring bore will also need to consider potential contaminant sources.

The groundwater monitoring network is considered to be fit for purpose for this assessment. Future changes to the network or the monitoring plan will be needed which are planned for and outlined in a proposed adaptive management strategy (see Section 7.1).

5.3.2. Current monitoring plan

All of the groundwater monitoring bores installed in 2019 (**hydrogeologist.com.au**, 2019) now form the groundwater monitoring network. A total of six monitoring bores were dry after drilling and construction, indicating that these bores are constructed above the regional groundwater table. The presence of dry holes provides useful information in conceptualising the groundwater system.

Groundwater level monitoring

The groundwater level monitoring of the groundwater monitoring network has been carried out monthly (for the first six months) then quarterly thereafter, and all monitoring bores were equipped with data loggers or pressure transducers, which automatically collect readings every four hours. The use of dataloggers will continue as part of on-going groundwater level monitoring. The manual groundwater level measurements collected at the site are summarised in Table 5-4.

From Table 5-4 it is observed that the groundwater elevations are generally between 180 mAHD and 220 mAHD in the southern portion of the Project area, and 230 mAHD to 240 mAHD in the north. The depth to groundwater measurements indicate that the depth to groundwater in the southern portion of the Project area is between 20 m to 35 m below ground level. Groundwater elevations are generally a subdued reflection of topography, that is deep beneath high land elevation (hills) and shallow beneath low land elevation (valleys).

In some instances (e.g. MB03), the depth to groundwater measurement collected after airlift development was influenced by the drilling and construction process, and in other instances the low permeability of the intersected formation (e.g. MB12). For this reason, the earlier measurements in Table 5-4 may not be representative.

Figure 5.2 shows the groundwater elevation hydrographs at the six monitoring bores (note that the hydrographs for MB04 or MB05 overlap) over a 12 month period from June 2019 through to September 2021. Except for the spikes in data observed at MB04, MB05 and MB12, the groundwater elevation hydrographs demonstrate a static system with no or very little (~centimetre magnitude) temporal variations in groundwater level. The notable spikes in data in mid-July, mid-August and mid-September are associated with the monthly groundwater sampling events. The bores with the spikes (MB04, MB05 and MB12) are constructed within low hydraulic conductivity formations and the groundwater is slow to recover following purging.

Table 5-4 Summary of manual groundwater level measurements

Site ID	Casing elevation (mAHD)	SWL														
		Jun 2019	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Dec 2019	Mar 2020	Jun 2020	Aug 2020	Oct 2020	Dec 2020	Mar 2021	May 2021	Jul 2021	Sep 2021
MB1	222.91	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB2	254.69	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB3	257.68	239.38	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB4	243.28	237.47	237.58	237.45	237.18	237.75	238.13	237.53	237.53	236.76	236.54	236.37	236.58	236.61	236.53	236.41
MB5	252.70	238.17	238.01	237.99	238.23	238.69	238.55	238.10	227.77	235.95	236.62	236.53	236.37	236.72	236.41	236.04
MB6	214.61	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB7	215.99	181.19	179.71	179.77	179.79	180.31	180.12	180.40	189.79	179.92	179.87	179.91	179.99	179.91	179.96	180.03
MB8	212.24	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB9	208.98	181.57	181.34	181.36	181.39	181.81	181.48	182.12	181.88	181.24	180.98	181.29	181.35	181.33	181.32	181.43
MB10	214.60	182.09	182.15	182.20	182.29	183.04	183.00	183.04	188.10	182.49	182.50	182.55	182.60	182.56	182.61	182.65
MB11	225.66	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
MB12	241.43	215.36	216.22	216.41	216.66	218.00	218.39	216.94	215.71	216.55	216.56	216.53	215.85	215.60	215.61	214.85
MB13	223.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	209.12	208.53	208.49	208.63

Notes: *Easting and northing coordinates are in GDA94, Zone 55 from differential GPS*

SWL – standing water level

mAHD – metres above Australian Height Datum from differential GPS

mbTOC – metres below top of casing (PVC)

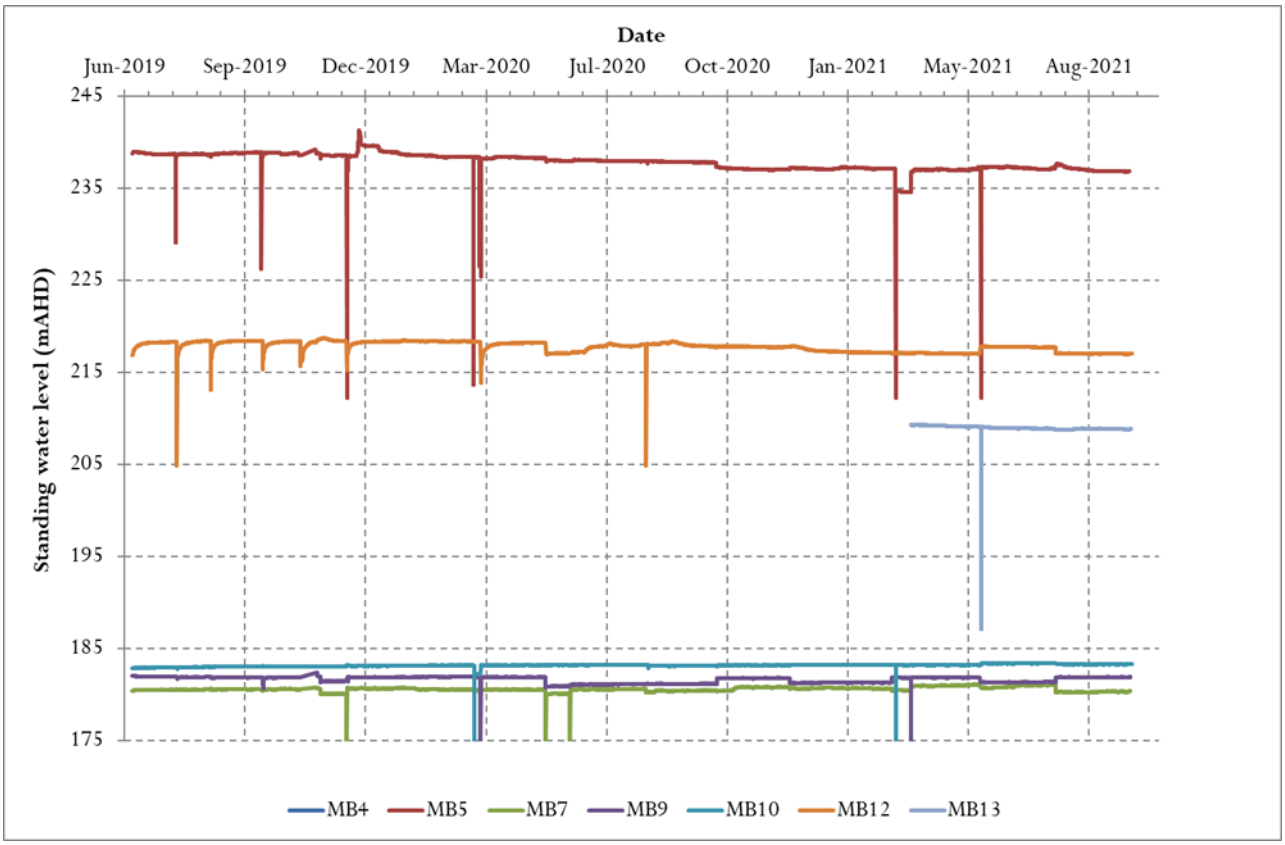


Figure 5.2 Groundwater hydrographs for Vulcan South monitoring bores

Groundwater sampling

Groundwater sampling is also regularly carried out (monthly for the first six months then quarterly thereafter) across the monitoring network to collect representative samples for baseline characterisation and for the derivation of trigger levels and contaminant limits (DES, 2021). The groundwater quality parameters monitored are consistent with those provided in Appendix A, which have been developed in consideration of the DES (2017) Guideline: Model mining conditions. The monitoring and sampling of the groundwater monitoring network is planned for and carried out in consideration of the Queensland Monitoring and Sampling Manual (DES, 2018a).

At the time of completing this report, results from eight monthly monitoring rounds are available. DES (2021) recommend at least eight groundwater samples be taken over a 12-month period to establish a robust baseline in order to derive site-specific triggers or limits for groundwater quality. Further sampling of the groundwater monitoring network will be carried out to further add to the dataset used derive interim trigger values. The derivation of trigger values will be carried out in consideration of DES (2021). Section 5.8 provides further discussion on groundwater quality including site specific data.

5.4. Hydraulic properties

Hydraulic testing in the form of slug testing and constant head testing was performed on the Project groundwater monitoring network summarised in Table 5-3. Slug testing (falling head tests) was completed on the monitoring bores recording a groundwater level, whereas constant head testing was completed on the dry monitoring bores. The recovery curve method was carried out for MB12 given the slow recovery response following sampling. The results of the testing are provided in Appendix B and are summarised below in Table 5-5.

Table 5-5 Summary of hydraulic testing from the Vulcan South monitoring bores

Site ID	Area	Target unit	Test method	Hydraulic conductivity (m/d)
MB01	Project	DLL coal seam	Constant head	3.9×10^{-2}
MB02	VCM	DLL coal seam	Constant head	5.3×10^{-2}
MB03	VCM	DLL coal seam	Constant head	3.2×10^{-2}
MB04	VCM	DLL coal seam	Slug test (Hvorslev, 1951)	9.7×10^{-2}
MB05	VCM	MAT coal seam	Slug test (Hvorslev, 1951)	2.4×10^{-2}
MB06	Project	Weathered Permian	Constant head	>0.1
MB07	Project	Weathered Permian	Slug test (Hvorslev, 1951)	0.21
MB08	Project	Weathered Permian	Constant head	>0.1
MB09	Project	DLL coal seam	Slug test (Hvorslev, 1951)	2.0×10^{-2}
MB10	Project	DLL coal seam	Slug test (Hvorslev, 1951)	0.41
MB11	Project	DLL coal seam	Constant head	2.9×10^{-2}
MB12	Project	Back Creek Group	Recovery test	2.8×10^{-4}

For two of the dry monitoring bores (MB06 and MB08) the rate at which the bore accepted water was higher than the rate it could be fed in. Therefore, it is assumed that the hydraulic conductivity of the intersected lithology at these monitoring bores is higher than 0.1 m/d.

The hydraulic testing of the monitoring bores indicates that generally the highest hydraulic conductivities are for the weathered Permian, moderate values for the DLL and MAT coal seams and the lowest results are for the Permian underburden. The following order of magnitude is observed in relation to hydraulic conductivities:

- Weathered Permian: low 10^{-1} m/d;
- DLL and MAT coal seams: 10^{-2} m/d; and
- Permian underburden: 10^{-4} m/d.

The horizontal hydraulic conductivities collated from various studies in the Moranbah-Dysart region are summarised in Table 5-6. Spatial variability, local geology, the different methods used to acquire data and uncertainties in interpretation explain the wide range of values which in some instances cover three or four orders of magnitude. Notwithstanding the above, the results in Table 5-5 are consistent with the description of the hydrogeology (Sections 5.1 and 5.2) and the majority of hydraulic conductivity ranges presented in Table 5-6.

Table 5-6 Horizontal hydraulic conductivity estimates (m/d) from studies in the Moranbah-Dysart region

Formation	URS (2009)	URS (2012)*	CDM Smith (2013)*	URS (2014)	AECOM (2016)	HydroSim. (2018)	Arrow (2016)
Quaternary alluvium	0.09 to 0.4	2.5 to 250	0.09 to 100	0.001	1×10^{-3}	2×10^{-1} to 9	1×10^{-2} to 1.5
Tertiary sediments/ regolith	-	0.1 to 10**	-	-	1×10^{-3} to 1×10^{-2}	1×10^{-1} to 6×10^{-1}	0.1 to 1
Triassic (Rewan F.)	-	5×10^{-4} to 5×10^{-2}	1×10^{-5} to 1×10^{-1}	-	-	2×10^{-6} to 5×10^{-3}	-
Permian coal measures	-	1×10^{-4} to 5×10^{-2}	-	-	-	-	0.2 to 1
Permian coal seams	1×10^{-2} to 5×10^{-1}	-	1×10^{-6} to 5	0.002 to 0.16	1×10^{-3} to 1×10^{-2}	5×10^{-4} to 1×10^{-1}	-
Permian interburden	2×10^{-2} to 3×10^{-2}	-	1×10^{-4} to 1×10^{-1}	-	-	6×10^{-7} to 6×10^{-3}	-
Permian Back Creek Group	-	1×10^{-4} to 1×10^{-2}	1×10^{-3} to 1×10^{-2}	-	-	-	-

*Note: *Collated data from literature ** (0.005 to 0.5 m/d for Duaringa Formation)*

The following sections provide commentary on the hydraulic parameters collated in Table 5-6.

Quaternary alluvium

Because of its thin saturated thickness (where it exists and is saturated) the Quaternary alluvium on its own would rarely form an aquifer. Rather, in combination with the underlying Tertiary sediments or Permian coal measures it may form a poor aquifer. The values reported by AECOM (2016) for the Quaternary alluvium appear to be low while the upper end of the reported values URS (2012) and CDM Smith (2013) appear high. The remaining data suggest a horizontal hydraulic conductivity in the order of 1×10^{-1} m/d to 1×10^{0} m/d, consistent with a (poor) aquifer. No Quaternary alluvium was intersected within the monitoring bore network and therefore Project specific data is unavailable.

Tertiary sediments

As discussed in Section 4.2.2, on-site observations during the construction of the Vulcan South monitoring bores indicate that the lithology intersected above the fresh Permian coal measures did not constitute Tertiary aged sediments, rather a weathering profile that had developed during the Tertiary on the Permian coal measures. As stated in Section 5.2.2, for the purposes of this report, Tertiary sediments are defined as a mix of specific Tertiary aged sediments and the weathered zone or regolith material.

For a mix of specific Tertiary aged sediments and the weathered zone or regolith, hydraulic conductivities in the order of 10^{-1} m/d appear reasonable (as provided by HydroSimulations, 2018, and Arrow Energy, 2016; in Table 5-6).

Permian coal measures

Throughout the Bowen Basin, the Permian coal seams are understood to be the main water bearing horizon within the Permian coal measures and the confining overburden, underburden and interburden strata are considered to be aquitards. Table 5-6 therefore lists the horizontal hydraulic conductivities for the coal measures (coal and over- and interburden), coal seams only, and interburden (including overburden) only.

The coal seams are considered dual-porosity strata where primary-porosity is provided by the matrix and a secondary porosity is the result of the presence of fractures (joints and cleats). These secondary porosity features within the coal seams likely dominate groundwater storage; and the main pathway for groundwater movement is dependent on the interconnectivity of these fractures (URS, 2009 and AECOM, 2016). Hence the hydraulic conductivity of the coal seams is expected to vary considerably spatially and also decrease with increasing depth of burial as the fractures close under increasing overburden pressure (HydroSimulations, 2018).

For the reasons listed above, the horizontal hydraulic conductivities in Table 5-6 cover a wide range. A range between 1×10^{-2} m/d and 1×10^{-1} m/d appears to be reasonable and consistent with the descriptions provided in Section 4.2.3 for the upper coal seams. For the interburden, a range between 1×10^{-5} m/d and 1×10^{-3} m/d appears to be realistic. For the coal measures (coal seams and inter- and overburden together), horizontal hydraulic conductivities between 1×10^{-4} m/d and 1×10^{-2} m/d appear to be reasonable. For the Permian Back Creek Group, horizontal hydraulic conductivities between 1×10^{-4} m/d and 1×10^{-2} m/d appear to be realistic and consistent with the material descriptions provided.

5.5. Groundwater flow, recharge, and discharge

5.5.1. Quaternary alluvium

AECOM (2016) and HydroSimulations (2018) suggest that the Quaternary alluvium is recharged primarily from creek flow events and by the infiltration of rainfall (and overland flow, where alluvium is exposed and no substantial clay barriers occur).

The mechanism of recharge described above is presented in Figure 5.3 below. The schematic represents a surface water system or creek within the Project area. There is very little Quaternary alluvium that has developed along the creek and a nominal thickness of 2 m is presented in this diagram. Given the ephemeral nature of the system, the creek is more often dry and, if present, the Quaternary alluvium is generally unsaturated. The groundwater table beneath the creek occurs at depth (greater than 10 m below ground level) and forms part of the regional groundwater table. If the local system has the ability to store water following a flow event and sub-surface conditions allow the stored water to infiltrate past the vegetation root zone, then this surface water flow may provide recharge to the groundwater system. This would be observed as localised mounding beneath the creeks and surface water systems. Otherwise, diffuse rainfall recharge would be expected to occur over a large area but at low rates.

The alluvial sediments may discharge to underlying Tertiary sediments and/or sub-cropping coal seams, especially during and immediately after periods of creek flow. Other discharge mechanisms from the alluvium include evapotranspiration (AECOM, 2016) where the water table is shallow, i.e. outside the Project area and near the Isaac River.

Groundwater flow, where and when the alluvium is present and saturated, is expected to follow topography. For example, groundwater in the alluvium follows the down-stream flow gradient of the Isaac River, with south-easterly flow gradients (HydroSimulations, 2018).

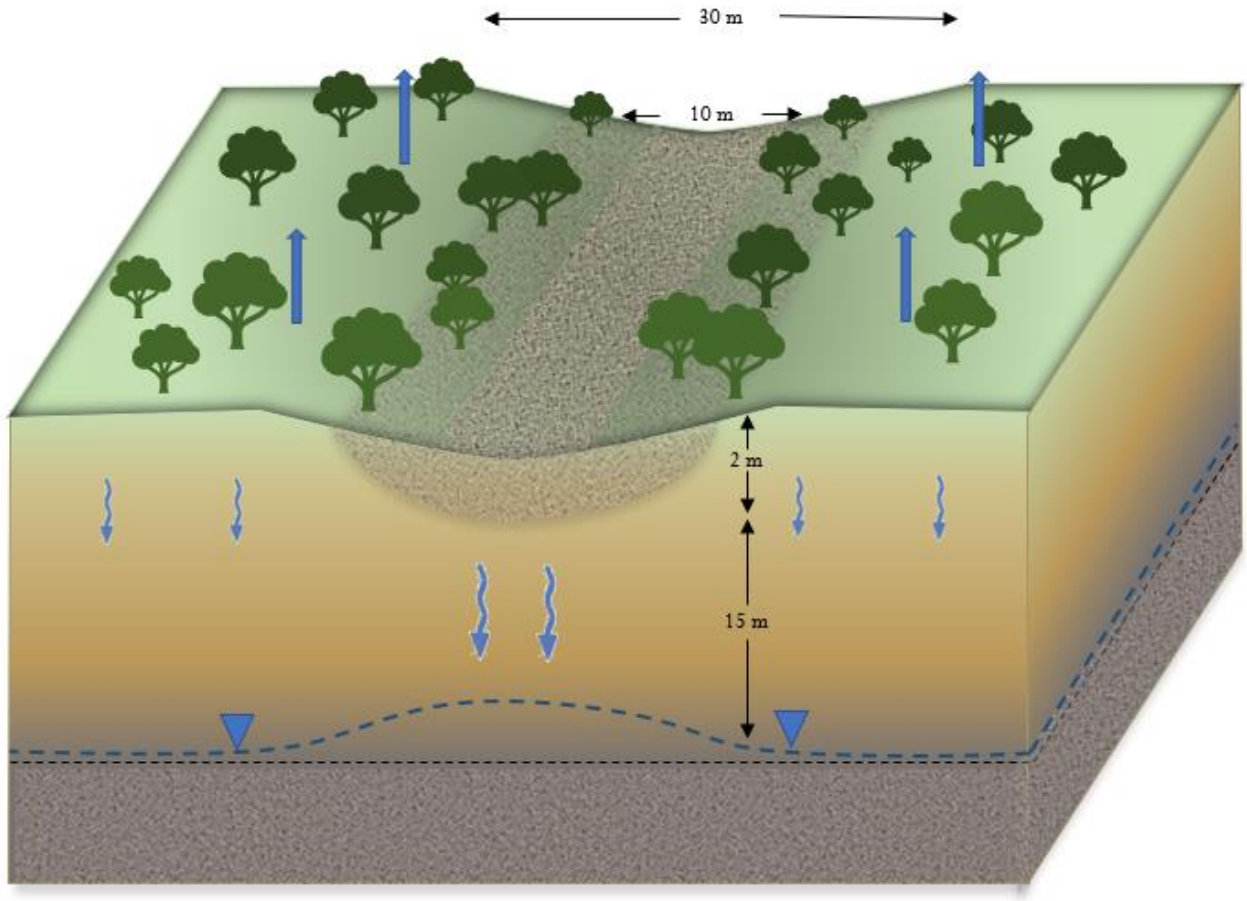


Figure 5.3 Schematic diagram of recharge processes

5.5.2. Tertiary sediments

Recharge to the Tertiary sediments is likely from creek flow (losing ephemeral streams) events and, where there is no Quaternary alluvium beneath surface water systems, from surface infiltration of rainfall and overland flow. Recharge may also occur by downward vertical seepage from overlying Quaternary alluvium (URS, 2009) where the alluvium is present. Given the clayey nature of the Tertiary sediments it would be expected that recharge rates would be very low.

Discharge from the Tertiary sediments, where they outcrop and the water table is shallow, may occur through evapotranspiration. The Tertiary sediments may also discharge to the Permian coal measures as, in general, there is a downward vertical hydraulic gradient between the Tertiary sediments and Permian coal measures.

Observations from open pits at Saraji Mine (AECOM, 2016) indicate that groundwater discharges relatively slowly from the sandy horizons within the Tertiary sediments. Based on these observations, the Tertiary sediments were considered by AECOM (2016) to contain a series of poorly connected aquifers of low to moderate permeability, with drainage from the upper to lower aquifers delayed by lower permeability horizons. Groundwater ingress rates are low as evaporation rates are higher than the seepage rate, hence groundwater does not report directly or require management in the pits (AECOM, 2016).

As for the Quaternary alluvium, groundwater flow in the Tertiary sediments is expected to follow topography and surface water drainage patterns. Groundwater levels within the Tertiary sediments from monitoring bores near the Saraji Mine were reported to be at depths shallower than the recorded water strikes from drilling and installation, interpreted by AECOM (2016) to indicate that groundwater is semi-confined to confined by the clayey sediments in the upper sections of the sequence (AECOM, 2016).

5.5.3. Permian coal measures

Within the Project area and in the vicinity of the proposed open pits, the Permian coal measures are known to be partially unsaturated and site-specific monitoring bores (i.e. MB01, MB02, MB03 and MB11) have confirmed this. Figure 5.4 illustrates how the Permian coal measures change in the vicinity of the proposed Vulcan main pit from unsaturated to partially saturated in the north-west, to unconfined and eventually to fully saturated and confined in the south-east.

As for the Tertiary sediments, groundwater recharge to the Permian coal measures is likely from creek flow (losing ephemeral streams) events where there are no Cainozoic sediments beneath surface water systems; and from surface infiltration of rainfall and overland flow, where the Permian coal measures are exposed, and no substantial clay barriers occur in the shallow sub-surface. Recharge may also occur from overlying Cainozoic sediments under downward vertical hydraulic gradient and along faults and other structural features (AECOM, 2016).

Discharge from the Permian coal measures, where they outcrop and the water table is shallow, may occur through evapotranspiration or along faults and by groundwater extraction from bores and mine dewatering/depressurisation (AECOM, 2016; HydroSimulations, 2018). For the shallower coal measures, groundwater elevations are generally at or below groundwater elevations within the overlying unconfined sediments, indicating a downward hydraulic gradient. However, with increased depth of cover and pressure, the hydraulic gradient within the Permian coal measures may reverse, coinciding with a decrease in hydraulic conductivity with depth (HydroSimulations, 2018).

As for the Cainozoic sediments, groundwater flow in the Permian coal measures is expected to follow topography and surface water drainage patterns, although the similarity to surface water drainage for the deeper confined units will be less pronounced than that for a shallow unconfined aquifer. Within the Permian coal measures, due to the low hydraulic conductivity of the interburden material, groundwater would largely flow along the bedding planes of the coal seams (HydroSimulations, 2018). In the vicinity of active mine dewatering sites, groundwater would flow into the pits but the spatial extent of the interference zone of individual pits would be limited because of the low hydraulic conductivity and storativity of the coal measures.

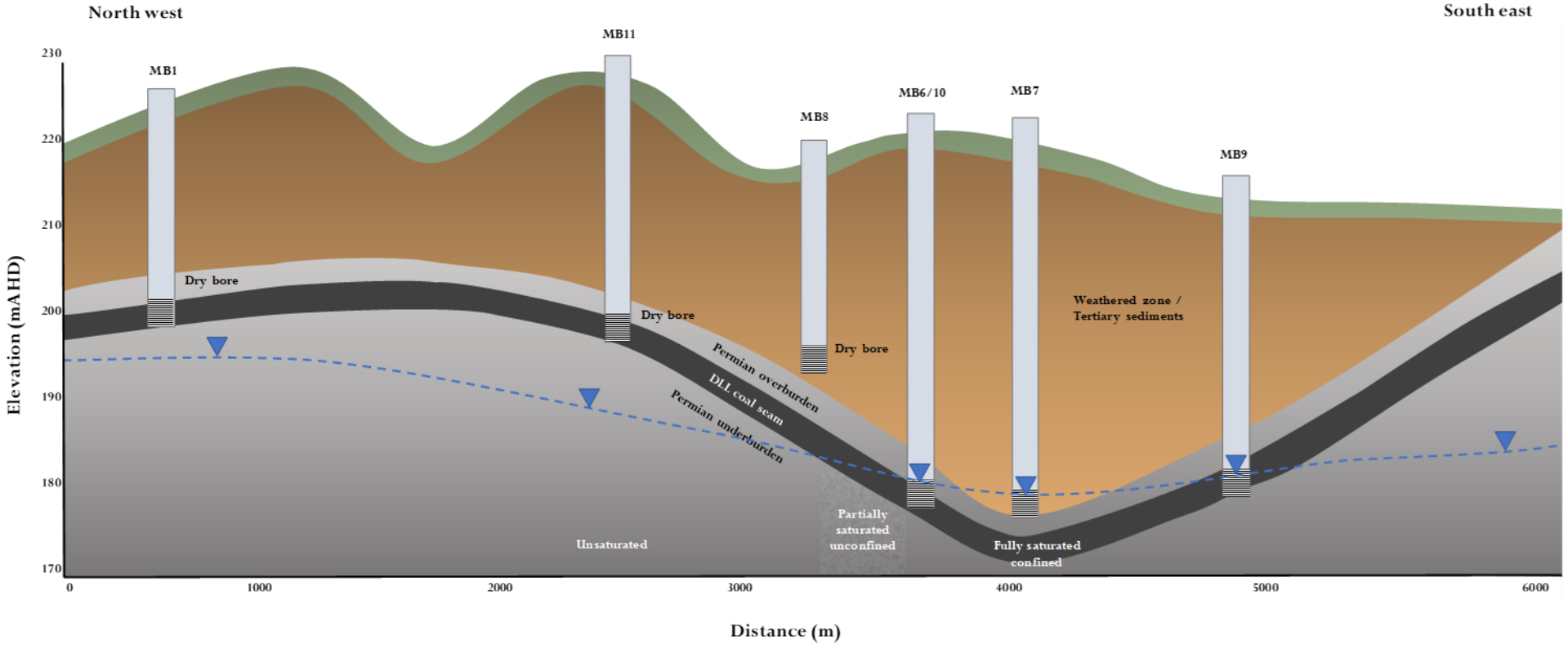


Figure 5.4 Saturation extent of the Permian coal measures in the Project area (looking north-east)

5.5.4. Recharge and discharge rates

While the literature generally agrees on the recharge and discharge mechanisms, the rates of recharge and discharge vary significantly. AECOM (2016) used a preliminary recharge rate of 1.43 mm/yr for the Quaternary alluvium and 0.89 mm/yr for the rest of the model domain. URS (2012) and Arrow (2016) used a minimum of 1 mm/yr for Triassic/Permian strata and "*more for alluvium*" (Arrow Energy, 2016).

HydroSimulations (2018) used model calibrated recharge rates of 2.8 mm/yr to 5.1 mm/yr for the Quaternary alluvium, 0.15 mm/yr for Tertiary sediments and 0.06 mm/yr for outcropping Permian coal measures. These recharge rates are summarised in Table 5-7 together with indicative long-term average recharge/rainfall percentages.

Table 5-7 Estimates of recharge rates (mm/yr)

Reference	Quaternary alluvium	Tertiary sediments	Permian coal measures
AECOM (2016)	1.43 (0.2%)	0.89 (0.1%)	0.89 (0.1%)
URS (2012)	>1 (>0.1%)	1 (0.1%)	1 (0.1%)
HydroSimulations (2018)	2.8 – 5.1 (0.4% - 0.7%)	0.15 (0.02%)	0.06 (0.009%)

Note: Value in brackets is the percent of recharge assuming an annual rainfall of 660 mm/yr.

HydroSimulations (2018) also refer to recharge rates used in Arrow Energy's Bowen Gas Project and other nearby projects (not sighted during the preparation of this report). According to HydroSimulations (2018), recharge at Lake Vermont was simulated as the equivalent of 2% mean annual rainfall and at Isaac Plains it was simulated as 0.5% (mean annual rainfall) to alluvium and 0.25% (mean annual rainfall) elsewhere. For the Arrow Energy Bowen Gas Project, recharge to the Quaternary alluvium was simulated as 1 mm/yr to 3 mm/yr (low recharge scenario) or 9 mm/yr to 27 mm/yr (high recharge scenario). Recharge was simulated as 0.3 mm/yr or 3 mm/yr for Tertiary sediments, 0 mm/yr for the Rewan Group and 0.33 mm/yr to 3 mm/yr for outcropping Permian coal measures.

For discharge, URS (2012) and Arrow (2016) modelled the difference between potential and actual evapotranspiration with an extinction depth of 10 m in their respective numerical models. HydroSimulations (2018) applied maximum potential evaporation rates using actual evapotranspiration values with an average value (600 mm/yr) used as the transient calibration evapotranspiration rate. Extinction depths were set to 2 m below ground across the model domain.

5.5.5. Groundwater flow

Based on the literature reviewed in this report, and published groundwater contour maps, horizontal (lateral) regional groundwater flow is expected to follow the same patterns as topography and the surface water drainage from all hydrogeological units, although the resemblance to surface water drainage for the deeper confined units will be less pronounced than that for the shallow unconfined aquifer.

URS (2012) presented regional groundwater elevations (not reproduced in this report) for the Permian Blackwater Group. Average groundwater "levels" (i.e. elevations) were used to create the map, both from non-coal units and coal seams, hence both temporal and vertical changes (within the Blackwater Group) in groundwater elevation were disregarded. URS (2012) indicated, in general, flow from the west (north-west) to the east (south-east) mimicking the surface water drainage pattern. URS (2012) commented that groundwater flow may also be constrained by major N-S strike fault systems. The interpretation of **hydrogeologist.com.au** is that there may be an indication for such influence on groundwater flow, however, it is difficult to say with certainty at the scale provided.

Groundwater contours by AGE 2012a (a memorandum on predicted inflows and drawdown for the Saraji East Underground Mine) in AECOM (2016; Saraji Mine) indicate a generally west to east flow pattern, similar to the URS (2012; Bowen Gas Project) interpretation. The pre-mining groundwater contours are model generated, and the elevations are typically up to 20 m different to the regional contours presented by URS.

Figure 5.5 shows composite groundwater elevation contours, prepared by **hydrogeologist.com.au**. The groundwater elevation contours are based on 412 individual datapoints collated from the DRDMW GWDB, site specific monitoring bores and Project exploration drill holes and groundwater elevations summarised as part of neighbouring projects (AECOM, 2016). For each datapoint, the depth to groundwater measurements were considered and corrected to an elevation based on surveyed or reported elevations or derived from an STRM (one second) digital elevation model (DEM). Notwithstanding that, the contours represented in Figure 5.5 are a composite groundwater elevation map (groundwater elevations from different times and from various hydro-stratigraphic units), it clearly indicates groundwater flow to the east within the Project area. To the east of the Project area, the inferred direction of groundwater flow turns to the south-east and eventually follows the alignment of the Isaac River, in agreement with the findings of HydroSimulations (2018).

Based on the literature reviewed and presented in this report, horizontal (lateral) regional groundwater flow is expected to follow the same patterns as topography and the surface water drainage for all hydrogeological units, although the resemblance to surface water drainage for the deeper confined units will be less pronounced as for the shallow unconfined groundwater systems. Near the Project area, the statement above would suggest a west to east groundwater flow, and this is consistent with the data assessed.

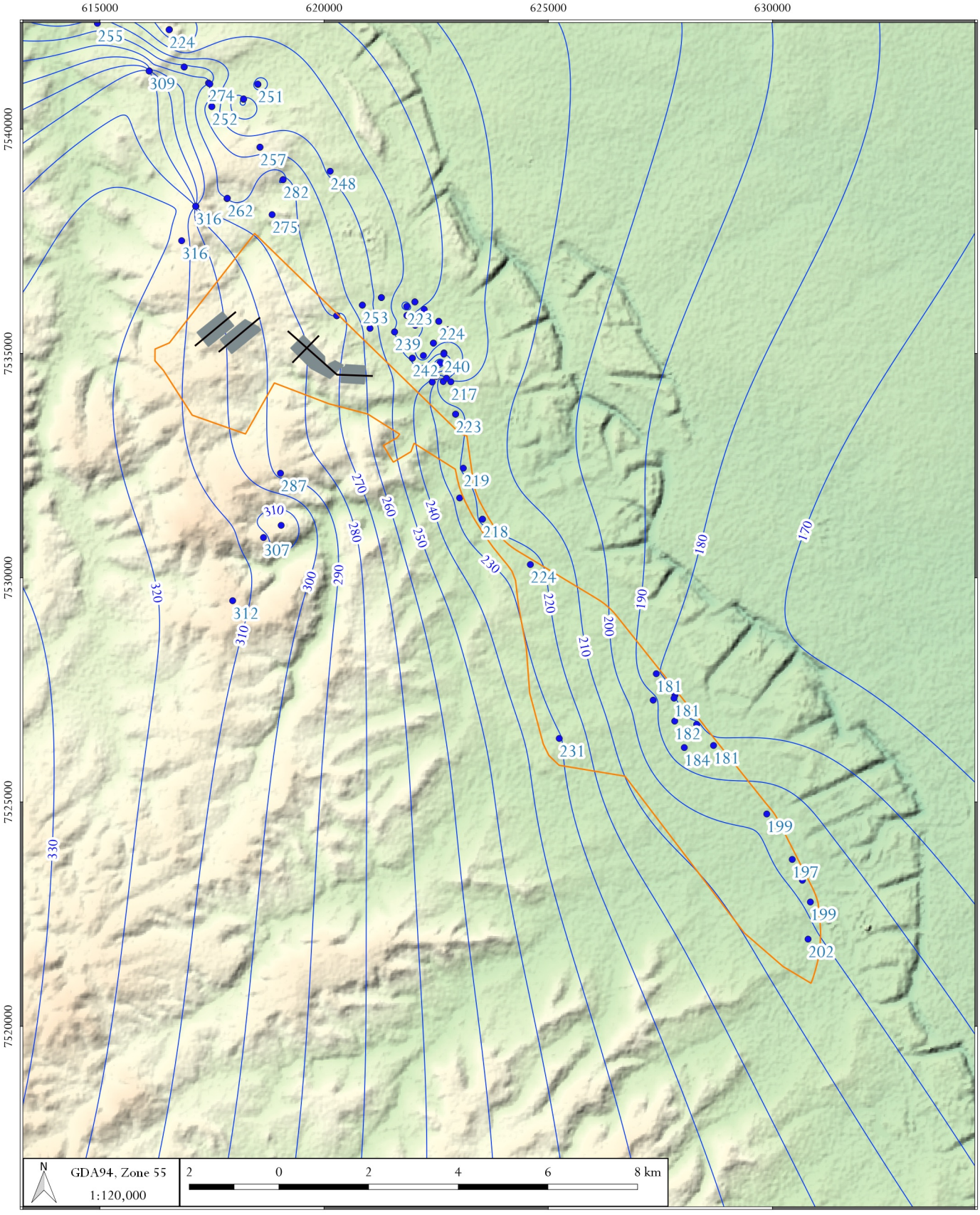
Vertically, the highest groundwater elevations were measured in the Quaternary and Tertiary units and upper Permian coal seams. Groundwater elevations also appear to decrease with the depth within the coal seams (URS, 2009 and AECOM, 2016). Vertical hydraulic gradients, where reported, are downward, suggesting potential downward leakage between the hydrogeological units (although HydroSimulations (2018) reported a single observation deep in the Permian where the vertical hydraulic gradient within the Permian coal measures reversed, coinciding with a decrease in hydraulic conductivity with depth). Groundwater elevations measured by AECOM (2016) in nested bores indicate downward hydraulic gradients in all measured bores between the Tertiary and Permian units and within the Permian units in all but one bore. These observations are consistent with those made by HydroSimulations (2018).

Highwall Mining Area

Within the Highwall Mining area the groundwater elevation contours are between 260 mAHD and 310 mAHD (Figure 5.5). Assessment of topographic data, the structure contours for the floor of the MAT coal seam and the groundwater elevation contours has been carried out to determine whether the highwall mining associated with the Project will intersect groundwater during operation.

A series of four cross-sections have been generated to demonstrate the relationship between the MAT seam floor and the groundwater contours (Figure 5.6). The cross-sections clearly demonstrate that the groundwater contours are typically greater than 10 m below the floor of the MAT coal seam in the Highwall Mining area. This has been confirmed by a number of coal exploration drill holes located within the Highwall Mining area that have been reported as dry during and after drilling.

On this basis it is assessed that the highwall mining proposed as part of the Project will not interact with groundwater. For impact assessment purposes the Highwall Mining area will no longer be discussed in this report.



LEGEND

Groundwater elevation contours (mAHD):

- contours compiled by hydrogeologist.com.au
- Groundwater elevation data point
- Highwall mining area
- Location of section (see Fig. 5.6)
- Mining lease application area

DATE
22/02/2022

hydrogeologist .com.au

Vulcan South - Groundwater Impact Assessment (4027)

Groundwater elevation contours

FIGURE No.
5.5

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
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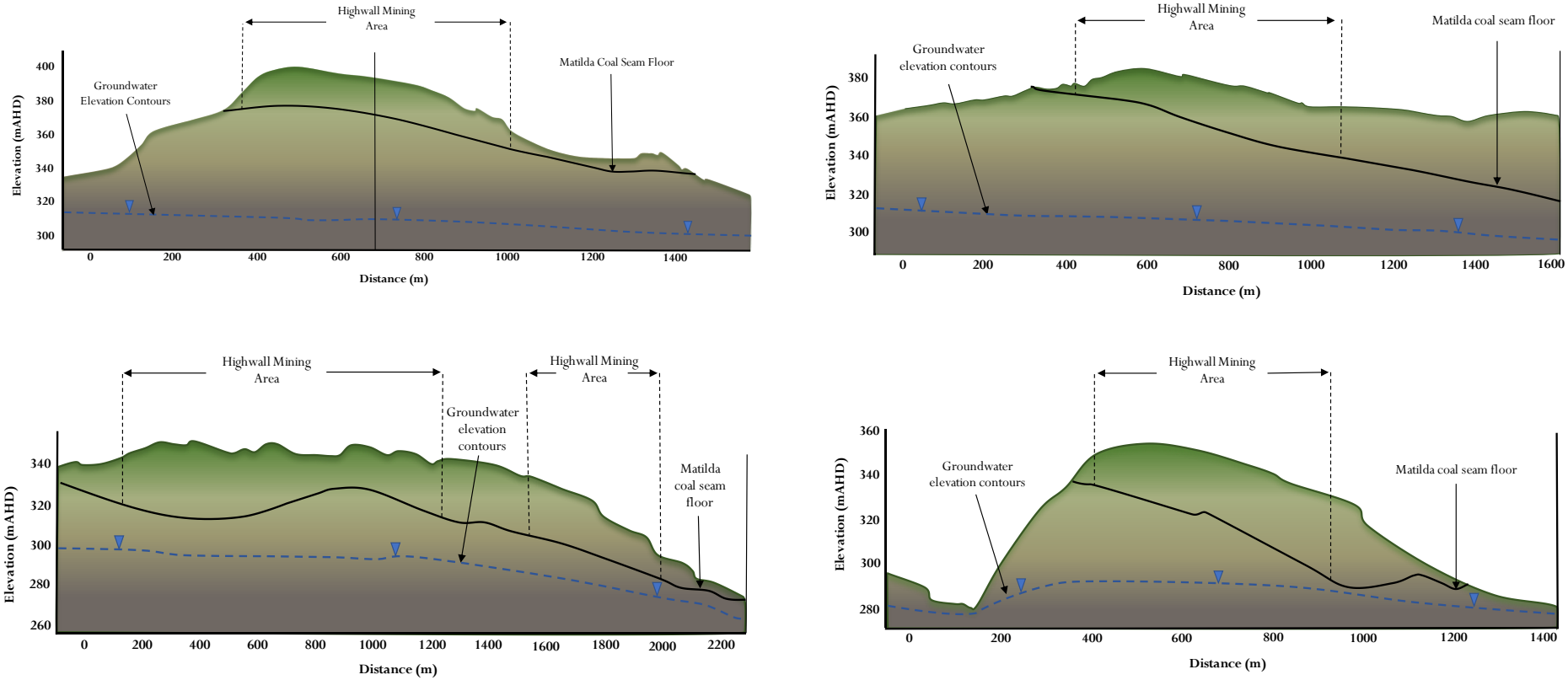


Figure 5.6 Highwall Mining area cross-sections

Effect of mining

AECOM (2016) noted that:

"Groundwater levels in the alluvium (MB2), Tertiary (PZ02A and PZ04A) and Permian (MB31, MB33 to MB37) strata, measured over time, do not indicate any impacts of mine dewatering even though coal mining at Saraji Mine has been undertaken since 1974". The monitoring bores referred to above are located between 600 m (MB2) and 1,500 m (MB33 and MB34) of the existing Saraji Mine open cut pits. The monitoring data would indicate that the zone of influence (or interference) is restricted to an area immediately adjacent to the open cut pit. This is likely due to low permeability of the mined strata and Permian overburden. AECOM (2016) therefore considered that the long term mine activities do not markedly impact on regional groundwater resources.

hydrogeologist.com.au concurs with this interpretation. The low hydraulic conductivity / transmissivity for most units, combined with low storage, would result in mine interference zones limited in lateral extent, except in areas where secondary porosity (fractures) opened extensive preferential pathways in the coal seams.

Structural control

CSIRO (2002) presents the distribution of faults, dykes and sills within the Project area and this is reproduced as Figure 5.7. In Figure 5.7 red lines represent thrust faults with > 3m throw, blue lines indicate normal fault with 1 m to 3 m throw, and turquoise lines show normal faults with > 3 m throw; purple rectangles signify inferred basement structures. The approximate location of the Project area is indicated on the figure to show the location relative to the Jellinbah Thrust Fault Zone and the structures mapped at Saraji Mine and Peak Downs Mine. The proposed open pits may be influenced to some degree by local structure mapped at the adjacent Saraji Mine.

The main geological structure in the region is the Jellinbah Thrust Fault Zone. The Jellinbah Thrust Fault Zone is highly faulted with several easterly dipping thrust faults. It is a north-west trending zone of thrust faults with throws in the order of 100 m to 500 m (URS, 2012). The Olive Downs Coal Project (HydroSimulations, 2018) is located within the Jellinbah Thrust Fault Zone and discusses several regional fault structures with a dominant north-north-west trend, including the Iffley Fault Zone (up to 100 m displacement). On the western side of the Olive Downs Coal Project is the Isaac Thrust Fault, which has up to 500 m vertical displacement.

The Jellinbah Thrust Fault Zone is truncated by the Tertiary unconformity, with little to no fault activity during the Cainozoic (CSIRO, 2002 and HydroSimulations, 2018). Faulting can result in higher permeabilities within strata parallel with the fault plane, and lower permeabilities within strata perpendicular to the fault plane. However; this can be dependent on whether faults are currently active or not. Faulting has been inactive within the Bowen Basin for over 140 million years, indicating that the fault zones are less likely to act as conduits to flow (HydroSimulations, 2018). This relates to filling of the fractured pore spaces over time through hydrothermal alteration and mineralisation. Drill core logs from the Olive Downs Coal Project show that where fractures and faults have been geologically logged, many fractures are "healed" with calcite and siderite. This indicates that, although the system is a fractured network, many of the existing fractures are cemented with the likely effect of reducing effective permeability when compared to any open fracture network.

The behaviour of faults was also assessed as part of the Bowen Gas Project using the movement of water and gas across a series of faults utilising stable isotope and water quality analyses. Higher gas production rates were observed on either side of a major fault, with differences in isotopic compositions of produced water for wells north and south of a major fault line at similar depths, implying little communication across the fault boundary, and suggesting that the fault acts as a barrier to water and gas flow. The results of the study showed that compartmentalisation was evident and that this was due to the structural geology (faulting) in the basin (HydroSimulations, 2018).

The Jellinbah Thrust Fault Zone occurs some 10 km to 15 km to the east of the proposed open pits and would be very unlikely to influence groundwater flow on a local scale. On a regional scale, however, the presence of the Jellinbah Thrust Fault Zone would act as a low permeability zone in the regional flow system of the Permian strata. The experience of **hydrogeologist.com.au**, with the Jellinbah Thrust Fault Zone, is that lateral groundwater flow within the fault zone is to the east (north-east). To the west of the fault zone, the presence of 'dense' groundwater head/elevation contours suggest a steep horizontal hydraulic gradient while to the east of fault zone the gradient is flatter, indicating that the fault zone is acting as an impediment, i.e. the hydraulic conductivity of the fault zone is lower than that of the host rocks.

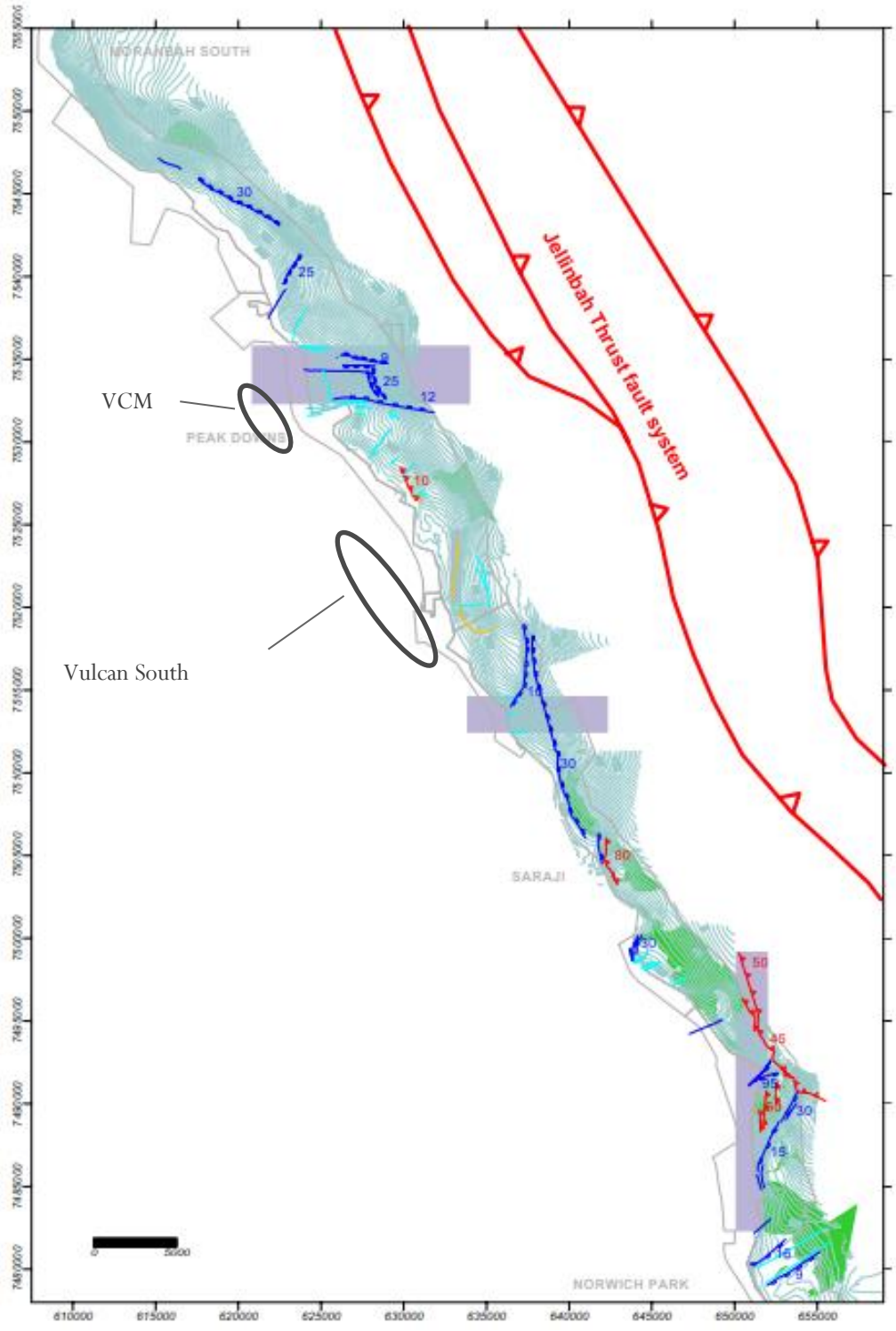


Figure 5.7 Faults with >1 m throw mapped in the Dysart seam of the Middle Tile, after CSIRO (2002)

5.6. Surface-groundwater interaction

Surface-groundwater interaction was investigated for the Olive Downs Coal Project (HydroSimulations, 2018), approximately 20 km to the north-east of the Project area. Despite the distance between the projects, the assessment appears to be directly transferable because the numerical groundwater model domain of HydroSimulations (2018) extends westward sufficiently enough to cover all important watercourses in the Project area.

In addition, HydroSimulations (2018) have:

- developed a conceptual hydrogeological model that is consistent with that presented in this report in Section 5.9;
- addressed surface water-groundwater interaction with the same or similar modelling tools used and described in Section 5.6;
- relied on a dataset almost identical to that available for this report because the most important stream gauging station, Phillips Creek at Tayglen (Figure 3.3) was closed in late 1988 (https://water-monitoring.information.qld.gov.au/, visited 21 August 2019); and
- the groundwater report and model of HydroSimulations (2018) appears to be the most recent and comprehensive groundwater assessment in the vicinity of the Project area.

Further, a careful evaluation of the differences between the Olive Downs Coal Project and the Project area suggests that surface and groundwater interact to a lesser degree at the Project area than at Olive Downs Coal Project:

- the Project area is to the west and at higher elevation than the Olive Downs Coal Project, resulting in generally deeper groundwater table and less flow in the watercourses than those at the Olive Downs Coal Project;
- the Quaternary alluvium of the Isaac River, through which most surface-groundwater interaction at the Olive Downs Coal Project occurs, is absent in the Project area; and
- the importance of the Isaac River (and its associated alluvium) on the groundwater regime of the Project area is significantly less, not just because of the distance, but because of the Jellinbah Thrust Fault Zone which is situated in between the Isaac River and the Project area, compartmentalising groundwater flow in the Permian strata.

The mechanism of recharge from surface water systems in the Project area is presented in Section 5.5.1 (Figure 5.3). The schematic represents a surface water system or creek within the region with little to no Quaternary alluvium development along the creek. The ephemeral nature of the surface water systems means that the creeks are dry for the majority of time and if present, the Quaternary alluvium would be unsaturated. The groundwater table beneath the creeks occurs within either the Tertiary sediments or Permian coal measures at depth (greater than 10 m below ground level) and forms part of the regional groundwater table. There is a significant thickness (generally greater than 10 m) of unsaturated material beneath the creek and above the groundwater table. For the reasons stated above, it is assessed that there is no significant surface-groundwater interaction in the Project area.

5.7. Groundwater use

Groundwater users in the vicinity of the Project area include mining companies (industrial use), private users (livestock beef cattle watering) and, potentially, GDEs (springs, surface water, stygofauna, wetlands etc).

5.7.1. Third party users

Third party groundwater use has been assessed through two mechanisms:

- consideration of the registered bores within 5 km of the numerical flow model domain on the DRDMW GWDB; and
- discussion with private landholders within 5 km of the proposed open pits.

The Groundwater Database – Queensland (DRDMW GWDB) stores registered water bore data from private water bores and Queensland Government groundwater investigation and monitoring bores. Data includes bore location, water levels, construction details, strata log and water quality. As such the DRDMW GWDB is the most reliable source of desktop information on groundwater use for the Project area.

Records within a 5 km distance of the numerical model domain (Section 6.1) extent were selected for subsequent analysis. Of the 83 DRDMW GWDB records within 5 km of the numerical flow model domain the following can be concluded:

- 65 (78%) are existing;
- 11 (13%) are abandoned and destroyed; and
- 7 (8%) are abandoned but still useable.

There are 69 records classifying bore use or purpose within 5 km of the numerical flow model domain. These records suggest that the overwhelming use of bores is for mining:

- 51 (74%) are for monitoring (41 for mine, 5 for petroleum or gas and 5 for sub-artesian monitoring);
- 14 (20%) are for water supply (these may be for mine supply or private supply as water supply is used as a broad term); and
- 4 (6%) are for investigation (stratigraphic, exploration or water resources investigation).

It is the experience of **hydrogeologist.com.au** that the name of a bore may also reveal its purpose, i.e. bore names containing long numbers, company abbreviations or sequences such as "MB" or "INV" or "PIEZO" are for monitoring or investigation while private bores are named after the farm or the owner. Of the 62 records with names available, 52 (84%) appear to be for the purpose of mine investigation and monitoring.

Groundwater quality is an important consideration for groundwater use because high salinity will generally preclude or limit certain uses. For this reason, groundwater salinity data was also analysed. For the 5 km vicinity of the numerical flow model domain, most of the groundwater salinity information in DRDMW GWDB is provided as field electrical conductivity (EC). Using the classification of Mayer *et al.* (2005) that is provided in Table 5-8, the 153 field EC records could be summarised as:

- none are fresh;
- one is marginal;
- 29 are brackish;
- 91 are saline; and
- 32 are highly saline.

The above statistics on field EC may somewhat be biased towards bores that are represented by several results (at different dates). The interpretation of **hydrogeologist.com.au** is that most bores in the vicinity of the Project area are for monitoring and investigation purposes (mostly for mining) and only a small fraction may be used for private groundwater use, probably for limited stock watering because of the high salinity of the groundwater.

The registered bores on the DRDMW GWDB are shown in Figure 5.1. It is clear that most registered bores are to the east and south-east and there are very few surrounding registered bores within close proximity of the Project. A private landholder bore (RN162506) is situated 300 m to the east of the Highwall Mining Area, the next closest private landholder bore is RN8606 which is located 3,000 m to the west of the Highwall Mining Area.

RN13040283, a Queensland government monitoring bore is located immediately to the east of the Vulcan main pit. The cluster of bores shown immediately to the east of the Vulcan main pit and Vulcan south pit have been drilled by BMA for the purposes of investigating and monitoring local water infrastructure.

Discussions have been held with the owners of the following property descriptions and Vitrinite to understand whether there are any groundwater bores on the property that may not be registered on the DRDMW GWDB:

- Lot 10 SP208611;
- Lot 2 SP296877;
- Lot 59 SP235297;
- Lot 7 CNS144;
- Lot 11 CNS394;
- Lot 14 CNS382; and
- Lot 9 SP235297.

The outcomes of the discussions indicate that there are no other groundwater supply bores in the Project area that are used by the local landholders. Potential impacts to third party groundwater users are discussed in Section 7.

5.7.2. Groundwater dependent ecosystems

A GDE is an ecosystem that requires access to groundwater on a permanent or intermittent basis to meet all, or some of its water requirements. For GDEs such as springs, wetlands, rivers and vegetation, groundwater plays an important role in sustaining aquatic and terrestrial ecosystems. A GDE therefore is a plant and/or animal community that is dependent on the availability of groundwater to maintain its structure and function.

The GDE Atlas (GDE Atlas, Bureau of Meteorology, 2016) was developed as a national dataset of Australian GDEs to inform groundwater planning and management. It is the first and only national inventory of GDEs in Australia. The GDE Atlas web-based mapping application allows the visualisation, analysis and downloading of GDE information for an area of interest (http://www.bom.gov.au/water/groundwater/gde/, visited 21 August 2019).

The GDE Atlas classifies ecosystems based on the potential for dependence on groundwater. Classification is based on multiple lines of scientific evidence, with categories for high, moderate, or low potential, allocated as follows:

- high potential for groundwater interaction (indicating a strong possibility the ecosystem is interacting with groundwater);
- moderate potential for groundwater interaction; or
- low potential for groundwater interaction (indicating it is relatively unlikely the ecosystem will be interacting with groundwater).

BOM (2018) maps areas for both aquatic and terrestrial GDE's and indicates that the following are mapped in the vicinity of the Project area:

- Aquatic GDEs rely on the surface expression of groundwater, including surface water ecosystems which may have a groundwater component such as rivers, wetlands, and springs. Aquatic GDEs associated with a number of separate water bodies along the Moranbah – Dysart Road, between Phillips Creek and Boomerang Creek and close to the Project area, are mapped as having a low, moderate or high potential to be associated with the surface expression of groundwater (Figure 5.8). These features all appear to be manmade impoundments associated with Saraji Mine or pastoral properties. Hughes Creek is mapped as having a moderate potential to be associated with the surface expression of groundwater.
- Terrestrial ecosystems rely on the subsurface presence of groundwater. This includes all vegetation ecosystems. Terrestrial GDEs to the west of Moranbah – Dysart Road are generally mapped as having a low to moderate potential to be dependent on the subsurface expression of groundwater (Figure 5.9). No subterranean GDEs (cave and aquifer ecosystems) have been identified by BOM, 2018 in the vicinity of the Project.

The depth to groundwater table map in Figure 5.10 was produced by subtracting the groundwater elevation grid (compiled and generated from publicly available information – see Figure 5.5) from the ground surface (SRTM data used for the regional area and LIDAR used for the local Project area) grid.

Figure 5.10 indicates that groundwater is generally between 5 m and 40 m deep in the area surrounding the proposed pits. The nearest areas with depth to groundwater less than 5 m (orange colours) are to the west and south of the Vulcan south pit. The area of shallow depth to groundwater to the west of the Vulcan south pit correlates with a moderate potential aquatic GDE associated with Hughes Creek (as presented in Figure 5.8).

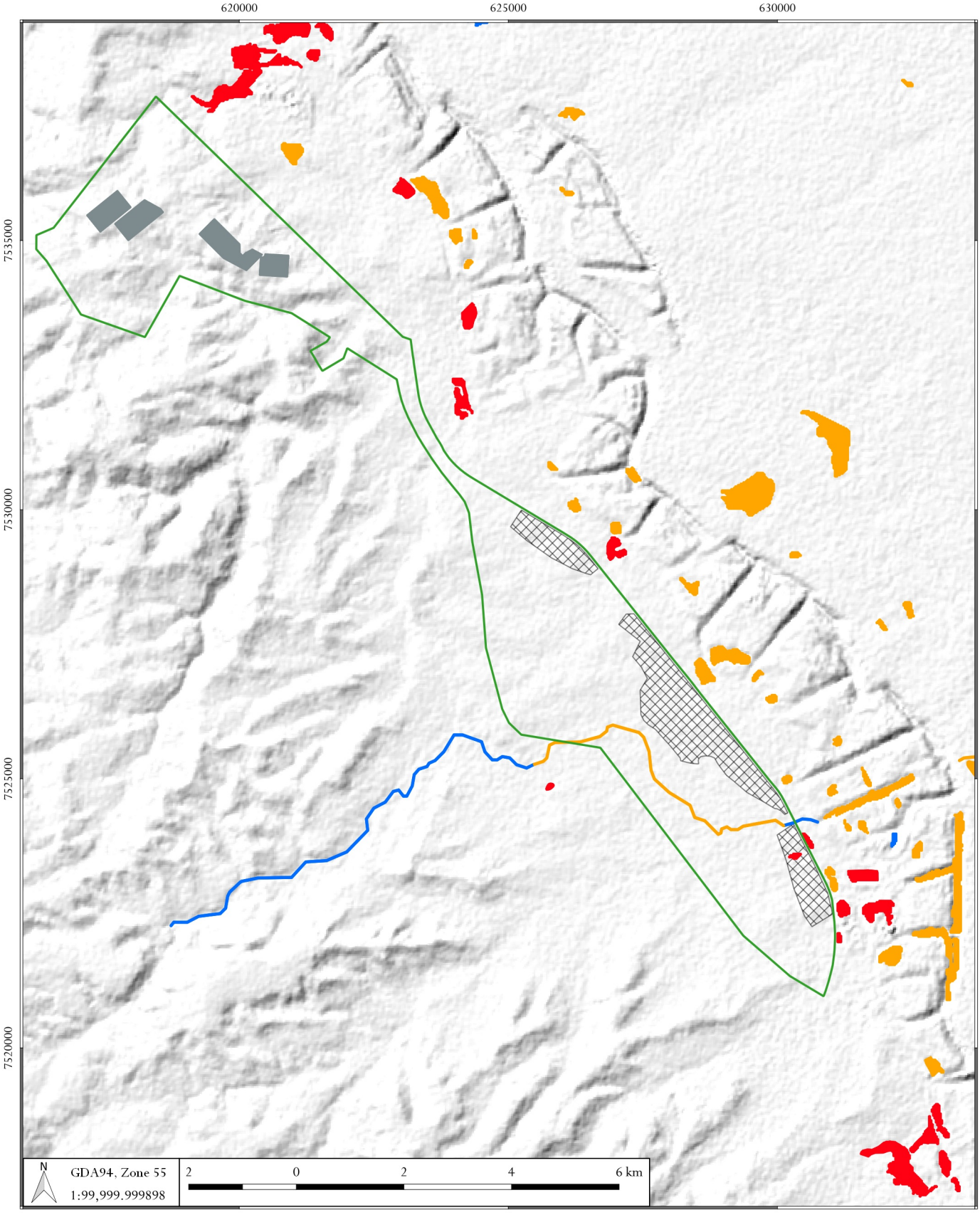
Aquatic GDEs with high or moderate potential for groundwater interaction are most likely to occur in areas where the seasonally high groundwater potentiometric heads are above or close to the corresponding surface water heads. This is necessary to maintain a hydraulic gradient from the groundwater to surface water, or at least have a hydraulically 'connected' system. In addition, groundwater in the Project area is brackish to saline and therefore unsuitable for the maintenance of freshwater GDEs (see Section 5.8 for further information on groundwater quality). It is the interpretation of **hydrogeologist.com.au** that it is highly unlikely for aquatic GDEs to be present within 1 km of the proposed pits.

In the experience of **hydrogeologist.com.au**, terrestrial GDEs with high or moderate potential for groundwater interaction are most likely to occur in areas where depth to groundwater is less than 10 m (i.e. the groundwater table is shallow, including alluvial deposits) and likely to be outside of the accessible reach of Eucalypt vegetation (Zolfaghar *et al*. 2014 in AECOM, (2016). There is an area of mapped terrestrial GDEs associated with Hughes Creek which is located within an area where the depth to groundwater is less than 10 m.

The reader is directed to the Vulcan South – Ecological Impact Assessment (METServe, 2022) report for further information regarding the presence of aquatic or terrestrial GDEs. Section 6.5 of this report discusses aquatic and terrestrial GDEs in relation to predicted groundwater impacts.

In addition, the Queensland Government maintains an inventory of identified springs in the Queensland Springs Database (https://data.qld.gov.au/dataset/springs/resource/4cdc89ef-b583-446e-a5c7-0836a91a3767, visited 21 August 2019) that can also be reviewed through QLD globe (https://qldglobe.information.qld.gov.au/). No springs have been identified in the vicinity of the Project area; with the nearest spring being situated at a distance greater than 100 km to the west.

A search of the EPBC Act 'Protected Matters Report' (http://www.environment.gov.au/epbc/pmst/index.html, visited 21 August 2019) found that there are no internationally or nationally important wetlands within 50 km of the Project area. Lake Elphinstone is the closest nationally important wetland, located approximately 100 km north of the Project area.



LEGEND

Aquatic groundwater dependent ecosystem:

- High potential GDE - from national assessment
- High potential GDE - from regional studies
- Moderate potential GDE - from national assessment
- Low potential GDE - from national assessment

- Proposed pit
- Highwall mining area
- Mining lease application area

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Vulcan South - Groundwater Impact Assessment (4027)

Aquatic groundwater dependent ecosystems

FIGURE No.
5.8

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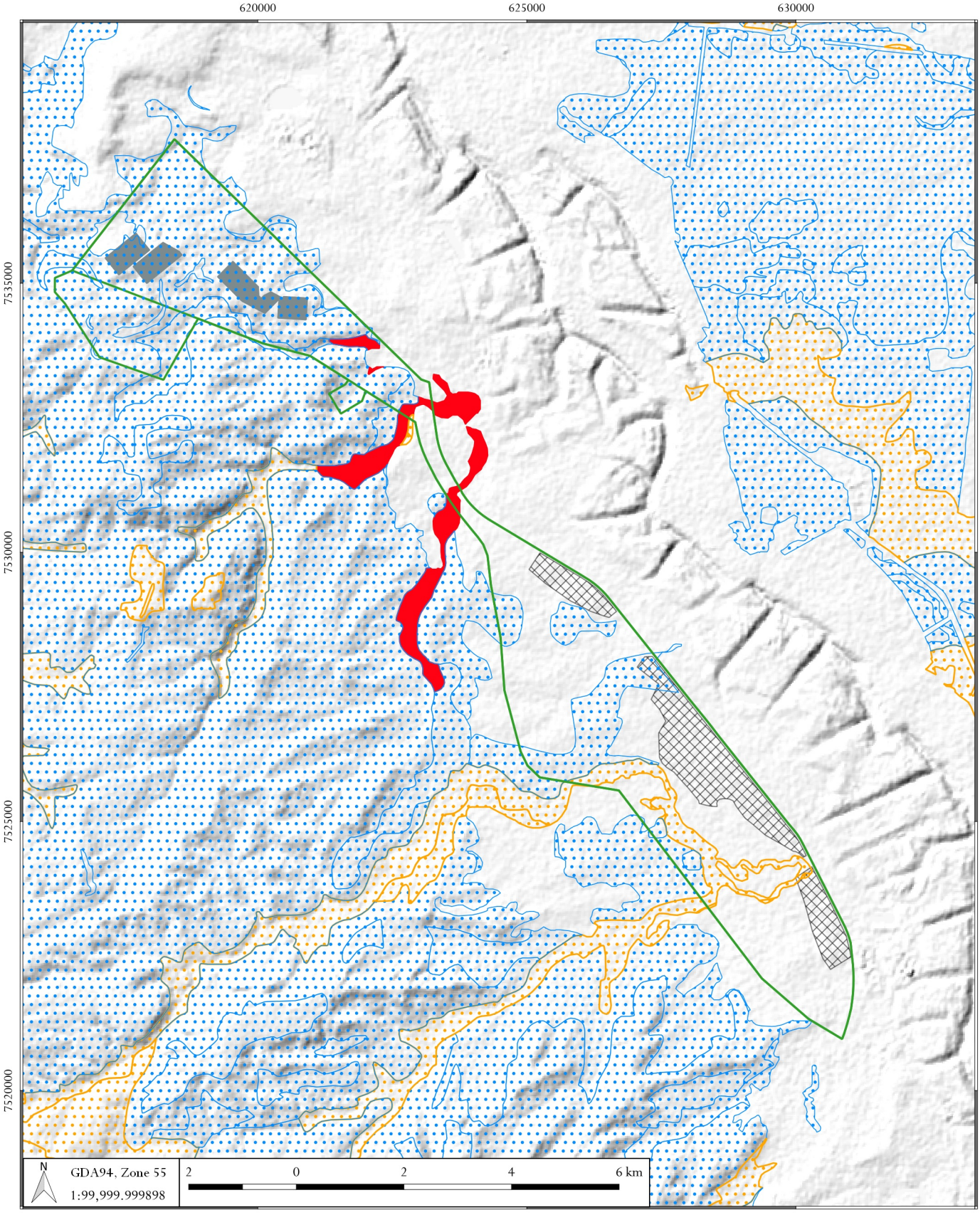

LEGEND

Terrestrial groundwater dependent ecosystem:

- High potential GDE - from national assessment
- Moderate potential GDE - from national assessment
- Moderate potential GDE - from regional studies
- Low potential GDE - from national assessment

- Proposed pit
- Highwall mining area
- Mining lease application area

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Vulcan South - Groundwater Impact Assessment (4027)

Terrestrial groundwater dependent ecosystems

FIGURE No.
5.9

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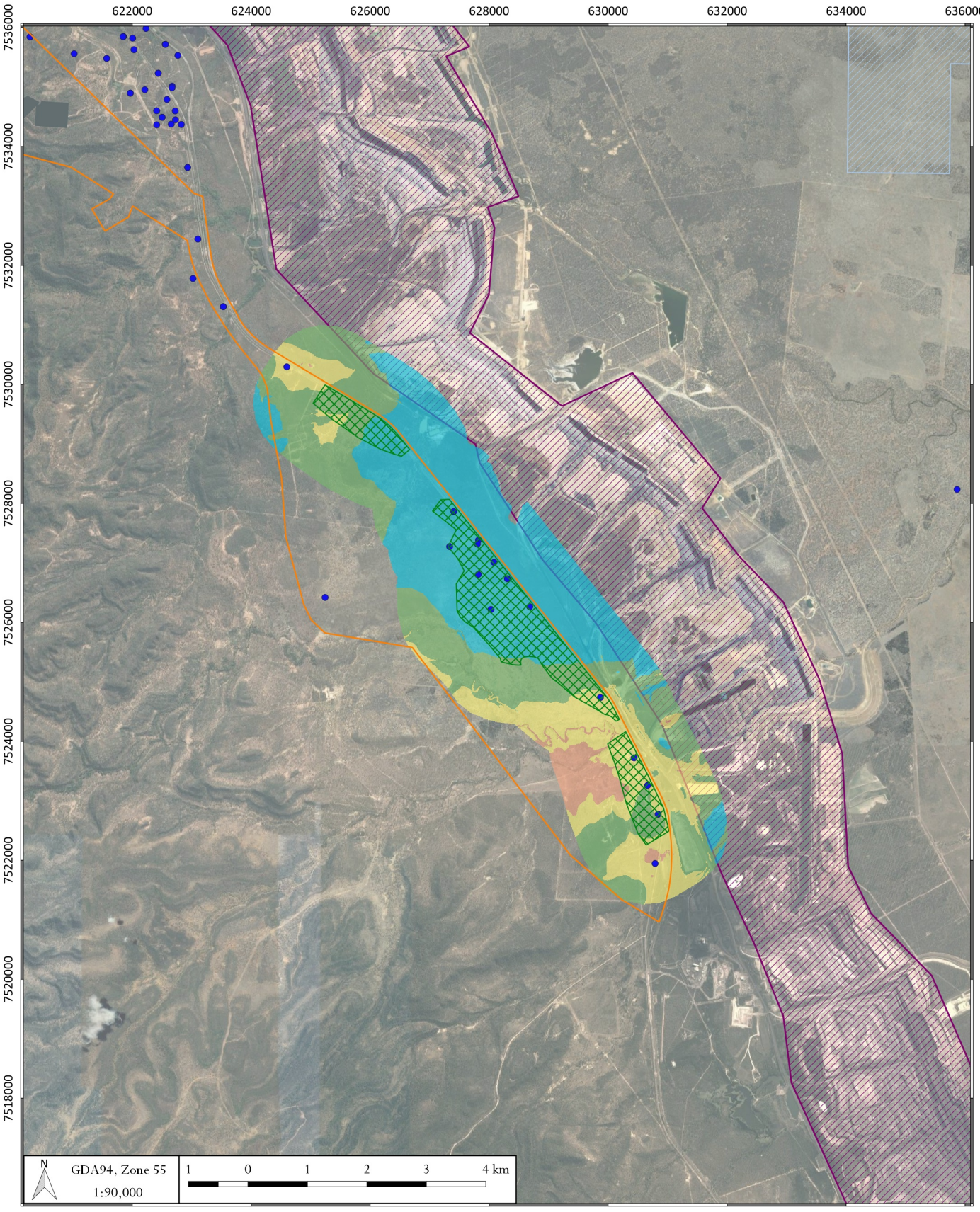

LEGEND

Depth to groundwater (m)

- <= 0
- 0 - 5
- 5 - 10
- 10 - 20
- 20 - 50

- Groundwater elevation data point
- Proposed pit
- Highwall mining area
- Mining lease application area
- Established mining operation

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Vulcan South - Groundwater Impact Assessment (4027)

Depth to groundwater

FIGURE No.
5.10

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5.8. Groundwater quality

5.8.1. Site specific data

At the time of completing this report, fifteen rounds of analytical laboratory and field results were available from the groundwater monitoring network (see Section 5.3 and Table 5-3). The monitoring and sampling of the groundwater monitoring network is planned for and carried out in consideration of the Queensland Monitoring and Sampling Manual (DES, 2018a).

Groundwater salinity was classified by **hydrogeologist.com.au** (2019) using a system based on local experience. In this report, however, the classification of Mayer *et al*. (2005, http://www.water.wa.gov.au/water-topics/water-quality/managing-water-quality/understanding-salinity, visited on 11 March 2022) will be used because it is more widely used and contains more categories, especially a 'marginal' category between fresh- and brackish water (Table 5-8).

Table 5-8 Groundwater salinity classification based on Mayer *et al*. (2005)

Salinity status	EC* (µS/cm)	Description and use
Fresh	<750	Drinking and all irrigation
Marginal	750 – 1,500	Most irrigation, adverse effects on ecosystems become apparent
Brackish	1,500 – 3,000	Irrigation certain crops only; useful for most stock
Saline	3,000 – 15,000	Useful for most livestock
Highly saline	15,000–52,000	Very saline groundwater, limited use for certain livestock
Brine	>52,000	Seawater; some mining and industrial uses exist

*Note: *converted from total dissolved solids (TDS in mg/L) using a conversion factor of 0.67; rounded values*

The field EC and pH are summarised in Table 5-9 and Table 5-10. None of the samples are assessed as fresh or marginal, with all samples returning a field EC above 2,600 µS/cm and some above 20,000 µS/cm (MB12). Using the classification of Mayer *et al*. (2005), groundwater from the Project area is brackish (MB05); to saline (MB04, MB07, MB09, MB10 and MB13) to highly saline (MB12).

Some of the monitoring bores show variable water quality but this is likely the result of the groundwater still being influenced by drilling and construction during early sampling. For example, it is anticipated that initial sample results for MB04 and MB09 were not representative and these initial samples may have been impacted by the grouting process (fresh mix water with alkalinity from the cement) explaining the increase in salinity and decrease in pH since the first round of monitoring.

Table 5-9 Historical summary of field electrical conductivity (µS/cm)

Bore ID	Area	Jun 2019	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Dec 2019	Mar 2020	Jun 2020	Aug 2020	Oct 2020	Dec 2020	Mar 2021	May 2021	Jul 2021	Sep 2021	Salinity status*
MB04	VCM	~~2,520~~	9,510	9,346	10,409	10,703	11,709	12,913	12,734	12,782	12,752	12,048	11,122	10,904	12,592	10,901	Saline
MB05	VCM	2,960	3,042	2,737	2,753	2,739	2,719	2,720	2,720#	2,840	2,757	2,754	2,651	2,858	2,712	2,625	Brackish to saline
MB07	Project	5,680	6,091	5,739	5,819	5,882	5,830	-	5,184	5,141	5,383	5,393	5,358	5,196	5,307	5,412	Saline
MB09	Project	~~5,520~~	13,758	15,130	13,909	13,566	11,582	12,117	11,989	11,933	11,909	11,845	11,735	11,506	12,064	11,403	Saline to highly saline
MB10	Project	-	5,668	4,846	4,322	4,353	4,034	4,170	4,121	4,028	3,980	3,876	3,881	3,818	3,806	3,762	Saline
MB12	Project	22,800	19,469	17,854	17,231	20,878	16,725	15,644	22,200#	22,444	22,178	22,840	22,533	21,998	21,953	21,470	Highly saline
MB13	VCM	-	-	-	-	-	-	-	-	-	-	-	4,110	4,021	4,084	3,970	Saline

Notes: ** from the classification of Mayer et al. (2005) and excluding the initial June samples for MB04 and MB09*

 # laboratory data substituted for field data

Table 5-10 Historical summary of field pH

Bore ID	Area	Jun 2019	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Dec 2019	Mar 2020	Jun 2020	Aug 2020	Oct 2020	Dec 2020	Mar 2021	May 2021	Jul 2021	Sep 2021
MB04	VCM	~~7.92~~	5.93	5.90	5.79	5.84	5.73	5.54	5.75	5.57	5.66	5.53	6.04	6.31	6.29	5.84
MB05	VCM	8.55	7.00	7.02	6.92	6.94	6.89	6.96	7.49#	6.84	6.90	6.67	7.21	7.63	7.44	6.92
MB07	Project	8.78	7.04	7.00	6.75	6.93	6.78	-	6.74	6.72	6.91	6.86	7.08	7.23	7.42	6.94
MB09	Project	~~8.58~~	6.90	7.00	6.90	6.87	6.93	7.08	6.78	6.64	6.72	6.71	7.26	7.21	7.51	6.96
MB10	Project	-	6.78	6.94	6.88	6.97	6.81	7.03	6.89	6.86	6.91	6.89	7.20	7.29	7.43	7.07
MB12	Project	8.29	6.86	6.79	6.66	6.57	6.62	6.78	7.08#	6.38	6.37	6.57	7.08	6.96	7.01	6.61
MB13	VCM	-	-	-	-	-	-	-	-	-	-	-	7.04	6.97	6.99	6.69

The Durov diagram (Figure 5.11) is best considered as a series of joint diagrams with the right side of Figure 5.11 being a scattergraph of sodium (as a percentage of all cations) vs TDS. The bottom diagram is a scatter of chloride (as a percentage of all anions) vs pH. The innermost square is the projection of the two scatters, i.e. it shows sodium (as a percentage of all cations) vs. chloride (as a percentage of all anions). The two ternary diagrams are for anion percentages (top) and cation percentages (left).

Figure 5.11 indicates that most of the site's groundwater is strongly dominated by sodium (Na) and moderate to strongly dominated by chloride (Cl). All the site-specific groundwater would fall into the sodic waters of marine origin category of Raymond and McNeil (2011). Chloride, as a percentage of anions, varies between 40% and nearly 100%; however, some samples (MB05, MB07, MB10 and MB13) indicate the presence of moderate bicarbonate (HCO_3). There does not appear to be a simple relationship between the hydro-stratigraphic unit and groundwater quality. For example, the markers for MB05, the deepest sampled coal seam (MAT), are indicating the lowest salinity and chloride percentage, contrary to the general observations made by URS (2012) and Arrow Energy (2016) indicating increase in salinity with increasing depth. There are three bores (MB04, MB09 and MB10) targeting the DLL seam, and as Figure 5.11 indicates, the markers for these bores are widely spread.

The Piper diagram in Figure 5.12 shows the major cation percentages on the left and the anion percentages on the right, the observations from the ternary diagram are next projected to the top rhomboid. The rhomboid indicates that all groundwater is of sodium-potassium (Na_K> 50%) and sulphate-chloride (SO_4-Cl (>50%) type. The ternary diagrams provide further breakdown, i.e. that the groundwater is dominated by sodium-potassium cations combined with mostly chloride as the dominant anion; although the MB05 samples contain 30-40% bicarbonate (HCO_3).

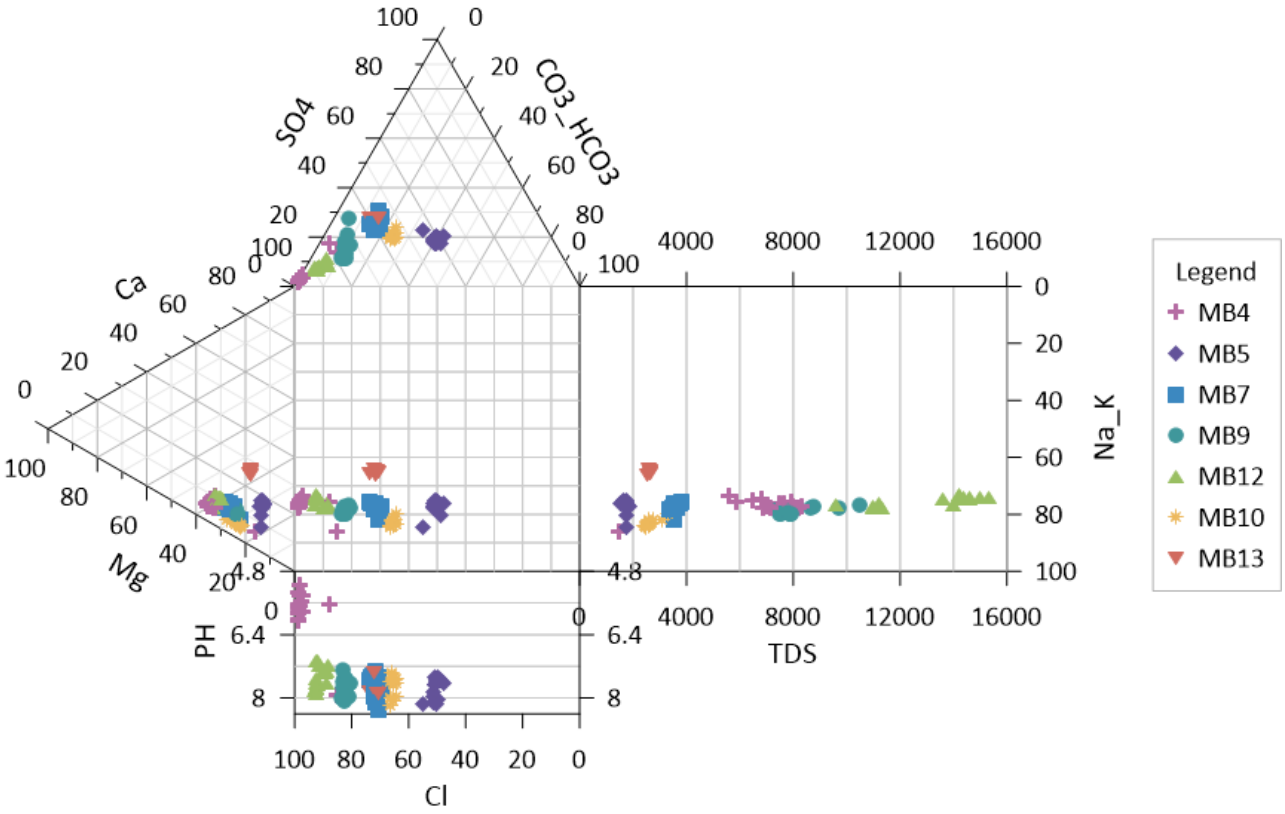


Figure 5.11 Extended Durov diagram for site specific monitoring bores

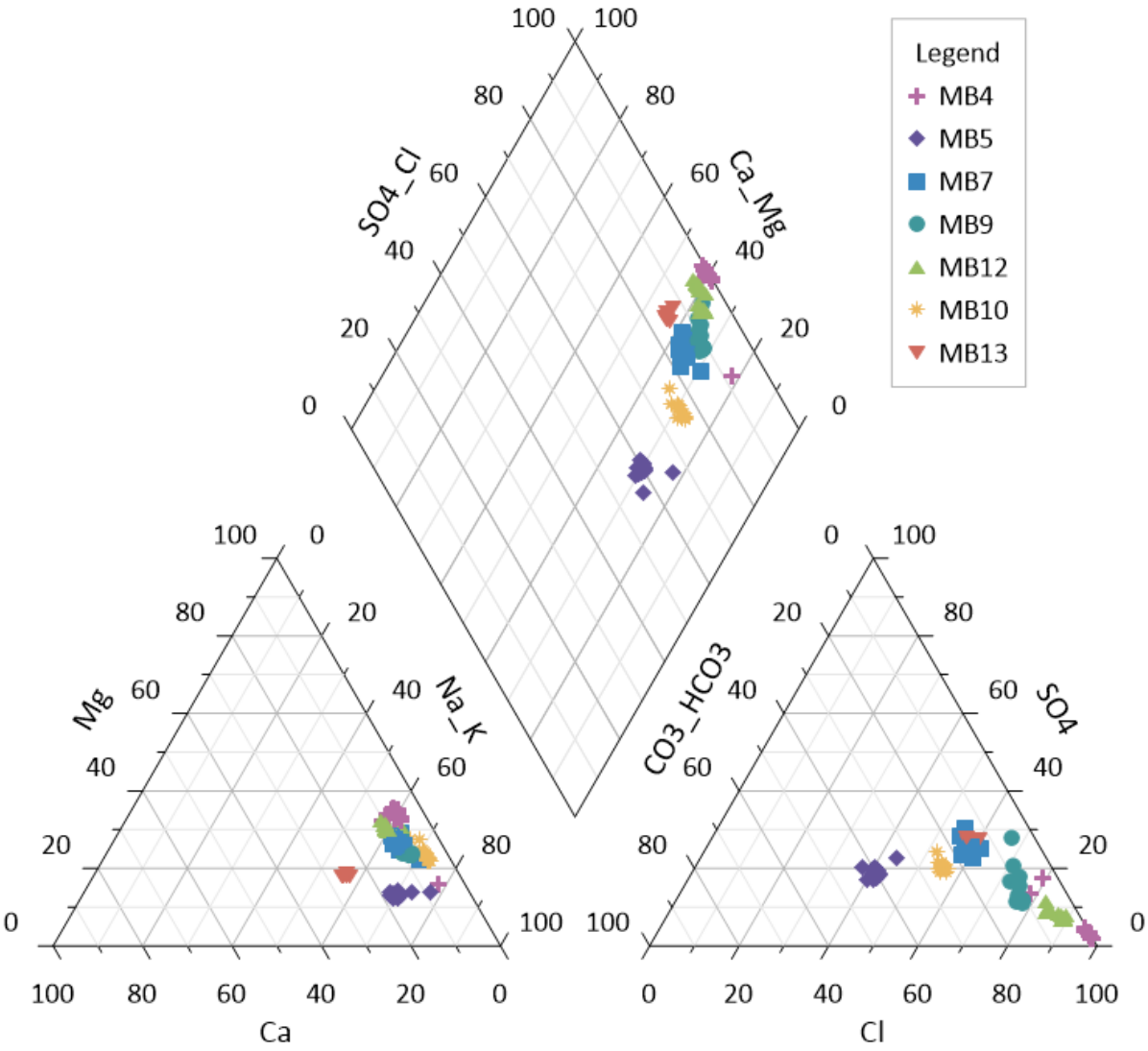


Figure 5.12 Piper diagram for site specific monitoring bores

5.8.2. Regional data

Regional data is presented here for various mining and energy projects and locations. The classification of salinity is adopted from the relevant publication and therefore may somewhat differ from that of Mayer *et al*. (2005); however, it has not significantly influenced the findings presented below.

URS, 2009 (Caval Ridge Mine)

Groundwater chemistry is typically of near-neutral pH for all formations near the Caval Ridge Mine (URS, 2009). The alluvium groundwater is fresh to brackish while the coal seam (and basalt formation) groundwater is brackish to saline. The laboratory analytical results indicate that sodium is the dominant cation in the groundwater from all monitoring bores but one in the alluvium that is calcium dominant. The dominant anion is chloride in most monitoring bores in the coal measures although the dominant anion is bicarbonate in some coal measures, basalt and alluvium bores (URS, 2009).

AECOM, 2016 (Saraji Mine)

At Saraji Mine, all groundwater analysed was sodium-chloride type with brackish water in the Quaternary, and brackish to saline water in the Tertiary and Permian coal measures. Salinity is generally the highest in the Permian and lowest in the Quaternary. None of the groundwater analysed was suitable for drinking, with the regional (Tertiary and Permian) groundwater generally not considered suitable for livestock (AECOM, 2016).

HydroSimulations, 2018 (Olive Downs Coal Project)

Alluvium groundwater is dominated by sodium-calcium (Na-Ca) or sodium-magnesium (Na-Mg) cations and is higher in bicarbonate than the other groundwater units. The proportion of chloride is higher within the regolith material, which can be classified as sodium-chloride or sulphate (Na-Cl-SO_4) or sodium-chloride or bicarbonate (Na-Cl-HCO_3) type water. The Permian coal measures generally contain sodium-chloride (Na-Cl) type water, with some also recording a high proportion of Mg but with very little sulphate compared to the other groundwater units (HydroSimulations, 2018).

Water within the Isaac River is largely fresh, while water within the alluvium is fresh to moderately saline with a range between 300 µS/cm and 5,200 µS/cm. Water within the regolith material is brackish to highly saline with a range between 2,200 µS/cm and 28,400 µS/cm. Water within the Permian coal measures can range between fresh and highly saline, but is generally saline within the coal seams, and brackish to moderately saline within the interburden units (HydroSimulations, 2018). Coal seam units of the Permian coal measures record an average EC of 11,040 µS/cm, ranging between 3,800 µS/cm and 22,000 µS/cm. The interburden units of the Permian coal measures record an average EC of 7,080 µS/cm, ranging between 630 µS/cm and 27,500 µS/cm (HydroSimulations, 2018).

In addition, salinity within the Isaac River and alluvium can be highly variable, both spatially and temporally. HydroSimulations (2018) provides examples where the river and groundwater salinity for the same sites vary in time between fresh through brackish to moderately saline waters.

URS, 2012 and Arrow Energy, 2016 (Bowen Gas project)

Arrow Energy (2016) has monitored groundwater quality since 2012 and concluded that groundwater quality:

- varies from brackish to saline in the Quaternary alluvium;
- varies from brackish to saline in the Tertiary basalt aquifer;
- is fresh to brackish in the Tertiary sediments;
- is brackish in the weathered coal measures;
- is fresh to brackish in the Fort Cooper Coal Measures; and
- is fresh to brackish in the Moranbah Coal Measures.

The description above appears to be based on URS (2012), which in turn, is based on groundwater quality studies by Pearce and Hansen (2006), Raymond and McNeil (2011) and site-specific data. Pearce and Hansen (2006) provided an overview of groundwater quality in the Isaac-Connors (and McKenzie) sub-catchments for pH and salinity.

Raymond and McNeil (2011), in URS (2012) interpreted groundwater in the Fitzroy catchment to two different types including:

- alluvial sequence with mostly rainfall related ionic composition, found near creeks and areas of relatively high rainfall; and
- sodic sequence, near marine origin and ionic composition; deep groundwater in low rainfall areas.

5.8.3. Environmental values

As described in Section 2.1.1, the Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011) is made pursuant to the provisions of the EPP Water, which is subordinate legislation under the EP Act. The EPP Water provides a framework for identifying EVs for Queensland waters, and deciding the WQO to protect or enhance those EV. The Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011) document contains EV (Section 2, Table 1) and WQO for waters (including groundwaters) in the Isaac River Sub-basin.

For Isaac groundwaters, the EV selected for protection are listed as follows:

- aquatic ecosystems;
- irrigation;
- farm supply/use;
- stock water;
- primary recreation;
- drinking water; and
- cultural and spiritual.

An assessment of groundwater quality is presented below, in terms of the relevant EV used in the Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011). Although EV are not selected for protection of industrial use, this has also been included for completeness as mine water use is an important aspect given the number of coal mines operating in the catchment.

Aquatic ecosystems

The WQO, for aquatic ecosystems, where groundwaters interact with surface waters, is that groundwater quality should not compromise the identified EV and WQO for those waters. For example, Table 1 lists a WQO of <720 µS/cm for Upper Isaac River catchment waters. **hydrogeologist.com.au** interprets that groundwater that is identified to support the Upper Isaac River catchment surface waters should not exceed 720 µS/cm. None of the site monitoring bores reported such a low salinity; with all reporting field ECs > 2,700 µS/cm.

The deep groundwater (Section 5.3) in all bores with the exception of MB05, in addition to the brackish to highly saline groundwater quality and the absence of significant groundwater-surface water interaction in the Project area (Section 5.6) would render almost all the local groundwater unsuitable for use for GDEs because it is mostly out of reach (too deep for terrestrial flora) and its quality could not support fresh- or even marginal water ecosystems.

Farm Use / Irrigation

Table 3 of the Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011) refers to the suitability for farm supply/use WQO as "*Objectives as per AWQG*". The AWQG (2018), however, bundles the guidelines, in Section 4.2, for irrigation and general water use. Hence, these EVs will be discussed together.

The objectives for pathogens and metals are provided in Tables 8 and 9 of the Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011). For indicators other than pathogens and metals, the WQOs are those included in the AWQG (2018). For most pastures and loams and clays, the salinity threshold in Table 4.2.5 of the AWQG (2018) is between 1,000 µS/cm and 7,300 µS/cm.

In addition, the AWQG (2018) warns that certain combinations of salinity and sodium adsorption ratio (SAR) are likely to induce degradation of soil structure and corrective management may be required (e.g. application of lime or gypsum). Most groundwater on-site would be classified as "marginal quality" in Figure 4.2.2 of the AWQG (2018) (i.e. soil degradation may occur if the water was used for irrigation depending on soil and rainfall) and would therefore need caution if used for irrigation.

hydrogeologist.com.au interprets that the brackish to highly saline groundwater, and all the indications for low sustainable bore yields (low airlift rates, low hydraulic conductivities, and thin coal seams), preclude the potential use of the local groundwater for irrigation supply. In other words, neither the quantity nor the quality of local groundwater is suitable for irrigation.

Livestock watering

The review of DRDMW GWDB and the bore census data indicate that groundwater in the area may be used for limited livestock beef cattle watering. There are 14 records within 5 km of the numerical flow model domain that are classified as "*water supply*" (Section 5.7.1). Some of these may be used for mine supply and others for private farm supply that may or may not include livestock watering.

Information (Section 5.8.1) from local monitoring bores suggests that groundwater quality (salinity) varies from brackish to highly saline. Although some groundwater is within the guidelines for livestock watering, Section 4.3.3.5 of the AWQG (2018) states that loss of production and a decline in animal health occurs if stock is exposed to high salinity water for prolonged periods. For beef cattle, decline or loss may occur if the EC is between 7,463 µS/cm and 14,925 µS/cm.

Of the local groundwater, MB05, MB07, MB10 and MB13 have EC that is less than 7,463 µS/cm; MB04 and MB09 are between 7,463 µS/cm and 14,925 µS/cm. Groundwater at MB12 is greater than 14,925 µS/cm.

At the Saraji Mine, adjacent to the Project area, the regional (Tertiary and Permian) groundwater was generally not considered suitable for livestock (AECOM, 2016). **hydrogeologist.com.au** concurs with this interpretation but note that, although the local groundwater is generally not considered suitable for livestock, limited livestock watering may occur and therefore should be recognised as an EV because of the three monitoring bores that returned EC less than 7,463 µS/cm.

Primary recreation

This category of EV is considered not applicable to local groundwater. There are no groundwater springs in the Project area (Section 5.7.2) that could be considered for recreational use. This EV is more common for surface water features that are readily accessible for recreation.

Drinking water suitability

The site specific groundwater quality data, as presented in Section 5.8.1, indicates that groundwater is generally unsuitable for human consumption before treatment primarily due to elevated levels of salinity. The WQO in Table 4 of the Isaac River Sub-basin Environmental Values and Water Quality Objectives (2011) specifies an EC of 400 µS/cm as suitable for drinking quality and none of the site monitoring bores yield groundwater of such low EC; in fact, all reported field ECs are greater than 2,700 µS/cm and the median field EC for all local samples (Table 5-9) is 6,091 µS/cm, 15 times higher than specified by Isaac River Sub-basin Environmental Values and Water Quality Objectives (2011).

Further, Table 4 of the Isaac River Sub-basin Environmental Values and Water Quality Objectives (2011) also refers to a sodium objective of 30 mg/L and a total hardness objective of 150 mg/L as $CaCO_3$ in raw water. The local groundwater contains both sodium and total hardness well in excess of those: the minimum concentration of sodium in any of the groundwater samples to date is 389 mg/L, and the minimum concentration of total hardness is 242 mg/L.

Groundwater within the Project area is therefore not considered suitable for drinking because it would require significant treatment.

Cultural and spiritual values

There are no groundwater springs or seeps (Section 5.7.2) that supply surface water bodies in the Project area known to have significant indigenous and/or non-indigenous cultural heritage associations.

Industrial use

Table 3 of the Isaac River Sub-basin Environmental Values and Water Quality Objectives (Department of Environment and Heritage Protection, 2011) provides no defined WQOs for industrial uses:

"Water quality requirements for industry vary within and between industries. The AWQG do not provide guidelines to protect industries, and indicate that industrial water quality requirements need to be considered on a case-by-case basis. This EV is usually protected by other values, such as the aquatic ecosystem EV".

The nearest industries to the Project area are coal mines. **hydrogeologist.com.au** understands that Vitrinite may intend to use some of the groundwater inflow to the proposed pits, if available after evaporation, for industrial purposes. It is understood that the nearest mine, Saraji Mine does not utilise groundwater for its operations. No industrial users, other than mines, appear to be within close proximity of the Project area and the salinity of the groundwater would likely impede most industrial uses. The local brackish to highly saline groundwater, which may report to the proposed pits, however, can potentially be used for mining use such as dust suppression. It is the view of **hydrogeologist.com.au**, therefore, that the EV associated with industrial use should be recognised in this report.

Summary

In summary, the evaluation of groundwater EV in the Project area indicates that groundwater in the "deep" hydrogeological units, associated with the regolith and/or Permian coal measures is of no, or limited value, for most uses and may potentially have the following EVs:

- livestock beef cattle watering (limited); and
- industrial purposes, limited to dust suppression in mining.

5.8.4. Water quality objectives

The Project area is adjacent to the Isaac-Dawson groundwater quality zone (No. 34) of Raymond and McNeil (2011). Groundwater within Zone 34 is described as slightly to moderately saline ('shallow' groundwater, within 30 mbgl) or slightly to very saline ('deep' groundwater, deeper than 30 mbgl). Groundwater within Zone 34, both shallow and deep, is of sodium-chloride (Na-Cl) type; that is, sodium is the dominant cation and chloride is the dominant anion.

Using Raymond and McNeil's (2011) shallow (<30 m deep) and deep (>30 m) categories, only MB04 is shallow and all other Project monitoring bores are classified as deep. MB04 is screened in the DLL coal seam of the Moranbah Coal Measures.

While MB04, strictly speaking, is less than 30 m deep and would therefore classify as 'shallow' according to Raymond and McNeil (2011), its target, the DLL coal seam and its water quality type (sodic-marine similar to deep bores on-site) together suggest that it would be more prudent to list it among the 'deep' monitoring bores. As Figure 5.11 indicates, MB04 is a Na-Cl type water that blends well with the markers for the bores that are greater than 30 m deep, plotting close on the ternary diagrams, in particular, to MB12 representing Permian underburden.

The WQOs is to maintain or improve the quality of groundwater within the zone, i.e. maintain or reduce salinity. The percentile statistics provided in the WQOs are broad and it is expected by **hydrogeologist.com.au** that local groundwater within the Project area would naturally differ somewhat from the percentiles provided for the entire Zone 34. The statistics and percentiles presented in the WQOs provide a general indication of expected groundwater quality and are not to be used as triggers or exceedance criteria.

The WQOs for Zone 34 (Table 14 Fitzroy groundwater: water quality objectives (aquatic ecosystem) according to water chemistry zones), provides the following EC percentiles for deep groundwaters in Zone 34:

- 20th percentile:3,419 µS/cm EC;
- 50th percentile or median: 6,100 µS/cm EC; and
- 80th percentile: 16,000 µS/cm.

Table 5-11 lists the statistics for Zone 34 (deep) for EC and other analytes. At the time of writing this report, data from fifteen monitoring rounds (each consisting of up to seven bores) was available (including duplicate samples). This is less than those recommended (minimum of 18 samples over at least 12 and preferably 24 months for each bore) for comparison with scheduled WQOs according to the guideline (Department of Environment and Science or DES, 2021) and therefore not sufficient to calculate bore-specific percentile statistics at present. However, the water quality dataset will be sufficient to derive interim guidelines (DES, 2021).

In Table 5-11, therefore, the data for Zone 34 (deep) are compared with the median of all data (maximum of 92 counts, from 15 rounds and up to seven bores in each round). Although the EC for these bores spans a wide range, the median for EC, 5,360 µS/cm, is below the 50th percentile statistics provided for Zone 34 (deep), 6,100 µS/cm.

Of the major constituents and physical measures, the median of local monitoring data compares well with the Zone 34 statistics for Ca; while total hardness, observed alkalinity, Mg, SO_4 and HCO_3 are in excess of the 50th percentile statistics provided for Zone 34. The observed median lab pH, Cl, Na and SAR are below those of the Zone 34 statistics.

Of the minor constituents, the median of local monitoring data is below the Zone 34 statistics for observed silicon (as SiO_2). The results for dissolved metals (Cu, Fe, and Zn) are probably unduly affected (biased towards the small values) by the large proportion of less than detectable results (for the purposes of Table 5-11, a value equivalent of less than the detectable limit was ignored).

Notwithstanding the above, more data are needed in order to provide reliable statistics and before defensible WQOs can be developed. WQOs and groundwater monitoring criteria and trigger levels, consistent with DES (2021), should be established and documented within a Water Management Plan (WMP) as soon as minimum of 18 samples over 12 to 24 months of data have been collected from the site monitoring bores. Interim guidelines will be developed using the existing water quality dataset from the groundwater monitoring network.

Table 5-11 Zone 34 deep percentiles and medians of preliminary local monitoring data

Analyte	Unit	20th	50th	80th	Median of local monitoring * data	Comments
EC	(µS/cm)	3,419	6,100	16,000	5,630	Lab EC excluding the initial results for June 2019 for MB04 and MB09
Total Hardness	(mgL^{-1}as CaCO3)	359	919	3,208	1,110	
pH		7.4	7.8	8.03	7.59	Lab pH excluding the initial results for June 2019 for MB04 and MB09
Alkalinity	(mg/L)	156	275	536	616	
Ca	(mg/L)	46	145	442	128	
Mg	(mg/L)	35	115	491	193	
Na	(mg/L)	480	1,100	2,565	867	
Cl	(mg/L)	753	1,900	5,905	1,320	
SO_4	(mg/L)	25	138	398	572	
HCO_3	(mg/L)	188	330	650	752	
NO_3	(mg/L)	0.01	2.15	14.92		Not analysed
SiO_2	(mg/L)	16	25	36	20.5	
F	(mg/L)	0.02	0.155	0.4	0.4	
Fe	(mg/L)	0	0.05	0.246	0.63	As dissolved Fe, influenced by large number of less than detectable, <0.05 results
Mn	(mg/L)	0	0.05	0.291	0.237	As dissolved Mn
Zn	(mg/L)	0.01	0.025	0.317	0.017	As dissolved Zn, influenced by large number of less than detectable,<0.005 results
Cu	(mg/L)	0.017	0.03	0.03	0.001	As dissolved Cu, influenced by large number of less than detectable,<0.001 results
SAR		10.5	15.6	24.65	12.5	
RAH	(meq/L)	0	0.24	6.25	N/A	Not analysed
Eh	(mV)	ID	ID	ID	N/A	Not analysed

*Note: *From fifteen monitoring rounds*

5.9. Conceptual model

The west to east conceptual hydrogeological cross-section of **hydrogeologist.com.au** is presented in Figure 5.13, based on the review of various reports, data and information, as summarised in Sections 3 to 5.8 of this report.

There are eight hydrogeological units shown in Figure 5.13:

1. Quaternary alluvium (localised only);
2. Tertiary sediments / weathered zone (regolith, extensive, generally between 1 m to 30 m);
3. Fort Cooper Coal Measures – Permian overburden;
4. Moranbah Coal Measures – Permian overburden;
5. DL coal seam (extracted at Saraji Mine);
6. Moranbah Coal Measures – Permian interburden;
7. DLL coal seam (proposed to be extracted at the VS pits); and
8. Back Creek Group.

The west to east section in Figure 5.13 is sub-parallel to the lateral groundwater flow direction (Section 5.5.5). The groundwater table is hosted by several units, from the outcropping/sub-cropping Back Creek Group in the west through the Tertiary sediments and Moranbah Coal Measures to the Fort Cooper Coal Measures in the east. As a result of the sloping groundwater table and the easterly dip of the hydrogeological units, some of the units may be partially unsaturated, particularly in the west, as is shown in Figure 5.4.

A minor component of rainfall recharge (Section 5.5) acts on the top of the land surface. Evapotranspiration occurs from groundwater that is situated within the extinction zone, however the groundwater table is often too deep, so significant (Figure 5.10) evaporation is likely only from the proposed and existing nearby mine pits. The interaction between surface and groundwater is insignificant within the model domain. The western boundary in Figure 5.13 is a catchment and groundwater divide in the Harrow Range. The eastern conceptual model boundary adopted is the Jellinbah Fault Zone, which is a north-west trending zone with several easterly dipping thrust faults with throws in the order of 100 m to 500 m (URS, 2012).

Near the proposed Vulcan South and the Saraji Mine, the Moranbah Coal Measures, down to the DLL coal seam (VS) and DL coal seam (at Saraji Mine) are depressurised and dewatered. Because of the low hydraulic conductivity and transmissivity, and the low storage of the units within the Moranbah Coal Measures, the cones of depression surrounding the mines are expected to be deep (to pit depth) but laterally limited. Once mining, depressurisation and dewatering cease, groundwater will start to recover and eventually will reach steady state in the backfilled material within the former pit. The recovery processes will largely be driven by the boundary conditions discussed above and the hydraulic parameters discussed in Section 5.4.

As discussed in Section 5.5.5, the MAT coal seam, which is proposed to be mined as part of the Highwall Mining area, is demonstrated to be dry and the highwall mining proposed as part of the Project will not interact with groundwater. On this basis, the Highwall Mining area has not been included in the conceptual model for the Project and has not been included in the numerical model predictions.

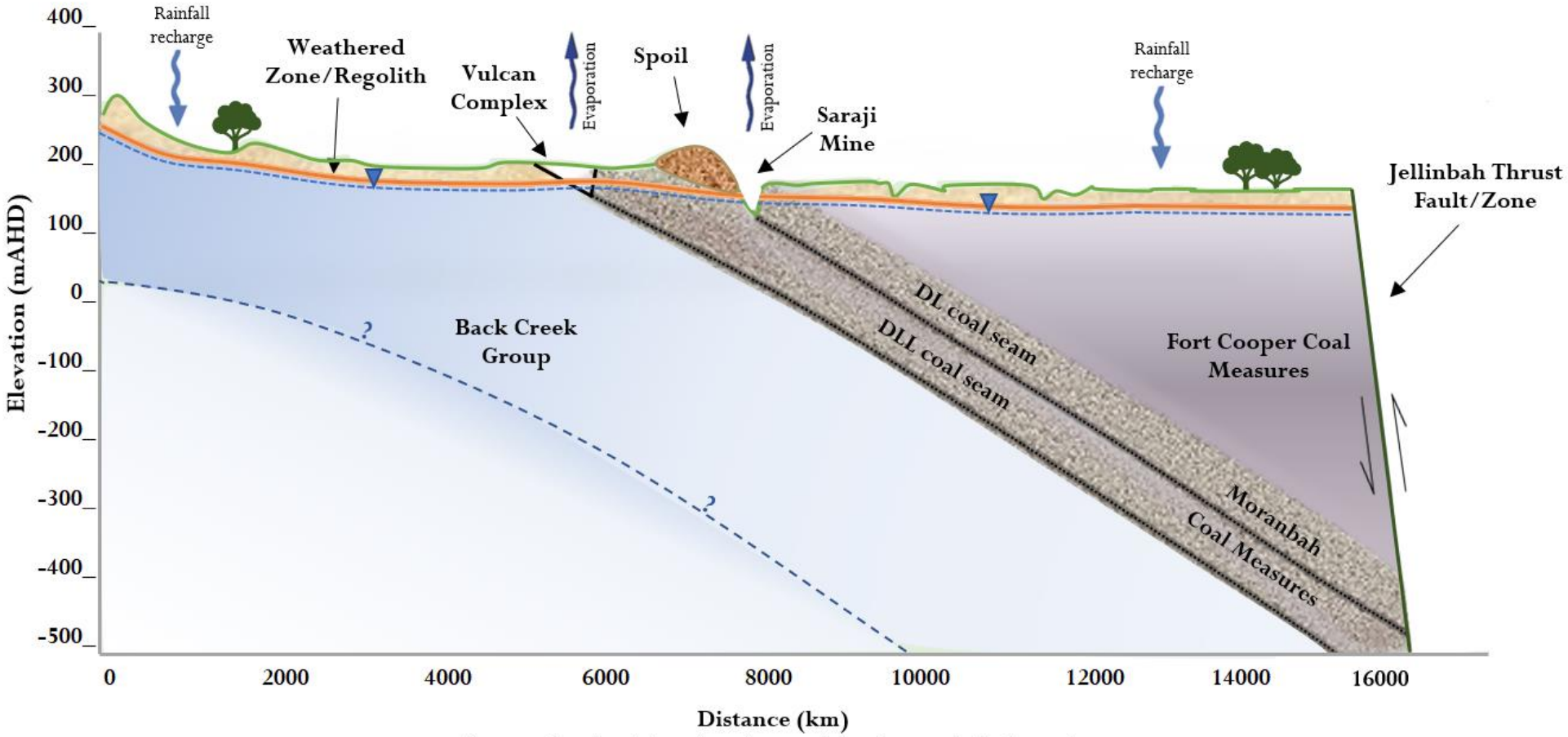


Figure 5.13 West to east conceptual hydrogeological cross-section

6. Impact assessment

6.1. Summary of numerical modelling

6.1.1. Objectives

The conceptual model presented in Section 5.9 has been used as the basis to develop a numerical groundwater flow model. This process, including model build, calibration and predictions is summarised in this section. A detailed description of the numerical model is provided in Appendix C.

The objectives of the numerical model are to assess the quantitative impacts of the Project both in terms of drawdown and groundwater fluxes. Due to the existence of numerous coal mines, especially Saraji Mine, in the close vicinity of the Project, groundwater impacts will need to be quantified both due to the Project only and cumulatively.

6.1.2. Design

The MODFLOW-USG (Panday *et al.*, 2015) code, based on the U.S. Geological Survey MODFLOW-2005 groundwater modelling code, was used. MODFLOW-USG simulates groundwater flow using a finite-difference approach and allows non-orthogonally structured grids to be used for groundwater flow simulations (Panday *et al.*, 2013). Model calibration and parameter sensitivity analysis was undertaken using Model-Independent Parameter Estimation and Uncertainty Analysis (or PEST, Doherty, 2019a and 2019b) and BEOPEST (or efficient parallel run management version of PEST, Doherty, 2012).

The model domain consists of a maximum of 22492 cells per layer extending over a total area of 650 km^2. The area of individual cells varies between 5,000 m^2 and 911,000 m^2. In general, this area is small for cells close to the proposed pits (50 m x 100 m), existing mines (150 m x 250 m) and main surface water drainages; and is large towards the outer margins of the model (Figure 6.1). This is to improve the convergence and resolution of the numerical model in places with the most potential to present changes in groundwater drawdown and flux.

The temporal discretisation adopted consists of a pre-calibration steady state model leading into 48 year-long calibration period (1972 – 2019) and a prediction (mining) period from 2020 through to 2032 (Table 6-1).

Table 6-1 Temporal discretisation – calibration and predictive models

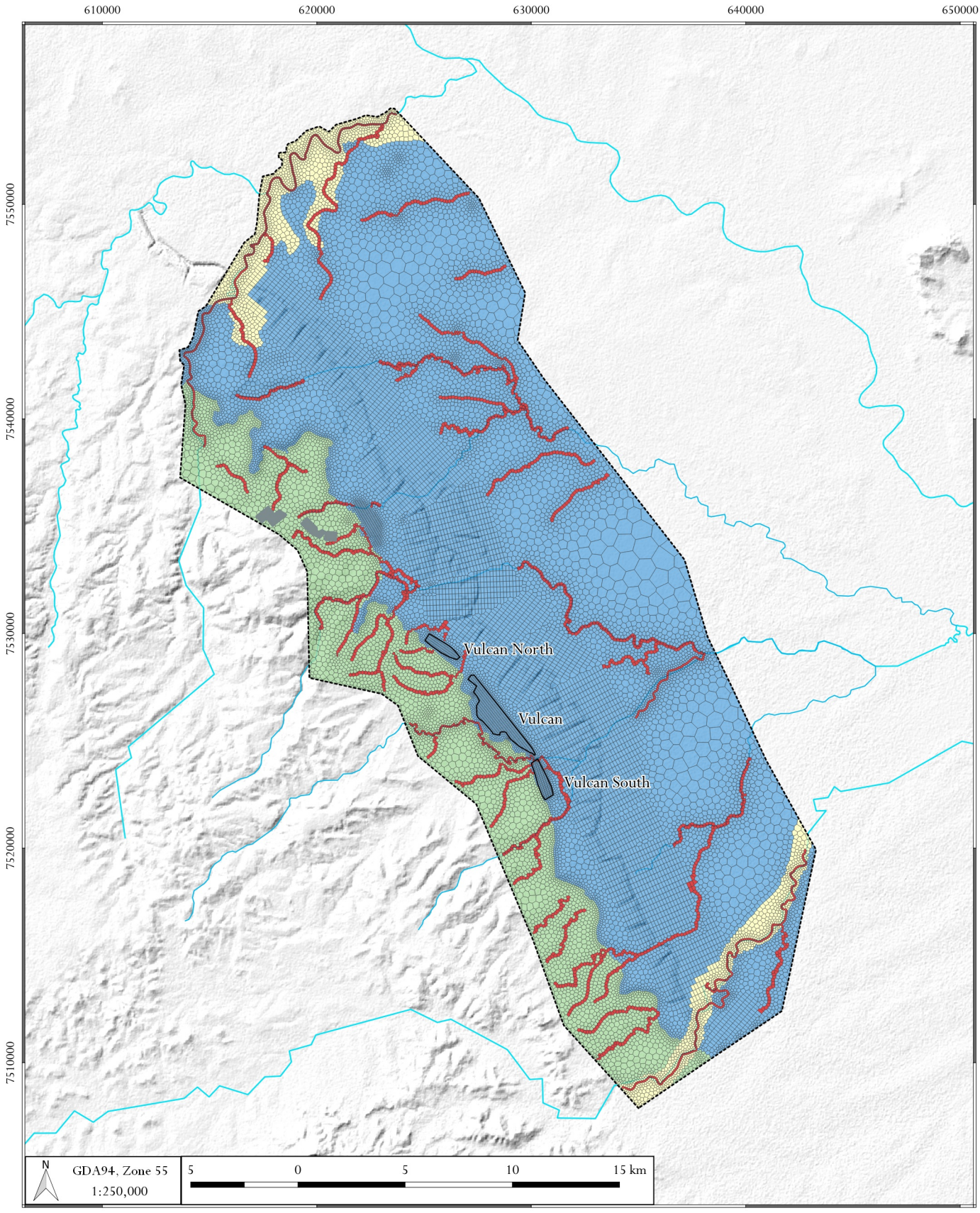
No. of stress periods	Stress period length	Dates	Modelling phase
Steady state	N/A	N/A	Pre-calibration
1 - 47	1 year	01/01/1972 – 31/12/2018	calibration
48 - 51	3 months	01/01/2019 – 31/12/2019	
52 - 55	3 months	01/01/2020 – 31/12/2020	prediction - mining
56 – 78	6 months	01/01/2021 – 30/06/2032	

The boundary conditions selected for the model are based on the description of the hydrogeology (Section 5, the numbers refer to Figure 6.2):

1. NW no-flow boundary (parallel to regional groundwater flow (Section 5.5.5) system in the north-west;
2. Jellinbah Fault Zone boundary;
3. SE no-flow boundary (parallel to regional groundwater flow (Section 5.5.5) system in the and south-east; and
4. SW no-flow boundary.

The eight hydro-stratigraphic units (Section 5.9) are represented by a total of eleven layers (Figure 6.3), from discrete and isolated zones of Quaternary alluvium through to the lowermost and extensive Permian Back Creek Group. Several hydro-stratigraphic units (Fort Cooper Coal Measures and overburden, and the Moranbah Coal Measures interburden between the DL and DLL coal seams) are represented by two (split) layers to improve model convergence.

Key model layers include layer 2 (Tertiary sediments) and layer 10 (DLL coal seam, representing mining from the Vulcan pits). Model layer 7 represents the DL coal seam which is mined at Saraji Mine.



LEGEND

Recharge zones

- 1 - Regolith
- 2 - Alluvium
- 3 - above DLL outcrop
- 4 - River cell

- Model domain
- Proposed pit
- Highwall mining area
- Watercourse

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Model mesh and recharge zones

FIGURE No.
6.1

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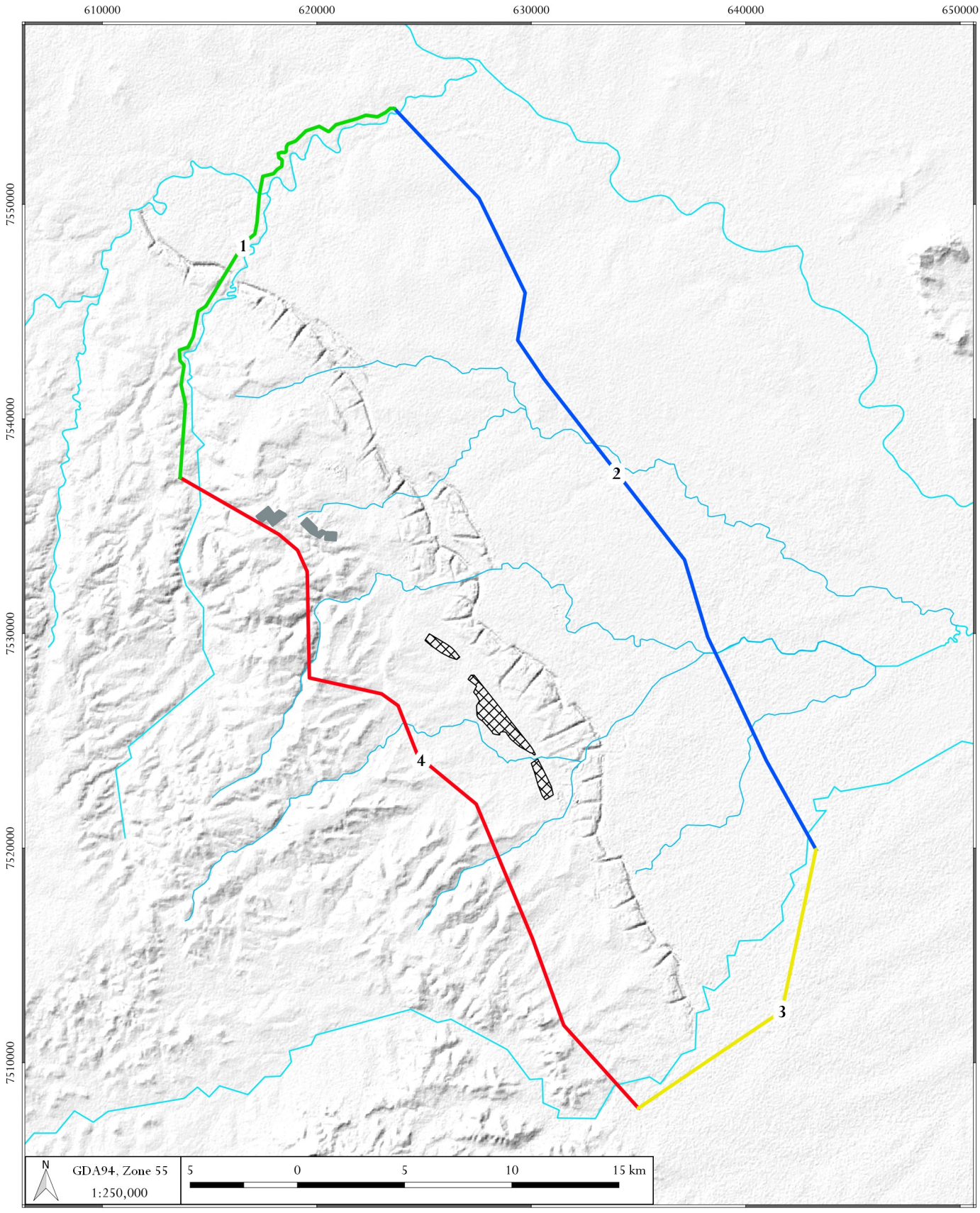

LEGEND

Model boundaries

- 1 - NW no-flow boundary
- 2 - Jellinbah Fault Zone boundary
- 3 - SE no-flow boundary
- 4 - SW no-flow boundary

- Proposed pit
- Highwall mining area
- Watercourse

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Boundaries of the model domain

FIGURE No.
6.2

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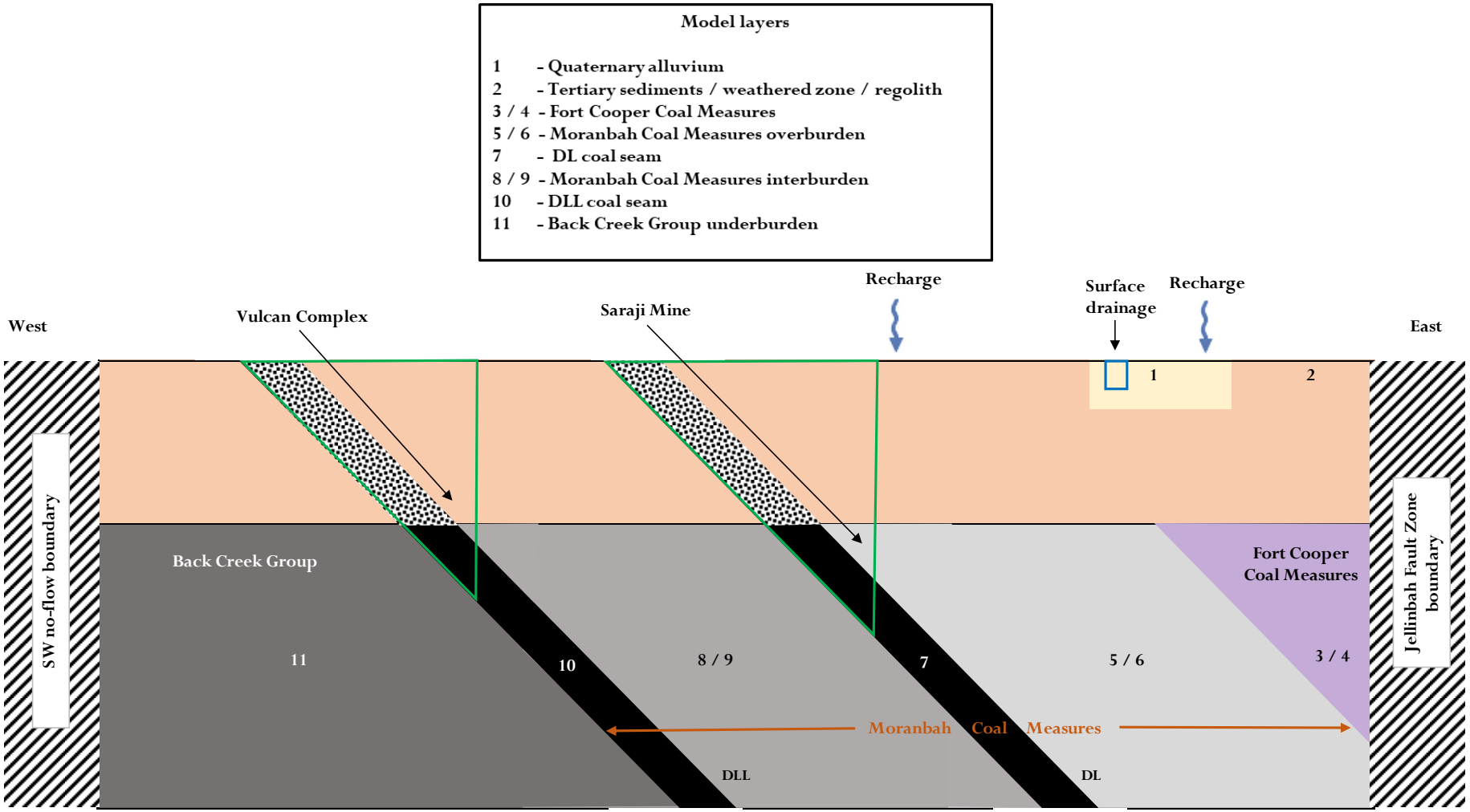


Figure 6.3 Model layers and boundary conditions

Surface water

Surface watercourses are represented by the MODFLOW-USG river (RIV) package. If the head (groundwater elevation) in the cell connected to the river drops below the bottom of the riverbed, water enters the groundwater system from the river at a constant rate. If the head is above the bottom of the river, water will either leave or enter the groundwater system depending on whether the head is above or below the head in the river. The calculated water flux is proportional to the difference between the groundwater and river heads.

Recharge/discharge

Groundwater recharge from rainfall was applied to the uppermost saturated model layer as a percentage of rainfall. Zonation was applied to the modelled recharge to represent the following key areas (Figure 6.1, numbers correspond to the recharge zones) or systems:

1. regolith (east of DLL subcrop);
2. Quaternary alluvium (associated with major creeks);
3. regolith (west of DLL subcrop); and
4. river cells.

Recharge to the steady state model was applied as a percentage of the annual average rainfall from the SILO data (Section 3.1, 582 mm/yr). Recharge for the transient calibration period of 1972-2019 (Table 6-1) was applied as a percentage of actual rainfall data (SILO data) accumulated over the stress period[1]. Recharge for the predictive model (2020-2032) was applied as a percentage based on long-term (1900-2018) averages (SILO data) for the stress period length. Evapotranspiration was not explicitly modelled as it was incorporated into the rainfall recharge applied to the model. For more information relating to the modelled recharge the reader is referred to Appendix C.

Initial hydraulic parameters

The initial hydraulic parameters (starting values, upper bound and lower bound) were based upon the values derived from existing reports, site specific data and a general knowledge and experience in the region. These values were applied on a trial and error basis initially to inform the general behaviour of the model, then applied using PEST to develop the calibrated solution.

Drains

Mining (both historical and proposed) was simulated using the drain (DRN) package. Site specific information on the Project enabled an accurate representation of mine progression in accordance with the proposed mining schedule. The drains were applied to the base of the DLL (layer 10) in the Project area.

For the representation of the Saraji Mine, historical mine development was captured in five yearly images downloaded from Landsat then digitised. The general extent of mining was then formulated into an annual sequence to approximate historical mine progression. The DRN cells were generally applied to the base of the DL coal seam (layer 7) for Saraji Mine.

[1] Stress periods are used to define time intervals during which the inputs for the model remain constant.

6.1.3. Transient calibration

The numerical model includes a steady-state and a transient calibration (1972 to 2019). The transient calibration captures historical development at Saraji Mine and Peak Downs Mine which was based upon an interpolated mine progression assessed from Landsat imagery.

In accordance with the Australian groundwater modelling guidelines (Barnett *et al.*, 2012), the objective of a model calibration is to replicate the groundwater levels measured in the site monitoring network and other bores. A set of 55 selected observation points (and a total of 176 observations) were used in the calibration process, some with single values and some with time-series observations. The observation points included historical observation data from mining investigations (AECOM, 2016), publicly available sources (AECOM, 2016; Department of Natural Resources, Mines and Energy, 2019), and on-site data collected from open drill-holes and data collected from the new monitoring bores (**hydrogeologist.com.au**, 2019).

A scatter diagram of observed vs. modelled groundwater elevations (Figure 6.4) indicates that most points are situated close to the 1:1 line (perfect fit). While outliers do exist, most of the observations are within ±5 m of the 1:1 line. It is important to note that no significant or obvious trends or systematic departures appear to occur from the 1:1 line (the various colours representing different hydrogeological units scatter around the 1:1 line in a generally random pattern).

An overall (all observations and all time steps) transient calibration was achieved with an RMS (root mean square error) of 3.6 m and an SRMS (scaled root mean square error) of 4%. The SRMS value of 4% (3.6 m / 90.5 m=0.04 or 4%) indicates a good fit between measured and modelled data. Notwithstanding that, other criteria (such as good correlation between measured and modelled hydrographs and contour maps) also apply, an SRMS that is less than 10% may be acceptable (Barnett *et al.*, 2012) while an SRMS < 5% represents generally good calibration in the experience of **hydrogeologist.com.au**.

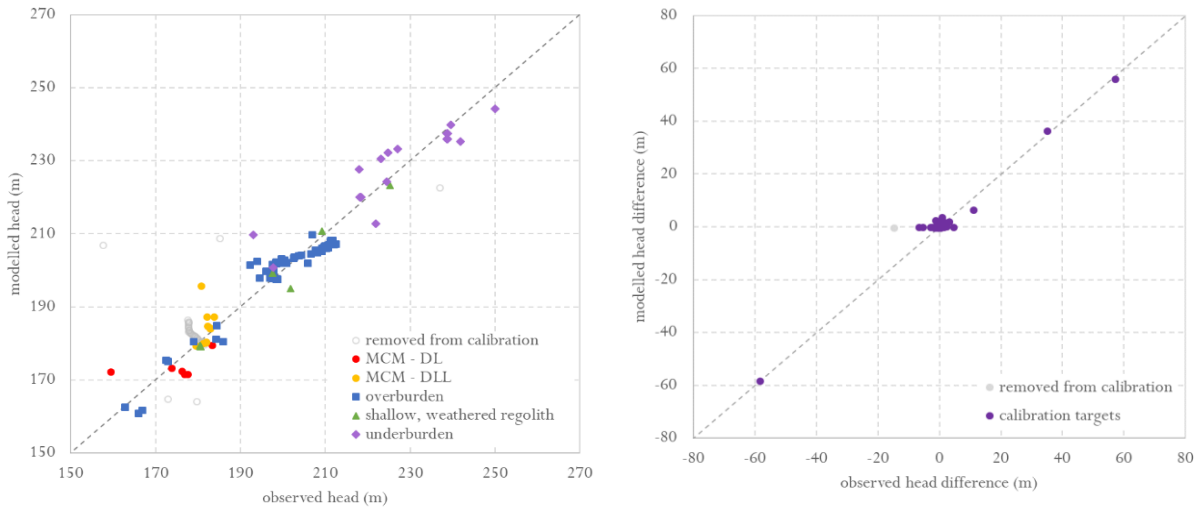


Figure 6.4 Model calibration scatter diagrams – observed and modelled heads and head differences

6.2. Predictions

The model predictions presented below are based upon 'mine' vs 'no mine' model scenarios to determine the true impact of the Project on the groundwater system. The 'mine' scenario simulates the VS, the VCM, along with Saraji Mine and Peak Downs Mine, and the 'no mine' scenario simulates the VCM, Saraji Mine and Peak Downs Mine only. The differences in drawdown and fluxes, between the 'mine' and 'no mine' scenarios, represent the impact of the Project on the groundwater system.

6.2.1. Mine inflows

Figure 6.5 shows the predicted inflow to the proposed VS Vulcan pits. The prediction shows a maximum inflow of less than 43 m^3/d occurring in Year 5 (or 2027) of mining. Vulcan North and Vulcan South pits are both predicted to have less than 5 m^3/d of groundwater inflow and will effectively be dry pits during mining. The majority of the inflow is predicted to occur during mining of the Vulcan main pit.

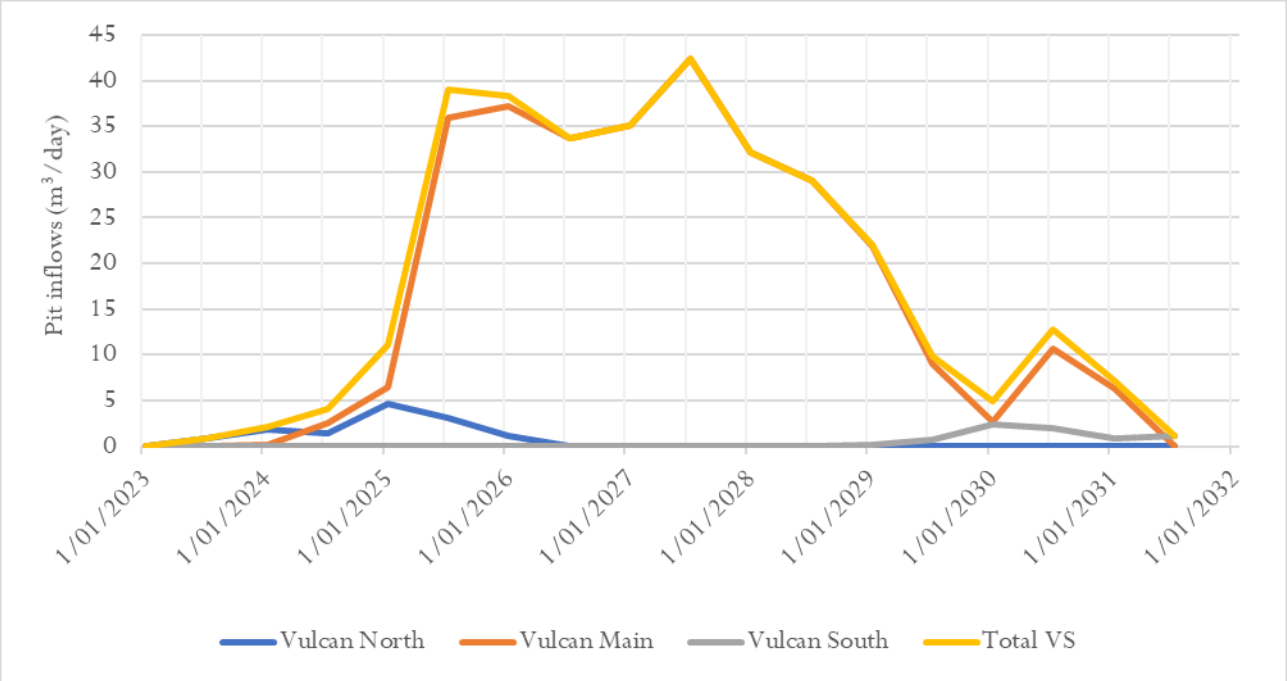


Figure 6.5 Predicted mine inflow rates

Table 6-2 summarises the predicted inflows rates and volumes for the proposed VS Vulcan pits. The rate of inflow to the Vulcan pits is consistent with Figure 6.5 and shows that the maximum inflow is less than 43 m^3/d occurring in Year 3 (or 2023) of mining. The maximum annual volume of predicted inflow to the VCM pit is less than 15 ML/yr.

Table 6-2 Numerical model – zone budget – predicted inflow rates for the Project

SP	days	SP end	DRN inflow (m^3/day)			Volume (ML)
			Vulcan North	Vulcan Main	Vulcan South	
59	184	01/01/2023	0.00	0.00	0.00	0.16
60	181	01/07/2023	0.88	0.00	0.00	
61	184	01/01/2024	1.86	0.21	0.00	1.12
62	182	01/07/2024	1.45	2.60	0.00	
63	184	01/01/2025	4.71	6.41	0.00	9.11
64	181	01/07/2025	3.09	35.93	0.00	
65	184	01/01/2026	1.15	37.14	0.00	13.15
66	181	01/07/2026	0.00	33.72	0.00	
67	184	01/01/2027	0.00	35.09	0.00	14.14
68	181	01/07/2027	0.00	42.42	0.00	
69	184	01/01/2028	0.00	32.20	0.00	11.20
70	182	01/07/2028	0.00	29.00	0.00	
71	184	01/01/2029	0.00	21.90	0.15	5.83
72	181	01/07/2029	0.00	9.05	0.77	
73	184	01/01/2030	0.00	2.62	2.34	3.23
74	181	01/07/2030	0.00	10.72	2.05	
75	184	01/01/2031	0.00	6.28	0.89	1.52
76	181	01/07/2031	0.00	0.00	1.10	

Overall, the predicted groundwater seepage to the proposed pits is low and will very likely be lost through evaporation on the pit face or as entrained moisture within the mined coal. Hence seepage to the pit is very unlikely to be observed during the Project.

6.2.2. Water fluxes (water budget)

The water budget of the model and the major components are:

- rainfall recharge (RCH boundary condition) inflow to the uppermost layer;
- groundwater outflow through the Jellinbah Fault Zone boundary;
- groundwater outflow to surface water outside the Project area (RIV cells); and
- when appropriate, groundwater outflow to mining voids.

Groundwater extraction for pastoral use is considered negligible and has not been included in the numerical model.

Table 6-3 shows the water fluxes (water budget) for the steady-state, transient calibration, and transient predictions. The outflow to the RIV cells and the balance of outflow-inflow for Jellinbah Fault Zone general head boundary (GHB) cells are largely driven by temporal changes in RCH which in turn is driven by rainfall. As Table 6-3 indicates, the predicted steady state recharge (1,360 m^3/d) is considerably less than the average for the transient calibration period (1972 to 2019). This is because at the beginning of the transient calibration, between 1973 and 1979, the annual average rainfall and therefore the predicted recharge rate is significantly higher (consistent with the CRD graph in Figure 3.2).

Table 6-3 also indicates that during the steady-state simulation (pre-1972) most of the inflow, from rainfall recharge, is balanced by outflow through the Jellinbah Fault Zone boundary and to RIV cells (surface watercourses mostly in the south and north).

Once Saraji Mine and Peak Downs Mine are simulated, groundwater outflows to mine voids (DRN) dominate the water balance and the groundwater outflow, in excess of inflows, is sourced from groundwater storage (drawdown near the pits). From 2023 the VS becomes active (transient-prediction). There is a significant increase in outflows to mine voids (DRN), however this is primarily due to the future representation of Saraji Mine and Peak Downs Mine as the VS is predicted to have very minor seepage.

Table 6-3 Numerical model water budget summary

Groundwater flow components		Steady state	Transient - calibration	Transient - prediction
		Average flow (m^3/d)		
in	recharge (RCH)	1,362	1,579	1,637
	Jellinbah Fault Zone boundary head dependant boundary (GHB)*	392	367	416
out	surface drainage (RIV)	635	801	644
	Jellinbah Fault Zone boundary head dependant boundary (GHB)*	1,119	1,007	870
	mining (DRN)	0	2,123	4,406

Notes: **Along the Jellinbah Fault Zone most of the GHB component of flow is out of the model although for technical reasons a small inflow exists, mainly in the north. For correctness, both are shown; however, for analysis the balance (for example, 1,119 m^3/d – 392 m^3/d = 727 m^3/d for steady state) can be used.*

The predicted changes in modelled flows due to the Project only (general head boundaries - GHB) and discharge to river (RIV) cells are shown in Figure 6.6. The predicted changes are calculated as the difference between the 'mine' and 'no mine' scenarios. 'RIV out' is a proxy for groundwater outflow (baseflow) that occurs from the groundwater system to surface waters. The change in flow in 'RIV out' is less than 0.10 m^3/d (or 100 L/d) over the entire model domain which is considered negligible.

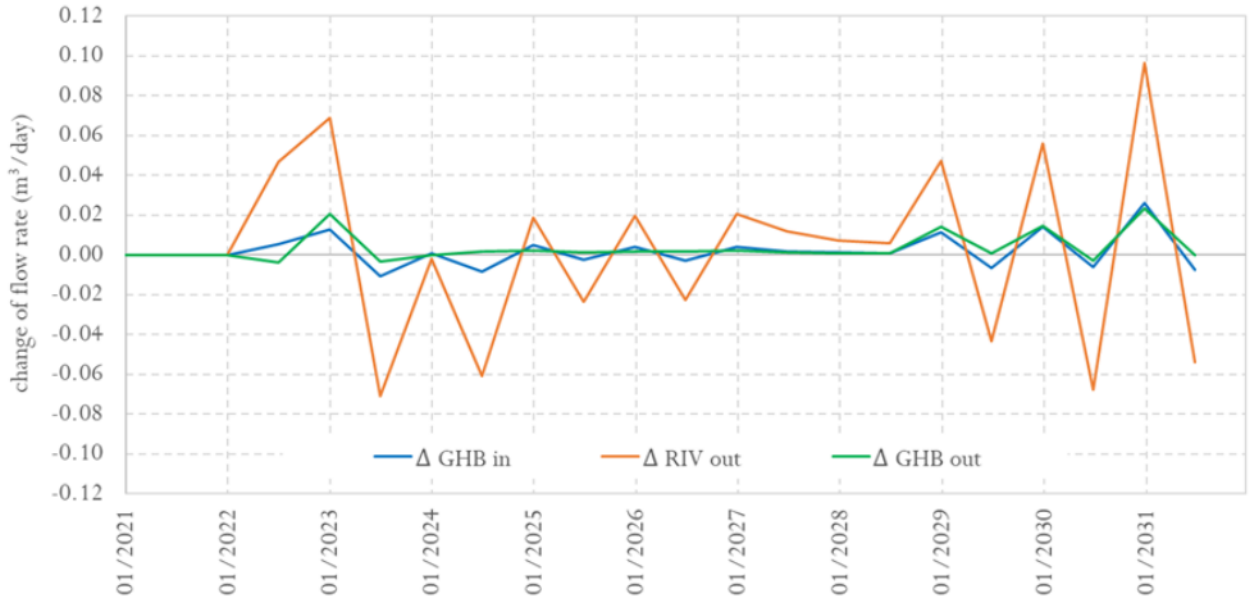


Figure 6.6 Predicted changes in flows - difference between the 'mine' vs 'no mine' scenarios

6.2.3. Drawdown

The predicted drawdown in the Tertiary / weathered zone (layer 2) and the DLL coal seam (layer 10) are shown in Figure 6.7 and Figure 6.8, respectively. The figures show the maximum predicted drawdown throughout the model simulation. The drawdowns represent the Project only drawdown and do not include the impacts of the VCM, Saraji Mine or Peak Downs Mine.

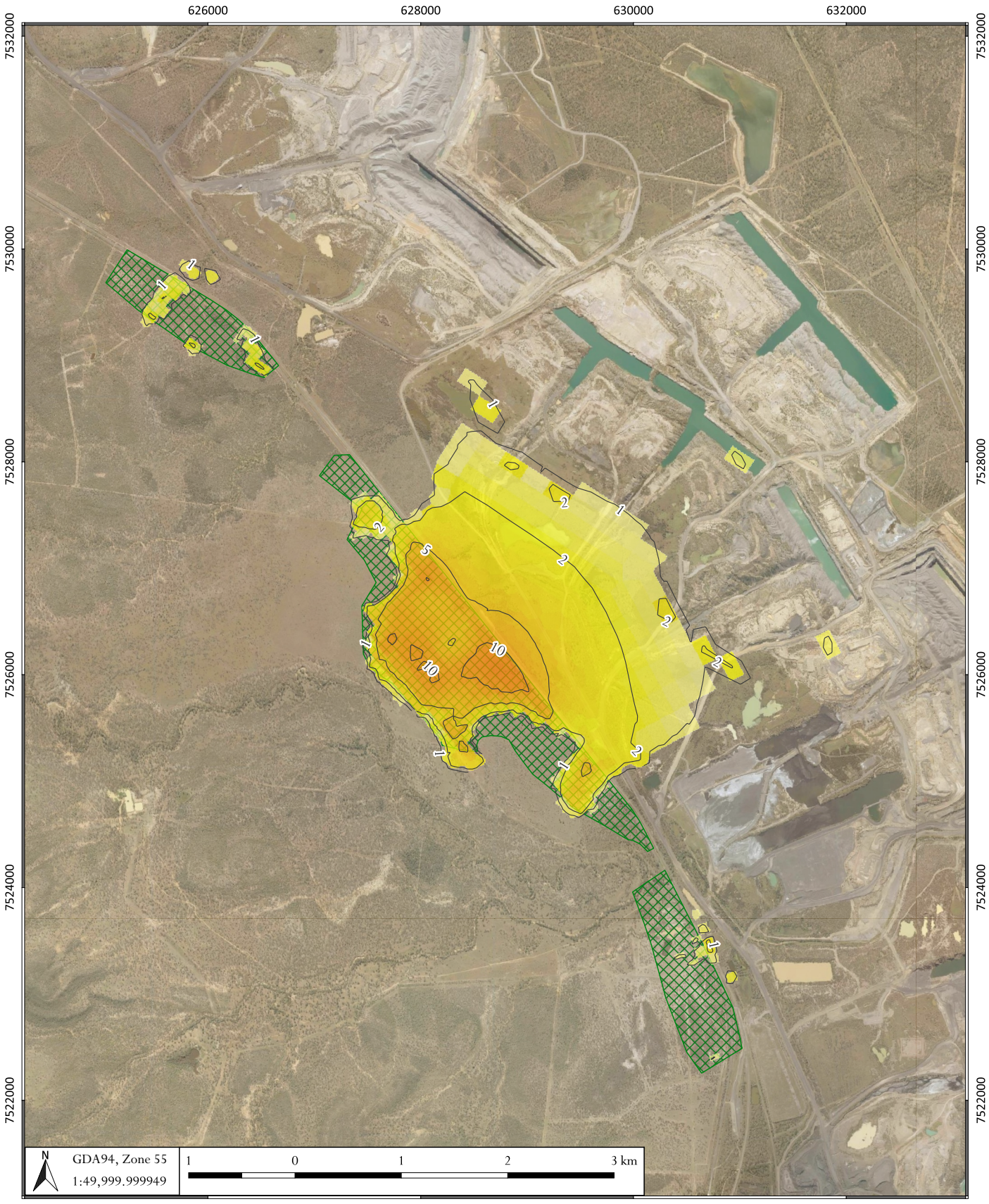
The maximum predicted drawdown in the Tertiary / weathered zone (layer 2) is approximately 10 m in the vicinity of the Vulcan Main pit. Negligible drawdown is predicted in layer 2 in the vicinity of the Vulcan North pit and Vulcan South pit. The drawdown extent occurs some 2,200 m (from the pit crest to the 1 m drawdown contour) and the predicted drawdown preferentially propagates towards the east and the existing Saraji Mine.

The proposed pits are to be backfilled following mining and therefore no residual drawdown is expected to occur post closure. There may be some minor change to the local groundwater elevations and flow directions post closure however these are expected to the negligible and will not result in impact to the groundwater regime.

The maximum drawdown in the DLL coal seam (layer 10) is predicted to be larger than, but of a similar magnitude to, that predicted for layer 2. The maximum magnitude of drawdown is approximately 10 m in the vicinity of the proposed Vulcan Main pit with negligible drawdown predicted in the vicinity of the Vulcan North pit and Vulcan South pit. The drawdown extent in layer 10 occurs some 2,400 m (from the pit crest to the 1 m drawdown contour) and the predicted drawdown preferentially propagates towards the east and existing Saraji Mine.

As per the layer 2 drawdown, the proposed pits are to be backfilled following mining and therefore no residual drawdown is expected to occur post closure in layer 10.

Predicted drawdown due to the proposed VS is limited to generally less than 2 km from the proposed pit (that is the lateral distance from the pit to the 1 m drawdown contour). This limited drawdown propagation is mainly due to the limited extent of saturation in the Project area, the low hydraulic conductivities and low storage coefficients. The predicted drawdown extends towards the east, toward Saraji Mine. The predicted maximum drawdowns in Figure 6.7 and Figure 6.8 are for any stage throughout the simulation for the weathered zone/regolith (layer 2) and the DLL coal seam (layer 10), respectively, and the actual drawdowns at any other times during the simulations will be less than those presented.



LEGEND

Maximum drawdown (m):

- 1
- 2
- 5
- 10

Proposed pit

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Predicted drawdown in Tertiary / weathered zone (L02)

FIGURE No.
6.7

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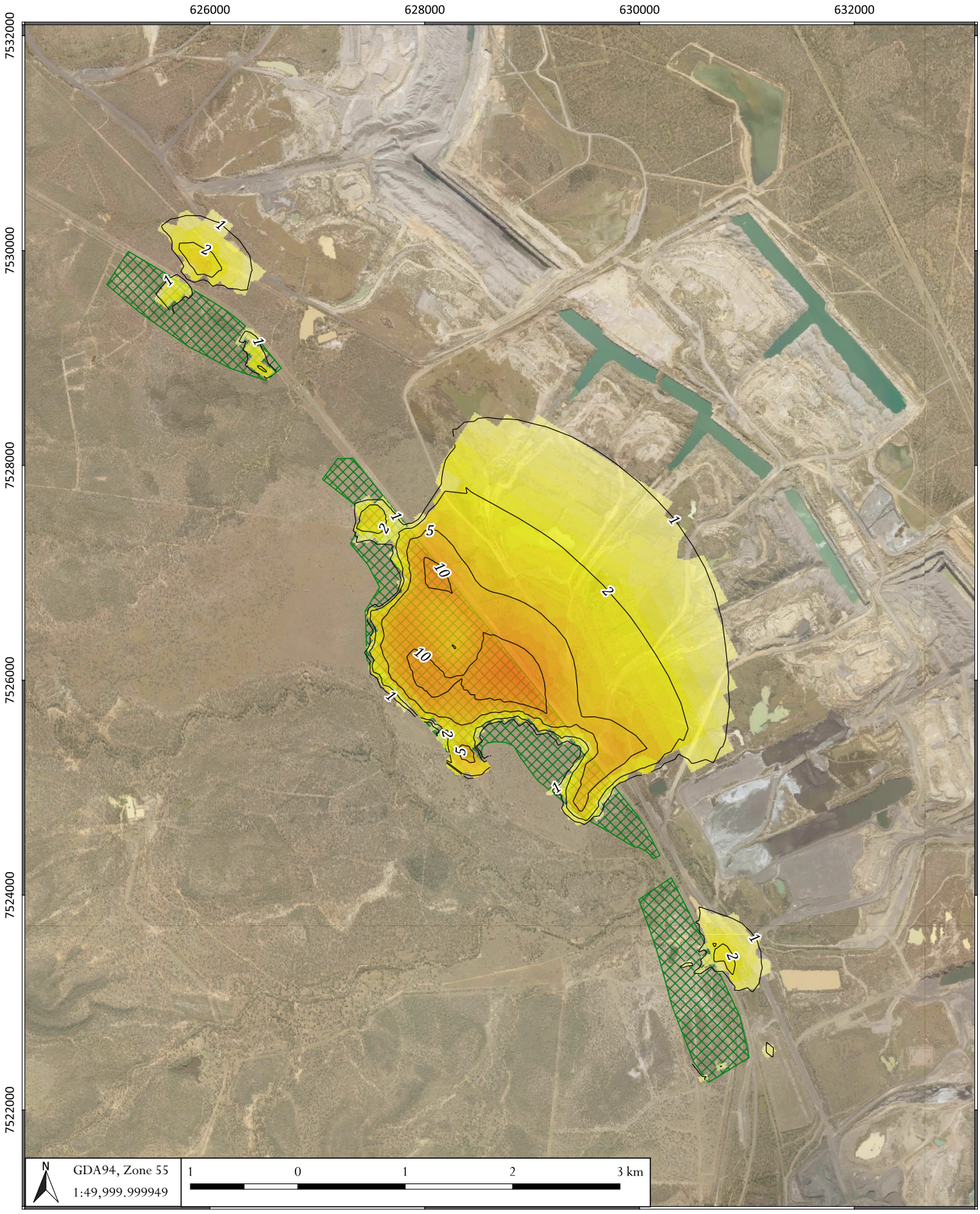

LEGEND

Maximum drawdown (m):

- 1
- 2
- 5
- 10

Proposed pit

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Vulcan South - Groundwater Impact Assessment (4027)

Predicted drawdown in DLL coal seam (L10)

FIGURE No.
6.8

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Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\06_08_4027_Vulcan South_Predicted drawdown in DLL.qgz

6.2.4. Uncertainty

Uncertainty analysis was carried out to understand the ranges of possible inflows and drawdown from the model under various parameter bounds. The analysis was completed in consultation with the IESC information guidelines on uncertainty analysis and was carried out using a calibration constrained, null space Monte Carlo stochastic method. A series of model parameter sets were generated and run using the 'mine' vs 'no mine' model scenarios. These models were compared against the calibrated 'basecase' model for calibration statistics such as SRMS and the objective function within PEST (that is phi which is equivalent to the sum of square residuals) to ensure the parameter sets generated acceptable results against the calibrated model. The predicted pit inflows and drawdown were then processed to determine pre-defined percentiles in accordance with the IESC information guidelines on uncertainty analysis. The following results present the outcome of the uncertainty analysis.

Figure 6.9 shows the uncertainty analysis of groundwater inflows (DRN) to the VS. The calibrated prediction or 'basecase' model is shown by a dashed black line and is consistent with the results presented in Figure 6.5 and Table 6-2. The coloured zones represent probability ranges, i.e. the dark green zone reflects the bottom 10th percentile of scenarios with DRN inflows generally < 25 m^3/d. The uncertainty analysis shows that there is a small probability (> 90th percentile) that the maximum inflow (in year 3 or 2025) would be between 60 m^3/d and 115 m^3/d, but would most likely be within the range of 30 m^3/d to 50 m^3/d for year 3. As discussed in Section 6.2.1, the predicted groundwater seepage to the VS is low and is highly likely to be lost through evaporation on the pit face or as entrained moisture within the mined coal. Hence seepage is unlikely to be observed during mining.

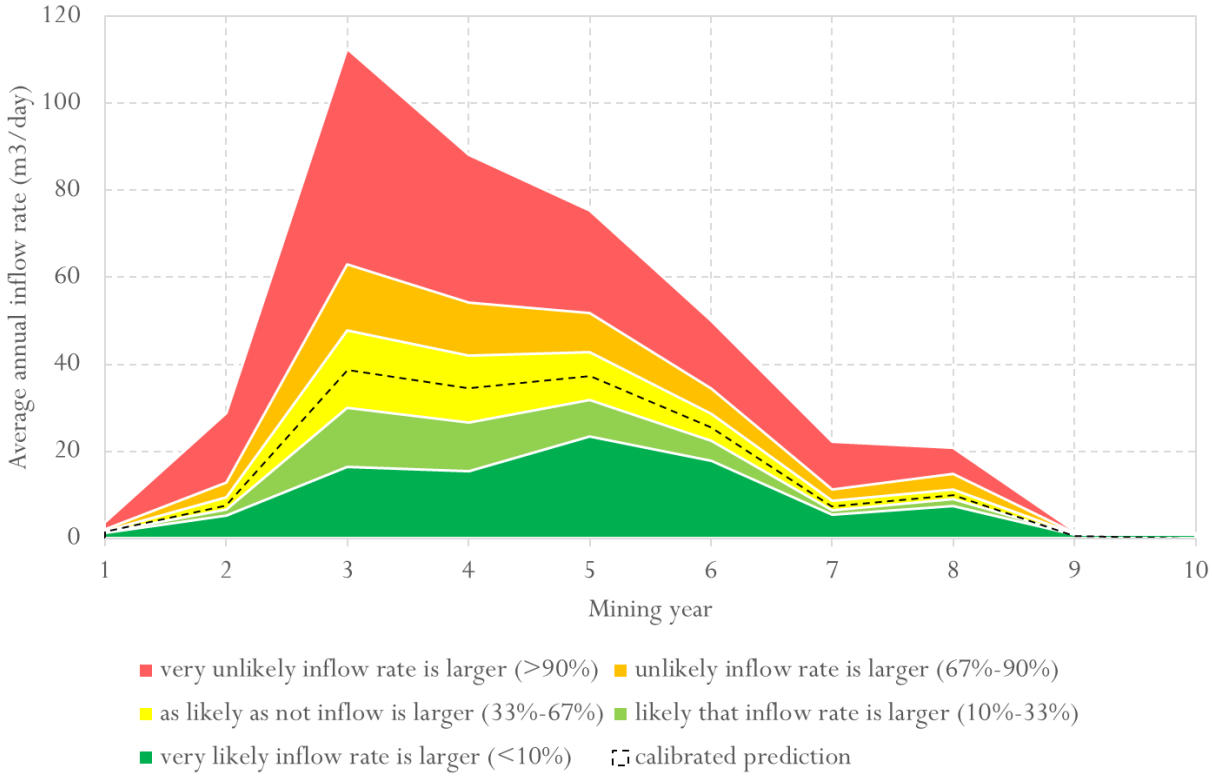
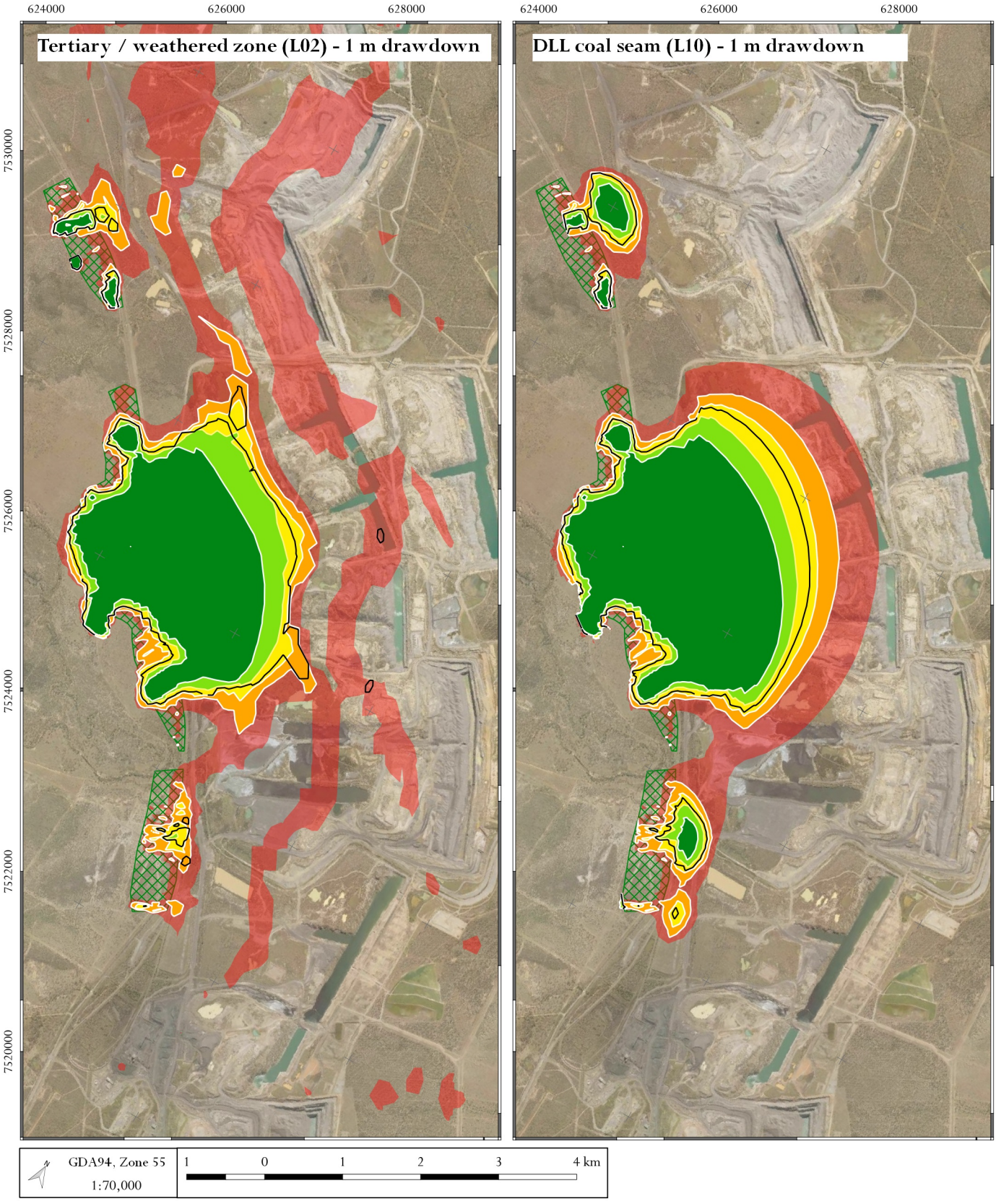


Figure 6.9 Uncertainty analysis – pit inflows

The maximum drawdowns (representing 1 m) generated from the uncertainty analysis for the Tertiary / weathered zone (layer 2) and the DLL coal seam (layer 10) are shown in Figure 6.10 along with the 'basecase' model predictions (solid line within the yellow envelope). The 'basecase' model predicted drawdowns are also shown in Figure 6.7 and Figure 6.8 for layers 2 and 10 respectively.

The coloured zones indicate the maximum extent for the 1 m drawdown within the probability envelopes, i.e. the light green coloured zone contains the 10th to 33rd percentiles of scenario results (the position of the 1 m drawdown contour), whereas the 67th percentile results indicate that the 1 m contour will be situated further to the east from the proposed pits.



LEGEND

- Proposed pit
- <10% - it is very likely that the outcome is larger than this value
- 10% - 33% - it is likely that the outcome is larger than this value
- 33% - 67% - it is as likely as not that the outcome is larger than this value
- 67% - 90% - it is unlikely that the outcome is larger than this value
- >90% - it is very unlikely that the outcome is larger than this value
- Maximum drawdown - basecase

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Uncertainty analysis - maximum drawdown

FIGURE No.
6.10

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6.3. Impacts on users

As Figure 6.7, Figure 6.8 and Figure 6.10 indicate, the predicted extent of maximum drawdown in the Tertiary / weathered zone (layer 2) and the DLL coal seam (layer 10) are limited. There are no third-party groundwater users within the predicted extent of drawdown and hence impacts on existing users are considered very unlikely. The nearest third party bores (to any of the VS pits) comprise a network of monitoring bores drilled at Saraji Mine by BMA. These are approximately 400 m from the 1 m predicted drawdown contour line.

The uncertainty analysis shows that the maximum probable drawdown extent (Figure 6.10) includes this BMA monitoring bore network. Whilst predicted drawdown at these monitoring bores is possible, the bores are not relied upon for water supply and they have been designed to monitor for mine related impact to the groundwater regime. On this basis impacts to third party groundwater users is unlikely and the proposed monitoring program (Section 7) will ensure that third-party bores are not put at undue risk by the Project.

6.4. Impacts on surface drainage

In Section 5.5.1 (Figure 5.3) the mechanism of recharge from surface water systems in the Project area was presented. Further discussion of the surface – groundwater interaction followed in Section 5.6 and it was concluded that there was no significant surface-groundwater interaction in the Project area.

Further, surface watercourses in the model were represented by RIV cells that are a more flexible option than DRN cells. This is because RIV cells allow groundwater inflow or outflow (depending on the relationship between surface water and groundwater heads) whereas DRN cells only allow groundwater outflow.

The predicted changes in modelled groundwater in- or out-flow from/to river (RIV) cells due to the Project only were shown in Figure 6.6. These changes, calculated as the difference between the 'mine' and 'no mine' scenarios, are due to the Project only and are generally less than 0.1 m^3/d (or 100 L/d) over the entire model domain and are therefore considered negligible. For these reasons impacts on surface waters are considered extremely unlikely.

6.5. Impacts on GDEs

Figure 6.11 shows the maximum predicted drawdowns anytime during the modelling and the location of mapped aquatic GDEs (same as Figure 5.8). The modelled drawdown in layer 2 would be considered representative of impact to the groundwater table and the shallowest aquifer.

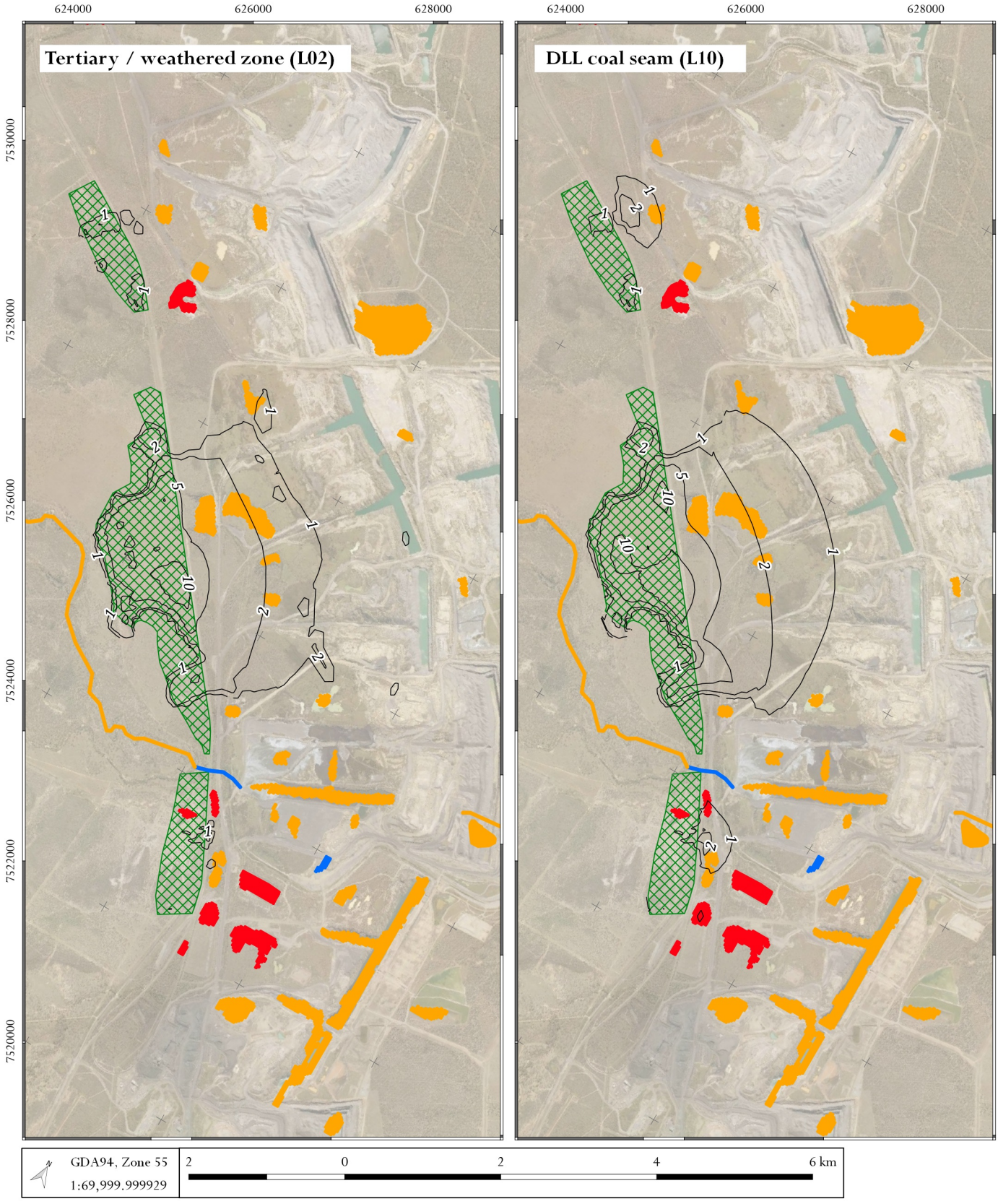
While there are small pockets of high- and moderate potential aquatic GDEs shown within the maximum drawdown associated with the Vulcan Main pit, in Section 5.7.2 it was the interpretation of **hydrogeologist.com.au** that it is highly unlikely for aquatic GDEs to be present within 1 km of the proposed pits. This is because aquatic GDEs with high or moderate potential for groundwater interaction are most likely to occur in areas where the seasonally high groundwater potentiometric heads are above or close to the corresponding surface water heads. This is necessary to maintain a hydraulic gradient from the groundwater to surface water, or at least have a hydraulically 'connected' system. Within or adjacent to the Project area, the surface water systems are above the groundwater table (see Section 5.6) and the surface water system is hydraulically disconnected from the groundwater system.

In addition, groundwater in the Project area is brackish to saline and therefore unsuitable for the maintenance of freshwater GDEs (see Section 5.8 for further information on groundwater quality). Further, with the exception of Hughes Creek, aquatic GDEs associated with a number of separate wetlands along the Moranbah – Dysart Road, between Phillips Creek and Boomerang Creek, all appear to be manmade impoundments associated with Saraji Mine or pastoral properties.

Figure 6.12 shows maximum predicted drawdowns anytime during the modelling and the position of mapped terrestrial GDEs (same as Figure 5.9). Figure 6.12 indicates very small and insignificant overlaps between the drawdown affected areas and mapped terrestrial GDEs adjacent to the proposed pits.

As stated in Section 5.7.2, it is the experience of **hydrogeologist.com.au** that terrestrial GDEs with high or moderate potential for groundwater interaction are most likely to occur in areas where depth to groundwater is less than 10 m. Analysis of the depth to groundwater data surrounding the Project area identified that groundwater was typically recorded at levels deeper than 10 m (Figure 5.10) and likely to be outside of the accessible reach of Eucalypt vegetation. There is an area of mapped terrestrial GDEs associated with Hughes Creek which is located within an area where the depth to groundwater is less than 10 m. However, the predicted drawdown does not extend into this mapped area and as a result impacts to terrestrial GDEs are highly unlikely.

For the reasons stated above, **hydrogeologist.com.au** interprets that there are no valid aquatic or terrestrial GDEs within the maximum drawdown zones and impacts on GDEs are considered highly unlikely. The reader is directed to the Vulcan South – Ecological Impact Assessment report for further information regarding the presence of aquatic or terrestrial GDEs.



LEGEND

Proposed pit

Aquatic GDEs

- High potential GDE - from national assessment
- Low potential GDE - from national assessment
- Moderate potential GDE - from national assessment

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Maximum drawdown and aquatic GDEs

FIGURE No.
6.11

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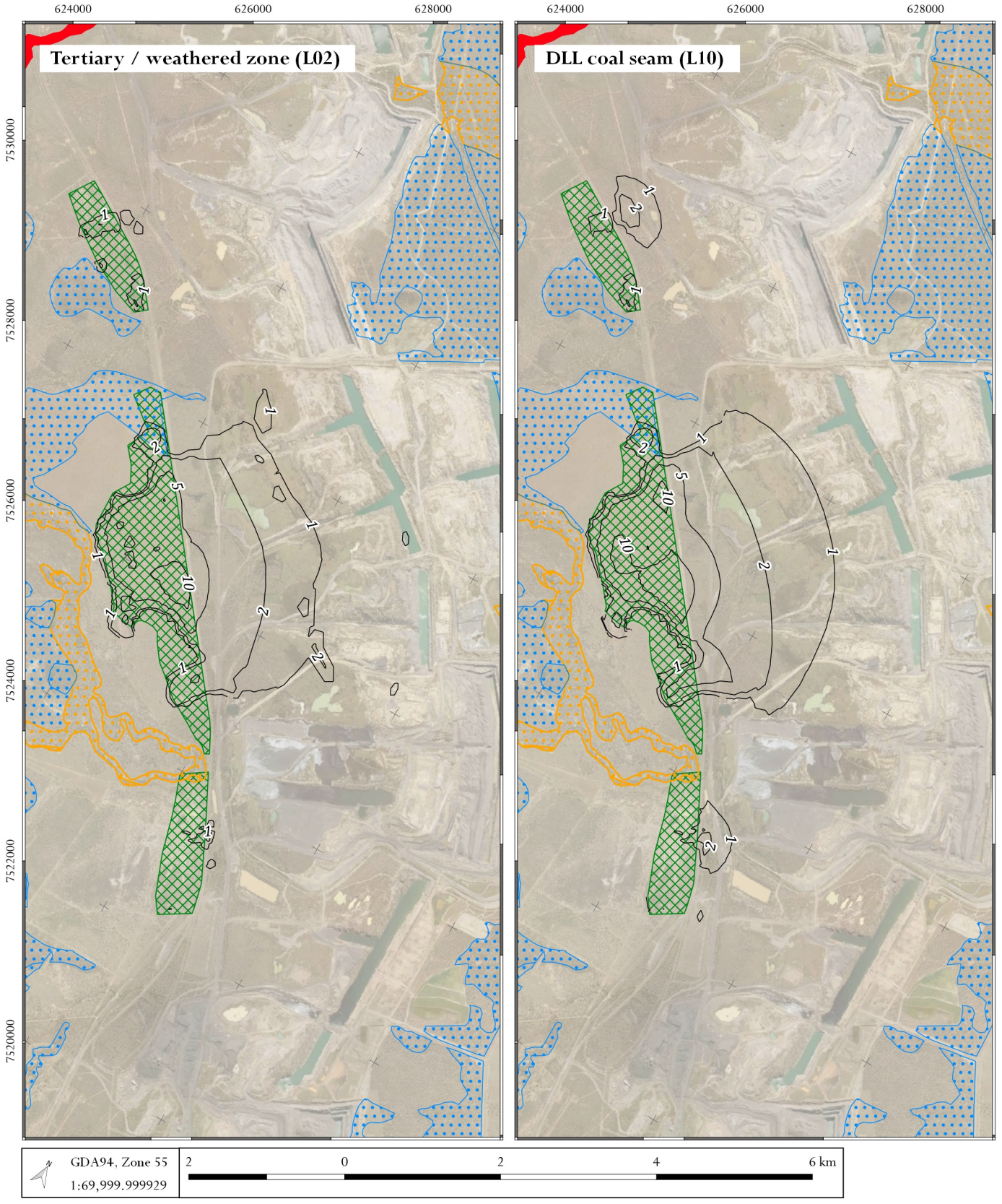

LEGEND

Proposed pit

Terrestrial GDEs

- High potential GDE - from national assessment
- Moderate potential GDE - from national assessment
- Low potential GDE - from national assessment

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Maximum drawdown and terrestrial GDEs

FIGURE No.
6.12

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6.6. Impacts on groundwater quality

During mining, the proposed pits and the Saraji Mine pits will act as sinks for surrounding groundwater. Any local contamination of the groundwater regime will report to the mine pit and will be contained during operations. The ex-pit and in-pit waste rock emplacement areas will be progressively rehabilitated during mine development and therefore no final voids or evaporative sinks will remain in the Project area. Groundwater is predicted to recover towards the pre-mining groundwater levels, subject to mining plans that include the adjacent Saraji and Peak Downs Mines. It is assumed that the pit voids at Saraji Mine and Peak Downs Mine will likely remain into perpetuity and will behave as regional evaporative sinks on the groundwater system hence minimising any eastward migration of potential contaminants.

The evaluation of groundwater EV in the Project area (Section 5.8.3) indicated that groundwater is of no, or limited value for most uses because of the high salinity. Local groundwater was found to be brackish to highly saline and even an unprecedented 50% increase in salinity would not impact on the beneficial uses identified (livestock beef cattle watering (limited); and industrial purposes, limited to dust suppression in mining). This is because the salinity of local groundwater is well in excess of the WQOs for aquatic ecosystems and drinking water suitability.

Therefore, the risk of groundwaters within the backfilled pit impacting on surrounding groundwater quality is highly unlikely.

All new mine infrastructure areas including workshops, fuel and chemical storage areas will include spill containment measures, for example bunding and / or spill kits. These structural and administrative controls will assist in preventing groundwater contamination. Impacts on groundwater quality, associated with local contamination from mine activities are considered highly unlikely.

6.7. Cumulative impacts

Cumulative impacts have been assessed by representing historical and proposed mining for the VCM, Saraji Mine and Peak Downs Mine, the latter have been active since the 1970s. The impacts of these approved mines have been predicted in isolation of the Project and in a cumulative sense through the development of the 'mine' vs 'no mine' model scenarios. For the purposes of this assessment, the cumulative impact on groundwater is represented in Figure 6.13. The graph shows the long-term model predicted inflows to the Saraji Mine and Peak Downs Mine with recent and proposed average annual inflow rates in the order of 3,000 m^3/day to 5,000 m^3/day. The proposed mining inflow rates correlate with AECOM (2016). The minimal inflow rates predicted for the Project (maximum inflow rate of 43 m^3/d) represent less than a 1% increase in groundwater seepage within the model domain.

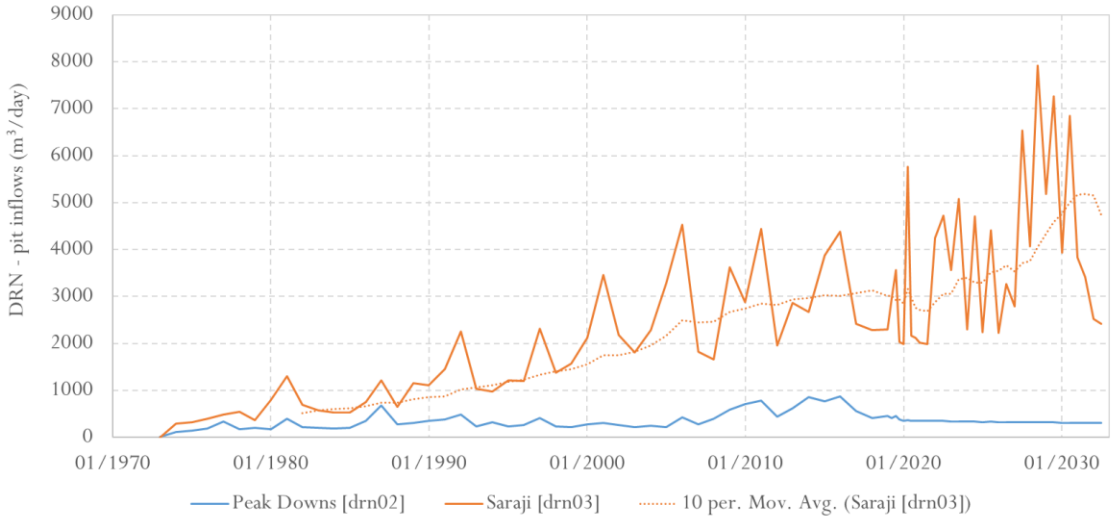

Figure 6.13 Predicted inflow rates – Saraji Mine and Peak Downs Mine

7. Management and mitigation

7.1. Licensing

The proposed pits will intercept groundwater from Groundwater Unit 2 (sub-artesian aquifers) under the Water Plan (Fitzroy Basin) 2011. The predicted take of groundwater, based on the numerical model (Section 6.2.1) and the life of the Project, will involve allocation of up to 14.1 ML/year from Groundwater Unit 2. This annual inflow rate was calculated as the product of the maximum daily inflow, 43 m^3/d (Figure 6.5) over the modelled stress periods.

Post mining there will be no requirement for a perpetual water licence as the pit will be progressively backfilled. No final void will remain in the Project area and therefore no evaporative sink will act on the groundwater regime. Groundwater is predicted to recover towards the pre-mining groundwater levels, subject to on-going mining that may occur at Saraji Mine and Peak Downs Mine.

7.1. Adaptive management strategy

The following section summarises the proposed framework for the on-going Groundwater Management Strategy to be developed to assist with the management and mitigation of drawdown and potential water quality impacts.

7.1.1. Drawdown

The predicted drawdown resulting from the Project is shown in Figure 6.7, Figure 6.8 and Figure 6.10. Section 6.2.3 discusses and summarises the extent and magnitude of drawdown, and Section 6.3 through to Section 6.7 discuss the resulting impacts of this predicted drawdown on the surrounding environment.

The groundwater monitoring network (Section 5.3 and Appendix A) established by **hydrogeologist.com.au** (2019) is considered fit for purpose for this assessment, and will form the basis for ongoing drawdown monitoring and management through the life of the Project. A number of the Project area monitoring bores will be disturbed by mining operations and replacement monitoring bores will be established to enable long term monitoring. Any replacement monitoring bore will also need to be representative and consider the potential contaminant sources. The groundwater monitoring network may be regularly amended to ensure it remains representative of groundwater conditions and fit for purpose.

Monitoring of groundwater levels from the groundwater monitoring network will enable natural groundwater level fluctuations (such as responses to rainfall recharge) to be distinguished from potential groundwater level impacts (drawdown) due to dewatering/depressurisation resulting from proposed mining activities. Automatic data loggers are currently installed in the groundwater monitoring network and they will continue to be used to enable daily measurements. These data loggers should be downloaded quarterly to coincide with groundwater quality sampling.

Queensland government monitoring bore RN13040283 is located adjacent to the Project area. Pending access to the bore, quarterly groundwater level monitoring of this bore would also provide benefit in understanding the regional behaviour of the groundwater regime in relation to mining.

A number of the site-specific monitoring bores are situated within (or adjacent to) the predicted drawdown zone. Other site-specific monitoring bores are distant from the proposed VS Vulcan pits, however groundwater level data from all monitoring bores within the groundwater monitoring network will be assessed in an annual comparison between actual and modelled drawdowns. This annual comparison and assessment will be completed in consideration of the DES (2021) guidelines for *using monitoring data to assess groundwater quality and potential environmental impacts*. This assessment will allow for verification of the numerical model predictions.

Private water supply bore RN 162506 is the nearest third party bore to the Vulcan pits. The bore is located in excess of 10 km from the predicted impact of drawdown. Pending agreement to access the bore, quarterly groundwater level monitoring of this bore would provide benefit in understanding the regional behaviour of the groundwater regime in relation to mining. Any Project related impacts at RN 162506 would be mitigated through Make Good Provisions under the Water Act (see Section 2.1.1).

There is merit in a groundwater data sharing arrangement between Vitrinite and BMA. Routine groundwater level and quality monitoring from Saraji Mine and Peak Downs Mine would provide Vitrinite with a greater understanding of the hydrogeological system responses during mining.

Given the low pit inflow predictions, limited extent of drawdown and unlikely impacts on the groundwater regime, regular updates to the numerical model are not likely to be required. However, it will be important to compare and assess on an annual basis the groundwater level observations against the modelled predictions to verify that observations are consistent with model outputs.

Every three years, consideration will be given for the redevelopment and or recalibration of the numerical groundwater model. Any such redevelopment or recalibration of the numerical groundwater model may require an iterative review of the conceptual hydrogeological model. This may result from measuring hydraulic responses that are inconsistent with the conceptual understanding or model predictions, changes to the mine plan, or modification of potential contamination sources.

The reporting obligations proposed as part of on-going Groundwater Management Strategy will be defined as conditions in the EA.

7.1.2. Groundwater quality

Quarterly groundwater quality monitoring and sampling of the groundwater monitoring network will continue in order to provide longer term baseline data for the formulation of site-specific triggers. The groundwater quality parameters to be monitored will be consistent with those provided in Appendix A, which have been developed in consideration of the DES (2017) Guideline: Model mining conditions. The monitoring and sampling will be carried out in consideration of DES (2018a).

Interim guidelines can be developed using the existing water quality dataset from the groundwater monitoring network and defined in the EA. The definition of compliance and reference sites in respect to target formations will be provided during the development of the interim guidelines which will be carried out in consideration of DES (2021).

Once interim triggers are established, groundwater quality data during operations will be compared to these interim trigger values, and potential exceedances will be investigated and reported. Once 12 to 24 months of groundwater quality data is available from the groundwater monitoring network the interim guidelines will be replaced with a series of groundwater trigger levels and contaminant limits. These groundwater trigger levels, and contaminant limits will be developed in consideration of DES (2021). The regulatory reporting obligations and conditions will be defined in the EA.

7.1.3. Summary

In summary, an adaptive management strategy is proposed to assist with the management and mitigation of drawdown and potential water quality impacts. The framework of the adaptive management strategy includes the following iterative components which will be defined in the EA:

- Acceptance of the groundwater monitoring network to include the site-specific monitoring bores, Queensland government monitoring bore RN 13040283 and private water supply bore RN 162506.
- Development of interim groundwater quality guidelines (in consideration of DES [2021]). These guidelines will be derived from the current dataset and would be included as conditions in the EA.
- Quarterly groundwater sample collection, level measurement and datalogger download.

- Development of groundwater trigger levels and contaminant limits once 12 to 24 months of groundwater quality data is available, to be included as amended conditions in the EA.
- Develop a suitable WMP for the Project that includes consideration of groundwater.
- Annual assessment of the suitability of the groundwater monitoring network for the Project to provide a representative and spatially adequate understanding of the groundwater regime.
- Annual assessment of groundwater level and quality data in consideration of DES (2021).
- Every three years consider the requirement to redevelop, and or recalibrate the numerical groundwater model.

7.2. Mitigation measures

No mitigation measures are currently proposed or required as part of the Project. There are no impacts predicted for third party groundwater users and surface water systems. Impacts to GDEs are considered highly unlikely as are impacts on groundwater quality and EV. Should monitoring and subsequent assessment determine potential impacts, mitigation strategies would be considered commensurate with the level and risk of environmental impact.

8. Conclusions

hydrogeologist.com.au has prepared a groundwater impact assessment to support the EA application for the Project. The Project is to the immediate west of the BMA Saraji Mine and Peak Downs Mine. The Project involves the open cut mining of coal from the DLL coal seam of the Permian Moranbah Coal Measures from three individual pits, and mining of the MAT coal seam in the Highwall Mining Area.

The main hydro-stratigraphic units occurring at the Project area include the Tertiary sediments or weathered zone (regolith) and the Permian coal measures. There is no Quaternary alluvium present within the Project area; however, it remains an important regional hydro-stratigraphic unit. The Permian DLL coal seam is partially / variably saturated over the Project area and the pit will intersect the regional groundwater table which has been historically depressurised by mining at Saraji Mine and Peak Downs Mine. A portion of mining will occur above the regional groundwater table. The highwall mining is not expected to intersect groundwater and is in an area of coal that is unsaturated.

Groundwater quality within the mined coal seam (and within other hydro-stratigraphic units) is generally brackish to saline and this is consistent with other mine sites in the region. The groundwater quality within the Project area has limited or no environmental value and potentially may be used for livestock beef cattle watering and / or industrial purposes (such as dust suppression in mining).

The groundwater quality is considered too saline to support aquatic GDEs and the depth to groundwater is generally considered too deep to support terrestrial GDEs. There are limited third party groundwater users in the region and Vitrinite has developed a clear understanding of where these third-party groundwater bores are located.

A numerical groundwater flow model has been developed to support the groundwater impact assessment and has been undertaken in accordance with relevant Australian guidelines. The model is assessed to be a reliable and acceptable simulator of historical mining activities and of groundwater level behaviour in and surrounding the Project area. Future predictions have been made by representing proposed mining at Saraji Mine and Peak Downs Mine, and the proposed mining schedule for the Project.

The model predictions show limited pit inflows (less than 43 m^3/day) to the pit and it is likely that most of the predicted inflows would be lost through evaporation on the pit face or as entrained moisture within the mined coal. Hence seepage to the pit is unlikely to be observed during the Project's life. The drawdown predicted from the Project is limited in extent (maximum up to 2,000 m to the east toward existing mining) and magnitude (up to 10 m in the deepest part of the Vulcan Main pit. The model demonstrates that given the variable saturation of the mined coal seam, some of the proposed pits will not be affected by drawdown as the coal seam is known to be unsaturated. Calibration constrained, null space Monte Carlo stochastic method uncertainty analysis has been carried out for the groundwater impact assessment. This uncertainty analysis has been completed in consideration of the IESC guidelines and confirms minimal inflows reporting to the pit, and limited drawdown extent and magnitude.

The extent of predicted drawdown does not encroach on any of the third-party groundwater users in the region and therefore impacts in this regard are considered very unlikely. The model predicts negligible change in the water balance components that represent surface water discharge and as a result impacts on surface waters are considered very unlikely. It is the assessment of **hydrogeologist.com.au** that there are no valid aquatic or terrestrial GDEs within the maximum drawdown zones and impacts on GDEs are considered very unlikely. Furthermore, impacts on groundwater quality are assessed to be very unlikely and there would need to be an unprecedented change in salinity to affect the current beneficial use and environmental values of the groundwater regime.

An adaptive management strategy is proposed for the Project to assist with the management and mitigation of drawdown and potential water quality impacts. The framework of the strategy includes iterative components which will be defined as conditions in the EA.

9. References

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Hydrogeological Drilling Report – Vulcan Complex Project

Prepared for

Vitrinite Coal Pty Ltd

1. Introduction

This report describes the hydrogeological drilling program for the Vulcan Complex Project (the project). Vitrinite Coal Pty Ltd (Vitrinite Coal) propose to develop the project comprising two open cut coal pits (Vulcan and Jupiter) located in the northern part of the Bowen Basin, Central Queensland.

The project is located approximately 15 km to the south of the township of Moranbah, within Exploration Permit Coal (EPC) 1233 and EPC 1234. The project involves the open cut mining of coal from two main areas (Vulcan and Jupiter) and transport of coal to a modular coal handling and preparation plant (CHPP) and central mine infrastructure area (MIA). The open cut mining footprint including in-pit and out of pit spoil dumps will cover an area of approximately 2500 ha (Vulcan extent) and 750 ha (Jupiter extent).

A hydrogeological monitoring program is required to characterise and understand the groundwater resource in response to the mine development, a requirement of the environmental approvals process. This report documents the establishment of the hydrogeological monitoring network to support the project. This follows on from the proposed hydrogeological monitoring program developed by **hydrogeologist.com.au** which outlined the requirements and specifications of the drilling and bore installation program.

2. Monitoring bore drilling

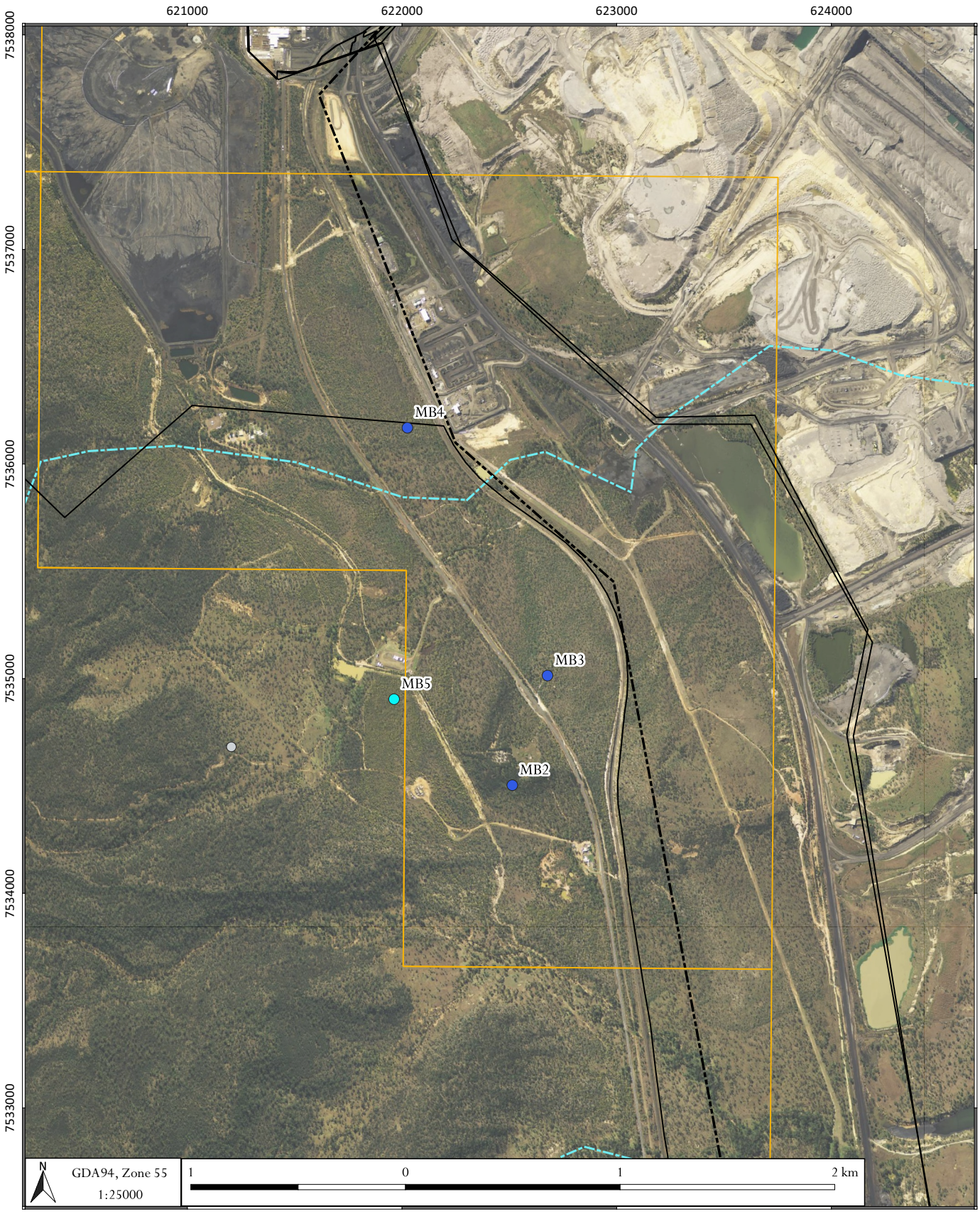
Twelve (12) monitoring bores were drilled between the 29th of May and 7th of June 2019. The drilling of four monitoring bores (MB13 to MB16) in the Tay Glen area (to the south) was postponed due to changes in the project description and may be drilled at a later date. A Mayhew 1000 drilling rig from Wizard Drilling Pty Ltd was used to drill and install the monitoring bores under the supervision of licenced driller Andrew Holmes (Lic. No. 3383). Table 2.1 below summarises the monitoring bore construction details.

Table 2.1 Vulcan Complex monitoring bores – construction details

ID	Area	Easting	Northing	Target unit	Casing height (maGL)	Hole depth (mbGL)	Screen interval (mbGL)	Airlift yield (L/min)
MB1	Vulcan	625608	7529692	DLL coal seam	0.70	24.9	21.9 – 24.9	Dry
MB2	Jupiter	622515	7534485	DLL coal seam	0.71	12.0	9.0 – 12.0	Dry
MB3	Jupiter	622665	7535021	DLL coal seam	0.70	33.8	30.8 – 33.8	<0.1
MB4	Jupiter	622016	7536148	DLL coal seam	0.71	21.5	18.5 – 21.5	1
MB5	Jupiter	621965	7534904	MAT coal seam	0.77	40.9	37.9 – 40.9	0.5
MB6	Vulcan	628121	7526477	Weathered Permian	0.70	24.6	21.6 – 24.6	Dry
MB7	Vulcan	628692	7526260	Weathered Permian	0.67	43.0	40.0 – 43.0	0.1
MB8	Vulcan	628094	7527017	Weathered Permian	0.70	24.0	21.0 – 24.0	Dry
MB9	Vulcan	629511	7525225	DLL coal seam	0.65	34.4	31.4 – 34.4	0.1
MB10	Vulcan	628125	7526470	DLL coal seam	0.70	40.3	37.3 – 40.3	<0.1
MB11	Vulcan	627405	7527854	DLL coal seam	0.70	29.9	26.9 – 29.9	Dry
MB12	Vulcan	625252	7526409	Permian underburden	0.66	38.2	32.2 – 38.2	1

Notes: Easting and northing coordinates are in GDA94, Zone 55
maGL – metres above ground level
mbGL – metres below ground level

Figure 2.1 shows the locations of the Jupiter monitoring bores and Figure 2.2 shows the locations of Vulcan monitoring bores. All monitoring bores were completed with a lockable monument cover. With the exception of dry monitoring bores, all bores were developed by airlifting after completion. The bore logs for each monitoring bores are included in Appendix A.



LEGEND

Groundwater monitoring bore

- DLL coal seam
- MAT coal seam
- Permian underburden
- Tertiary

- Registered bore
- Mining lease (ML)
- Exploration permit coal (EPC)
- Watercourse, non-perennial

DATE
19/06/2019

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Vitrinite Coal - Hydrogeological Drilling Report – Vulcan Complex Project (4015)

Bore location plan - Jupiter

FIGURE No.
2.1

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
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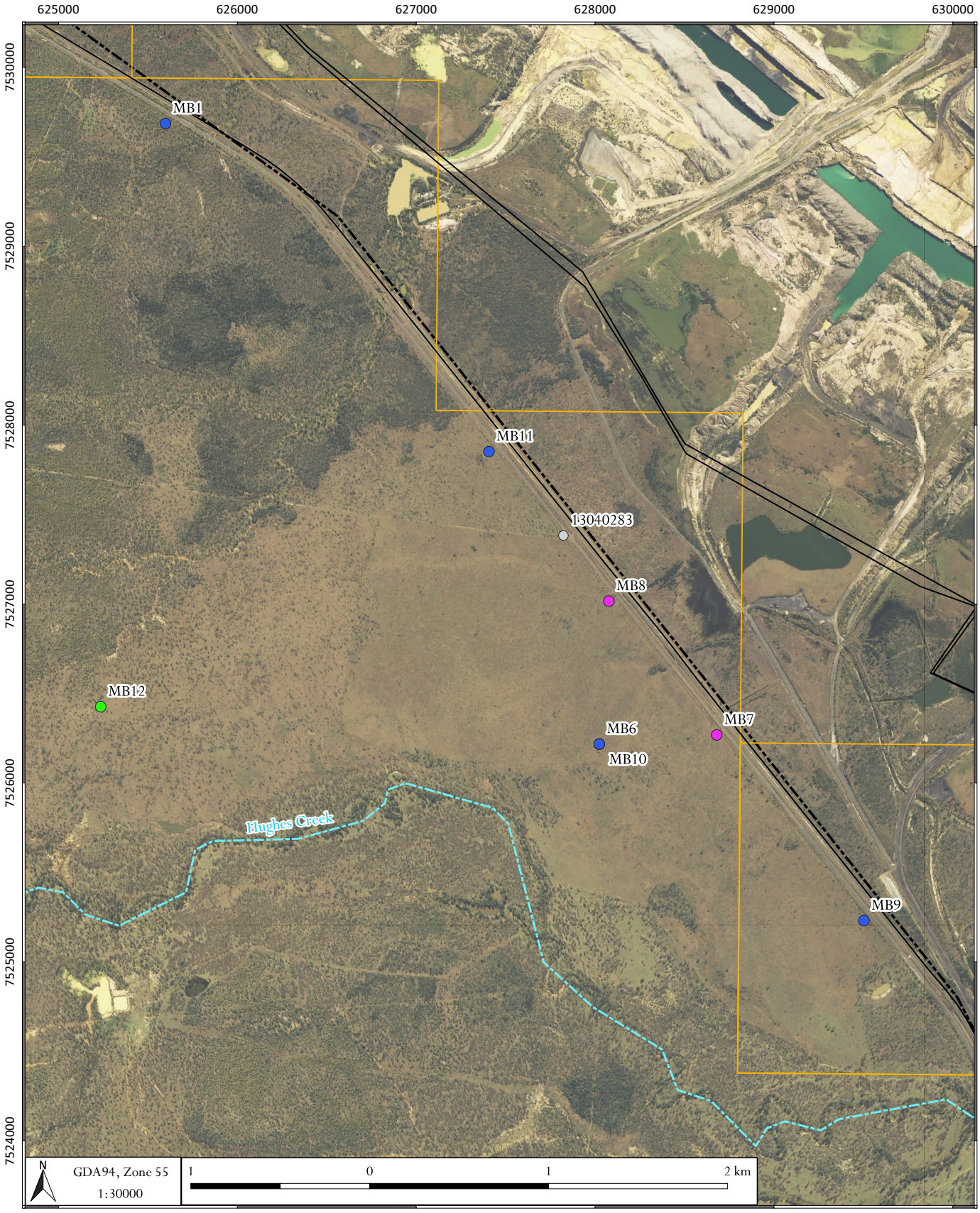

LEGEND

Groundwater monitoring bore

- DLL coal seam
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- Watercourse, non-perennial

DATE
19/06/2019

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Bore location plan - Vulcan

FIGURE No.
2.2

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3. Groundwater levels

Groundwater level measurements were recorded at each bore following construction and after airlift development. In some instances, the groundwater level measurement collected after airlift development was influenced by the development process and the low permeability of the intersected formation. The measured groundwater levels are summarised in Table 3.1.

Table 3.1 Vulcan Complex monitoring bores – groundwater levels

Bore ID	Elevation (mAHD)	Total depth (mbgl)	SWL (mbTOC)	SWL (mAHD)	Target unit
MB1	225	24.9	Dry	Dry	DLL coal seam
MB2	255	12.0	Dry	Dry	DLL coal seam
MB3	267	33.8	34.30	232.7	DLL coal seam
MB4	253	21.5	5.83	247.2	DLL coal seam
MB5	257	40.9	14.53	242.5	MAT coal seam
MB6	223	24.6	Dry	Dry	Weathered Permian
MB7	222	43.0	34.80	187.2	Weathered Permian
MB8	219	24.0	Dry	Dry	Weathered Permian
MB9	216	34.4	27.41	188.6	DLL coal seam
MB10	223	40.3	32.51	190.5	DLL coal seam
MB11	228	29.9	Dry	Dry	DLL coal seam
MB12	244	38.2	26.82	217.2	Permian underburden

Notes: *mAHD – metres above Australian Height Datum*
mbGL – metres below ground level
mbTOC – metres below top of casing

A total of five monitoring bores were dry following drilling and construction. It is expected that these bores will eventually recharge to provide a groundwater level however this will be confirmed during on-going monitoring.

The monitoring bores have not been surveyed at this stage. However, as the bores were constructed only 5 m to 10 m away from an exploration hole, the collar elevations for the nearby exploration hole were adopted for the monitoring bores.

The groundwater levels are generally between 185 mAHD and 220 mAHD for Vulcan, and 230 mAHD and 250 mAHD for Jupiter. The groundwater levels shown in Table 3.1 should be recognised as initial measurements only and on-going regular monitoring will define the baseline groundwater levels at the site.

In-situ dataloggers (LevelTROLL 400 with 60 psi range) have been installed in all monitoring bores and a barometric logger installed also in MB6. The dataloggers have been set to record every four hours.

Groundwater level data has been captured by Vitrinite from exploration drill holes at the project site. Figure 3.1 shows the groundwater flow contours (in mAHD) generated from this data and the general groundwater flow direction is from the north to the south and south-east. The groundwater level data captured from the exploration drill holes is generally consistent with the levels measured in the monitoring bores and demonstrates that groundwater flow generally follows topography.

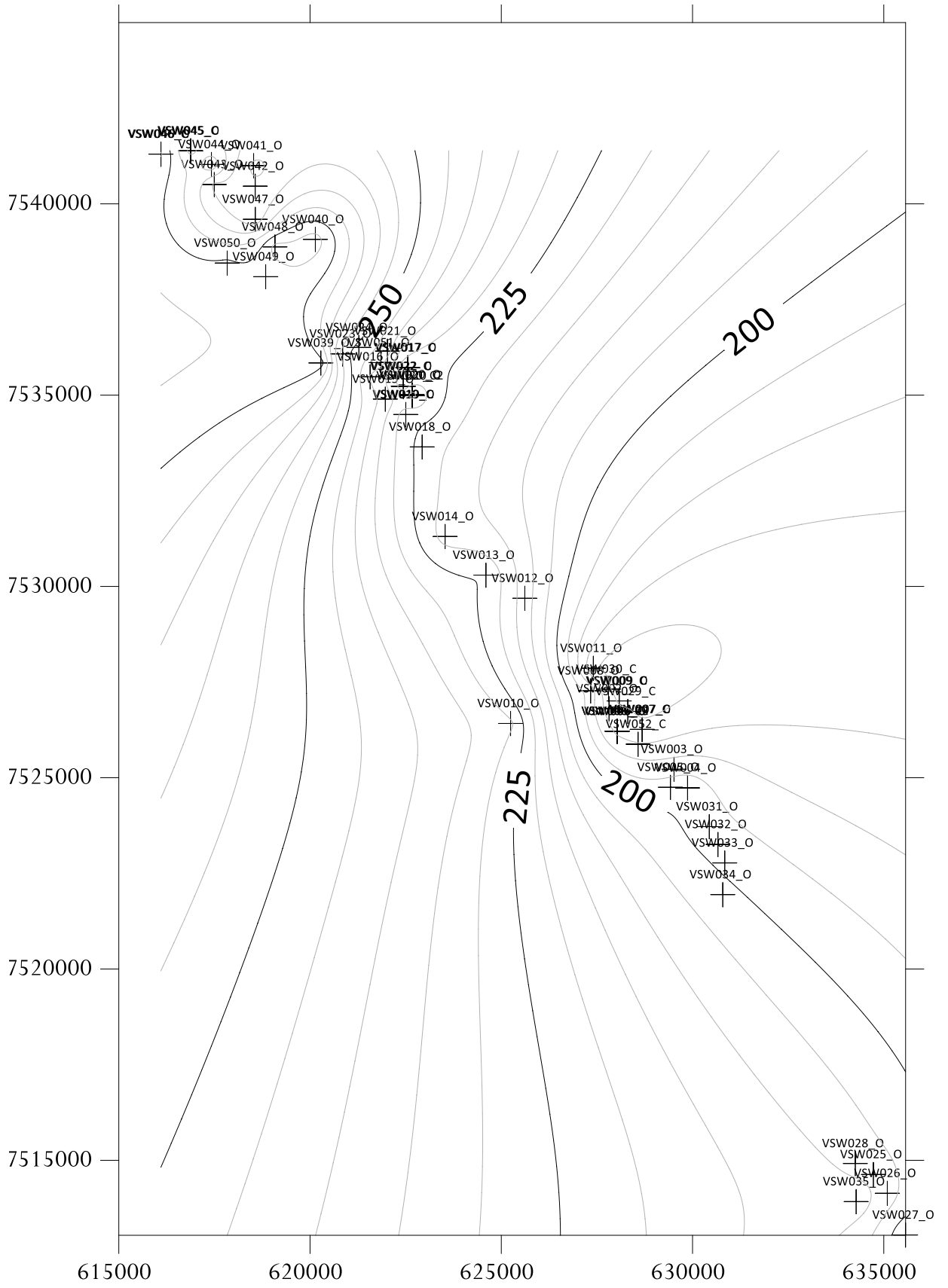


Figure 3.1 Groundwater flow contours (mAHD) from exploration drill hole data

4. Groundwater quality

The monitoring bores were airlifted by Wizard Drilling Pty Ltd following drilling and completion. A groundwater sample was taken at the end of the airlifting process. Most monitoring bores were airlifted and sampled on the 6th and 7th June after completion of the drilling program, however five monitoring bores remained dry and two monitoring bores did not yield sufficient groundwater during the airlifting process to recover a sample to surface. Table 4.1 summarises the field groundwater quality from the Vulcan Complex monitoring bores.

Table 4.1 Vulcan Complex monitoring bores – groundwater quality

Bore ID	EC - field (µS/cm)	EC - lab (µS/cm)	pH - field	pH - lab	Temp – field (°C)	Target unit	Comments
MB1	-	-	-	-	-	DLL coal seam	Dry
MB2	-	-	-	-	-	DLL coal seam	Dry
MB3	-	-	-	-	-	DLL coal seam	Insufficient water to develop, no sample taken
MB4	2520	2280	7.92	7.94	18.2	DLL coal seam	Clear, slightly yellow
MB5	2960	2680	8.55	8.17	19.0	MAT coal seam	Clear
MB6	-	-	-	-	-	Weathered Permian	Dry
MB7	5680	5430	8.78	8.31	18.9	Weathered Permian	Muddy, yellow brown
MB8	-	-	-	-	-	Weathered Permian	Dry
MB9	5520	16200	8.58	7.95	19.4	DLL coal seam	Very cloudy, yellow brown
MB10	-	-	-	-	-	DLL coal seam	Insufficient water to develop, no sample taken
MB11	-	-	-	-	-	DLL coal seam	Dry
MB12	22800	21600	8.29	7.81	19.0	Permian underburden	Slightly cloudy, olive grey

Notes: *EC – electrical conductivity*

The laboratory results for electrical conductivity (EC) and pH generally confirm the field measurements. Field EC of the groundwaters ranges from about 2500 µS/cm to 23000 µS/cm, and as such the groundwater is classified as moderately saline to saline. The field EC measurement for MB9 did not compare well with the laboratory measurement and this is considered due to the very small volumes of groundwater being discharged from the bore during airlifting. On-going monitoring and sampling will confirm the groundwater salinity. The field pH ranges from 7.9 to 8.8 and is slightly alkaline.

Groundwater salinity is important to understanding for water management and use. Salinity can be generally categorised by total dissolved solids (TDS) concentrations and the following salinity ranges are commonly used:

- Fresh 0 to 500 mg/L (0 to 750 µS/cm)
- Brackish 500 to 1500 mg/L (750-2500 µS/cm)
- Moderately saline 1500 to 7000 mg/L (2500-10000 µS/cm)
- Saline 7000 to 15000 mg/L (10000-25000 µS/cm)

Typically, groundwater quality will change as water migrates through the groundwater system. Salinity and EC can be used to infer both residence time in the aquifer and also proximity to the recharge source. For example, groundwater with an EC of less than 500 µS/cm will be closer to the recharge source and will have a shorter residence time in the aquifer, whereas groundwater of 5000 µS/cm will be further from the recharge source and will have a greater residence time.

Samples were collected in the field using laboratory supplied containers. The samples were field filtered where required using either disposable syringes and 45 micron disc filters, or steri-cups and vacuum pump for the more turbid samples. The samples were immediately stored on ice and refrigerated were possible. All samples were freighted on ice under a chain of custody (CoC) with TNT in laboratory supplied eskies. The samples were delivered directly to ALS (Mackay) and analysed at ALS (Brisbane), a NATA certified laboratory.

Laboratory certificates for all groundwaters are included in Appendix B. The laboratory water quality results of all groundwaters are summarised in Table 4.2 for major ions, Table 4.3 for dissolved metals; and Table 4.4 for total metals.

A piper diagram is presented in Figure 4.1 and extended Durov diagram presented in Figure 4.2 which shows the distribution of water types in the project area. The groundwaters are Sodium (Na) dominant with dominant Chloride (Cl) and minor bicarbonate (HCO_3) and sulphate (SO_4) anions.

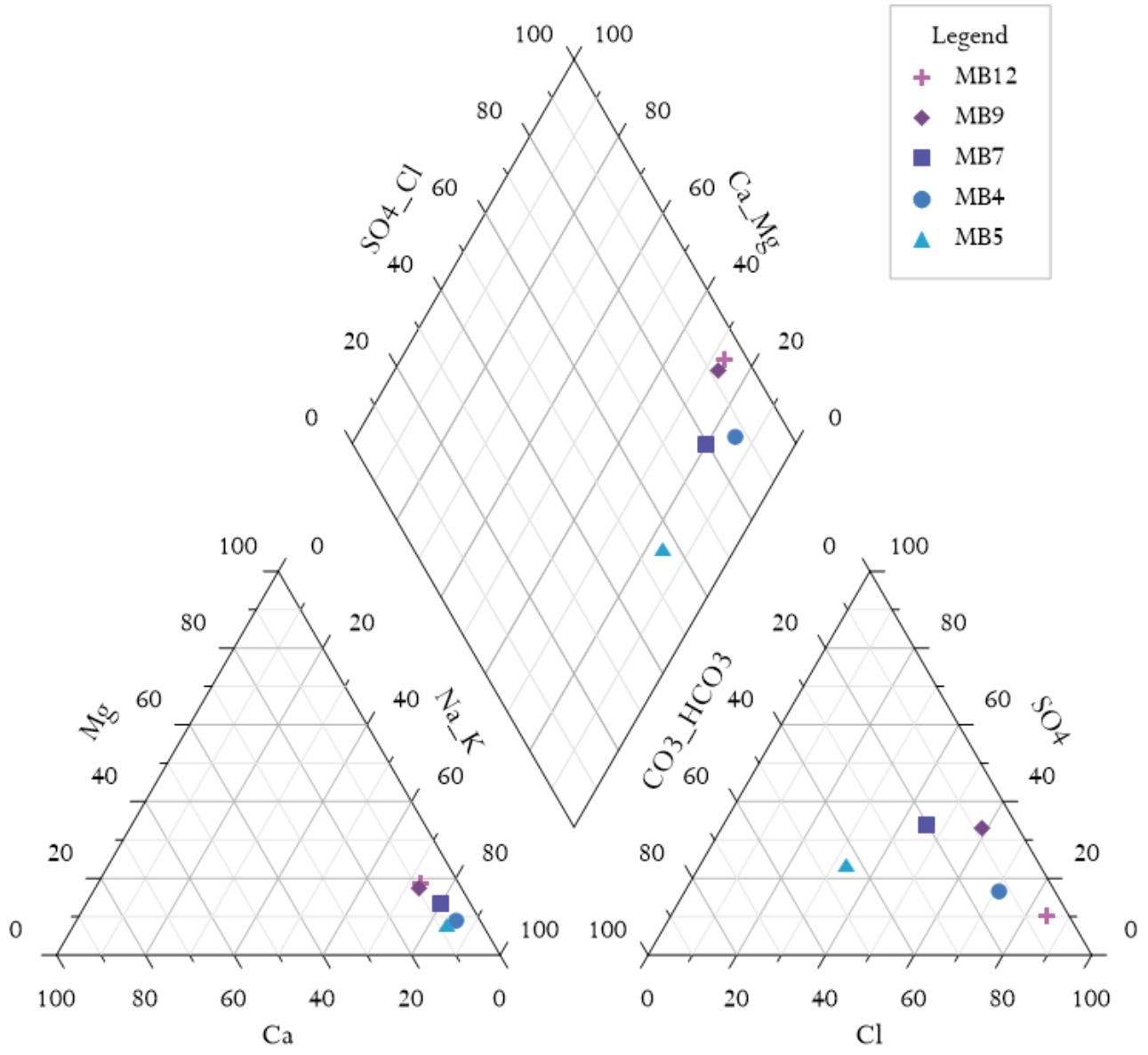


Figure 4.1 Piper diagram

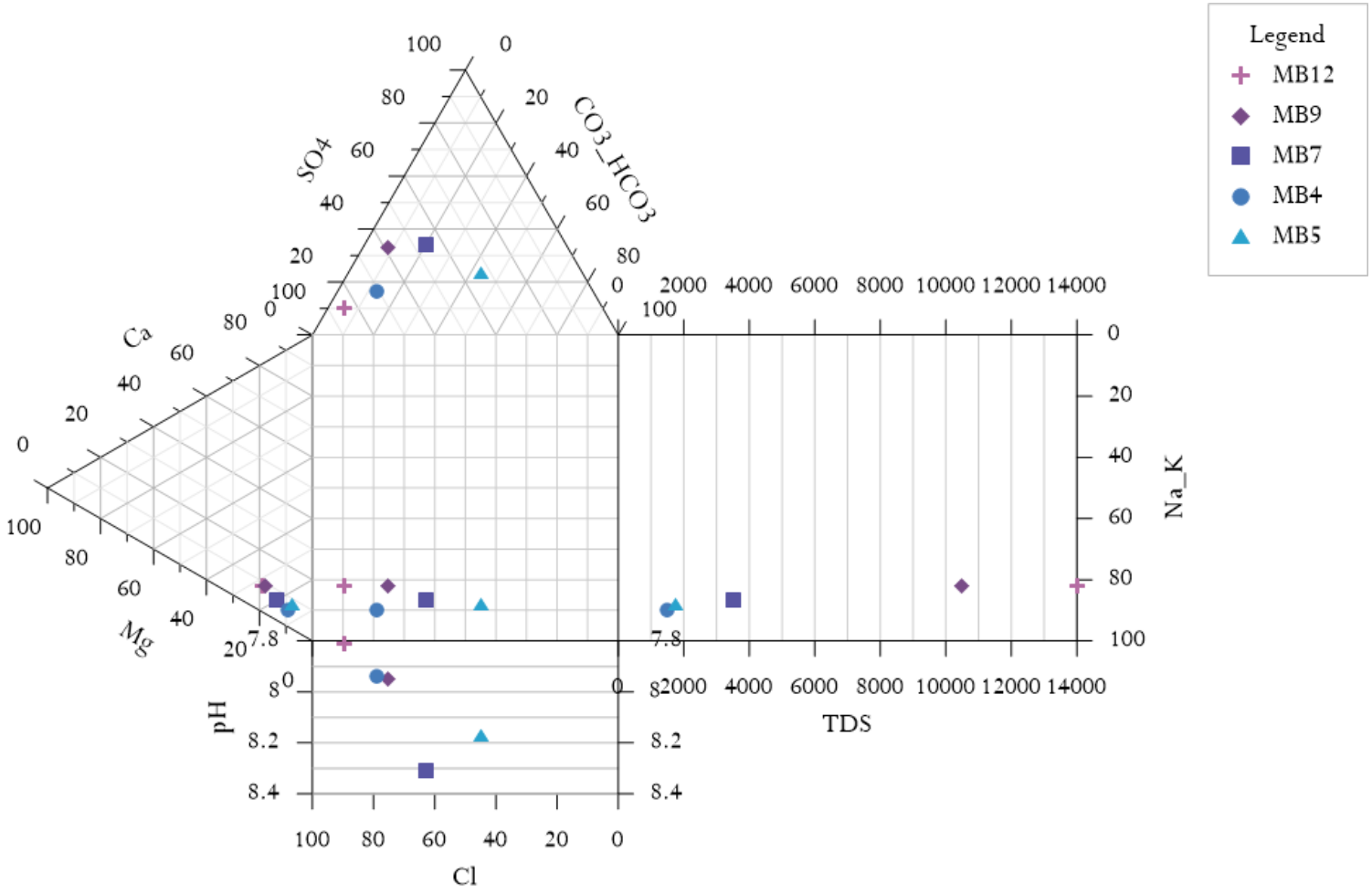


Figure 4.2 Extended Durov diagram

Table 4.2 Laboratory water quality data – major ions

			ALS Sample Number:	EB1915096001	EB1915096002	EB1915096003	EB1915096004	EB1915096005
			Sample Date:	06/06/2019	06/06/2019	06/06/2019	07/06/2019	07/06/2019
			Client sample ID (1st):	MB12	MB9	MB7	MB4	MB5
Analyte grouping/Analyte	CAS Number	Unit	Limit of reporting					
EA005P: pH by PC Titrator								
pH Value		pH Unit	0.01	7.81	7.95	8.31	7.94	8.17
EA006: Sodium Adsorption Ratio (SAR)								
Sodium Adsorption Ratio			0.01	22.1	20.0	14.4	10.9	12.5
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C		µS/cm	1	21600	16200	5430	2280	2680
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)		mg/L	1	14000	10500	3530	1480	1740
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3		mg/L	1	4710	3780	905	242	345
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	mg/L	1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	mg/L	1	<1	<1	4	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	mg/L	1	468	632	486	108	550
Total Alkalinity as CaCO3		mg/L	1	468	632	490	108	550
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	mg/L	1	908	2580	819	140	293
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	mg/L	1	7650	4590	1100	603	416
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	mg/L	1	408	369	87	26	54
Magnesium	7439-95-4	mg/L	1	897	694	167	43	51
Sodium	7440-23-5	mg/L	1	3490	2820	997	389	534
Potassium	7440-09-7	mg/L	1	19	73	8	16	17
EG052F: Dissolved Silica by ICPAES								
Silicon as SiO2	14464-46-1	mg/L	0.1	22.5	27.8	24.2	12.7	21.8
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	mg/L	0.1	0.3	0.7	0.8	1.0	0.3
ED009: Anions								
Bromide	24959-67-9	mg/L	0.010	14.8	10.1	2.60	1.09	0.980
EN055: Ionic Balance								
Total Anions		meq/L	0.01	244	196	57.9	22.1	28.8
Total Cations		meq/L	0.01	246	200	61.6	22.2	30.6
Ionic Balance		%	0.01	0.49	1.07	3.17	0.19	2.91

Table 4.3 Laboratory water quality data – dissolved metals

			ALS Sample Number:	EB1915096001	EB1915096002	EB1915096003	EB1915096004	EB1915096005
			Sample Date:	06/06/2019	06/06/2019	06/06/2019	07/06/2019	07/06/2019
			Client sample ID (1st):	MB12	MB9	MB7	MB4	MB5
Analyte grouping/Analyte	CAS Number	Unit	Limit of reporting					
Aluminium	7429-90-5	mg/L	0.01	0.04	0.01	0.02	<0.01	0.02
Antimony	7440-36-0	mg/L	0.001	0.002	<0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	mg/L	0.001	0.002	0.001	0.001	<0.001	<0.001
Beryllium	7440-41-7	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	7440-39-3	mg/L	0.001	0.143	0.100	0.070	0.094	0.028
Cadmium	7440-43-9	mg/L	0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001
Chromium	7440-47-3	mg/L	0.001	<0.001	0.001	<0.001	<0.001	<0.001
Cobalt	7440-48-4	mg/L	0.001	0.008	0.004	0.004	0.004	<0.001
Copper	7440-50-8	mg/L	0.001	0.001	0.022	<0.001	<0.001	<0.001
Lead	7439-92-1	mg/L	0.001	0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	mg/L	0.001	0.173	0.264	0.384	0.820	0.019
Molybdenum	7439-98-7	mg/L	0.001	0.003	0.003	0.007	<0.001	<0.001
Nickel	7440-02-0	mg/L	0.001	0.012	0.010	0.003	0.006	0.002
Selenium	7782-49-2	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	7440-22-4	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	7440-24-6	mg/L	0.001	6.27	8.28	1.69	0.171	0.392
Uranium	7440-61-1	mg/L	0.001	0.008	0.030	0.016	0.001	0.001
Vanadium	7440-62-2	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	7440-66-6	mg/L	0.005	1.17	0.116	<0.005	<0.005	0.056
Boron	7440-42-8	mg/L	0.05	0.63	1.08	0.66	0.13	0.21
Iron	7439-89-6	mg/L	0.05	<0.05	<0.05	<0.05	0.36	<0.05
Mercury	7439-97-6	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 4.4 Laboratory water quality data – total metals

			ALS Sample Number:	EB1915096001	EB1915096002	EB1915096003	EB1915096004	EB1915096005
			Sample Date:	06/06/2019	06/06/2019	06/06/2019	07/06/2019	07/06/2019
			Client sample ID (1st):	MB12	MB9	MB7	MB4	MB5
Analyte grouping/Analyte	CAS Number	Unit	Limit of reporting					
Aluminium	7429-90-5	mg/L	0.01	1.61	8.38	16.5	0.12	0.65
Antimony	7440-36-0	mg/L	0.001	0.002	<0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	mg/L	0.001	0.004	0.004	0.022	<0.001	<0.001
Beryllium	7440-41-7	mg/L	0.001	<0.001	0.001	0.004	<0.001	<0.001
Barium	7440-39-3	mg/L	0.001	0.168	0.125	0.664	0.108	0.036
Cadmium	7440-43-9	mg/L	0.0001	<0.0001	0.0006	<0.0001	<0.0001	<0.0001
Chromium	7440-47-3	mg/L	0.001	0.004	0.034	0.032	<0.001	<0.001
Cobalt	7440-48-4	mg/L	0.001	0.011	0.010	0.042	0.005	0.002
Copper	7440-50-8	mg/L	0.001	0.006	0.047	0.085	0.002	0.002
Lead	7439-92-1	mg/L	0.001	0.006	0.010	0.059	<0.001	0.002
Manganese	7439-96-5	mg/L	0.001	0.222	0.332	0.627	0.846	0.027
Molybdenum	7439-98-7	mg/L	0.001	0.004	0.003	0.004	<0.001	<0.001
Nickel	7440-02-0	mg/L	0.001	0.018	0.032	0.045	0.007	0.004
Selenium	7782-49-2	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	7440-22-4	mg/L	0.001	0.001	<0.001	0.001	<0.001	<0.001
Strontium	7440-24-6	mg/L	0.001	7.09	9.36	1.94	0.167	0.411
Uranium	7440-61-1	mg/L	0.001	0.009	0.031	0.017	0.001	0.002
Vanadium	7440-62-2	mg/L	0.01	<0.01	0.04	0.05	<0.01	<0.01
Zinc	7440-66-6	mg/L	0.005	1.51	0.613	0.253	0.012	0.103
Boron	7440-42-8	mg/L	0.05	0.64	1.09	0.66	0.13	0.20
Iron	7439-89-6	mg/L	0.05	3.50	10.1	20.1	3.38	0.78
Mercury	7439-97-6	mg/L	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001

5. Further work

The following activities and data collection are still to be carried out to complete the groundwater monitoring network and to understand the groundwater occurrence within the project area.

- Hydraulic testing of each monitoring bore is to be carried out to understand the hydraulic conductivity of the screened interval. Ideally this should occur following stabilisation of a groundwater level in each monitoring bore.
- Regular groundwater level and quality monitoring is required to establish baseline groundwater conditions for the project approval.
- Stygofauna sampling should be completed on the monitoring bore network after six months (December 2019).

Appendix A Monitoring bore logs

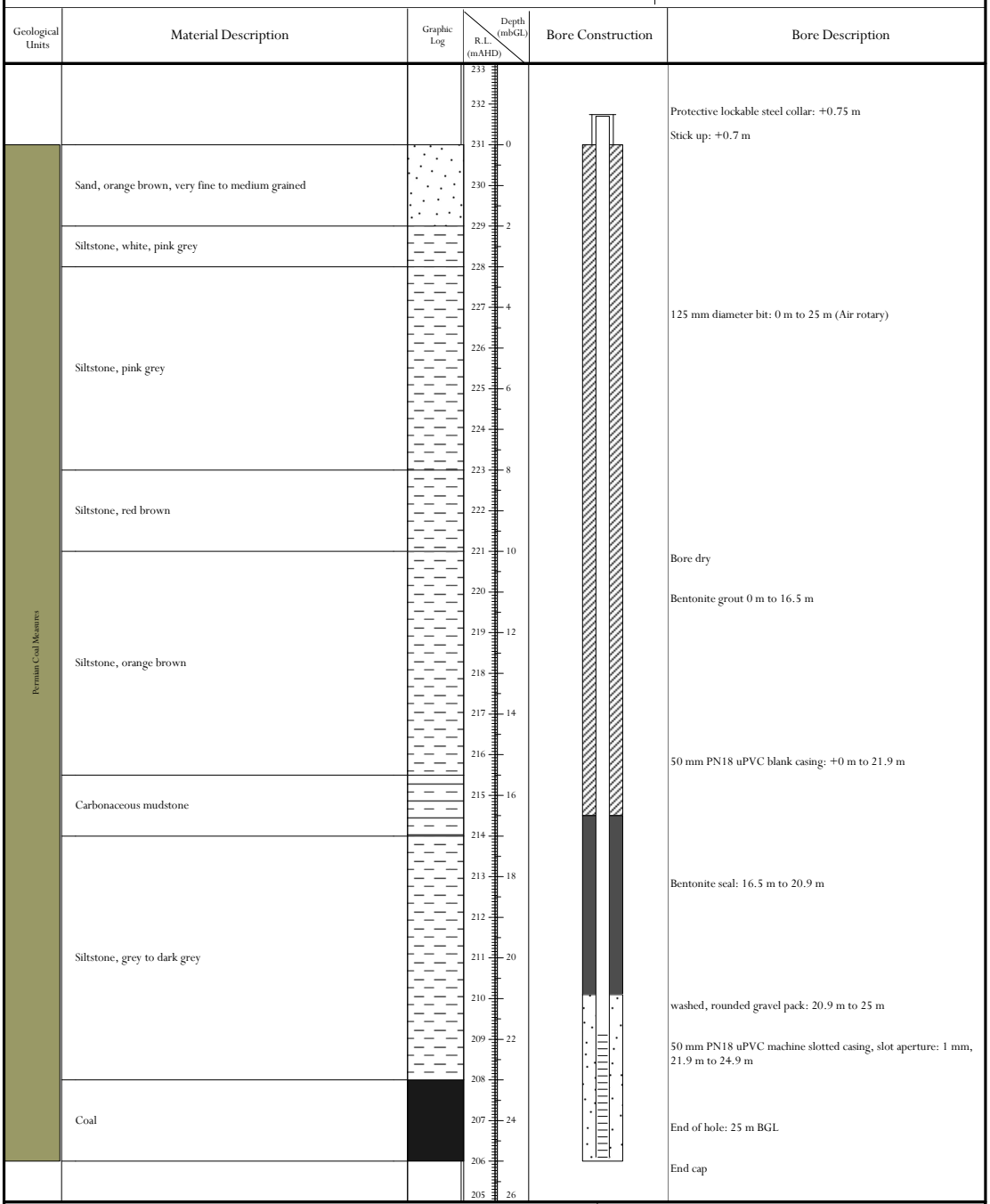
hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB1



Date Drilled: 07.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 625608 RL: 231.0

Northing: 7529692 TD: 24.9

Datum: MGA94 Zone55

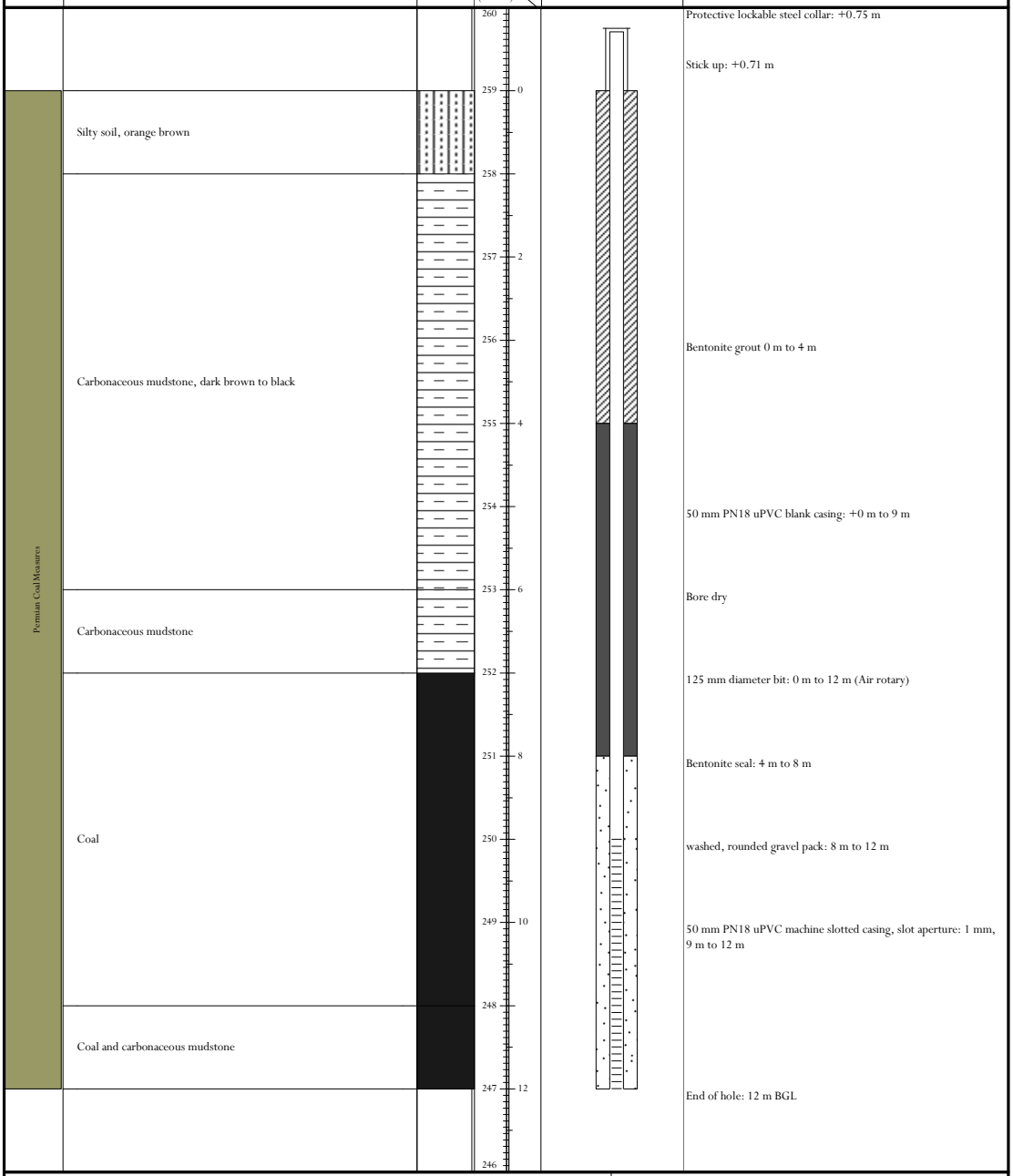
hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB2



Date Drilled: 07.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 622515 RL: 259.0

Northing: 7534485 TD: 12.0

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB3

Geological Units	Material Description	Graphic Log	Depth (mbGL) / R.L. (mAHD)	Bore Construction	Bore Description
			265 / 0		Protective lockable steel collar: +0.9 m Stick up: +0.7 m
Permian Coal Measures	Sandstone, light grey, orange brown, very fine to medium grained		263 / 2		
	Sandstone, light grey to white, very fine to coarse grained		261 / 4		
	Sandstone, light grey to red brown, very fine to fine grained		259 / 6		
	Carbonaceous mudstone		257 / 8		
	Carbonaceous mudstone and grey siltstone		255 / 10		
	Coal		254 / 11		
	Carbonaceous mudstone and grey siltstone		253 / 12		
	Siltstone, grey		251 / 14		125 mm diameter bit: 0 m to 34m (Air rotary)
			249 / 16		
			247 / 18		
			245 / 20		
			243 / 22		Bentonite grout 0 m to 26 m
			241 / 24		Bore development: No water produced during airlift
	Siltstone, dark grey with carbonaceous mudstone		239 / 26		50 mm PN18 uPVC blank casing: +0 m to 30.8 m
			237 / 28		Bentonite seal: 26 m to 30 m
			235 / 30		washed, rounded gravel pack: 30 m to 34 m
	Siltstone, dark grey with carbonaceous mudstone		233 / 32		50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 30.8 m to 33.8 m SWL: 34.3 mbtoc on the 07.06.2019
	Coal		231 / 34		End of hole: 34 m BGL End cap

Date Drilled: 07.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 622665 RL: 263.0

Northing: 7535021 TD: 33.8

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB4

Geological Units	Material Description	Graphic Log	R.L. (mAHD) / Depth (mbGL)	Bore Construction	Bore Description
			251		Protective lockable steel collar: +0.77 m
			250		Stick up: +0.71 m
Permian Coal Measures	Sand, yellow to brown, fine to coarse grained		249 – 0		
	Sand, grey, very fine to coarse grained		248		
	Sand, orange brown to white, quartzose, very fine to coarse grained		247 – 2		
	Sandstone, white, very fine to coarse grained, quartzose		246 / 245 – 4		125 mm diameter bit: 0 m to 21.5m (Air rotary)
	Coal		244 / 243 – 6		SWL: 5.83 mbtoc on the 07.06.2019
	Carbonaceous mudstone		242 / 241 – 8		
	Dark grey siltstone and carbonaceous mudstone		240		
	Carbonaceous mudstone		239 – 10 / 238		Bentonite grout 0 m to 13 m
	Siltstone, dark grey with carbonaceous mudstone		237 – 12 / 236		Bentonite seal: 13 m to 17.5 m
			235 – 14 / 234		50 mm PN18 uPVC blank casing: +0 m to 18.5 m
	Carbonaceous mudstone, dark grey		233 – 16 / 232		Airlift flow rate: 0.1 L/min Bore development: 1.5 hrs; EC: 2520 uS/cm; pH: 7.92
			231 – 18		washed, rounded gravel pack: 17.5 m to 21.5 m
	Coal		230 / 229 – 20		50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 18.5 m to 21.5 m
	Carbonaceous mudstone, dark grey and coal		228 / 227 – 22		End of hole: 22.1 m BGL

Date Drilled: 07.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 622016 RL: 249.0

Northing: 7536148 TD: 21.5

Datum: MGA94 Zone55

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Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB5

Geological Units	Material Description	Graphic Log	R.L. (mAHD) / Depth (mbGL)	Bore Construction	Bore Description
			259		
			258		
			257 / 0		Protective lockable steel collar: +0.81 m Stick up: +0.77 m
Permian Coal Measures	Sandstone, light red to brown, very fine to fine grained		256		
	Sandstone, light grey, very fine grained, minor siltstone		255 / 2		
			254		
			253 / 4		
			252		
	Sandstone, grey silty, very fine grained		251 / 6		
	Mudstone, dark grey and siltstone		250		
			249 / 8		
	Mudstone, grey and siltstone		248		
			247 / 10		
			246		
			245 / 12		
			244		
	Siltstone, grey		243 / 14		SWL: 14.53 mbtoc on the 07.06.2019
			242		50 mm PN18 uPVC blank casing: +0 m to 37.9 m
			241 / 16		
	Carbonaceous mudstone		240		
	Siltstone, grey to very fine sandstone		239 / 18		Bore development: 1 hr; EC: 2960 uS/cm; pH: 8.55 Airlift flow rate: 0.2 L/min
			238		
	Sandstone, grey, very fine to medium grained		237 / 20		125 mm diameter bit: 0 m to 41 m (Air rotary)
			236		
			235 / 22		
			234		
	Carbonaceous mudstone, dark grey		233 / 24		
	Sandstone, grey, very fine grained		232		Bentonite grout 0 m to 32 m
			231 / 26		
	Mudstone, dark grey with siltstone		230		
			229 / 28		
			228		
	Siltstone, dark grey		227 / 30		
	Sandstone, grey, very fine to fine grained		226		
			225 / 32		
	Sandstone, grey, very fine grained		224		Bentonite seal: 32 m to 36.8 m
			223 / 34		
	Carbonaceous mudstone, dark grey		222		
	Siltstone, dark grey		221 / 36		
	Carbonaceous mudstone with grey silstone		220		
			219 / 38		washed, rounded gravel pack: 36.8 m to 41 m 50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 37.9 m to 40.9 m End of hole: 41 m BGL
	Coal		218		
			217 / 40		End cap
	Siltstone, grey		216		
			215 / 42		

Date Drilled: 07.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 621965 RL: 257.0

Northing: 7534904 TD: 40.9

Datum: MGA94 Zone55

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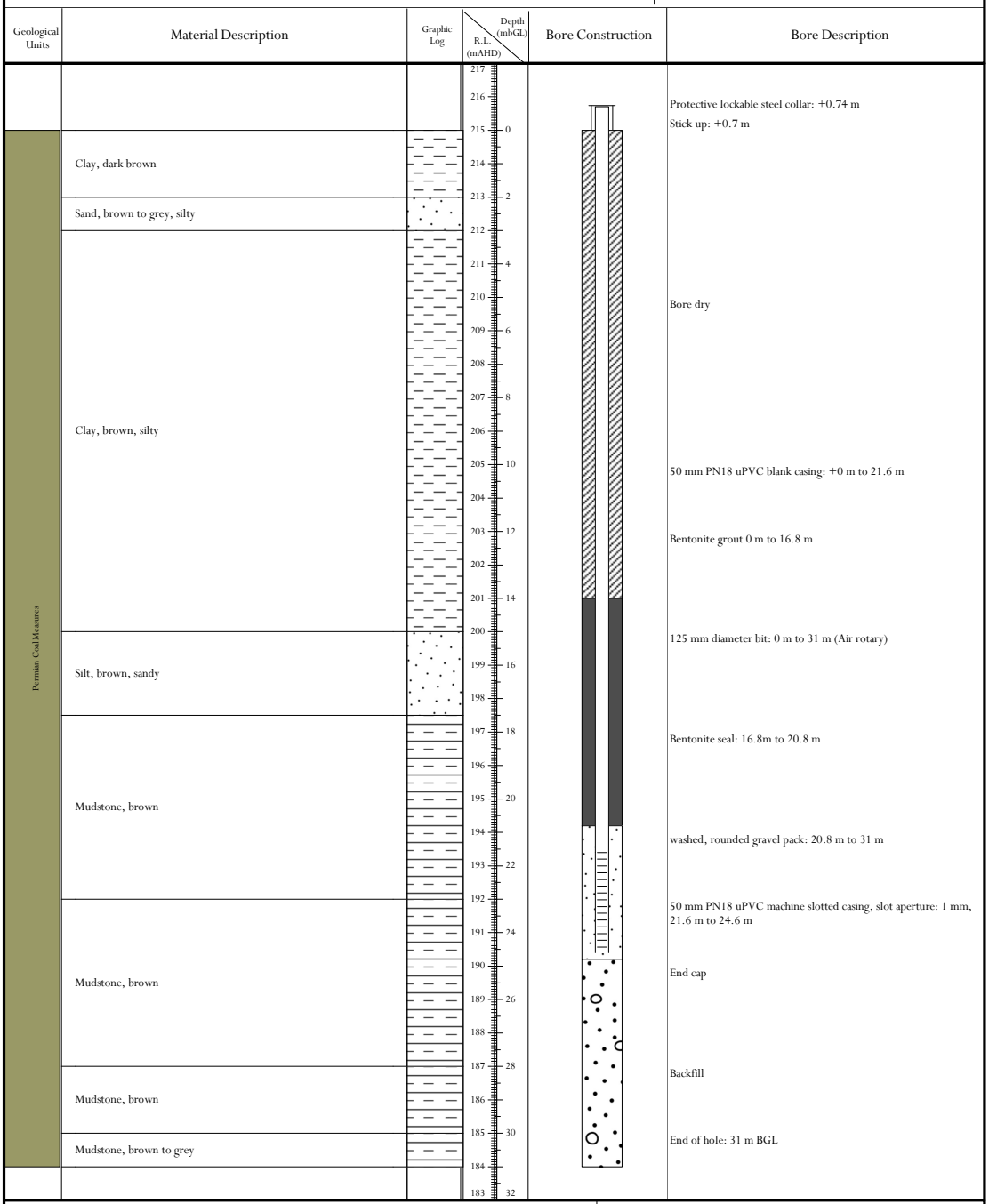
Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB6



Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 628121 RL: 215.0

Northing: 7526477 TD: 24.6

Datum: MGA94 Zone55

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Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB7

Geological Units	Material Description	Graphic Log	R.L. (mAHD) / Depth (mbGL)	Bore Construction	Bore Description
			221		
			220		
			219		
			218		
			217 / 0		Protective lockable steel collar: +0.71 m Stick up: +0.67 m
Permian Coal Measures	Clay, dark grey		216		
	Clay, dark brown, silty		215 / 2		
	Clay, brown, silty with silcrete bands		214		
	Clay, light brown, silty, weathered siltstone		213 / 4		
			212		
			211 / 6		
	Gravel, 1 mm to 30 mm subrounded lithic clasts		210		
			209 / 8		
	Sand, silty, light brown, very fine to fine grained		208		
			207 / 10		50 mm PN18 uPVC blank casing: +0 m to 40.0 m
	Sand, silty, brown		206		
			205 / 12		
			204		
			203 / 14		
	Sand, silty, very fine to fine grained		202		
			201 / 16		
			200		Bore development: 0.5 hr; EC: 5680 uS/cm; pH: 8.78
			199 / 18		Airlift flow rate: 0.5 L/min
			198		
	Sand, gravelly, 1 mm to 15 mm quartz with lithic clasts		197 / 20		125 mm diameter bit: 0 m to 43 m (Air rotary)
			196		
	Silt, orange brown		195 / 22		
			194		
			193 / 24		
	Sandstone, light grey to orange brown, quartzose, very fine to medium grained		192		
			191 / 26		Bentonite grout 0 m to 34.5 m
			190		
	Sandstone, light grey to orange brown, quartzose, very fine to medium grained		189 / 28		
			188		
			187 / 30		
			186		
			185 / 32		
			184		
	Sandstone, orange brown, silty		183 / 34		SWL: 34.80 mbtoc on the 06.06.2019
			182		
			181 / 36		Bentonite seal: 34.5 m to 38.6 m
			180		
			179 / 38		
	Sandstone, light grey to light brown, very fine to coarse grained quartzose, minor gravel at base		178		
			177 / 40		washed, rounded gravel pack: 38.6 m to 43 m 50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 40.0 m to 43.0 m
			176		
			175 / 42		
	Siltstone, brown with dark brown siltstone at base		174		
			173 / 44		End of hole: 43 m BGL

Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 628692 RL: 217.0

Northing: 7526260 TD: 43.0

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB8

Geological Units	Material Description	Graphic Log	R.L. (mAHD) / Depth (mbGL)	Bore Construction	Bore Description
			216 / 0		Protective lockable steel collar: +0.75 m
			215		Stick up: +0.7 m
Permian Coal Measures	Clay, dark brown to black, stiff		214 / 1		
	Clay, brown to orange brown		213 / 2		
	Clay, light grey to grey		212 / 3		
	Clay, light grey, silty, sandy		211 / 4		125 mm diameter bit: 0 m to 24.4 m (Air rotary)
	Sand, white to light grey, silty, very fine to medium grained		210 / 5		
			209 / 6		
			208 / 7		
			207 / 8		
			206 / 9		
	Sand, white, silty, very fine grained		205 / 10		Bentonite grout 0 m to 16.1 m
			204 / 11		
			203 / 12		
	Sand, white, very fine grained to medium grained		202 / 13		
			201 / 14		50 mm PN18 uPVC blank casing: +0 m to 21 m
	Sand, white to light grey, silty, quartzose, very fine to medium grained		200 / 15		
			199 / 16		Bore dry
			198 / 17		
			197 / 18		
			196 / 19		Bentonite seal: 16.1 m to 20 m
			195 / 20		
			194 / 21		
			193 / 22		washed, rounded gravel pack: 20 m to 24.4 m
	Siltstone, light orange brown, very minor sandstone, very fine to fine grained lenses		192 / 23		50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 21 m to 24 m
			191 / 24		End of hole: 24.4 m BGL
			190 / 25		End cap
			189 / 26		
			188		

Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 628094 RL: 214.0

Northing: 7527017 TD: 24.0

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB9

Geological Units	Material Description	Graphic Log	Depth (mbGL) / R.L. (mAHD)	Bore Construction	Bore Description
			215		
			214		Protective lockable steel collar: +0.7 m Stick up: +0.65 m
Permian Coal Measures	Clay, brown grey, silty		213 / 0		
	Sand, orange to brown, silty, very fine to medium grained		212 211 / 2		
	Sand, orange to brown, silty, very fine to medium grained		210 209 / 4		125 mm diameter bit: 0 m to 35.8 m (Air rotary)
	Clay, brown to grey, silty		208 207 / 6		
	Clay, grey to brown, silty		206		50 mm PN18 uPVC blank casing: +0 m to 31.4 m
	Gravel, orange to brown, clayey, subrounded 10 mm to 25 mm		205 / 8		
	Sandstone, grey to brown, silty, very fine to fine grained		204 203 / 10		
	Clay, brown to grey, mottled		202 201 / 12 200 199 / 14 198		Bentonite grout 0 m to 27.5 m
	Sandstone, light grey, very fine to fine grained with brown mudstone		197 / 16 196		Bore development: 0.5 hrs; EC: 5520 uS/cm; pH: 8.58
	Mudstone, grey to brown		195 / 18		Airlift flow rate: spray and dripping
	Mudstone, brown and grey sandstone, very fine grained		194 193 / 20 192		
	Sandstone, brown, silty with brown mudstone		191 / 22 190		
	Sandstone, brown to grey, very fine grained		189 / 24		
	Sandstone, brown, very fine to medium grained		188 187 / 26		
	Mudstone, brown to grey		186		SWL: 27.41 mbtoc on the 06.06.2019
	Siltstone, light brown and very fine grained sandstone		185 / 28 184		
	Carbonaceous mudstone		183 / 30 182		Bentonite seal: 27.5 m to 31.0 m
	Coal and mudstone		181 / 32 180		washed, rounded gravel pack: 31.0 m to 35.8 m 50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 31.4 m to 34.4 m
			179 / 34 178		End of hole: 35.8 m BGL
			177 / 36		

Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 629511 RL: 213.0

Northing: 7525225 TD: 34.4

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB10

Geological Units	Material Description	Graphic Log	R.L. (mAHD) / Depth (mbGL)	Bore Construction	Bore Description
			217 / 0		Protective lockable steel collar: +0.75 m Stick up: +0.70 m
Permian Coal Measures	Clay, dark brown		215 / 2		
	Sand, brown to grey, silty		213 / 4		Bentonite grout 0 m to 2 m
	Clay, brown, silty		211 / 6 209 / 8 207 / 10 205 / 12 203 / 14		125 mm diameter bit: 0 m to 42 m (Air rotary) Backfill 2 m to 32.5 m 50 mm PN18 uPVC blank casing: +0 m to 37.3 m
	Silt, brown, sandy		201 / 16		
	Mudstone, brown		199 / 18 197 / 20 195 / 22		Airlift flow rate: spray and dripping
	Mudstone, brown		193 / 24 191 / 26		
	Mudstone, brown		189 / 28		
	Mudstone, brown to grey		187 / 30 185 / 32		SWL: 32.51 mbtoc on the 06.06.2019
	Mudstone, grey		183 / 34 181 / 36		Bentonite seal: 32.5 m to 36.5 m
	Carbonaceous mudstone		179		
	Coal		177 / 38		washed, rounded gravel pack: 36.5 m to 42 m
	Carbonaceous mudstone		175 / 40		50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 37.3 m to 40.3 m
	Carbonaceous mudstone and siltstone		173 / 42		End of hole: 42 m BGL

Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 628125 RL: 215.0

Northing: 7526470 TD: 40.3

Datum: MGA94 Zone55

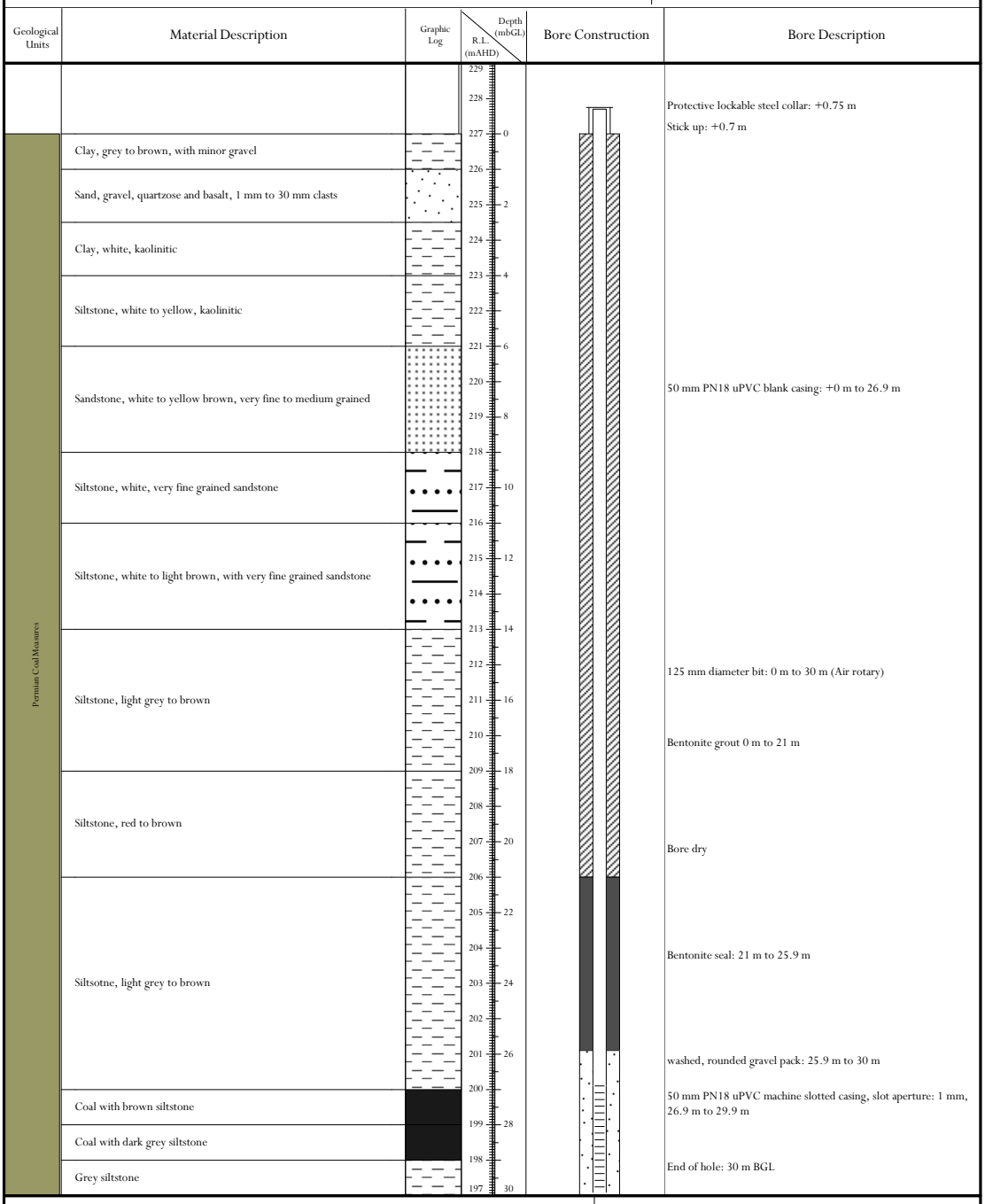
hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB11



Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 627405 RL: 227.0

Northing: 7527854 TD: 29.9

Datum: MGA94 Zone55

hydrogeologist.com.au

Project No.: 4015

Project Name: Vulcan Complex Project

MONITORING BORE

MB12

Geological Units	Material Description	Graphic Log	Depth (mbGL) / R.L. (mAHD)	Bore Construction	Bore Description
			249 / 0		Protective lockable steel collar: +0.77 m Stick up: +0.66 m
Permian Coal Measures	Silt, brown, clayey		247 / 2		
	Sandstone, orange brown, very fine grained		246 / 4		
	Siltstone, light grey		245 / 6		
	Sandstone, light grey, very fine to coarse grained		243 / 8		
	Sandstone, light grey brown, fine to coarse grained		239 / 10		
	Sandstone, light grey, very fine to medium grained		237 / 12		
	Sandstone, light grey brown, silty, very fine grained		234 / 14		
	Carbonaceous mudstone		232 / 16		125 mm diameter bit: 0 m to 38.3 m (Air rotary) Bentonite grout 0 m to 20 m
	Siltstone, dark grey, with very fine grained sandstone		230 / 18		Bore development: 1 hr; EC: 2280 uS/cm; pH: 8.29 Airlift flow rate: 0.1 L/min
	Siltstone, dark grey		227 / 20		50 mm PN18 uPVC blank casing: +0 m to 32.2 m
	Sandstone, light orange brown, very fine grained		223 / 24		Bentonite seal: 20 m to 24 m
	Sandstone, light grey, very fine grained		221 / 26		SWL: 26.82 mbtoc on the 07.06.2019
	Siltstone, grey		217 / 30		washed, rounded gravel pack: 24 m to 38.3 m
	Siltstone, dark grey		214 / 32		50 mm PN18 uPVC machine slotted casing, slot aperture: 1 mm, 32.2 m to 38.2 m
			209 / 38		End of hole: 38.3 m BGL End cap
			207 / 40		

Date Drilled: 06.06.2019

Driller: Andrew Holmes

Drill Rig: Mayhew 1000

Drilling Company: Wizard Drilling

Drilling Method: Rotary open hole

Logged By: DFB

Easting: 625252 RL: 247.0

Northing: 7526409 TD: 38.2

Datum: MGA94 Zone55

Appendix B ALS Certificate of analysis

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1915096**	Page	: 1 of 5
Client	: **VITRINITE PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: Mike Cavanagh	Contact	: Customer Services EB
Address	: Level 6 Suite 2 12 Creek Street Brisbane 4000	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: 4015 Vulcan	Date Samples Received	: 13-Jun-2019 09:30
Order number	:	Date Analysis Commenced	: 14-Jun-2019
C-O-C number	: ----	Issue Date	: 21-Jun-2019 11:36
Sampler	: Thomas Muehe		
Site	: ----		
Quote number	: TV/029/19 v2		
No. of samples received	: 5		
No. of samples analysed	: 5		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Mark Hallas	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Tom Maloney	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Tom Maloney	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EG035T (Total Mercury): Positive mercury results have been confirmed by re-extraction and re-analysis.
- It is recognised that EG020T (Total Metals) is less than EG020F (Dissolved Metals) for some samples. However, the difference is within experimental variation of the methods.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	MB12	MB9	MB7	MB4	MB5
				Client sampling date / time	06-Jun-2019 12:50	06-Jun-2019 15:10	06-Jun-2019 16:15	07-Jun-2019 09:30	07-Jun-2019 11:40
Compound	CAS Number	LOR	Unit		EB1915096-001	EB1915096-002	EB1915096-003	EB1915096-004	EB1915096-005
					Result	Result	Result	Result	Result
EA005P: pH by PC Titrator									
pH Value	----	0.01	pH Unit		7.81	7.95	8.31	7.94	8.17
EA006: Sodium Adsorption Ratio (SAR)									
^ Sodium Adsorption Ratio	----	0.01	-		22.1	20.0	14.4	10.9	12.5
EA010P: Conductivity by PC Titrator									
Electrical Conductivity @ 25°C	----	1	µS/cm		21600	16200	5430	2280	2680
EA016: Calculated TDS (from Electrical Conductivity)									
Total Dissolved Solids (Calc.)	----	1	mg/L		14000	10500	3530	1480	1740
EA065: Total Hardness as CaCO3									
Total Hardness as CaCO3	----	1	mg/L		4710	3780	905	242	345
ED037P: Alkalinity by PC Titrator									
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L		<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L		<1	<1	4	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L		468	632	486	108	550
Total Alkalinity as CaCO3	----	1	mg/L		468	632	490	108	550
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA									
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L		908	2580	819	140	293
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	1	mg/L		7650	4590	1100	603	416
ED093F: Dissolved Major Cations									
Calcium	7440-70-2	1	mg/L		408	369	87	26	54
Magnesium	7439-95-4	1	mg/L		897	694	167	43	51
Sodium	7440-23-5	1	mg/L		3490	2820	997	389	534
Potassium	7440-09-7	1	mg/L		19	73	8	16	17
EG020F: Dissolved Metals by ICP-MS									
Aluminium	7429-90-5	0.01	mg/L		0.04	0.01	0.02	<0.01	0.02
Antimony	7440-36-0	0.001	mg/L		0.002	<0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	0.001	mg/L		0.002	0.001	0.001	<0.001	<0.001
Beryllium	7440-41-7	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	<0.001
Barium	7440-39-3	0.001	mg/L		0.143	0.100	0.070	0.094	0.028
Cadmium	7440-43-9	0.0001	mg/L		<0.0001	0.0005	<0.0001	<0.0001	<0.0001
Chromium	7440-47-3	0.001	mg/L		<0.001	0.001	<0.001	<0.001	<0.001
Cobalt	7440-48-4	0.001	mg/L		0.008	0.004	0.004	0.004	<0.001
Copper	7440-50-8	0.001	mg/L		0.001	0.022	<0.001	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L		0.001	<0.001	<0.001	<0.001	<0.001

Analytical Results

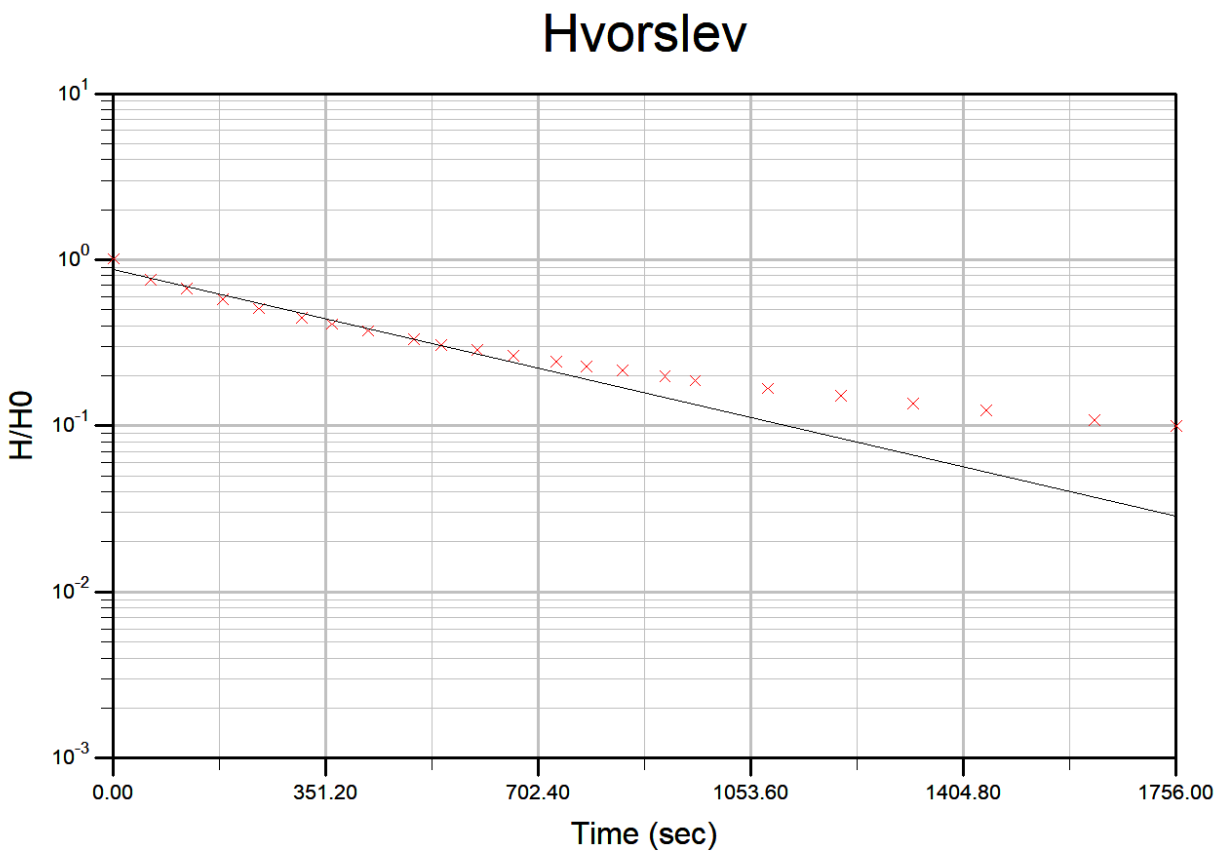
Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	MB12	MB9	MB7	MB4	MB5
				Client sampling date / time	06-Jun-2019 12:50	06-Jun-2019 15:10	06-Jun-2019 16:15	07-Jun-2019 09:30	07-Jun-2019 11:40
Compound	CAS Number	LOR	Unit		EB1915096-001	EB1915096-002	EB1915096-003	EB1915096-004	EB1915096-005
					Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued									
Manganese	7439-96-5	0.001	mg/L		**0.173**	**0.264**	**0.384**	**0.820**	**0.019**
Molybdenum	7439-98-7	0.001	mg/L		**0.003**	**0.003**	**0.007**	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L		**0.012**	**0.010**	**0.003**	**0.006**	**0.002**
Selenium	7782-49-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Silver	7440-22-4	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	7440-24-6	0.001	mg/L		**6.27**	**8.28**	**1.69**	**0.171**	**0.392**
Uranium	7440-61-1	0.001	mg/L		**0.008**	**0.030**	**0.016**	**0.001**	**0.001**
Vanadium	7440-62-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	7440-66-6	0.005	mg/L		**1.17**	**0.116**	<0.005	<0.005	**0.056**
Boron	7440-42-8	0.05	mg/L		**0.63**	**1.08**	**0.66**	**0.13**	**0.21**
Iron	7439-89-6	0.05	mg/L		<0.05	<0.05	<0.05	**0.36**	<0.05
EG020T: Total Metals by ICP-MS									
Aluminium	7429-90-5	0.01	mg/L		**1.61**	**8.38**	**16.5**	**0.12**	**0.65**
Antimony	7440-36-0	0.001	mg/L		**0.002**	<0.001	<0.001	<0.001	<0.001
Arsenic	7440-38-2	0.001	mg/L		**0.004**	**0.004**	**0.022**	<0.001	<0.001
Beryllium	7440-41-7	0.001	mg/L		<0.001	**0.001**	**0.004**	<0.001	<0.001
Barium	7440-39-3	0.001	mg/L		**0.168**	**0.125**	**0.664**	**0.108**	**0.036**
Cadmium	7440-43-9	0.0001	mg/L		<0.0001	**0.0006**	<0.0001	<0.0001	<0.0001
Chromium	7440-47-3	0.001	mg/L		**0.004**	**0.034**	**0.032**	<0.001	<0.001
Cobalt	7440-48-4	0.001	mg/L		**0.011**	**0.010**	**0.042**	**0.005**	**0.002**
Copper	7440-50-8	0.001	mg/L		**0.006**	**0.047**	**0.085**	**0.002**	**0.002**
Lead	7439-92-1	0.001	mg/L		**0.006**	**0.010**	**0.059**	<0.001	**0.002**
Manganese	7439-96-5	0.001	mg/L		**0.222**	**0.332**	**0.627**	**0.846**	**0.027**
Molybdenum	7439-98-7	0.001	mg/L		**0.004**	**0.003**	**0.004**	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L		**0.018**	**0.032**	**0.045**	**0.007**	**0.004**
Selenium	7782-49-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	<0.01
Silver	7440-22-4	0.001	mg/L		**0.001**	<0.001	**0.001**	<0.001	<0.001
Strontium	7440-24-6	0.001	mg/L		**7.09**	**9.36**	**1.94**	**0.167**	**0.411**
Uranium	7440-61-1	0.001	mg/L		**0.009**	**0.031**	**0.017**	**0.001**	**0.002**
Vanadium	7440-62-2	0.01	mg/L		<0.01	**0.04**	**0.05**	<0.01	<0.01
Zinc	7440-66-6	0.005	mg/L		**1.51**	**0.613**	**0.253**	**0.012**	**0.103**
Boron	7440-42-8	0.05	mg/L		**0.64**	**1.09**	**0.66**	**0.13**	**0.20**
Iron	7439-89-6	0.05	mg/L		**3.50**	**10.1**	**20.1**	**3.38**	**0.78**
EG035F: Dissolved Mercury by FIMS									

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	MB12	MB9	MB7	MB4	MB5
				Client sampling date / time	06-Jun-2019 12:50	06-Jun-2019 15:10	06-Jun-2019 16:15	07-Jun-2019 09:30	07-Jun-2019 11:40
Compound	CAS Number	LOR	Unit		EB1915096-001	EB1915096-002	EB1915096-003	EB1915096-004	EB1915096-005
					Result	Result	Result	Result	Result
EG035F: Dissolved Mercury by FIMS - Continued									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	**0.0001**	<0.0001	<0.0001
EG052F: Dissolved Silica by ICPAES									
Silicon as SiO2	14464-46-1	0.1	mg/L		**22.5**	**27.8**	**24.2**	**12.7**	**21.8**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.3**	**0.7**	**0.8**	**1.0**	**0.3**
EN055: Ionic Balance									
ø Total Anions	----	0.01	meq/L		**244**	**196**	**57.9**	**22.1**	**28.8**
ø Total Cations	----	0.01	meq/L		**246**	**200**	**61.6**	**22.2**	**30.6**
ø Ionic Balance	----	0.01	%		**0.49**	**1.07**	**3.17**	**0.19**	**2.91**
ED009: Anions									
Bromide	24959-67-9	0.010	mg/L		**14.8**	**10.1**	**2.60**	**1.09**	**0.980**

Appendix B Hydraulic testing results

MB4


Hvorslev
H/H0
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
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1053.60
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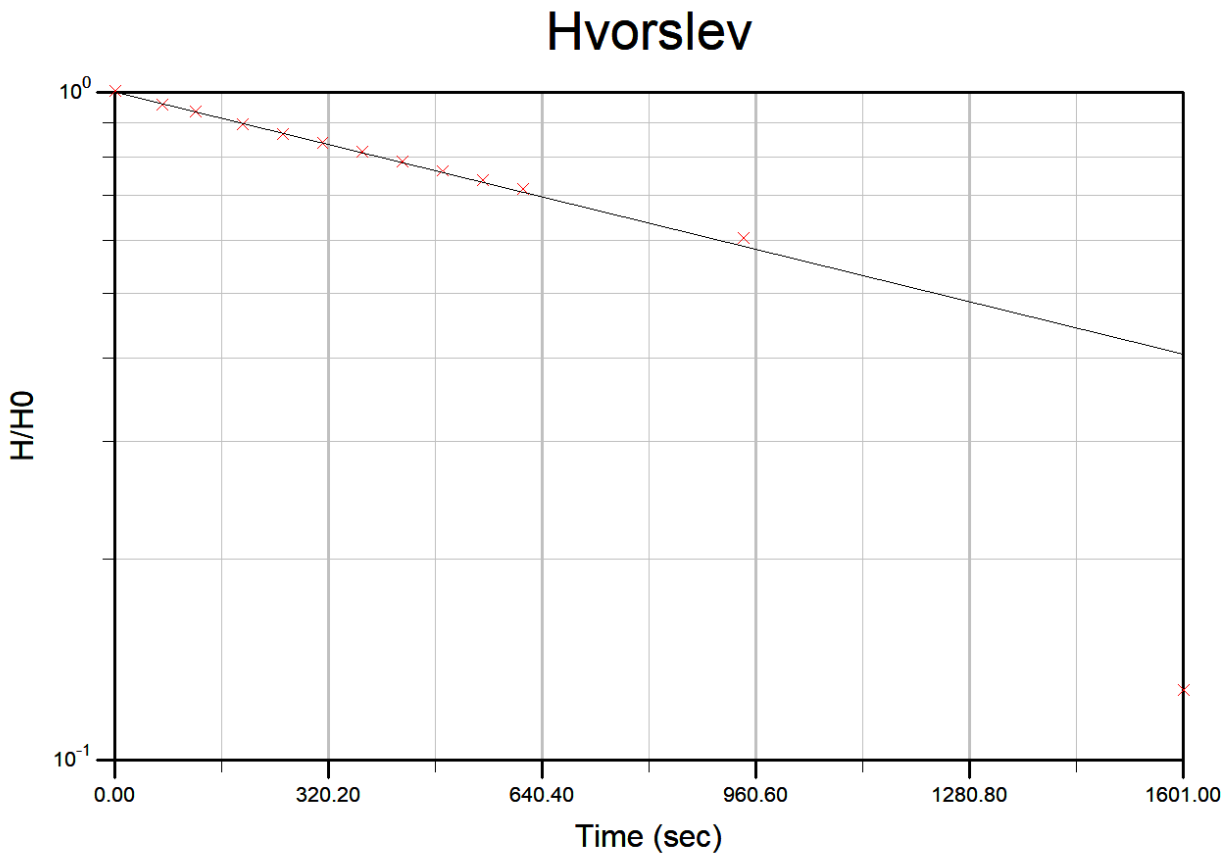
1756.00
Time (sec)

MB5


Hvorslev
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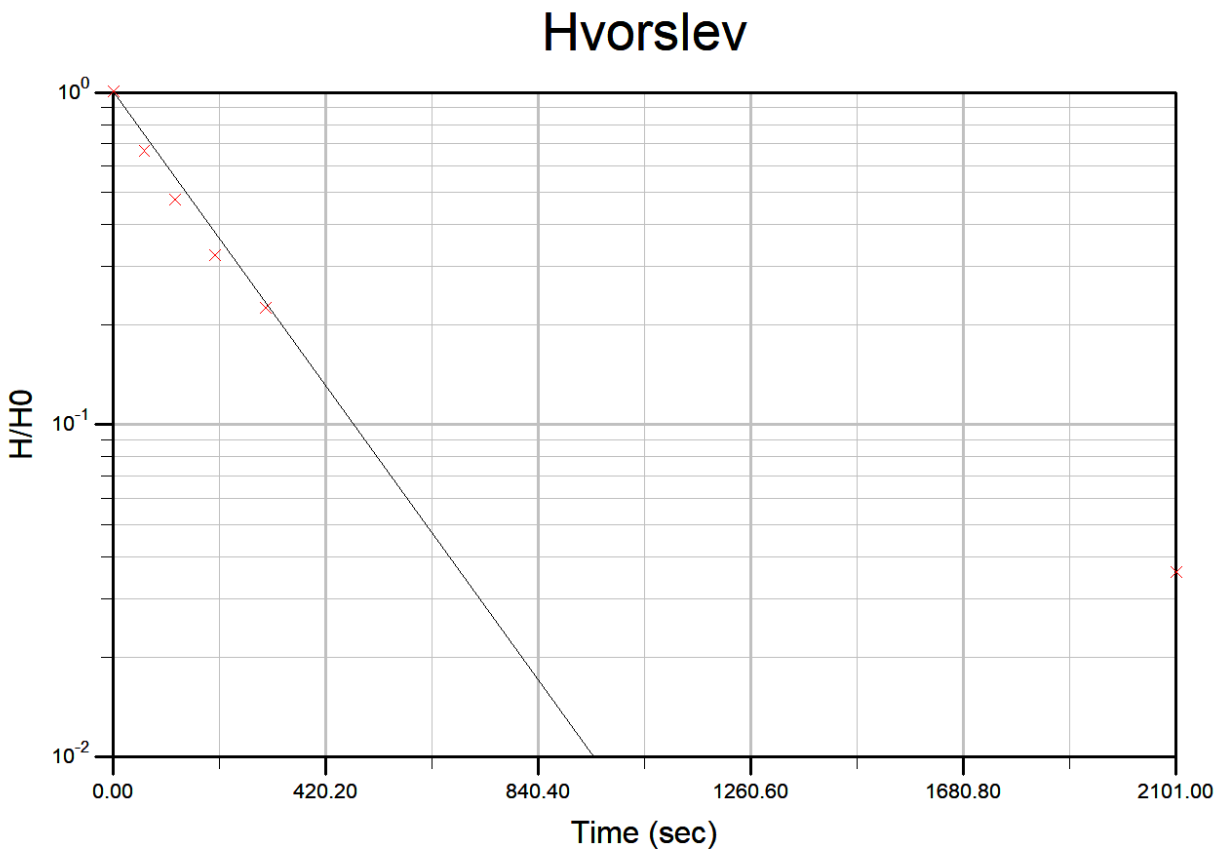
1280.80
1601.00
Time (sec)

MB7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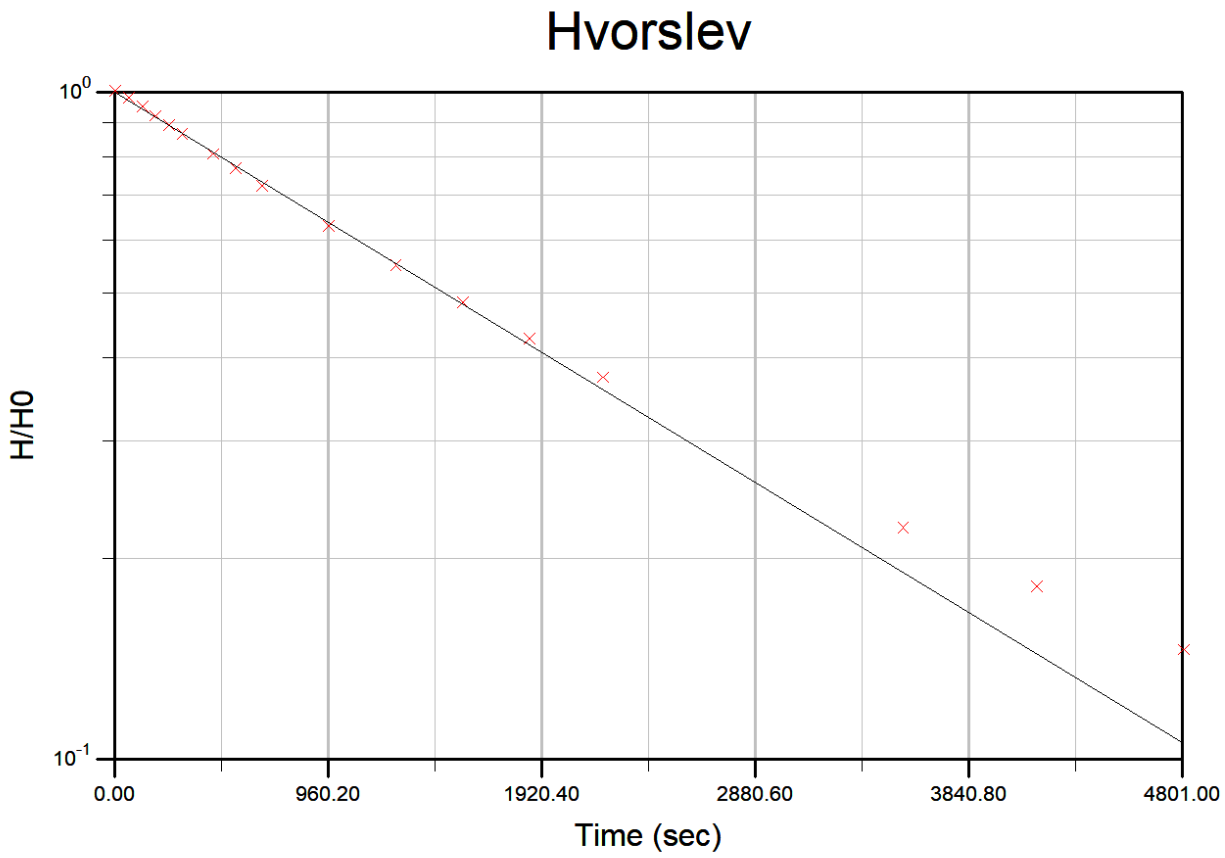
1680.80
2101.00
Time (sec)

MB9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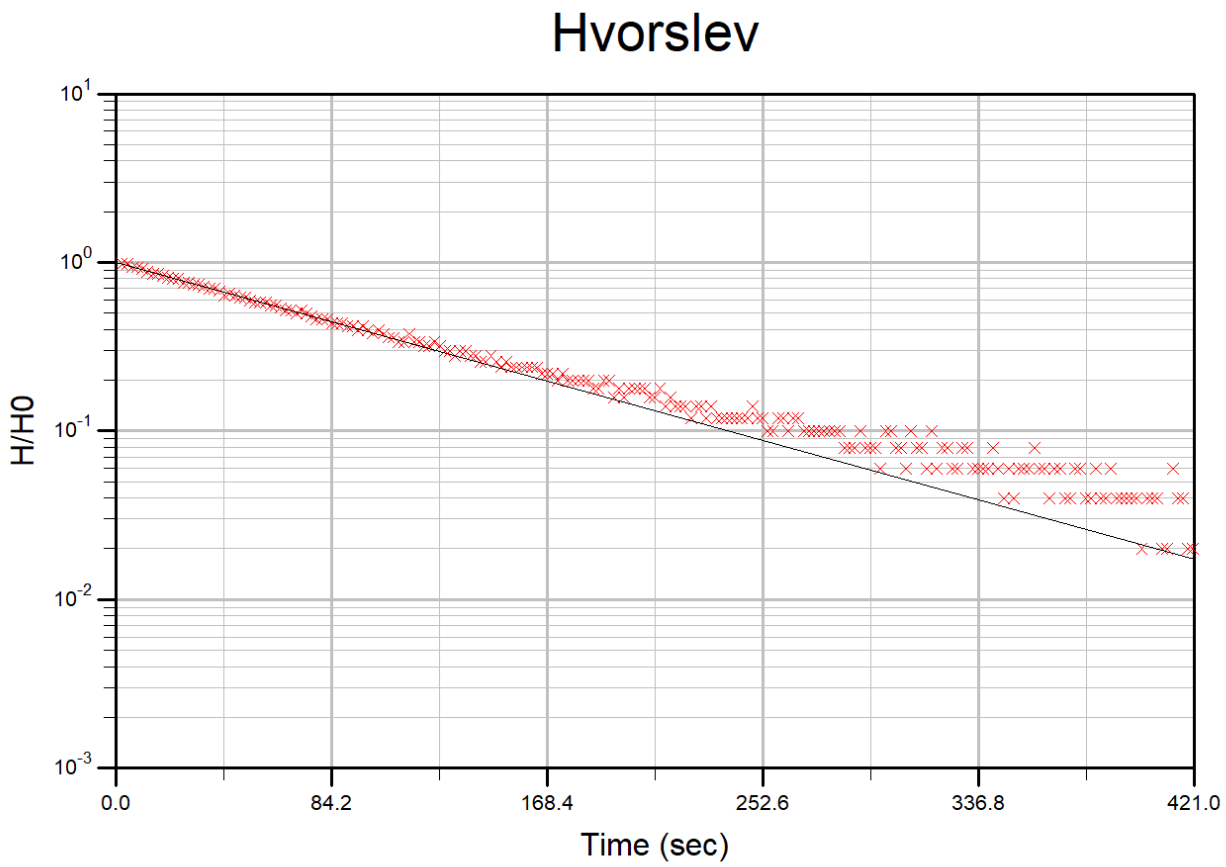
Time (sec)

MB10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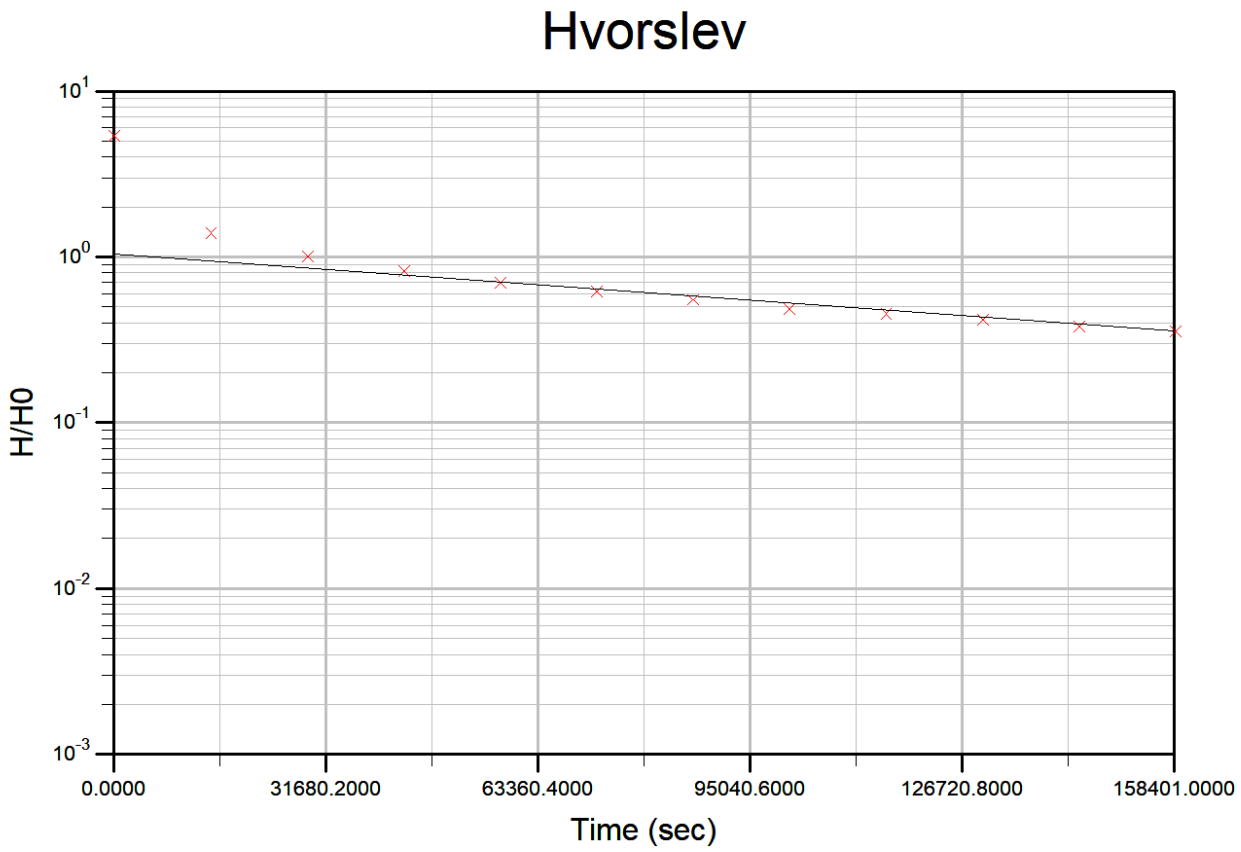
Time (sec)

MB12


Hvorslev
H/H0
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10^{0}
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10^{-2}
10^{-3}
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126720.8000
158401.0000
Time (sec)

Appendix C Groundwater modelling

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Appendix C1 Parameter sampling distributions

Vulcan South – Groundwater Impact Assessment

Groundwater Modelling Appendix

Prepared for

Vitrinite Pty Ltd

1. Introduction

Numerical groundwater flow modelling requires an understanding of the hydrogeological conceptualisation, the modelling process and the requirements of the key stakeholders. The numerical groundwater model is often reviewed and assessed to determine whether the model outputs that are created (e.g. calibration and predictions) are fit for purpose (Barnett *et al.*, 2012).

The groundwater modelling appendix presents the modelling objectives, design and construction, calibration and predictions for the Vulcan South (the Project) and is designed to provide a standalone technical document for the key stakeholders to assess and review the project impact assessment numerical groundwater flow model (the numerical model).

1.1. Stakeholders

METServe has been engaged by Vitrinite to manage the environmental approval process for the Project. Vitrinite has commissioned environmental assessment work for the purposes of preparing a mining lease application (MLA) and EA application. The groundwater impact assessment will also support the likely referral of the Project to the Commonwealth Department of the Environment and Energy (DoEE) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Stakeholders actively involved in the project are:

- Vitrinite – Project owner;
- MET Serve – manager of the project environmental approval; and
- **hydrogeologist.com.au** – groundwater impact assessment including groundwater monitoring (groundwater levels and groundwater quality), hydrogeological conceptualisation, and prediction of groundwater impacts using the numerical model.

Other stakeholders not directly involved with the Project include:

- Queensland and Commonwealth Governments and their respective agencies including:
    - Queensland Department of Natural Resources Mines and Energy (DNRME);
    - Queensland Department of Environment and Science (DES);
    - Commonwealth Department of the Environment and Energy (DoEE); and
    - Independent Expert Scientific Committee (IESC).
- local landholders, water users (agricultural activity, recreation) – assessment of change to availability of groundwater or changes in groundwater quality; and
- other industrial groundwater users in the region (e.g. BMA and Arrow Energy) – assessment of change to availability of groundwater or changes in groundwater quality.

1.2. Modelling objectives

The objective of the assessment is to identify the impacts of the Project on groundwater in a robust manner that meets the expectations of multiple stakeholders. To achieve this objective, the numerical model has been developed to support the impact assessment and the environmental approvals process. The numerical model needs to quantify the response of groundwater levels and flows to the proposed future stresses on the groundwater system, that is groundwater extraction due to coal mining activities. The quantification of impacts will be provided in the form of:

- Drawdown - providing spatial and temporal information about the extent and magnitude of impacts on the groundwater resource and third-party users (e.g. landholders or groundwater dependant ecosystems [GDE]).
- Groundwater balance of individual hydro-stratigraphic units. This will provide an insight into changes in flow within the groundwater system and will allow for the quantification of pit inflows (or seepage). Understanding the predicted changes in flow rates between individual hydro-stratigraphic units may also provide an indication of changes in groundwater quality.

Given the existence of historical coal mining in the close vicinity to the project (that is BMA Saraji Mine), the analysis of groundwater impacts will be shown in a cumulative sense, as well as groundwater impacts solely due to the project.

1.3. Confidence level classification

The degree of confidence with which model predictions can be used are described using a 'confidence classification' scale which is presented as part of the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). The classification scale conveys understanding about the model complexity, level of calibration and potential for the predictions to be incorrect. The model can fall into three classes:

- *Class 1* – the simplest model, often not calibrated, used as starting points for more complex models, used for prediction of low-value aquifers, least amount of confidence in the modelling results;
- *Class 2* – more complex models, prediction capability could vary depending on the location within the model domain, calibration and prediction runs can vary in terms of magnitude of model stresses and time discretisation, used for prediction in medium- or high-value aquifers; and
- *Class 3* – detailed and complex models, high trust in validity of modelling predictions, used to simulate detailed, small scale processes, used for predictions in high-value aquifers, the highest amount of confidence in the results of the modelling.

Barnett *et al.* (2012) state that every model should be evaluated using multiple criteria, that is:

- *Available data*, accuracy of the data, spatial and temporal distribution of the data. Is the dataset sufficiently representing the described system (in place and in time)? Is the dataset giving us sufficient insight into the system behaviour?
- *Quality of calibration* process undertaken during model development. What type of data was used to calibrate the model? To what level does the model replicate past behaviour given the properties of the model and model inputs (boundary conditions)? Is the higher level of calibration localized in specific area or is it evenly distributed throughout the whole model domain?
- *Consistency between the calibration and predictive analysis*. Are the calibration run and prediction run consistent with respect to length of the model run, temporal discretisation, model stresses?

1.3.1. Data quality indicators

Table 1 below summarises the classification indicators suggested by groundwater modelling guidelines (Barnett *et al.*, 2012) for the available data. A self-assessment has been completed by **hydrogeologist.com.au** and the resultant classification for each indicator is presented.

Table 1 Model classification – available data indicators

Classification indicator	Classification
Climate data	*Class 2*
• Long term rainfall and evaporation data is available in the form of long-term synthetic/interpolated dataset only. (Class 2)	
Landuse information	*Class 3*
• Ecological field survey/mapping undertaken to complement generalised state-wide datasets. (Class 3)	
Surface drainage (streams) and SW/GW interaction	*Class 2*
• Streamflow data and baseflow estimates available at a few points. (Class 2)	
Groundwater flow system – hydraulic properties	*Class 3*
• Key aquifer parameters were defined by in-situ (or laboratory) aquifer tests. The tests spatially cover either the whole model domain or at least the area of interest and adjacent aquifer (hydro-stratigraphic) units (Class 3)	
Groundwater flow system – structure, aquifer geometry	*Class 3*
• Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation. (Class 3) • Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. (Class 3)	
Observations of water levels	*Class 2*
• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. • Transient observation data are available for only few bores with temporal extent not covering the whole calibration period.	
Groundwater and surface water use (recharge and discharge)	*Class 1*
• No available records of metered groundwater extraction or injection. • Little useful data on river flows and/or stage elevations.	

1.3.2. Level of calibration

Table 2 below summarises the classification indicators presented by (Barnett *et al.*, 2012) for the calibration. A self-assessment has been completed by **hydrogeologist.com.au** and the resultant classification for each indicator is presented.

Table 2 Model classification – calibration indicators

Classification indicator	Classification
Calibration statistics	*Class 3*
• Calibration statistics are acceptable. (Class 3) • Mass balance closure error is less than 0.5% of total. (Class 3)	
Long term trends replication, temporal discretization	*Class 2 – Class 3*
• Long-term trends are adequately replicated where these are important. (Class 3) • Seasonal fluctuations are adequately replicated where these are important. (Class 3) • Validation either not undertaken or is not demonstrated for the full model domain. (Class 2) • Transient calibration to historic data but not extending to the present day. (Class 2)	
Types of calibration targets, spatial distribution of calibration targets	*Class 2 – Class 3*
• Transient calibration is current, i.e. uses recent data. (Class 3) • Observations of the key modelling outcomes (water levels in Project observation bores) is used in calibration. (Class 3) • Calibration only to water level dataset, predicting both water levels (water levels change) and flows (pit inflows). (Class 2)	

1.3.3. Consistency between calibration and prediction

Table 3 below summarises the classification indicators presented by (Barnett *et al.*, 2012) for the consistency between model calibration and model predictions. A self-assessment has been completed by **hydrogeologist.com.au** and the resultant classification for each indicator is presented.

Table 3 Model classification – consistency between calibration and prediction

Classification indicator	Classification
Model run length and temporal discretization	*Class 2 – Class 3*
• Length of predictive model is not excessive compared to length of calibration period. (Class 3) • Model predictive time frame is less than 3 times the duration of transient calibration. (*Class 3*) • Temporal discretization used in the prediction is different that used in transient calibration (Class 2)	
Boundary conditions and stresses	*Class 3*
• Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. (Class 3)	
Steady state vs. transient	*Class 3*
• Both calibration and prediction are based on transient model. Steady state model is used to establish initial conditions for the transient predictive model. (Class 3)	

Based upon the results summarised and presented above (Table 1, Table 2 and Table 3) the model has been self-assessed by **hydrogeologist.com.au** and has been classified as a Class 2 model under the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

2. Conceptual model development

2.1. Time

Temporal discretisation is one of the drivers impacting numerical solution of groundwater flow equation. It influences speed of the numerical solution and impacts outcomes (precision) of the numerical solution – calculation of both heads and flows within modelled groundwater flow domain. As such, the proposed temporal discretisation is usually constrained by requested level of detail of model prediction (for example 'actual daily inflow rates' versus 'annual average inflow rates') which in turn depend on the detail of the modelled stresses (such as extraction rates, recharge) and observation data (frequency of historical water levels measurements, rates of water flow observations).

The timing for the Project with respect to system stresses and frequency of observations is outlined in Table 4.

Table 4 Modelling timeframe, frequency of stresses and observations

Interval		Length	Stress or observation	Stress frequency	Observation frequency	Comment
A	1/01/1972 to 31/12/2018	47 years	in - RCH	continuous	daily	daily interpolated rainfall data available from SILO
			in - recharge from stream to aquifer	continuous	hourly/daily	hourly stream flow data available, however frequency of surface stream flow events could be in months to years - stream flow is intermittent
			out - EVT	continuous	daily	daily EVT estimates available from SILO
			out - discharge from aquifer to stream	continuous	hourly/daily	see above
			out - GW extraction / mining	continuous	1-5 years	the mining progression at Saraji from historical satellite snapshots, interpolated between individual years to refine
			GW levels	-	monthly	monthly measurements only from 4 bores, otherwise one-off - standing water level data
B	1/1/2019 to 31/12/2020	2 years	in – RCH	continuous	daily	see above
			in - recharge from stream to aquifer	continuous	hourly/daily	see above
			out – EVT	continuous	daily	see above
			out - discharge from aquifer to stream	continuous	hourly/daily	see above
			out - GW extraction / mining	continuous	yearly	the mining progression at Saraji from UWIR report
			GW levels	-	4 hours - monthly	Project observation bores installed, pressure transducer data available; existing GW monitoring bores being dipped in approximately monthly schedule
C	1/1/2021 to 30/06/2032	11 years, 6 months	in – RCH	continuous	-	use average value based on historical data
			in - recharge from stream to aquifer	continuous	-	use average value based on historical data
			out - EVT	continuous	-	use average value based on historical data

Interval	Length	Stress or observation	Stress frequency	Observation frequency	Comment
		out - discharge from aquifer to stream	continuous	-	use average value based on historical data
		out - GW extraction / mining	continuous	yearly	the mining progression at Saraji from UWIR report, mining at Project site as planned - annual snapshots for Project mining progression available
		GW levels	-	-	assumed continuation of future observations as part of future GMMP

2.2. Hydrogeological domain

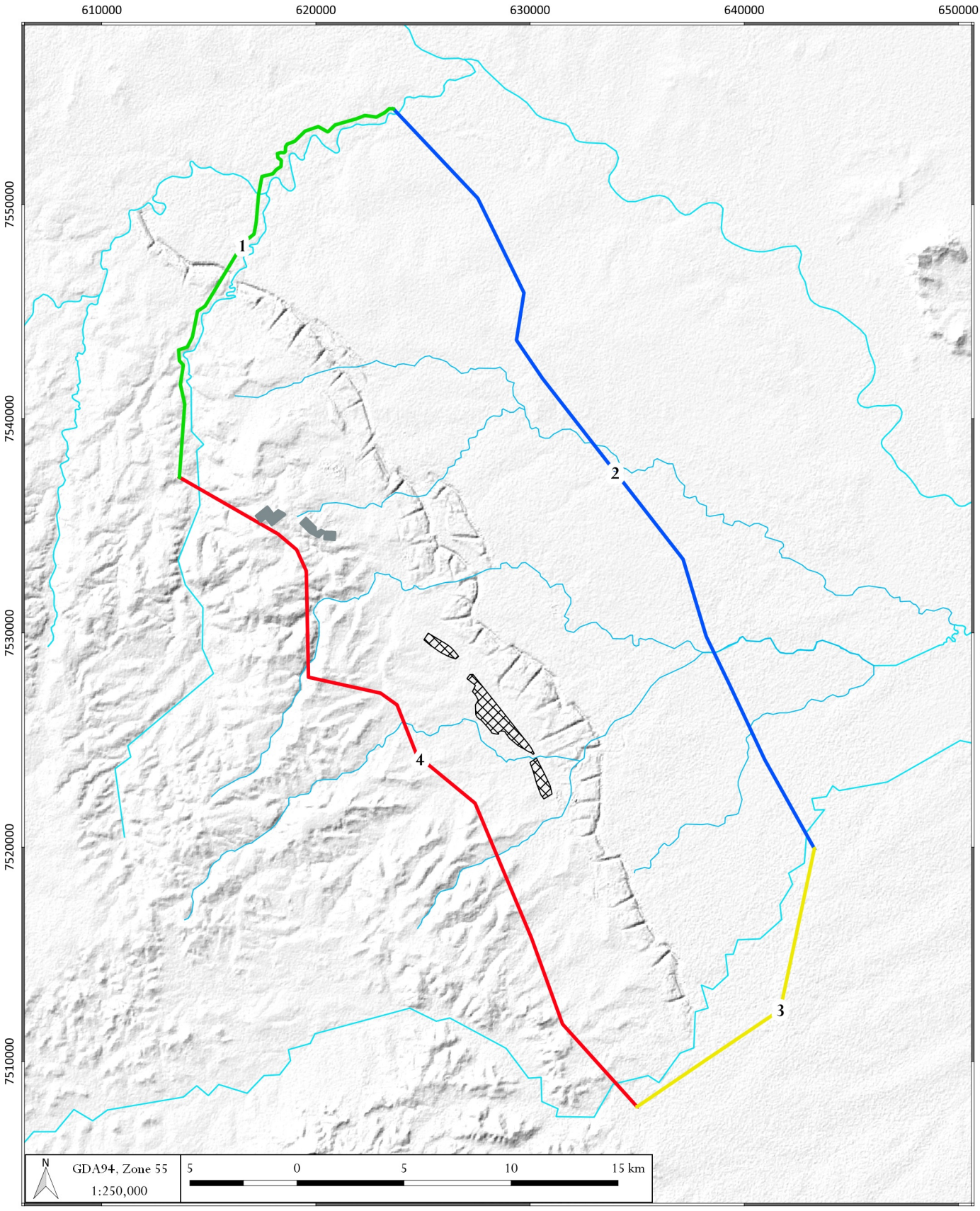
The hydrogeological domain relevant to the Project is defined as the part of the groundwater system potentially impacted by project related activities (mining). Given presence of a large open-cut mine(s) in the close vicinity of the Project, we assume that the historical and current mining of Dysart Lower seam at Saraji Mine had impacted (and will continue to impact) the groundwater system of the Project site as proposed by AECOM (2016, chaps. 10, 11). In order to capture the impact of historical mining on the groundwater flow system within the Project area, the majority of the Saraji Mine has been included in the groundwater flow model.

In terms of depth (vertical) extent, the Project targets the lowermost coal seams of the Moranbah Coal Measures, that is the Dysart Lower Lower (DLL) and ALEX coal seams.

Given the current groundwater conditions observed at the Project area (that is the partial saturation of the Tertiary sediments and weathered profile including upper parts of the target Permian coal seams), the impact of the Project is expected to be relatively minor and localised. Any drawdown will likely develop along the subcrop of the target Permian coal seams (DLL) in a north-south direction (along geological strike); drawdown expansion across the subcrop zone (in west-east direction) is expected to be minimal.

The boundaries of the model domain (Figure 1) were delineated as follows:

- Boundaries parallel to regional groundwater flow system (or perpendicular to regional system groundwater flow contours - north-western [1] and south-eastern [3] boundaries). These boundaries are by default 'no-flow'.
- South-western inflow boundary [4] runs through the higher elevations of the Harrow Range. This boundary does not follow any physical feature, it was located parallel to the DLL subcrop, approximately 3 km from the subcrop line. The cross-boundary flow will be simulated using general head boundary condition (GHB) or will be compensated by higher recharge in the hilly areas.
- North-eastern outflow boundary [2] was located into the Jellinbah Thrust Fault zone. The zone is expected to act as a barrier to flow, however the groundwater will still move within the overlying weathered regolith zone. The cross-boundary outflow will again be simulated using general head boundary condition, however only in the semi-consolidated or unconsolidated weathered regolith zone; the fault zone itself will be considered 'no-flow'.



LEGEND

Model boundaries

- 1 - No flow
- 2 - Cross-boundary outflow
- 3 - No flow
- 4 - Cross-boundary inflow

- Proposed pit
- Watercourse
- Highwall mining area

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22/02/2022

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Vulcan South - Groundwater Modelling Appendix (4027)

Boundaries of the model domain

FIGURE No.
1

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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2.3. Hydro-stratigraphy and layering

As defined by Maxey (1964) and updated by Seaber (1988), a hydro-stratigraphic unit can be defined as a part of a body of rock with distinct hydrologic properties (hydraulic conductivity, porosity and transmissivity), regardless of other types of classification (such as unit age or lithology). Definition of individual hydrostratigraphic units divides the hydrogeologic system into its relatively more permeable parts (aquifers) or less permeable parts (aquitards).

2.3.1. Quaternary alluvium

Within the model area, Quaternary alluvium was mapped adjacent to Cherwell Creek in the north. This unit is described as poorly consolidated sand, silt, clay, minor gravel (Department of Natural Resources, Mines and Energy, 2018). In the south, Quaternary alluvium was mapped and described around Phillips Creek. The flood plain unconsolidated deposits were classified as clays, silts, sands and gravels (Department of Natural Resources, Mines and Energy, 2018) 10 m to 25 m deep (AECOM, 2016; Department of Natural Resources, Mines and Energy, 2019a).

Given the ephemeral nature of the surface streams in the area, the alluvial deposits are not considered permanent sources of groundwater with most of the shallow monitoring bores within the alluvium being dry (AECOM, 2016). The stratigraphic logs also indicate that the coarser alluvial sediments are discontinuous along the creek, presenting a limited storage environment (AECOM, 2016). This observation is also supported by lack of government classification of the creek alluvial zones under the Fitzroy Basin Water Resource Plan (Queensland government, 2014) where the mapped alluvial zones of Cherwell and Phillips Creeks are not included within the "Isaac Connors Alluvium Groundwater Sub-area".

2.3.1. Tertiary sediments / Weathered zone / Regolith

Tertiary sediments comprise unconsolidated to semi-consolidated heterogeneously distributed colluvial and fluvial sediments which include clay, silty clay, sandy clay, clayey sand, sand and gravel in clay-rich matrix (AECOM, 2016). Thickness of Tertiary sediments varies from 15 m to approximately 60 m. The lower Tertiary is defined by up to 3 m thick, locally discontinuous basal sand and gravel sand layer considered to be a remnant of paleo-channel system related to current Phillips Creek (AECOM, 2016). The transition zone between Tertiary units and consolidated, unweathered Permian bedrock material is frequently delineated by spatially discontinuous clayey layer (AECOM, 2016) that is likely to be a product of in-situ weathering of Permian material (hydrogeologist.com.au, 2019).

The Tertiary sediments are recharged by either rainfall or surface water runoff with a possibility of interaction (both recharge from and discharge to) with underlying Permian coal measures. Groundwater within Tertiary sediments most frequently occurs within the basal gravel layer under unconfined or semi-confined conditions (AECOM, 2016). Direction of groundwater flow within the Tertiary sediments is expected to reflect topography, from topographically elevated areas in the west towards the east (AECOM, 2016).

Thickness of the Tertiary sediments (including weathered zone / regolith) was estimated using two data sources: stratigraphic records from Queensland Groundwater Database (Department of Natural Resources, Mines and Energy, 2019a) and average depth of regolith dataset from CSIRO Soil and Landscape Grid of Australia (Wilford *et al.*, 2018). The boundary between the Tertiary sediments / weathered zone / regolith and fresh bedrock was manually identified from 353 stratigraphic logs from bores within and outside of the Project area and then compared to the estimated depth of regolith dataset. The analysis of the data (Figure 2) showed the bias of the estimated regolith thickness dataset – the thicker the weathered zone estimate was, the larger difference there was between the estimate and thickness derived from stratigraphic logs. In general, the CSIRO estimated the weathered zone to be thicker than the lithology logs showed.

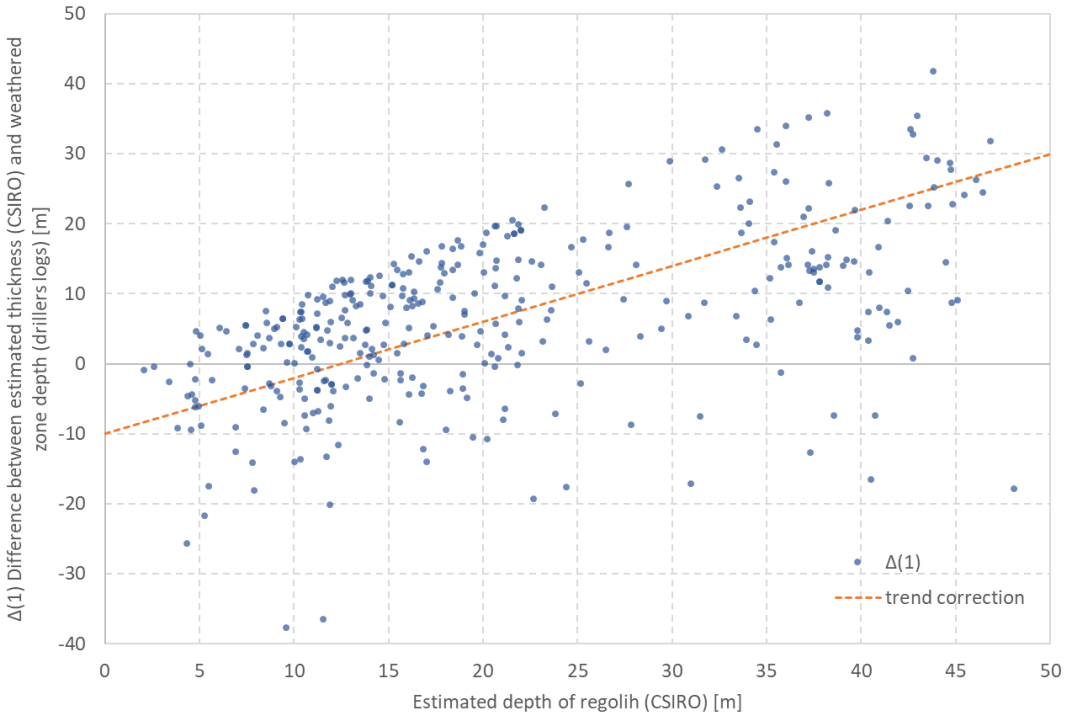


Figure 2 Estimated error of regolith thickness as a function of the thickness

The thickness of weathered zone was then adjusted in two steps; first using the general trend correction (Figure 2) to make the weathered zone thinner in thick (deep) areas and thicker in thin (shallow) areas; and second rectifying the dataset based on spatial distribution of actual localised differences between the stratigraphic logs and CSIRO thickness estimate. The resulting adjusted weathered regolith thickness dataset (corrected depth) was then compared to the depth of regolith information obtained from stratigraphic logs (measured depth) the verify the validity of the adjustment process (Figure 3). Although the general trend shows good fit between the adjusted CSIRO dataset and the stratigraphic logs data, the outliers indicate misidentification of the weathered zone boundary on some of the stratigraphic logs.

The spatial distribution of the Tertiary sediments / weathered zone / regolith (Layer 2) is extensive over the entire model domain.

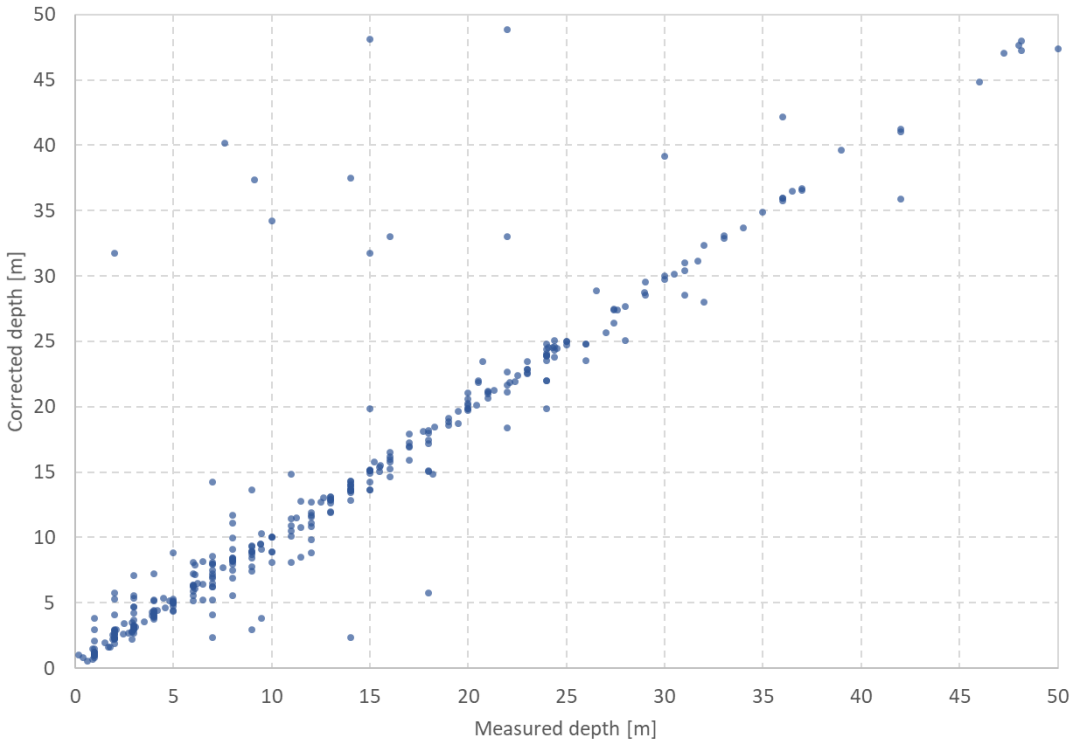


Figure 3 Validation of adjusted regolith thickness data (corrected depth) against the thickness data obtained from stratigraphic logs (measured depth)

2.3.2. Permian coal measures

Permian coal measures comprising sandstones, mudstones and coal seams generally dip in eastern or north-eastern direction, subcropping under the weathered regolith and alluvium layers. The Permian coal measures were observed to be at least partially unsaturated in the Project area. In the areas where the subcrops are shallow, groundwater recharge to the Permian coal measures is likely combination of rainfall and overland flow infiltration. Recharge may also occur through overlying Cainozoic sediments under downward vertical hydraulic gradient and along faults and other structural features (AECOM, 2016).

Within the Permian coal measures, the interburden material (sandstone and mudstone) will act as aquitard with lower hydraulic conductivity then the coal seams, in which the groundwater can move along the bedding planes (or open cleats) of the coal (HydroSimulations, 2018).

2.4. Hydraulic properties

Estimates of hydraulic properties were based on both historical information from work undertaken in the general vicinity of the Project area (AECOM, 2016; Arris, 2017; Arrow Energy, 2016; HydroSimulations, 2018; URS, 2014, 2012, 2009) as well as on-site hydraulic testing (Table 5). The on-site tests targeted the weathered regolith zone (three tests), interburden (one test) and DLL and MAT coal seams (eight tests).

Table 5 Summary of horizontal K values (m/day) – regional studies, on-site tests, adopted values

HSU	K_h (m/day) regional studies		K_h (m/day) on-site tests		K_h (m/day) adopted values	
	avg min	avg max	min	max	min	max
alluvium	4.13×10^{-1}	$7.22\times10^{+1}$	n/a		1.00×10^{-1}	$1.00\times10^{+0}$
weathered regolith	7.53×10^{-2}	$2.90\times10^{+0}$	1.00×10^{-1}	2.10×10^{-1}	1.00×10^{-2}	$1.00\times10^{+0}$
interburden / overburden	4.01×10^{-2}	2.33×10^{-1}	2.80×10^{-4}		1.00×10^{-4}	1.00×10^{-2}
coal seams	8.75×10^{-4}	$1.32\times10^{+0}$	2.00×10^{-2}	4.10×10^{-1}	1.00×10^{-3}	$1.00\times10^{+0}$

Vertical hydraulic conductivity (K_v) value was specified as a fraction of horizontal conductivity value, with the ratio (K_h:K_v) between 10:1 for unconsolidated sediments (alluvium, weathered regolith zone) and 1000:1 for consolidated sediments (sandstone, mudstone or shale of interburden and coal).

As the type of hydraulic test undertaken on-site was not suitable to ascertain storage parameter values (S_y - specific yield and S_s - specific storage), the initial range of values was based on values obtained from studies focusing on the same hydrostratigraphic units surrounding the Project area.

2.5. Boundary conditions and system stresses

2.5.1. Rainfall and evapotranspiration

Climate plays major role in defining two of the characteristics of the groundwater system; recharge and evapotranspiration. Based on the Australian Bureau of Meteorology (Bureau of Meteorology, 2016) classification criteria, the Project area can be characterised as subtropical, with mostly hot dry summer and mild winter. In terms of rainfall, the Project area is "summer rainfall dominant" with annual rainfall between 350 mm and 650 mm and majority of the rain falling between November and March.

To characterise the rainfall trend, the precipitation information from five monitoring stations (Table 6, Figure 4) surrounding the project area were used.

Table 6 Average monthly rainfall (2010-2019) for monitoring stations surrounding Project area

Station	SILO interpolated	Moranbah WTP	Wentworth	Mount Lebanon	Seloh Nolem	Booroondarra
Station number	-	34038	34015	34055	34086	35109
Lat (decimal degrees)	-22.35	-21.9947	-22.0656	-22.2211	-22.3069	-22.8181
Long (decimal degrees)	148.20	148.0308	147.7219	147.9703	148.4822	148.4900
Elevation (m)	258.0	260.0	225.0	294.0	170.0	200.0
Month	*Average monthly rainfall 2010-2019 (mm)*					
January	117.6	101.7	73.6	101.8	119.4	130.2
February	107.7	113.4	62.8	105.1	98.1	84.2

Station	SILO interpolated	Moranbah WTP	Wentworth	Mount Lebanon	Seloh Nolem	Booroondarra
March	102.1	96.2	62.5	88.9	116.9	121.8
April	28.3	24.2	24.1	27.5	25.2	35.2
May	25.1	21.1	21.7	22.8	21.8	16.9
June	21.0	17.0	15.0	19.3	19.9	20.1
July	26.6	24.4	26.1	25.8	25.0	25.7
August	25.3	24.6	20.4	23.1	25.1	25.0
September	20.1	13.0	12.6	19.2	18.1	30.6
October	28.6	25.2	14.6	22.3	29.8	32.3
November	58.5	60.8	59.0	58.6	60.9	63.9
December	98.5	106.2	76.5	95.6	97.9	119.2

The average precipitation data for all sites displays the same short-term trend (Figure 4): most of the rain (60 mm to 130 mm) falls over summer months (December to March) while autumn and winter months show lower precipitation between 10 mm and 30 mm. The SILO interpolated dataset is consistent with the data from all BOM stations except Wentworth which appears to be relatively dryer, receiving 30% less of rainfall on annual basis.

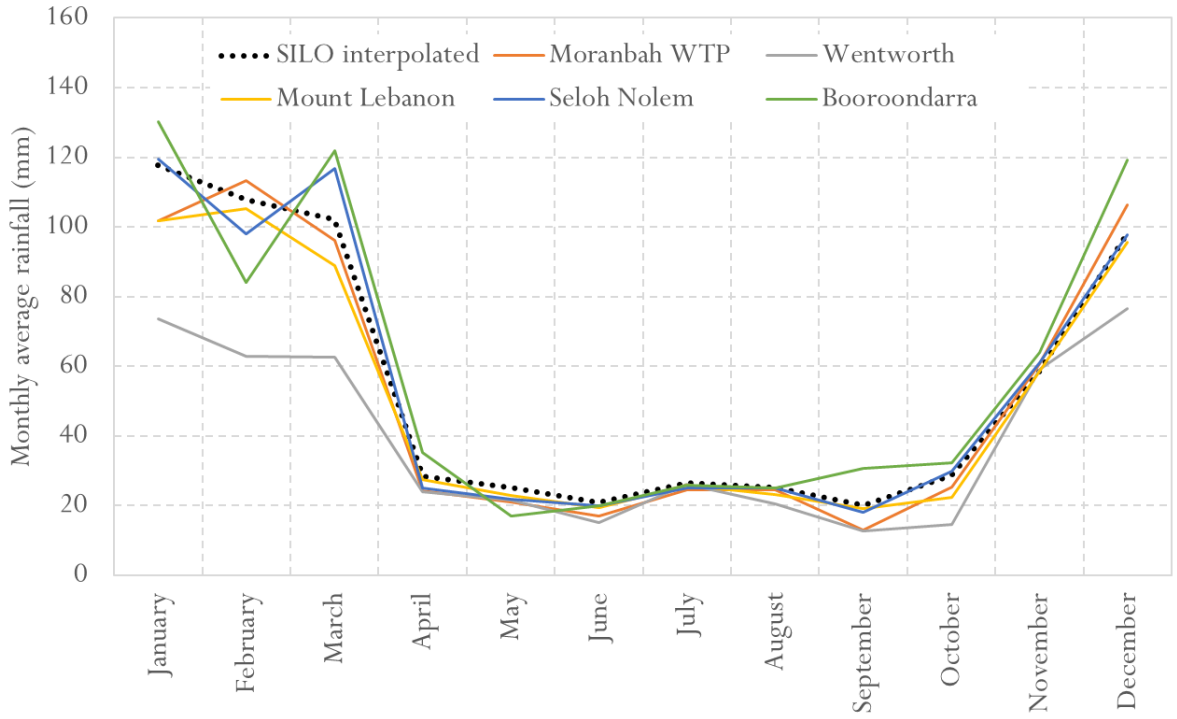


Figure 4 Average monthly rainfall (2010-2019) for monitoring stations surrounding Project area

As the long term data is not available from either of the stations, in order to establish long term rainfall and evapotranspiration trend, synthetic (interpolated) SILO data (Jeffrey *et al.*, 2001) was used. Analysis of long term evapotranspiration data (Table 7 and Figure 5) shows evapotranspiration consistently higher than rainfall. The higher EVT can potentially limit localised recharge of the groundwater system from precipitation; the rain either evaporates or is used by plants before it reaches the groundwater table.

Table 7 Comparison of mean monthly rainfall and mean monthly EVT

Month	Data interval	Mean rainfall (mm)	Mean EVT [Mact] (mm)
January	1900 - 2019	105.0	136.6
February	1900 - 2019	98.8	120.8
March	1900 - 2019	63.6	117.6
April	1900 - 2019	30.2	85.7
May	1900 - 2019	28.0	56.7
June	1900 - 2019	29.6	38.9
July	1900 - 2019	22.0	43.4
August	1900 - 2018	18.9	64.5
September	1900 - 2018	15.4	85.1
October	1900 - 2018	31.7	108.4
November	1900 - 2018	52.0	120.4
December	1900 - 2018	86.5	136.0
Annual	1900 - 2018	581.4	1115.1

Note: Mact – Morton actual EVT value

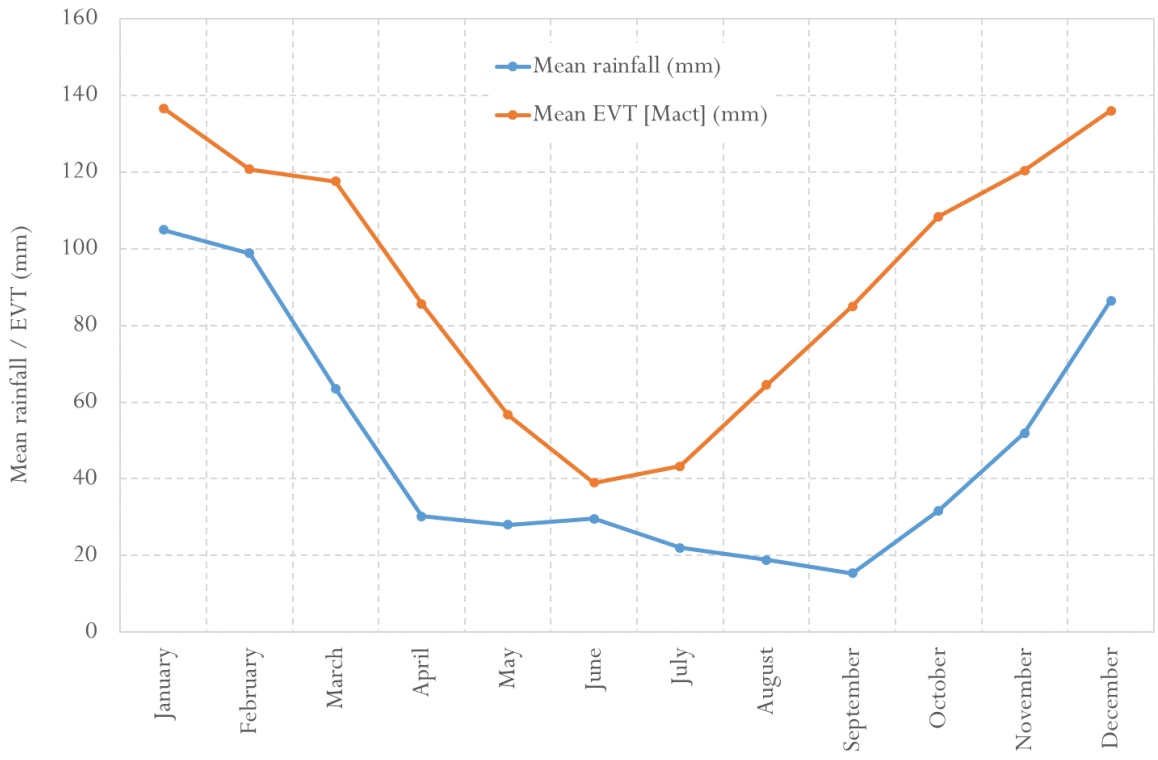


Figure 5 Comparison of mean monthly rainfall and mean monthly EVT

2.5.2. Surface stream discharge and recharge

The groundwater / surface water interaction assessment was based on data from a single stream gauging station (Philips Creek @ Tayglen – station 130409A). There is no other known monitoring data related to the surface drainage network near the Project area and given the similarity between Phillips Creek and other 'major' drainage (Boomerang Creek, Harrow Creek, Cherwell Creek) we consider it to be representative drainage feature.

Out of 7441 days when the gauge was monitored, sensors recorded 1527 days (~20% of time) of intermittent creek flow. The gauging station was active between May 1968 and September 1988, just over 20 years. The flow of the Phillips Creek was recorded only after rainfall; if the monthly rainfall was higher than monthly average rainfall (Figure 6 – time interval A), the frequency of the creek flows increases (on average 13 days of creek flow per month over period between October 1973 and July 1979), if the rainfall is lower than average (Figure 6 – time interval B) or average (Figure 6 – time interval C), the creek flow frequency decreases (on average 3 days of creek flow per month over period between November 1980 and September 1988). Unfortunately, the stream flow data from the time period of sustained drought 1991-1998 and 2000-2007 (Millennium Drought) is not available.

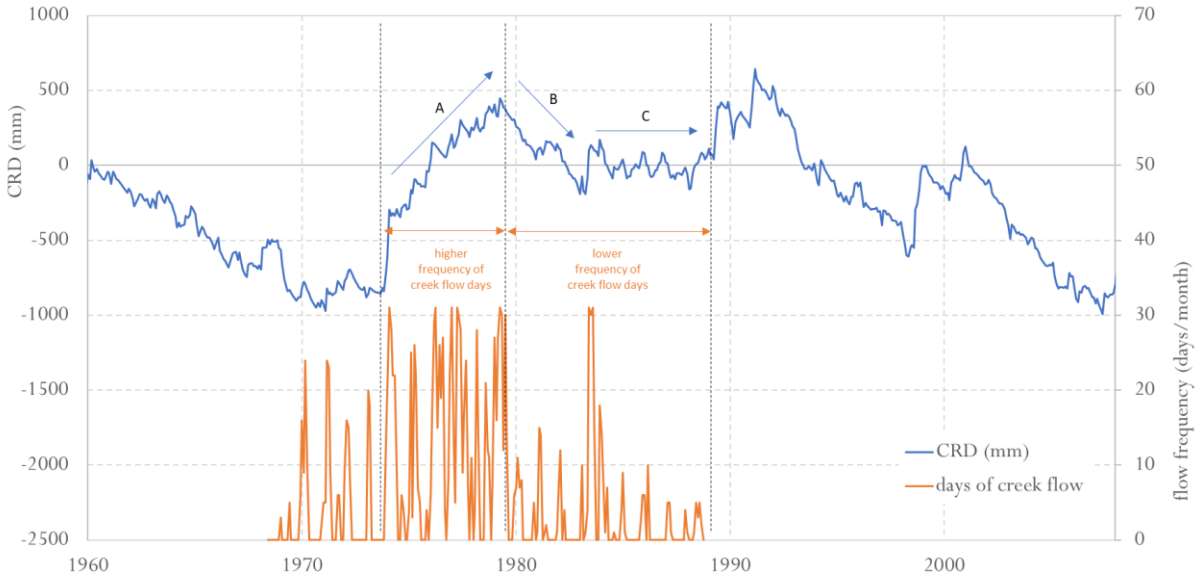


Figure 6 Frequency of creek flow compared to cumulative rainfall departure

Based on the available data, the flow of the Phillips Creek (and by proxy, flow of the other 'major' creeks in the area) appear to be supported purely by localised runoff, and there is no indication of flow supported by discharge from shallow aquifer. This assumption is also supported by the observation of lack of groundwater in shallow weathered regolith profile.

Given the perceived low impact of surface water flow on overall recharge to the groundwater system, the creek network was conceptualised as 'drainage-only'. It removes surface runoff water from the model domain, and it has potential for removing the groundwater under the condition that the groundwater table in the vicinity of the creek is above the bottom of the creek.

2.5.3. Water extraction due to mining

Saraji Mine is the closest mine to the Project and may potentially impact the groundwater system adjacent to the proposed open pit. Saraji Mine has been in operation since 1974 with the estimated overall mine inflow between 1.6 GL/year and 2.1 GL/year (~4.4 ML/day to ~5.8 ML/day) (AECOM, 2016). This water is extracted from the groundwater system as moisture locked in coal or minor seepage in the highwall, removed by evaporation. The transient observation data from BMA monitoring bores (alluvium bore MB2, Tertiary bores PZ02A and PZ04A and Permian bores MB31, MB33 to MB37) indicate that the impact of mining at Saraji Mine appears to be contained in the area adjacent to the pits, likely due to low permeability of the mined strata and Permian overburden (AECOM, 2016).

Given the hydraulic properties of the Permian strata combined with only partially saturated shallow weathered / Tertiary aquifer, the water extraction rates for the Project are expected to be low.

2.6. Observations

A set of 55 selected observation points were used in the calibration process. These observation points, as outlined in Table 8 below, include historical observation data from publicly available sources (AECOM, 2016; Department of Natural Resources, Mines and Energy, 2019a), on-site one-off data collected from open drill-holes and data collected from new monitoring bores (hydrogeologist.com.au, 2019).

Table 8 Observation points – target stratigraphy and data sources

Bore ID / RN	Easting	Northing	Target stratigraphic unit	Data source
32924	638285.0	7514125.0	Moranbah coal measures - overburden	2
42182	637746.0	7514257.0	Moranbah coal measures - overburden	2
43639	638938.6	7511033.0	Moranbah coal measures - DLL coal seam	1
44336	634974.7	7509309.7	Back Creek group	1
46899	636931.8	7515269.0	Moranbah coal measures - DL coal seam	2
49995	637834.7	7514392.0	Moranbah coal measures - DL coal seam	2
49997	637879.3	7514635.0	Moranbah coal measures - DL coal seam	2
84538	641353.3	7516737.0	Moranbah coal measures - DL coal seam	1
100291	626431.5	7542882.6	Fort Cooper coal measures	1
136092	633415.8	7512196.5	Tertiary sediments, weathered zone, regolith	1
136689	635867.8	7528233.7	Back Creek group	1
141382	628490.0	7542693.0	Fort Cooper coal measures	1
141384	623784.0	7549391.0	Moranbah coal measures - overburden	1
141386	626507.0	7544152.0	Fort Cooper coal measures	1
158010	642528.4	7519938.8	Fort Cooper coal measures	1
158011	640035.0	7514094.9	Moranbah coal measures - overburden	1
158012	632270.5	7515394.7	Back Creek group	1
158013	637781.5	7518065.5	Moranbah coal measures - overburden	1
158014	636495.7	7519991.1	Moranbah coal measures - overburden	1
162138	620083.8	7547612.9	Moranbah coal measures - overburden	1
162177	616863.0	7547756.0	Moranbah coal measures - overburden	1
162506	621630.0	7534800.0	Back Creek group	1

Bore ID / RN	Easting	Northing	Target stratigraphic unit	Data source
162816	618975.0	7552309.0	Tertiary sediments, weathered zone, regolith	1
162829	623671.0	7549482.0	Tertiary sediments, weathered zone, regolith	1
13040283	627823.3	7527382.7	Moranbah coal measures - DLL coal seam	1
MB04	622014.3	7536148.2	Back Creek group	4
MB05	621964.5	7534905.0	Back Creek group	4
MB07	628691.1	7526258.1	Tertiary sediments, weathered zone, regolith	4
MB09	629511.2	7525222.7	Moranbah coal measures - DLL coal seam	4
MB10	628123.6	7526469.3	Moranbah coal measures - DLL coal seam	4
MB12	625251.5	7526409.2	Back Creek group	4
MB30	642503.0	7519162.0	Fort Cooper coal measures	2
MB32	637481.0	7510535.0	Back Creek group	2
MB4	635928.0	7527934.0	Moranbah coal measures - overburden	2
PC056	640288.3	7516655.0	Moranbah coal measures - DL coal seam	2
PC058XC	640054.7	7516179.0	Moranbah coal measures - DL coal seam	2
PC066XC	639328.9	7517206.0	Moranbah coal measures - DL coal seam	2
PZ06A	639272.0	7513326.0	Moranbah coal measures - overburden	2
PZ06C	639272.0	7513326.0	Moranbah coal measures - DL coal seam	2
PZ08A	634647.0	7523069.0	Moranbah coal measures - DL coal seam	2
TG1	635215.0	7508903.0	Tertiary sediments, weathered zone, regolith	2
VSW002	627811.8	7526808.7	Moranbah coal measures - DLL coal seam	3
VSW006	628024.8	7526217.7	Moranbah coal measures - DLL coal seam	3
VSW007	628679.8	7526268.7	Moranbah coal measures - DLL coal seam	3
VSW008	627335.8	7527263.7	Back Creek group	3
VSW009	628076.8	7527016.7	Moranbah coal measures - DLL coal seam	3
VSW011	627406.8	7527852.8	Moranbah coal measures - DLL coal seam	3
VSW013	624599.8	7530294.8	Back Creek group	3
VSW014	623534.8	7531296.8	Back Creek group	3
VSW016	621573.8	7535486.8	Back Creek group	3
VSW017	622555.8	7535727.8	Back Creek group	3
VSW018	622937.8	7533623.8	Back Creek group	3
VSW019	622513.8	7534503.8	Back Creek group	3
VSW020	622672.8	7535009.8	Moranbah coal measures - DLL coal seam	3
VSW021	622024.8	7536169.8	Back Creek group	3

Data sources:

1 - Groundwater database – Queensland (Department of Natural Resources, Mines and Energy, 2019a)
2 - Saraji Open Cut Extension Project, Underground Water Impact Report (AECOM, 2016)
3 - on-site core drillholes, one-off measurement (November-December 2018, pers. comm.)
4 - Hydrogeological drilling report, Vulcan complex project (hydrogeologist.com.au, 2019)

3. Numerical model development

3.1. Software used

MODFLOW-USG (Panday *et al.*, 2015), based on the U.S. Geological Survey MODFLOW-2005 groundwater modelling code, was used as modelling code of choice. MODFLOW-USG simulates groundwater flow using a generalised control volume finite-difference approach, which allows non-orthogonally structured grids to be used for groundwater flow simulations (Panday *et al.*, 2013).

The model mesh was constructed using AlgoMesh (Merrick, 2016). The spatial discretisation of the model domain is discussed in more detail in Section 3.3.

Post processing of the model outputs was using combination of Groundwater utilities (Doherty, 2019a), in-house Fortran and Python code and QGIS (QGIS Development Team, 2019); QGIS was also used to manage all the spatial data and produce map outputs.

Model calibration and parameter sensitivity analysis was undertaken using PEST (Doherty, 2019b, 2019c) and BeoPEST (Doherty, 2012).

3.2. Temporal discretisation and Output control (OC)

Based on the understanding of temporal discretisation of stresses and observation combined with required model output timing (Section 2.1), the timing of the model run was defined as described in Table 9 below:

Table 9 Temporal discretisation – calibration and prediction runs

Stress period	Stress period length	Dates	Modelling phase
1 - 47	1 year	01/01/1972 – 31/12/2018	calibration
48 - 51	3 months	01/01/2019 – 31/12/2019	
52 - 55	3 months	01/01/2020 – 31/12/2020	prediction - mining
56 - 76	6 months	01/01/2021 – 30/06/2032	

The length of each stress period in MODFLOW-USG is defined in the discretisation (DISU) file, while discretisation of time within each individual stress period is defined in Output Control (OC) package. Every stress period has variable-length time-stepping with minimum timestep length of 0.1 of a day and maximum timestep length of ½ of stress period length.

3.3. Spatial discretisation – mesh definition

A mostly non-orthogonally structured polygonal mesh was designed to cover the model domain. The mesh combines rectangular cells blocks in the area of mining ('no-refine' regular cell size imposed on mining areas - Table 10) and Voronoi polygonal cells in the remaining areas. The non-mining areas of the mesh were refined around surface streams, geological boundaries (alluvium boundary, DLL subcrop boundary) and observation points. The mesh consists of 22492 polygons. Area of the cells varies between 1000 m^2 to 911000 m^2. The extent of the full model mesh (including spatial definition features) is presented in Figure 7 below.

Table 10 Model mesh definition – 'no-refine' polygons representing mining areas

Pit	Rotation	Cell size (m)
Vulcan Coal Mine	120°	50×100
VS Vulcan north pit	145°	50×100
VS Vulcan main pit	128°	50×100
VS Vulcan south pit	109°	50×100
Peak Downs	50°	150×250
Saraji – Yura Nth	43°	150×250
Saraji – Yura Sth	15°	150×250
Saraji – Boomerang Nth	2°	150×250
Saraji – Boomerang Sth	52°	150×250
Saraji – Acacia	57°	150×250
Saraji - Bauhinia	28°	150×250
Saraji – Coolibah	-1.5°	150×250
Saraji – Dogwood	27°	150×250
Saraji – Ebony	24°	150×250
Saraji – Grevillia	25°	150×250
Saraji – Hakea	50°	150×250

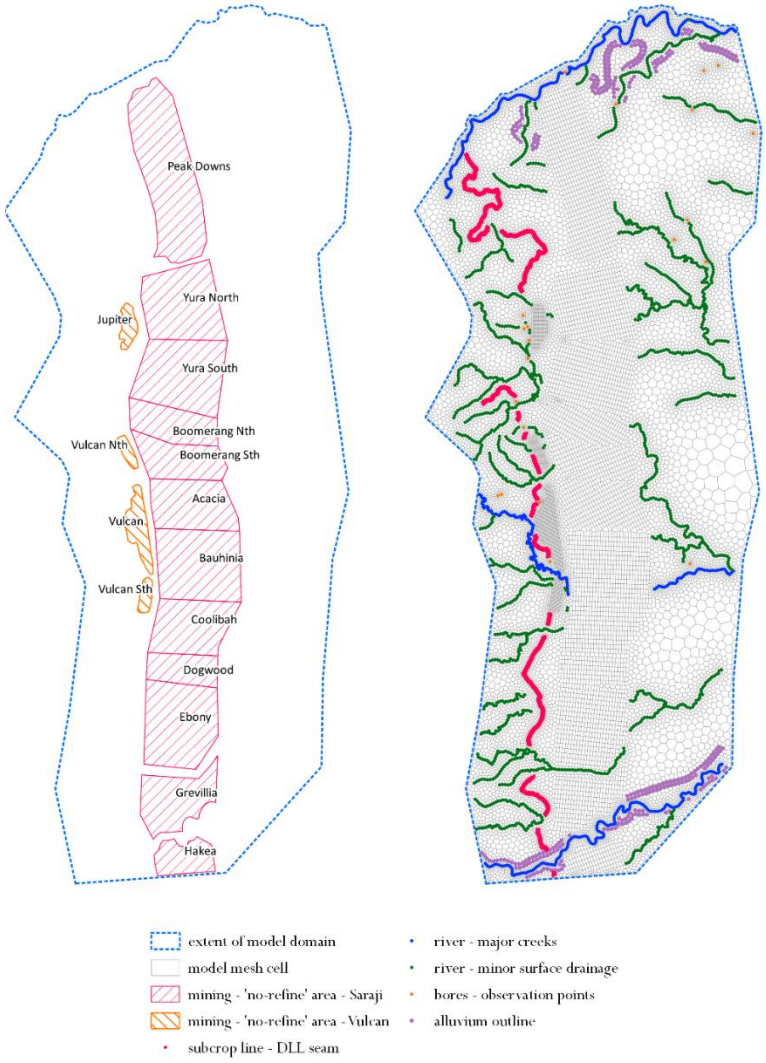


Figure 7 Mesh definition features for mining ('no-refine' zones) and non-mining areas

3.4. Spatial discretisation – model layers

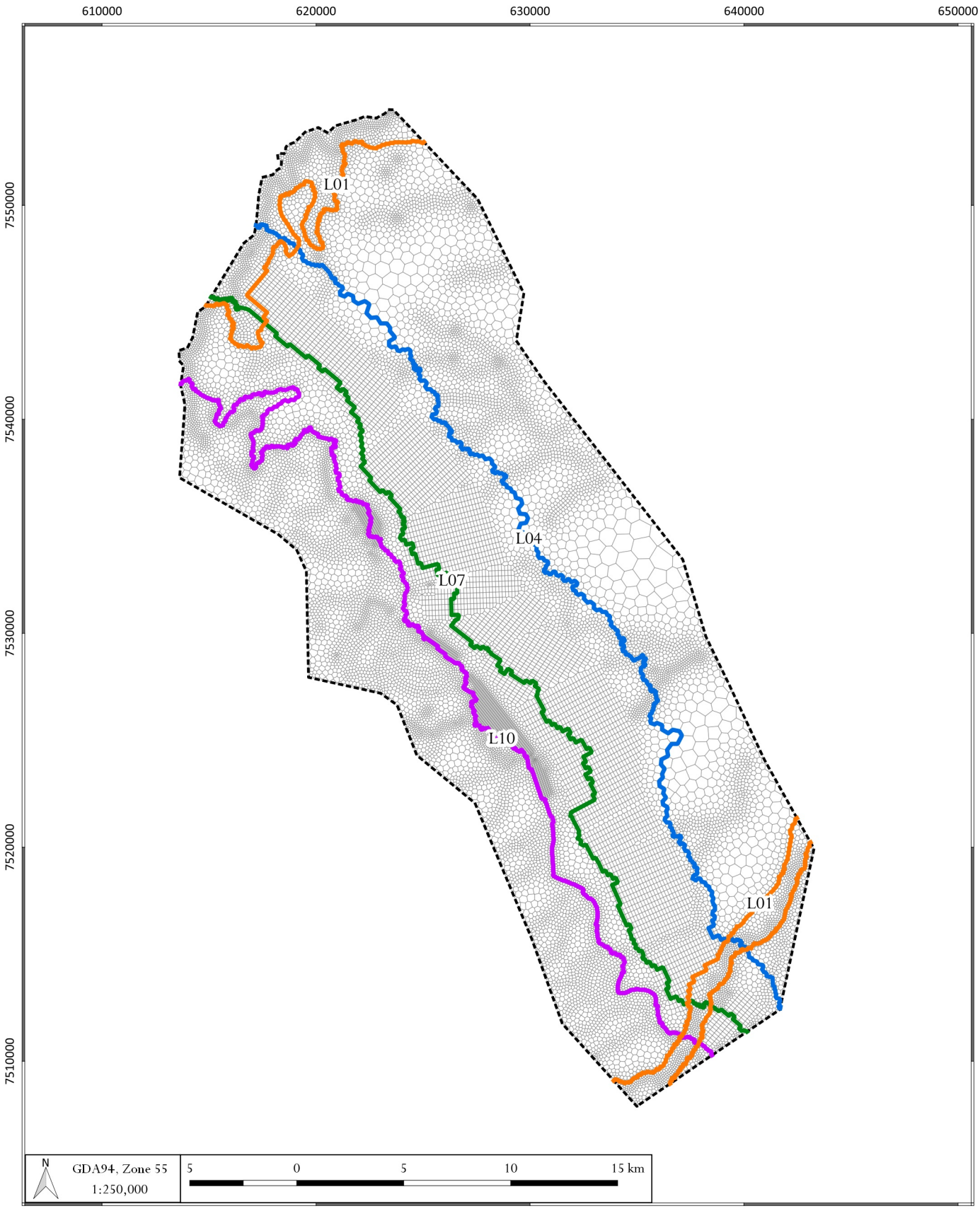
The vertical discretisation of the model domain is based on analysis of the hydrostratigraphic units (Section 2.3). The unconsolidated layers (alluvium and weathered regolith) and coal seams are expected to be the more permeable aquifers while the overburden and underlying material are expected to act as less permeable aquitard. Although individual hydrostratigraphic units could be used directly as model layers, in order to facilitate numerical convergence of the model as well as the calibration process, the overburden Permian (aquitard) layers were split in two; mainly to decrease the layer thickness. The definition of model layers, compared to previously defined hydrostratigraphic units, is summarised in Table 11.

Table 11 Model layer definition

Hydro-stratigraphic unit	Unit function	Model layer	Cells per layer
Quaternary alluvium	*aquifer*	1	2649
Tertiary sediments / weathered Zone / regolith	*aquifer*	2	22492
Fort Cooper Coal Measures	aquitard	3	3214
	aquitard	4	5784
Moranbah Coal Measures overburden	aquitard	5	8375
	aquitard	6	11037
DL coal seam	*aquifer*	7	11108
Moranbah Coal Measures interburden	aquitard	8	12380
	aquitard	9	15278
DLL coal seam	*aquifer*	10	15582
Back Creek Group	aquitard	11	22492

The elevation of layer floors were established using a combination of regional structural data such as mapped and extrapolated floors of stratigraphic units (Esterle and Sliwa, 2002), location (and elevation) of outcrops using local and regional mapping (Department of Natural Resources, Mines and Energy, 2018), drilling logs (Department of Natural Resources, Mines and Energy, 2019b). Within the footprint of the proposed pit, the elevation of the DLL seam floor was derived from detailed exploration drilling data.

The extent of the major hydrostratigraphic units (layer floors subcrop lines) within the model grid is shown on Figure 8, elevation contours and isopachs representing the floors of weathered regolith layer (L02), Fort Cooper coal measures (L04), and floors of Dysart Lower seam (DL – L07) and Dysart Lower Lower (DLL – L10) are shown on Figure 9, Figure 10, Figure 11 and Figure 12.



LEGEND

Extent of unit

- L01 extent - alluvium
- L04 subcrop line - Fort Cooper Coal Measures floor
- L07 subcrop line - MCM DL floor
- L10 subcrop line - MCM DLL floor

- Model domain
- Model mesh

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Extent of alluvium and major stratigraphic units

FIGURE No.
8

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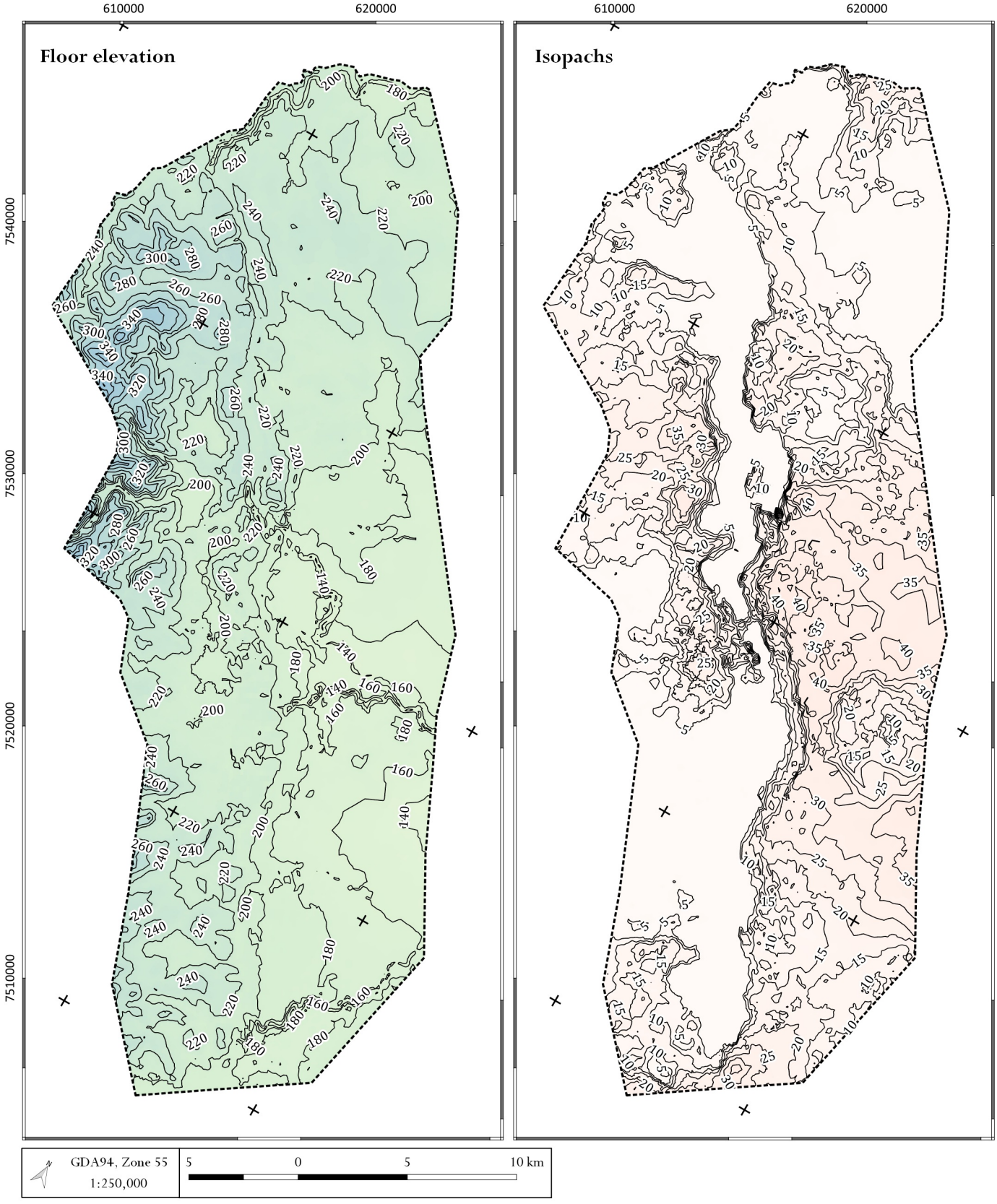

GDA94, Zone 55
1:250,000

5 0 5 10 km

LEGEND

Floor elevation (mRL)

-400 -300 -200 -100 0 100 200 300 400

Isopach (m)

0 50 100 200 300 400 500

Model domain

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Layer floor elevations and isopachs (L02)

FIGURE No.
9

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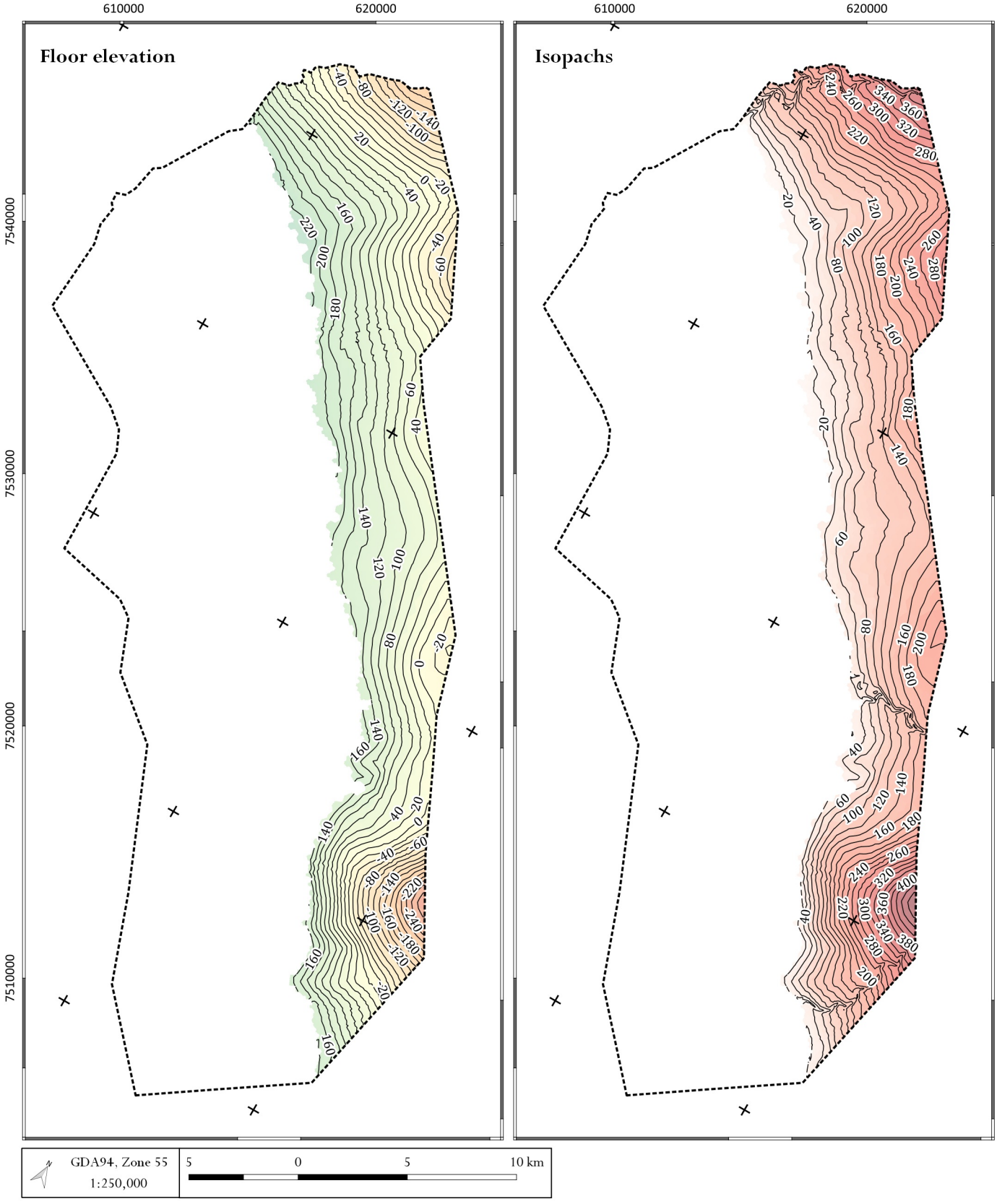
Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\Modelling appendix\09_4027_Vulcan South_App_Floor_isopachs Weathered Zone L02.qgz



LEGEND

Floor elevation (mRL)

-400 -300 -200 -100 0 100 200 300 400

Isopach (m)

0 50 100 200 300 400 500

Model domain

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Layer floor elevations and isopachs (L04)

FIGURE No.
10

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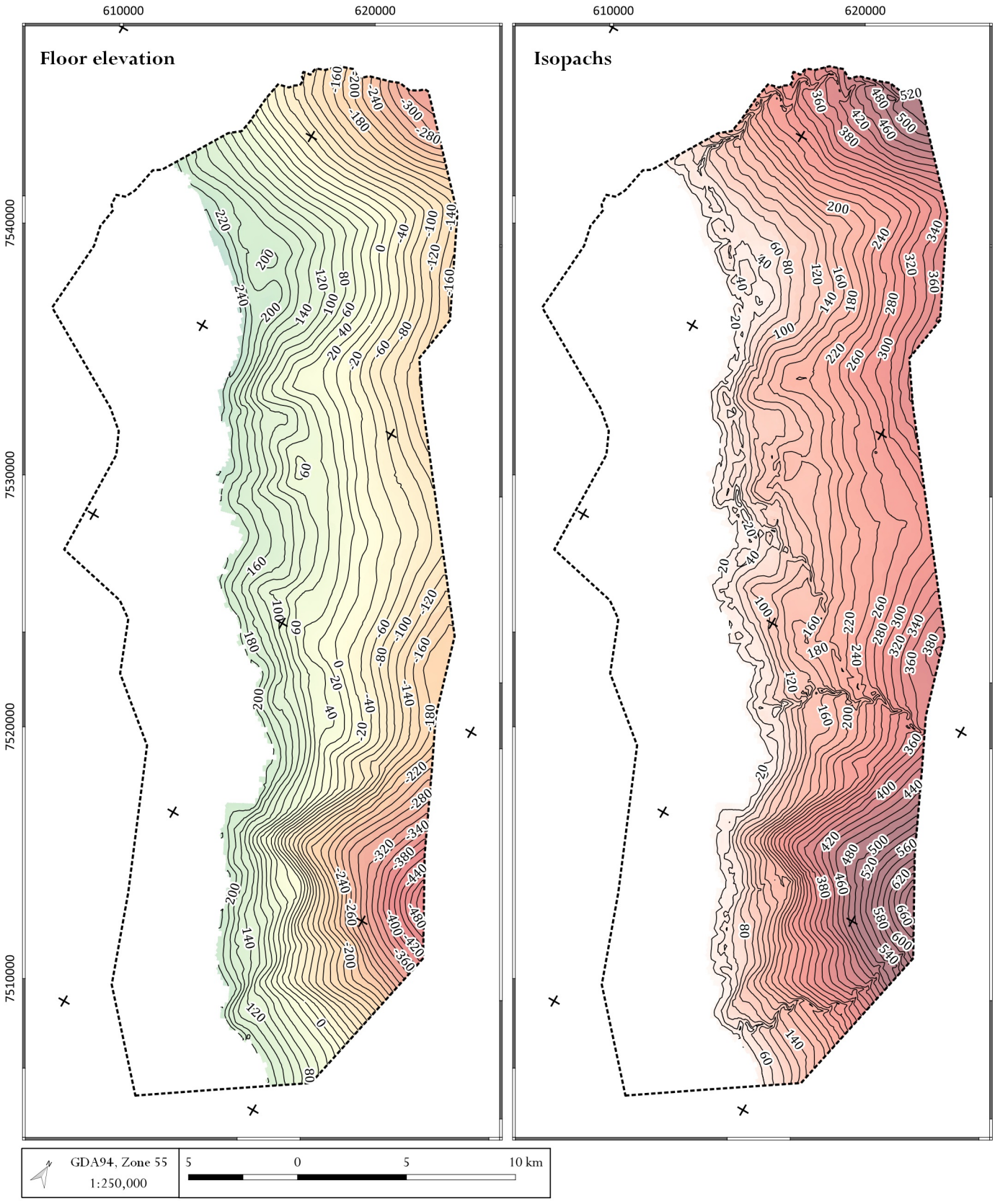
Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\Modelling appendix\10_4027_Vulcan South_App_Floor isopachs Fort Cooper L04.qgz



LEGEND

Floor elevation (mRL)

-400	100
-300	200
-200	300
-100	400
0	

Isopach (m)

0	300
50	400
100	500
200	

Model domain

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Vulcan South - Groundwater Modelling Appendix (4027)

Layer floor elevations and isopachs (L07)

FIGURE No.
11

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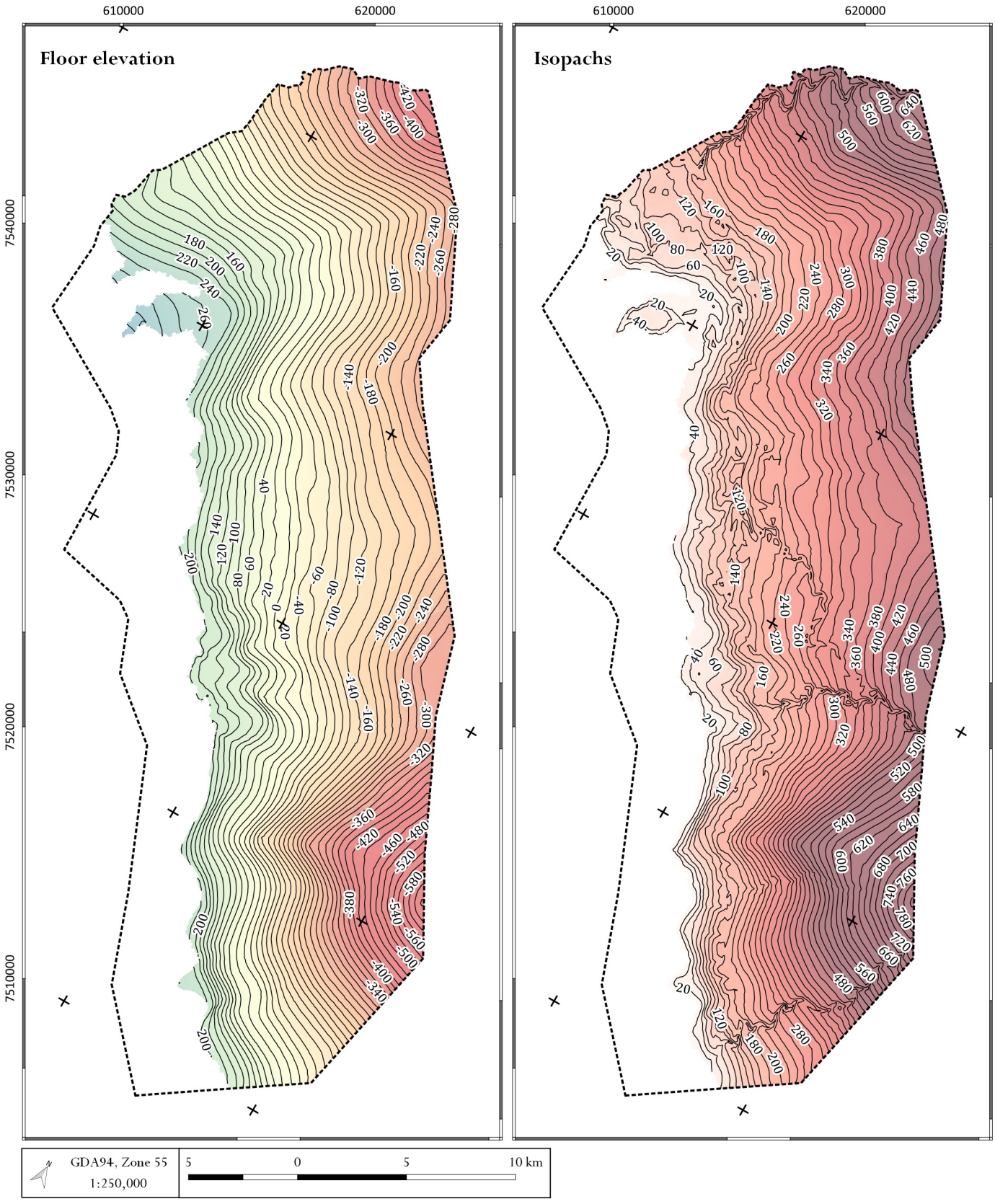

LEGEND

Floor elevation (mRL)

-400	100
-300	200
-200	300
-100	400
0	

Isopach (m)

0	300
50	400
100	500
200	

Model domain

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Layer floor elevations and isopachs (L10)

FIGURE No.
12

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Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\Modelling appendix\12_4027_Vulcan South_App_Floor isopachs DLL seam L10.qgz

3.5. Aquifer properties (LPF)

The Layer-Property Flow module (Harbaugh *et al.*, 2000) is used to control flow between individual model cells. The module reads arrays of horizontal and vertical hydraulic conductivities and, for transient models, storage parameters (specific yield and specific storage) and calculates conductance for cell-cell connections using the hydraulic properties and cell geometry information. Other flow control definitions include type of layer (confined, unconfined, convertible), isotropy/anisotropy and re-wetting parameters.

The hydraulic properties can be assigned to individual grid cells either on layer basis or zone basis. The Project numerical model assigns a 'single value per layer'.

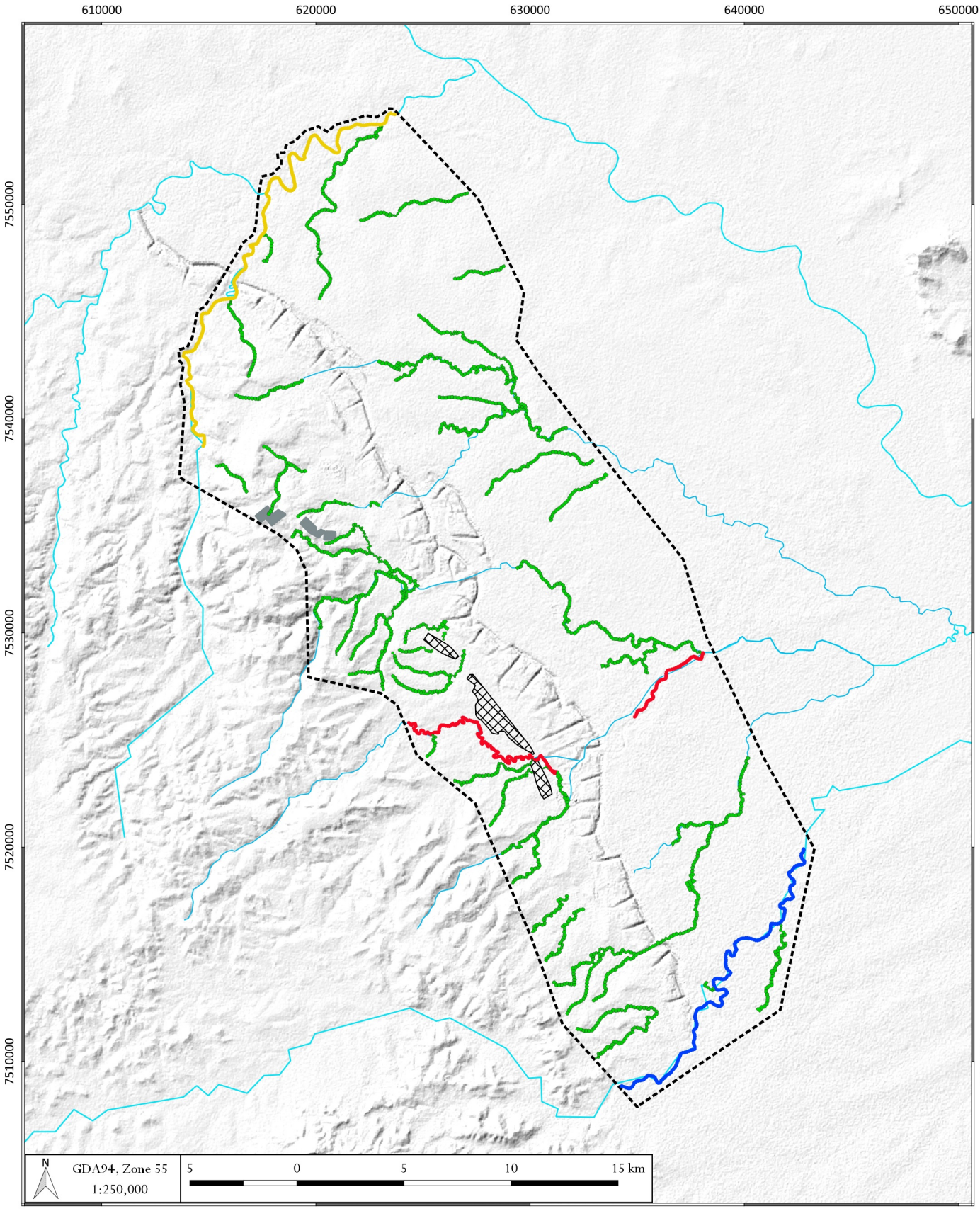
3.6. Surface drainage (RIV)

Groundwater / surface water interaction was modelled using the MODFLOW river (RIV) module. The river module simulates a head-dependent flux boundary (Harbaugh *et al.*, 2000); if the head in the cell falls below a certain threshold, the flux from the river to the model cell is set to a specified lower bound. In our numerical representation, all the surface streams were set as *dry* with no head in the streams which means the streams act only as drains. If a groundwater gradient towards the river cell exists, it will remove the water out of the system. In the opposite scenario, there will be no flux from the river to the aquifer. Hydraulic conductance for each of the river cells is calculated individually based on cell geometry (length of the stream within the cell) and dimensions of the stream itself (width, depth, thickness and vertical K of the stream bed - Table 12).

Table 12 Definition of RIV zones

Zone	Creek name	Vertical K (m/day)	Stream width (m)	Stream depth (m)	Bed thickness (m)
1	Phillips Ck.	1.00	5.00	0.50	1.00
2	Boomerang Ck.	1.00	5.00	0.50	1.00
3	Harrow, Cherwell Ck.	1.00	5.00	0.50	1.00
4	minor surface drainage	1.00	2.00	0.50	1.00

The river cells were placed into the highest active layer in the model, which was mostly layer 1 (alluvium) or layer 2 (weathered regolith/tertiary). Spatial distribution of modelled surface drainage is presented on Figure 13.



LEGEND

River zones

- 1 - Phillips Creek
- 2 - Boomerang Creek
- 3 - Harrow Creek, Cherwell Creek
- 4 - Minor drainage

- Model domain
- Proposed pit
- Highwall mining area
- Watercourse

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River zones

FIGURE No.
13

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3.7. Recharge (RCH)

Diffuse rainfall recharge was modelled using the MODFLOW Recharge (RCH) module, a representation of specified flux boundary condition spread over the upper most active model layer. Diffuse recharge is calculated from rainfall by applying a multiplication factor that depends on the recharge zone.

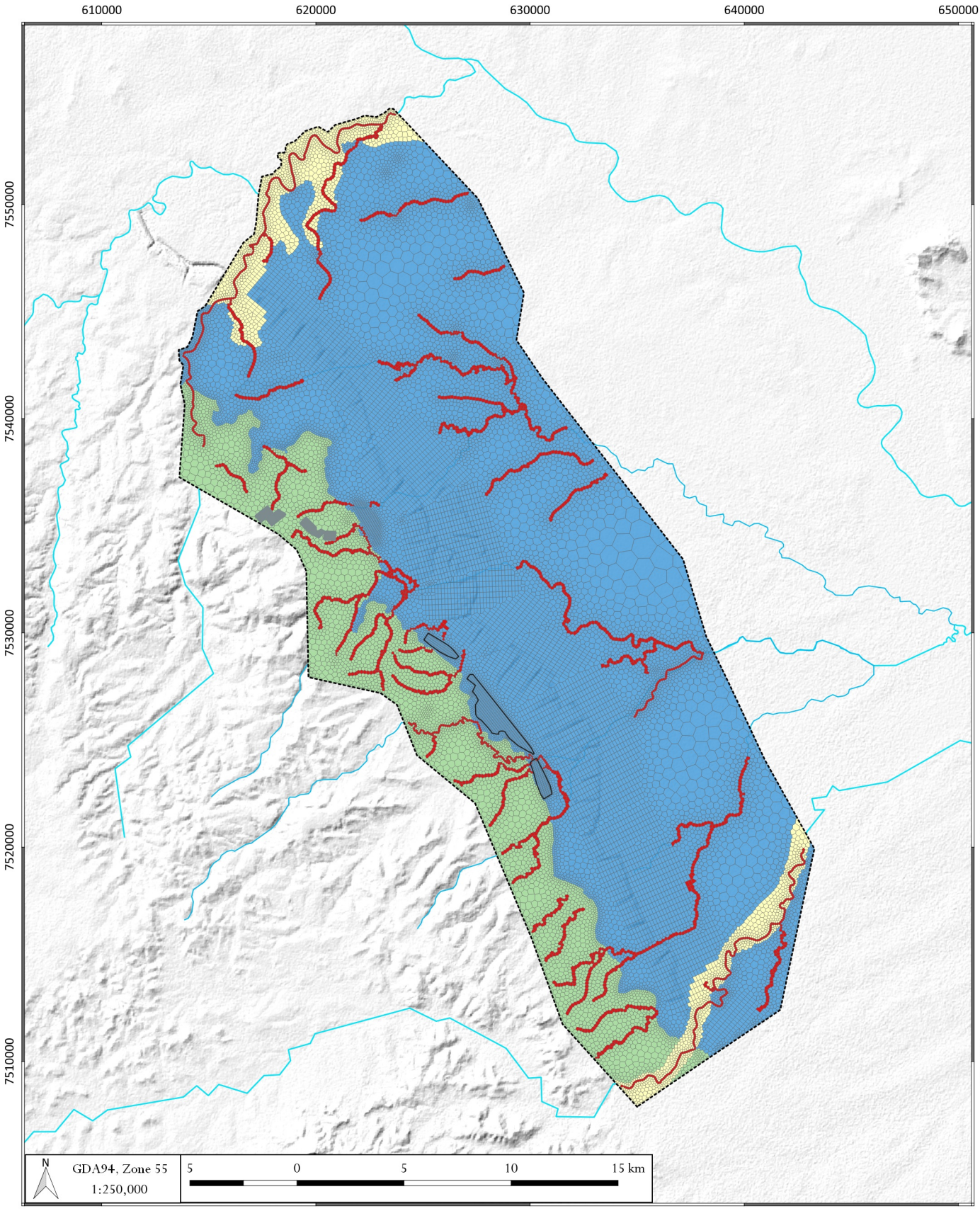
For the steady state run, the recharge factors were applied on the average annual rainfall (582.13 mm/year) where the average was calculated using the time interval between 1900 and 1972. The transient run uses interpolated SILO rainfall between 1973 and 2019 and synthetic data (based on quarterly or six-monthly average calculated from the historical rainfall data). The rainfall values for each stress period are listed in Table 13. Recharge factors were estimated as part of calibration process and are listed in Table 18 (Section 4.6). The spatial extent of recharge zones is shown in Figure 14.

Table 13 Historical (calibration) and synthetic (prediction) rainfall

SP	Start date	End date	SP length (days)	Annual rainfall (mm/SP)
1	1/01/1972	31/12/1972	366	474.6
2	1/01/1973	31/12/1973	365	846.5
3	1/01/1974	31/12/1974	365	910.7
4	1/01/1975	31/12/1975	365	908.1
5	1/01/1976	31/12/1976	366	749.8
6	1/01/1977	31/12/1977	365	608.2
7	1/01/1978	31/12/1978	365	751.8
8	1/01/1979	31/12/1979	365	430.7
9	1/01/1980	31/12/1980	366	423.8
10	1/01/1981	31/12/1981	365	596.6
11	1/01/1982	31/12/1982	365	275.5
12	1/01/1983	31/12/1983	365	895.2
13	1/01/1984	31/12/1984	366	500.2
14	1/01/1985	31/12/1985	365	624.4
15	1/01/1986	31/12/1986	365	522.4
16	1/01/1987	31/12/1987	365	505.6
17	1/01/1988	31/12/1988	366	749.3
18	1/01/1989	31/12/1989	365	818.8
19	1/01/1990	31/12/1990	365	617.4
20	1/01/1991	31/12/1991	365	725.0
21	1/01/1992	31/12/1992	366	296.8
22	1/01/1993	31/12/1993	365	298.9
23	1/01/1994	31/12/1994	365	424.8
24	1/01/1995	31/12/1995	365	633.3
25	1/01/1996	31/12/1996	366	418.8

SP	Start date	End date	SP length (days)	Annual rainfall (mm/SP)
26	1/01/1997	31/12/1997	365	509.6
27	1/01/1998	31/12/1998	365	956.3
28	1/01/1999	31/12/1999	365	419.0
29	1/01/2000	31/12/2000	366	871.5
30	1/01/2001	31/12/2001	365	338.0
31	1/01/2002	31/12/2002	365	300.5
32	1/01/2003	31/12/2003	365	482.1
33	1/01/2004	31/12/2004	366	415.3
34	1/01/2005	31/12/2005	365	506.3
35	1/01/2006	31/12/2006	365	443.0
36	1/01/2007	31/12/2007	365	672.5
37	1/01/2008	31/12/2008	366	788.6
38	1/01/2009	31/12/2009	365	412.3
39	1/01/2010	31/12/2010	365	1152.7
40	1/01/2011	31/12/2011	365	689.8
41	1/01/2012	31/12/2012	366	696.9
42	1/01/2013	31/12/2013	365	652.4
43	1/01/2014	31/12/2014	365	589.4
44	1/01/2015	31/12/2015	365	397.6
45	1/01/2016	31/12/2016	366	774.4
46	1/01/2017	31/12/2017	365	605.8
47	1/01/2018	31/12/2018	365	402.1
48	1/01/2019	31/03/2019	90	330.0
49	1/04/2019	30/06/2019	91	56.8
50	1/07/2019	30/09/2019	92	56.29
51	1/10/2019	31/12/2019	92	170.14
52	1/01/2020	31/03/2020	91	330
53	1/04/2020	30/06/2020	91	56.8
54	1/07/2020	30/09/2020	92	56.29
55	1/10/2020	31/12/2020	92	170.14
56	1/01/2021	30/06/2021	181	386.8
57	1/07/2021	31/12/2021	184	226.43
58	1/01/2022	30/06/2022	181	386.8
59	1/07/2022	31/12/2022	184	226.43

SP	Start date	End date	SP length (days)	Annual rainfall (mm/SP)
60	1/01/2023	30/06/2023	181	386.8
61	1/07/2023	31/12/2023	184	226.43
62	1/01/2024	30/06/2024	182	386.8
63	1/07/2024	31/12/2024	184	226.43
64	1/01/2025	30/06/2025	181	386.8
65	1/07/2025	31/12/2025	184	226.43
66	1/01/2026	30/06/2026	181	386.8
67	1/07/2026	31/12/2026	184	226.43
68	1/01/2027	30/06/2027	181	386.8
69	1/07/2027	31/12/2027	184	226.43
70	1/01/2028	30/06/2028	182	386.8
71	1/07/2028	31/12/2028	184	226.43
72	1/01/2029	30/06/2029	181	386.8
73	1/07/2029	31/12/2029	184	226.43
74	1/01/2030	30/06/2030	181	386.8
75	1/07/2030	31/12/2030	184	226.43
76	1/01/2031	30/06/2031	181	386.8



LEGEND

Recharge zones

- 1 - Regolith
- 2 - Alluvium
- 3 - Above DLL outcrop
- 4 - River cell

- Model domain
- Proposed pit
- Highwall mining area
- Watercourse

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Diffuse recharge zones

FIGURE No.
14

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3.8. Extraction due to mining (DRN)

The mining progression was simulated using drain (DRN) package. The schedule of placement of 'active mine' (open pit) cells within Saraji Mine and Peak Downs Mine was estimated using historical satellite photography, the schedule for the Project was provided by Vitrinite (annual intervals).

The elevation of each drain cell was based on the elevation of the target coal seam (DL in case of Saraji Mine, DLL in case of the Project) and to guarantee full desaturation of the layers above target coal seams, within the open pit footprint, drain cells were placed on the floor of each overlying layer. The conductance of the drain cells were set to 100 m^2/day, regardless of actual cell size.

4. Calibration

4.1. Methodology

Model calibration is a process of adjusting model parameters (hydraulic properties and boundary conditions such as recharge rates or cross-boundary flow rates) so that the model replicates the behaviour of the physical groundwater system. The quality of this replication can be assessed by comparing model outputs (modelled heads and flows) with calibration targets - observed behaviour of the actual groundwater flow system (observed heads and flows).

4.2. Calibration targets (observations)

Structural information (model layer, mesh node ID, global node ID) for each of the observation locations is provided in Table 14. The surveyed ground surface elevation of bores associated with the Project (MBx, VSWx) can vary from the elevation of upper-most model layer. The top elevation of every model cell is represented by elevation of the centroid of that cell. Because of the size (area) of each cell combined with potentially variable (steep) terrain, a difference between surveyed and model elevations will always occur; this difference represents a compromise in a construction of the numerical model as it is a simplification of a groundwater flow system. The difference between surveyed and modelled elevation is one of many indicators of the scale of 'structural uncertainty' of the numerical model and can have an impact on quality of calibration. The 'structural uncertainty' will be discussed in greater detail in Section 6.

Table 14 Observation points – mesh nodes and model layers

Bore ID / RN	Mesh node ID (rnode)	Model layer	Global node ID (gnode)	Topo surface elevation (model) mRL	Topo surface elevation (surveyed) mRL
32924	20435	6	53243	204.90	-
42182	20604	6	53344	210.61	-
43639	21469	10	107767	211.56	-
44336	22331	11	130230	217.08	-
46899	20662	7	64464	209.25	-
49995	20523	7	64391	211.25	-
49997	20409	7	64315	209.96	-
84538	17948	7	62743	190.70	-
100291	633	4	28816	223.11	-
136092	21671	2	24320	233.47	-

Bore ID / RN	Mesh node ID (rnode)	Model layer	Global node ID (gnode)	Topo surface elevation (model) mRL	Topo surface elevation (surveyed) mRL
136689	11475	11	119374	188.45	-
141382	1782	4	29477	212.71	-
141384	551	5	34688	213.62	-
141386	1785	4	29480	219.21	-
158010	17260	4	33205	185.91	-
158011	19890	5	42374	198.86	-
158012	20105	11	128004	237.35	-
158013	18909	5	41873	197.72	-
158014	18467	5	41662	186.29	-
162138	5157	5	37371	223.50	-
162177	11583	6	49395	186.31	-
162506	6476	11	114375	257.83	-
162816	6801	2	9450	196.30	-
162829	554	2	3203	213.01	-
13040283	7355	10	98747	218.92	-
MB04	3762	11	111661	245.31	243.28
MB05	5290	11	113189	254.35	252.70
MB07	8934	2	11583	217.48	215.99
MB09	9090	10	99947	210.53	208.98
MB10	10854	10	101110	215.88	214.60
MB12	13044	11	120943	243.14	241.43
MB30	17093	4	33117	162.33	-
MB32	21898	11	129797	206.81	-
MB4	12375	6	49645	189.47	-
PC056	18580	7	63149	193.80	-
PC058XC	18692	7	63216	194.36	-
PC066XC	19017	7	63420	196.23	-
PZ06A	20276	6	53150	202.23	-
PZ06C	20276	7	64245	202.23	-
PZ08A	16852	7	61993	203.39	-
TG1	22430	2	25079	218.63	-
VSW002	9888	10	100463	217.66	215.94
VSW006	11794	10	101721	217.96	216.82

Bore ID / RN	Mesh node ID (rnode)	Model layer	Global node ID (gnode)	Topo surface elevation (model) mRL	Topo surface elevation (surveyed) mRL
VSW007	8931	10	99790	216.99	215.76
VSW008	8908	11	116807	221.43	219.74
VSW009	8512	10	99510	213.94	212.25
VSW011	7344	10	98736	226.06	225.49
VSW013	7293	11	115192	231.05	229.49
VSW014	6900	11	114799	228.79	227.20
VSW016	5740	11	113639	257.43	255.88
VSW017	2072	11	109971	243.62	242.50
VSW018	6118	11	114017	235.32	236.23
VSW019	5285	11	113184	260.68	254.99
VSW020	3719	10	95975	259.50	257.79
VSW021	3396	11	111295	244.93	243.36

Of the 55 observation bores, 44 bores have only a single water level observation, either a standing water level value obtained when the bore was drilled, or average (composite, 'representative' value). Some of the 'representative' values obtained from the Saraji UWIR (AECOM, 2016) do not have dates associated with water level information, in these cases the publication date of the cited report was used. A summary of the groundwater level observation data used in the model calibration is provided in Table 15.

Eleven bores have transient water level measurements. Six of these are current, non-dry Project observation bores (MB04-MB12), five are long-term observation bores, sampled by QLD government organisations, usually in monthly intervals. Existing pre-mining (at Saraji) observations were incorporated into the observation dataset with a date of 31/12/2017 (end of the first annual stress period). The Project water level information (bores MB04-MB12) is recorded in 4-hourly interval, however for the purpose of the model calibration, the data was down-sampled to monthly interval.

Table 15 Observation points – dates, number of measurements and observed head

Bore ID / RN	# of observations	Observation date		Head			
		From	To	Min	Avg	Max	Δ
32924	1	01/01/2007			184.34		
42182	1	01/01/2007			184.19		
43639	1	31/12/1972			182.07		
44336	1	31/12/1972			185.15		
46899	1	01/01/2007			167.31		
49995	1	01/01/2007			172.83		
49997	1	01/01/2007			179.77		
84538	1	31/12/1972			173.80		
100291	1	09/02/2006			205.82		

Bore ID / RN	# of observations	Observation date		Head			
		From	To	Min	Avg	Max	Δ
136092	1	30/10/2002			225.23		
136689	1	18/01/2007			157.58		
141382	25	09/04/2008	07/01/2014	194.47	198.00	198.68	4.21
141384	29	19/04/2008	07/01/2014	195.97	197.28	197.89	1.92
141386	30	19/04/2008	07/01/2014	199.97	200.45	200.87	0.90
158010	1	08/07/2012			166.87		
158011	1	06/07/2012			178.97		
158012	1	08/07/2012			221.86		
158013	1	09/07/2012			172.51		
158014	1	03/07/2012			172.83		
162138	1	01/08/2012			206.94		
162177	36	01/06/2008	25/10/2017	192.28	206.62	212.50	20.22
162506	1	28/10/2015			268.49		
162816	1	08/02/2006			201.71		
162829	1	09/02/2006			197.49		
13040283	36	29/08/2004	17/04/2018	177.62	179.24	181.57	3.95
MB04	3	15/06/2019	11/08/2019	238.60	238.69	238.75	0.15
MB05	3	15/06/2019	11/08/2019	238.66	238.74	238.87	0.21
MB07	3	15/06/2019	11/08/2019	180.48	180.51	180.55	0.07
MB09	3	15/06/2019	11/08/2019	181.89	181.91	181.93	0.04
MB10	3	15/06/2019	12/08/2019	182.83	182.88	182.91	0.08
MB12	3	15/06/2019	11/08/2019	218.09	218.26	218.42	0.33
MB30	1	01/01/2015			162.71		
MB32	1	01/01/2015			197.73		
MB4	1	01/01/2015			165.91		
PC056	1	01/01/2015			176.82		
PC058XC	1	01/01/2015			176.29		
PC066XC	1	01/01/2015			159.49		
PZ06A	1	01/01/2015			185.90		
PZ06C	1	01/01/2015			183.40		
PZ08A	1	01/01/2015			177.60		
TG1	1	01/01/2015			209.16		
VSW002	1	15/11/2018			182.24		
VSW006	1	09/12/2018			183.72		

Bore ID / RN	# of observations	Observation date		Head			
		From	To	Min	Avg	Max	Δ
VSW007	1	18/11/2018			181.16		
VSW008	1	19/11/2018			192.94		
VSW009	1	19/11/2018			179.55		
VSW011	1	01/12/2018			180.79		
VSW013	1	02/12/2018			224.49		
VSW014	1	02/12/2018			218.00		
VSW016	1	04/12/2018			239.48		
VSW017	1	04/12/2018			224.80		
VSW018	1	06/12/2018			223.13		
VSW019	1	07/12/2018			226.99		
VSW020	1	11/12/2018			236.99		
VSW021	1	07/12/2018			241.76		

4.3. Initial observation sensitivities

The observation sensitivities are calculated during initial PEST iterations (Jacobian calculation). They show which observations are the most sensitive to changes in input parameters. Not surprisingly, given the magnitude of impact caused by mining, observations associated with DL seams and its overburden appear to be more sensitive than the weathered regolith observations and observations located in basement bedrock (underburden) see Figure 15.

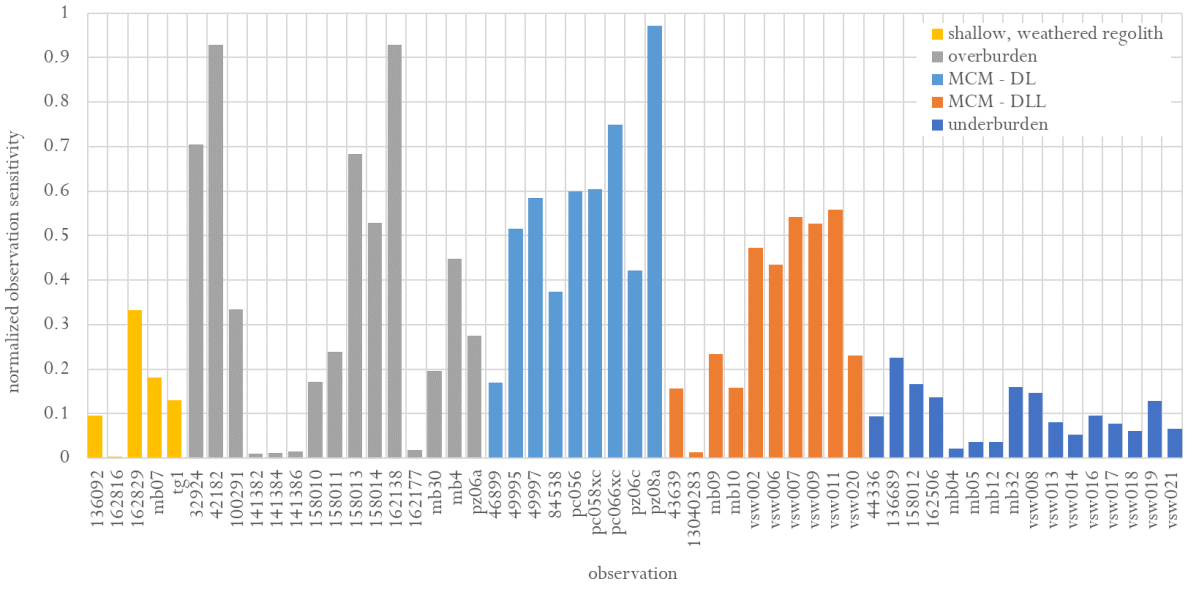

Figure 15 Normalised observation sensitivities

4.4. Initial parameter sensitivities

The calibration process appears to be the most sensitive against transient recharge into the weathered regolith profile (rch01tr), storage properties of the weathered zone (sy_z02) and horizontal hydraulic conductivity of the DLL overburden (kx_z09). The composite parameter sensitivities are presented in Figure 16.

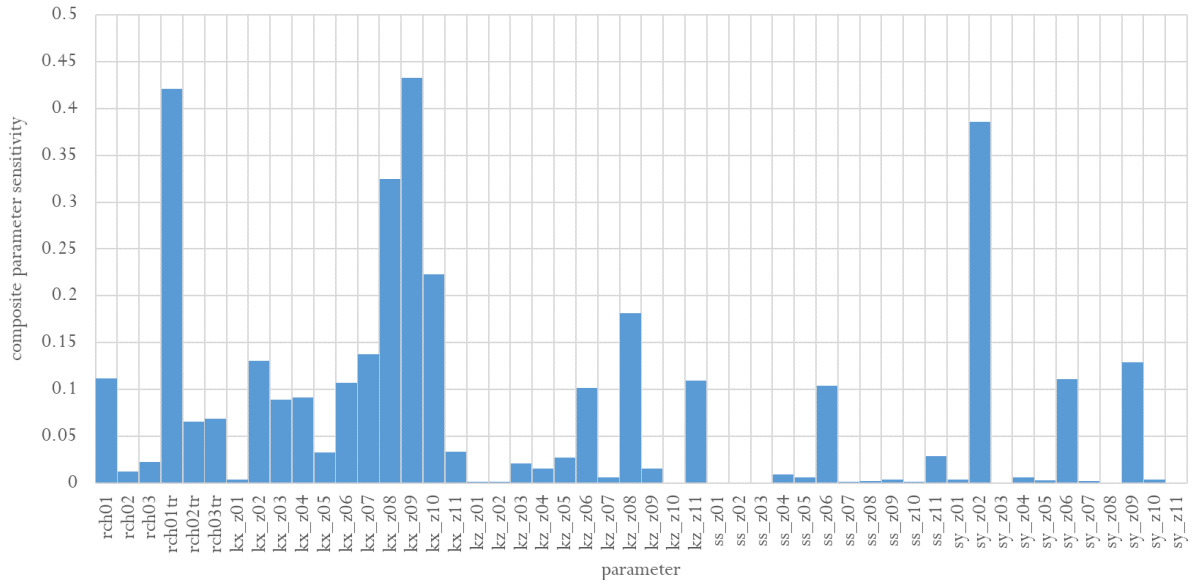

Figure 16 Composite parameter sensitivities

4.5. Calibration results – calibration statistics

The numerical model includes a steady-state and a transient calibration (1972 to 2019). The transient calibration captures historical development at Saraji Mine and Peak Downs Mine which was based upon an interpolated mine progression assessed from Landsat imagery.

In accordance with the Australian groundwater modelling guidelines (Barnett *et al.*, 2012), the objective of a model calibration is to replicate the groundwater levels measured in the site monitoring network and other bores. A set of 55 selected observation points (and a total of 176 observations) were used in the calibration process, some with single values and some with time-series observations. The observation points included historical observation data from mining investigations (AECOM, 2016), publicly available sources (AECOM, 2016; Department of Natural Resources, Mines and Energy, 2019), and on-site data collected from open drill-holes and data collected from the new monitoring bores (**hydrogeologist.com.au**, 2019).

An overall (all observations and all time steps) transient calibration was achieved with an RMS (root mean square error) of 3.6 m and an SRMS (scaled root mean square error) of 4% (Table 16). The SRMS value of 4% (3.6 m / 90.5 m=0.04 or 4%) indicates a good fit between measured and modelled data. Notwithstanding that, other criteria (such as good correlation between measured and modelled hydrographs and contour maps) also apply, an SRMS that is less than 10% may be acceptable (Barnett *et al.*, 2012) while an SRMS < 5% represents generally good calibration in the experience of **hydrogeologist.com.au**.

Table 16 Model calibration – calibration statistics

Calibration measure		Value	Unit
number of observations	n	176	-
range of measured heads	-	90.51	m
sum of squared residuals	SSQ, Φ	2292.3	m^2
mean sum of residuals	MSR	2.7	m
scaled mean sum of residuals	SMSR	2.9	%
root mean squared error	RMS	3.6	m
scaled root mean squared error	SRMS	4.0	%

A scatter diagram of observed vs. modelled groundwater elevations (Figure 17) indicates that most points are situated close to the 1:1 line (perfect fit). While outliers do exist, most of the observations are within ±5 m of the 1:1 line. It is important to note that no significant or obvious trends or systematic departures appear to occur from the 1:1 line (the various colours representing different hydrogeological units scatter around the 1:1 line in a generally random pattern). The weighted residual of the model calibration are presented in Table 17 and shown for the various model layers in Figure 18, Figure 19 and Figure 20.

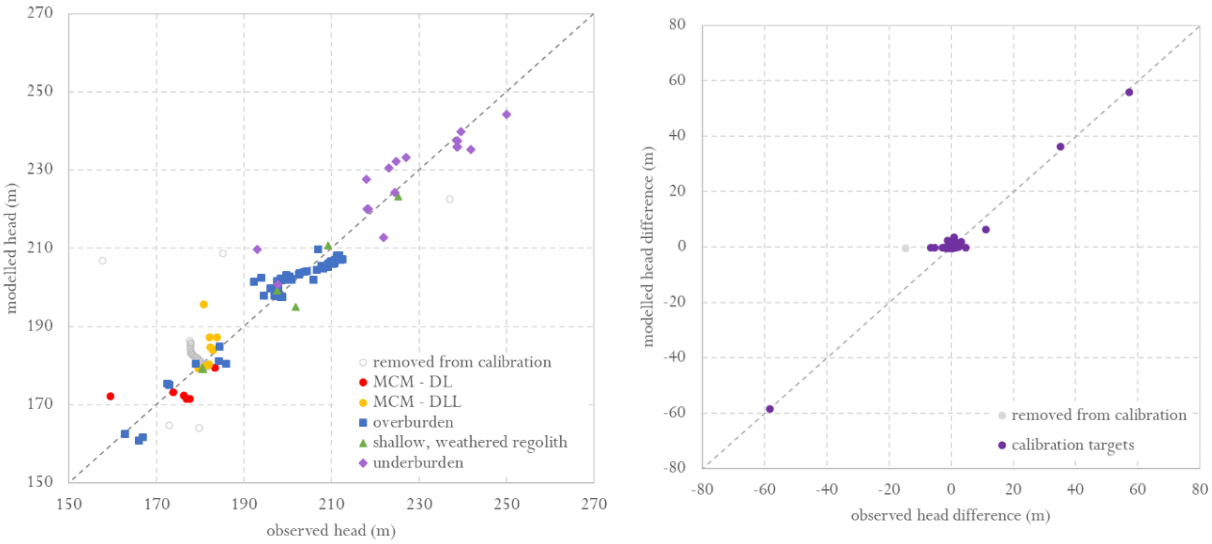

Figure 17 Model calibration scatter diagrams – observed and modelled heads and head differences

Table 17 Model calibration – weighted residuals

Bore ID	Easting	Northing	Number of observations	Observation group	Weighted sum of residuals
136092	633415.8	7512196.5	1	shallow, weathered regolith	1.94
162816	618975.0	7552309.0	1	shallow, weathered regolith	6.67
162829	623671.0	7549482.0	1	shallow, weathered regolith	-1.76
mb07	628691.1	7526258.1	3	shallow, weathered regolith	1.31
tg1	635215.0	7508903.0	1	shallow, weathered regolith	-1.54

Bore ID	Easting	Northing	Number of observations	Observation group	Weighted sum of residuals
32924	638285.0	7514125.0	1	overburden	-0.49
42182	637746.0	7514257.0	1	overburden	3.03
100291	626431.5	7542882.6	1	overburden	3.92
141382	628490.0	7542693.0	25	overburden	0.33
141384	623784.0	7549391.0	29	overburden	-2.37
141386	626507.0	7544152.0	30	overburden	-1.50
158010	642528.4	7519938.8	1	overburden	5.24
158011	640035.0	7514094.9	1	overburden	-1.45
158013	637781.5	7518065.5	1	overburden	-2.81
158014	636495.7	7519991.1	1	overburden	-2.17
162138	620083.8	7547612.9	1	overburden	-2.77
162177	616863.0	7547756.0	36	overburden	1.33
mb30	642503.0	7519162.0	1	overburden	0.14
mb4	635928.0	7527934.0	1	overburden	5.15
pz06a	639272.0	7513326.0	1	overburden	5.47
84538	641353.3	7516737.0	1	MCM - DL	0.66
pc056	640288.3	7516655.0	1	MCM - DL	5.37
pc058xc	640054.7	7516179.0	1	MCM - DL	4.02
pc066xc	639328.9	7517206.0	1	MCM - DL	-12.66
pz06c	639272.0	7513326.0	1	MCM - DL	3.95
pz08a	634647.0	7523069.0	1	MCM - DL	6.14
43639	638938.6	7511033.0	1	MCM - DLL	-5.22
mb09	629511.2	7525222.7	3	MCM - DLL	1.65
mb10	628123.6	7526469.3	3	MCM - DLL	-1.18
vsw002	627811.8	7526808.7	1	MCM - DLL	-2.42
vsw006	628024.8	7526217.7	1	MCM - DLL	-3.50
vsw007	628679.8	7526268.7	1	MCM - DLL	1.25
vsw009	628076.8	7527016.7	1	MCM - DLL	0.21
vsw011	627406.8	7527852.8	1	MCM - DLL	-14.93
158012	632270.5	7515394.7	1	underburden	9.05
162506	621630.0	7534800.0	1	underburden	5.78

Bore ID	Easting	Northing	Number of observations	Observation group	Weighted sum of residuals
mb04	622014.3	7536148.2	3	underburden	2.79
mb05	621964.5	7534905.0	3	underburden	1.36
mb12	625251.5	7526409.2	3	underburden	-1.78
mb32	637481.0	7510535.0	1	underburden	-3.01
vsw008	627335.8	7527263.7	1	underburden	-16.75
vsw013	624599.8	7530294.8	1	underburden	0.19
vsw014	623534.8	7531296.8	1	underburden	-9.60
vsw016	621573.8	7535486.8	1	underburden	-0.37
vsw017	622555.8	7535727.8	1	underburden	-7.40
vsw018	622937.8	7533623.8	1	underburden	-7.47
vsw019	622513.8	7534503.8	1	underburden	-6.31
vsw021	622024.8	7536169.8	1	underburden	6.57



LEGEND

Residuals (m)

- -15.0 - -10.0
- -10.0 - -5.0
- -5.0 - -3.0
- -3.0 - -1.0
- -1.0 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0

- Model domain
- Proposed pit
- Highwall mining area
- Established mining operation

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Spatial distribution of residuals – weathered zone, MCM

FIGURE No.
18

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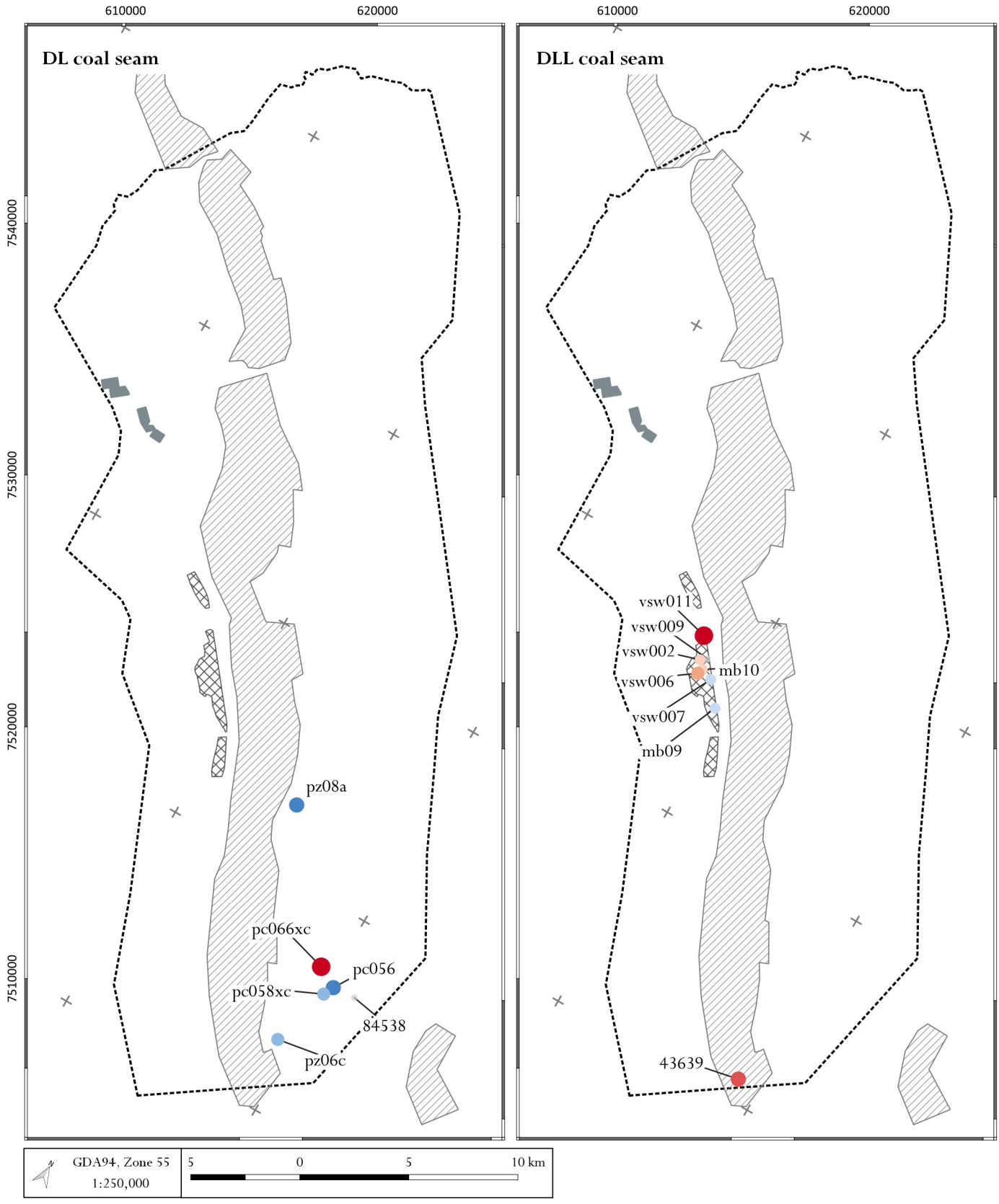

LEGEND

Residuals (m)

- -15.0 - -10.0
- -10.0 - -5.0
- -5.0 - -3.0
- -3.0 - -1.0
- -1.0 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0

- Model domain
- Proposed pit
- Highwall mining area
- Established mining operation

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Vulcan South - Groundwater Modelling Appendix (4027)

Spatial distribution of residuals – MCM DL, MCM DLL

FIGURE No.
19

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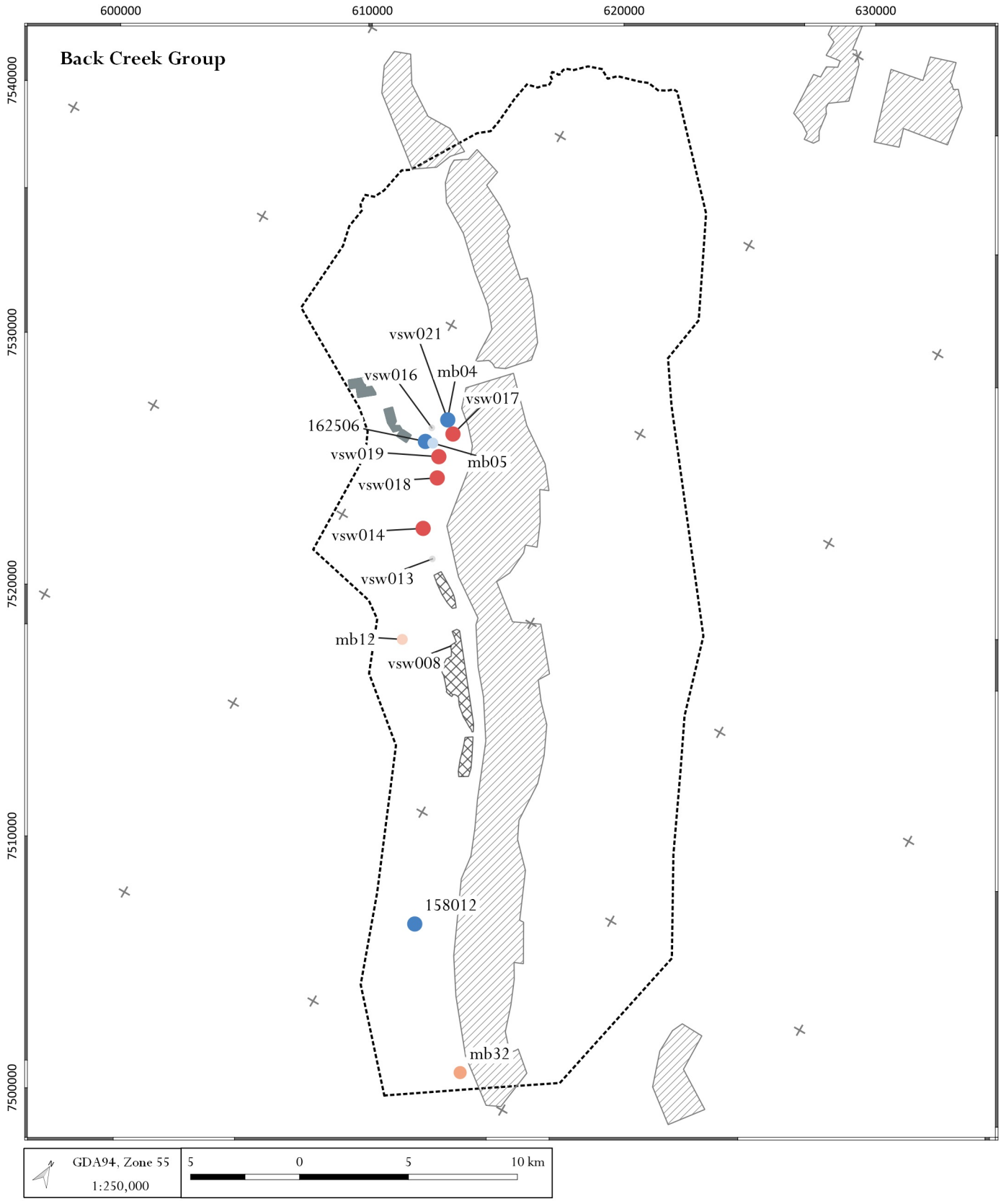

LEGEND

Residuals (m)

- -15.0 - -10.0
- -10.0 - -5.0
- -5.0 - -3.0
- -3.0 - -1.0
- -1.0 - 1.0
- 1.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0

- Model domain
- Proposed pit
- Highwall mining area
- Established mining operation

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Vulcan South - Groundwater Modelling Appendix (4027)

Spatial distribution of residuals – Back Creek Group

FIGURE No.
20

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4.6. Calibration results – final parameter values

The final model calibrated parameter values for recharge, hydraulic conductivity and storage are summarised in Table 18, Table 19 and Table 20 respectively.

Table 18 Model calibration – parameter values – recharge

RCH zone		Zone area (km^2)	RCH rate factor (-)	
			steady state	transient
1	weathered regolith east of DLL subcrop	459.14	1.6611×10^{-3}	1.0000×10^{-3}
2	alluvium	35.36	1.0000×10^{-3}	1.0000×10^{-2}
3	weathered regolith west of DLL subcrop	114.11	5.0000×10^{-4}	1.3355×10^{-3}
4	surface drainage cells	38.97	$0.0000\times10^{+0}$	$0.0000\times10^{+0}$

Table 19 Model calibration – parameter values – hydraulic conductivity

HSU (geo zone)		model layer	K_h (m/day)	K_h factor (-)	K_v (m/day)
1	Alluvium	1	5.0000×10^{-1}	2.5000×10^{-2}	1.2500×10^{-2}
2	weathered regolith / tertiary	2	5.0000×10^{-1}	3.0000×10^{-2}	1.5000×10^{-2}
3	overburden - Fort Cooper CM	3	5.0000×10^{-2}	3.9354×10^{-2}	1.9677×10^{-3}
4	overburden - Fort Cooper CM	4	5.0000×10^{-2}	8.9302×10^{-3}	4.4651×10^{-4}
5	overburden - Moranbah CM	5	3.0515×10^{-3}	1.9493×10^{-2}	5.9485×10^{-5}
6	overburden - Moranbah CM	6	1.7230×10^{-3}	2.0546×10^{-2}	3.5400×10^{-5}
7	Dysart Lower (DL) seam - Moranbah CM	7	1.0000×10^{-2}	2.0930×10^{-2}	2.0930×10^{-4}
8	overburden - Moranbah CM	8	5.0000×10^{-4}	3.9383×10^{-2}	1.9692×10^{-5}
9	overburden - Moranbah CM	9	4.5428×10^{-2}	1.0000×10^{-3}	4.5428×10^{-5}
10	Dysart Lower Lower (DLL) seam - Moranbah CM	10	1.5511×10^{-1}	2.4871×10^{-2}	3.8577×10^{-3}
11	underburden - Back Creek Group	11	1.0000×10^{-4}	1.0000×10^{-3}	1.0000×10^{-7}

Table 20 Model calibration – parameter values – storage

HSU (geo zone)		model layer	Ss (m^{-1})	Sy (-)
1	alluvium	1	2.0000×10^{-6}	9.0000×10^{-2}
2	weathered regolith / tertiary	2	2.4900×10^{-6}	5.0000×10^{-3}
3	overburden - Fort Cooper CM	3	1.0000×10^{-6}	5.0000×10^{-3}
4	overburden - Fort Cooper CM	4	2.0000×10^{-5}	1.0000×10^{-4}
5	overburden - Moranbah CM	5	1.0000×10^{-6}	1.7598×10^{-4}
6	overburden - Moranbah CM	6	1.0000×10^{-5}	5.0000×10^{-3}
7	Dysart Lower (DL) seam - Moranbah CM	7	2.0000×10^{-5}	1.0000×10^{-3}
8	overburden - Moranbah CM	8	1.0000×10^{-5}	1.0000×10^{-4}
9	overburden - Moranbah CM	9	1.0000×10^{-5}	2.7871×10^{-3}
10	Dysart Lower Lower (DLL) seam - Moranbah CM	10	2.0000×10^{-5}	1.0000×10^{-3}
11	underburden - Back Creek Group	11	1.0000×10^{-5}	2.5000×10^{-4}

5. Predictions

5.1. Budgets

Water budget (or water balance) of the numerical model reflects and quantifies flows entering and leaving the model domain. The inflows into the model domain are through diffuse aerial recharge (RCH boundary condition) and cross-boundary flow (GHB boundary condition). The outflows from the model domain are via surface drainage (RIV boundary condition), cross-boundary flow (GHB boundary condition) and, for transient part of the simulation, water removal through mining (DRN boundary condition)

The flow rates and volumes across individual boundaries are summarised in Table 21 and flow rate trends for individual boundaries are presented in Figure 21 (inflows) and Figure 22 (outflows). Table 22 summarises the predicted inflows rates and volumes for the Project, whereas Figure 23 and Figure 24 present the predicted inflow rates for the BMA mines and the Project respectively.

Table 21 Numerical model – water budget summary

boundary condition		steady state	transient - calibration		transient - prediction	
		flow rate (m^3/day)	cumulative volume (m^3)	average flow rate (m^3/day)	cumulative volume (m^3)	average flow rate (m^3/day)
	number of days	-	17532.0		4565.0	
in	recharge (RCH)	1362.3	27,684,805.8	1579.1	6,880,887.4	1638.7
	head dependant boundary (GHB)	391.8	6,436,659.1	367.1	1,704,982.7	406.0
out	surface drainage (RIV)	634.8	14,044,678.5	801.1	2,719,386.7	647.6
	head dependant boundary (GHB)	1119.3	17,648,669.8	1006.7	3,633,140.5	865.2
	mining (DRN)	0	37,221,053.8	2123.0	19,059,994.9	4539.2

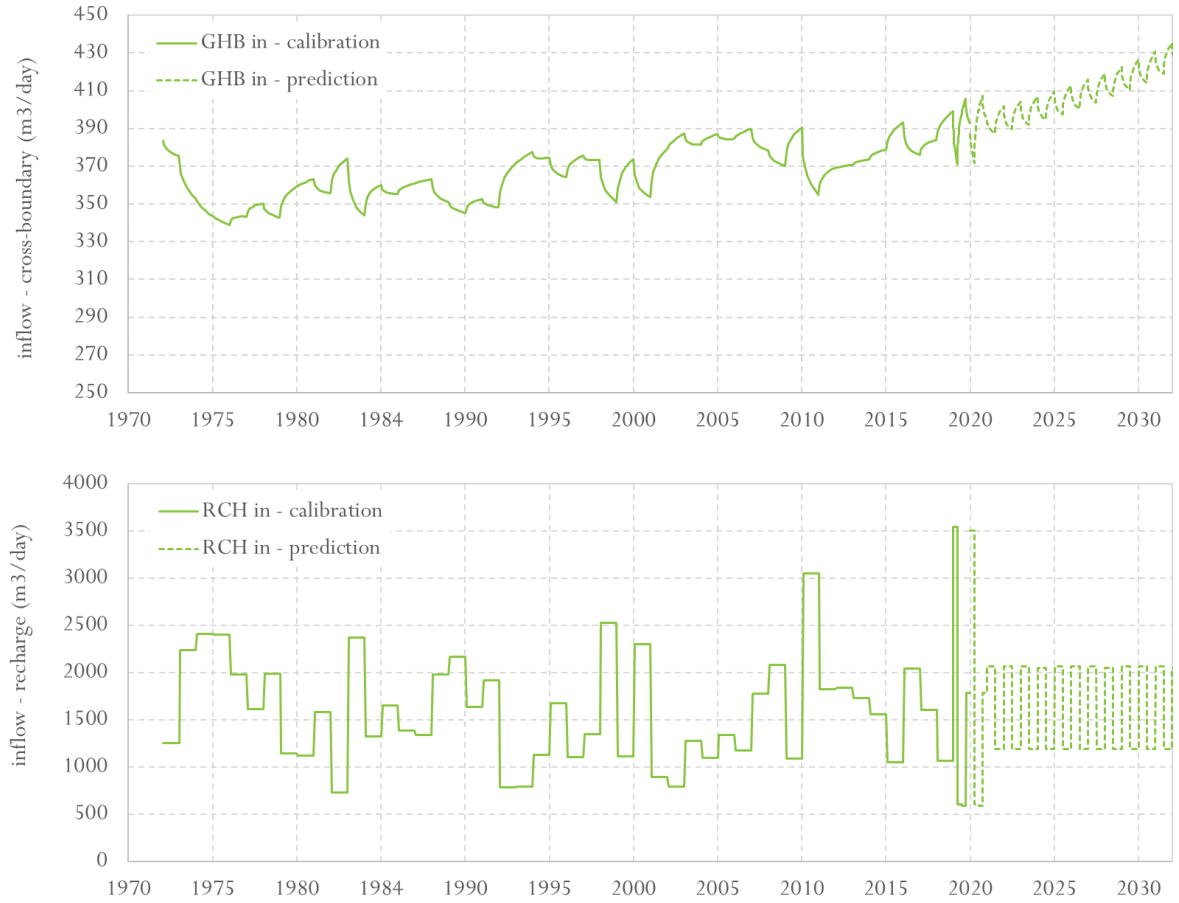


Figure 21 Numerical model budget – inflows (cross-boundary flow, rainfall related recharge)

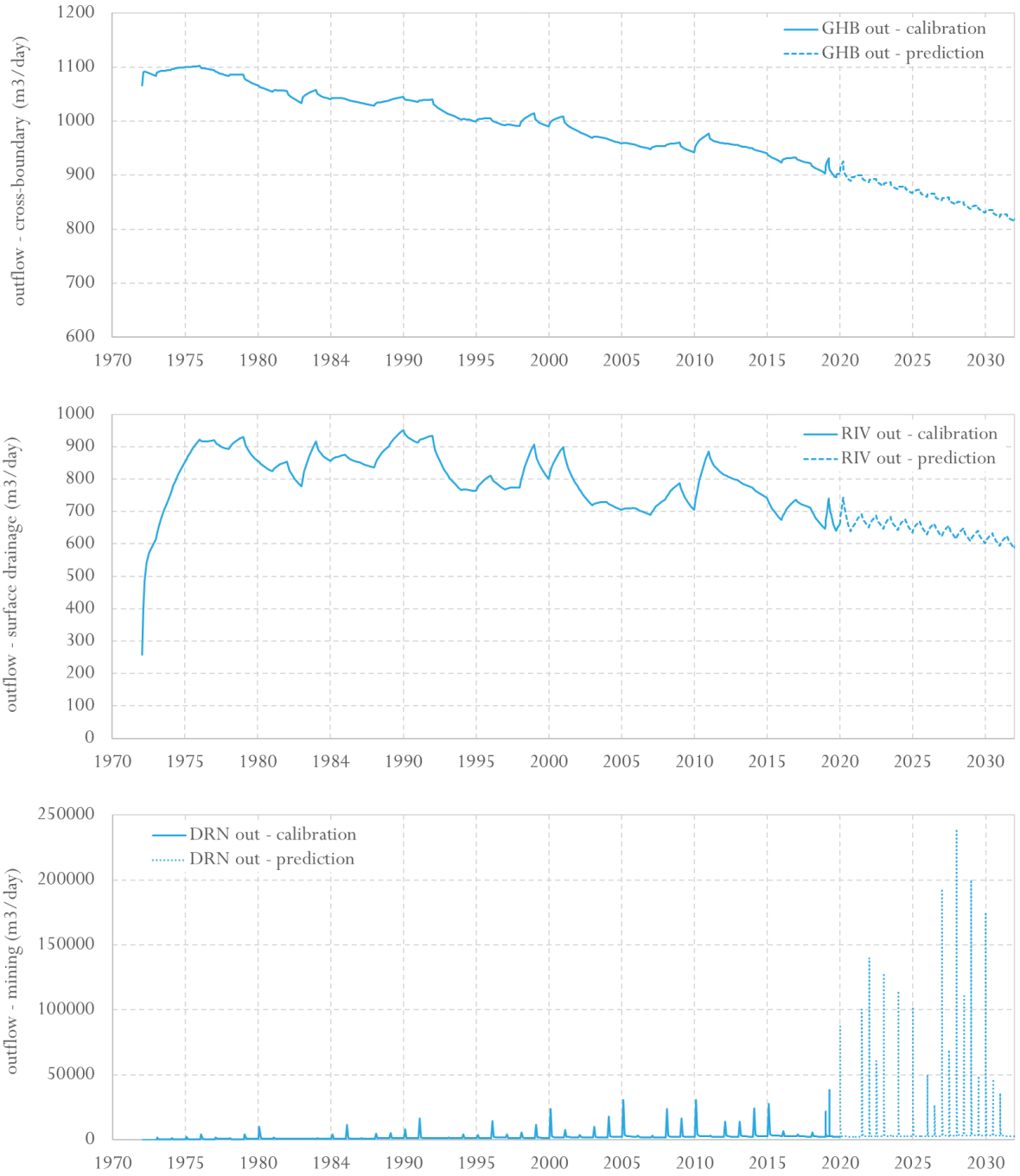


Figure 22 Numerical model budget – outflows (cross-boundary flow, surface drainage, mining)

Table 22 Numerical model – zone budget – predicted inflow rates for the Project

SP	days	SP end	DRN inflow (m³/day)			Volume (ML)
			Vulcan North	Vulcan Main	Vulcan South	
59	184	01/01/2023	0.00	0.00	0.00	0.16
60	181	01/07/2023	0.88	0.00	0.00	
61	184	01/01/2024	1.86	0.21	0.00	1.12
62	182	01/07/2024	1.45	2.60	0.00	
63	184	01/01/2025	4.71	6.41	0.00	9.11
64	181	01/07/2025	3.09	35.93	0.00	
65	184	01/01/2026	1.15	37.14	0.00	13.15
66	181	01/07/2026	0.00	33.72	0.00	
67	184	01/01/2027	0.00	35.09	0.00	14.14
68	181	01/07/2027	0.00	42.42	0.00	
69	184	01/01/2028	0.00	32.20	0.00	11.20
70	182	01/07/2028	0.00	29.00	0.00	
71	184	01/01/2029	0.00	21.90	0.15	5.83
72	181	01/07/2029	0.00	9.05	0.77	
73	184	01/01/2030	0.00	2.62	2.34	3.23
74	181	01/07/2030	0.00	10.72	2.05	
75	184	01/01/2031	0.00	6.28	0.89	1.52
76	181	01/07/2031	0.00	0.00	1.10	

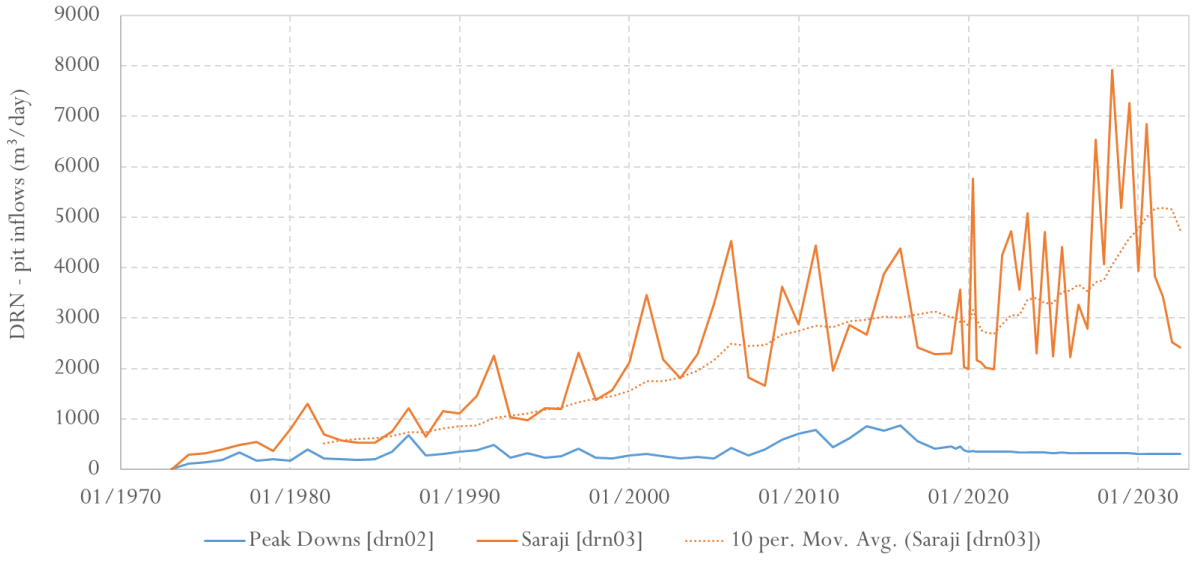


Figure 23 Numerical model zone budget – inflow rates – Peak Downs, Saraji

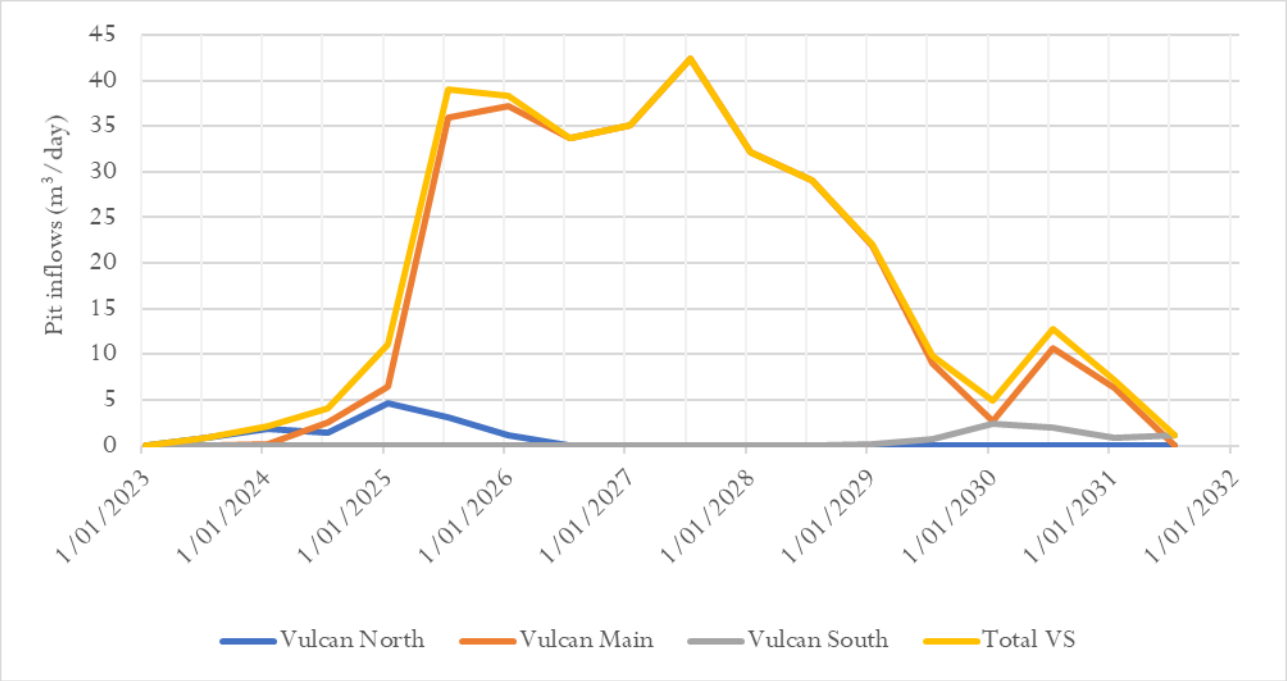
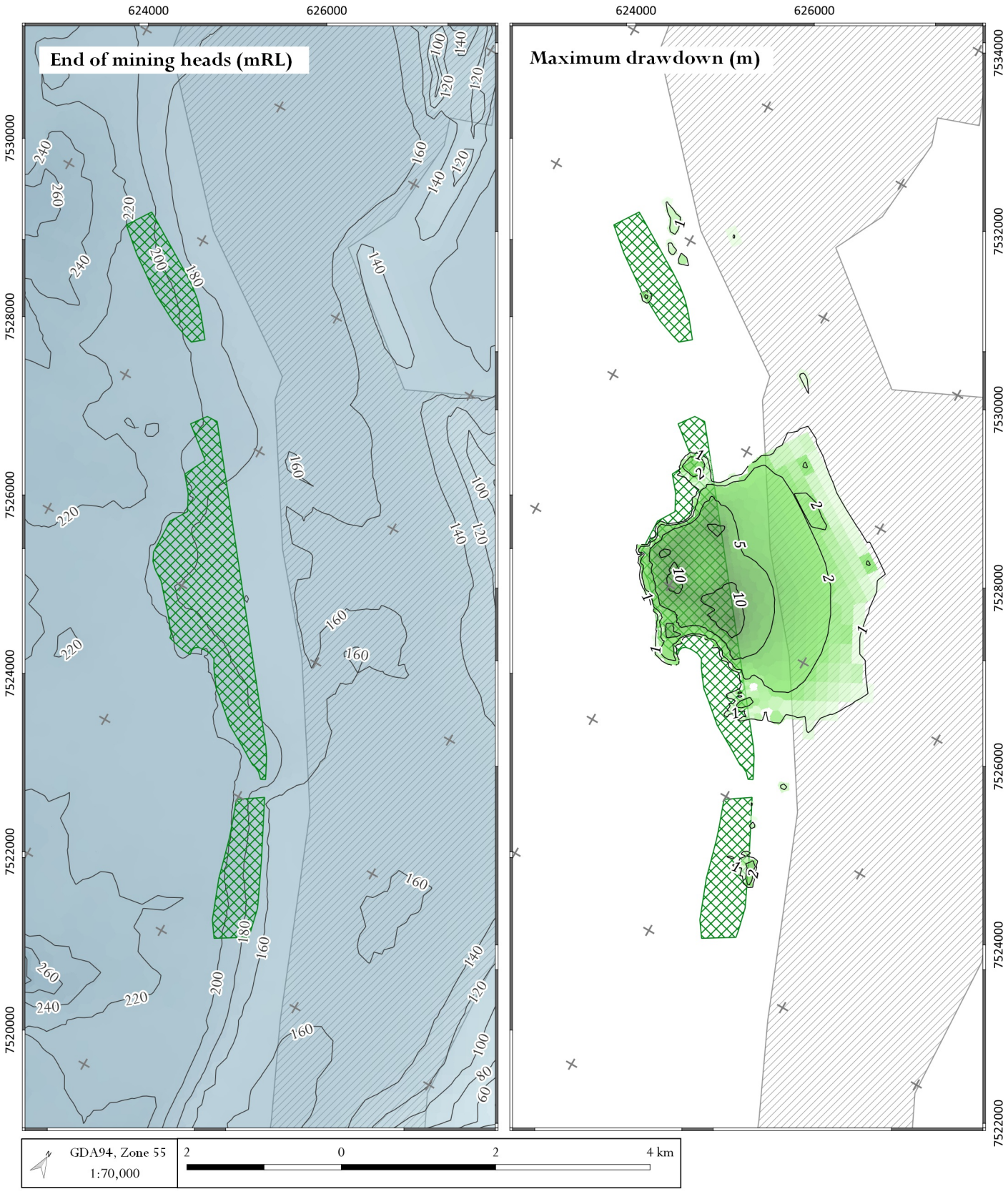


Figure 24 Numerical model zone budget – inflow rates – Project only

5.2. Heads and drawdown

The modelled end of mining heads and maximum drawdown are shown for the weathered zone and the DLL coal seam in Figure 25 and Figure 26 respectively. Figure 27 shows the model predicted heads at the start of mining for the weathered zone, whereas Figure 28 shows the model predicted heads at the start of mining for the DLL coal seam.

The impacts of the mine development on the groundwater regime are discussed in the main groundwater impact assessment report.



LEGEND

- Model domain
- Proposed pit
- Established mining operation

DATE
22/02/2022

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Vulcan South - Groundwater Modelling Appendix (4027)

Modelled heads and drawdown - weathered zone

FIGURE No.
25

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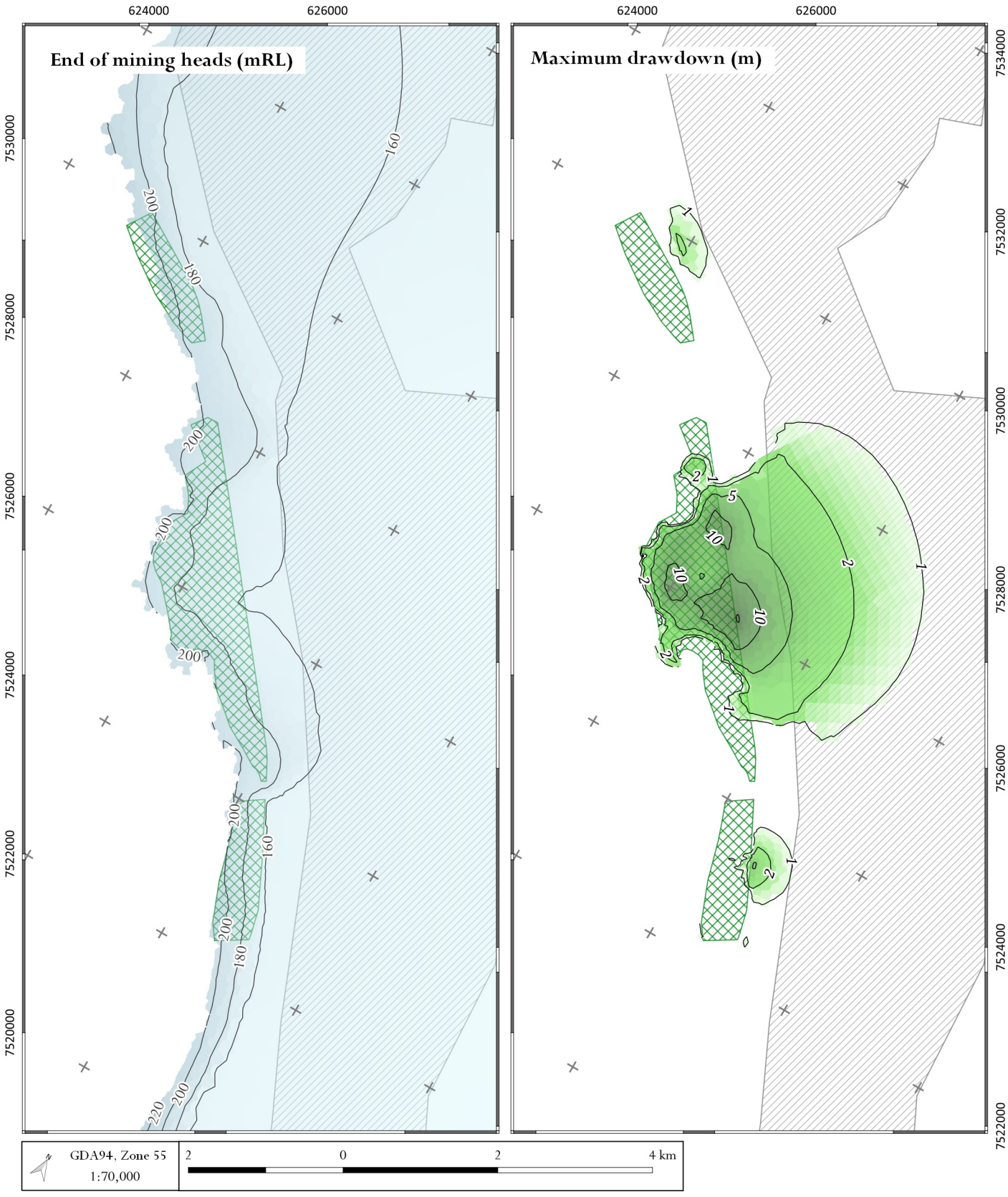

LEGEND

- Model domain
- Proposed pit
- Established mining operation

DATE
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Vulcan South - Groundwater Modelling Appendix (4027)

Modelled heads and drawdown - DLL coal seam

FIGURE No.
26

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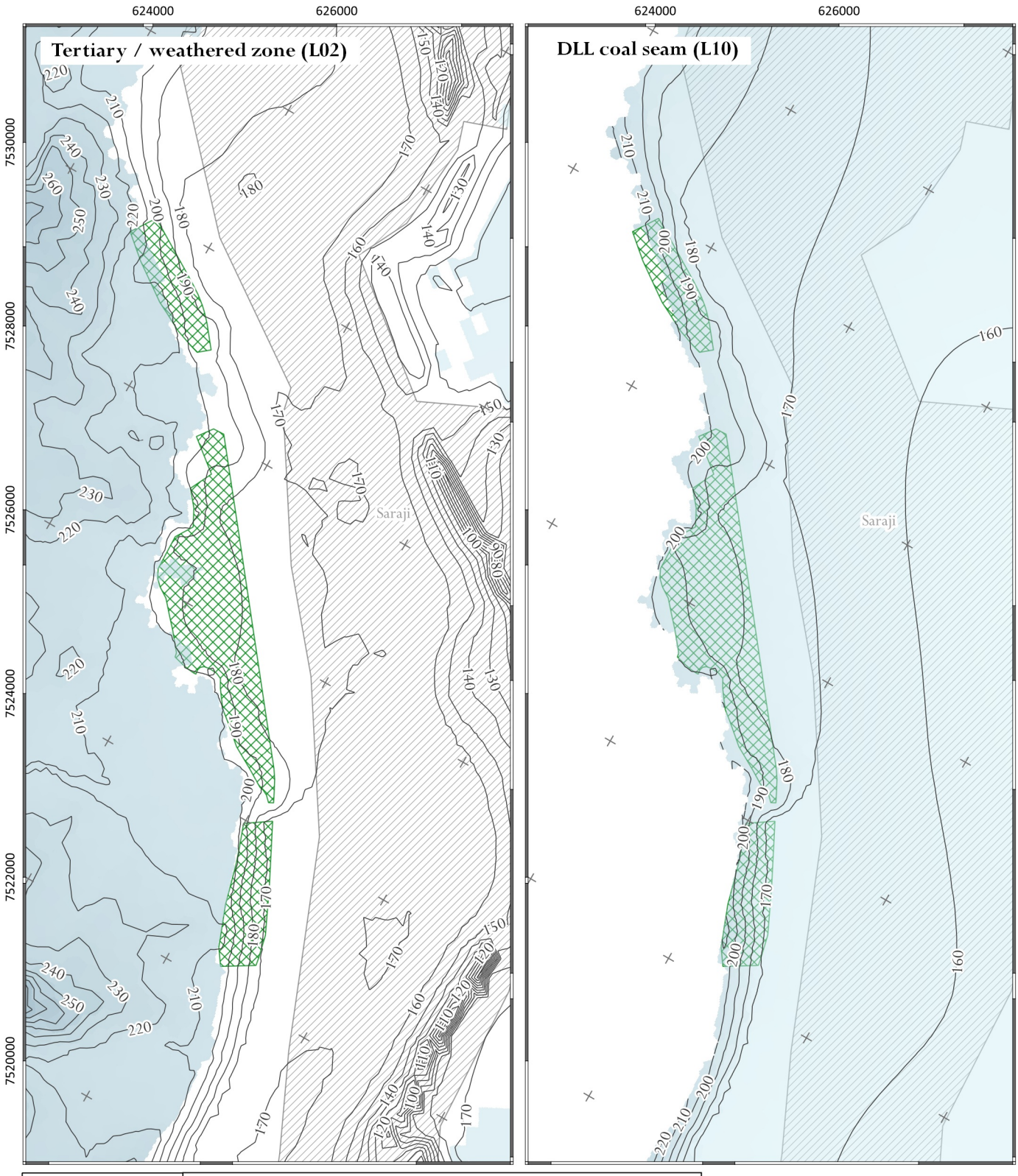

LEGEND

Saturated heads (mAHD)

140
170
200
230
260
290
320
350
380

Model domain
Proposed pit
Established mining operation

DATE
22/02/2022

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Vulcan South - Groundwater Modelling Appendix (4027)

Model predicted heads - start of mining (SP51)

FIGURE No.
27

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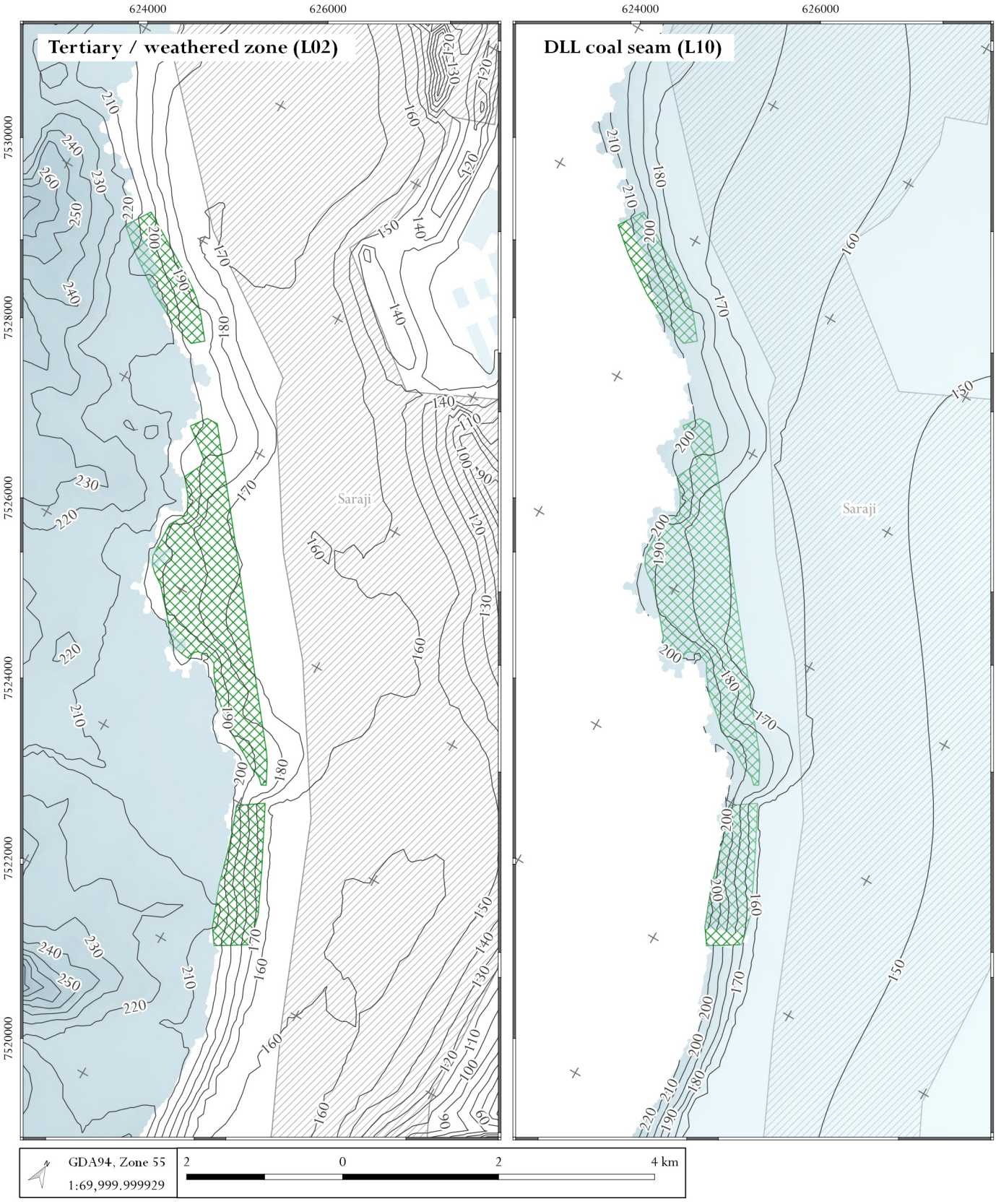

LEGEND

Saturated heads (mAHD)

- 140
- 170
- 200
- 230
- 260
- 290
- 320
- 350
- 380

- Model domain
- Proposed pit
- Established mining operation

DATE
22/02/2022

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Vulcan South - Groundwater Modelling Appendix (4027)

Model predicted heads - end of mining (SP76)

FIGURE No.
28

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6. Uncertainty analysis

In the context of model-based decision support or risk assessment or management, uncertainty can be defined as *any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system* (Walker *et al.*, 2003). Understanding where the unknowns are hidden and what their impact on modelling prediction is (or might be) is a strength of the model and a necessary tool supporting the decision-making effort (Johnson, 2010).

In more current (and Australian) context Peeters *et al.* (2018) pilot a combination of approaches to discuss impact of limitations of knowledge on modelling predictions in the context of decreasing risks associated with the environmental impact assessments. Authors further refined their recommendations in the form of guidelines (Middlemis and Peeters, 2018) where they recommend both qualitative and quantitative approach to uncertainty analysis.

6.1. Qualitative uncertainty

Qualitative uncertainties are defined by lack of knowledge with respect to either structure or processes within the groundwater flow system. They can be usually reduced by collecting more data or collecting data from areas that were not previously sampled or monitored.

The 'conceptual/knowledge' issues recognised during the evaluation of the impacts of the Project on the groundwater system are:

- precision of topographic elevation data, precision of observation elevation data;
- precision of structural elevation data – elevation/thickness of individual hydrostratigraphic units;
- existence and function of structural geological features (faults) – impact on cross-boundary flow definition;
- spatial heterogeneity of hydrostratigraphic units;
- timing of system stresses – dewatering (pumping, mining) or recharge (water storage in pits); and
- lack of relevant surface water flow information.

Precision of topographic elevation data

The information about topographic elevation was obtained from multiple sources – Lidar dataset for the Project site, SRTM dataset for the surrounding areas and elevation survey information for some of the bores on site or in the close vicinity of the site. Each of the dataset has different precision and built-in error (0.15 m for the Lidar data, ~20 m for the SRTM data, 0.01 m for the elevation survey data), however these errors can be increased by further data processing and interpolation. The uncertainty in topographic elevation data can have a flow-on effect on observations (groundwater level) or hydrologic features (elevation of surface stream bed, elevations of water storage dams).

The most precise elevation dataset covers the Project site, the less precise dataset covers area associated with Saraji. The groundwater observation sites that were suspected have incorrect elevation data were removed from the 'calibration targets' dataset.

The groundwater elevations are usually calculated using topographic surface information and depth to water. If the topography is off, the groundwater levels can be off. Any other topographic elevation errors have potential impact on surface water elevation (in case of flowing water such as stream or standing water elevation such as dam storage), potentially impacting water gradients and direction and rate of groundwater flow. As the groundwater table elevations are usually used as calibration targets and the quality of calibration is assessed by comparing the 'observed' and modelled heads, incorrect 'observed' elevation can derail the calibration process by trying to fit to wrong targets.

Given the spatial scale of the model, number of groundwater observations (calibration targets) and possibility of identification and removal of the incorrect observations from the calibration targets dataset, the impact of this issue on the modelling predictions is low.

The precision of the topographic elevation dataset can be improved by either spatially extending the Lidar dataset and/or by undertaking elevation survey in specific locations (such as selected observation bores, riverbed sections, dams). These precise elevation measurements can be then used to rectify the less-precise SRTM data.

Precision of structural elevation data

The elevation data for geological (or hydrostratigraphic units) floors is coming from multiple sources: In case of project target DLL seam, the elevation data was obtained from detailed geomodel based on on-site resource validation drill data. Precision of the elevations of the on-site geomodel dataset is ~1 m. In case of DL seam, the initial data was obtained by digitising and then re-interpolating the DL floor contours presented in the Bowen Basin Supermodel report (Esterle and Sliwa, 2002). These structure contours were originally based on CSG exploration data. Where the 'Supermodel' interpreted contours did not extend all the way to the edges of the Project model domain, the existing slope/trend was just extended to the edge with a use of existing CSG drill logs. Floor of Fort Cooper Coal Measures was based on mapped subcrop line (Department of Natural Resources, Mines and Energy, 2018) and an assumption that the dip of the structure will be similar to that of underlying DL seams. The error of these elevations could be in tens of metres, up-to 150 m.

In order to assess impact of the Project, two prediction models were run: (1) the 'null' scenario, simulating mining at Saraji only and (2) the 'baseline' scenario with mining at both Saraji and the Project. The impact of mining the Project is then expressed as difference between outputs of these two scenarios; difference in heads produces drawdown induced by the Project, difference in DRN budgets produces pit inflow estimates. As the 'uncertain' mining at Saraji is modelled identically in both scenarios, the impact of these uncertainties literally cancels itself out.

The elevation of mined coal seams (geological structures or hydrostratigraphic units in general) is important because if the elevations of the pit floors are not explicitly known, they are used to position a dewatering boundary condition (DRN boundary condition) in the numerical model. Having a groundwater flow system to be dewatered in a wrong time, wrong place or into wrong depth will create an incorrect flow gradient end will cause model to predict incorrect inflows into the mine. As this issue is directly connected with later 'timing and location of system stresses', it will be discussed in more detail there.

Given the used methodology, the impact of this issue is considered low.

Given the history of mining at Saraji and their extent of mining operations, detailed geological and stratigraphic information exists. The uncertainty of the issue could be decreased by making the existing data public, acquiring the data from secondary sources (publicly available technical reports) or obtaining the information via data sharing agreement with owners of the Saraji Mine.

Timing and location of system stresses

The most prominent system stress is dewatering associated with mining at Saraji, with the Saraji Mine boundary located 600 m to 1000 m to the east of the Project. The Saraji Mine is over 30 km long in NW-SE direction with mining pits reaching depth of ~150 m. The mining has been occurring since 1972. The mining activity would have significant drawdown impact on groundwater table in the direct vicinity of the mine and would override any other potential system stress (such as low recharge).

In the numerical model, the mining progression is simulated using drain (DRN) boundary condition, placed (in case of Saraji Mine) to the floor of Dysart Lower (DL) coal seam. The timing of the progression was estimated using satellite imagery in 5 year intervals. The location of the active mine in between the 5 year snapshots was estimated by linearly interpolating between known position of pits.

If any of the monitoring bores are impacted, the influence of the mine would be impossible to replicate in the numerical model without understanding the precise timing, location and depth of mining.

During the model calibration, monitoring bores were assessed and those assumed to be impacted by mining related drawdown were removed from the 'calibration target' dataset.

As discussed above, because the identical impact from mining at Saraji is implemented in both 'null' and 'baseline' scenarios, it effectively cancels itself out. As such, impact of this issue on the predictive capability of the numerical model with respect to the Project assessment is low.

The detailed information describing historical mining progression at Saraji Mine should be available from operators of Saraji Mine.

Existence and function of structural geological features

Small and larger scale faults were observed and mapped throughout the model domain and regional scale fault system (Jellinbah Thrust Fault zone) was used in place of model domain boundary. Based on the previous regional scale assessment of the structural features (Esterle and Sliwa, 2002), the proposed pit may be influenced to some degree by local structure mapped at the adjacent Saraji Mine and Peak Downs Mine.

Both small- and large-scale structural features can have impact the groundwater flow; in specific cases, they can obstruct, block or divert the groundwater flow, or, if behaving as conduits, creating preferential flow pathways. Given the lack of the small-scale features identified directly at the Project area, they do not present, impact of their absence on modelling prediction is low. As for structural features associated with Saraji and Peak Downs Mines, they might have impact on the flow regime within these sites, however their impact on the Project is most likely negligible.

The small-scale structural features (faults) were omitted from the numerical model. The regional-scale Jellinbah Thrust Fault zone was incorporated into the model in the form of 'no-flow' boundary condition.

Information concerning small- and large-scale geological structures is usually obtained through (core) drilling work, complemented by geophysics. Local, small-scale faults on neighbouring sites (Saraji) should be documented within their geological databases.

Spatial heterogeneity of hydrostratigraphic units

The hydraulic properties are distributed heterogeneously within each hydrostratigraphic unit. Impact of these heterogeneities depends on modelling scale – it is more important in small-scale models while in large-scale (regional) models the properties of individual hydrostratigraphic units are often modelled using 'bulk property' or 'average property' approach. Although implementation of the heterogeneous hydraulic properties within the numerical model is relatively simple, it sharply increases computational complexity of the model and without basing the heterogeneity in real world observations it can contribute towards non-uniqueness of the model calibration.

Hydraulic properties used in the numerical model have impact on predictions of both heads and flows. Combined with recharge distribution, they contribute towards a non-unique solution to the inverse-modelling (calibration) process. On local scale, the lack of spatial heterogeneity on specific, spatially limited modelling prediction can be medium to high.

The understanding of spatial variability of the hydraulic properties could be improved by hydraulic testing.

On regional scale, the lack of modelled heterogeneity was compensated by varying the bulk hydraulic properties and its impact on heads and flows prediction was quantified using stochastic analysis of the modelling impacts (see Section 6.2).

Lack of relevant surface water flow information

The information concerning surface water flow is relatively sparse in both temporal and spatial sense (see Section 3). Together with current field observation of no-flow conditions, the historical data from single stream gauge is informed the 'drain-only' conceptualisation of the surface stream network.

We adopted the 'limited-recharge' or 'drain-only' conceptualisation as plausible.

The 'drain-only' conceptualisation assumes very low or no recharge from the creeks into the groundwater system. If we underestimated the amount of surface-water related recharge into the system, it could have had impact on model calibration by adjusting rate of aerial (rainfall related) recharge or hydraulic properties to compensate for the low recharge from the streams. The impact of low resolution surface water flow data on modelling predictions under current conceptualisation is low. If more (future) data leads us to the change of the conceptualisation to 'recharge / discharge' model, the lack of historical flow data would be more important.

Longer stream gauge record would have been helpful, especially during the periods of sustained drought.

6.2. Quantitative uncertainty

Quantitative uncertainty analysis is a technique that aims to understand behaviour of the groundwater system by using mathematical and statistical approach to evaluate modelling inputs and outputs and assign a 'probability of occurrence' to selected impacts.

6.2.1. Methodology

The method quantifying the probability of impacts exceeding certain value follows these steps:

- Define sampling distributions for all model parameters.
- Generate model input dataset (model 'realisation') honouring the sampling distributions.
- Run the model for each 'realization' and extract predictions (heads, flows). Check for calibration statistics (SSQ and SRMS) to assess level of 'miscalibration'. Remove predictions from runs that would be considered not sufficiently calibrated.
- Calculate impacts (in our case pit inflows and drawdown) for each of the accepted 'realizations'.
- Calculate minimum, maximum and selected percentile values for both pit inflow rates and drawdowns.
- Use the percentile values to describe the probability of exceedance of modelled outcome (Table 23) in accordance with ISEC Uncertainty guidelines (Middlemis and Peeters, 2018).

Table 23 Combined numeric, narrative and visual description of likelihood (Middlemis and Peeters, 2018)

Percentile	Colour code	Description (in terms of likelihood of exceedance)	Alternative description or framing
<10%		It is **very likely** that the outcome is **larger** than this value	It is **very unlikely** that the outcome is **smaller** than this value
10–33%		It is **likely** that the outcome is **larger** than this value	It is **unlikely** that the outcome is **smaller** than this value
33–67%		It is as **likely as not** that the outcome is **larger** than this value	It is as **likely as not** that the outcome is **smaller** than this value
67–90%		It is **unlikely** that the outcome is **larger** than this value	It is **likely** that the outcome is **smaller** than this value
>90%		It is **very unlikely** that the outcome is **larger** than this value	It is **very likely** that the outcome is **smaller** than this value

6.2.2. Definition of parameter sampling distributions

The method uses 'calibrated' model and information associated with all calibrated model parameters (such as calibrated parameter value, parameter ranges, existing jacobian matrix etc.) to define a sampling distribution for each of the analysed parameters and then sample these distributions multiple times to create multiple model 'realisations' (datasets of possible inputs). The sampling (cumulative) distribution for each parameter is presented in Appendix C1 in tabular (Table C1 1) and graphical form (Figure C1 1).

6.2.3. Evaluation of model runs – calibration statistical measures

Two versions of the numerical model ('null' and 'project' scenarios) are then run with each of the generated input datasets and model predictions for each of the scenarios (heads and inflows) are extracted. For each model 'realisation', calibration statistics were calculated in order to assess the validity of that particular model prediction. In case the calibration statistics (value of SSQ and SRMS) indicated the selected dataset de-calibrated the model too much, the prediction would have been removed.

In total, 680 model pairs (680 different realisations of the input dataset) were run. None of these failed to converge, all model runs finished. Out of these, 62 (9.1%) had lower SSQ (Figure 29) which means these 'realisations' showed better calibration level than the 'calibrated' dataset (calibrated value of SSQ was 2292.3 m^2).

Value of SRMS varied between 3.9 % and 5.3 % with 72 realisations (10.6%) having better SRMS (Figure 30) than the 'calibrated' value of 4.0 %.

As the groundwater modelling guidelines suggest that SRMS of 5 % (or less) for transient observation can be considered acceptable, all 680 of the model realisations were considered as 'sufficiently calibrated' and none of the realisations were removed from further statistical evaluation of model impacts.

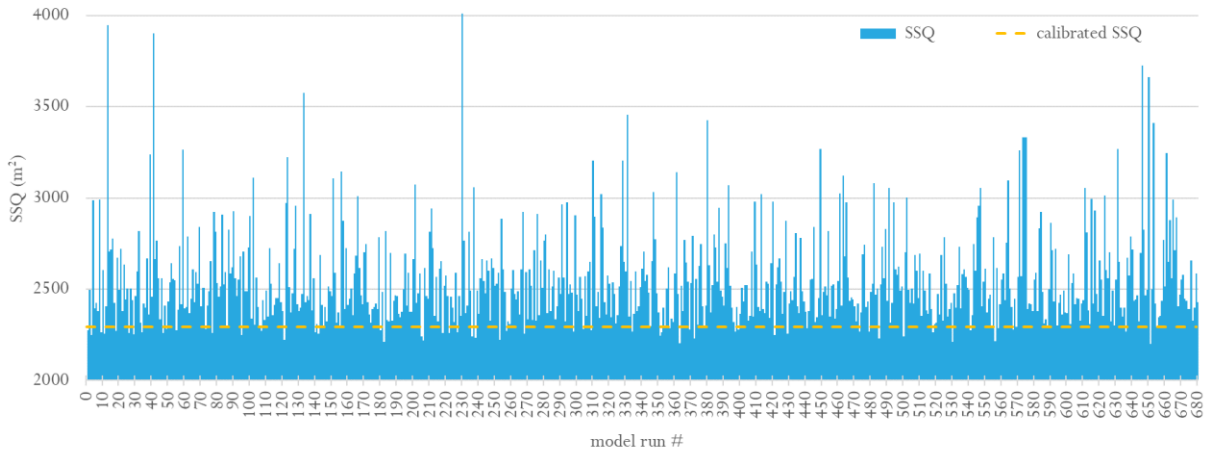


Figure 29 Evaluation of uncertainty runs – calibration statistical measures - SSQ

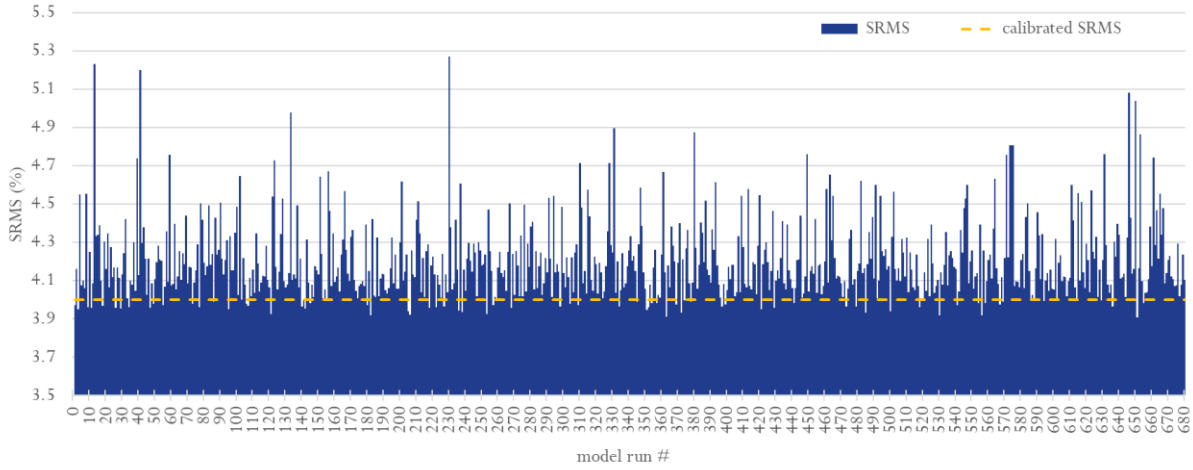


Figure 30 Uncertainty runs – SRMS

6.2.4. Uncertainty analysis of impacts

The uncertainty of exceedance of particular pit inflow rate is presented in Figure 31. The original model prediction (see Figure 24) lies within the expected 'as likely as not' exceedance probability range. This indicates that the model prediction is not 'over-calibrated' and unrealistic. The highest possible inflow rate was quantified to be 115 m³/day.

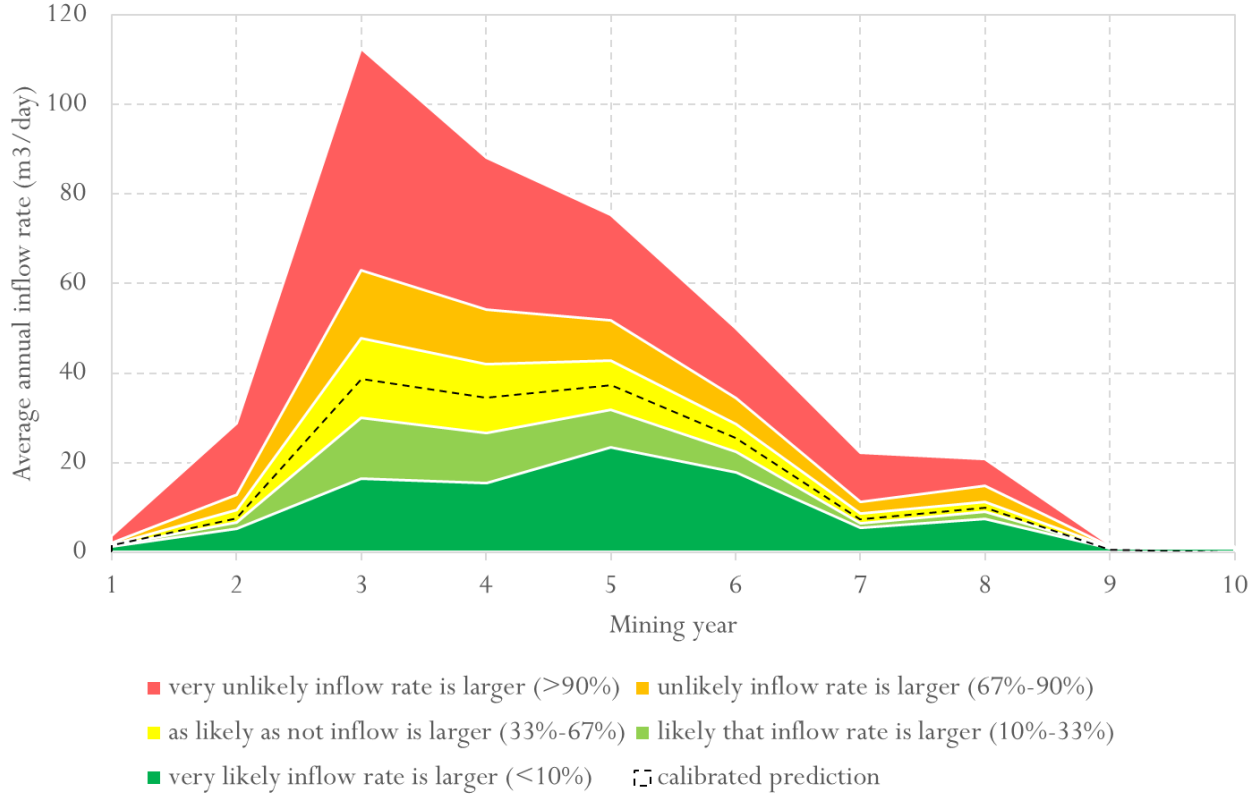
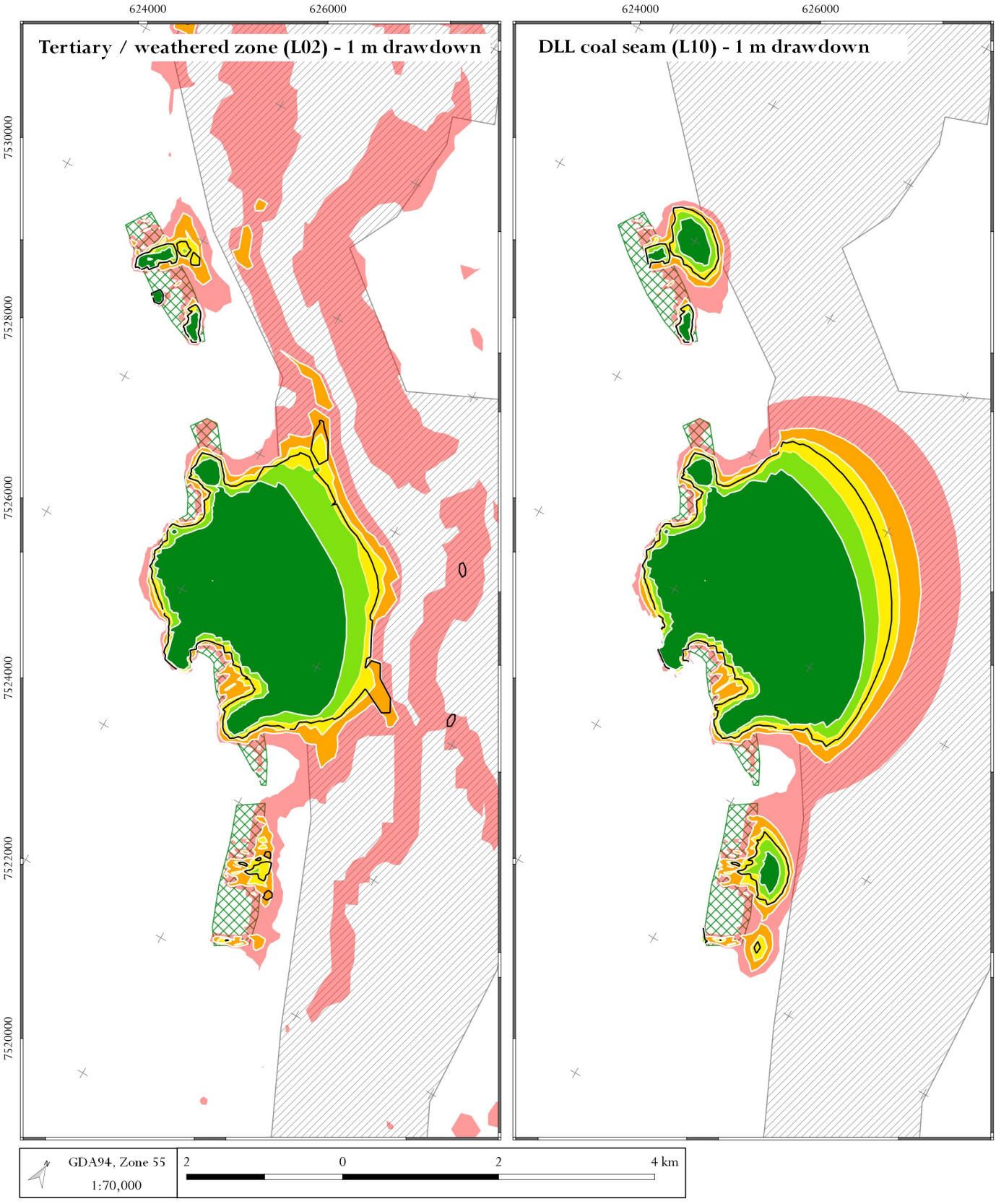


Figure 31 Uncertainty runs – Project pit inflow rates

The spatial extent of maximum drawdown (Figure 32) is represented by 1 m contour. The zones of probability of exceedance of drawdown values are again based on the ISEC Uncertainty guidelines – the green zone presents 90% probability of larger extent than presented, yellow zone means the drawdown will be larger as likely as not, the red zone shows area where the probability of exceedance of 1 m drawdown is very low – with likelihood of less than 10%. The calibrated prediction of 1 m drawdown extent (the 'basecase') is shown as black dashed line.



LEGEND

- Proposed pit
- Existing mining operation
- <10% - it is very likely that the outcome is larger than this value
- 10% - 33% - it is likely that the outcome is larger than this value
- 33% - 67% - it is as likely as not that the outcome is larger than this value
- 67% - 90% - it is unlikely that the outcome is larger than this value
- >90% - it is very unlikely that the outcome is larger than this value
- Basecase - 'calibrated' model prediction

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Vulcan South - Groundwater Modelling Appendix (4027)

Uncertainty analysis - maximum drawdown

FIGURE No.
32

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
Z:\4000_Projects\4027_Metserve_Vulcan_GIA\3_GIS\Workspaces\Vulcan South figures\Modelling appendix\32_4027_Vulcan South_App_Uncertainty drawdown in L02 and L10.qgz

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Appendix C1 Parameter sampling distributions

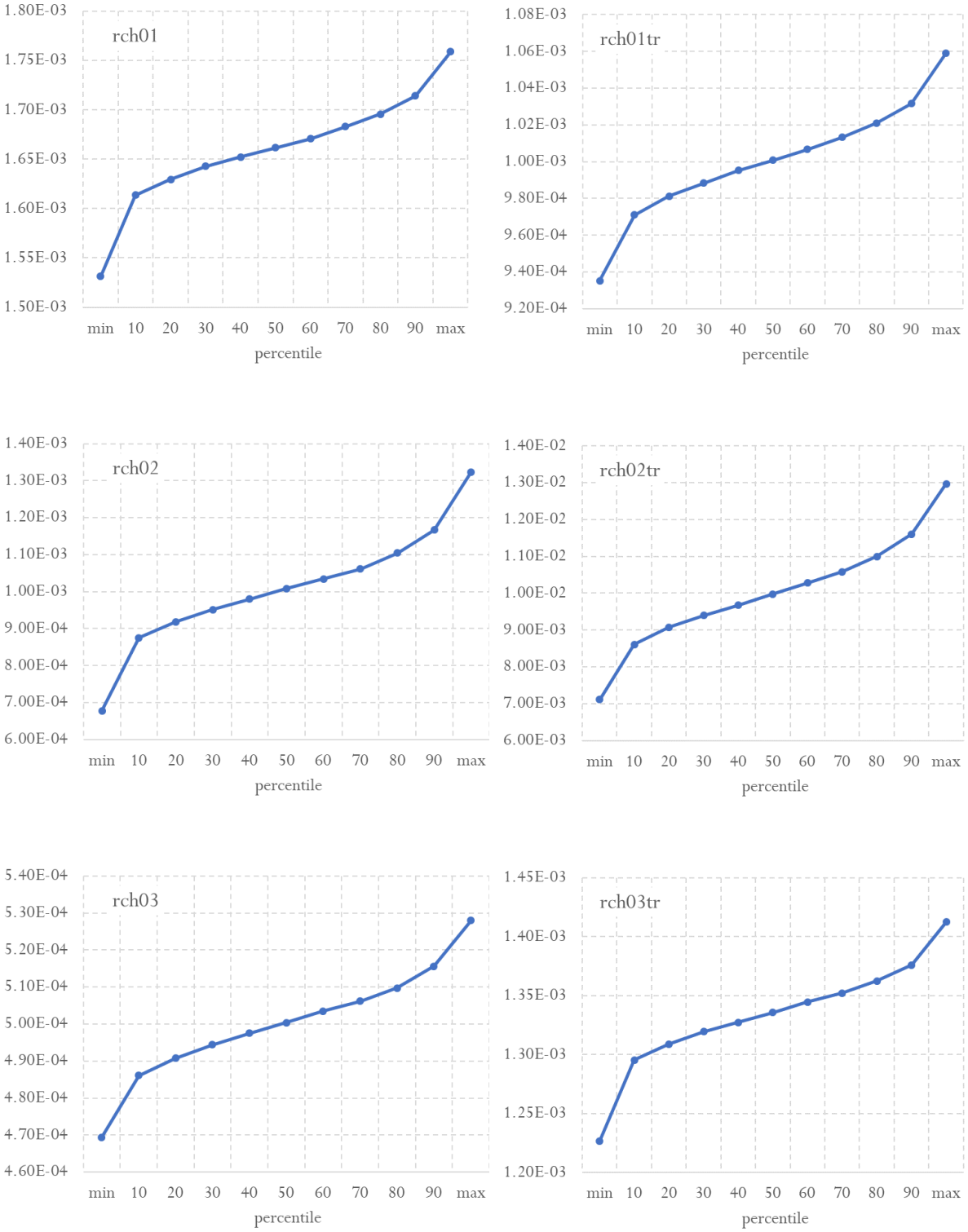
Table C1 1 Parameter distributions – cumulative percentiles

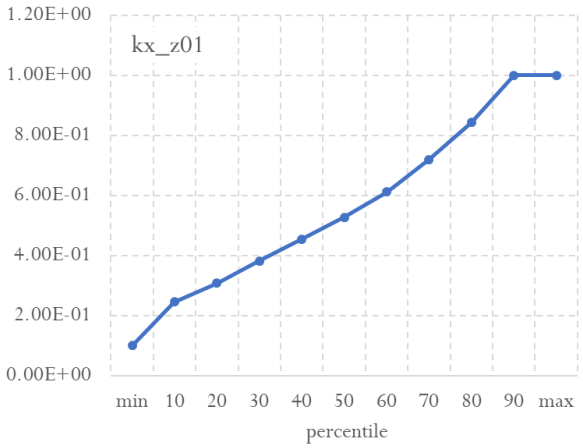
param	calibrated value	PE ST definition		parameter distribution - cumulative percentiles											
		lower bound	upper bound	min	10th	20th	30th	40th	50th	60th	70th	80th	90th	max
rch01	1.661×10^{-3}	5.000×10^{-4}	2.000×10^{-2}	1.531×10^{-3}	1.614×10^{-3}	1.630×10^{-3}	1.643×10^{-3}	1.652×10^{-3}	1.662×10^{-3}	1.671×10^{-3}	1.683×10^{-3}	1.696×10^{-3}	1.714×10^{-3}	1.759×10^{-3}
rch02	1.000×10^{-3}	5.000×10^{-4}	5.000×10^{-2}	6.783×10^{-4}	8.752×10^{-4}	9.184×10^{-4}	9.515×10^{-4}	9.797×10^{-4}	1.008×10^{-3}	1.035×10^{-3}	1.062×10^{-3}	1.104×10^{-3}	1.167×10^{-3}	1.323×10^{-3}
rch03	5.000×10^{-4}	1.000×10^{-4}	2.000×10^{-2}	4.694×10^{-4}	4.861×10^{-4}	4.907×10^{-4}	4.944×10^{-4}	4.976×10^{-4}	5.004×10^{-4}	5.035×10^{-4}	5.062×10^{-4}	5.098×10^{-4}	5.156×10^{-4}	5.280×10^{-4}
rch01tr	1.000×10^{-3}	5.000×10^{-4}	2.000×10^{-2}	9.353×10^{-4}	9.712×10^{-4}	9.813×10^{-4}	9.883×10^{-4}	9.953×10^{-4}	1.001×10^{-3}	1.007×10^{-3}	1.013×10^{-3}	1.021×10^{-3}	1.032×10^{-3}	1.059×10^{-3}
rch02tr	1.000×10^{-2}	5.000×10^{-4}	5.000×10^{-2}	7.110×10^{-3}	8.612×10^{-3}	9.076×10^{-3}	9.394×10^{-3}	9.678×10^{-3}	9.973×10^{-3}	1.028×10^{-2}	1.059×10^{-2}	1.100×10^{-2}	1.160×10^{-2}	1.297×10^{-2}
rch03tr	1.335×10^{-3}	1.000×10^{-4}	2.000×10^{-2}	1.227×10^{-3}	1.295×10^{-3}	1.309×10^{-3}	1.319×10^{-3}	1.327×10^{-3}	1.336×10^{-3}	1.345×10^{-3}	1.352×10^{-3}	1.363×10^{-3}	1.376×10^{-3}	1.413×10^{-3}
kx_z01	5.000×10^{-1}	1.000×10^{-1}	$1.000\times10^{+0}$	1.000×10^{-1}	2.463×10^{-1}	3.080×10^{-1}	3.825×10^{-1}	4.547×10^{-1}	5.280×10^{-1}	6.113×10^{-1}	7.193×10^{-1}	8.435×10^{-1}	1.000×10^{0}	1.000×10^{0}
kx_z02	5.000×10^{-1}	1.000×10^{-1}	$1.000\times10^{+0}$	1.000×10^{-1}	2.402×10^{-1}	3.069×10^{-1}	3.756×10^{-1}	4.397×10^{-1}	5.061×10^{-1}	6.015×10^{-1}	6.935×10^{-1}	8.420×10^{-1}	1.000×10^{0}	1.000×10^{0}
kx_z03	5.000×10^{-2}	5.000×10^{-4}	1.000×10^{-1}	3.437×10^{-2}	4.366×10^{-2}	4.596×10^{-2}	4.737×10^{-2}	4.875×10^{-2}	5.028×10^{-2}	5.156×10^{-2}	5.312×10^{-2}	5.513×10^{-2}	5.787×10^{-2}	6.368×10^{-2}
kx_z04	5.000×10^{-2}	5.000×10^{-4}	1.000×10^{-1}	3.489×10^{-2}	4.339×10^{-2}	4.538×10^{-2}	4.718×10^{-2}	4.883×10^{-2}	5.009×10^{-2}	5.144×10^{-2}	5.302×10^{-2}	5.490×10^{-2}	5.785×10^{-2}	6.495×10^{-2}
kx_z05	3.052×10^{-3}	5.000×10^{-4}	1.000×10^{-1}	2.112×10^{-3}	2.633×10^{-3}	2.768×10^{-3}	2.866×10^{-3}	2.961×10^{-3}	3.056×10^{-3}	3.146×10^{-3}	3.236×10^{-3}	3.362×10^{-3}	3.520×10^{-3}	4.011×10^{-3}
kx_z06	1.723×10^{-3}	5.000×10^{-4}	1.000×10^{-1}	1.147×10^{-3}	1.499×10^{-3}	1.571×10^{-3}	1.628×10^{-3}	1.674×10^{-3}	1.725×10^{-3}	1.771×10^{-3}	1.826×10^{-3}	1.889×10^{-3}	1.991×10^{-3}	2.247×10^{-3}
kx_z07	1.000×10^{-2}	5.000×10^{-3}	1.000×10^{-1}	5.000×10^{-3}	5.000×10^{-3}	5.936×10^{-3}	7.091×10^{-3}	8.335×10^{-3}	9.781×10^{-3}	1.117×10^{-2}	1.324×10^{-2}	1.576×10^{-2}	2.018×10^{-2}	3.807×10^{-2}
kx_z08	5.000×10^{-4}	1.000×10^{-4}	5.000×10^{-2}	3.052×10^{-4}	4.327×10^{-4}	4.561×10^{-4}	4.712×10^{-4}	4.859×10^{-4}	5.017×10^{-4}	5.185×10^{-4}	5.320×10^{-4}	5.489×10^{-4}	5.827×10^{-4}	6.573×10^{-4}
kx_z09	4.543×10^{-2}	1.000×10^{-4}	5.000×10^{-2}	3.185×10^{-2}	3.931×10^{-2}	4.112×10^{-2}	4.254×10^{-2}	4.384×10^{-2}	4.503×10^{-2}	4.656×10^{-2}	4.824×10^{-2}	5.006×10^{-2}	5.252×10^{-2}	5.881×10^{-2}
kx_z10	1.551×10^{-1}	5.000×10^{-2}	5.000×10^{-1}	5.000×10^{-2}	7.246×10^{-2}	9.469×10^{-2}	1.152×10^{-1}	1.338×10^{-1}	1.576×10^{-1}	1.867×10^{-1}	2.149×10^{-1}	2.540×10^{-1}	3.253×10^{-1}	5.000×10^{-1}
kx_z11	1.000×10^{-4}	1.000×10^{-5}	1.000×10^{-2}	9.297×10^{-5}	9.716×10^{-5}	9.807×10^{-5}	9.877×10^{-5}	9.943×10^{-5}	1.001×10^{-4}	1.007×10^{-4}	1.012×10^{-4}	1.019×10^{-4}	1.029×10^{-4}	1.056×10^{-4}

param	calibrated value	PE ST definition		parameter distribution - cumulative percentiles										
		lower bound	upper bound	min	10th	20th	30th	40th	50th	60th	70th	80th	90th	max
kz_z01	2.500×10^{-2}	1.000×10^{-2}	1.000×10^{-1}	1.681×10^{-2}	2.171×10^{-2}	2.285×10^{-2}	2.359×10^{-2}	2.435×10^{-2}	2.504×10^{-2}	2.578×10^{-2}	2.660×10^{-2}	2.753×10^{-2}	2.875×10^{-2}	3.216×10^{-2}
kz_z02	3.000×10^{-2}	1.000×10^{-2}	1.000×10^{-1}	2.088×10^{-2}	2.593×10^{-2}	2.726×10^{-2}	2.814×10^{-2}	2.914×10^{-2}	3.009×10^{-2}	3.103×10^{-2}	3.200×10^{-2}	3.308×10^{-2}	3.470×10^{-2}	3.909×10^{-2}
kz_z03	3.935×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	2.682×10^{-2}	3.391×10^{-2}	3.573×10^{-2}	3.695×10^{-2}	3.815×10^{-2}	3.937×10^{-2}	4.041×10^{-2}	4.176×10^{-2}	4.329×10^{-2}	4.619×10^{-2}	5.000×10^{-2}
kz_z04	8.930×10^{-3}	1.000×10^{-3}	5.000×10^{-2}	6.061×10^{-3}	7.728×10^{-3}	8.131×10^{-3}	8.414×10^{-3}	8.645×10^{-3}	8.901×10^{-3}	9.160×10^{-3}	9.452×10^{-3}	9.821×10^{-3}	1.041×10^{-2}	1.172×10^{-2}
kz_z05	1.949×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	1.356×10^{-2}	1.691×10^{-2}	1.777×10^{-2}	1.839×10^{-2}	1.891×10^{-2}	1.945×10^{-2}	1.999×10^{-2}	2.058×10^{-2}	2.130×10^{-2}	2.225×10^{-2}	2.577×10^{-2}
kz_z06	2.055×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	1.465×10^{-2}	1.777×10^{-2}	1.870×10^{-2}	1.931×10^{-2}	1.990×10^{-2}	2.044×10^{-2}	2.104×10^{-2}	2.170×10^{-2}	2.251×10^{-2}	2.360×10^{-2}	2.707×10^{-2}
kz_z07	2.093×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	1.328×10^{-2}	1.794×10^{-2}	1.894×10^{-2}	1.961×10^{-2}	2.022×10^{-2}	2.079×10^{-2}	2.148×10^{-2}	2.216×10^{-2}	2.291×10^{-2}	2.415×10^{-2}	2.726×10^{-2}
kz_z08	3.938×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	2.665×10^{-2}	3.385×10^{-2}	3.547×10^{-2}	3.686×10^{-2}	3.794×10^{-2}	3.936×10^{-2}	4.034×10^{-2}	4.150×10^{-2}	4.310×10^{-2}	4.529×10^{-2}	5.000×10^{-2}
kz_z09	1.000×10^{-3}	1.000×10^{-3}	5.000×10^{-2}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.027×10^{-3}	1.062×10^{-3}	1.102×10^{-3}	1.165×10^{-3}	1.311×10^{-3}
kz_z10	2.487×10^{-2}	1.000×10^{-3}	5.000×10^{-2}	1.575×10^{-2}	2.147×10^{-2}	2.251×10^{-2}	2.334×10^{-2}	2.406×10^{-2}	2.487×10^{-2}	2.556×10^{-2}	2.638×10^{-2}	2.730×10^{-2}	2.881×10^{-2}	3.292×10^{-2}
kz_z11	1.000×10^{-3}	1.000×10^{-3}	5.000×10^{-2}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.000×10^{-3}	1.012×10^{-3}	1.024×10^{-3}	1.040×10^{-3}	1.062×10^{-3}	1.122×10^{-3}
ss_z01	2.000×10^{-6}	2.000×10^{-7}	5.000×10^{-5}	1.994×10^{-6}	1.997×10^{-6}	1.998×10^{-6}	1.999×10^{-6}	2.000×10^{-6}	2.000×10^{-6}	2.001×10^{-6}	2.001×10^{-6}	2.002×10^{-6}	2.003×10^{-6}	2.005×10^{-6}
ss_z02	2.490×10^{-6}	5.000×10^{-7}	5.000×10^{-5}	2.480×10^{-6}	2.486×10^{-6}	2.488×10^{-6}	2.488×10^{-6}	2.489×10^{-6}	2.490×10^{-6}	2.491×10^{-6}	2.491×10^{-6}	2.492×10^{-6}	2.493×10^{-6}	2.497×10^{-6}
ss_z03	1.000×10^{-6}	5.000×10^{-7}	5.000×10^{-5}	9.957×10^{-7}	9.985×10^{-7}	9.991×10^{-7}	9.995×10^{-7}	9.997×10^{-7}	1.000×10^{-6}	1.000×10^{-6}	1.001×10^{-6}	1.001×10^{-6}	1.002×10^{-6}	1.003×10^{-6}
ss_z04	2.000×10^{-5}	5.000×10^{-7}	5.000×10^{-5}	1.992×10^{-5}	1.997×10^{-5}	1.998×10^{-5}	1.999×10^{-5}	1.999×10^{-5}	2.000×10^{-5}	2.001×10^{-5}	2.001×10^{-5}	2.002×10^{-5}	2.003×10^{-5}	2.005×10^{-5}
ss_z05	1.000×10^{-6}	5.000×10^{-7}	5.000×10^{-5}	9.965×10^{-7}	9.985×10^{-7}	9.989×10^{-7}	9.993×10^{-7}	9.997×10^{-7}	1.000×10^{-6}	1.000×10^{-6}	1.001×10^{-6}	1.001×10^{-6}	1.001×10^{-6}	1.002×10^{-6}
ss_z06	1.000×10^{-5}	5.000×10^{-7}	7.500×10^{-5}	9.960×10^{-6}	9.985×10^{-6}	9.990×10^{-6}	9.995×10^{-6}	9.997×10^{-6}	1.000×10^{-5}	1.000×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.003×10^{-5}
ss_z07	2.000×10^{-5}	5.000×10^{-7}	1.000×10^{-4}	1.993×10^{-5}	1.997×10^{-5}	1.998×10^{-5}	1.999×10^{-5}	1.999×10^{-5}	2.000×10^{-5}	2.000×10^{-5}	2.001×10^{-5}	2.002×10^{-5}	2.003×10^{-5}	2.005×10^{-5}

param	calibrated value	PE ST definition		parameter distribution - cumulative percentiles										
		lower bound	upper bound	min	10th	20th	30th	40th	50th	60th	70th	80th	90th	max
ss_z08	1.000×10^{-5}	5.000×10^{-7}	1.000×10^{-4}	9.961×10^{-6}	9.985×10^{-6}	9.989×10^{-6}	9.993×10^{-6}	9.996×10^{-6}	9.999×10^{-6}	1.000×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.003×10^{-5}
ss_z09	1.000×10^{-5}	5.000×10^{-7}	1.000×10^{-4}	9.966×10^{-6}	9.985×10^{-6}	9.991×10^{-6}	9.995×10^{-6}	9.998×10^{-6}	1.000×10^{-5}	1.000×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.003×10^{-5}
ss_z10	2.000×10^{-5}	5.000×10^{-7}	1.000×10^{-4}	1.992×10^{-5}	1.997×10^{-5}	1.998×10^{-5}	1.999×10^{-5}	1.999×10^{-5}	2.000×10^{-5}	2.001×10^{-5}	2.001×10^{-5}	2.002×10^{-5}	2.003×10^{-5}	2.005×10^{-5}
ss_z11	1.000×10^{-5}	5.000×10^{-7}	1.000×10^{-4}	9.965×10^{-6}	9.985×10^{-6}	9.990×10^{-6}	9.994×10^{-6}	9.997×10^{-6}	1.000×10^{-5}	1.000×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.001×10^{-5}	1.003×10^{-5}
sy_z01	9.000×10^{-2}	1.000×10^{-3}	1.000×10^{-1}	6.194×10^{-2}	7.799×10^{-2}	8.169×10^{-2}	8.490×10^{-2}	8.753×10^{-2}	9.022×10^{-2}	9.264×10^{-2}	9.551×10^{-2}	9.918×10^{-2}	1.000×10^{-1}	1.000×10^{-1}
sy_z02	5.000×10^{-3}	1.000×10^{-3}	1.000×10^{-1}	3.484×10^{-3}	4.302×10^{-3}	4.543×10^{-3}	4.708×10^{-3}	4.881×10^{-3}	5.039×10^{-3}	5.182×10^{-3}	5.353×10^{-3}	5.567×10^{-3}	5.817×10^{-3}	6.639×10^{-3}
sy_z03	5.000×10^{-3}	5.000×10^{-4}	1.000×10^{-2}	4.652×10^{-3}	4.851×10^{-3}	4.898×10^{-3}	4.942×10^{-3}	4.975×10^{-3}	5.002×10^{-3}	5.029×10^{-3}	5.061×10^{-3}	5.102×10^{-3}	5.162×10^{-3}	5.262×10^{-3}
sy_z04	1.000×10^{-4}	5.000×10^{-5}	5.000×10^{-3}	9.041×10^{-5}	9.717×10^{-5}	9.805×10^{-5}	9.875×10^{-5}	9.943×10^{-5}	1.000×10^{-4}	1.006×10^{-4}	1.012×10^{-4}	1.020×10^{-4}	1.031×10^{-4}	1.054×10^{-4}
sy_z05	1.760×10^{-4}	5.000×10^{-5}	5.000×10^{-3}	1.647×10^{-4}	1.711×10^{-4}	1.727×10^{-4}	1.737×10^{-4}	1.750×10^{-4}	1.760×10^{-4}	1.771×10^{-4}	1.781×10^{-4}	1.794×10^{-4}	1.812×10^{-4}	1.855×10^{-4}
sy_z06	5.000×10^{-3}	5.000×10^{-5}	5.000×10^{-3}	4.641×10^{-3}	4.855×10^{-3}	4.901×10^{-3}	4.936×10^{-3}	4.971×10^{-3}	5.002×10^{-3}	5.027×10^{-3}	5.059×10^{-3}	5.094×10^{-3}	5.139×10^{-3}	5.258×10^{-3}
sy_z07	1.000×10^{-3}	5.000×10^{-5}	1.000×10^{-2}	9.324×10^{-4}	9.719×10^{-4}	9.808×10^{-4}	9.883×10^{-4}	9.954×10^{-4}	1.002×10^{-3}	1.008×10^{-3}	1.015×10^{-3}	1.022×10^{-3}	1.032×10^{-3}	1.053×10^{-3}
sy_z08	1.000×10^{-4}	5.000×10^{-5}	5.000×10^{-3}	9.287×10^{-5}	9.720×10^{-5}	9.811×10^{-5}	9.882×10^{-5}	9.944×10^{-5}	1.001×10^{-4}	1.006×10^{-4}	1.012×10^{-4}	1.019×10^{-4}	1.029×10^{-4}	1.058×10^{-4}
sy_z09	2.787×10^{-3}	5.000×10^{-5}	5.000×10^{-3}	2.627×10^{-3}	2.709×10^{-3}	2.734×10^{-3}	2.757×10^{-3}	2.775×10^{-3}	2.788×10^{-3}	2.802×10^{-3}	2.824×10^{-3}	2.844×10^{-3}	2.872×10^{-3}	2.940×10^{-3}
sy_z10	1.000×10^{-3}	1.000×10^{-4}	1.000×10^{-2}	9.207×10^{-4}	9.708×10^{-4}	9.814×10^{-4}	9.881×10^{-4}	9.947×10^{-4}	1.000×10^{-3}	1.005×10^{-3}	1.013×10^{-3}	1.020×10^{-3}	1.030×10^{-3}	1.059×10^{-3}
sy_z11	2.500×10^{-4}	1.000×10^{-5}	5.000×10^{-3}	2.344×10^{-4}	2.432×10^{-4}	2.454×10^{-4}	2.471×10^{-4}	2.486×10^{-4}	2.502×10^{-4}	2.516×10^{-4}	2.529×10^{-4}	2.547×10^{-4}	2.575×10^{-4}	2.641×10^{-4}

Figure C1 1 Parameter distributions – cumulative percentiles

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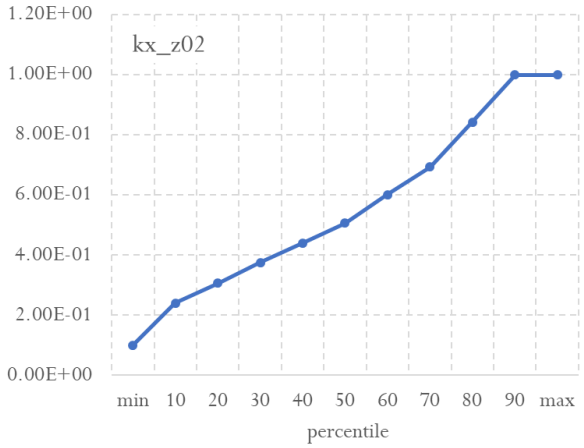
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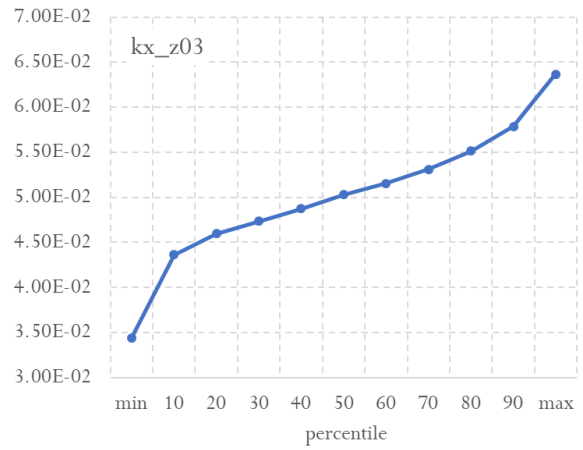
percentile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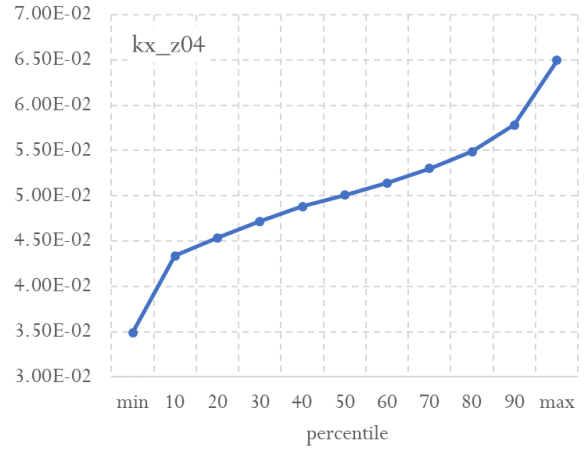
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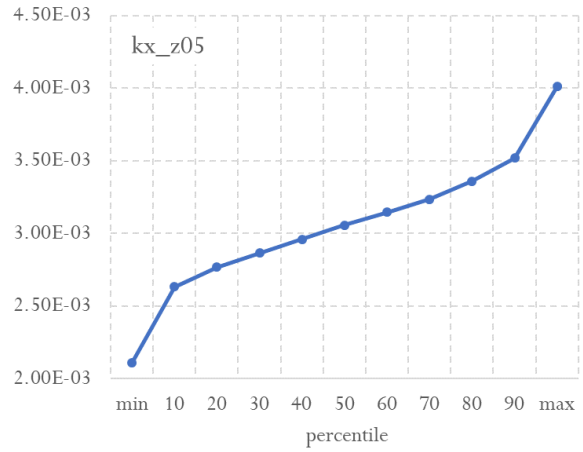
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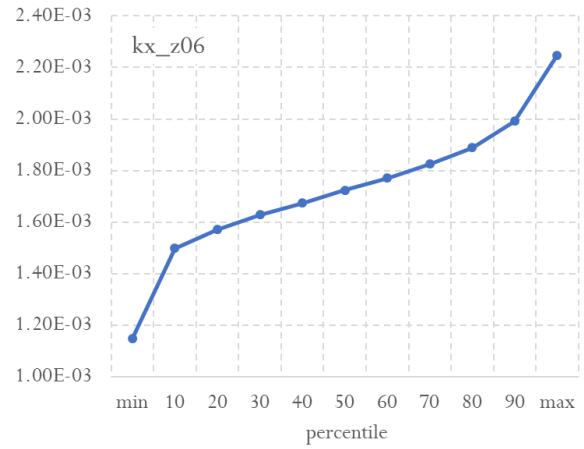
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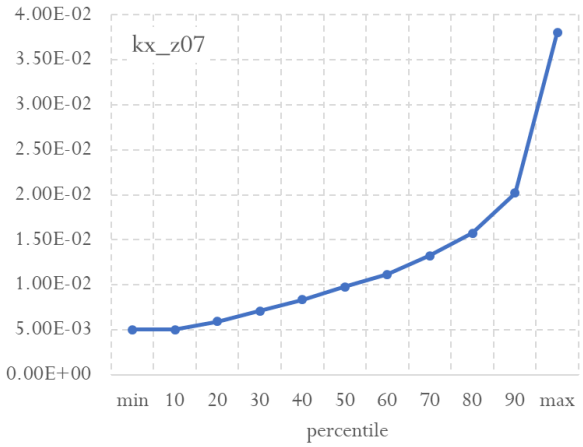
percentile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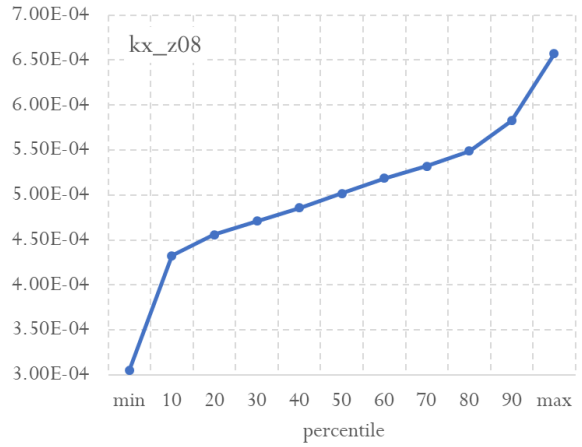
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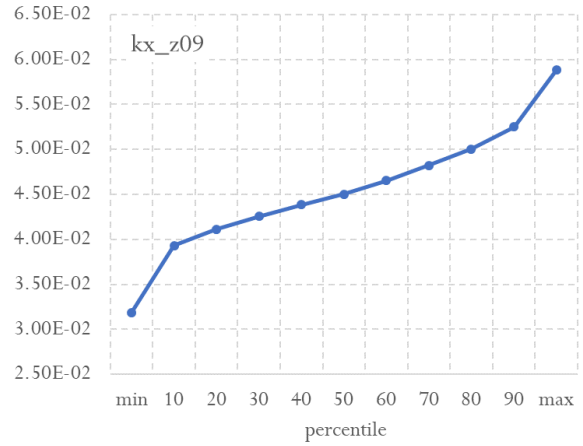
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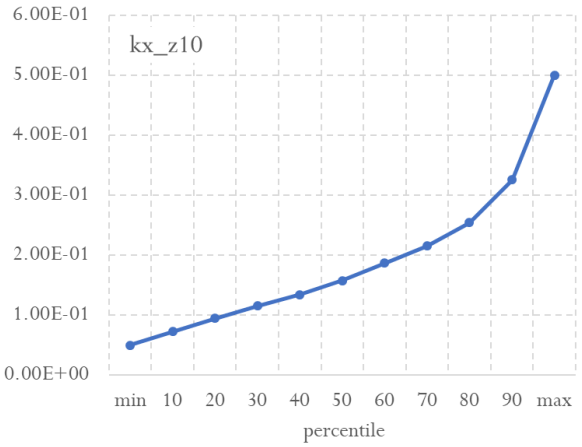
percentile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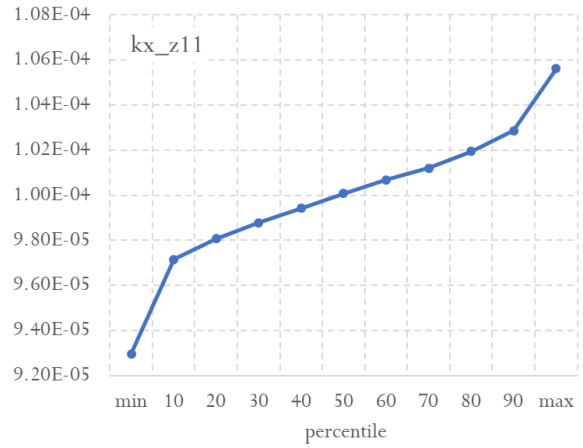
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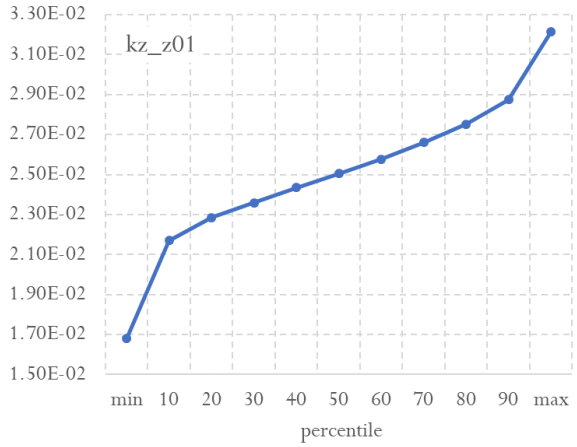
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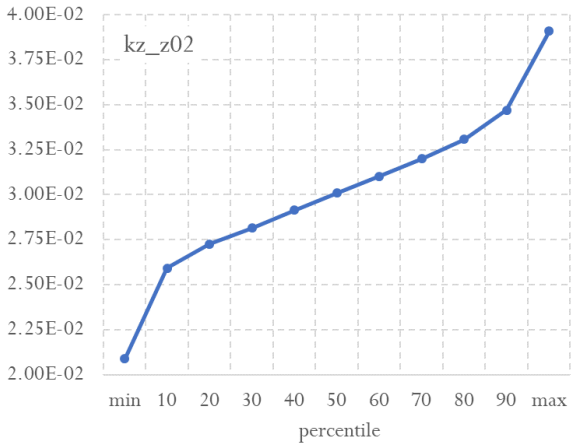
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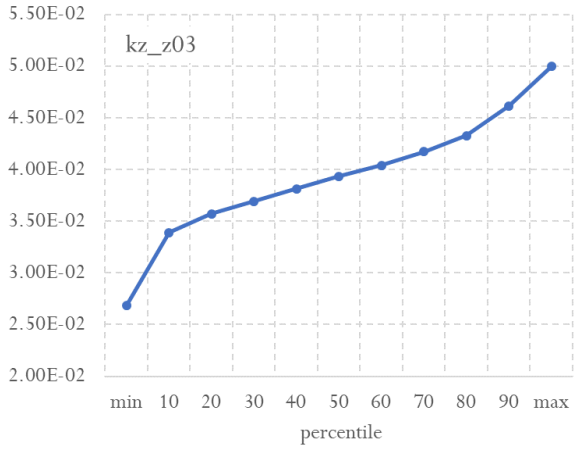
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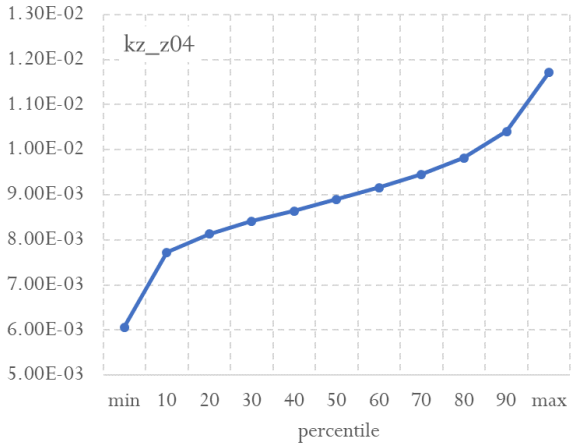
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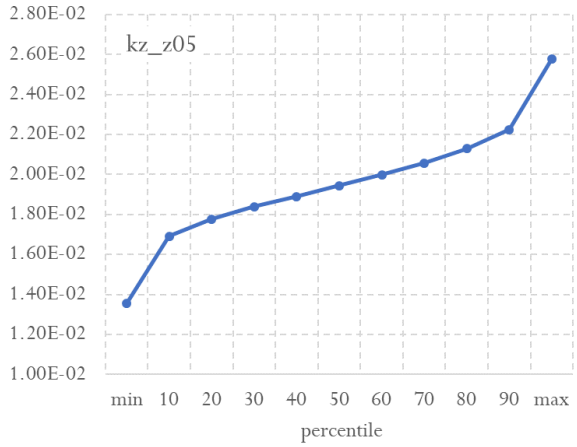
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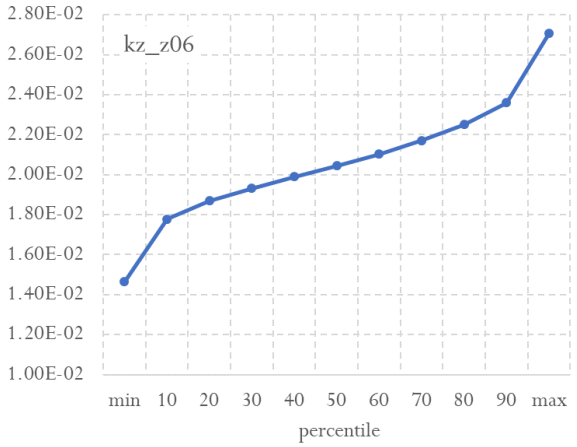
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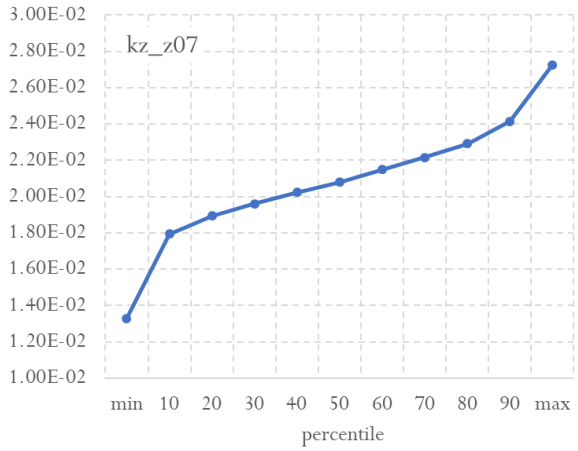
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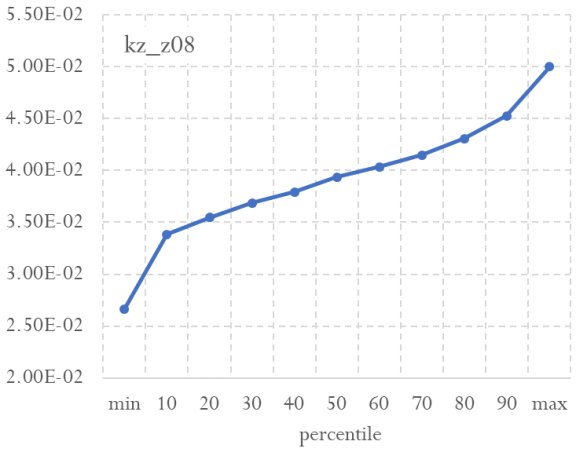
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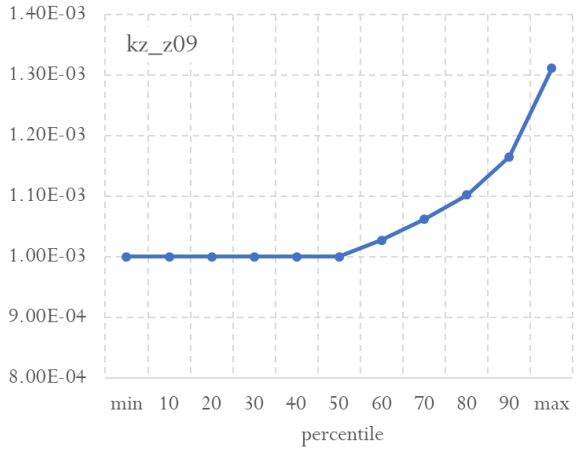
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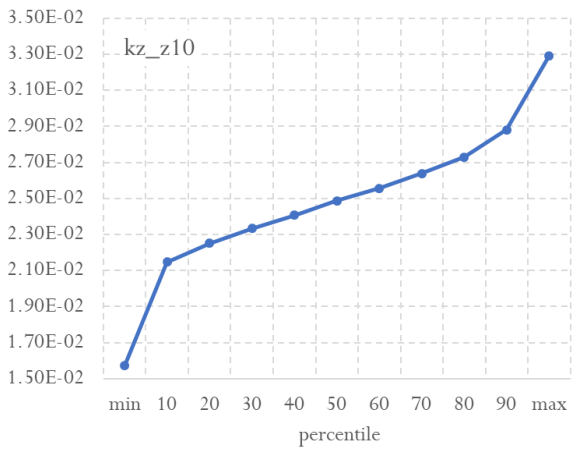
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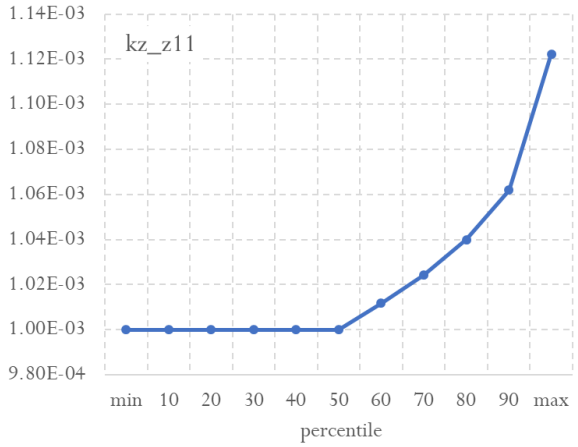
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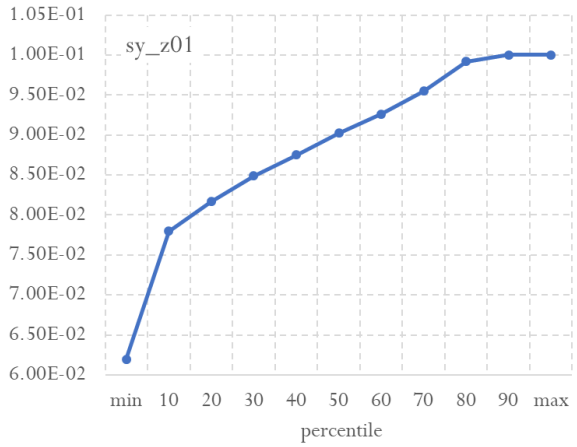
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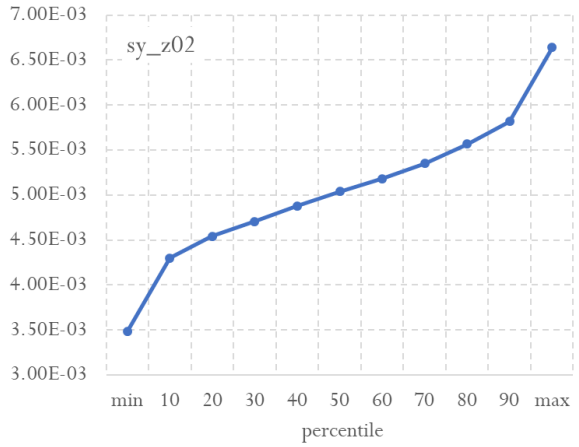
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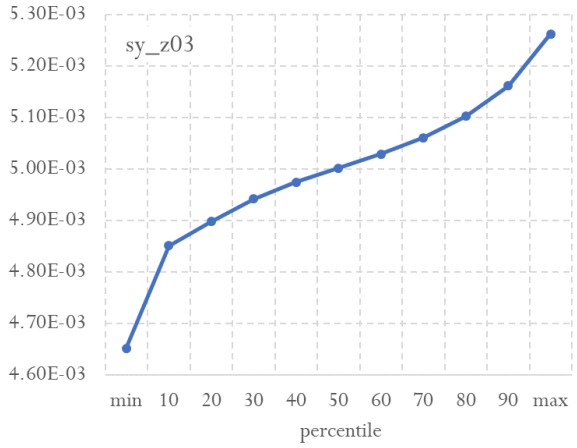
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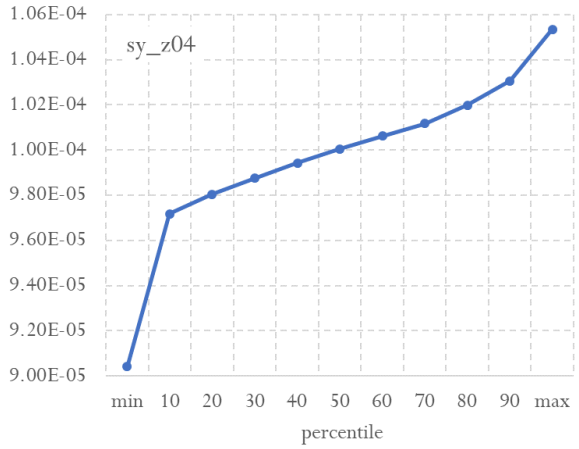
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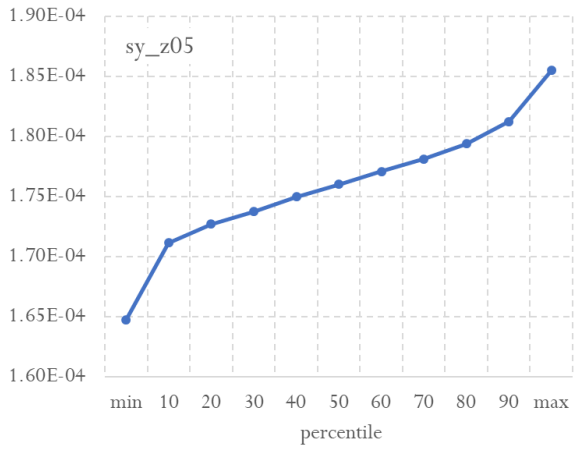
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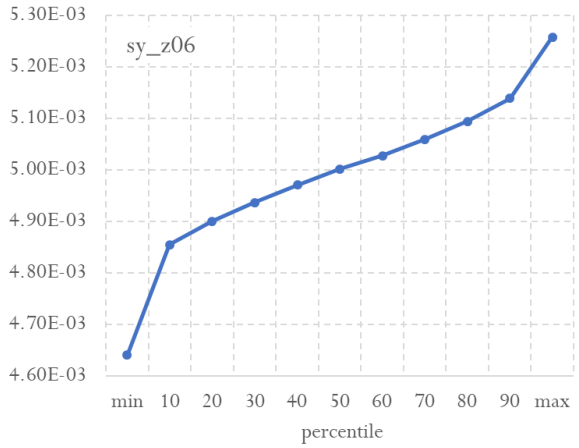
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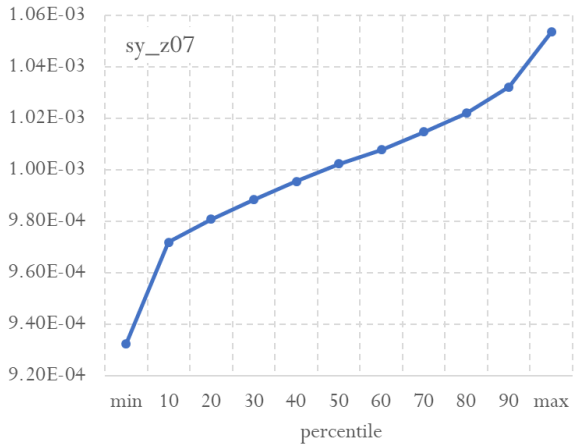
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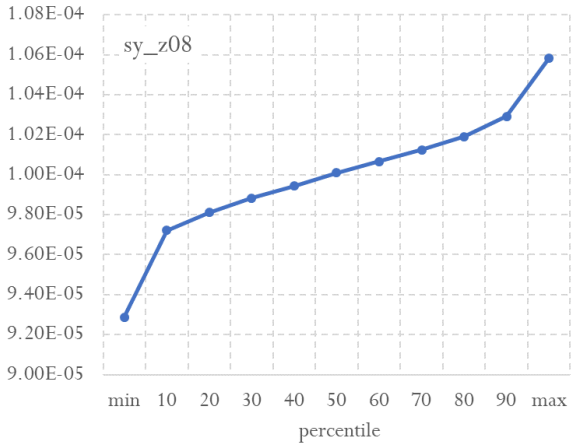
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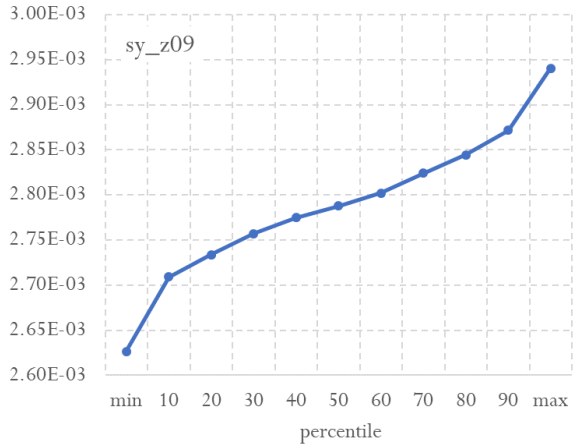
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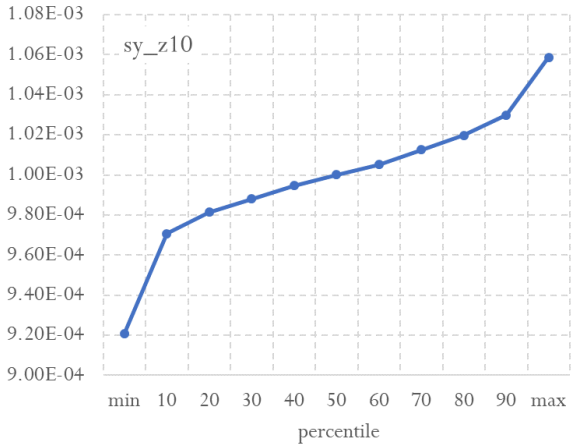
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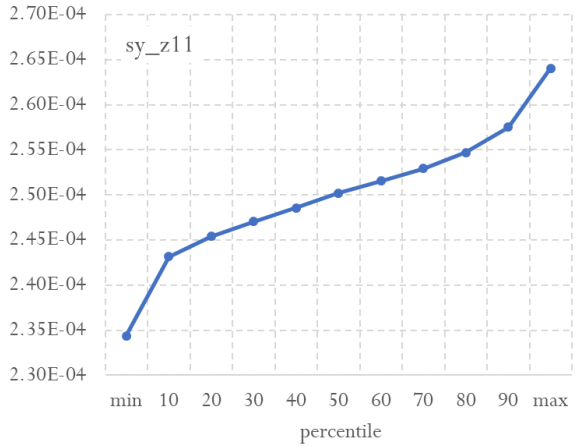
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Appendix C – Soil and Land Suitability Assessment

VULCAN SOUTH

SOIL AND LAND SUITABILITY ASSESSMENT



PREPARED FOR

METSERVE PTY LTD

MARCH 2022

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List of Abbreviations

AARC	AARC Environmental Solutions Pty Ltd
Ca/Mg	Calcium/Magnesium Ratio
CEC	Cation Exchange Capacity
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
MLA	Mining Lease Application
NATA	National Association of Testing Authorities
PAWC	Plant Available Water Capacity
ROM	Run-of-mine
SCL	Strategic Cropping Land
SLSA	Soil and Land Suitability Assessment
SMU	Soil Management Unit
VCM	Vulcan Coal Mine
VCP	Vulcan Complex Project
VS	Vulcan South

1 Introduction

AARC Environmental Solutions Pty Ltd (AARC) was commissioned by Mining and Energy Technical Services Pty Ltd (METServe), on behalf of Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), to conduct a Soil and Land Suitability Assessment (SLSA) for Vulcan South (VS, the Project). The Project is located north of Dysart and approximately 45 km south of Moranbah in Queensland's Bowen Basin (Figure 1). The Project is located immediately to the south of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM) as well as to the west of several established mining operations including BHPs Peak Downs and Saraji mines. The closest major town to the site is Emerald, approximately 125 km south of the Project site.

As part of early Project planning and feasibility assessment, the proponent nominated a considerably larger area (the study area). The baseline data collected within this larger study area has been used in the assessment of the Project, and for context, as required.

This SLSA documents the nature and distribution of major soil types in the study area and assesses their suitability for the land uses of both cattle grazing and dryland cropping. This assessment establishes baseline environmental characteristics and values relating to land use and suitability and provides recommendations for the management of soil resources within the Project areas.

1.1 Objectives

The objectives of the SLSA are to:

- Describe the agricultural use(s) of the Project site and the surrounding area.
- Describe, map and illustrate soil types and profiles according to the *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain 2009), *Guidelines for Surveying Soil and Land Resources* (McKenzie et. al. 2008) and *Australian Soil Classification* (Isbell 2002).
- Identify soils that would require specialised management due to wetness, erosivity, depth, acidity, salinity or other features.
- Identify soils from representative samples down the soil profile, based on their physical and chemical properties that are likely to, or have potential to be subject to erosion from storm water runoff. Similarly, soils proposed to be used for rehabilitation, and particularly where agriculture is the final land use, will be assessed for their suitability for this use.
- Describe and map land suitability classes of the study area in accordance with the *Guidelines for Agricultural Land Evaluation in Queensland—Second Edition* (Draft) (State of Queensland 2012), and the *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland—Land Suitability Assessment Techniques* (DME 1995).
- Assess the potential impacts of the Project on the soil and land use values of the area and provide recommended mitigation measures to minimise negative impacts.
- Include the findings in a stand-alone report suitable for inclusion in an environmental impact statement.

2 Project Background

The Project is located immediately to the south of Vitrinite's initial mining project, VCM. The Project is situated in the Bowen Basin, central Queensland, approximately 30 km north of the township of Dysart, 125 km north of Emerald, and 270 km north-west of Rockhampton (Figure 1).

The Project will operate for approximately nine years and will extract approximately 13.5 Mt of ROM coal consisting predominantly of hard coking coal (with an incidental thermal secondary product) at a rate of up to 1.95 Mtpa. The VS is defined and selected for open cut development via three (3) separate open cut pits that form the primary mining focus of the study area.

Truck and shovel mining operations will be employed to develop the pit. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO) at a location between the northern and central pits. The CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product for permanent storage within active waste rock dumps. No wet tailings wastes are proposed and therefore no tailings dams are required.

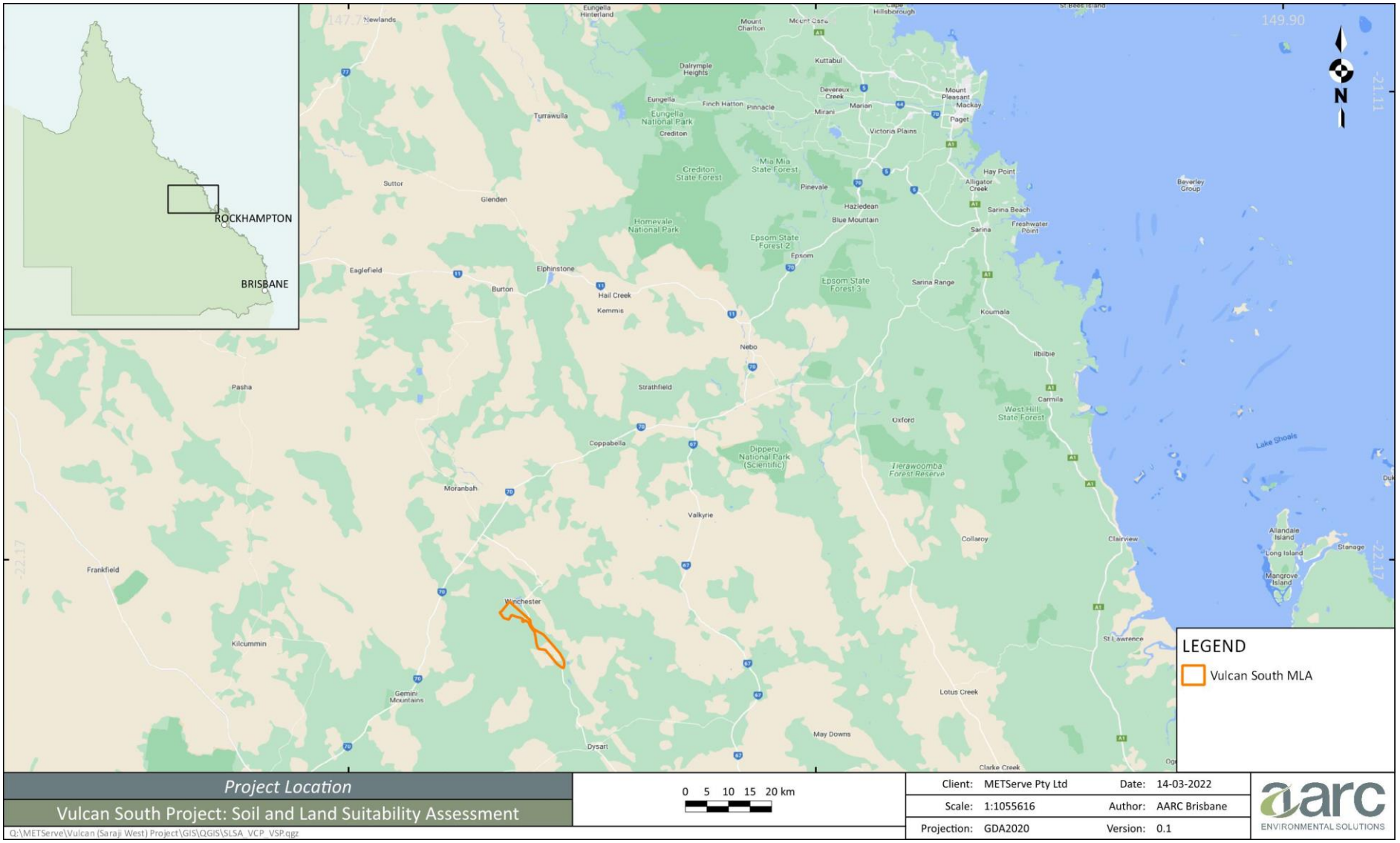


Figure 1: Project location

2.1 Local topography and landform

The Project lies within the Fitzroy River Basin. This basin encompasses an area of 142,545 km^2, and contains the Comet, Dawson, Fitzroy, Isaac, Mackenzie and Nogoa Rivers, which make up six sub-catchment areas (Department of Environment and Science 2019).

The Project exists within the Isaac River sub-catchment, which is situated in the northern region of the Fitzroy River Basin and has a total area of 22,364 km^2. The major water bodies associated with the site are the Boomerang and Hughes Creeks. Boomerang Creek dissects the study area in a north-easterly direction and flows just to the south of the Project area. Hughes Creek flows in an easterly direction across the southern region of the study area. Both creeks form within approximately 10 km beyond the western boundary of the study area, flowing east to north-east. Boomerang Creek joins Hughes Creek near the south-eastern boundary of the study area before its confluence with the Isaac River and finally the Fitzroy River; eventually flowing to the Pacific Ocean approximately 46 km north of Gladstone.

The topography within the study area varies from hilly, rocky terrain to the north to flat plains and undulating hills to the south, with elevation ranging between 200 m to 400 m above sea level. Vegetation in the region includes grassy plains, riparian vegetation and woodlands.

2.2 Regional geology

The geology of the area is influenced by its position within the Bowen Basin, one of Queensland's largest depositional zones, forming through a period of rifting and subsidence lasting from the Early Permian to the Mid-Triassic. The area surrounding the Project is dominated by clastic sedimentary rocks of marine and lacustrine origin, including sandstones, mudstones, siltstones and coal (Geoscience Australia 2019).

The coal seams found in the east-central part of the Bowen Basin are of Permian age and contain higher quality coking coal deposits, with the rank falling below the coking range farther south and west (Hutton 2009, Mutton 2003).

The solid geology of the region is described as including:

- Moranbah Coal Measures—Permian comprising of coal and interseam material composed of sandstone, shale, siltstone with minor clay stone; and
- Back Creek Group—Early to Late Permian comprising of quartzose to lithic sandstone, conglomerate, siltstone, carbonaceous shale and coal.

While surface geology includes the following:

- Qr–Qr–(QLD) (Qr) – Quaternary clay, silt, sand, gravel and soil with colluvial and residual deposits; and
- TQa–QLD (TQa)—Late Tertiary to Quaternary poorly consolidated sand, silt, clay, minor gravel and high-level alluvial deposits.

2.3 Regional climate

The regional climate is classified as semi-arid, with characteristic hot summers and mild to warm winters. Climate statistics have been sourced from the Bureau of Meteorology for the Clermont Post Office, located approximately 77 km south-west of the Project. The data indicates average rainfall for the region to be approximately 665 mm with a characteristic wet season between November and March. Long term temperature statistics demonstrate that the average maximum daily temperature in summer is 34°C with overnight minimum temperatures averaging at 21°C. In winter, the average maximum temperature is 24°C with an average minimum temperature of 8°C (Bureau of Meterology 2019).

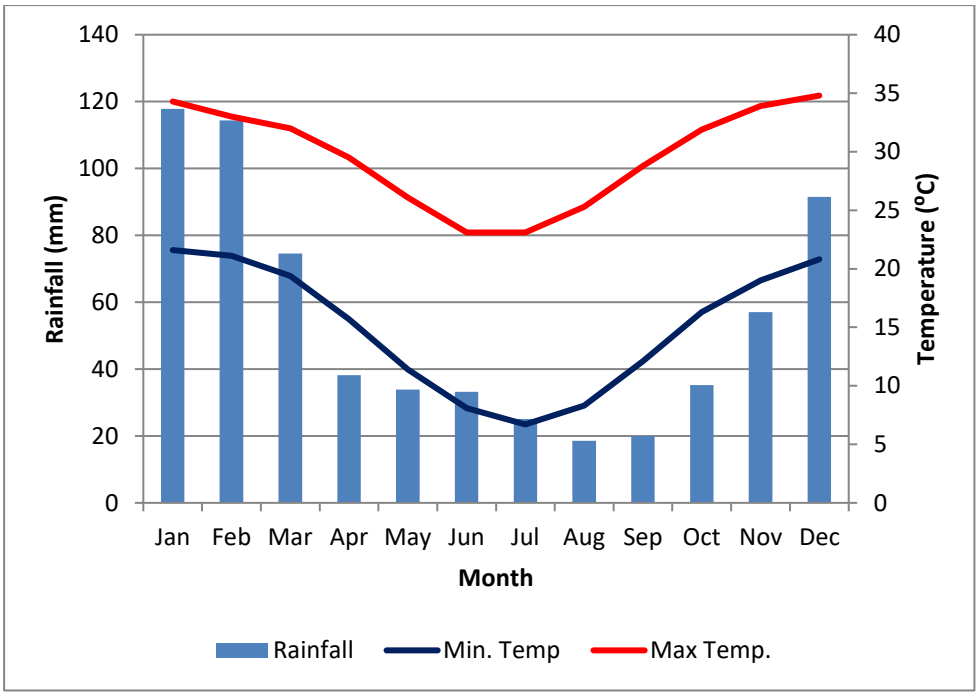


Figure 2: Climate statistics (Clermont Post Office)

2.4 Current land use

The land within the Project boundary is currently used for low intensity cattle grazing, and small commercial operations with few significant disturbances apart from small farm dams and dirt tracks.

2.5 Strategic cropping land

The *Regional Planning Interests Act 2014* (RPI Act) is administered by the Department of State Development, Manufacturing, Infrastructure and Planning and regulates impacts from resource and other regulated activities on identified areas of regional interest. This includes the strategic cropping area which consists of areas shown on the strategic cropping land (SCL) trigger map as SCL. SCL is land that is, or is likely to be, highly suitable for cropping because of a combination of the land's soil, climate and landscape features.

The Department of Natural Resources, Mines and Energy makes and certifies the SCL trigger map. None of the lands within the study area are included within the SCL trigger map.

2.6 Land systems

The Report on Lands of The Isaac-Comet Area (Story *et al.* 1967) mapped at a scale of 1:500,000 indicates the study area contains the land system units described in the following sections.

2.6.1 Carborough land system

The Carborough Land System is characterised by mountains and hills with broken and dissected local relief ranging between 30 m to 400 m. Structural benches and cliffs are common landforms with severe weathering occurring in some areas. This mountainous land system has formed shallow coarse-textured rocky soils with species such as bloodwood (*Corymbia erythrophloia*), lancewood (*Acacia shirleyi*) and narrow-leaved ironbark (*Eucalyptus crebra*) populating the area. A small area of the Carborough Land System is also characterised by lower slopes and hills and alluvial flats with a local relief between 10 m to 60 m. Texture-contrast soils have

formed in these areas and possess a thick sandy topsoil. Savannah woodland dominated by narrow-leaved iron bark (*Eucalyptus crebra*) is established in this area.

Geology in this land system is comprised of partly weathered quartz sandstone.

2.6.2 Connors land system

The Connors Land System is characterised by alluvial plains composed of terraces and levees up to 3 km wide. Texture-contrast soils have developed in this area and are characterised by a thick sandy topsoil and neutral to strongly alkaline subsoil. Vegetation consists of savannah woodlands dominated by Poplar box (*Eucalyptus populnea*) and mixed shrub woodland.

2.6.3 Cotherstone land system

The Cotherstone Land System is characterised by hills and prominent strike ridges as well as gentler undulating terrain associated with low indefinite strike ridges and colluvial foot slopes. The more prominent strike ridges possess a local relief varying between 10 m to 30 m and have developed shallow course-textured to rocky soils that support savannah woodland consisting mostly of narrow-leaved iron bark (*Eucalyptus crebra*) and lancewood (*Acacia shirleyi*). The gentler undulating terrain has a local relief of less than 15 m and is associated with texture-contrast soils with a sandy upper-horizon. Depending on the steepness of terrain either narrow-leaved iron bark dominated savannah woodland (slopes of <10%) or mixed shrub woodland (slopes of <5%) have been established.

The geology in this land system is weathered Permian sandstone and shale.

2.6.4 Monteagle land system

The Monteagle Land System is predominantly characterised by low-lying plains and colluvial foot slopes with local relief generally below 6 m. This land system is associated with texture-contrast soils composed of a thick sandy topsoil and neutral to strongly alkaline subsoils. Savannah woodlands consisting largely of Poplar box (*Eucalyptus populnea*) and some narrow-leaved iron bark (*Eucalyptus crebra*) dominate the area.

Geology in this land system is comprised of undissected Tertiary sandstones and clays.

3 Soil Survey Methodology

3.1 Desktop analysis

A desktop analysis was conducted prior to field sampling. This analysis was comprised of background research and evaluation of available information for the study area. Resources used included:

- The Digital Atlas of Australian Soils (Bureau of Rural Science 1991). Australian soils were mapped at a scale of 1:2,000,000. Although this scale is broad it provided a good foundation for understanding the soils that may be present in the study area region.
- Government maps featuring regional topography, geology, contour data and watercourse locations were used to help refine mapping boundaries, particularly where soil types are a function of gradient.
- *Reference information for land systems: Land Systems of the Isaac-Comet Area, Queensland* (Story *et al.* 1967).
- Reference Information for regional geology: *Geology of the Bowen Basin, Queensland* (Dickins and Malone 1973).
- Reference information for land management: *Understanding and Managing Soils in the Central Highlands* (Bourne and Tuck 1993).

3.2 Survey design

Methodologies employed throughout this study followed procedures detailed in the *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain 2009) and the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). The soil survey was based on a free-survey technique with soil profile and observation sites located to best represent all soil types present in the study area.

As part of the Project planning and feasibility assessment, the proponent commissioned environmental assessments of a considerably larger study area than the proposed MLA Project area. As a result, the SLSA study area surveyed comprises a significantly larger area of 10,150 ha which incorporates the Project area as well as lands lying predominantly to the west and south of the Project area.

Mapping scales for the study area were selected in order to satisfy the requirements of an environmental impact statement taking into consideration available resources, land access and soil complexity. For the study area, a scale between 1:25,000 to 1:100,000 was deemed most appropriate. This scale was selected based on information contained within the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). The final mapping scale of 1:85,000 for the study area fell within the specified range.

To achieve a mapping scale of 1:25,000 to 1:100,000, McKenzie *et al.* (2008) suggest a minimum recommended sampling density of one site per 25 ha with data collection comprising detailed soil profile descriptions (15-35% of sites), representative profile sampling for lab analysis (1-5%) and mapping observations sites (55-83%).

The number of sites surveyed for the SLSA (refer Table 1) exceeded these minimum requirements.

Table 1: Survey site numbers for SLSA 2019

Survey site	Scale	Detailed soil profiles	Representative profiles for analysis	Mapping observations	Total
Study Area (10,150 ha)	1:100,000	42	12	66	121

3.3 Field Investigations

AARC undertook field sampling at the Project from 19 to 26 July 2019, consisting of both primary sampling sites (profiles) and secondary visual assessments (observations).

Sampling site locations were determined based on the desktop analysis, land management units, landform and vehicle access. Visual assessments were conducted continually while traversing the landscape to confirm major soil types and boundaries between soil units. The GPS coordinates of each location were recorded.

Detailed soil profiles were undertaken at 42 sites within the Project boundaries. A jackhammer-operated soil corer was used to excavate cores to a maximum depth of 120 cm. Soil samples were collected from profiles at standard depths of 0–10 cm, 20–30 cm, 50–60 cm, 80–90 cm and 110–120 cm where possible. Samples were sealed in clean, plastic zip-lock bags and labelled with the site number, date, depth of sampling and the initials of the sampler.

Parameters recorded included micro relief, permeability, drainage, substrate, site disturbance, landform (slope percentage, relief, elevation, morphological type, landform element and landform pattern), runoff, erosion, surface coarse fragments, rock outcrops, surface condition and dominant vegetation type. Soil profile morphology was described in the field in terms of horizon type, horizon depth, boundary, colour, mottles, texture, coarse fragments, structure, segregations, consistency and field pH.

3.4 Laboratory analysis

Samples from a total of 12 representative sites were chosen for analysis through Australian Laboratory Services for NATA approved physical and chemical analyses. Samples from all standard depths at the chosen sites were analysed to:

- confirm the classification of the described soil profile;
- assist in the description of soil characteristics;
- assist in the determination of land suitability classes;
- assist in the determination of topsoil and subsoil as a suitable topdressing media; and
- assist in the identification of soils that would require specialised management.

Physical and chemical parameters analysed for all samples included:

- pH;
- electrical conductivity (EC);
- moisture content;
- chloride (soluble);
- exchangeable cations (Ca, Mg, Na, K);
- Cation Exchange Capacity (CEC); and
- Exchangeable Sodium Percentage (ESP).

Additional physical and chemical parameters analysed for topsoil samples included:

- organic matter (%);
- Particle Size Analysis (PSA);
- extractable trace elements/metals (Fe, Cu, Zn, Mn);
- boron ($CaCl_2$ extractable);
- N as nitrate;
- SO_4 (water soluble S as sulphate);

- phosphorus and potassium (Colwell); and
- Emerson Class.

3.5 Characterisation of soil management units

Soil classification was undertaken using the methodologies specified in *The Australian Soil Classification* (Isbell 1996). Soil Management Units (SMUs) were then defined based on grouping soils of like soil morphology, parent material, and land attributes in accordance with the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). Each SMU has been described in terms of its soil profile class with the attributes and limitations of the soil interpreted using the *Guidelines for Agricultural Land Evaluation in Queensland—Second Edition* (DSITI and DNRM 2015) to determine their suitability for cattle grazing and broadacre cropping. SMUs were mapped at a scale of 1:85,000 across the study area.

3.6 Interpretation of chemical data

The characteristics and chemical data for each SMU have been described in Section 4. The following guidelines were used to assist in interpretation of the SMU physical and chemical properties and to determine ratings and categories of the assessed soil parameters.

- *Interpreting Soil Test Results* (Hazelton and Murphy 2016);
- *Soil Chemical Methods of Australasia* (Rayment GE and Lyons D 2011); and
- *Standard Soil Test Methods and Guidelines for Interpretation of Soil Results* (Government of South Australia 2013).

Broad descriptions for each soil parameter have been provided below and where applicable, a summary of the rating system used.

3.6.1 pH

Soil pH influences the availability of plant available nutrients and toxic elements by controlling the solubility of these elements. At extreme pH, the availability of essential plant nutrients can be severely reduced while toxic elements can become mobile within the soil solution. The soil pH ratings used are shown in Table 2. In general, a suitable soil pH ranges from 5.5 to 9.0 as at this pH all essential nutrients are available to some degree.

Table 2: Electrical conductivity ratings after interpreting soil test results (2016)

pH water	Rating	Soil chemistry indications
< 4.0	Very strongly acid	Typical of disturbed acid sulphate soils
4.0 to < 5.0	Strongly acid	Acidified soils
5.0 to < 6.0	Moderately acid	Range most suitable for plant growth
6.0 to < 7.0	Slightly acid	
7.0	Neutral	
> 7.0 to < 8.0	Slightly alkaline	
8.0 to < 9.0	Moderately alkaline	
9.0 to 10.0	Strongly alkaline	Some nutrients becoming unavailable, indication of sodicity
> 10.0	Very strongly alkaline	Extreme pH, high sodicity and carbonates

3.6.2 Electrical conductivity

EC provides an indication of the presence of soluble salts in the soil profile. High levels of soluble salts can interfere with the osmotic capacity of plants. This compromises the plant's ability to take up water as needed resulting in water stress regardless of the water content in the soil. The texture of soil needs to be considered when interpreting EC as the clay content determines the amount of salt present that will affect plant growth. Table 3 provides soil salinity ratings sourced from Rayment and Lyons (2011).

Table 3: Soil salinity ratings (based on EC values in dS/m)

Soil salinity rating	10– 20% clay	20– 40% clay
Very low	< 0.07	< 0.09
Low	0.07–0.15	0.09–0.19
Medium	0.15–0.34	0.19–0.45
High	0.34–0.63	0.45–0.76
Very high	0.63–0.93	0.75–1.21
Extreme	> 0.93	> 1.21

3.6.3 Chloride

Chloride is associated with EC as soluble salts contain chloride, thus the presence of soluble salts in soils is directly proportional to chloride in soil. A high chloride concentration can induce chloride toxicity and interfere with the osmotic capacity of plants. Table 4 provides chloride ratings (Rayment and Bruce 1984).

Table 4: Chloride concentration ratings

Chloride rating	Concentration (mg/kg)
Very low	< 100
Low	100–300
Medium	300–600
High	600–2,000
Very high	> 2,000

3.6.4 Cation exchange capacity and exchangeable cations

CEC is an indication of the soil's capacity to adsorb cationic nutrients to the surface of soil particles. This process of adsorption prevents nutrients leaching from the soil and buffers the concentration of plant available nutrients in the soil solution. A high CEC of the soil contributes to larger quantities of exchangeable cations (Ca, K, Mg, Na) available. The ratio of cations on the exchange is also an important consideration as cations that dominate the exchange can interfere with the availability of other cations. Table 5 and Table 6 provide ratings for soil CEC and extractable cations sourced from the guide *Interpreting Soil Test Results* (2016).

Table 5: Soil CEC ratings

CEC rating	CEC (cmol(+)/kg)
Very low	< 6
Low	6–12
Medium	12–25
High	25–40
Very high	> 40

Table 6: Ratings for extractable cations (cmol(+)/kg)

Cation	Very low	Low	Moderate	High	Very high	Ideal range (% of CEC)
Ca	0–2	2–5	5–10	10–20	> 20	65–80
K	0–0.2	0.2–0.3	0.3–0.7	0.7–2	> 2	1–5
Mg	0–0.3	0.3–1	1–3	3–8	> 8	10–15
Na	0–0.1	0.1–0.3	0.3–0.7	0.7–2	> 2	< 1

3.6.5 Exchangeable sodium percentage

ESP is defined as the amount of exchangeable sodium as a percentage of the total CEC of the soil. It provides a measure of how much of the CEC of the soil is dominated by sodium. Due to the chemical characteristics of sodium ions, an increasing ESP indicates increasing sodicity thus increasing the risk of dispersion. Table 7 provides ESP ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 7: Soil ESP ratings

ESP (%)	ESP rating
< 6	Non-sodic
6–15	Sodic
> 15	Strongly sodic

3.6.6 Organic matter

Organic matter is an essential constituent of soil. It is an important component of microbial processes and nutrient cycling. Furthermore, it contributes to the ability of a soil to buffer changes to pH and nutrient content and supports the aggregation of soils thereby improving the structural stability of the soil. Table 8 provides soil organic matter ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 8: Soil organic matter ratings

Organic matter rating	Organic matter content (g/100 g)
Extremely low	< 0.7
Very low	0.7–1
Low	1–1.7
Moderate	1.7–3
High	3–5.15
Very High	> 5.15

3.6.7 Particle size analysis

Particle size analysis determines the percentage composition of sand, silt and clay sized particles which controls the soil texture. Soil texture influences the structural stability and water holding characteristics of a soil as the particle size distribution influences the porosity and permeability of soil.

3.6.8 Extractable trace elements/metals

Trace elements such as copper, iron, manganese, zinc and boron are essential nutrients required for plant growth, although needed in much smaller quantities than exchangeable cations. Table 9 provides trace element/metal ratings sourced from the guide *Standard Soil Test Methods and Guidelines for Interpretation of Soil Results* (2013).

Table 9: Ideal concentration ranges for trace elements/metals

Trace element/metal	Rating	Concentration
Boron	Low	< 0.5
	High	> 15
Copper	Low	< 0.3
	High	> 1
Iron	Low	< 10
	High	> 70
Manganese	Low	< 1
	High	> 10
Zinc	Low	< 0.5
	High	> 1

3.6.9 Nitrate

Nitrate is a plant-available form of nitrogen. It is an essential nutrient and is often the most limiting to plant growth. It is also susceptible to nitrification and leaching which reduces nitrate concentration in soil. Table 10 provides soil nitrate ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 10: Soil nitrate ratings

Rating	Nitrate concentration (mg/kg)
Very low	0–6
Low	7–15
Moderate	16–22
High	23–30
Very high	> 30

3.6.10 Sulphate

Sulphate is another essential plant nutrient and has a similar behaviour to nitrate in that it is susceptible to leaching and is important in microbial processes. Table 11 provides soil sulphate ratings sourced from Government of South Australia (2013).

Table 11: Soil sulphate ratings

Rating	Sulphate concentration (mg/kg)
Low	< 5
Marginal	5–10
High	> 10

3.6.11 Phosphorous and potassium

Both phosphorous and potassium are the next most essential nutrients after nitrogen and sulphate. Phosphorous and potassium are involved in several chemically- and microbially-driven processes within the soil with most forms of these nutrients being unavailable for plant uptake. Table 12 and Table 13 provide ratings for soil phosphorous and potassium levels sourced from the guide *Interpreting Soil Test Results* (2016).

Table 12: Soil phosphorous ratings

Rating	Phosphorous concentration (mg/kg)
Very low	< 5
Low	5–10
Moderate	10–17
High	17–25
Very high	> 25

Table 13: Soil potassium ratings

Soil texture	Critical concentration (mg/kg)*
Sand	126
Sandy loam	129
Sandy clay loam	143
Clay loam	161

* Critical concentration is that concentration where 95% of maximum yield is achieved

3.6.12 Emerson class

Emerson class is a class assigned to soil that is determined on the stability of dry aggregates in water. The Emerson Class Number of a soil is assigned as an indication of the dispersion and slaking ability of a soil. Table 14 describes the Emerson Dispersion Class (Emerson 1967).

Table 14: Emerson class numbers

Emerson aggregate class	Level of dispersion
1	Slaking and complete dispersion
2	Slaking and some dispersion
3	Slaking and no dispersion
4	CaCO3/CaSO4 present. No dispersion at field capacity
5	No CaCO3/CaSO4 present. No dispersion at field capacity, however, dispersion in an aggregate-water suspension
6	No CaCO3/CaSO4 present. No dispersion at field capacity, however, flocculation in an aggregate-water suspension
7	No slaking and swelling
8	No slaking and no swelling

4 Soil Survey Results

Eight SMUs have been described within the study area. Table 15 provides an overview of each SMU and its extent within the study area and Table 16 lists the SMUs present within the Project areas. The spatial distribution of the SMUs has been mapped at a scale of 1:85,000 and is illustrated in Figure 3. The coordinates for each sampling site have been provided in Appendix 4. Two small areas resulting from subsequent minor changes to the Project MLA boundary extended beyond the original study area boundary. Desktop assessment has determined that these areas constitute Kei SMU for the south adjustment area and Crocodile SMU for the northern adjustment area.

Table 15: Soil management units—study area

SMU	Surface area (ha)	Per cent of study area (%)
Crocodile	2,526	24.9
Fish	76	0.7
Kei	183	1.8
Komati	262	2.6
Limpopo	3,316	32.6
Orange	471	4.6
Sabie	1,865	18.4
Zambezi	1,451	14.4
Total Area	10,150	100

Table 16: Soil management units—VS Project area

SMU	Surface area (ha)	Per cent of Project area (%)
Crocodile	1,195	31.3
Fish	76	2.0
Kei	174	4.6
Komati	262	6.9
Limpopo	1,015	26.6
Orange	472	12.4
Sabie	47	1.2
Zambezi	577	15.0
Total Area	3,818	100

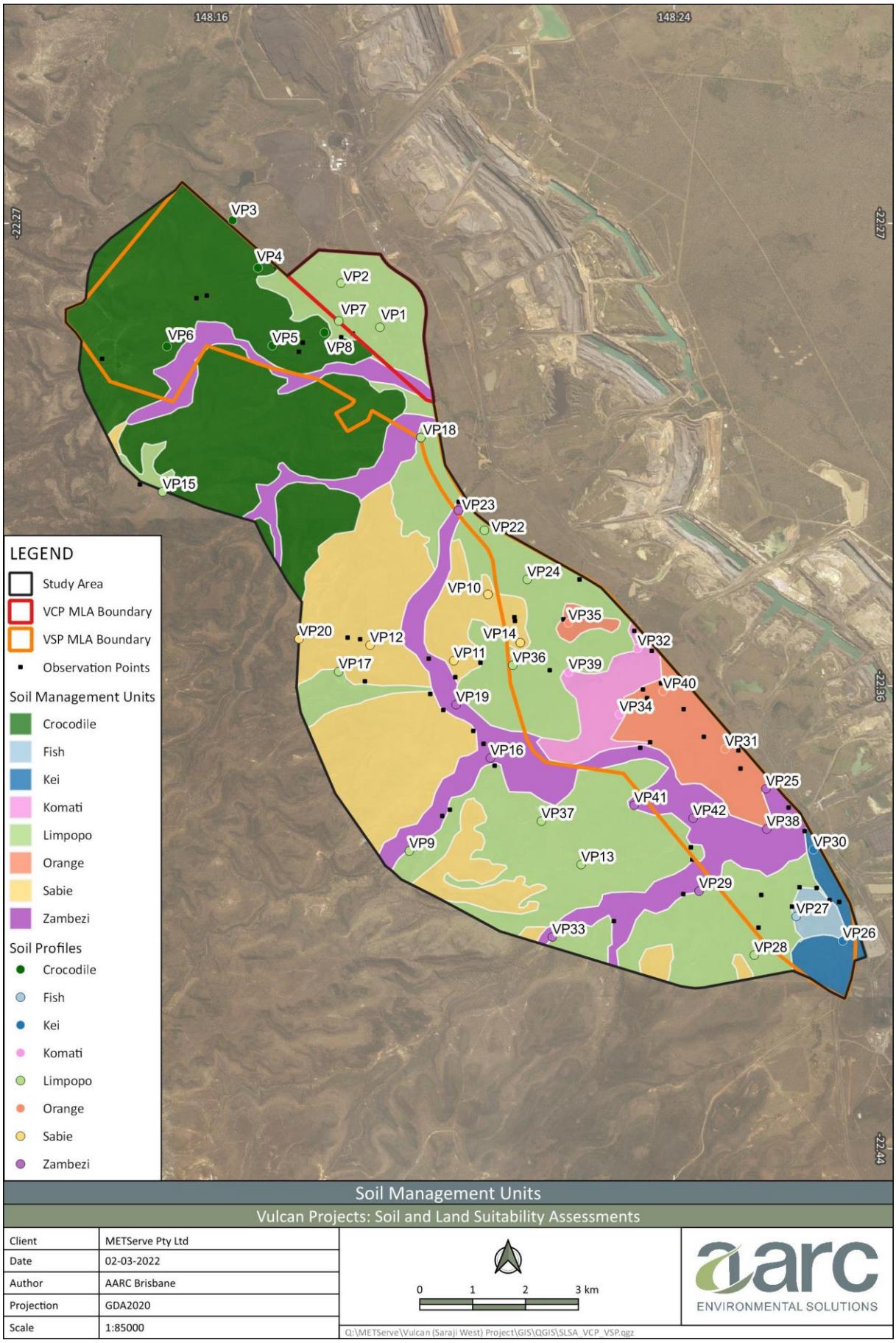


Figure 3: Distribution of soil management units (1:85,000)

4.1 Crocodile soil management unit

4.1.1 Soil unit description

A shallow rocky soil unit associated with hill slopes and plateaus. Soil textures grade from loam at the surface, to loamy sands with depth; often containing rock material with little to no pedologic development throughout the solum. Vegetation associated with this unit includes *Eucalyptus crebra* and Bloodwood *Corymbia erythrophloia*.



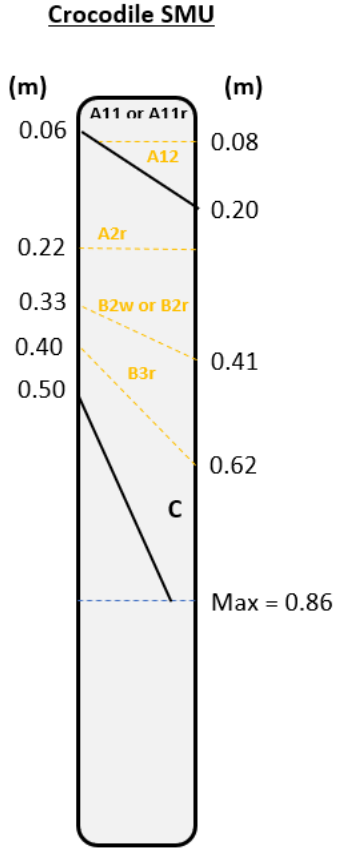
Figure 4: Crocodile SMU vegetation

Table 17: Key Crocodile SMU parameters

Parameter	Soil unit description
Profile Site Numbers	VP3, VP4, VP5, VP6, VP8
Observation Site Numbers	OP1, OP3, OP6, OP8, OP10, OP14, OP15, OP16
Landform	Rises and Plateaus
Australian Soil Classification	Arenic Rudosol
Land System	Carborough Land System
Slope	1 to 10%
Geology	Back Creek Group
Vegetation	Narrow-leaved ironbark (Eucalyptus crebra), Bloodwood (Corymbia erythrophloia)
Runoff	Moderate
Permeability	Slow to moderately permeable
Drainage	Moderate to rapidly drained

Profile description—representative sites VP5 and VP8





The **surface soil** (A11/A11r/A12) is a black to very dark greyish brown (10YR2/1, 10YR3/2) sand to sandy loam with loose to weak polyhedral structure with some profiles containing moderately strong to strong sub-angular rock material. The soil unit has a field pH of 4.5–5.5, demonstrating an abrupt to clear change to;

The **lower surface soil** (A2r) is not a common horizon observed for this SMU. It is a dark brown (10YR3/3) loamy sand with an abundance (comprising 50–90% of this horizon) of moderately strong coarse fragments approximately 2–6 cm in diameter. It has loose structure and a field pH of 5.5 to 5.0. Gradual change to;

The **subsoil** (B2w/B2r) is a dark greyish to reddish brown (10YR3/2, 2.5YR2.5/4) loamy sand to clay loam with weak to moderate polyhedral structure. It can contain rounded to angular course fragments which make up < 10% of the horizon. This horizon has a field pH of 4.5 to 5.5, with a gradual change to;

The **lower profile** (C) contains either consolidated or unconsolidated partly weathered rock material that appear to have originated from underlying sandstone and siltstone with some profiles possessing an overlying transitionary horizon (B3r). Depending on the rock material present, this horizon can range from dark red to light yellow-brown colour.

Chemical and physical analysis

Table 18: Chemical properties of the Crocodile SMU

Representative site: VP5								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	#	Rating	dS/m	Rating	(mg/kg)	%	Rating	(%)
0–0.1	5.4	Strongly Acid	0.014	Low	< 10	1.5	Non-sodic	2.9
0.2–0.3	5.4	Strongly Acid	0.007	Very low	< 10	1.3	Non-sodic	2.6
0.5–0.6	5.6	Moderatel y Acid	0.006	Very low	< 10	1.5	Non-sodic	1.9
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	7.3	Low	3.1	1.5	0.8	0.1	2.1	8
0.2–0.3	3.1	Very Low	0.1	1	0.2	< 0.1	< 0.1	7
0.5–0.6	2.4	Very Low	< 0.1	1	0.1	< 0.1	< 0.1	7
Nutrient Distribution in Topsoil (%)			42.5%	20.6%	10.9%	1.4%		

The Crocodile SMU is strongly acidic throughout the solum with only a minor increase in pH at depth. In the upper part of the profile (to an approximate depth of 0.3 m), this has the potential to limit the availability of essential nutrients and increase the risk of aluminium toxicity. Throughout the profile, both EC and chloride concentration remain very low with EC ranging between 0.014 dS/m in the topsoil to 0.006 dS/m at depth and chloride concentration remaining below 10 mg/kg. This indicates this SMU is not affected by issues associated with salinity and toxic chloride concentrations (Rayment and Lyons 2011).

CEC levels for this SMU are considered low (7.3 meq/100g) and decrease to 2.4 meq/100g with depth. All extractable cations except sodium (Na) fall below suitable plant concentrations according to (Hazelton and Murphy 2016). These low CEC values can be attributed to the predominantly sandy texture of this SMU. The distribution of exchangeable cations within the topsoil indicates a misbalance between nutrients with the proportion of K on the exchange lower than ideal while all other cations are higher (Hazelton and Murphy 2016). However, this is not likely to have a negative effect on soil quality due to low ESP values and Emerson class numbers.

The calcium to magnesium ratio (Ca/Mg) indicates that, relative to Mg, soil Ca concentration is considered low to deficient. This is not expected to affect plant growth in the topsoil; however, Ca concentration decreases below 0.5 meq/100g in the subsoil which may have potential to impact growth. Although the Ca:Mg ratio in the subsoil indicates that it has the potential to enhance sodicity (Ca/Mg <1), ESP values fall below 4% thus the risk of dispersion is extremely low. This is supported by the Emerson Class Number.

Table 19: Surface Soil (0–10 cm) Properties of the Crocodile SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
8	10	52	30		1.88		3.5	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
8	617	< 10	22	< 0.2	< 1	89.6	9.81	< 1

The topsoil is dominated by sand (52%) and gravel (30%) with 10% silt and 8% clay. This particle size distribution could limit the ability of the soil to hold and store plant available water. Organic matter content is considered as high providing a buffering capacity to pH changes, as well as imparting good structural stability and enhancing the capacity of the soil to retain nutrients and water. Regardless, the sandy composition of the surface horizon is a key limitation to the water holding capacity of a soil.

According to guidelines (Hazelton and Murphy 2016), extractable nutrients measured in the SMU, with the exception of potassium (617 mg/kg), indicate poor growing conditions with phosphorous (8 mg/kg), nitrate (2.2 mg/kg) and sulphate (<10 mg/kg) considered to be outside the ideal range for plant life. In terms of extractable metals, iron (Fe) and manganese (Mn) fall within an acceptable range for plant growth with copper (Cu) and zinc (Zn) considered below plant suitable levels (Government of South Australia 2013).

4.2 Fish management unit

4.2.1 Soil unit description

Predominantly sandy soil unit occurring on the flats of the south-eastern end of the study area. Soil textures grade from loamy sand at the surface, to clay and silty sands with depth. Vegetation associated with this unit includes largely *Acacia excelsa* and *Eucalyptus populnea*.



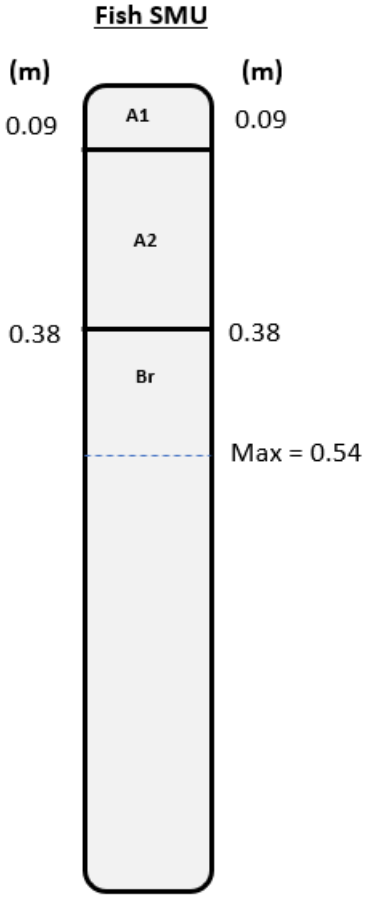
Figure 5: Fish SMU vegetation

Table 20: Key Fish SMU parameters

Parameter	Soil unit description
Profile Site Numbers	VP27
Observation Site Numbers	OP46, OP50, OP51, OP52
Landform	Plains
Australian Soil Classification	Grey Kurosol
Land System	Cotherstone Land System
Slope	0%
Geology	Back Creek Group
Vegetation	Rosewood (*Acacia excelsa*), Poplar Box (*Eucalyptus populnea*)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderate to well drained

Profile description—representative sites VP27





The **surface soil** (A1) is a dark grey (10YR4/1) loamy sand with weak platy structure with the deeper horizons of the profile exhibiting diffuse red to orange mottling. It has a field pH of 5.5 to 6, demonstrating a clear change to;

The **lower surface soil** (A2) is a grey (10YR5/1) clayey loam sand. This horizon has a weak polyhedral structure and a field pH of 5.5. Abrupt change to;

The **subsoil** (Br) is a grey (10YR5/1) silty clay loam with moderate polyhedral structure. This horizon has minor occurrence of indistinct red and orange mottle with diameters of <1.5cm. This horizon has a field pH of 4.5 to 5.5.

Chemical and physical analysis

Table 21: Chemical properties of the Fish SMU

Representative site: VP27								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	5.5	Moderately Acid	0.046	Very low	40	5.2	Non-sodic	1
0.2–0.3	5.2	Strongly Acid	0.042	Very low	50	8.2	Sodic	4.3
0.5–0.6	5.3	Strongly Acid	0.059	Very low	110	8.9	Sodic	5.3
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson Class No.**
(m)	**meq / 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg Ratio**	
0–0.1	2.5	Very Low	1.3	1	0.1	0.1	1.3	3
0.2–0.3	4.2	Very Low	0.6	2.4	< 0.1	0.3	0.2	3
0.5–0.6	4.9	Very Low	0.6	3.5	< 0.1	0.4	0.2	3
Nutrient distribution in topsoil (%)			52.0%	40.0%	4.0%	4.0%		

The pH of the Fish SMU is considered strongly acidic throughout the profile, becoming more severe with depth to the point of introducing a risk of aluminium toxicity (pH less than 5.5). All EC values are very low which indicate the soil will not be at risk to issues associated with salinity. Chloride values are also very low and are not expected to compromise the plant environment (Rayment and Lyons 2011).

The CEC of this soil indicates low availability of plant nutrients with all values considered below suitable levels according to guidelines (Hazelton and Murphy 2016). There is a slight increase in CEC with depth which is likely attributed to the slight increase in clay content in deeper horizons. Of the exchangeable cations, both potassium and calcium rate as very low with manganese and sodium content considered moderate in the topsoil but increasing to high levels at depth. Nutrient distribution in topsoil indicates magnesium occupies a large proportion of the exchange capacity of the soil, contributing to the low Ca/Mg ratio.

Soil ESP values increase to what is considered sodic with depth. The very low Ca/Mg ratio in conjunction with an Emerson Class Number of 3 indicate that the subsoil of this unit is at risk of dispersion.

Table 22: Surface soil (0–10 cm) properties of the Fish SMU

Particle size analysis %					**Soil particle density (g/cm^3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
15	23	60	2		2.37		2.5	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	< 100	30	0.3	< 0.2	< 1	163	5.16	< 1

The surface soil is dominated by sand (60%) and silt (23%) with 15% clay and 2% gravel. Moderate organic matter content offers adequate structural stability while ESP and the Ca/Mg ratio indicate that the topsoil is at risk of becoming dispersive if physically disturbed.

All extractable nutrients in this SMU are deficient with phosphorous, potassium and nitrate expected to be severely limiting to plant growth. The extractable metals iron, zinc and manganese are deemed adequate for plant growth, however, both copper and boron are considered deficient (Government of South Australia 2013)

4.3 Kei management unit

4.3.1 Soil unit description

Brown coloured soil unit occurring on the flats of the south-eastern end of the study area. Soil textures grade from clayey to loamy sands at the surface, to medium clay with depth and orange to yellow mottles present in the deeper horizons. Vegetation associated with this unit largely includes *Eucalyptus populnea*.



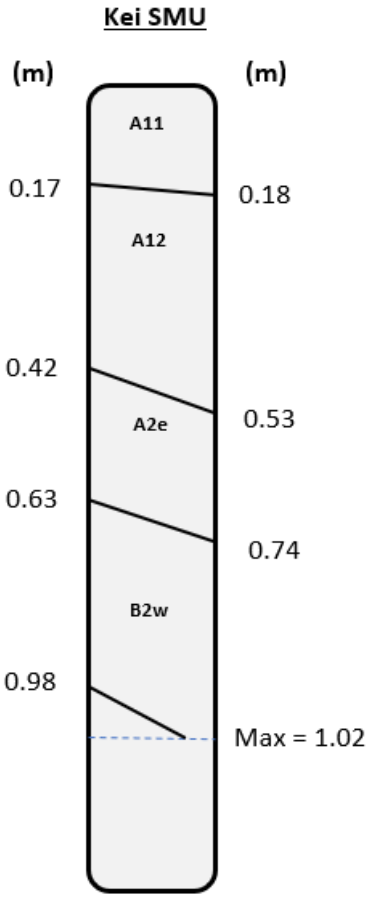
Figure 6: Kei SMU vegetation

Table 23: Key Kei SMU parameters

Parameter	Soil unit description
Profile site numbers	VP26, VP30
Observation site numbers	OP30, OP52, OP58
Landform	Plains
Australian soil classification	Brown chromosol
Land system	Cotherstone Land System
Slope	0%
Geology	TQa–Tqa– QLD
Vegetation	Poplar Box (*Eucalyptus populnea*)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderately well drained

Profile description—representative sites VP26 and VP30





The **surface soil** (A11/A12) is a very dark greyish brown to dark yellowish brown (7.5YR3/2, 7.5YR3/4) clayey sand to sandy loam with a loose to weak platy structure. It has a field pH of 6 to 7, demonstrating a gradual to diffuse change to;

The **lower surface soil** (A2e) is a bleached brown (10YR4/4) loamy sand. This horizon has a loose structure and a field pH of 7–7.5. Clear to gradual change to;

The **subsoil** (B2w) is a dark greyish brown (10YR4/2) silty clay loam to medium clay with moderate strength polyhedral structure. This horizon has occurrence of faint yellow and orange mottles with diameters of <1.5cm. This horizon has a field pH of 7 to 7.5.

Chemical and physical analysis

Table 24: Chemical properties of the Kei SMU

Representative site: VP30								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.4	Slightly Acid	0.013	Very low	< 10	1	Non-sodic	1.5
0.2–0.3	7	Neutral	0.014	Very low	< 10	1.4	Non-sodic	2.4
0.5–0.6	7.4	Slightly Alkaline	0.009	Very low	< 10	< 0.2	Non-sodic	1.7
0.8–0.9	8.6	Moderately Alkaline	0.101	Low	20	< 0.2	Non-sodic	8
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	4.5	Very Low	2.9	1.1	0.5	0.1	2.6	3
0.2–0.3	4.4	Very Low	2.8	1.1	0.5	< 0.1	2.5	3
0.5–0.6	1.5	Very Low	1.5	< 0.2	< 0.2	< 0.2	< 7.5	3
0.8–0.9	9.4	Low	8.4	0.6	0.4	< 0.2	12.9	4
Nutrient distribution in topsoil (%)			64.4%	24.4%	11.1%	2.2%		

The Kei SMU has a neutral to slightly acidic pH in the upper horizons with an increase in alkalinity with depth. The pH in the upper 0.6 m is not considered plant limiting, however, in the deeper horizons of the profile this has potential to reduce plant available nutrients. This soil unit is not likely to be affected by issues associated with salinity and chloride toxicity with EC and chloride well within appropriate bounds (Rayment and Lyons 2011). ESP values in conjunction with the Ca/Mg ratio indicate a very low risk of dispersion throughout the entire profile.

CEC values in the upper 0.6 m of the profile are all very low (CEC less than 6) indicating that the soil has a poor ability to retain nutrients (Hazelton and Murphy 2016). The CEC of soil is considered low with calcium, manganese and potassium below levels ideal for plant growth. Nutrient holding capacity and exchangeable cation content increase below this depth. The distribution of nutrients in the topsoil reflects an adequate balance of nutrients on the soil exchange with only potassium above the ideal proportion. This is not anticipated to influence the risk of dispersion of the soil (Hazelton and Murphy 2016).

Table 25: Surface soil (0–10 cm) properties of the Kei SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
12	25	62	1		2.31		2.4	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	477	< 10	0.7	< 0.2	< 1	30.6	13.8	1.52

The surface soil of this unit is predominantly comprised of sand-sized particles (62%) with 25% silt, 12% clay and 1% gravel which is a contributing factor of the very low CEC. The topsoil is non-sodic with a Ca/Mg ratio above 2. This, along with the moderate organic matter content of 2.4%, indicates this soil is not likely to disperse.

The low phosphorous and nitrate concentration of the soil suggest deficiency in these nutrients which may be limiting to plant growth (Hazelton and Murphy 2016). Both potassium and sulphate content are within acceptable bounds for plant growth. Excluding manganese and boron, all extractable metals are sufficiently concentrated in the soil with boron likely deficient (<0.5 mg/kg) and manganese content rated high (>10 mg/kg) which has potential to induce manganese toxicity in plants (Government of South Australia 2013).

4.4 Komati management unit

4.4.1 Soil unit description

Dark brown coloured soil unit displaying vertic properties. Soil textures predominantly grade from light to medium clays with calcareous segregations occurring within the deeper horizons. Vegetation associated with this unit includes *Eucalyptus papuana* and open grassland.



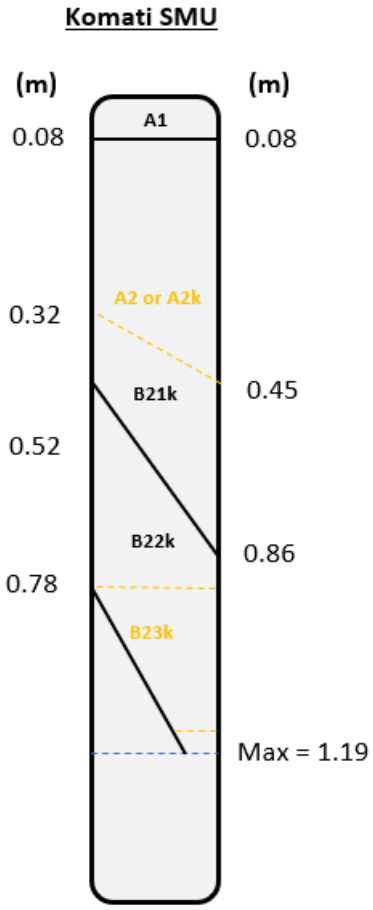
Figure 7: Komati SMU vegetation

Table 26: Key Komati SMU parameters

Parameter	Soil unit description
Profile site numbers	VP32, VP34, VP39
Observation site numbers	OP23, OP24, OP25, OP42, OP43, OP65
Landform	Plains
Australian soil classification	Brown Vertosol
Land system	Monteagle land system
Slope	0%
Geology	Qr–Qr–QLD
Vegetation	Dallachy's ghost gum (Eucalyptus papuana), grasses and shrubs
Runoff	Slow
Permeability	Slowly permeable
Drainage	Imperfectly to moderately well drained

Profile description—representative sites VP32 and VP39





The **surface soil** (A1) is black to a very dark brown (7.5YR2.5/1, 7.5YR3/3) sandy clay loam to light medium clay with a polyhedral structure of moderate strength. It has a field pH of 7-8.5, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2 or A2k) this horizon was not observed in all profiles of this SMU. It is a brown to very dark brown (7.5YR4/4, 10YR2/2) light medium to medium clay with a moderately strong polyhedral structure and a field pH of 8–8.5. Some profiles display a minor occurrence (< 10%) of calcareous segregations. Clear to gradual change to;

The **subsoil** (B21k, B22k, B23k) is separated into several B2 horizons depending on colour, however, all contain an abundance of calcareous segregations (20–50% of the horizon). Colours range from strong browns (7.5YR4/6, 7.5YR5/6) to browns and light browns 7.5YR4/4, 7.5YR6/4). Textures grade as medium clay with moderate strength lenticular to polyhedral structure. This horizon has a field pH of 8.5-9.

Chemical and physical analysis

Table 27: Chemical properties of the Komati SMU

Representative site: VP32								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.8	Neutral	0.011	Very low	< 10	2.4	Non-sodic	2.4
0.2–0.3	8.5	Moderately alkaline	0.142	Low	80	13	Sodic	7.8
0.5–0.6	9.5	Strongly alkaline	0.582	High	620	18.2	Strongly Sodic	8
0.8–0.9	9.5	Strongly alkaline	0.641	High	730	21.6	Strongly Sodic	7.6
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	7	Low	3.7	3	0.2	0.2	1.2	3
0.2–0.3	16.4	Moderate	4.3	10	< 0.2	2.1	0.4	3
0.5–0.6	15.3	Moderate	3	9.5	< 0.2	2.8	0.3	4
0.8–0.9	14.9	Moderate	2.1	9.6	< 0.2	3.2	0.2	4
Nutrient distribution in topsoil (%)			52.9%	42.9%	2.9%	2.9%		

The Komati SMU is predominantly a strongly alkaline unit with pH ranging from 6.8 (neutral) at the surface to 9.5 (very strongly alkaline) in the subsoil. The higher pH has the potential to severely reduce the availability of essential plant nutrients such as nitrogen and phosphorous (Hazelton and Murphy 2016). EC values indicate that salinity is low in the upper 0.3 m the profile. Below this depth EC increases to 0.582-0.641 dS/m which is considered high. Chloride concentration increases from an acceptable concentration in the topsoil (<80 mg/kg) to 730 mg/kg in the subsoil (Rayment and Lyons 2011). This increase in EC and chloride has the potential to induce chloride toxicity which can interfere with the osmotic capacity of plants.

CEC is regarded low in the surface soil (7 meq/100g) and increases to moderate levels (approximately 15 meq/100g) in deeper horizons (Hazelton and Murphy 2016). Only magnesium (>1.6 meq/100g) is present on the soil exchange at a suitable concentration. However, and particularly in the subsoil, magnesium concentration is disproportionately large relative to other cations. This contributes to a very low Ca/Mg ratio which increases the risk of dispersion of the soil. Both calcium (<5 meq/100g) and potassium (<0.5 meq/100g) are below ideal levels throughout the profile. The distribution of nutrients within the topsoil again, reflects the imbalance between calcium and magnesium while the presence of potassium and sodium on the exchange is considered appropriate and high respectively (Hazelton and Murphy 2016).

ESP values increase rapidly with depth indicating a high risk of dispersion from as shallow as 0.2 m below the surface. This risk of dispersion is further exacerbated by the very low Ca/Mg ratio discussed above. However, below the depth of 0.5 m, the Emerson class numbers indicate that the soil is not dispersive due to the presence of carbonate ($CaCO_3$) at this depth (Emerson 1967).

Table 28: Surface soil (0–10 cm) properties of the Komati SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
32	11	55	2		2.24		2.7	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	146	< 10	0.2	< 0.2	< 1	26.6	6.8	< 1

The surface soil of the Komati SMU is composed of a moderately high clay content (32%), with 55% sand, 11% silt and 2% gravel. It has a moderate polyhedral structure with cracking occurring at the surface. The topsoil is non-sodic, however, the Emerson Class Number (3) in conjunction with a Ca/Mg ratio of 1.2 indicate that disturbance may give rise to dispersion. The particle size distribution and organic matter content (2.7%) suggest good stability of the surface horizon.

Extractable nutrient content for the surface soil is considered poor with nitrate (0.2 mg/kg), potassium (146 mg/kg) and phosphorous (<5 mg/kg) all below suitable levels for plant life and sulphate (<10 mg/kg) considered marginal (Hazelton and Murphy 2016). Of the extractable metals detected, only manganese (6.8 mg/kg) and iron (26.6 mg/kg) are present at adequate levels for plant life. Copper (<1 mg/kg), zinc (<1 mg/kg) and boron (<0.2 mg/kg) are all below concentrations suitable for plant growth (Government of South Australia 2013).

4.5 Limpopo management unit

4.5.1 Soil unit description

The Limpopo unit is a brown texture-contrast soil. Soil textures predominantly grade from sands to clay sands in the surface soils to light clays in deeper horizons. Vegetation associated with this unit includes *Eucalyptus populnea* and *Eucalyptus crebra*.

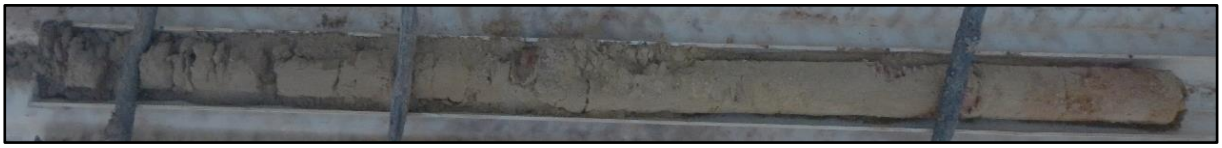


Figure 8: Limpopo SMU vegetation

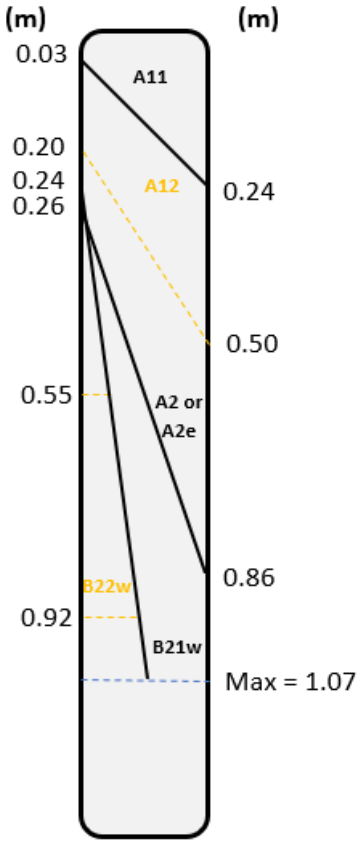
Table 29: Key Limpopo SMU parameters

Parameter	Soil Unit Description
Profile site numbers	VP1, VP2, VP7, VP9, VP13, VP15, VP17, VP18, VP22, VP24, VP28, VP36, VP37
Observation site numbers	OP6, OP8, OP10, OP11, OP18, OP19, OP22, OP23, OP26, OP32, OP33, OP39, OP41, OP45, OP46, OP47, OP48, OP49, OP55, OP56, OP57
Landform	Low rises to plains
Australian soil classification	Brown Sodosol
Land system	Cotherstone land system
Slope	< 3%
Geology	Back Creek Group
Vegetation	Poplar box (Eucalyptus populnea), narrow-leaved ironbark (Eucalyptus crebra),
Runoff	Slow
Permeability	Slow to moderately permeable
Drainage	Well drained

Profile description—representative sites VP7, VP15, VP17, VP18, VP22



Limpopo SMU



The **surface soil** (A11, A12) is brown to a dark brown (7.5YR4/4, 7.5YR3/3) sand to loamy sand with a loose structure. It has a field pH that ranges between 5 and 6, demonstrating a clear to gradual change to;

The **lower surface soil** (A2 or A2e) is a brown to greyish brown (7.5YR4/4, 10YR5/2) with some profiles within this soil unit displaying bleaching in this horizon (A2e). Predominant textures observed in this horizon range from sandy loams to sandy clay loams with a loose to weak polyhedral structure and a field pH of 6. Clear to gradual change to;

The **subsoil** (B21w, B22w) includes dark yellowish brown to a dark greyish brown (10YR4/4, 10YR4/2) clayey or sandy loams and light clays clay with weak to moderate strength polyhedral structure. Mottling was often observed in this horizon with colours ranging between red, orange and yellow. This horizon has a field pH of 5.5-7.

Chemical and physical analysis

Table 30: Chemical properties of the Limpopo SMU

Representative site: VP17								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	5.5	Moderately Acid	0.004	Very low	< 10	1	Non-sodic	1.6
0.2–0.3	5.5	Moderately Acid	0.005	Very low	< 10	2.6	Non-sodic	2.4
0.5–0.6	5.8	Moderately Acid	0.035	Very low	50	12.1	Sodic	3.8
0.8–0.9	5.6	Moderately Acid	0.154	Low	110	21.5	Strongly Sodic	8.6
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	2.3	Very Low	0.8	0.5	0.4	0.1	1.6	3
0.2–0.3	1.8	Very Low	0.1	0.6	0.3	< 0.1	0.2	4
0.5–0.6	2.7	Very Low	< 0.1	1.8	0.2	0.3	< 0.1	4
0.8–0.9	7.3	Low	< 0.1	5.4	0.2	1.5	< 0.1	4
Nutrient distribution in topsoil (%)			34.78%	21.74%	17.39%	4.35%		

The upper 0.3 m of the Limpopo SMU is strongly acidic with a pH of 5.5, increasing only slightly beyond this depth. This pH is not within the bounds best suited to plant growth (Hazelton and Murphy 2016). EC and chloride concentration across the profile indicate salinity is very low with EC values ranging from 0.004 dS/m in the topsoil to 0.154 dS/m in the subsoil. Chloride concentration reflects this ranging from <10 mg/kg in the topsoil and increasing to 110 mg/kg in the subsoil which is below the limits of toxicity (Rayment and Lyons 2011).

CEC is considered very low (CEC < 6 meq/100g) across the majority of the profile increasing only slightly with depth (Hazelton and Murphy 2016). This is likely attributed to the sandy texture of the upper horizons. Potassium and calcium are present at very low concentrations throughout the soil profile with potassium consistently below 0.5 meq/100g and calcium consistently below 5 meq/100g). Although not as severe, manganese concentration is also regarded as low in the topsoil increasing to a more appropriate range in the subsoil. The Ca/Mg ratio reflects this with the ratio ranging from 1.6 in the topsoil to <0.1 in the subsoil; indicating calcium is deficient (Hazelton and Murphy 2016).

ESP values that range between 1% to 2.6% indicate the topsoil is not likely to be at risk of dispersion; however, ESP increases with depth to 21.5% in the subsoil indicating the subsoil is susceptible to dispersion. This is further supported by the very low Ca/Mg ratio discussed above although Emerson class numbers do not support this.

Table 31: Surface soil (0–10 cm) properties of the Limpopo SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
10	8	79	3		2.48		1.8	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	335	< 10	0.2	< 0.2	< 1	82.1	4.64	< 1

The particle size distribution reveals the A11 horizon of this SMU is strongly dominated by sand (79%) with silt and clay size particles comprising 8% and 10% of this horizon respectively. Organic matter content is regarded as moderate, contributing to average structural stability and low cohesiveness and suggesting the soil unit may be at a greater risk of erosion-induced movement.

Extractable nutrients are considered poorly balanced with both phosphorus (<5 mg/kg) and nitrate (0.2 mg/kg) concentration well below appropriate bounds for plant growth (Hazelton and Murphy 2016). Sulphate (<10 mg/kg) presence in the topsoil is considered marginal and only potassium (335 mg/kg) content is considered suitable. Extractable metals were mostly found below suitable concentrations with copper and zinc detected at <1 mg/kg and boron at <0.2 mg/kg. Only iron (82.1 mg/kg) and manganese (4.64 mg/kg) were present at suitable concentrations (Hazelton and Murphy 2016).

4.6 Orange management unit

4.6.1 Soil unit description

Dark cracking clays associated with the flat grassy plains of the mid-eastern edge of the study area. The predominant textures of soils within this unit range from light clays in surface soils to light medium clays in deeper horizons. Vegetation associated with this unit is predominantly open grassland.



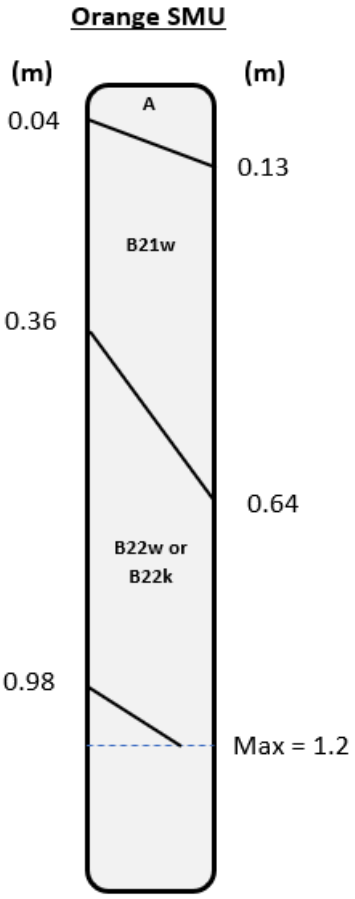
Figure 9: Orange SMU vegetation

Table 32: Key Orange SMU parameters

Parameter	Soil unit description
Profile site numbers	VP31, VP35, VP40
Observation site numbers	OP21, OP24, OP25, OP44, OP60, OP61, OP62, OP65,
Landform	Plains
Australian soil classification	Grey Vertosol
Land system	Monteagle land system
Slope	0%
Geology	Qr–Qr–QLD
Vegetation	Open grassland
Runoff	Slow
Permeability	Slowly permeable
Drainage	Imperfectly to moderately well drained

Profile description—representative sites VP31, VP35, VP40





The **surface soil** (A) is black (10YR2/1, 2.5Y2.5/1) light clay with moderate lenticular structure. It has a field pH of 6–7, demonstrating an abrupt change to;

The **upper subsoil** (B21w) is a black to a very dark grey (10YR2.5/1, 2.5Y3/1) light medium clay with strong lenticular structure and a field pH of 7.5–8.5. Clear to diffuse change to;

The **lower subsoil** (B22w/B22k) is a very dark grey (10YR3/1, 2.5Y3/1) light medium to medium clay with strong lenticular structure. This horizon has a field pH of 8.5–9.

Chemical and physical analysis

Table 33: Chemical properties of the Orange SMU

Representative site: VP31								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	8.1	Moderately alkaline	0.135	Low	10	1.4	Non-sodic	5.5
0.2–0.3	8.4	Moderately alkaline	0.054	Very low	40	7	Sodic	12.2
0.5–0.6	9.5	Strongly alkaline	0.321	Medium	180	16.9	Strongly Sodic	13.1
0.8–0.9	9.6	Strongly alkaline	0.575	High	540	20.8	Strongly Sodic	12.9
Depth	**CEC**		**Exchangeable Cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	15.5	Moderate	8.8	6.2	0.3	0.2	1.4	4
0.2–0.3	21	Moderate	9.4	10.1	<0.2	1.5	0.9	3
0.5–0.6	26.6	High	5.7	16.4	<0.2	4.5	0.3	3
0.8–0.9	27.7	High	4.3	17.7	<0.2	5.8	0.2	4
Nutrient distribution in topsoil (%)			56.8%	40.0%	1.9%	1.3%		

The Orange SMU is characterised by high pH ranging from 8.1 in the topsoil to 9.6 in the subsoil, this is beyond the pH range at which all plant nutrients are available and thus not ideal for plant growth. EC values indicate low salinity in the upper 0.3 m of the profile and increases from what is considered medium to high at depth. This has potential to compromise the health of sensitive and moderately tolerant plant species. Chloride concentrations increase from 10 mg/kg in the topsoil to 540 mg/kg in the subsoil which is considered within acceptable limits (Rayment and Lyons 2011).

CEC increases with depth, ranging from moderate (15.5 meq/100g) in the topsoil, to high (27.7 meq/100g) in the subsoil layer. Calcium is present in the topsoil layer at a concentration of 8.8 meq/100g and decreases to 4.3 meq/100g. Magnesium concentration increases with depth from 6.2 meq/100g at the surface to 17.7 meq/100g. While the absolute concentration of calcium and magnesium are at suitable levels for plant growth, magnesium concentration is considered disproportionately high relative to calcium. This is reflected in the Ca/Mg ratio that decreases from 1.4 (calcium low) in the topsoil to 0.2 (calcium deficient) in the subsoil. In the topsoil potassium content is below the ideal concentration (0.3 meq/100mg), this decreases further with depth to <0.2 meq/100g in the subsoil. The distribution of nutrients within the topsoil shows magnesium occupying a large proportion of the exchange while the proportion of calcium on the exchange is considered lower than ideal. Both potassium and sodium are at appropriate levels (Hazelton and Murphy 2016).

ESP values indicate the upper 0.1 m is non-sodic (1.4%), however, ESP increases beyond this depth to 20.8% in the subsoil. These ESP values in conjunction with the Ca/Mg ratio (discussed above) suggest that soil below 0.2 m in depth is prone to dispersion. In the deeper horizons (below 0.8 m), Emerson class numbers indicate this soil is not likely to disperse due to the presence of carbonate (Emerson 1967).

Table 34: Surface soil (0–10cm) properties of the Orange SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
28	19	51	2		2.13		3.6	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	182	< 10	0.2	< 0.2	< 1	27	24.5	<1

The surface soil of the Orange SMU is composed of 51% sand, 28% clay, 19% silt and 2% gravel. It has a moderate lenticular structure with a cracking, self-mulching surface. This particle size distribution in conjunction with a high organic matter content (3.5%) will contribute to good structural stability of the topsoil. ESP values suggest the topsoil is not considered to be at risk of dispersion which is supported by the Emerson Class Number of 4.

Extractable nutrients are mostly considered to be low with phosphorous (<5 mg/kg), sulphate (<10 mg/kg) and nitrate (0.2 mg/kg) all below suitable concentrations for plant life and only potassium (182 mg/kg) above the critical concentration (Hazelton and Murphy 2016). The majority of extractable metals are present at low concentrations with boron <0.2 mg/kg and both copper and zinc at <1 mg/kg. Iron (27 mg/kg) is considered adequate; however, manganese (24.5 mg/kg) is regarded as high potentially inducing manganese toxicity in plants.

4.7 Sabie management unit

4.7.1 Soil unit description

A dark-coloured texture-contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display red to orange mottles. Vegetation associated with this unit is dominated by *Eucalyptus crebra.*



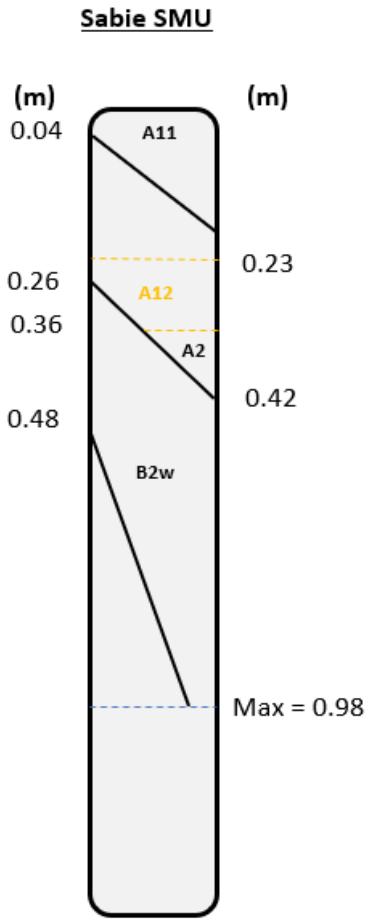
Figure 10: Sabie SMU vegetation

Table 35: Key Sabie SMU parameters

Parameter	Soil unit description
Profile site numbers	VP10, VP11, VP12, VP14, VP20, VP21,
Observation site numbers	OP10, OP19, OP27, OP30, OP32, OP33, OP35, OP41
Landform	Rises and Plains
Australian soil classification	Red Sodosol
Land system	Carborough land system
Slope	<10%
Geology	Back creek group
Vegetation	Narrow-leaved ironbark (Eucalyptus crebra), Bloodwood (Corymbia erythrophloia)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderate to well drained

Profile description—representative sites VP10, VP11, VP12, VP20





The **surface soil** (A11/A12) is black to very dark brown (2.5YR2.5/1, 7.5YR2.3/3) sand to loamy sand with loose to very weak platy structure. It has a field pH of 5–7, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2) is a brown to a dark reddish brown (7.5YR4/4, 5YR3/3) clayey sand to sandy clay loam with loose or very weak polyhedral structure and a field pH of 5–6. Clear to gradual change to;

The **lower subsoil** (B2w) is a dark reddish brown to dusky red (5YR3/3, 2.5Y3/2) clayey loam to medium clay with moderate polyhedral structure. This horizon has a field pH of 5–6.

Chemical and physical analysis

Table 36: Chemical properties of the Sabie SMU

Representative site: VP10								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	4.6	Strongly acid	0.128	Low	50	3.2	Non-sodic	2
0.2–0.3	4.9	Strongly acid	0.025	Very low	10	9.2	Sodic	5
0.5–0.6	5.9	Moderately acid	0.02	Very low	20	8.4	Sodic	11.6
0.8–0.9	6	Slightly acid	0.108	Low	140	15.4	Strongly sodic	9.9
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	3.7	Very Low	1.3	0.6	0.5	0.1	2.2	3
0.2–0.3	3.5	Very Low	0.1	0.5	0.3	0.1	0.2	3
0.5–0.6	8.1	Low	< 0.1	5.6	0.6	0.6	< 0.1	3
0.8–0.9	9.6	Low	< 0.1	7.4	0.4	1.4	< 0.1	2
Nutrient distribution in topsoil (%)			35.1%	16.2%	13.5%	2.7%		

The surface soil of the Sabie SMU is strongly acidic (pH < 5) to a depth of 0.3 m which has potential to reduce plant available nutrients and induce aluminium toxicity. Beyond this depth pH increases to 6 which is suitable for plant life. EC is low throughout the profile, with EC values varying between 0.02 dS/m to 0.128 dS/m with no obvious trend associated with depth. The chloride concentration reflects the low EC with chloride consistently below 300 mg/kg.

CEC values are considered very low in the topsoil (3.7 meq/100g) and increase with depth to 9.6 meq/100g in the subsoil. Throughout the profile calcium is below ideal levels and decreases from 1.3 meq/100g to <0.1 meq/100g in the subsoil. Topsoil magnesium concentration is also below ideal levels at 0.6 meq/100g, however, with depth this increases to an acceptable concentration. Overall potassium concentration is sufficient for plant life as it varies within close-proximity of the critical concentration of 0.5 meq/100g. Nutrients in the topsoil are poorly distributed with the proportion of the exchange occupied by calcium considered below ideal while both sodium and potassium in particular are considered high (Hazelton and Murphy 2016).

ESP increases from 3.2% in the topsoil to 15.4% in the subsoil. This information in conjunction with the Ca/Mg ratio indicates the risk of dispersion increases substantially below 0.2m. The Emerson class numbers of 3 and 2 support this (Emerson 1967).

Table 37: Surface soil (0–10cm) properties of the Sabie SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
12	10	75	3		2.29		4.1	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	446	30	35.8	0.3	< 1	226	8	< 1

The A11/A12 horizon of this SMU is dominated by sand-sized particles (75%) with 12% clay, 10% silt and 3% gravel. It has a loose single grain to weak platy structure with high organic matter content (4.1%). This information in conjunction with the ESP and Ca/Mg ratio of this topsoil layer suggest the topsoil is not prone to dispersion if undisturbed.

Apart from phosphorous (<5 mg/kg), all extractable nutrients are present in the topsoil at concentrations suitable for plant life (Hazelton and Murphy 2016). Of the extractable metals, only manganese (8 mg/kg) is detected at a suitable concentration. Both copper (<1 mg/kg) and zinc (<1 mg/kg) are low for plant growth and iron concentration is found to be very high with the capacity to induce iron toxicity in plants.

4.8 Zambezi management unit

4.8.1 Soil unit description

A predominantly grey coloured texture-contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display diffuse orange to yellow mottles. Vegetation associated with this unit is dominated by *Eucalyptus populnea.*



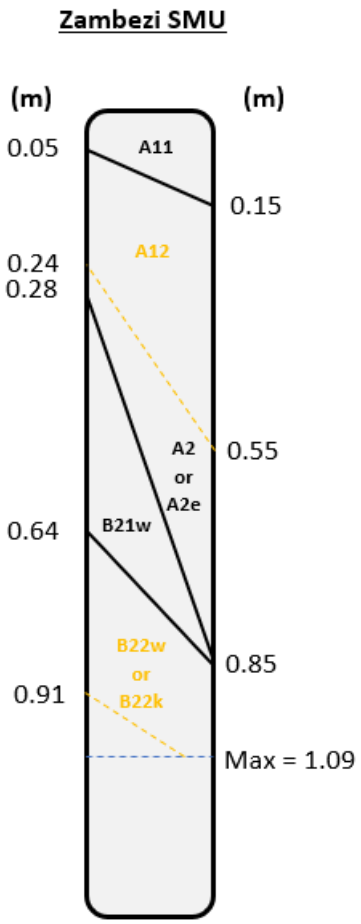
Figure 11: Zambezi SMU vegetation

Table 38: Key Zambezi SMU parameters

Parameter	Soil unit description
Profile site numbers	VP16, VP19, VP23, VP25, VP29, VP33, VP38, VP41. VP42
Observation site numbers	OP18, OP28, OP29, OP32, OP34, OP35, OP37, OP39, OP40, OP41, OP43, OP45, OP47, OP55, OP56, OP57, OP58
Landform	Plains
Australian soil classification	Grey Sodosol
Land system	Cotherstone land system
Slope	<3%
Geology	TQa–Tqa–QLD
Vegetation	Poplar-box (*Eucalyptus populnea*), Narrow-leaved ironbark (*Eucalyptus crebra*)
Runoff	Slow
Permeability	Moderately permeable
Drainage	Moderately well drained

Profile description—representative sites VP25, VP29





The **surface soil** (A11/A12) is dark brown to a very dark greyish brown (7.5YR2.2.5/5, 10YR3/2) coarse grained loamy sand with loose to very weak platy structure. It has a field pH of 5.5–7, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2/A2e) is a brown to greyish brown (7.5YR5/4, 10YR5/2) loamy sand with some profiles displaying this as a bleached horizon with loose single-grained structure and a field pH of 6–7.5. Clear to abrupt change to;

The **lower subsoil** (B2w) is a light grey to grey (10YR7/2, 7.5YR6/1) clayey loam sand to silty clay loam with moderate polyhedral structure. This horizon has a field pH of 7–9.

Chemical and physical analysis

Table 39: Chemical properties of the Zambezi SMU

Representative site: VP25								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.4	Slightly acid	0.018	Very low	< 10	0.6	Non-sodic	1.8
0.2–0.3	6.7	Slightly acid	0.005	Very low	< 10	0.1	Non-sodic	2.8
0.5–0.6	7.8	Slightly alkaline	0.059	Very low	40	18.5	Strongly sodic	7.2
0.8–0.9	9	Strongly alkaline	0.174	Low	160	23.3	Strongly sodic	9.1
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	3.4	Very low	2.3	0.8	0.4	0.1	2.9	3
0.2–0.3	1.8	Very low	1.3	0.4	0.1	0.1	3.2	4
0.5–0.6	5.1	Very low	1.1	3.1	< 0.2	0.9	0.4	2
0.8–0.9	10	Low	1.7	5.7	< 0.2	2.3	0.3	2
Nutrient distribution in topsoil (%)			67.7%	23.5%	11.8%	2.9%		

The Zambezi SMU has a slightly acidic (6.4–6.7) pH in the upper 0.3 m of the profile which is not considered plant limiting. However, beyond this depth pH rises to very strongly alkaline (9), which is beyond the suitable pH range for plants (Hazelton and Murphy 2016). EC values and chloride concentration are both well below appropriate limits. EC values range from 0.0018 dS/m in the topsoil to 0.174 dS/m in the subsoil. The chloride concentration is consistently below 300 mg/kg throughout the profile.

CEC is predominantly regarded as very low (<6 meq/100g) with a slight increase in the deepest observed horizon. This is reflected in the low concentrations of extractable cations with calcium and potassium consistently below 5 meq/100g and 0.5 meq/100g respectively. Topsoil magnesium concentrations are considered low (<1.6 meq/100g) but increase to concentrations suitable for plant life with depth. Within the topsoil, the proportion of the exchange occupied by calcium is considered appropriate, however the presence of magnesium, potassium and sodium on the exchange is above ideal (Hazelton and Murphy 2016).

The upper 0.3 m of the profile is non-sodic with ESP values well below 6%. Below this point ESP values increase to 23.2% indicating high potential for dispersion. This is supported by the very low Ca/Mg ratios and an Emerson Class Number of 2 in the subsoil (Emerson 1967).

Table 40: Surface soil (0–10cm) properties of the Zambezi SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Coarse sand**	**Gravel**					
9	14	77	< 1		2.43		2	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	311	< 10	2.6	< 2	< 1	60.7	8.92	<1

The surface horizon (A11) of the Zambezi SMU is dominated by sand (77%) with 14% silt, 9% clay and <1% gravel and has a loose to weak platy structure. This, in conjunction with the low organic matter content (2%) suggests poor structural stability of topsoil layer. The topsoil is non-sodic with very low Ca/Mg ratio indicating the topsoil is not dispersive if undisturbed.

Nutrient levels in the topsoil layer are generally poor, with nitrate (2.6 mg/kg), sulphate (<10 mg/kg) and phosphorous (<5 mg/kg) below suitable levels and potassium (311 mg/kg) above the critical concentration indicating potassium is not deficient. Extractable metals vary in suitability with iron (60.7 mg/kg), manganese (8.92 mg/kg), and boron (<2 mg/kg) present in suitable concentrations and both copper (<1 mg/kg) and zinc (<1 mg/kg) at lower than preferred levels for plant growth (Hazelton and Murphy 2016).

5 Strategic Cropping Land Assessment

The RPI Act aims to identify areas of Queensland that are of regional interest because they contribute, or are likely to contribute, to Queensland's economic, social and environmental prosperity. The RPI Act also aims to give effect to the policies about matters of State interest stated in regional plans, and to effectively manage the impact of resource activities on the areas of regional interest.

Areas of regional interest that the RPI Act aims to protect are classified as:

- living areas in regional communities (Priority Living Areas);
- high-quality agricultural areas from dislocation (Priority Agricultural Areas);
- strategic cropping areas; and
- regionally important environmental areas (Strategic Environmental Areas).

Detailed descriptions of what constitutes each type of area of regional interest are provided in Sections 8 to 11 of the RPI Act as well as the Regional Planning Interests Regulation 2014 (RPI regulation). The RPI Act and RPI Regulation seek to strike an appropriate balance between protecting priority land uses and delivering a diverse and prosperous economic future for our regions.

There are no areas of regional interest within the study area. The nearest mapped strategic cropping areas are located between 13–15 km to the north-west, south-west and south-east of the study area.

6 Land Suitability Assessment

Land suitability refers to the adequacy of land for a defined use. Land suitability assessment considers environmental factors including climate, soils, geology, geomorphology, erosion, topography and the effects of past land uses. The classification does not always represent the current land use. Rather, it indicates the potential of the land to be used for specific agricultural activities. The aim of this land suitability assessment is to evaluate the suitability of the Project area for agricultural land uses including cattle grazing and dryland cropping, prior to the development of the mine.

The assessment for land suitability (cattle grazing and rainfed broadacre cropping) has been carried out in accordance with the methodologies described in:

- DSITI and DNRM (2015). *Guidelines for Agricultural Land Evaluation in Queensland* (2nd edition); and
- DME (1995). *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland—Land suitability Assessment Techniques*.

The five land suitability classes used for assessing land are defined in Table 41. Land is considered less suitable as the severity of limitations for a land use increase. The land suitability class reflects the score of the most limiting attribute for a given SMU. An increase in limitations may reflect either:

- reduced potential for production;
- increased inputs to achieve an acceptable level of production;
- increased inputs to prepare the land for successful production; and/or
- increased inputs required to prevent land degradation.

Table 41: Agricultural and conservation land classes

Class	Agricultural description	Conservation description
Class 1	**Suitable land with negligible limitations**—this is highly productive land requiring only simple management practices to maintain economic production.	Areas well suited for conservation uses must possess significant conservation benefits in the pre-mining environment and be capable of being returned to that use post-mining.
Class 2	**Suitable land with minor limitations** which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.	Areas suited to conservation use in that a significant component of the pre-mining conservation values can be restored post-mining. There will however be some loss in conservation values where soil terrain or hydrological post-mining conditions may inhibit the full replication of the pre-mining values.
Class 3	**Suitable land with moderate limitations** which either further lower production or require more than those management practices of class 2 land to maintain economic production.	These lands contain significant conservation values pre-mining, however restoration of all of these values may not be feasible. These areas could, however, be restored to a form of conservation use which provides alternative conservation benefits.
Class 4	Marginal land, which is presently considered unsuitable due to severe limitations. The long-term significance of these limitations on the proposed land use is unknown or not quantified. The use of this land is dependent upon undertaking additional studies to determine whether the effect of the limitation(s) can be reduced to achieve sustained economic production.	These lands contain limited conservation value pre-mining and/or are incapable of being effectively restored post-mining to any alternative conservation use which provides similar benefits. The area could however be restored to provide a stable form of use which does not impact on surrounding conservation values.
Class 5	Unsuitable land with extreme limitations that preclude its use.	These lands contain no significant conservation values.

6.1 Cattle grazing

Limitations for the assessment of grazing land suitability on improved pastures as outlined in the Land Suitability Assessment Technique (QDME 1995) Guidelines (Table 2.2) are:

- water availability;
- nutrient deficiency;
- soil physical factors;
- salinity;
- rockiness;
- micro relief;
- pH;
- ESP;
- wetness;
- topography;
- water erosion;
- flooding; and
- vegetation.

Numerous parameters outlined in this assessment require determination of the 'rootzone'. The rootzone is the depth to hard or weathered rock, or the depth to a significant salt bulge within the soil profile. Where these limitations are not encountered within the sampling depth, a value of 0.6 m can be assumed as the rootzone as described in the QDME guidelines (1995).

For cattle grazing, **Class 1** and **Class 2** land is considered suitable for grazing improved pastures with maximum grazing productivity achieved in most seasons. **Class 3** land is considered suitable for grazing improved pastures however, it is less productive than **Classes 1** and **2**. **Class 4** land is categorised as marginal for grazing improved pastures although it is largely considered suitable for grazing native pastures of variable quality. **Class 5** land is unsuitable for any form of pasture improvement and is limited to low productivity grazing of native pastures. Due to the poor soil quality **Class 5** land may require destocking in poor seasons.

Each of the limitations listed above is assessed in the following subsections on the basis of Table 2.2 of the QDME guidelines (1995).

6.1.1 Water availability

The availability of water in soils is vital for both plants and soil organisms as they require water to survive. The PAWC cut-off levels for each of the land suitability classes for beef cattle grazing are as follows:

- **Class 1:** > 125 mm
- **Class 2:** 100–125 mm
- **Class 3:** 75–100 mm
- **Class 4:** 50–75 mm
- **Class 5:** < 50 mm

These cut-off levels are not based on a specific species of pasture, but on pasture as a general land use. The soils are assessed on the depth to weathered rock, or other root inhibiting factors such as a salt bulge or significant sodicity. Table 42 provides the outcomes of the land suitability class assessment on the basis of plant available water capacity.

Table 42: Land suitability for cattle grazing based on PAWC

Soil management unit	Limiting features	PAWC (mm)	Land suitability class
Crocodile	Shallow sands and sandy loams ≤ 45 cm deep	≤ 50 mm	5
Fish	Sands and sandy loams 45–90 cm deep	50–75 mm	4
Kei	Sands and sandy loams > 90 cm deep	75–100 mm	3
Komati	Cracking clays: alkaline to neutral pH throughout and 60– 90 cm depth to ESP ≥ 15	100–125 mm	2
Limpopo	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	3
Orange	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	2
Sabie	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	3
Zambezi	Duplex soils with a sodic subsoil (ESP 6–14) becoming strongly sodic (ESP ≥ 15) within 60 cm of surface	50–75 mm	4

6.1.2 Nutrient deficiency

The nutrient status of each SMU identified has been assessed and the results are presented in Table 43. Note that bicarbonate phosphorus was only analysed within the topsoil layer (0–10 cm). Soil nutrients are vital for plant and animal growth and metabolism.

Table 43: Land suitability for cattle grazing based on nutrient status

Soil management unit	Limiting features	Land suitability class
Crocodile	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P 5–10 ppm,	4
Fish	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Kei	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Komati	Other soils with bicarbonate P 5–10 ppm	3
Limpopo	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Orange	Other soils with bicarbonate P 5–10 ppm	3
Sabie	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Zambezi	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4

6.1.3 Soil physical factors

Soil physical factors for each SMU identified have been assessed with results presented in Table 44. The physical condition of soils plays a direct role with seed germination and emergence. Adverse conditions such as hard-setting or crusting of surface soils reduces plant establishment through creating a barrier, reducing seed soil contact.

Table 44: Land suitability for cattle grazing based on soil physical factors

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a loose, soft or firm surface when dry	1
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Sabie	Rigid soils with a hard-setting surface when dry	3
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.1.4 Salinity

Land suitability class for each SMU based on salinity has been assessed with the results provided in Table 45. Given salinity can inhibit plant growth, the highest EC recorded is considered the most limiting factor and dictates the rating given to each SMU. Significant levels of salinity present in the rootzone can negatively impact plant growth and production.

Table 45: Land suitability for cattle grazing based on salinity

Soil management unit	Limiting features	Land suitability class
Crocodile	Rootzone EC < 0.15 mS/cm	1
Fish	Rootzone EC < 0.15 mS/cm	1
Kei	Rootzone EC < 0.15 mS/cm	1
Komati	Rootzone EC 0.3–0.9 mS/cm	3
Limpopo	Rootzone EC < 0.15 mS/cm	1
Orange	Rootzone EC 0.15–0.3 mS/cm2	2
Sabie	Rootzone EC < 0.15 mS/cm	1
Zambezi	Rootzone EC < 0.15 mS/cm	1

Notes: The 0.5–0.6m Orange horizon marginally exceeds the 0.3 threshold but given the EC values for adjacent upper horizons it is considered sufficiently close to the threshold to warrant the classification provided.

6.1.5 Rockiness

The land suitability for each SMU based on rockiness was assessed with results presented in Table 46. The impacts of rockiness are more extreme for cropping than for grazing. With respect to grazing, rock outcrops reduce the area available to grow pasture, indirectly impacting the carrying capacity of the land.

Table 46: Land suitability cattle grazing based on rockiness

Soil management unit	Limiting features	Land suitability class
Crocodile	20–50% surface cobble (6–20 cm diameter) and rock outcrop	3
Fish	< 10 course surface gravel (> 6 cm diameter)	1
Kei	< 10 course surface gravel (> 6 cm diameter)	1
Komati	< 10 course surface gravel (> 6 cm diameter)	1
Limpopo	< 10 course surface gravel (> 6 cm diameter)	1
Orange	< 10 course surface gravel (> 6 cm diameter)	1
Sabie	< 10 course surface gravel (> 6 cm diameter)	1
Zambezi	< 10 course surface gravel (> 6 cm diameter)	1

6.1.6 Microrelief

The microrelief for each SMU identified has been assessed with results presented in Table 47. Microrelief refers to local relief (up to several metres) around the plane of the land (National Committee on Soil and Terrain 2009). Impacts of microrelief on the suitability of land for cattle grazing are only experienced when soil is severely melonholed. Ponding of water in the depressions can reduce pasture yield, indirectly impacting the land's carrying capacity.

Table 47: Land suitability for cattle grazing based on microrelief

Soil management unit	Limiting features	Land suitability class
Crocodile	Melonholes cover <20% surface area	1
Fish	Melonholes cover <20% surface area	1
Kei	Melonholes cover <20% surface area	1
Komati	Melonholes cover <20% surface area	1
Limpopo	Melonholes cover <20% surface area	1
Orange	Melonholes cover <20% surface area	1
Sabie	Melonholes cover <20% surface area	1
Zambezi	Melonholes cover <20% surface area	1

6.1.7 pH

The land suitability class for pH has been assessed with results presented in Table 48. Soil pH determines the availability of nutrients for plant intake. Where a soil material is strongly acidic, aluminium and manganese toxicity may limit root growth and plant productivity. Were an improved pasture post-mining land use to be targeted, there may be a need to for ameliorants to correct soil pH and increase nutrient availability.

Table 48: Land suitability for cattle grazing based on pH

Soil management unit	Limiting features	Land suitability class
Crocodile	pH 5.0–5.6	2
Fish	pH 5.0–5.6	2
Kei	pH 6.6–8.0	2
Komati	pH 6.6–8.0	2
Limpopo	pH 5.0–5.6	2
Orange	pH 8.0–9.0	3
Sabie	pH 4.5–5.0	3
Zambezi	pH 6.6–8.0	2

6.1.8 Exchangeable sodium percentage (ESP)

The ESP of each SMU identified has been assessed with results presented in Table 49. ESP is used to determine the erosion potential of soils. The land suitability class identified for each SMU based on ESP in the upper 100 mm of soil.

Table 49: Land suitability for cattle grazing based on ESP

Soil management unit	Limiting features	Land suitability class
Crocodile	ESP < 5%	1
Fish	ESP 5–10%	2
Kei	ESP < 5%	1
Komati	ESP < 5%	1
Limpopo	ESP < 5%	1
Orange	ESP < 5%	1
Sabie	ESP < 5%	1
Zambezi	ESP < 5%	1

6.1.9 Wetness

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 50. The wetness limitation refers to any excess water both in and on the soil profile. The adverse effects of excess water include reducing plant growth, impeding oxygen supply to plant roots (possibly leading to denitrification) and increased risk of plant disease.

Table 50: Land suitability for cattle grazing based on wetness

Soil management unit	Limiting features	Land suitability class
Crocodile	Undulating terrain or elevated plains	1
Fish	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	2
Kei	Low-lying level plains	2
Komati	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	2
Limpopo	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	2
Orange	Low-lying level plains	2
Sabie	Undulating terrain or elevated plains	1
Zambezi	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	2

6.1.10 Water erosion

The land suitability class identified for each SMU based on water erosion has been assessed with the results presented in Table 51. Erosion of topsoil reduces the productivity of the land through the loss of key nutrients in the soil's upper horizons.

Table 51: Land suitability for cattle grazing based on water erosion

Soil management unit	Limiting features	Land suitability class
Crocodile	Slopes 3–12% on non-sodic rigid soils	2
Fish	Slopes < 3% on non-sodic soils	1
Kei	Slopes < 3% on non-sodic soils	1
Komati	Slopes < 3% on non-sodic soils	1
Limpopo	Slopes < 3% on non-sodic soils	1
Orange	Slopes < 3% on non-sodic soils	1
Sabie	Slopes < 3% on non-sodic soils	1
Zambezi	Slopes < 3% on non-sodic soils	1

6.1.11 Flooding

The land suitability class identified for each SMU based on flooding risk has been assessed with results presented in Table 52. Flooding may result in plant death or reduced growth. In severe cases where land is inundated for a prolonged period stock loss and loss of grazing production may also occur.

Table 52: Land suitability for cattle grazing based on flooding

Soil management unit	Limiting features	Land suitability class
Crocodile	No flooding	1
Fish	No flooding	1
Kei	No flooding	1
Komati	Periodic flooding	2
Limpopo	No flooding	1
Orange	Periodic flooding	2
Sabie	No flooding	1
Zambezi	Periodic flooding	2

6.1.12 Vegetation regrowth (management limitation)

The land suitability class identified for each SMU based on vegetation regrowth has been assessed with results presented in Table 53. Vegetation communities may contain poisonous species or woody weeds that will limit the productivity of grazing pastures to varying degrees and increase the need for land management. The density of tree species and presence of a woody shrub layer may also limit the carrying capacity of the land.

Table 53: Land suitability for cattle grazing based on vegetation

Soil management unit	Limiting features	Land suitability class
Crocodile	Bloodwood and ironbark open woodland	1
Fish	Acacia scrub without melonholes	1
Kei	Acacia scrub without melonholes	1
Komati	Box woodlands without wattle understorey	2
Limpopo	Box and ironbark woodlands without wattle understorey	2
Orange	Grasslands	1
Sabie	Bloodwood and ironbark open woodlands	1
Zambezi	Box and ironbark woodlands without wattle understorey	2

6.1.13 Summary of land suitability for cattle grazing

Table 54 provides a summary of the assessed land suitability limitations for a beef cattle grazing land use.

In the study area, the suitability of land for cattle grazing is mostly limited by pH controlled nutrient deficiency and water availability.

Unsuitable pH conditions can greatly reduce nutrient levels in the soil. This has potential to impact livestock production through a reduction in pasture growth and the nutrient value of pasture species. Additionally, water availability can also compromise pasture growth by inducing water stress in pasture species and preventing the mobilisation of nutrients in the root zone.

While no Class 1 or Class 2 land was identified for the study area, examination of the land suitability limitations for cattle grazing (Table 54) indicates that 734 ha is suitable for cattle grazing with moderate limitations (Class 3). The majority of the study area (6,892 ha) is considered marginal land with the remaining area (2,524 ha) comprised of Class 5 land.

It is important to note that although the SMUs present in the Project areas are classified as Class 4 (marginally suitable) and Class 5 (unsuitable); given this is the current land use of the area, the land is considered suitable for grazing. The land suitability framework is used as a guide to determine potential land suitability and should be considered alongside historical land use. One of the two limiting factors which produced a land suitability class of 4 is limited soil phosphorous (< 10 mg/kg), which is able to be overcome with the addition of phosphorous to topsoil before re-spreading.

Figure 12 shows the distribution of land suitability classes for cattle grazing across the study area.

Table 54: Summary of land suitability limitations for cattle grazing

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	4	3	2	3	2	3	4
Nutrient deficiency	4	4	4	3	4	3	4	4
Soil physical factors	1	1	1	2	1	2	3	1
Salinity	1	1	1	3	1	2	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	1	1	1	1	1
pH	2	2	2	2	2	3	3	2
ESP (10cm) %	1	2	1	1	1	1	1	1
Wetness	1	2	2	2	2	2	1	2
Water erosion	2	1	1	1	1	1	1	1
Flooding	1	1	1	2	1	2	1	2
Vegetation Regrowth	1	1	1	2	2	1	1	2
Overall Suitability Rating	5	4	4	3	4	3	4	4

Notes: Green shading = suitable, red shading = unsuitable.

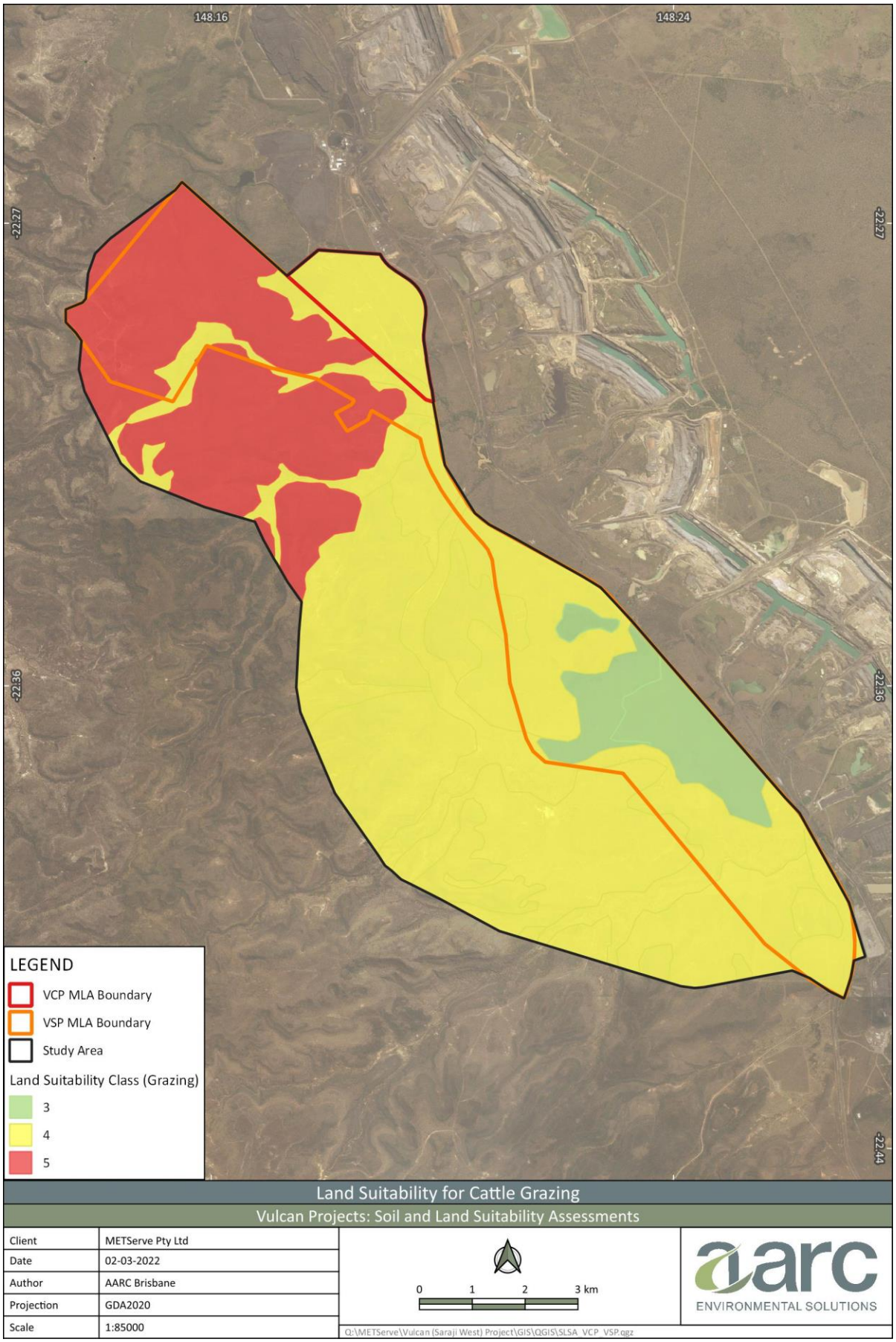


Figure 12: Cattle grazing land suitability classes

6.2 Rainfed broadacre cropping

Limitations for the assessment of rainfed broadacre cropping as outlined in the Land Suitability Assessment Technique (QDME 1995) Guidelines (Table 2.1) are:

- water availability;
- nutrient deficiency;
- soil physical factors;
- soil workability
- salinity;
- rockiness;
- micro relief;
- wetness;
- topography;
- water erosion; and
- flooding.

Numerous parameters outlined in this assessment require determination of the 'rootzone'. The rootzone is the depth to hard or weathered rock, or the depth to a significant salt bulge within the soil profile. Where these limitations are not encountered within the sampling depth, a rootzone value of 0.6 m can be assumed as described in the QDME guidelines (1995).

Class 1 and **Class 2** land is considered suitable for rainfed broadacre cropping with negligible or minor limitations and limited management requirements to sustain this use. **Class 3** land is considered suitable however, it is likely to be less productive than lands of Class **1 or 2**. **Class 4** land is categorised as marginally suitable for rainfed broadacre cropping or would require significant inputs to ensure land use sustainability. **Class 5** land is unsuitable having extreme limitations and cannot be sustainably used for the rainfed broadacre cropping.

Each of the limitations listed above are assessed below on the basis of Table 2.1 of the QDME guidelines (1995).

6.2.1 Water availability

The PAWC cut-off levels for each of the land suitability classes are as follows:

Class 1: > 150 mm

Class 2: 125–150 mm

Class 3: 100–125 mm

Class 4: 75 –100 mm

Class 5: < 75 mm

These cut-off levels are not based on a specific crop-type, but on rainfed broadacre cropping as a general land use. The soils are assessed on the depth to weathered rock, or other root inhibiting factors such as a salt bulge or significant sodicity. The availability of water in soils is vital for both plants and soil organisms as they require water to survive. Table 55 provides the outcomes of the land suitability class assessment on the basis of plant available water capacity.

Table 55: Land suitability for rainfed broadacre cropping based on PAWC

Soil management unit	Limiting features	PAWC (mm)	Land suitability class
Crocodile	Shallow sands and sandy loams ≤45 cm deep	< 75 mm	5
Fish	Sands and sandy loams 45–90 cm deep	< 75 mm	5
Kei	Sands and sandy loams >90 cm deep	75–100 mm	4
Komati	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	3
Limpopo	Duplex soils with subsoil becoming sodic (ESP 614) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	4
Orange	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	3
Sabie	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	4
Zambezi	Duplex soils with a sodic subsoil (ESP 6–14) becoming strongly sodic (ESP ≥ 15) within 60 cm of surface	< 75 mm	5

6.2.2 Nutrient deficiency

The nutrient status of each SMU identified has been assessed and the results are presented in Table 56. Note that bicarbonate phosphorus was only analysed within the topsoil layer (0–10 cm). Soil nutrients are vital for plant growth and metabolism.

Table 56: Land suitability for rainfed broadacre cropping based on nutrient status

Soil management unit	Limiting features	Land suitability class
Crocodile	Bicarbonate P 5–10 ppm and exchangeable K ≤ 0.3 meq %	3
Fish	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Kei	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq	4
Komati	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Limpopo	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Orange	Bicarbonate P 5–10 ppm and exchangeable K ≤ 0.3 meq %	3
Sabie	pH < 5 within 30 cm of the surface	5
Zambezi	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4

6.2.3 Soil physical factors

Soil physical factors for each SMU identified have been assessed with results presented in Table 57. The physical condition of soils plays a direct role with seed germination and emergence. Adverse conditions such as hard-setting or crusting of surface soils reduces plant establishment through creating a barrier, reducing seed soil contact.

Table 57: Land suitability for rainfed broadacre cropping based on soil physical factors

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a hard-setting surface when dry	3
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Sabie	Rigid soils with a hard-setting surface when dry	3
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.2.4 Soil workability

Soil physical factors for each SMU identified have been assessed with results presented in Table 58. The workability of soils refers to the capacity of the soil to support machinery during management practices such as tillage.

Table 58: Land suitability for rainfed broadacre cropping based on soil workability

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a hard-setting surface when dry	2
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Firm cracking clays	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Firm cracking clays	2
Sabie	Rigid soils with a loose, soft or firm surface when dry	1
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.2.5 Salinity

Land suitability class for each SMU based on salinity has been assessed with the results provided in Table 59. Given salinity can inhibit plant growth, the highest EC recorded is considered the most limiting factor and dictates the rating given to each SMU. Significant levels of salinity present in the rootzone can negatively impact plant growth and production.

Table 59: Land suitability for rainfed broadacre cropping based on salinity

Soil management unit	Limiting features	Land suitability class
Crocodile	Rootzone EC < 0.15 mS/cm	1
Fish	Rootzone EC < 0.15 mS/cm	1
Kei	Rootzone EC < 0.15 mS/cm	1
Komati	Rootzone EC 0.3–0.9 mS/cm	3
Limpopo	Rootzone EC < 0.15 mS/cm	1
Orange	Rootzone EC 0.3–0.9 mS/cm	3
Sabie	Rootzone EC < 0.15 mS/cm	1
Zambezi	Rootzone EC < 0.15 mS/cm	1

6.2.6 Rockiness

The land suitability for each SMU based on rockiness was assessed with results presented in Table 60. The impacts of rockiness are more extreme for cropping than for grazing. In regard to cropping, rock outcrops reduce the area available to grow crops, as land cannot be easily traversed or mechanised.

Table 60: Land suitability for rainfed broadacre cropping based on rockiness

Soil management unit	Limiting features	Land suitability class
Crocodile	20–50% surface cobble (6–20 cm diameter) and rock outcrop	3
Fish	<10 course surface gravel (>6 cm diameter)	1
Kei	<10 course surface gravel (>6 cm diameter)	1
Komati	<10 course surface gravel (>6 cm diameter)	1
Limpopo	<10 course surface gravel (>6 cm diameter)	1
Orange	<10 course surface gravel (>6 cm diameter)	1
Sabie	<10 course surface gravel (>6 cm diameter)	1
Zambezi	<10 course surface gravel (>6 cm diameter)	1

6.2.7 Microrelief

The microrelief for each SMU identified has been assessed with results presented in Table 61. Microrelief refers to local relief (up to several metres) around the plane of the land (National Committee on Soil and Terrain 2009). Impacts of microrelief on the suitability of land for rainfed broadacre cropping are only experienced when soil is severely melonholed. Ponding of water in the depressions can compromise growing conditions directly impacting on crop growth and yield.

Table 61: Land suitability for rainfed broadacre cropping based on microrelief

Soil management unit	Limiting features	Land suitability class
Crocodile	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Fish	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Kei	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Komati	Melonholes cover <20% surface area	2
Limpopo	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Orange	Melonholes cover <20% surface area	2
Sabie	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Zambezi	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1

6.2.8 Wetness

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 62. The wetness limitation refers to any excess water both in and on the soil profile. The adverse effects of excess water include reducing plant growth, impeding oxygen supply to plant roots (possibly leading to denitrification) and increased risk of plant disease.

Table 62: Land suitability for rainfed broadacre cropping based on wetness

Soil management unit	Limiting features	Land suitability class
Crocodile	Undulating terrain or elevated plains	1
Fish	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	3
Kei	Low-lying level plains with melonholes covering <25 % surface area	2
Komati	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3
Limpopo	Rigid soils with sodic subsoil (ESP 6–14) within 60 cm of the surface	2
Orange	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3
Sabie	Rigid soils with sodic subsoil (ESP 6–14) within 60 cm of the surface	2
Zambezi	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3

6.2.9 Topography

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 63. The topography limitation refers to the surface features of the land. Substantial variation in slope and elevation of an area can introduce limitations for cropping by reducing the area of land on which cropping is viable.

Table 63: Land suitability for rainfed broadacre cropping based on topography

Soil management unit	Limiting features	Land suitability class
Crocodile	Many deep gullies make the arable areas too small to cultivate	4
Fish	No gully dissection	1
Kei	No gully dissection	1
Komati	No gully dissection	1
Limpopo	No gully dissection	1
Orange	No gully dissection	1
Sabie	Occasional deep gullies impede cultivation slightly	2
Zambezi	Occasional deep gullies impede cultivation slightly	2

6.2.10 Water erosion

The land suitability class identified for each SMU based on water erosion has been assessed with the results presented in Table 64. Erosion of topsoil reduces the productivity of the land through the loss of key nutrients in the upper horizons of the soil.

Table 64: Land suitability for rainfed broadacre cropping based on water erosion

Soil management unit	Limiting features	Land suitability class
Crocodile	Slopes >6% on non-sodic rigid soils	5
Fish	Slopes 1–2 % on non-sodic soils	2
Kei	Slopes 1–2 % on non-sodic soils	2
Komati	Slopes <1% on non-sodic rigid soils	1
Limpopo	Slopes 1–2 % on non-sodic soils	2
Orange	Slopes <1% on non-sodic rigid soils	1
Sabie	Slopes 1–2 % on non-sodic soils	2
Zambezi	Slopes 1–2 % on non-sodic soils	2

6.2.11 Flooding

The land suitability class identified for each SMU based on flooding risk has been assessed with results presented in Table 65. Flooding may result in plant death or reduced growth. In severe cases where land is inundated for a prolonged period crop failure may occur.

Table 65: Land suitability for rainfed broadacre cropping based on flooding

Soil management unit	Limiting features	Land suitability class
Crocodile	No flooding	1
Fish	No flooding	1
Kei	No flooding	1
Komati	Rare flooding	2
Limpopo	No flooding	1
Orange	Rare flooding	2
Sabie	No flooding	1
Zambezi	Infrequent flooding	3

6.2.12 Summary of Land suitability for Rainfed Broadacre Cropping

Table 66 provides a summary of the assessed land suitability limitations for a rainfed broadacre cropping land use.

In the study area, the suitability of land for rainfed broadacre cropping is primarily limited by nutrient deficiency and water availability. Unsuitable nutrient availability in the soil has potential to impact crop health and yield. Fertiliser application is thus required to overcome this limitation, which is an additional expense to agricultural systems, subsequently reducing profitability of a farm. Additionally, water availability can also compromise crop growth by inducing water stress in crops and preventing the mobilisation of nutrients in the root zone.

No Class 1 or Class 2 land were identified within the study area. Examination of the land suitability limitations for rainfed broadacre cropping (Table 66) indicates that 471 ha of the study area is considered suitable land (Class 3), 3,760 ha of the Project area is considered marginal land (Class 4) with the remainder of the study area (5,919 ha) comprised of Class 5 land.

Figure 13 shows the distribution of land suitability classes for cattle grazing across the study area.

Table 66: Summary of land suitability limitations for rainfed broadacre cropping

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	5	4	3	4	3	4	5
Nutrient deficiency	3	4	4	4	4	3	5	4
Soil physical factors	3	1	1	2	1	2	3	1
Soil workability	2	1	1	2	1	2	1	1
Salinity	1	1	1	3	1	3	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	2	1	2	1	1
Wetness	1	3	2	3	2	3	2	3
Topography	4	1	1	1	1	1	2	2
Water erosion	5	2	2	1	2	1	2	2
Flooding	1	1	1	2	1	2	1	3
Overall Suitability Rating	5	5	4	4	4	3	5	5

Notes: Green shading = suitable, red shading = unsuitable.

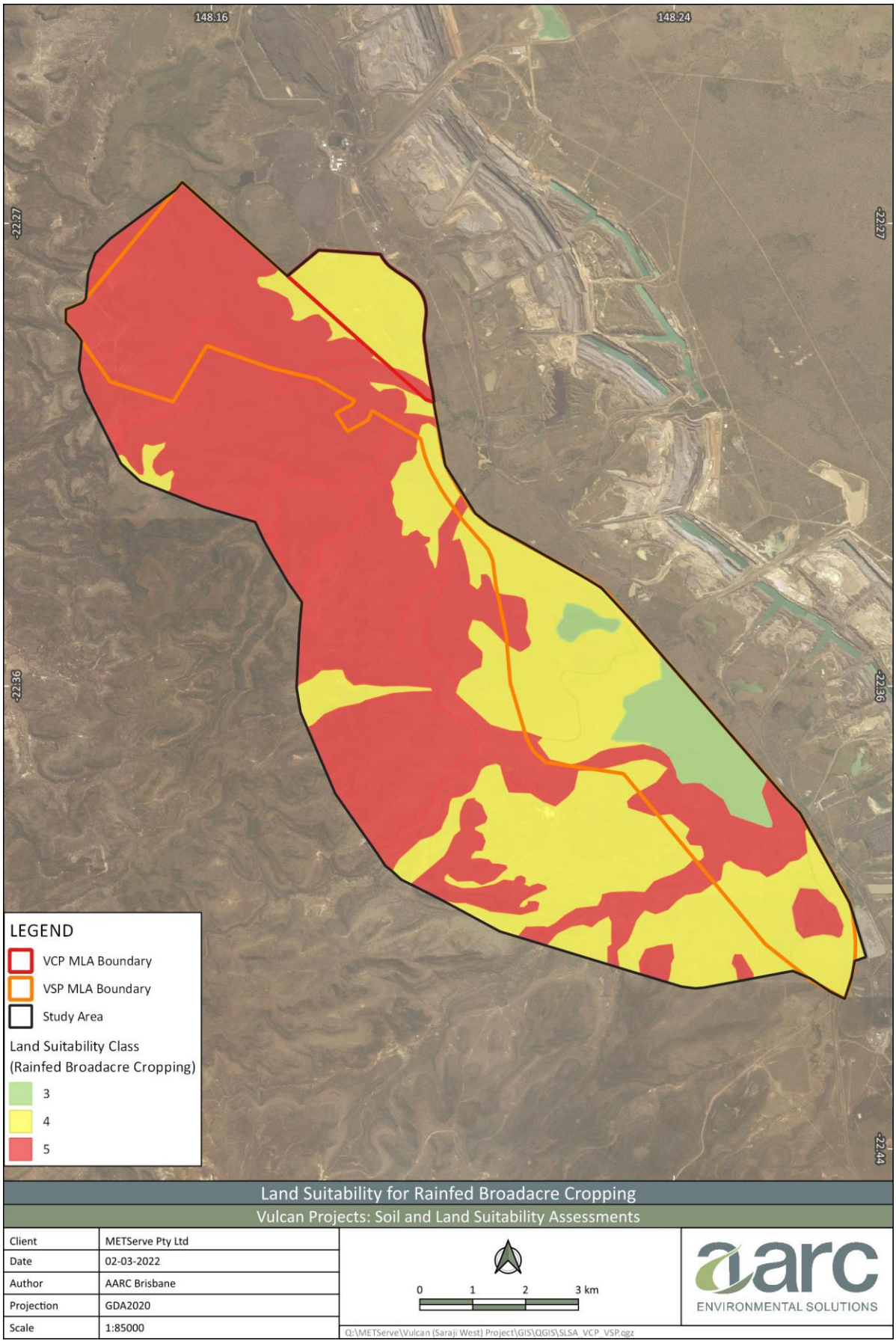


Figure 13: Rainfed broadacre cropping land suitability classes

7 Agricultural Land Assessment

Agricultural land class classification follows a hierarchical scheme in order to identify land that can be used sustainably for a particular land use to limit land degradation. There are three broad classes of agricultural land, namely Class A, Class B and Class C with one non-agricultural land class (Class D). Descriptions of agricultural land classes relevant to this agricultural assessment are provided in Table 67 (DNRM/DSITIA 2015).

Table 67: Description of agricultural land classes

Class	Description
A	Cropping land—land that is suitable for a wide range of crops with nil to moderate limitations.
B	Limited cropping land—land that is suitable for a narrow range of crop types.
C1	Pasture land—land suitable for grazing on native pastures on higher fertility soils.
C2	Pasture land—land suitable for grazing on native pastures on lower fertility soils.
C3	Pasture land—Land suitable for light grazing on native pastures in accessible areas, and includes steep land.
D	Non-agricultural land—land not suitable for agricultural use.

Based on the outcome of the land suitability assessment, study area SMUs have been assigned the agricultural land classes as per Table 68.

Table 68: Summary of agricultural land classes

Agricultural land class assessment		
Soil management unit	**Class**	**Area (ha)**
Crocodile	C3	2,524
Fish	C3	77
Kei	C2	140
Komati	C2	263
Limpopo	C2	3,328
Orange	C2	474
Sabie	C3	1,869
Zambezi	C3	1,445

8 Soil Handling Recommendations

8.1 Topsoil suitability and stripping

In general, fertility decreases with depth in response to the variation with depth of the various parameters impacting on soil fertility. For the study area, usable soil resources are mainly confined to the surface horizons, which contain the seedstock, micro-organisms and nutrients necessary for plant growth. This section lists the SMUs and the maximum depth to which suitable material may be stripped for stockpiling and future rehabilitation. Stripping recommendations have been determined based on the SMU characteristics detailed in Section 4.

Where practicable, stripping should be timed to avoid periods of excessive rain or prolonged dry periods. Where practicable, topsoil should be directly placed in prepared rehabilitation areas and used immediately rather than stockpiled for later use. Where topsoils have been identified as requiring amelioration and where practicable, the areas where they have been re-spread and/or the stockpiles where they have been stored should be delineated and recorded to ensure the appropriate treatment subsequently occurs.

Table 69 summarises the maximum depths to which each SMU should be stripped, a detailed discussion of each SMUs topsoil resource is outlined in the following sections.

Table 69: Maximum topsoil stripping depths for all soil management units

SMU	Topsoil stripping depth (m)
Crocodile[2]	0.1
Fish[2]	0.1
Kei[2]	0.6
Komati[2]	0.1
Limpopo[1,2]	0.3
Orange[2]	0.1
Sabie	0.1
Zambezi[1,2]	0.3

Notes: 1 = SMUs present within the VCP area
2 = SMUs present within VS area

8.1.1 Crocodile soil management unit (stripping depth 0.1 m)

The Crocodile SMU is limited in its suitability as a topsoil medium where an improved pasture post-mining land use is to be implemented. The land within this SMU has uneven, rocky terrain which may introduce accessibility challenges for earth-moving machinery. Given this, the total volume of topsoil able to be sourced from this SMU may be reduced. The soil is very strongly acidic at the surface (pH 5.4) remaining so with depth. pH values such as these have potential to limit soil nutrient content and thus plant growth. Furthermore, this soil unit is very shallow often containing large quantities of unweathered rock material.

The Crocodile SMU may be better suited to use where a native ecosystem post-mining land use similar to that existing on this SMU is to be re-instated. In these circumstances, this material could be stripped to 0.1 to 0.2 m depth but should be segregated to ensure its use in an appropriate post-mining land use.

8.1.2 Fish soil management unit (stripping depth 0.1 m)

The topsoil to 0.1 m of the Fish SMU is suitable for rehabilitation purposes. Although acidic with a pH of 5.5, the topsoil of this unit is within the range suitable for plant growth. Due to a very low nutrient holding capacity (CEC 2.5 meq/100g), its use in an improved pasture post-mining land use would benefit from fertiliser additions. Below the depth of 0.1 m, the Fish SMU becomes sodic and thus dispersive. Therefore, a stripping depth of 0.1 m is recommended.

8.1.3 Kei soil management unit (stripping depth 0.6 m)

The upper 0.6 m of the Kei SMU is suitable for most rehabilitation end-uses as this soil has suitable pH and low ESP and salinity. Below this depth, the soil becomes moderately alkaline (pH 8.6), which can affect plant productivity by reducing plant-available nutrients. The Kei SMU has low nutrient content (CEC > 4.5 meq/100g) and would therefore benefit from fertiliser addition when revegetating. A stripping depth of 0.6 m is recommended.

8.1.4 Komati soil management unit (stripping depth 0.1 m)

Soil to a depth of 0.1 m in the Komati SMU is considered suitable for most rehabilitation purposes. Below this depth, the soil is severely limited by its chemical characteristics with pH increasing to 8.5 and continuing to become more alkaline with depth. This pH level will limit plant available nutrients compromising plant growth and health. Furthermore, the soil becomes more susceptible to dispersion with ESP values of 13% also increasing with depth. A stripping depth of 0.1 m is recommended.

8.1.5 Limpopo soil management unit (stripping depth 0.3 m)

The Limpopo SMU is suitable for most rehabilitation end-uses in the top 0.3 m of the profile. Below this depth, sodicity increases to strongly sodic levels, increasing the risk of dispersion and susceptibility to erosion. The nutrient holding capacity of this soil is very low with CEC at 2.3 meq/100g. The addition of fertiliser would enhance revegetation success. Importantly, the topsoil associated with this SMU is predominantly composed of sand (79%) and should therefore not be placed on slopes exceeding 3% without appropriate measures to manage stability.

8.1.6 Orange soil management unit (stripping depth 0.1 m)

The topsoil of the Orange SMU to 0.1 m is suitable for most rehabilitation end-uses. This soil possesses adequate plant nutrients and is not saline. However, surface soil in this unit is moderately alkaline (pH 8.1) which is towards the top of the suitable pH range for plant growth. Depending on the desired rehabilitation outcome, pH adjustment may be desirable. Below a depth of 0.1 m, pH becomes moderately to strongly alkaline and may be limiting for plant growth. In addition, ESP values increase to 7% and continue to increase with depth. Therefore, below 0.1 m this SMU is at risk of dispersion and will be limited in its potential to be used as a topsoil /growth medium.

8.1.7 Sabie soil management unit (stripping depth 0.1 m)

Due to several constraining factors, the Sabie SMU is not considered suitable for rehabilitation use except where a native ecosystem outcome similar to the pre-mining situation is intended. The surface soil of this unit is very strongly acidic (pH 4.6) limiting the availability of essential plant nutrients. The risk of aluminium toxicity is also high. The additional constraint of sodicity becomes apparent below the depth of 0.1 m with ESP values of 9% which increase throughout the profile.

8.1.8 Zambezi soil management unit (stripping depth 0.3 m)

The Zambezi SMU is suitable for most rehabilitation purposes to a depth of 0.3 m. This surface layer has suitable pH, low salinity and is not sodic. Below this depth, the soil becomes strongly sodic with an ESP of 18.5% and is therefore at high risk of dispersion and subsequent erosion. Stripping is therefore only recommended to a depth of 0.3 m. To assist initial revegetation success, it may be beneficial to supplement this surface soil with fertiliser to improve the inherent low nutrient value of soil. The surface soil of this unit is predominantly composed of sand-sized particles (77% sand) and it is therefore recommended that the use of this soil on rehabilitated surfaces exceeding a 3% slope should be limited.

8.2 Topsoil stockpiling

Stockpiling of topsoil for extended periods can lead to physiochemical and biological deterioration in the soil and affect the viability of the soil seed bank. Where possible, topsoil should be directly placed in prepared rehabilitation areas rather than stockpiled to assist in maintaining a viable seedbank and promote timely revegetation.

Where stockpiling of topsoil is required, the following recommendations for soil management will reduce the risk of soil degradation and improve the chances of rehabilitation success:

- Where practicable, stockpiles should be less than 2m high and be constructed and positioned in a manner that encourages water drainage and discourages erosion, and with appropriate erosion and sediment controls in place.
- If there is a risk of a grass cover not establishing voluntarily, stockpiles will need to be ripped and seeded with a quick establishment pasture. Topsoil should ideally be stockpiled for the minimum time. Studies in the Hunter Valley have shown that most deterioration occurs within the first year (Keipert *et al.* 2005).
- Stockpiles should be monitored for erosion and weeds and control measures implemented as appropriate.
- Where soil has been stockpiled for extended periods, soil testing is recommended before use for rehabilitation purposes. If required, fertilisers and soil ameliorants should be applied.

Table 70 shows the estimated volumes of topsoil resource per SMU within the Project disturbance area, given the stripping depths outlined in section 8.1. The proposed disturbance area for the Project is shown in Figure 14.

Table 70: Estimated soil volumes—VS disturbance area

SMU	Topsoil Stripping Depth (m)	SMU area (m^2)	Potential Soil Volume (m^3)
Crocodile*	0.1	3,224,647	322,465
Fish*	0.1	751,423	75,142
Kei*	0.6	738,470	433,082
Komati*	0.1	2,351,969	235,197
Limpopo*	0.3	4,775,797	1,432,739
Orange*	0.1	4,546,246	454,625
Zambezi*	0.3	1,165,646	349,694
Total topsoil = 3,302,944 m^3			

Notes: SMUs with an asterisk (*) indicate soils where amelioration measures (e.g. liming agents, fertiliser), or actions (e.g. mixing) are considered beneficial to achieve a grazing land use outcome.

8.3 Topsoil placement

The proposed disturbance area (Figure 14) within the Project area suggests that topsoil material will be sourced predominantly from the Limpopo SMU. The Limpopo SMU is characterised as having moderate organic matter content and a high sand content and may therefore be at a greater risk of erosion-induced movement (Section 1.1). For this SMU, establishing a sufficient vegetative cover to mitigate erosion risk is important, particularly as rehabilitated slopes increase. To create a favourable environment for vegetation growth, topsoil from the Limpopo SMU will require application of one or more of the amelioration measures outlined in the following sub-sections.

Where possible, placement of topsoil at a minimum thickness of 0.2m is recommended for rehabilitation areas to create a growth medium of sufficient depth to hold water and support revegetation. For all rehabilitated areas, contour ripping and/or ploughing of the landform after topsoil placement should be undertaken to key the topsoil and subsoil layers together, and to improve seed germination conditions. Placement of armour rock or mulch cover to assist in stabilising the landform and reducing topsoil loss should be considered for slopes above 10%.

8.3.1 Topsoil amelioration

8.3.1.1 Organic matter application

Sandy soils such as the Limpopo SMU, usually have poor soil structure, low moisture retention and low available nutrient concentrations. The addition of organic matter to such soils helps to bind soil aggregates together and resist physical breakdown, improving soil structure; in turn increasing soil moisture retention and re-incorporating nutrients back into the soil. Where possible, topsoil should be stripped with its existing ground cover vegetation and, if subject to stockpiling, relocated with its cover crop vegetation.

Depending on availability, additional organic matter (such as mulches, manures, or compost), could be incorporated into the topsoil. Organic materials incorporated into the topsoil will increase organic carbon levels, providing more exchange sites for necessary cations, increase water holding capacity, and ensure less organic matter is oxidised into carbon dioxide and nitrous oxide or reduced into methane (Smith *et. al*. 2018). Application rates will vary depending on mulch type. Straw mulch should be applied at a rate of 5 t/ha (NSW Government 2015). Note that fresh mulch should not be used in acidic soils. Manure should be incorporated at rates of 5–30 t/ha (depending on the type of manure) (MLA n.d.). If available, compost can be applied at 70-150 t/ha (Kelly 2006).

8.3.1.2 Fertiliser application

Fertilisers can be utilised to increase nutrient concentrations in soil. As the Limpopo SMU is moderately acidic (pH of 5.5) care must be taken when fertilising, as some fertilisers (such as ammonium-based fertilisers) can have an acidifying effect on the soil. Were this to occur, lime applications would be required to mitigate the fertiliser's acidifying effects.

A calcium nitrate-based fertiliser such as calcium ammonium nitrate (15 to 27% N) is suitable for this application as it has near neutral effect on soil pH and can be used to increase both nitrogen and calcium levels in the soil. An application rate of 25–50 kg N/ha should be sufficient for successful vegetation establishment (CRDC 2020). This could be complemented with an application of sulphate of potash (41% K) to increase potassium levels in the soil. This fertiliser would also increase sulphur and can be applied with seeds (unlike other potassium fertilisers such as muriate of potash which can damage seed germination). Typical application rates of potassium for pastures in light soils are typically about 20 kg K/ha (Department of Primary Industries n.d.).

Alternatively, urea (46.7% N) could be applied as a nitrogen fertiliser (usually the most economical nitrogen fertiliser), but this would need to be applied in combination with lime (calcium carbonate), to overcome the acidifying effects of urea. A rate of 150 kg/ha of urea is recommended for soils in low rainfall areas where soil nitrate content is below 3 mg/kg. Limestone application rates should be around 1 t/ha of lime. It is expected that 1 t/ha of lime (incorporated in the first 10 cm of soil) can increase the pH of sandy soils by 0.6 units

(Department of Primary Industries n.d.). It is important to do follow up pH testing to evaluate the need to add more lime. Lime should be added initially at small doses and then at gradually increasing application rates as necessary.

Phosphorus application rates should be carefully determined, as many Australian native species are adapted to low phosphorus concentrations in the soil. Application rates of 10–20 kg P/ha have been suggested for grazing pastures (Victoria Government 2013) and mine restoration (Daws *et al.* 2013). To achieve this, single superphosphate (8.8% P) could be applied, which would also supply sulphate. (Note this fertiliser should not be blended with urea).

It is important that after application, soil ameliorants are incorporated into the soil to preferably a depth of about 0.3 m (for example by using a scarifier or ripper tynes) so they are not lost by wind or washed away by rainfall. After vegetation establishment (after 6 to 12 months since sowing), soils should be re-tested to determine if any follow-up application of ameliorants is required.

Besides using fertilisers, incorporating native leguminous forbs such as *Rhynchosia minima (*Rhynchosia) and *Glycine tabacina* (Variable Glycine) to the seed mix is a more natural method of increasing soil nitrogen levels due to the nitrogen fixing capabilities of legume species. This could establish natural nitrogen cycling within the topsoil resulting in long-term improvements in soil fertility and self-sustaining vegetation.

8.3.2 Cover crops

A fast-establishing sterile annual cover crop is recommended to be included in the seed mix. This will help to rapidly establish ground cover and minimise topsoil loss. This approach will also help to supress weeds and assist in restarting biological processes in the soil, creating a favourable micro-environment for the germination and emergence of the native seeds. Considering the sandy nature of the Limpopo topsoil, it is recommended that a cover crop is sown at a high seed density, of approximately 30 kg/ha. This should provide a rapid ground cover and assist in achieving soil stabilisation. *Echinochloa esculenta* (Japanese Millet) could be used for summer applications and *Lolium sp*. (Rye Grass) for winter applications. In the transition between cold and warm seasons, a combination of both species should be used.

8.3.3 Hydromulching

The use of hydromulching as an alternative to direct seeding is a further option that can be considered in zones at higher risk of erosion. Hydromulch consists of a semi-liquid water-based mixture composed of seed, water, mulch and other components (such as fertiliser, coir and tackifiers) which can be added depending on the site's amelioration requirements. The seed mix is included in the hydromulch slurry, which is sprayed onto the revegetation site as a thin layer (approximately 10 mm) to the soil surface, usually at a rate of approximately 50 m^3/ha for topsoil applications. The aim of using hydromulch is to cover and protect the soil, together with providing a suitable germination environment for seeds. The use of hydromulch can be effective at controlling erosion and stabilising the soil, by providing an erosion resistant layer for the period of time it takes for vegetation to become established.

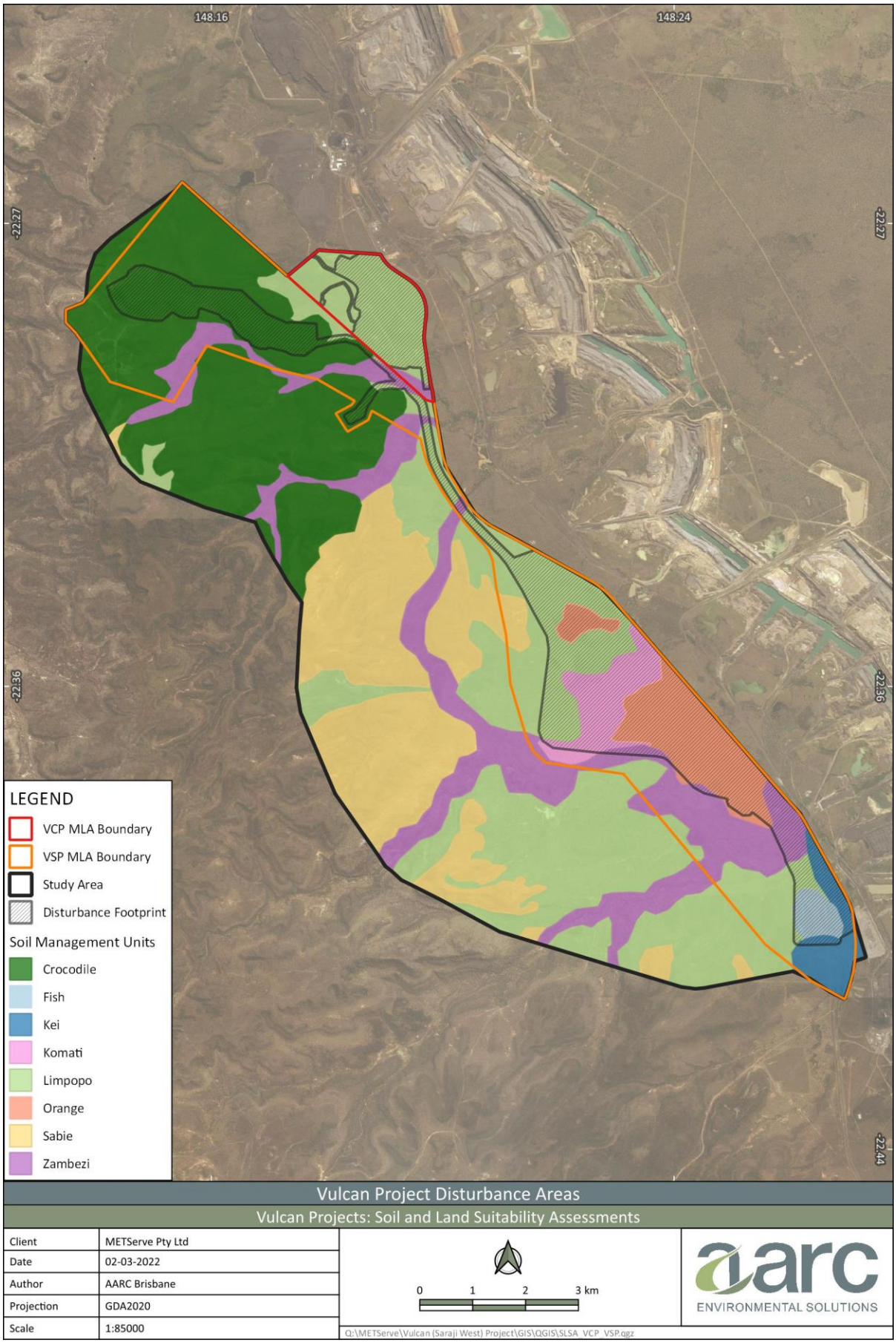


Figure 14: VS disturbance area

8.4 Subsoil management

Excluding the Crocodile and Kei units, the subsoil layers (soil located below the recommended stripping depth of each SMU) of all other SMUs are severely constrained by elevated ESP values which place these materials at a high risk of dispersion. These constraints suggest that consideration of the use of these subsoils needs to be weighed against the geochemical and physical qualities of the waste rock materials being excavated. In particular, the requirements for separate handling, storage, placement and amelioration for these subsoils, may not provide sufficient benefit over their non-use.

Outside of the Project area, the subsoil characteristics of the Crocodile and Kei units do represent an opportunity for use as a soil resource, given their non-sodic nature throughout the depth profile. If used as a soil resource, consideration should be given to incorporating ameliorants to address the pH limitations of these materials and improve their potential to support a rapid and successful rehabilitation outcome.

Sodic subsoils left exposed after topsoil stripping has occurred will represent an erosion and potential downstream sedimentation risk. Appropriate erosion and sediment control methods should be incorporated into stripping plans for these areas.

8.4.1 Subsoil amelioration

Where dispersive materials are to be used as subsoil, they should be treated with gypsum (calcium sulphate) prior to sowing/planting. Dispersive soils generally have low porosity, low air movement and therefore low oxygen availability for plants. They also have slow water infiltration which can lead to waterlogging. Gypsum application rates for moderate to severe dispersive soils usually range from 2.5 to 5 t/ha depending on site-specific characteristics (DPIRD 2020). Given the high exchangeable sodium percentage (21.5 %) and low pH present in the Limpopo subsoil, an application of 5 t/ha of gypsum is recommended. Gypsum causes soil particles to flocculate, therefore improving soil structure, increasing water and plant root penetration into the soil. Irrigation is also important; these soils should be well irrigated so that sodium is leached down the soil profile. In contrast, low amounts of water in the soil can result in sodium move up the soil profile by evaporation.

9 Potential Impacts and Management

9.1 Land suitability

The development of the Project will disturb land through the construction of infrastructure and operation of the mine. This disturbance will impact the land suitability of the Project areas throughout the life of the mine and potentially after its closure. Pre-mining land suitability classes are outlined in Section 6 and are summarised in Table 71.

Table 71: Summary of the size and suitability classes for Project area SMUs

SMU	Land suitability class (Grazing)	Land suitability class (Cropping)	Area (ha)
Crocodile	5*	5	1,195
Fish	4*	5	76
Kei	4*	4	174
Komati	3	4	262
Limpopo	4*	4	1,015
Orange	3	3	472
Sabie	4*	5	47
Zambezi	4*	5	577

Notes: Green = suitable, red = unsuitable. Items displayed with an asterisk (*) are considered suitable based on current land use of low intensity grazing.

Based on the pre-mining land use and the results of this SLSA, it is anticipated that rehabilitated landforms will be able to support a post-mining land use of cattle grazing, on the basis that current land use is low intensity cattle grazing and that appropriate soil amelioration strategies are implemented.

The economic viability of using rehabilitated land for grazing will be considered based on post-mine land suitability, as well as the total area available for cattle grazing. If developed, improved pastures will likely incorporate species such as Buffel, Rhodes and other grasses that perform well in local conditions. The areas classed as suitable for low intensity cattle grazing are extensive and are considered to offer a land use value equivalent to that existing pre-mining.

It should be noted that mining activities, including the stripping, stockpiling and handling, of soil, have the potential to impact its physical, chemical and biological properties. Therefore, the pre-mining land suitability for cattle grazing may be reduced for some rehabilitated landforms. These potential adverse impacts can be mitigated through:

- good topsoil management practices (See Section 8);
- the addition of fertilisers and soil ameliorants;
- timely seeding with suitable species; and
- post-establishment management of rehabilitated areas.

Where final landforms represent a relatively flat landscape (e.g. slopes less than 5%) it is envisaged that the post-mining land suitability for cattle grazing will reflect that of the pre-mining landscape.

Other areas, such as steeper outer slopes of spoil (e.g. slopes of > 10%) may be subject to increased risk of erosion. These areas will require management to ensure they remain safe, non-polluting, stable and able to sustain an agreed post-mining land use.

9.2 Erosion

Disturbance of vegetation and the topsoil layer can lead to the mobilisation of soil through the process of erosion, particularly water erosion through heavy rainfall or overland flow. The risk of erosion at the Project will be increased by the following activities:

- clearing of vegetation;
- topsoil stripping and stockpiling;
- construction of infrastructure; and
- exposure of slopes.

Management recommendations to be considered, as required, to reduce the risk and impacts of erosion include:

- Limiting land clearing to the minimum amount of land required for safe operation of the Project.
- Diversion of overland flow/runoff around disturbed areas.
- Amelioration of sodic soils through the addition of gypsum, or addition of rock for stability if used in rehabilitation.
- Progressive rehabilitation of landforms and direct placement of topsoil to help preserve the seed bank and reduce erosion.
- Seeding of topsoil as soon as possible after placement onto rehabilitated areas, to ensure root masses assist in mitigating erosion.
- Topsoil stockpiles placed away from drainage areas, roads, machinery, transport corridors, and stock grazing areas.
- Topsoil stockpiles seeded or covered with a water-shedding lining to prevent unnecessary erosion of soil.
- The use of sediment control structures such as retention ponds, to minimise the release of water and suspended sediments into the receiving environment.

9.3 Topsoil erodibility and erosion risk

The topsoil of the Limpopo SMU has been identified as having a high sand composition making it susceptible to erosion, particularly if used on rehabilitated landforms with steep gradients. A soil erosion assessment was undertaken to determine potential erosion rates for the use of the Limpopo SMU in rehabilitation. The Limpopo SMU was utilised being the SMU most susceptible to erosion and of most importance as a topsoil resource.

The Revised Universal Soil Loss Equation (RUSLE) is a calculation used to estimate average annual soil loss caused by hillslope and rill erosion. The equation is limited to making predictions for long-term annual soil loss. The RUSLE equation is:

$$A = R \times K \times LS \times C \times P$$

Where:

- A is the predicted rate of soil loss in tonnes per hectare per year;
- R is the rainfall erosivity factor based on the total erosive power of storms during an average year and is dependent on local weather conditions;
- K is the soil erodibility factor, which has been specifically derived for the Project area SMUs;
- LS is the slope length-gradient factor which describes the combined effect of slope length and gradient on soil loss. The LS factor is a ratio that corresponds to soil loss per unit area of an experimental plot of known length and gradient;
- C is referred to as the cover and management factor which compares cropping practices, residue management, and soil cover to a standard clean fallow plot. C-factors for different agricultural uses and management practices are developed based on their observed deviation from the standard clean fallow plot; and
- P is the conservation or support practice factor and reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up-and-down slope.

The K factor was determined according to methodology described in the *Prediction of Sheet and Rill Erosion over the Australian Continent, Incorporating Monthly Soil Loss Distribution* (Lu et al 2001) using the equation:

$$K = 2.77(100\ P_{125})^{1.14}(10^{-7})\ (12\text{-}2OC) + (3.29\times10^{-3})\ (PP\text{-}3)$$

Where:

- K is the RUSLE soil erodibility factor, SI Units of t ha h ha^{-1} MJ^{-1} mm^{-1}
- P_{125} is the percentage of soil clay, silt and sand particles less than 0.125mm diameter
- OC is the Organic Carbon content; and
- PP is the soil profile permeability class.

Table 72 displays all the parameters relevant to the determination of the soil K factor and the resultant K factor for topsoil of the Limpopo SMU.

Table 72: Soil RUSLE K factors

P_{125} (%)	**OC (%)**	**PP**	**K (t.ha.h)/(ha.MJ.mm)**
38	1	3	0.033

The R factor for the Limpopo SMU soil type within the VS boundary has been derived from the *Queensland Spatial Catalogue* (Queensland Government 2020) which contains input R factor datasets available for use in the RUSLE. An average R value of 1,729.45 MJ/mm per ha/hr/yr for land within the Project area was determined using a vector analysis GIS tool to extract the available factor data. Although, grid cells that occupy less than 10% of the Project area were excluded from the analysis.

A P-factor of 0.9 has been adopted for this assessment based on ripping along the contour of the rehabilitated landform that is assumed to be undertaken after the placement of topsoil.

For the assessment of soil erosion on the rehabilitated landform, slope length and steepness (L and S factor) and the cover management factor (C-factor) are the principal variables impacting the assessment results. These factors have been manipulated independently to predict how changes to these factors influence the erosion potential of the landform.

Slope analysis

An investigation regarding how gradient influences erosion potential was included in this assessment to quantify the erosion risk associated with the design of the rehabilitated landform.

Gradient values used in the analysis vary from 1%, 5%, 10%, and 15% as these are reflective of the slopes proposed across the rehabilitated landform. An assumed conservative uninterrupted slope length of 100 m between contour banks has been used.

Cover-type analysis

For each slope type, a range of C-factors representative of various land management practices were incorporated to identify the practices that are likely most effective at reducing erosion potential. Land management practices include the application of biodegradable ground cover products, hydromulch and grass cover. It should be noted that this prediction of erosion rates for the Project is assumption based. Therefore, results should be used for comparative purposes as opposed to being considered as absolute values.

Using remote sensing technology, national averages for erosion have been determined (Lu et. al 2001) and are presented for comparison; these include:

- that the average Australian erosion rate is 6.3 tonnes per hectare per year;
- that a low rate of erosion is defined as less than 0.5 tonnes per hectare per year; and
- that a high erosion rate is defined as greater than 10 tonnes per hectare per year.

The output from the erosion analysis is presented in Table 73.

As expected, results suggest erosion is most effectively controlled through the establishment of grass cover across the land surface as vegetation protects the soil surface and slows surface run-off whilst root systems stabilise the sub-surface. On newly constructed landforms where vegetation is not yet established, the spreading of mulch is likely the most effective intermediate management practice as it offers protection comparable to that of hydromulching.

Results suggest that both slope and management practices greatly influence the erosion potential of the landform. Slopes across the rehabilitated landform have been designed to a maximum gradient of 15%. Erosion potential should, therefore, be able to be controlled through a combination of management practices.

Table 73: Predicted soil loss as a factor of slope and management practice

Management type	C	Gradient (%)	A (tonnes/ha.yr)
Jute Mesh	0.4	1	3
Jute Mesh	0.4	5	24
Jute Mesh	0.4	10	57
Jute Mesh	0.4	15	104
50% grass cover on recently disturbed soils	0.15	1	1
50% grass cover on recently disturbed soils	0.15	5	9

Management type	C	Gradient (%)	A (tonnes/ha.yr)
50% grass cover on recently disturbed soils	0.15	10	21
50% grass cover on recently disturbed soils	0.15	15	39
Wood Mulch	0.08	1	1
Wood Mulch	0.08	5	5
Wood Mulch	0.08	10	11
Wood Mulch	0.08	15	21
Hydromulch	0.07	1	1
Hydromulch	0.07	5	4
Hydromulch	0.07	10	10
Hydromulch	0.07	15	18
70% grass cover on recently disturbed soils	0.05	1	1
70% grass cover on recently disturbed soils	0.05	5	3
70% grass cover on recently disturbed soils	0.05	10	8
70% grass cover on recently disturbed soils	0.05	15	15

9.4 Erosion of rehabilitated landforms

Erosion of rehabilitated landforms reduces the likelihood of revegetation success, and in extreme cases can compromise the structural integrity of the landform, making it unstable and unsafe. In addition, if not managed correctly, erosion can result in the release of suspended sediments and potential contaminants into the receiving environment.

The topsoil of the SMUs within the Project area largely composed of sand whilst subsoils have dispersive characteristics. Soil is likely at high risk of erosion, particularly if this risk is not considered during the design of rehabilitated landforms. The rehabilitated landform design for the Project should consider implementing controls to manage surface runoff on final landform slopes. Such controls may include:

- Limiting side slopes of spoil to a maximum slope of 1V:6H (approximately 16%) or less.
- Construction of contour banks on slopes at a recommended spacing of 80 m for slopes of 1V:6H (MCA 1998). Larger contour drains are generally more stable and longer lasting. It is recommended that drains/berms are a minimum of 5 m wide and a minimum of 500 mm in height. Berms should be constructed of compacted material (IE Aust Erosion and Sediment Control Guidelines).
- Contour banks should convey water to engineered rock-lined spine drains on steep slopes. A competent basalt or alternative rock source is recommended. The use of geofabric in construction of rock-lined spine drains is also recommended.
- To reduce the need for engineered drains on steep slopes, landform modelling can be centred around gentle concave slopes or terraced profiles, or in accordance with geomorphic principles. For materials prone to erosion, designs such as these can significantly reduce runoff velocity and erosion by a magnitude of two or three times, however, this approach can be difficult to implement where space is a limiting factor.

- Maintaining a high vegetative ground cover across the rehabilitation landform, particularly where the gradient exceeds 10% (Section 9.3).
- The incorporation of rock into the topsoil medium can also assist in reducing erodibility, as well as increasing infiltration (Commonwealth of Australia 2016).
- Rehabilitated areas should be ripped to reduce compaction from heavy machinery, encourage infiltration of water and prevent erosion. If engineered waterways are included in the landform, areas should be ripped on a grade (e.g. 0.5%). Otherwise, areas should be ripped on the contour. Ripping depths will vary depending on the type of spoil material, depth of topsoil and equipment used for rehabilitation operations. Typical ripping depths for this Project would be about 400–500 mm.
- Avoiding the use of any sodic subsoil material for use as a subsoil medium (see section 6.4).

9.5 Soil degradation

Stripping, stockpiling and handling of topsoil can potentially have a negative impact on the chemical and physical attributes of the soil. Impacts associated with mining activities include the following:

- exposure of sodic subsoils during soil stripping. This is applicable to all SMUs within the Project areas excluding Crocodile and Sabie;
- loss of soil physical structure due to excavation and handling;
- loss of the soil seedbank; and
- impacts on soil fertility due to mixing with subsoils and resulting changes in soil chemistry as subsoils are exposed to oxygen.

Physiochemical changes to the soil may impact on the viability of the soil seed bank and reduce the likelihood of successful rehabilitation if not well managed. Management recommendations to reduce the risk of soil degradation and improve the chances of rehabilitation success include:

- Segregation of saline or sodic soils and clear demarcation and labelling/recording of stockpiles to ensure appropriate use of the resource;
- Minimising the handling of topsoil;
- Ensuring that when required, stockpiles are generally less than 2 m high and contoured to encourage water to drain;
- If topsoil resources are to be stockpiled for a period in excess of six months, testing of soil properties prior to use in rehabilitation should be carried out. The proponent could consider conducting soil physiochemical analysis of stockpiled topsoil resources to assess for changes in topsoil quality (changes to soil chemistry and biological activity as a result of being stockpiled). Key parameters that should be considered during this additional testing, if undertaken, include pH, ESP, CEC (major cations), organic matter content and other essential nutrients such as nitrate, phosphorous and sulphate; and
- The application of fertilisers, soil ameliorants and an appropriate seed mix are recommended for some SMUs to increase the likelihood of rehabilitation success. Recommendations relevant to SMUs requiring amendments are discussed in Section 6.1.

9.6 Erosion monitoring on rehabilitated landforms

Erosion monitoring across the landform will be integral to the early detection of erosion and will allow for early intervention. Erosion monitoring can be undertaken using physical observation in the field or remotely with the use of aerial photography and lidar imagery. A brief description of suitable methodologies is provided below.

9.6.1 Field assessment methodologies

In-field erosion monitoring is based on visual assessments taken over time. Permanent monitoring transects, 50 m in length should be established across the landform to provide a basis for temporal assessments. Visual observations should be taken whilst traversing the 50 m transects on foot and recording the number and average depth of any erosion features, rill lines or gullies. It should be noted that the placement of the permanent transects may not be a true reflection of erosion across the rehabilitated landforms. General observations should therefore also be undertaken during the monitoring event. Visual assessments should identify any evidence of excessive sediment movement, including the formation of rills, removal of soil around the base of plants and accumulation of loose sediment at the base of slopes. In-field erosion monitoring should also include an assessment of the water quality of run-off water released from the catchment of a given rehabilitation area.

Table 74 records and classifies the severity of erosion observations. The overall classification of the erosion on each transect was based on the most severe characteristic of the erosion observed, i.e. either the number of rills/gullies or the average depth. For example, a transect may present only one or two rills, however, if an average depth of 25 cm is recorded, the transect will be classified as having moderate erosion.

Table 74: Erosion classifications

Erosion classification	Minor	Moderate	Major	Extensive
No. of rill(s)/gully(ies)*	< 15	15–30	31–50	> 50
Average depth (cm)	< 10	10–30	30–60	> 60

*Gully: highly visible form of soil erosion, with steep-sided, incised, drainage lines greater than 30 cm deep

9.6.2 Remote sensing methodologies

The advent of remote sensing technologies, the increasing availability of satellite imagery and the development of accurate, near-field, point-cloud surveying capability (e.g. LiDAR) creates a number of options for monitoring indicators relevant to the assessment of rehabilitated areas and sheet, rill and/ or gully erosion development more specifically. For rehabilitation assessments, there needs to be a good understanding of how such technologies work, as they bring their own specific requirements which must be addressed (e.g. coordinate reference systems, datum points, object interference etc.).

Various remote sensing technologies are now able to be used for the assessment of rehabilitated areas. They can be used for assessing the same area over time which can be useful to assess sheet erosion and or the development of rill and gully erosion over time, as well as detection of existing rill and gully erosion. It is generally recommended that such technologies be used in conjunction with the in-field monitoring technologies discussed above to provide a calibration for what is being measured.

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Appendix 1 Lab Results

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1920844**	Page	: 1 of 29
Client	: **AARC ENVIRONMENTAL SOLUTIONS PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR GARETH BRAMSTON	Contact	: Customer Services EB
Address	:	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3217 8772	Telephone	: +61-7-3243 7222
Project	: Vulcan Project Soils	Date Samples Received	: 08-Aug-2019 13:40
Order number	:	Date Analysis Commenced	: 09-Aug-2019
C-O-C number	: ----	Issue Date	: 20-Aug-2019 16:53
Sampler	: MEGHAN BARNARD		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 43		
No. of samples analysed	: 43		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
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General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- ALS is not NATA accredited for the analysis of Exchangeable Aluminium and Exchange Acidity in soils when performed under ALS Method ED005.
- ALS is not NATA accredited for the analysis of Exchangeable Cations on Alkaline Soils when performed under ALS Method ED006.
- **Bulk Density analysis will be conducted by ALS Environmental, Sydney, NATA accreditation no. 825, Site No. 10911 (Micro site no. 14913).**
- ED092 (DTPA Extractable Metals): Sample EB1920844 – 009 (VP2 - 10-10cm) shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.
- EG005T (Total Metals by ICP-AES): Sample EB1920844 – 031 (VP20 - 10-10cm) shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.
- ED006 (Exchangeable Cations on Alkaline Soils): Unable to calculate Calcium/Magnesium Ratio results as required Calcium and/or Magnesium results are less than the limit of reporting.
- ED006 (Exchangeable Cations on Alkaline Soils): Unable to calculate Magnesium/Potassium Ratio result as required Potassium and/or Magnesium results are less than the limit of reporting.
- ED005 (Exchange Acidity by 1M Potassium Chloride): It is recognised that the Exchange Acidity is less than the Exchangeable Aluminium for certain samples. However, the difference is within experimental variation of the methods.
- ED007 (Exchangeable Cations): Unable to calculate Magnesium/Potassium Ratio result as required Exchangeable Potassium results are less than the limit of reporting.
- ED005 (Exchange Acidity by 1M Potassium Chloride): Sample EB1920844 – 015 (VP29 - 80-90cm) shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.
- EA058 Emerson: V. = Very, D. = Dark, L. = Light, VD. = Very Dark
- ED007 and ED008: When Exchangeable Al is reported from these methods, it should be noted that Rayment & Lyons (2011) suggests Exchange Acidity by 1M KCl - Method 15G1 (ED005) is a more suitable method for the determination of exchange acidity (H+ + Al3+).
- ALS is not NATA accredited for the analysis of bulk density in a soil matrix.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP25 - 10-10cm	VP25 - 20-30cm	VP25 - 50-60cm	VP25 - 80-90cm	VP30 - 10-10cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-001	EB1920844-002	EB1920844-003	EB1920844-004	EB1920844-005
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	6.4	6.7	7.8	9.0	6.4
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	18	5	59	174	13
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	1580	----	----	----	2130
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	1.8	2.8	7.2	9.1	1.5
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Very Dark Brown (7.5YR 2.5/2)	Dark Brown (7.5YR 3/4)	Brown (10YR 4/3)	Dark Grayish Brown (10YR 4/2)	Very Dark Brown (10YR 2/2)
Texture	----	-	-	Clayey Sand	Loamy Sand	Sandy Clay Loam	Clay Loam, Sandy	Sandy Clay Loam
Emerson Class Number	EC/TC	-	-	3	4	2	2	3
EA150: Particle Sizing								
+75µm	----	1	%	75	----	----	----	59
+150µm	----	1	%	43	----	----	----	39
+300µm	----	1	%	19	----	----	----	26
+425µm	----	1	%	10	----	----	----	18
+600µm	----	1	%	4	----	----	----	10
+1180µm	----	1	%	1	----	----	----	2
+2.36mm	----	1	%	<1	----	----	----	<1
+4.75mm	----	1	%	<1	----	----	----	<1
+9.5mm	----	1	%	<1	----	----	----	<1
+19.0mm	----	1	%	<1	----	----	----	<1
+37.5mm	----	1	%	<1	----	----	----	<1
+75.0mm	----	1	%	<1	----	----	----	<1
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	9	----	----	----	12
Silt (2-60 µm)	----	1	%	14	----	----	----	25
Sand (0.06-2.00 mm)	----	1	%	77	----	----	----	62
Gravel (>2mm)	----	1	%	<1	----	----	----	1
Cobbles (>6cm)	----	1	%	<1	----	----	----	<1
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	2.43	----	----	----	2.31
ED006: Exchangeable Cations on Alkaline Soils								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP25 - 10-10cm	VP25 - 20-30cm	VP25 - 50-60cm	VP25 - 80-90cm	VP30 - 10-10cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-001	EB1920844-002	EB1920844-003	EB1920844-004	EB1920844-005
					Result	Result	Result	Result	Result
ED006: Exchangeable Cations on Alkaline Soils - Continued									
ø Exchangeable Calcium	----	0.2	meq/100g		----	----	1.1	1.7	----
ø Exchangeable Magnesium	----	0.2	meq/100g		----	----	3.1	5.7	----
ø Exchangeable Potassium	----	0.2	meq/100g		----	----	<0.2	<0.2	----
ø Exchangeable Sodium	----	0.2	meq/100g		----	----	0.9	2.3	----
ø Cation Exchange Capacity	----	0.2	meq/100g		----	----	5.1	10.0	----
ø Exchangeable Sodium Percent	----	0.2	%		----	----	18.5	23.3	----
ø Calcium/Magnesium Ratio	----	0.2	-		----	----	0.4	0.3	----
ED007: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		2.3	1.3	----	----	2.9
Exchangeable Magnesium	----	0.1	meq/100g		0.8	0.4	----	----	1.1
Exchangeable Potassium	----	0.1	meq/100g		0.4	0.1	----	----	0.5
Exchangeable Sodium	----	0.1	meq/100g		<0.1	<0.1	----	----	<0.1
Cation Exchange Capacity	----	0.1	meq/100g		3.4	1.8	----	----	4.5
Exchangeable Sodium Percent	----	0.1	%		0.6	1.0	----	----	1.0
Calcium/Magnesium Ratio	----	0.1	-		2.9	3.2	----	----	2.6
Magnesium/Potassium Ratio	----	0.1	-		2.3	3.2	----	----	2.1
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		311	105	<100	133	477
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		<10	----	----	----	<10
Sulfur as S	63705-05-5	10	mg/kg		<10	----	----	----	<10
Silica	7631-86-9	1	mg/kg		48	----	----	----	36
Silicon	7440-21-3	1	mg/kg		23	----	----	----	17
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		<10	<10	40	160	<10
ED091 : Calcium Chloride Extractable Boron									
ø Boron	7440-42-8	0.2	mg/kg		<0.2	----	----	----	<0.2
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		<1.00	----	----	----	<1.00
ø Iron	7439-89-6	1.00	mg/kg		60.7	----	----	----	30.6
ø Manganese	7439-96-5	1.00	mg/kg		8.92	----	----	----	13.8
ø Zinc	7440-66-6	1.00	mg/kg		<1.00	----	----	----	1.52
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		<0.1	----	----	----	0.3

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP25 - 10-10cm	VP25 - 20-30cm	VP25 - 50-60cm	VP25 - 80-90cm	VP30 - 10-10cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-001	EB1920844-002	EB1920844-003	EB1920844-004	EB1920844-005
					Result	Result	Result	Result	Result
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		**2.6**	----	----	----	**0.7**
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		**2.6**	----	----	----	**1.0**
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		**2.0**	----	----	----	**2.4**
Total Organic Carbon	----	0.5	%		**1.1**	----	----	----	**1.4**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP30 - 20-30cm	VP30 - 50-60cm	VP30 - 80-90cm	VP2 - 10-10cm	VP2 - 20-30cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-006	EB1920844-007	EB1920844-008	EB1920844-009	EB1920844-010
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	7.0	7.4	8.6	5.8	5.2
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	14	9	101	16	7
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	----	----	----	5030	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	2.4	1.7	8.0	0.9	3.8
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Very Dark Grayish Brown (10YR 3/2)	Brown (10YR 4/3)	Brown (10YR 4/3)	Black (10YR 2/1)	Gray (10YR 5/1)
Texture	----	-	-	Sandy Clay Loam	Clayey Sand	Sandy Clay	Loamy Sand	Loamy Sand
Emerson Class Number	EC/TC	-	-	3	3	4	4	3
EA150: Particle Sizing								
+75µm	----	1	%	----	----	----	89	----
+150µm	----	1	%	----	----	----	83	----
+300µm	----	1	%	----	----	----	62	----
+425µm	----	1	%	----	----	----	40	----
+600µm	----	1	%	----	----	----	20	----
+1180µm	----	1	%	----	----	----	3	----
+2.36mm	----	1	%	----	----	----	<1	----
+4.75mm	----	1	%	----	----	----	<1	----
+9.5mm	----	1	%	----	----	----	<1	----
+19.0mm	----	1	%	----	----	----	<1	----
+37.5mm	----	1	%	----	----	----	<1	----
+75.0mm	----	1	%	----	----	----	<1	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	----	----	----	3	----
Silt (2-60 µm)	----	1	%	----	----	----	8	----
Sand (0.06-2.00 mm)	----	1	%	----	----	----	88	----
Gravel (>2mm)	----	1	%	----	----	----	1	----
Cobbles (>6cm)	----	1	%	----	----	----	<1	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	----	----	----	2.50	----
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP30 - 20-30cm	VP30 - 50-60cm	VP30 - 80-90cm	VP2 - 10-10cm	VP2 - 20-30cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-006	EB1920844-007	EB1920844-008	EB1920844-009	EB1920844-010
					Result	Result	Result	Result	Result
ED005: Exchange Acidity - Continued									
ø Exchange Acidity	----	0.1	meq/100g		----	----	----	<0.1	1.4
ø Exchangeable Aluminium	----	0.1	meq/100g		----	----	----	<0.1	1.4
ED006: Exchangeable Cations on Alkaline Soils									
ø Exchangeable Calcium	----	0.2	meq/100g		----	1.5	8.4	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g		----	<0.2	0.6	----	----
ø Exchangeable Potassium	----	0.2	meq/100g		----	<0.2	0.4	----	----
ø Exchangeable Sodium	----	0.2	meq/100g		----	<0.2	<0.2	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g		----	1.5	9.4	----	----
ø Exchangeable Sodium Percent	----	0.2	%		----	<0.2	<0.2	----	----
ø Calcium/Magnesium Ratio	----	0.2	-		----	----	12.9	----	----
ø Magnesium/Potassium Ratio	----	0.2	-		----	----	1.8	----	----
ED007: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		2.8	----	----	1.0	<0.1
Exchangeable Magnesium	----	0.1	meq/100g		1.1	----	----	0.5	0.2
Exchangeable Potassium	----	0.1	meq/100g		0.5	----	----	0.2	0.1
Exchangeable Sodium	----	0.1	meq/100g		<0.1	----	----	<0.1	<0.1
Cation Exchange Capacity	----	0.1	meq/100g		----	----	----	----	1.9
Cation Exchange Capacity	----	0.1	meq/100g		4.4	----	----	1.8	----
Exchangeable Sodium Percent	----	0.1	%		1.4	----	----	1.7	6.6
Calcium/Magnesium Ratio	----	0.1	-		2.5	----	----	2.0	<0.1
Magnesium/Potassium Ratio	----	0.1	-		2.1	----	----	2.7	2.3
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		122	126	259	179	118
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		----	----	----	<10	----
Sulfur as S	63705-05-5	10	mg/kg		----	----	----	<10	----
Silica	7631-86-9	1	mg/kg		----	----	----	36	----
Silicon	7440-21-3	1	mg/kg		----	----	----	17	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		<10	<10	20	10	<10
ED091 : Calcium Chloride Extractable Boron									
ø Boron	7440-42-8	0.2	mg/kg		----	----	----	<0.2	----
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		----	----	----	<1.00	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP30 - 20-30cm	VP30 - 50-60cm	VP30 - 80-90cm	VP2 - 10-10cm	VP2 - 20-30cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-006	EB1920844-007	EB1920844-008	EB1920844-009	EB1920844-010
					Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued									
ø **Iron**	7439-89-6	1.00	mg/kg		----	----	----	**48.1**	----
ø **Manganese**	7439-96-5	1.00	mg/kg		----	----	----	**5.67**	----
ø **Zinc**	7440-66-6	1.00	mg/kg		----	----	----	<1.00	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		----	----	----	**0.1**	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		----	----	----	**1.5**	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	----	----	**1.6**	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	----	----	**1.7**	----
Total Organic Carbon	----	0.5	%		----	----	----	**1.0**	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP2 - 50-60cm	VP29 - 10-10cm	VP29 - 20-30cm	VP29 - 50-60cm	VP29 - 80-90cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-011	EB1920844-012	EB1920844-013	EB1920844-014	EB1920844-015
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.0	6.6	6.8	5.5	5.7
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	19	57	12	161	312
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	----	2640	----	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	11.6	1.1	1.1	9.0	8.2
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Brown (10YR 5/3)	Very Dark Grayish Brown (10YR 3/2)	Brown (7.5YR 4/3)	Brown (10YR 5/3)	Light Yellowish Brown (10YR 6/4)
Texture	----	-	-	Sandy Clay Loam	Loamy Sand	Loamy Sand	Sandy Clay	Sandy Clay
Emerson Class Number	EC/TC	-	-	4	4	4	3	3
EA150: Particle Sizing								
+75µm	----	1	%	----	86	----	----	----
+150µm	----	1	%	----	74	----	----	----
+300µm	----	1	%	----	51	----	----	----
+425µm	----	1	%	----	22	----	----	----
+600µm	----	1	%	----	8	----	----	----
+1180µm	----	1	%	----	2	----	----	----
+2.36mm	----	1	%	----	<1	----	----	----
+4.75mm	----	1	%	----	<1	----	----	----
+9.5mm	----	1	%	----	<1	----	----	----
+19.0mm	----	1	%	----	<1	----	----	----
+37.5mm	----	1	%	----	<1	----	----	----
+75.0mm	----	1	%	----	<1	----	----	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	----	6	----	----	----
Silt (2-60 µm)	----	1	%	----	6	----	----	----
Sand (0.06-2.00 mm)	----	1	%	----	87	----	----	----
Gravel (>2mm)	----	1	%	----	1	----	----	----
Cobbles (>6cm)	----	1	%	----	<1	----	----	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	----	2.48	----	----	----
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP2 - 50-60cm	VP29 - 10-10cm	VP29 - 20-30cm	VP29 - 50-60cm	VP29 - 80-90cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-011	EB1920844-012	EB1920844-013	EB1920844-014	EB1920844-015
					Result	Result	Result	Result	Result
ED005: Exchange Acidity - Continued									
ø Exchange Acidity	----	0.1	meq/100g		6.0	----	----	0.6	1.0
ø Exchangeable Aluminium	----	0.1	meq/100g		6.9	----	----	0.4	0.1
ED007: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		<0.1	1.5	0.3	0.3	----
Exchangeable Magnesium	----	0.1	meq/100g		1.2	0.8	0.2	7.7	----
Exchangeable Potassium	----	0.1	meq/100g		0.2	0.6	0.2	0.8	----
Exchangeable Sodium	----	0.1	meq/100g		0.1	<0.1	<0.1	1.1	----
Cation Exchange Capacity	----	0.1	meq/100g		10.5	----	----	9.4	----
Cation Exchange Capacity	----	0.1	meq/100g		----	3.0	0.7	----	----
Exchangeable Sodium Percent	----	0.1	%		9.8	0.6	1.6	11.0	----
Calcium/Magnesium Ratio	----	0.1	-		<0.1	1.9	1.5	<0.1	----
Magnesium/Potassium Ratio	----	0.1	-		7.4	1.4	1.1	10.3	----
ED008: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		----	----	----	----	0.1
Exchangeable Magnesium	----	0.1	meq/100g		----	----	----	----	10.0
Exchangeable Potassium	----	0.1	meq/100g		----	----	----	----	0.5
Exchangeable Sodium	----	0.1	meq/100g		----	----	----	----	1.1
Cation Exchange Capacity	----	0.1	meq/100g		----	----	----	----	12.8
Exchangeable Sodium Percent	----	0.1	%		----	----	----	----	9.6
Calcium/Magnesium Ratio	----	0.1	-		----	----	----	----	<0.1
Magnesium/Potassium Ratio	----	0.1	-		----	----	----	----	20.8
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		<100	418	211	498	410
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		----	10	----	----	----
Sulfur as S	63705-05-5	10	mg/kg		----	<10	----	----	----
Silica	7631-86-9	1	mg/kg		----	40	----	----	----
Silicon	7440-21-3	1	mg/kg		----	19	----	----	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		10	20	<10	200	420
ED091 : Calcium Chloride Extractable Boron									
ø Boron	7440-42-8	0.2	mg/kg		----	<0.2	----	----	----
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		----	<1.00	----	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP2 - 50-60cm	VP29 - 10-10cm	VP29 - 20-30cm	VP29 - 50-60cm	VP29 - 80-90cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-011	EB1920844-012	EB1920844-013	EB1920844-014	EB1920844-015
					Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued									
ø **Iron**	7439-89-6	1.00	mg/kg		----	**63.3**	----	----	----
ø **Manganese**	7439-96-5	1.00	mg/kg		----	**8.80**	----	----	----
ø **Zinc**	7440-66-6	1.00	mg/kg		----	**2.20**	----	----	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		----	**0.2**	----	----	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		----	**7.1**	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	**7.3**	----	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	**15**	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	**2.2**	----	----	----
Total Organic Carbon	----	0.5	%		----	**1.2**	----	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP17 - 10-10cm	VP17 - 20-30cm	VP17 - 50-60cm	VP17 - 80-90cm	VP31 - 10-10cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-016	EB1920844-017	EB1920844-018	EB1920844-019	EB1920844-020
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.5	5.5	5.8	5.6	8.1
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	4	5	35	154	135
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	2160	----	----	----	1830
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	1.6	2.4	3.8	8.6	5.5
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Very Dark Brown (10YR 2/2)	Dark Brown (10YR 3/3)	Brown (10YR 5/3)	Dark Yellowish Brown (10YR 4/4)	Black (10YR 2/1)
Texture	----	-	-	Loamy Sand	Loamy Sand	Clay Loam, Sandy	Clay Loam, Sandy	Sandy Clay
Emerson Class Number	EC/TC	-	-	3	4	4	4	4
EA150: Particle Sizing								
+75µm	----	1	%	80	----	----	----	51
+150µm	----	1	%	62	----	----	----	34
+300µm	----	1	%	37	----	----	----	18
+425µm	----	1	%	25	----	----	----	12
+600µm	----	1	%	16	----	----	----	8
+1180µm	----	1	%	6	----	----	----	4
+2.36mm	----	1	%	2	----	----	----	2
+4.75mm	----	1	%	<1	----	----	----	<1
+9.5mm	----	1	%	<1	----	----	----	<1
+19.0mm	----	1	%	<1	----	----	----	<1
+37.5mm	----	1	%	<1	----	----	----	<1
+75.0mm	----	1	%	<1	----	----	----	<1
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	10	----	----	----	28
Silt (2-60 µm)	----	1	%	8	----	----	----	19
Sand (0.06-2.00 mm)	----	1	%	79	----	----	----	51
Gravel (>2mm)	----	1	%	3	----	----	----	2
Cobbles (>6cm)	----	1	%	<1	----	----	----	<1
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	2.48	----	----	----	2.13
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP17 - 10-10cm	VP17 - 20-30cm	VP17 - 50-60cm	VP17 - 80-90cm	VP31 - 10-10cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-016	EB1920844-017	EB1920844-018	EB1920844-019	EB1920844-020
				Result	Result	Result	Result	Result
ED005: Exchange Acidity - Continued								
ø Exchange Acidity	----	0.1	meq/100g	0.7	0.8	0.4	0.3	----
ø Exchangeable Aluminium	----	0.1	meq/100g	0.6	0.8	0.4	0.2	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	----	----	----	8.8
ø Exchangeable Magnesium	----	0.2	meq/100g	----	----	----	----	6.2
ø Exchangeable Potassium	----	0.2	meq/100g	----	----	----	----	0.3
ø Exchangeable Sodium	----	0.2	meq/100g	----	----	----	----	0.2
ø Cation Exchange Capacity	----	0.2	meq/100g	----	----	----	----	15.5
ø Exchangeable Sodium Percent	----	0.2	%	----	----	----	----	1.4
ø Calcium/Magnesium Ratio	----	0.2	-	----	----	----	----	1.4
ø Magnesium/Potassium Ratio	----	0.2	-	----	----	----	----	22.4
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	0.8	0.1	<0.1	<0.1	----
Exchangeable Magnesium	----	0.1	meq/100g	0.5	0.6	1.8	5.4	----
Exchangeable Potassium	----	0.1	meq/100g	0.4	0.3	0.2	0.2	----
Exchangeable Sodium	----	0.1	meq/100g	<0.1	<0.1	0.3	1.5	----
Cation Exchange Capacity	----	0.1	meq/100g	2.3	1.8	2.7	7.3	----
Exchangeable Sodium Percent	----	0.1	%	1.0	2.6	12.1	21.5	----
Calcium/Magnesium Ratio	----	0.1	-	1.6	0.2	<0.1	<0.1	----
Magnesium/Potassium Ratio	----	0.1	-	1.5	2.2	11.4	33.3	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	335	224	175	118	182
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	<10	----	----	----	<10
Sulfur as S	63705-05-5	10	mg/kg	<10	----	----	----	<10
Silica	7631-86-9	1	mg/kg	34	----	----	----	62
Silicon	7440-21-3	1	mg/kg	16	----	----	----	29
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	<10	<10	50	110	10
ED091 : Calcium Chloride Extractable Boron								
ø Boron	7440-42-8	0.2	mg/kg	<0.2	----	----	----	<0.2
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	<1.00	----	----	----	<1.00
ø Iron	7439-89-6	1.00	mg/kg	82.1	----	----	----	27.0

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP17 - 10-10cm	VP17 - 20-30cm	VP17 - 50-60cm	VP17 - 80-90cm	VP31 - 10-10cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-016	EB1920844-017	EB1920844-018	EB1920844-019	EB1920844-020
					Result	Result	Result	Result	Result
ED092: DTPA Extractable Metals - Continued									
ø **Manganese**	7439-96-5	1.00	mg/kg		**4.64**	----	----	----	**24.5**
ø **Zinc**	7440-66-6	1.00	mg/kg		<1.00	----	----	----	<1.00
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		**0.1**	----	----	----	**0.2**
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		**0.2**	----	----	----	**0.2**
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		**0.3**	----	----	----	**0.4**
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		**1.8**	----	----	----	**3.6**
Total Organic Carbon	----	0.5	%		**1.0**	----	----	----	**2.1**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP31 - 20-30cm	VP31 - 50-60cm	VP31 - 80-90cm	VP32 - 10-10cm	VP32 - 20-30cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-021	EB1920844-022	EB1920844-023	EB1920844-024	EB1920844-025
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	8.4	9.5	9.6	6.8	8.5
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	54	321	575	11	142
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	----	----	----	2890	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	12.2	13.1	12.9	2.4	7.8
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Black (10YR 2/1)	Black (10YR 2/1)	Black (10YR 2/1)	Very Dark Brown (7.5YR 2.5/2)	Very Dark Brown (7.5YR 2.5/3)
Texture	----	-	-	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay Loam	Clay Loam, Sandy
Emerson Class Number	EC/TC	-	-	3	3	4	3	3
EA150: Particle Sizing								
+75µm	----	1	%	----	----	----	55	----
+150µm	----	1	%	----	----	----	44	----
+300µm	----	1	%	----	----	----	27	----
+425µm	----	1	%	----	----	----	18	----
+600µm	----	1	%	----	----	----	11	----
+1180µm	----	1	%	----	----	----	4	----
+2.36mm	----	1	%	----	----	----	<1	----
+4.75mm	----	1	%	----	----	----	<1	----
+9.5mm	----	1	%	----	----	----	<1	----
+19.0mm	----	1	%	----	----	----	<1	----
+37.5mm	----	1	%	----	----	----	<1	----
+75.0mm	----	1	%	----	----	----	<1	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	----	----	----	32	----
Silt (2-60 µm)	----	1	%	----	----	----	11	----
Sand (0.06-2.00 mm)	----	1	%	----	----	----	55	----
Gravel (>2mm)	----	1	%	----	----	----	2	----
Cobbles (>6cm)	----	1	%	----	----	----	<1	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	----	----	----	2.24	----
ED006: Exchangeable Cations on Alkaline Soils								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP31 - 20-30cm	VP31 - 50-60cm	VP31 - 80-90cm	VP32 - 10-10cm	VP32 - 20-30cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-021	EB1920844-022	EB1920844-023	EB1920844-024	EB1920844-025
					Result	Result	Result	Result	Result
ED006: Exchangeable Cations on Alkaline Soils - Continued									
ø Exchangeable Calcium	----	0.2	meq/100g		9.4	5.7	4.3	----	4.3
ø Exchangeable Magnesium	----	0.2	meq/100g		10.1	16.4	17.7	----	10.0
ø Exchangeable Potassium	----	0.2	meq/100g		<0.2	<0.2	<0.2	----	<0.2
ø Exchangeable Sodium	----	0.2	meq/100g		1.5	4.5	5.8	----	2.1
ø Cation Exchange Capacity	----	0.2	meq/100g		21.0	26.6	27.7	----	16.4
ø Exchangeable Sodium Percent	----	0.2	%		7.0	16.9	20.8	----	13.0
ø Calcium/Magnesium Ratio	----	0.2	-		0.9	0.3	0.2	----	0.4
ED007: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		----	----	----	3.7	----
Exchangeable Magnesium	----	0.1	meq/100g		----	----	----	3.0	----
Exchangeable Potassium	----	0.1	meq/100g		----	----	----	0.2	----
Exchangeable Sodium	----	0.1	meq/100g		----	----	----	0.2	----
Cation Exchange Capacity	----	0.1	meq/100g		----	----	----	7.0	----
Exchangeable Sodium Percent	----	0.1	%		----	----	----	2.4	----
Calcium/Magnesium Ratio	----	0.1	-		----	----	----	1.2	----
Magnesium/Potassium Ratio	----	0.1	-		----	----	----	14.1	----
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		<100	<100	<100	146	<100
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		----	----	----	<10	----
Sulfur as S	63705-05-5	10	mg/kg		----	----	----	<10	----
Silica	7631-86-9	1	mg/kg		----	----	----	38	----
Silicon	7440-21-3	1	mg/kg		----	----	----	18	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		40	180	540	<10	80
ED091 : Calcium Chloride Extractable Boron									
ø Boron	7440-42-8	0.2	mg/kg		----	----	----	<0.2	----
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		----	----	----	<1.00	----
ø Iron	7439-89-6	1.00	mg/kg		----	----	----	26.6	----
ø Manganese	7439-96-5	1.00	mg/kg		----	----	----	6.80	----
ø Zinc	7440-66-6	1.00	mg/kg		----	----	----	<1.00	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		----	----	----	0.2	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP31 - 20-30cm	VP31 - 50-60cm	VP31 - 80-90cm	VP32 - 10-10cm	VP32 - 20-30cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-021	EB1920844-022	EB1920844-023	EB1920844-024	EB1920844-025
					Result	Result	Result	Result	Result
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		----	----	----	0.3	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	----	----	0.5	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	----	----	2.7	----
Total Organic Carbon	----	0.5	%		----	----	----	1.6	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP32 - 50-60cm	VP32 - 80-90cm	VP23 - 10-10cm	VP23 - 20-30cm	VP23 - 50-60cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-026	EB1920844-027	EB1920844-028	EB1920844-029	EB1920844-030
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	9.5	9.5	6.1	6.1	6.1
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	582	641	12	5	2
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	----	----	2880	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	8.0	7.6	2.4	3.0	1.5
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Brown (7.5YR 4/3)	Dark Yellowish Brown (10YR 4/4)	Very Dark Grayish Brown (10YR 3/2)	Very Dark Grayish Brown (10YR 3/2)	Dark Brown (10YR 3/3)
Texture	----	-	-	Sandy Clay	Clay Loam, Sandy	Loamy Sand	Loamy Sand	Loamy Sand
Emerson Class Number	EC/TC	-	-	4	4	3	3	4
EA150: Particle Sizing								
+75µm	----	1	%	----	----	86	----	----
+150µm	----	1	%	----	----	61	----	----
+300µm	----	1	%	----	----	39	----	----
+425µm	----	1	%	----	----	26	----	----
+600µm	----	1	%	----	----	14	----	----
+1180µm	----	1	%	----	----	3	----	----
+2.36mm	----	1	%	----	----	<1	----	----
+4.75mm	----	1	%	----	----	<1	----	----
+9.5mm	----	1	%	----	----	<1	----	----
+19.0mm	----	1	%	----	----	<1	----	----
+37.5mm	----	1	%	----	----	<1	----	----
+75.0mm	----	1	%	----	----	<1	----	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	----	----	7	----	----
Silt (2-60 µm)	----	1	%	----	----	6	----	----
Sand (0.06-2.00 mm)	----	1	%	----	----	86	----	----
Gravel (>2mm)	----	1	%	----	----	1	----	----
Cobbles (>6cm)	----	1	%	----	----	<1	----	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	----	----	2.56	----	----
ED006: Exchangeable Cations on Alkaline Soils								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP32 - 50-60cm	VP32 - 80-90cm	VP23 - 10-10cm	VP23 - 20-30cm	VP23 - 50-60cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-026	EB1920844-027	EB1920844-028	EB1920844-029	EB1920844-030
					Result	Result	Result	Result	Result
ED006: Exchangeable Cations on Alkaline Soils - Continued									
ø Exchangeable Calcium	----	0.2	meq/100g		**3.0**	**2.1**	----	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g		**9.5**	**9.6**	----	----	----
ø Exchangeable Potassium	----	0.2	meq/100g		<0.2	<0.2	----	----	----
ø Exchangeable Sodium	----	0.2	meq/100g		**2.8**	**3.2**	----	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g		**15.3**	**14.9**	----	----	----
ø Exchangeable Sodium Percent	----	0.2	%		**18.2**	**21.6**	----	----	----
ø Calcium/Magnesium Ratio	----	0.2	-		**0.3**	**0.2**	----	----	----
ED007: Exchangeable Cations									
Exchangeable Calcium	----	0.1	meq/100g		----	----	**1.3**	**1.2**	**0.9**
Exchangeable Magnesium	----	0.1	meq/100g		----	----	**0.7**	**0.6**	**0.5**
Exchangeable Potassium	----	0.1	meq/100g		----	----	**0.2**	**0.2**	**0.1**
Exchangeable Sodium	----	0.1	meq/100g		----	----	<0.1	<0.1	<0.1
Cation Exchange Capacity	----	0.1	meq/100g		----	----	**2.2**	**2.1**	**1.6**
Exchangeable Sodium Percent	----	0.1	%		----	----	**0.5**	**0.8**	**1.4**
Calcium/Magnesium Ratio	----	0.1	-		----	----	**1.8**	**2.0**	**1.8**
Magnesium/Potassium Ratio	----	0.1	-		----	----	**3.9**	**3.2**	**3.8**
ED021: Bicarbonate Extractable Potassium (Colwell)									
Bicarbonate Extractable K (Colwell)	----	100	mg/kg		<100	<100	**208**	**218**	**164**
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		----	----	<10	----	----
Sulfur as S	63705-05-5	10	mg/kg		----	----	<10	----	----
Silica	7631-86-9	1	mg/kg		----	----	**38**	----	----
Silicon	7440-21-3	1	mg/kg		----	----	**18**	----	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		**620**	**730**	<10	<10	<10
ED091 : Calcium Chloride Extractable Boron									
ø Boron	7440-42-8	0.2	mg/kg		----	----	<0.2	----	----
ED092: DTPA Extractable Metals									
ø Copper	7440-50-8	1.00	mg/kg		----	----	<1.00	----	----
ø Iron	7439-89-6	1.00	mg/kg		----	----	**76.0**	----	----
ø Manganese	7439-96-5	1.00	mg/kg		----	----	**4.24**	----	----
ø Zinc	7440-66-6	1.00	mg/kg		----	----	<1.00	----	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg		----	----	<0.1	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP32 - 50-60cm	VP32 - 80-90cm	VP23 - 10-10cm	VP23 - 20-30cm	VP23 - 50-60cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-026	EB1920844-027	EB1920844-028	EB1920844-029	EB1920844-030
					Result	Result	Result	Result	Result
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg		----	----	**1.0**	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg		----	----	**1.0**	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		----	----	**2.1**	----	----
Total Organic Carbon	----	0.5	%		----	----	**1.2**	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP20 - 10-10cm	VP20 - 20-30cm	VP20 - 50-60m	VP10 - 10-10cm	VP10 - 20-30cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-031	EB1920844-032	EB1920844-033	EB1920844-034	EB1920844-035
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.6	5.3	5.4	4.6	4.9
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	32	11	21	128	25
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	2620	----	----	2870	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	2.2	3.2	12.3	2.0	5.0
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Very Dark Gray (10YR 3/1)	Dark Brown (7.5YR 3/4)	Dark Reddish Brown (2.5YR 2.5/4)	Black (10YR 2/1)	Very Dark Brown (10YR 2/2)
Texture	----	-	-	Loamy Sand	Loamy Sand	Sandy Clay	Clayey Sand	Clayey Sand
Emerson Class Number	EC/TC	-	-	3	3	4	3	3
EA150: Particle Sizing								
+75µm	----	1	%	65	----	----	73	----
+150µm	----	1	%	39	----	----	49	----
+300µm	----	1	%	13	----	----	38	----
+425µm	----	1	%	8	----	----	26	----
+600µm	----	1	%	5	----	----	15	----
+1180µm	----	1	%	2	----	----	5	----
+2.36mm	----	1	%	<1	----	----	2	----
+4.75mm	----	1	%	<1	----	----	<1	----
+9.5mm	----	1	%	<1	----	----	<1	----
+19.0mm	----	1	%	<1	----	----	<1	----
+37.5mm	----	1	%	<1	----	----	<1	----
+75.0mm	----	1	%	<1	----	----	<1	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	14	----	----	12	----
Silt (2-60 µm)	----	1	%	19	----	----	10	----
Sand (0.06-2.00 mm)	----	1	%	66	----	----	75	----
Gravel (>2mm)	----	1	%	1	----	----	3	----
Cobbles (>6cm)	----	1	%	<1	----	----	<1	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	2.30	----	----	2.29	----
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP20 - 10-10cm	VP20 - 20-30cm	VP20 - 50-60m	VP10 - 10-10cm	VP10 - 20-30cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-031	EB1920844-032	EB1920844-033	EB1920844-034	EB1920844-035
				Result	Result	Result	Result	Result
ED005: Exchange Acidity - Continued								
ø Exchange Acidity	----	0.1	meq/100g	<0.1	1.1	1.8	1.1	2.4
ø Exchangeable Aluminium	----	0.1	meq/100g	<0.1	1.0	2.0	0.9	2.8
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	3.6	1.0	1.5	1.3	0.1
Exchangeable Magnesium	----	0.1	meq/100g	0.7	0.6	3.2	0.6	0.5
Exchangeable Potassium	----	0.1	meq/100g	0.4	0.2	0.2	0.5	0.3
Exchangeable Sodium	----	0.1	meq/100g	<0.1	<0.1	0.2	<0.1	<0.1
Cation Exchange Capacity	----	0.1	meq/100g	----	2.9	6.9	3.7	3.5
Cation Exchange Capacity	----	0.1	meq/100g	4.8	----	----	----	----
Exchangeable Sodium Percent	----	0.1	%	1.3	1.9	3.8	3.2	9.2
Calcium/Magnesium Ratio	----	0.1	-	5.1	1.7	0.5	2.2	0.2
Magnesium/Potassium Ratio	----	0.1	-	1.6	3.0	16.0	1.2	1.4
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	361	216	143	446	380
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	10	----	----	30	----
Sulfur as S	63705-05-5	10	mg/kg	<10	----	----	<10	----
Silica	7631-86-9	1	mg/kg	25	----	----	31	----
Silicon	7440-21-3	1	mg/kg	12	----	----	14	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	<10	<10	10	50	10
ED091 : Calcium Chloride Extractable Boron								
ø Boron	7440-42-8	0.2	mg/kg	<0.2	----	----	0.3	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	<1.00	----	----	<1.00	----
ø Iron	7439-89-6	1.00	mg/kg	45.4	----	----	226	----
ø Manganese	7439-96-5	1.00	mg/kg	12.0	----	----	8.00	----
ø Zinc	7440-66-6	1.00	mg/kg	1.40	----	----	<1.00	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	0.1	----	----	0.2	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	10.9	----	----	35.8	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	11.0	----	----	36.0	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP20 - 10-10cm	VP20 - 20-30cm	VP20 - 50-60m	VP10 - 10-10cm	VP10 - 20-30cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-031	EB1920844-032	EB1920844-033	EB1920844-034	EB1920844-035
					Result	Result	Result	Result	Result
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	<5
EP004: Organic Matter									
Organic Matter	----	0.5	%		**2.5**	**----**	**----**	**4.1**	**----**
Total Organic Carbon	----	0.5	%		**1.4**	**----**	**----**	**2.4**	**----**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP10 - 50-60cm	VP10 - 80-90cm	VP27 - 10-10cm	VP27 - 20-30cm	VP27 - 50-60cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-036	EB1920844-037	EB1920844-038	EB1920844-039	EB1920844-040
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.9	6.0	5.5	5.2	5.3
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	20	108	46	42	59
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	----	----	2780	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	11.6	9.9	1.0	4.3	5.3
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Dark Reddish Brown (5YR 3/4)	Dark Reddish Brown (5YR 3/4)	Very Dark Gray (10YR 3/1)	Dark Gray (10YR 4/1)	Dark Gray (10YR 4/1)
Texture	----	-	-	Sandy Clay Loam	Sandy Clay	Sandy Clay Loam	Sandy Clay	Sandy Clay
Emerson Class Number	EC/TC	-	-	3	2	3	3	3
EA150: Particle Sizing								
+75µm	----	1	%	----	----	60	----	----
+150µm	----	1	%	----	----	41	----	----
+300µm	----	1	%	----	----	21	----	----
+425µm	----	1	%	----	----	13	----	----
+600µm	----	1	%	----	----	7	----	----
+1180µm	----	1	%	----	----	3	----	----
+2.36mm	----	1	%	----	----	2	----	----
+4.75mm	----	1	%	----	----	<1	----	----
+9.5mm	----	1	%	----	----	<1	----	----
+19.0mm	----	1	%	----	----	<1	----	----
+37.5mm	----	1	%	----	----	<1	----	----
+75.0mm	----	1	%	----	----	<1	----	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	----	----	15	----	----
Silt (2-60 µm)	----	1	%	----	----	23	----	----
Sand (0.06-2.00 mm)	----	1	%	----	----	60	----	----
Gravel (>2mm)	----	1	%	----	----	2	----	----
Cobbles (>6cm)	----	1	%	----	----	<1	----	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	----	----	2.37	----	----
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP10 - 50-60cm	VP10 - 80-90cm	VP27 - 10-10cm	VP27 - 20-30cm	VP27 - 50-60cm
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit	EB1920844-036	EB1920844-037	EB1920844-038	EB1920844-039	EB1920844-040
				Result	Result	Result	Result	Result
ED005: Exchange Acidity - Continued								
ø Exchange Acidity	----	0.1	meq/100g	1.2	0.2	<0.1	0.8	0.5
ø Exchangeable Aluminium	----	0.1	meq/100g	1.2	0.2	<0.1	0.6	0.4
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	<0.1	<0.1	1.3	0.6	0.6
Exchangeable Magnesium	----	0.1	meq/100g	5.6	7.4	1.0	2.4	3.5
Exchangeable Potassium	----	0.1	meq/100g	0.6	0.4	<0.1	<0.1	<0.1
Exchangeable Sodium	----	0.1	meq/100g	0.6	1.4	0.1	0.3	0.4
Cation Exchange Capacity	----	0.1	meq/100g	8.1	9.6	----	4.2	4.9
Cation Exchange Capacity	----	0.1	meq/100g	----	----	2.5	----	----
Exchangeable Sodium Percent	----	0.1	%	8.4	15.4	5.2	8.2	8.9
Calcium/Magnesium Ratio	----	0.1	-	<0.1	<0.1	1.3	0.2	0.2
Magnesium/Potassium Ratio	----	0.1	-	9.5	16.3	----	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	385	292	<100	<100	<100
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	----	----	30	----	----
Sulfur as S	63705-05-5	10	mg/kg	----	----	<10	----	----
Silica	7631-86-9	1	mg/kg	----	----	158	----	----
Silicon	7440-21-3	1	mg/kg	----	----	74	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	20	140	40	50	110
ED091 : Calcium Chloride Extractable Boron								
ø Boron	7440-42-8	0.2	mg/kg	----	----	<0.2	----	----
ED092: DTPA Extractable Metals								
ø Copper	7440-50-8	1.00	mg/kg	----	----	<1.00	----	----
ø Iron	7439-89-6	1.00	mg/kg	----	----	163	----	----
ø Manganese	7439-96-5	1.00	mg/kg	----	----	5.16	----	----
ø Zinc	7440-66-6	1.00	mg/kg	----	----	<1.00	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	----	----	0.2	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	----	----	0.3	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	----	----	0.5	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP10 - 50-60cm	VP10 - 80-90cm	VP27 - 10-10cm	VP27 - 20-30cm	VP27 - 50-60cm
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00
Compound	CAS Number	LOR	Unit		EB1920844-036	EB1920844-037	EB1920844-038	EB1920844-039	EB1920844-040
					Result	Result	Result	Result	Result
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		<5	<5	<5	<5	**12**
EP004: Organic Matter									
Organic Matter	----	0.5	%		**----**	**----**	**2.5**	**----**	**----**
Total Organic Carbon	----	0.5	%		**----**	**----**	**1.4**	**----**	**----**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP5 - 0-10cm	VP5 - 20-30cm	VP5 - 50-60cm	----	----
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	----	----
Compound	CAS Number	LOR	Unit	EB1920844-041	EB1920844-042	EB1920844-043	--------	--------
				Result	Result	Result	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	5.4	5.4	5.6	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	14	7	6	----	----
EA051 : Bulk Density								
ø Bulk Density	BULK_DENSITY	1	kg/m3	2110	----	----	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	0.1	%	2.9	2.6	1.9	----	----
EA058: Emerson Aggregate Test								
Color (Munsell)	----	-	-	Dark Reddish Brown (2.5YR 2.5/3)	Reddish Brown (2.5YR 5/3)	Reddish Brown (2.5YR 4/4)	----	----
Texture	----	-	-	Gravelly Sand	Gravelly Sand	Gravelly Sand	----	----
Emerson Class Number	EC/TC	-	-	8	7	7	----	----
EA150: Particle Sizing								
+75µm	----	1	%	80	----	----	----	----
+150µm	----	1	%	67	----	----	----	----
+300µm	----	1	%	54	----	----	----	----
+425µm	----	1	%	48	----	----	----	----
+600µm	----	1	%	42	----	----	----	----
+1180µm	----	1	%	35	----	----	----	----
+2.36mm	----	1	%	28	----	----	----	----
+4.75mm	----	1	%	20	----	----	----	----
+9.5mm	----	1	%	7	----	----	----	----
+19.0mm	----	1	%	<1	----	----	----	----
+37.5mm	----	1	%	<1	----	----	----	----
+75.0mm	----	1	%	<1	----	----	----	----
EA150: Soil Classification based on Particle Size								
Clay (<2 µm)	----	1	%	8	----	----	----	----
Silt (2-60 µm)	----	1	%	10	----	----	----	----
Sand (0.06-2.00 mm)	----	1	%	52	----	----	----	----
Gravel (>2mm)	----	1	%	30	----	----	----	----
Cobbles (>6cm)	----	1	%	<1	----	----	----	----
EA152: Soil Particle Density								
Soil Particle Density (Clay/Silt/Sand)	----	0.01	g/cm3	1.88	----	----	----	----
ED005: Exchange Acidity								

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	VP5 - 0-10cm	VP5 - 20-30cm	VP5 - 50-60cm	----	----
			Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	----	----
Compound	CAS Number	LOR	Unit	EB1920844-041	EB1920844-042	EB1920844-043	--------	--------
				Result	Result	Result	----	----
ED005: Exchange Acidity - Continued								
ø **Exchange Acidity**	----	0.1	meq/100g	**1.7**	**1.7**	**1.3**	----	----
ø **Exchangeable Aluminium**	----	0.1	meq/100g	**1.7**	**1.9**	**1.4**	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	**3.1**	**0.1**	<0.1	----	----
Exchangeable Magnesium	----	0.1	meq/100g	**1.5**	**1.0**	**1.0**	----	----
Exchangeable Potassium	----	0.1	meq/100g	**0.8**	**0.2**	**0.1**	----	----
Exchangeable Sodium	----	0.1	meq/100g	<0.1	<0.1	<0.1	----	----
Cation Exchange Capacity	----	0.1	meq/100g	**7.3**	**3.1**	**2.4**	----	----
Exchangeable Sodium Percent	----	0.1	%	**1.5**	**1.3**	**1.5**	----	----
Calcium/Magnesium Ratio	----	0.1	-	**2.1**	**0.1**	<0.1	----	----
Magnesium/Potassium Ratio	----	0.1	-	**1.9**	**4.0**	**7.6**	----	----
ED021: Bicarbonate Extractable Potassium (Colwell)								
Bicarbonate Extractable K (Colwell)	----	100	mg/kg	**617**	**208**	**144**	----	----
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	<10	----	----	----	----
Sulfur as S	63705-05-5	10	mg/kg	<10	----	----	----	----
Silica	7631-86-9	1	mg/kg	**36**	----	----	----	----
Silicon	7440-21-3	1	mg/kg	**17**	----	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	<10	<10	<10	----	----
ED091 : Calcium Chloride Extractable Boron								
ø **Boron**	7440-42-8	0.2	mg/kg	<0.2	----	----	----	----
ED092: DTPA Extractable Metals								
ø **Copper**	7440-50-8	1.00	mg/kg	<1.00	----	----	----	----
ø **Iron**	7439-89-6	1.00	mg/kg	**89.6**	----	----	----	----
ø **Manganese**	7439-96-5	1.00	mg/kg	**9.81**	----	----	----	----
ø **Zinc**	7440-66-6	1.00	mg/kg	<1.00	----	----	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N (Sol.)	14797-65-0	0.1	mg/kg	**0.1**	----	----	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N (Sol.)	14797-55-8	0.1	mg/kg	**2.2**	----	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N (Sol.)	----	0.1	mg/kg	**2.3**	----	----	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	VP5 - 0-10cm	VP5 - 20-30cm	VP5 - 50-60cm	----	----
				Client sampling date / time	08-Aug-2019 00:00	08-Aug-2019 00:00	08-Aug-2019 00:00	----	----
Compound	CAS Number	LOR	Unit		EB1920844-041	EB1920844-042	EB1920844-043	--------	--------
					Result	Result	Result	----	----
EK080: Bicarbonate Extractable Phosphorus (Colwell)									
Bicarbonate Ext. P (Colwell)	----	5	mg/kg		**8**	<5	<5	**----**	**----**
EP004: Organic Matter									
Organic Matter	----	0.5	%		**6.0**	**----**	**----**	**----**	**----**
Total Organic Carbon	----	0.5	%		**3.5**	**----**	**----**	**----**	**----**

Appendix 2 Soil Profile Data

Project Name:

Zambezi

Date:	20/07		**Site:**	**VP1**	
Location:	Close to dyno gate		**Coordinates:**	**E 0622172**	**N 7534691**
Landform Pattern:	PLA		**Micro Relief:**	**0**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**0**	
Site Disturbance:	1		**Substrate:**	**0**	
Erosion:	SWXCS0		**Surface Condition:**	**S**	
Landform	Elevation:	251	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A	0-130		7.5YR4/3	0	S	0	G	0	D00N0	5.5	100
B1	130-300	CS	7.5YR4/4	0	S	0	G	0	D00N0	6	220
B2	300-880	DT	10YR5/4	M33D(OY)D	SCL	0	VS94PO	0	TSVN2	7	600

Vegetation: silver and yellow present

Notes: similar colours to vp7

Project Name:

Limpopo

Date:	20/07		**Site:**	**VP2**	
Location:	SE CORNER OF SIM CARD OPENER		**Coordinates:**	**E 0621443**	**N 7535596**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**0**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	SW1C0S1		**Surface Condition:**	**S**	
Landform	Elevation:	266	**Permeability:**	**3**	
	Slope (%):	2	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A	0-240		5YR5/1	0	S	0	G	0	D00M0	6	100
B	240-600	DI	5YR5/2	M4P(5YR5/8)C	CS	0	VS8CO	0	T42N2	5.5	400

Vegetation:

Notes:

Project Name:

Crocodile

Date:	20/07/2019		**Site:**	**VP3**	
Location:	Far northern corner		**Coordinates:**	**E 0619398**	**N 7536891**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	HSL		**Rock Outcrops:**	**0**	
Morphological Type:	M		**S C Fragments:**	**53STMOT**	
Site Disturbance:	2		**Substrate:**	**1AF**	
Erosion:	PWXCXS1		**Surface Condition:**	**F(QFK)M**	
Landform	Elevation:	286	**Permeability:**	**2**	
	Slope (%):	8	**Drainage:**	**4**	
	Relief:	9-30	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
01	1-2										
A1	240		7.5YR3/4	M21DRC	SCL	21APM (Source: SC)	G	0	D10N0	4.5	100
B	330	CT	2.5YR2.5/4	M42DRD	CL	0	VM23	0	D10N1	4,5	280
C	860	GI	*								

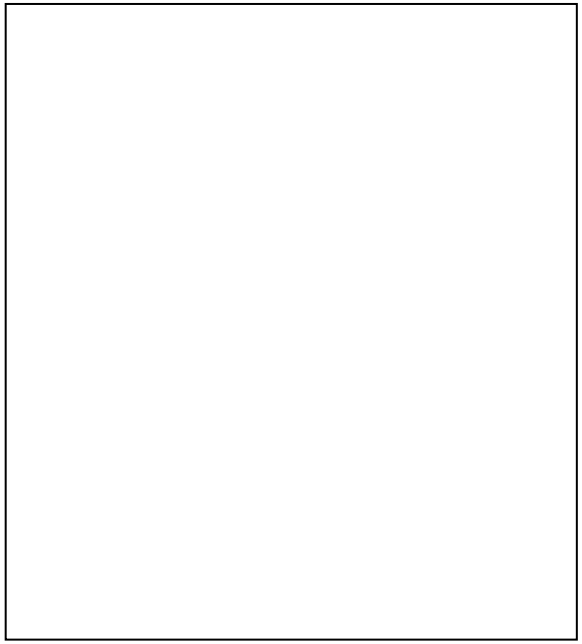
Vegetation: rock or substrate – rocks outer edge are bleached/grey, whilst inner core bright red

Notes:inner core: 2.5yr3/6, outer core: 2.5yr5/1

Project Name:

Crocodile

Date:	20/07/2019		**Site:**	**VP4**	
Location:	S-W SIDE OF SIM CARD OPENER BEND		**Coordinates:**	**E0619869**	**7535917N**
Landform Pattern:	PLT		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**2SA**	
Morphological Type:	F		**S C Fragments:**	**34S**	
Site Disturbance:	2		**Substrate:**	**2XV(QF)VS**	
Erosion:	SWXCXS1		**Surface Condition:**	**S**	
Landform	Elevation:	306	**Permeability:**	**3**	
	Slope (%):	1	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**3**	



[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	consistency	Field pH	
A	200		10YR2/1	0	LS	FINE SAND	VW2PO	0	D10N0	5	100
B2	400	CI	2.5YR5/8	0	S		VS5PO	0	D10N0	5.5	300
B3	500	AS	5YR5/8	0	S		G	0	D10N0	5.5	450

Vegetation: some yellow plants present

Notes: om present in a horizon

Project Name:

Crocodile

Date:	20/07		**Site:**	**VP5**	
Location:	End of lower road		**Coordinates:**	**E 0620132**	**N 7534334**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	HSL		**Rock Outcrops:**	**1SA**	
Morphological Type:	M		**S C Fragments:**	**44AROT + CHARCOAL**	
Site Disturbance:	2		**Substrate:**	**2XV(QF)M**	
Erosion:	SWXCXS1		**Surface Condition:**	**F**	
Landform	Elevation:	327	**Permeability:**	**3**	
	Slope (%):	5	**Drainage:**	**4**	
	Relief:	9-30	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A			10YR2/1	M1PYD	S	31A_CC	G	0	D00NO	5.5	100
ROCK	200-530	GB	10YR5/2	N	ROCK	67RPROT	0	0		5	350
B	530-800	AS	7.5YR5/3	M2DYD	S	N	VM7PL	0	D40N0	5	700

Vegetation: yellow fluff ball tree

Notes: A lot of charcoal present contributing to the dark colour of A

Project Name:

Crocodile

Date:	19/07/2019		**Site:**	**VP6**	
Location:	N-W CORNER		**Coordinates:**	**E0618158**	**N7534318**
Landform Pattern:	PLT		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**22ST**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	SWXC0S0		**Surface Condition:**	**S**	
Landform	Elevation:	331	**Permeability:**	**3**	
	Slope (%):	4 º	**Drainage:**	**6**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
O1	SURFACE										
A	0-180		10YR2/2	0	CS	11R(U)M	W3PO	0	D10N0	5.5	170
UPPER B	180-255	AS	10YR3/2	0	LS	12R(U)VS	W3PO	0	D10N0	5.5	220
CONFINING	244-350	SS	R/O/Y	0		63A(U)VS	S5AB	0	D60_0	N	300
LOWER B	410	SS	10YR3/1	0	LS	12A(U)M	W3PO	0	D10N0	5.5	380

Vegetation:

Notes:

Project Name:

Limpopo

Date:	20/07		**Site:**	**VP7**	
Location:	Just past second N gate		**Coordinates:**	**E 0621394**	**N 7534825**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**0**	
Site Disturbance:	1		**Substrate:**	**0**	
Erosion:	SWXCXS1		**Surface Condition:**	**F**	
Landform	Elevation:	265	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2 (GRASSCOVER)**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A	0-150		10YR3/2	0	S	0	G	0	D00N0	5	100
B1	150-550	GS	10YR5/6	0	S	0	VW2PO	0	D10N0	6	330
B2	550-1000	DT	10YR4/4	M43PRC	SL	0	VM3PO	0	T31N2	5.5	830

Vegetation: Silver trees present and grass cover

Notes:

Project Name:

Crocodile

Date:	21/07		**Site:**	**VP8**	
Location:	Along upper road next to valley		**Coordinates:**	**E 0621121**	**N 7534592**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	HSL		**Rock Outcrops:**	**2ZS (**ROCK OUT CROP STRONGER THAN SUBSTRATE)	
Morphological Type:	U		**S C Fragments:**	**62SPMOT**	
Site Disturbance:	1		**Substrate:**	**1AB(DL)m**	
Erosion:	PWXCXS2		**Surface Condition:**	**F**	
Landform	Elevation:	287	**Permeability:**	**1**	
	Slope (%):	10	**Drainage:**	**5**	
	Relief:	9-30	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-60		10YR3/2	0	LS	44ATMM	G		D10N0	5.5	30
A2	60-220	AS	10YR3/3	0	LS	55ATMM	G		D10NO	5.5	130
C	220-690	GB	DARK TO RED SHALE	0						5.5	470

Vegetation: On a shaley ridge

Project Name:
Notes:

Limpopo

Date:	23/07/19		**Site:**	**VP9**	
Location:	AT SW OF UNCONNECTED RD		**Coordinates:**	**E 0622643**	**N 7524033**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**11U_(OT/IS)**	
Site Disturbance:	1		**Substrate:**		
Erosion:	PWXCXS1G2		**Surface Condition:**	**H**	
Landform	Elevation:	256	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

*MORE RED MOTTLING (>80%) HOWEVER SOME BROWN SIOL FROM UB STILL PRESENT

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-30		5YR2.5/1		CS		VW2PL		D10N0	7	20
A2	30-200	AS	7.5YR2.5/2		SL		VW3PO		D10N0	7	120
UB	200-860	AS	10YR3/2	M12FYD	LC		VS4PO		T51N3	8.5	620
LB	860-1070	DB	5YR4/6	*	MC		VS3PO		T53N3	8.5	920

Vegetation: LSLDB SOME BLACK WATTLE IN DISTANCE

Project Name:
Notes:

Sabie

Date:	21/07/19		**Site:**	**VP10**	
Location:	INWARDS OF E ROAD ZIG ZAG BEND		**Coordinates:**	**E 0624173**	**N 752924**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**SANDSTONE**	
Morphological Type:	F		**S C Fragments:**	**21S_OT**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	S		**Surface Condition:**	**F**	
Landform	Elevation:	256	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-100		2.5YR2.5/1	0	LS	0	VW2PO	0	D01N0	4.5	50
A2	100-500	CS	2.5YR3/1	0	SL	0	G	0	D00N0	4.5	200
B	500-980	DB	2.5YR5/1	M43DRC	CLS	22SRS	VM3PO	0	T42N3	5	660

Vegetation: GRASSCOVER AND SHRUBS

Project Name:

Notes:

Sabie

Date:	24/07/2019		**Site:**	**VP 11**	
Location:	Rd towards triple gate		**Coordinates:**	**E 0623518**	**N 7527898**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21A_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**F SOME C**	
Landform	Elevation:	253	**Permeability:**	**3**	
	Slope (%):	2	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-70		5YR2.5/2		LS		G		D00N0	5.8	20
A2	70-420	AS	7.5YR4/4		CS		G		D00N0	5.5	180
B	420-970	CS	7.5YR4/1	M32DRD	MC		VM3PO		T31N3	5.5	

Vegetation: SIMILAR TO VP 20 MAYBE

Project Name:

Notes:

Sabie

Date:	22/07/19		**Site:**	**VP12**	
Location:	JUST BELOW RIDGE BY SNAKE TONGUE		**Coordinates:**	**E 0621935**	**N 7528227**
Landform Pattern:	HIL		**Micro Relief:**	**D**	
Landform Element:	FOO		**Rock Outcrops:**	**3SA**	
Morphological Type:	L		**S C Fragments:**	**56AROT**	
Site Disturbance:	2		**Substrate:**	**2PM(QFMmaybeS)M**	
Erosion:	S		**Surface Condition:**	**F**	
Landform	Elevation:	279	**3**	**F**	
	Slope (%):	8	**5**	**3**	
	Relief:	9-30	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	50		2.5YR2.5/2		S		VW2PO		D10N0	5	30
A2	50-260	AS	2.5YR3/3	M11FOD	SL		VW2PO		D10N0	5	200
B	260-480	GS	2.5YR3/2		CL	42STMM	VW2PO		D21N2	5	350

Vegetation: ACACIA MONO. S, FEW BLOODWOOD* (CHECK)

Project Name:
Notes:

Limpopo

Date:	24/07/19		**Site:**	**VP13**	
Location:	AT THE END OF COW ROAD		**Coordinates:**	**E 0625893**	**N 7523732**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21S_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	231	**Permeability:**	**4**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-90		75YR4/4		S (K)		G		D00N0	7	20
A12	90-360	CS	10YR3/2		LS		VW3PO		D10N0	6	300
A2	360-710	CSGS	10YR5/2		LS (Z)		VW3PO		D10N0	6	550
B	710-980	GI	10YR4/2	M22D(OY)D	ZCL		VM3PO		T22N2	8	800R

Vegetation: SIMILAR VP20 POTENTIALLY

Project Name:

Sabie

Date:	22/07/19		**Site:**	**VP14**	
Location:	SW OF S DYNO GATE		**Coordinates:**	**E 0624777**	**N 7528253**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	US		**S C Fragments:**	**21S_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS1G1		**Surface Condition:**	**H -> MINOR G**	
Landform	Elevation:	221	**Permeability:**	**2**	
	Slope (%):	3	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

**A HORIZON WAS NOT AS WET AS APPEARS IN PICTURE DUE TO DIFFICULTY OF REMOVAL FROM CORE

DEPTHS, BOUNDARY AND STRUCTURE INNACURATE DUE TO DIFFICULTY OF REMOVAL

[Soil Description]

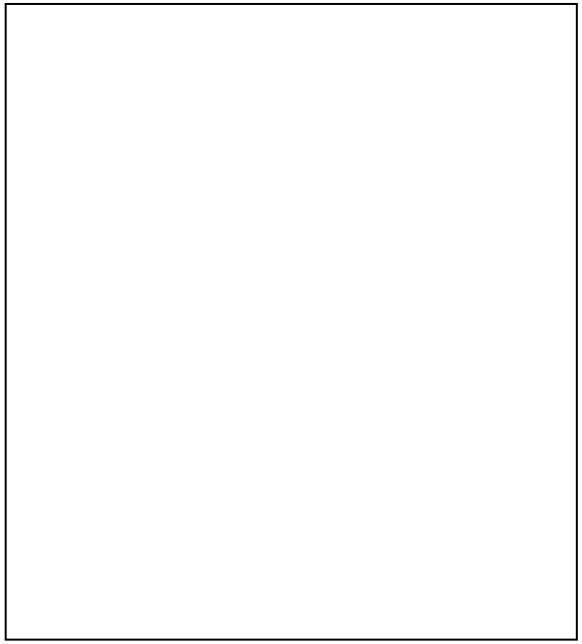
Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	140		7.5YR3/3		S		G		D00N0	5.5	70
A2	140-330	CS	7.5YR4/4		S	42U_S	G		D00N0	5.5	240
ROCK	330-520	GS	RED & BROWN ROCKS		S	65ST_VS	G			6	470
B	520-1030	CS	7.5YR5/1	M>44PRD	MC	42U_S	VM3PO		T41N3	5.5	740
			A LOT OF RED MOTTLE	HOWEVER, SOIL STILL GREY							

Vegetation: SW SIDE HAS BLACK WATTLE, NE SIDE HAS DARK SHRUBBY

Project Name:

Limpopo

Date:	21/07		**Site:**	**VP15**	
Location:	E of right angled bend		**Coordinates:**	**E 0618033**	**N 7531375**
Landform Pattern:			**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**2SA**	
Morphological Type:	PLA		**S C Fragments:**	**0**	
Site Disturbance:	F		**Substrate:**	**2XV(QFM)M**	
Erosion:	0		**Surface Condition:**	**F**	
Landform	Elevation:	415	**Permeability:**	**3**	
	Slope (%):	3	**Drainage:**	**5**	
	Relief:	<9	**Run-off:**	**2**	



[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-50		2.5YR3/1	0	S	0	G	0	D0N0	5.5	20
A2	50-280	BS	2.5YR4/2	M22DYD	S	0	G	0	D1N0	5.5	200
B	280-390	BG	5YR5/2	M33PRC	CS	0	V3PO	0	T3N1	5.5	330
C	390-410	AS									

Vegetation: yellow and silver trees

Notes: similar to VP2

Project Name:

Sabie

Date:	23/07/19		**Site:**	**VP16**	
Location:	EN ROUTE TO TRIPLE GATE		**Coordinates:**	**E 0624196**	**N 7525914**
Landform Pattern:	PLS		**Micro Relief:**	**D**	
Landform Element:	HSL		**Rock Outcrops:**		
Morphological Type:	M		**S C Fragments:**	**ONLY UNDECOMPOSED OM**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	244	**Permeability:**	**3**	
	Slope (%):	4	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-230		7.5YR3/3		S		G		D00N0	7	200
A12	230-360	GS	7.5YR3/4		S		G		D00N0	6.5	370
A2	360-670	CS	7.5YR4/6		S		G		D00N0	7	700
B	670-770	AS	5YR4/6		CSL		G(CONSOLIDATED)		T21N1	6.5	820

Vegetation: VARIATIONS OF GUM

Notes:

Project Name:

Limpopo

Date:	23/07/19		**Site:**	**VP17**	
Location:	SOUTH OF VP12/20		**Coordinates:**	**E 0621336**	**N 7527694**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	FOO		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**11S_OY**	
Site Disturbance:	2		**Substrate:**	**2PV(QFMmS)**	
Erosion:	PWXCXS1G2		**Surface Condition:**	**S**	
Landform	Elevation:	295	**Permeability:**	**3**	
	Slope (%):	3	**Drainage:**	**4**	
	Relief:	9-30	**Run-off:**	**4**	

A2->b – similar colour but texture difference

Ub->lb – similar texture but different colour

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-200		7.5YR3/4		LS		GW2PO		D10N0	5	20
A2	200-500	GS	7.5YR4/6		LS		GW3PO		D10N0	5	30
UB	500-700	GS	7.5YR4/6	M22F(OY)D	SCL	22URS	GM4PO		T30N1	6	660
LB	700-1000	CB	10YR4/4	M32D(OR)C	CL	22URS	GM4PO		T31N2	6	860

Vegetation:lower plain dominated by silver boys&blackwattle w/ eucalypts on ridge

Notes:

Project Name:

Limpopo

Date:	21/07		**Site:**	**VP18**	
Location:	Northerly point on triple gate		**Coordinates:**	**E 0622928**	**7532441 N**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**1SA**	
Morphological Type:	F		**S C Fragments:**	**21S_OT**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	SWXCXSX		**Surface Condition:**	**S**	
Landform	Elevation:	243	**Permeability:**	**3**	
	Slope (%):	2	**Drainage:**	**5**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-150		0	S	S	-	G	-	D00N0	5	90
A2	150-560	CS	0	CS	CS	-	G	-	D10N0	5.5	360
B	560-1010	AS	M23DRD	CL	CL	-	V3PO	-	T32N3	6.5	840

Vegetation: Yellow, long skinny-dark bark and silver

Notes:

Project Name:

Zambezi

Date:	23/07/19		**Site:**	**VP19**	
Location:	Open plain , s of VP11		**Coordinates:**	**E 0623552**	**N 7527004**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**1(SA/ZS)**	
Morphological Type:	F		**S C Fragments:**	**11R_OT**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**F**	
Landform	Elevation:	254	**Permeability:**		
	Slope (%):	0	**Drainage:**	**REFER TO PHOTOS**	
	Relief:	<9	**Run-off:**		

*A1 couldve probably been further subdivided into A11 AND A12

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-120		7.5YR3/3		LS		GW2PL		D10N0	5	50
A2	120-390	AS	7.5YR4/3		LS		GW3PL		D10N0	6	200
UB	390-640	AW	7.5YR6/1	M32DYD	ZCL	22RS	GM4PO		T31N2	6	470
LB	640-910	DS	7.5YR6/1	M32D(YO)D	ZCL	22RS	GM4PO	1KN2	T31N3	6	800

Vegetation: LSLDB, KNEE HEIGHT AND YELLOW GRASS

Notes:

Project Name:

Sabie

Date:	22/07/19		**Site:**	**VP20**	
Location:	NEAR END OF SNAKE TONGUE		**Coordinates:**	**E 0620593**	**N 7528364**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	FOO		**Rock Outcrops:**		
Morphological Type:	L		**S C Fragments:**	**21A_IS**	
Site Disturbance:	2		**Substrate:**	**2PV(QFMmaybeS)VW**	
Erosion:	PWXCXS1		**Surface Condition:**	**SLIGHT C**	
Landform	Elevation:	354	**Permeability:**	**3**	
	Slope (%):	5	**Drainage:**	**5**	
	Relief:	9-30	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-40		2.5YR2.5/1		LS		VM3CO		D10N0	5	20
A2	40-330	AS	5YR3/3		CS		G		D00N0	5	180
B	330-600	CS	5YR5/1	M43DRD	CLS	12S_OT	VM3PO		T41N2	5	500

Vegetation: ACACIA MONO. S, GUM -> SIMILAR TO RED MOTTLED STUFF SEEN EARLIER

Project Name:

Sabie

Date:	21/07		**Site:**	**VP21**	
Location:	NW CORNER, SW OF RED DAM		**Coordinates:**	**E 0616998**	**N 75322415**
Landform Pattern:	RIS		**Micro Relief:**	**D**	
Landform Element:	HSL		**Rock Outcrops:**	**Q (SURROUNDING OUTCROPS)**	
Morphological Type:	F		**S C Fragments:**	**11UROT**	
Site Disturbance:	1		**Substrate:**	**X**	
Erosion:	PWXCXS2		**Surface Condition:**	**H**	
Landform	Elevation:	368	**Permeability:**	**3**	
	Slope (%):	3	**Drainage:**	**4**	
	Relief:	9-30	**Run-off:**	**2 (ALMOST 100% GROUNDCO**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	140		5YR2.5/1	0	L	0	V3PO	0	D20N1	6	50
A2	140-410	CS	5YR2.5/2	0	SCL	0	V4PO	0	D20N1	6	250
B	410-820	GI	5YR3/3	M23RD	CL	0	V4SB	0	T42N3	6	600

Vegetation: A lot of gum trees and dark bark long skinny leaves

Project Name:

Notes:

Limpopo

Date:	21/07/19		**Site:**	**VP22**	
Location:	// TO HIGHWAY		**Coordinates:**	**E**	**N**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**21S_OT**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	242	**Permeability:**	**4**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	100		2.5YR2.5/2	0	S	0	G	0	D00N0	5.5	50
A2	100-480	CS	2.5YR5/3	M22FYD	S	0	G	0	D10N0	5.5	300
B	480-900	DS	2.5YR6/1	M43PRC	SL	21S_S	G	0	T41N3	5.5	700

Vegetation:

Project Name:
Notes:

Zambezi

Date:	21/07/19		**Site:**	**VP23**	
Location:	Near melaleuca watercourse		**Coordinates:**	**E**	**N**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**0**	
Morphological Type:	F		**S C Fragments:**	**0**	
Site Disturbance:	2		**Substrate:**	**0**	
Erosion:	S		**Surface Condition:**	**M**	
Landform	Elevation:	210	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**5**	
	Relief:	9-30	**Run-off:**	**2**	

Anomaly

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-140	AS	5YR2.5/2	0	S	0	G	0	T0010	5.5	90
A2	140-310	SS	5YR2.5/2	0	S	0	G	0	“”	6	290
B	310-700	AS	7.5YR4/4	0	S	0	G	0	D0010	6	580

Vegetation: A1 AND A2 WERE INCREDIBLY SIMILAR HOWEVER, SEPERATED BY A THIN YELLOW SANDY BAND. GUM TREES, MALALEUCA, BLACK WATTLE

Project Name:

Notes:

Limpopo

Date:	22/07/19		**Site:**	**VP24**	
Location:	JUST NE OF DYNO GATE		**Coordinates:**	**E062492**	**N 7529540**
Landform Pattern:	PLS		**Micro Relief:**	**D**	
Landform Element:	PLS		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**11ST_OT**	
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS1G1		**Surface Condition:**	**L**	
Landform	Elevation:	231	**Permeability:**	**3**	
	Slope (%):	1	**Drainage:**	**5**	
	Relief:	<9M	**Run-off:**	**1 VEG + SANDY SOIL**	

Anomaly

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-180		2.5Y3/2		S		G		D00N0	5	80
A2	180- 850	GS	2.5Y5/4		S		G		T00N0	5	500

Vegetation: BLACK WATTLE, MALALEUCA

Project Name:
Notes:

Zambezi

Date:	24/07/2019		**Site:**	**VP25**	
Location:	South of VP39		**Coordinates:**	**E 0629401**	**N 7525245**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	1		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	202	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-150		2.5YR2.5/2		LS		G		T00NO	6.5	20
A2	150-385	GS	7.5YR4/4		LS		G		T00N0	8	260
UB	385-680	CI	10YR5/6	M3D(YO)D	SCL		VM3PO		T21U1	7.5	600
LB	680-960	GS	10YR5/4	M3D(OY)D	CLS		VM3PO		T21N2	8.5	810

Vegetation: dense grass, more trees than VP31, POPLAR boxes (compare with VP16 as this also had polar box)

Project Name:

Notes:

Kei

Date:	25/07/19		**Site:**	**VP26**	
Location:	Pointy corner		**Coordinates:**	**E 0630829**	**N 7522138**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	1		**Substrate:**		
Erosion:	PWXCX51G1		**Surface Condition:**	**F**	
Landform	Elevation:	215	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**1**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-170		10YR3/2		SL (F)		G		D00N0	5.5	20
A12	170-420	DS	10YR4/4		SL		G		D00N0	6.5	300
A2	420-630	GS	10YR4/4		SL		G		D00N0	7	550
B	630-980	CS	10YR4/3	M33D0C	ZCL		VM3PO		T31N3	7	850

Vegetation: Poplar boxes, black spear grass

Project Name:

Notes:

Fish

Date:	25/07/19		**Site:**	**VP27**	
Location:	Nxt to car graveyard		**Coordinates:**	**E 0629951**	**N 7522644**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**22S_IS (maybe sesquioxides)**	
Site Disturbance:	2		**Substrate:**	**2XV(QMD)S**	
Erosion:	PWXCXS1G1		**Surface Condition:**	**S,C**	
Landform	Elevation:	218	**Permeability:**	**3**	
	Slope (%):	3	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	¾	

Bloodwood-low fertility, skeletal soils

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-90		10YR4/1		LS		VW3PL		D10N0	6	20
A2	90-380	CS	10YR5/1		CLS		VW2PO		D11N2	5.5	240
B	380-540	AS	10YR5/1	M12D(RO)D	ZCL	1(1/2)S_S	VM3PO		T32N3	5.5	520
SUBS	540	SS									

Vegetation: Poplar box, some black wattle, dominant was bloodwood

Project Name:

Notes:

Limpopo

Date:	25/07/19		**Site:**	**VP28**	
Location:	Far south		**Coordinates:**	**E 0629153**	**N 7521863**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**214S_IS/OT**	
Site Disturbance:	2		**Substrate:**	**-**	
Erosion:	S		**Surface Condition:**	**F**	
Landform	Elevation:	218	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**2 (SANDY TOP,SOIL, FLAT+VEG**	

-Had a 40mm band of sand between UB and LB (had same colour and texture as A2 but consistency different T21N0 and pH 6.5)

-LB had a much sandier texture than UB

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-70		10YR4/3	-	LS (F)	-	G		D00N0	6	20
A12	70-280	GS	10YR4/4	-	LS (F)	-	G		D00N0	5.5	200
A2	280-360	CS	10YR5/4	-	LS (F)	-	G		D00N0	5.5	320
UB	360-520	CS	10YR5/3	M1FYD	CLS	-	VM3PO		D41N3	5.5	410
LB	560-920	GI	10YR5/3	M1FYD	SL	11S_S	G (MASSIVE)		D00N1	7	630

Vegetation: Black wattle, silver leaf iron bark

Project Name:
Notes:

Zambezi

Date:	24/07/2019		**Site:**	**VP29**	
Location:	Near nose shaped watercourse		**Coordinates:**	**E 0628119**	**N 7523174**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	3		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	217	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**Slow run-off**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-140		10YR3/2		LS (K)		G		D00N0	6.5	40
A2	140-260	CS	10YR5/4		LS (K)		G		D00N0	7	220
UB	260-550	AS	10YR6/2	M42D(RBO)D	CLS		VM3PO		T32N2	6.5	410
LB	550-920	GS	10YR7/2	M22D(OY)D	CLS		VM3PO		T32N2	6	780

Vegetation: Poplar Boxes and grassy (black wattle further south)

Project Name:

Notes:

Kei

Date:	25/07/19		**Site:**	**VP30**	
Location:	@southern cow yards		**Coordinates:**	**E 0630290**	**N 7523999**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	4		**Substrate:**		
Erosion:	PWXCXS1		**Surface Condition:**	**F**	
Landform	Elevation:	208	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**3**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-180		7.5YR3/2		CS		VW3PO/PL		D10N0	6	20
A12	180-530	GS	7.5YR3/4		LS (F)		G		D00N0	7	400
A2	530-740	CS	10YR4/4		LS (F)		G		D00N0	7.5	660
B	740-1020	GB	10YR4/2	M12FYD	MC		VM4PO		T33N3	7.5	809

Vegetation: Poplar box

Project Name:

Notes:

Orange

Date:	24/07/2019		**Site:**	**VP31**	
Location:	S of OP 40		**Coordinates:**	**E 0628635**	**N 7526061**
Landform Pattern:	PLA		**Micro Relief:**	**N (maybe S)**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**G, potentially M**	
Landform	Elevation:	213	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**		
	Relief:	<9M	**Run-off:**	**2 -> flat**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-40		2.5Y2.5/1		LC		VM2PO		D21N3	7	20
A2	40-360	AS	2.5Y3/1		LMC	11SRS	VS4PO		T42N2	8.5	200
B	360-980	AS	2.5Y3/1		LMC	21SRS	VS4PO	2KN2	T262N2	9	650

Vegetation: Open grassland with shrubs (concaberry…carissa xxx)

Project Name:

Notes:

Komati

Date:	22/07/19		**Site:**	**VP32**	
Location:	// WITH SARAJI ROAD		**Coordinates:**	**E 0626996**	**N 7528119**
Landform Pattern:	PLA		**Micro Relief:**	**N SOME CRACKING**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21S_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**G/H**	
Landform	Elevation:	229	**Permeability:**	**2**	
	Slope (%):	2	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-80		7.5YR3/3		CS		GW3PO		D10N0	5	50
A2	80-450	CS	7.5 YR 4/4	M32DOD	SCL		GM3PO		T32N2	8	300
U B	450-860	AS	7.5YR5/6		CL		GM4PR	4KN2	T42N3	9	700
L B	860-1040	DS	7.5YR4/4		CL		GM4PR	4KN2	T42N3	9	1000

Vegetation: GHOST GUM (CONFIRM ON PHOTOS) -> CALCAROUS SODOSOL

Project Name:
Notes:

Limpopo

Date:	24/07/2019		**Site:**	**VP 33**	
Location:	Near tributary confluence		**Coordinates:**	**E 0625335**	**N 7522263**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21S_(IS/OT)**	
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS1		**Surface Condition:**	**F SOME C**	
Landform	Elevation:		**Permeability:**		
	Slope (%):	0	**Drainage:**		
	Relief:	<9M	**Run-off:**		

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-100		7.5YR4/3		SL		VW2PL		D10N0	6	40
A12	100-270	AS	7.5YR3/4		SL		G		D00N0	6	240
A2	270-400	CS	7.5YR4/6		SL		G		D00N0	6	360
UB	400-860	CS	7.5YR5/8		SCL		VW3PO		T21W1	5.5	560
LB	860-920	AS	5YR4/6		CLS		VW3PO		T21N2	5,5	900

Vegetation: Silver leaf iron bark, couple black wattle, some poplar

Project Name:

Notes:

Komati

Date:	23/07/2019		**Site:**	**VP34**	
Location:	IN PUNCHBOWL		**Coordinates:**	**E 0626643**	**N 7526781**
Landform Pattern:	PLA		**Micro Relief:**	**N/S (GILGAI APPROX 20CM)**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	3		**Substrate:**		
Erosion:	S		**Surface Condition:**	**G**	
Landform	Elevation:	236	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**3**	
	Relief:	<9	**Run-off:**	**3**	

UPPER HALF, BLACK AND CRACKY LIKE VERT, BUT BOTTM HALF IS A BROWN CLAY

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-80		10YR2/1		LMC		VM2PO		T21N1	8.5	21
A2	80-320	AS	10YR2/2		LMC	11S_2	VM3PO	2KN2	T21N1	8.5	160
UB	320-790	GS	7.5YR4/6		MC	11S_S	VW2PO	4KN3	T12N3	8.5	500
LB	790-1190	CB	7.5YR6/4		CLS		VW2PO	5KN3	T12N2	8.5	1070

Vegetation:

Project Name:

Notes:

Orange

Date:	22/07/19		**Site:**	**VP35**	
Location:	Off the southern border of zig zag bend		**Coordinates:**	**E0625692**	**N 7528649**
Landform Pattern:	PLA		**Micro Relief:**	**N**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**11U_OT**	
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS2		**Surface Condition:**	**G MAYBE M TOO**	
Landform	Elevation:	233	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	130		10YR2/1		LC		VM3PO		D32N3	6	100
A2	130-640	DS	10YR2/1		LMC		VM5SB		T52N3	8.5	380
B	640-1200	DS	10YR3/1		LMC	SOME SAND PRESENT IN PATCHES	G		T52N3	8.5	1000

Vegetation: ACACIA MONO S.

Project Name:
Notes:

Zambezi

Date:	23/07/2019		**Site:**	**VP36`**	
Location:	PAST VD11 TOWARDS TRIP GATE		**Coordinates:**	**E 0624632**	**N 7527796**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**	**X - assume sandstone**	
Morphological Type:	F		**S C Fragments:**	**Only veg**	
Site Disturbance:	2		**Substrate:**	**2XV(QMmS)**	
Erosion:	PWXCXS2		**Surface Condition:**	**F**	
Landform	Elevation:	246	**Permeability:**	¾	
	Slope (%):	3	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-200		7.5YR4/2		S		G		D00N0	5.5	20
A2	200-360	CS	7.5YR5/4		S		G		D00N0	5.5	310
B	360-640	CI	10YR5/2	M32D(RO)D	CLS	11SRS	VM3PO		T32N2	6.5	500
C	640-680	AS	2XV(QFmS)								

Vegetation: Some black wattle and eucalypts

Project Name:
Notes:

Zambezi

Date:	23/07/19		**Site:**	**VP37**	
Location:	NEAR CATTLE YARDS		**Coordinates:**	**E 0625149**	**N 7524622**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS1G2		**Surface Condition:**	**F341**	
Landform	Elevation:	229	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**1**	

- Ph COULD BE OFF DUE TO PRESENCE of COWS IN CATTLE YARD

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	50		7.5YR2.5/2		LS		GW2PO		D10N0	8.5	35
A12	50-240	AS	7.5YR3/3		LS		GW2PL		D10N0	7.5	320
A2	240-490	GS	7.5YR5/4	M1DYC	LS		GW2PO		D10N0	7	520
UB	490-700	AS	7.5YR5/4	M2D(OR)C	ZCL	11U_S	GM4PL		T31N2	7	600
LB	700-850	AS	7.5YR6/1		LC	11U_S	GS4PO		T41N3	8	780

Vegetation: GUM TREES, FEW BLACK WATTLE, EUCALYPTS

Project Name:
Notes:

Zambezi

Date:	24/07/2019		**Site:**	**VP38**	
Location:	@ hook corner		**Coordinates:**	**E 0624909**	**N 7524427**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S**	
Landform	Elevation:	208	**Permeability:**	**4 (ONLY SAND OBSERVED)**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9m	**Run-off:**	**1**	

Suspicious that this is the same as VP25, just the B horizon is deeper therefore was not observed.

- Split A horizons

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-130		7.5YR2.5/2		ZL		VW2PO		D21N0	7	60
A12	130-550	AS	7.5YR3/2		LS		VW2PL		D20N0	6.5	300
A2	550-950	GS	10YR4/4		S		G		T00N0	7	800

Vegetation: Poplar box and grass

Project Name:
Notes:

Komati

Date:	22/07/19		**Site:**	**VP39**	
Location:	Close to triple gate		**Coordinates:**	**E 0625688**	**N 7527648**
Landform Pattern:	PLA		**Micro Relief:**	**N**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21A_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	S		**Surface Condition:**	**G**	
Landform	Elevation:	227	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-80		7.5YR2.5/1		SCL		GM3PO		D21N2	7	
A2	80-520	AS	7.5YR3/3	M22DOD	MC	51A_VSA	GM4PO		D21N2	8.5	
U B	520-780	CB	7.5YR3/4		MC	51A_VSM	GM4PO	3KN2W	T42N3	8.5	
L B	780-1020	DS	7.5YR5/8		MC	51A_VSM	GM4PO	5KN3W	T42N3	8.5	

Vegetation: GUMS, GRASS , SHRUB WITH SMALL ROUND LEAVES -> LOOKS LIKE THE SODOSOL

Project Name:
Notes:

Orange

Date:	23/07/19		**Site:**	**VP40**	
Location:	IN Punchbowl next to saraji rd		**Coordinates:**	**E 0627472**	**N 7527245**
Landform Pattern:	PLA		**Micro Relief:**	**N/S GILGAI**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	3		**Substrate:**		
Erosion:	S		**Surface Condition:**	**G**	
Landform	Elevation:	218	**Permeability:**	**2**	
	Slope (%):	0	**Drainage:**	**2**	
	Relief:	<9	**Run-off:**	**M**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-100		10YR2/1		LMC	11S_5	G (MASSIVE)		D21N1	7	10
UB	100-600	AS	7.5YR2.5/1		LMC	11S_5	V3PO		T32N1	7.5	320
LB	600-1110	DS	10YR3/1		LMC	11S_5	V3PO	2NK2	T43N1	9	1030

Vegetation: OPEN GRASSLAND

Project Name:
Notes:

Zambezi

Date:	24/07/2019		**Site:**	**VP41**	
Location:	Wnw of VP 37		**Coordinates:**	**E 0626905**	**N 7524931**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**	**21S_IS**	
Site Disturbance:	2		**Substrate:**		
Erosion:	PWXCXS1		**Surface Condition:**	**G, F**	
Landform	Elevation:	226	**Permeability:**		
	Slope (%):	0	**Drainage:**		
	Relief:	<9M	**Run-off:**		

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A1	0-130		7.5YR4/2		LS		VW3PL		D10N0	6	80
A2	130-280	CS	7.5YR5/2		LS		G		D00N0	7	220
UB	280-770	GI	2.5Y5/3	M2F(YD)D	CLS		VM4PO		T32N2	9	450
LB	770-1090	CS	2.5Y5/1	M1F(Y)D	ZCL	11S_S	VM4PO		T31N2	9	970

Vegetation: Poplar box, shrubs

Project Name:

Notes:

Zambezi

Date:	24/07/2019		**Site:**	**VP42**	
Location:	Off the “track”		**Coordinates:**	**E 0628019**	**N 7524657**
Landform Pattern:	PLA		**Micro Relief:**	**D**	
Landform Element:	PLA		**Rock Outcrops:**		
Morphological Type:	F		**S C Fragments:**		
Site Disturbance:	1		**Substrate:**		
Erosion:	S		**Surface Condition:**	**S/F**	
Landform	Elevation:	200	**Permeability:**	**3**	
	Slope (%):	0	**Drainage:**	**4**	
	Relief:	<9M	**Run-off:**	**2**	

[Soil Description]

Horizon	Depth (mm)	Boundary	Colour	Mottles	Texture	Coarse Fragments	Structure	Segregations	Consistency	Field pH	
A11	0-80		7.5YR2.5/2		LS		GW2PL		D10N0	6.5	20
A12	80-460	CS	7.5YR3/2		LS		GW2PO		D10N0	6.5	180
A2	460-610	GS	7.5YR2.5/3		ZCL		GM3PO		T33N1	7	540
UB	610-780	CS	7.5YR3/4		ZCL	21S_S	GM3PO		T33N1	7	700
LB	780-940	GS	5YR5/6		LMC		GM3PO		T33N3	7	900

Vegetation:Poplar, shrubs and grass

Appendix 3 Soil Observation Data

Obs	Date	Site ID	Vegetation	Soil Description/Unit	Notes
1	19-Jul	OP1	Eucalyptus crebra	Crocodile	W to E, change from yellow to red soil
2	19-Jul	OP2	Eucalyptus populnea	Boundary	West side = red, east side + yellow
3	20-Jul	OP3	Eucalyptus crebra	Boundary	W=valley, E = similar to VP3
4	20-Jul	OP4	Eucalyptus populnea	Limpopo	Pale sandy
5	20-Jul	OP5	Eucalyptus crebra	Crocodile	similar to VP3
6	20-Jul	OP6	Eucalyptus crebra, grass	Limpopo	
7	20-Jul	OP7	Eucalyptus crebra, grass	Crocodile	
8	20-Jul	OP8	Eucalyptus populnea, Eucalyptus crebra	Boundary	NE- Yellow sandy, SW - red rocky
9	20-Jul	OP9	Eucalyptus populnea, Eucalyptus crebra	Limpopo	Yellow sandy
10	21-Jul	OP10	Eucalyptus crebra	Boundary	W-red rocky E - yellow sandy
11	21-Jul	OP11	Eucalyptus populnea, Eucalyptus crebra	Boundary	E - red rocky , W - yellow sandy
12	21-Jul	OP12	Eucalyptus populnea, Eucalyptus crebra	Limpopo	Pale sandy, footlsope to SW
13	21-Jul	OP13	Eucalyptus populnea	Boundary	NW - brown sandy, SE - yellower
14	21-Jul	OP14	Eucalyptus populnea, Eucalyptus crebra	Boundary	W-red rocky E - yellow sandy
15	21-Jul	OP15	Type of Gum trees?	Komati	S - valley, N - flat
16	21-Jul	OP16		Crocodile	Brown shaley soil with sz substrate exposed
17	21-Jul	OP17		Crocodile	Brown shaley soil with sz substrate exposed
18	21-Jul	OP18	Malaleuca - watercourse	Zambezi	
19	22-Jul	OP19	Eucalyptus populnea, Eucalyptus crebra	Boundary	S - red rocky, N - yellow sandy
20	22-Jul	OP20	Eucalyptus populnea	Limpopo	S-wards - yellow sandy
21	22-Jul	OP21	Looks like sheoak? Confirm	Boundary	N - red sandy, S vertosol
22	22-Jul	OP22	Gum/ Eucalyptus populnea	Boundary	SE - red brown, like VP 32
23	22-Jul	OP23	""	Boundary	E-wards, change to vert
24	22-Jul	OP24	Change from dense eucalypt to grassy	Boundary	SE- red/brown cracking to dark vert
25	22-Jul	OP25		Boundary	
26	22-Jul	OP26	Change to Eucalyptus populnea	Boundary	We-wards - brown to sandy
27	22-Jul	OP27	Disappearance of Eucalyptus populnea	Boundary	W- less sandy , red to cracky
28	22-Jul	OP28	Change to Eucalyptus populnea	Boundary	W- less sandy more red brown
29	22-Jul	OP29	Eucalyptus crebra	Boundary	W - no sandy, hard brown

Obs	Date	Site ID	Vegetation	Soil Description/Unit	Notes
30	22-Jul	OP30	Eucalyptus populnea, Corymbia erythophloia	Boundary	NW - yellow sandy, SE - red rocky
31	22-Jul	OP31		Boundary	SE - going from VP 20 ground cover down ridge to yellow sandy
32	23-Jul	OP32	Eucalyptus populnea	Komati	Red brown cracking
33	23-Jul	OP33	Eucalyptus crebra	Boundary	Goes from yellow sandy to red cracky
34	23-Jul	OP34	Eucalyptus populnea	Boundary	NE - away from red to sandy yellow
35	23-Jul	OP35	Open grassland with Eucalyptus crebra	Boundary	Still sandy but firmer
36	23-Jul	OP36		Boundary	Orangey sandy soil, sevee erosion
37	23-Jul	OP37	Dense veg with shrubs	Boundary	SW-wards - sandy to firm orange/brown cracking
38	23-Jul	OP38	Change from Eucalyptus crebra, to Eucalyptus populnea	Boundary	SW-wards, change from brown cracking to yellow sandy
39	23-Jul	OP39	Change from Eucalyptus populnea to Eucalyptus crebra	Boundary	change to brown cracking
40	23-Jul	OP40	Change from Eucalyptus crebra, to Eucalyptus populnea	Boundary	NE - orange firm to yellow sandy
41	23-Jul	OP41	Eucalyptus crebra	Limpopo	
42	23-Jul	OP42	Open grassland with eucalpyts	Boundary	S - change to dark cracking
43	23-Jul	OP43	Dense eucalypts	Boundary	change from dark cracking to brown cracking
44	24-Jul	OP44	Change to Eucalyptus populnea	Boundary	S - dark cracking to brown cracking
45	24-Jul	OP45	Eucalyptus populnea	Limpopo	S - yellow sandy
46	24-Jul	OP46	Change to Eucalyptus populnea	Limpopo	S - yellow sandy
47	24-Jul	OP47	Change to shrublands	Limpopo	Ground lighter coloured
48	25-Jul	OP48	Change to Eucalyptus populnea		S-N - becomes browner
49	25-Jul	OP49	Malaleuca - watercourse	Zambezi	sandy
50	25-Jul	OP50	Acacia Excelsa	Fish	skeletal looking soil
51	25-Jul	OP51	Malaleuca - watercourse	Zambezi	
52	25-Jul	OP52	Spear head grass	Kei	Soil gets sandier and lighter
53	25-Jul	OP53	Acacia Excelsa	Fish	Light grey sand
54	25-Jul	OP54	Acacia Excelsa	Fish	Light grey sand

Obs	Date	Site ID	Vegetation	Soil Description/Unit	Notes
55	25-Jul	OP55	Eucalyptus crebra	Boundary	N-wards - less sand to brown cracking
56	25-Jul	OP56	Malaleuca - watercourse	Zambezi	Yellow sandy
57	25-Jul	OP57	Change to shrublands	Boundary	Soil darker
58	25-Jul	OP58	Eucalyptus populnea	Boundary	Ground firmer wqith cracking
59	25-Jul	OP59	Malaleuca - watercourse	Zambezi	Sandy
60	25-Jul	OP60	Open shrubby	Orange	change to dark vert
61	25-Jul	OP61	Open shrubby	Orange	
62	25-Jul	OP62	Open shrubby	Komati	Soil becomes brown cracking
63	25-Jul	OP63	Open shrubby	Orange	W - change from vert to brown cracking
64	25-Jul	OP64		Boundary	S - change from brown to vert
65	25-Jul	OP65		Boundary	Boundary between dark vert and brown cracking
66	25-Jul	OP66		Boundary	W - change to brown cracking

Appendix 4 Sampling Site Locations

ID	Sample Location	SMU	Latitude (GDA94)	Longitude (GDA94)	Elevation (m)	Time	Sample Type
66	VP1	Limpopo	-22.2891	148.186	221.958	2019-07-20T06:31:56Z	Detailed Profile
67	VP10	Sabie	-22.3382	148.206	253.123	2019-07-21T06:01:13Z	Detailed Profile
67	VP10	Sabie	-22.3382	148.206	253.123	2019-07-21T06:01:13Z	Detailed Profile
68	VP11	Sabie	-22.3504	148.2	247.991	2019-07-22T05:42:39Z	Detailed Profile
69	VP12	Sabie	-22.3475	148.184	262.36	2019-07-22T05:07:01Z	Detailed Profile
70	VP13	Limpopo	-22.3878	148.223	167.617	2019-07-24T03:40:18Z	Detailed Profile
71	VP14	Sabie	-22.3471	148.212	205.387	2019-07-21T20:49:12Z	Detailed Profile
71	VP14	Sabie	-22.3471	148.212	205.387	2019-07-21T20:49:12Z	Detailed Profile
72	VP15	Limpopo	-22.3194	148.146	364.653	2019-07-20T22:44:08Z	Detailed Profile
73	VP16	Zambezi	-22.3683	148.206	188.452	2019-07-23T02:58:12Z	Detailed Profile
74	VP17	Limpopo	-22.3524	148.178	242.206	2019-07-22T21:05:54Z	Detailed Profile
75	VP18	Limpopo	-22.3094	148.193	205.966	2019-07-21T02:45:16Z	Detailed Profile
75	VP18	Limpopo	-22.3094	148.193	205.966	2019-07-21T02:45:16Z	Detailed Profile
75	VP18	Zambezi	-22.3094	148.193	205.966	2019-07-21T02:45:16Z	Detailed Profile
76	VP19	Zambezi	-22.3585	148.2	193.061	2019-07-22T22:27:01Z	Detailed Profile
77	VP2	Limpopo	-22.281	148.179	206.507	2019-07-20T02:12:40Z	Detailed Profile
78	VP20	Sabie	-22.3464	148.171	330.941	2019-07-22T03:40:15Z	Detailed Profile
80	VP22	Limpopo	-22.3264	148.205	225.635	2019-07-21T04:58:00Z	Detailed Profile
81	VP23	Zambezi	-22.3227	148.2	210.286	2019-07-21T04:11:54Z	Detailed Profile
82	VP24	Limpopo	-22.3355	148.213	190.831	2019-07-22T00:12:20Z	Detailed Profile
83	VP25	Zambezi	-22.3739	148.257	137.049	2019-07-23T21:44:31Z	Detailed Profile
84	VP26	Kei	-22.4019	148.271	133.606	2019-07-25T01:12:13Z	Detailed Profile
85	VP27	Fish	-22.3974	148.262	135.174	2019-07-24T23:50:48Z	Detailed Profile
86	VP28	Limpopo	-22.4045	148.255	157.437	2019-07-24T20:42:42Z	Detailed Profile

ID	Sample Location	SMU	Latitude (GDA94)	Longitude (GDA94)	Elevation (m)	Time	Sample Type
87	VP29	Zambezi	-22.3927	148.245	139.214	2019-07-24T00:38:58Z	Detailed Profile
88	VP3	Crocodile	-22.2694	148.159	213.906	2019-07-19T22:28:23Z	Detailed Profile
89	VP30	Kei	-22.3851	148.266	127.093	2019-07-24T22:33:57Z	Detailed Profile
90	VP31	Orange	-22.3666	148.249	154.395	2019-07-23T20:27:47Z	Detailed Profile
91	VP32	Komati	-22.3481	148.233	192.306	2019-07-22T01:13:23Z	Detailed Profile
92	VP33	Zambezi	-22.4011	148.218	153.994	2019-07-24T01:50:39Z	Detailed Profile
93	VP34	Komati	-22.3602	148.23	197.857	2019-07-23T04:56:11Z	Detailed Profile
94	VP35	Orange	-22.3434	148.221	190.981	2019-07-21T22:50:59Z	Detailed Profile
95	VP36	Limpopo	-22.3512	148.21	207.953	2019-07-23T04:01:39Z	Detailed Profile
96	VP37	Limpopo	-22.3799	148.216	164.519	2019-07-22T23:55:17Z	Detailed Profile
97	VP38	Zambezi	-22.3813	148.257	128.586	2019-07-23T22:56:37Z	Detailed Profile
98	VP39	Komati	-22.3525	148.221	223.283	2019-07-22T06:33:02Z	Detailed Profile
99	VP4	Crocodile	-22.2782	148.164	246.741	2019-07-20T01:02:42Z	Detailed Profile
100	VP40	Orange	-22.356	148.238	185.746	2019-07-23T06:02:30Z	Detailed Profile
101	VP41	Zambezi	-22.3769	148.233	170.22	2019-07-24T04:43:05Z	Detailed Profile
102	VP42	Zambezi	-22.3793	148.244	163.268	2019-07-24T06:12:48Z	Detailed Profile
103	VP5	Crocodile	-22.2925	148.166	279.986	2019-07-20T03:50:31Z	Detailed Profile
104	VP6	Crocodile	-22.2927	148.147	331.062	2019-07-19T05:26:33Z	Detailed Profile
105	VP7	Limpopo	-22.288	148.178	230.795	2019-07-20T05:26:45Z	Detailed Profile
106	VP8	Crocodile	-22.2901	148.176	235.049	2019-07-21T00:35:31Z	Detailed Profile
107	VP9	Limpopo	-22.3854	148.191	191.344	2019-07-23T01:11:31Z	Detailed Profile

Appendix D – Terrestrial Ecology Assessment Report



Terrestrial Ecology Assessment for Vulcan South

for Vitrinite Pty Ltd



VITRINITE
BRIGHTER COAL

METSERVE
Mining & Energy Technical Services Pty Ltd

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1 EXECUTIVE SUMMARY

Vitrinite Pty Ltd proposes to construct a small open-cut coal mine on a proposed Mining Lease (ML) within its exploration tenements EPC 1233, 1234 and 1732, midway between Dysart and Moranbah, Queensland. This proposed mine forms the project, Vulcan South. As Vulcan South qualifies as an environmentally relevant activity, an Environmental Authority (EA) will be required. An ecological impact assessment (this report) has been prepared to inform the EA application.

This ecological impact assessment is based on a combination of field surveys and a review of past records of matters of environmental significance from the general region. Field surveys were undertaken in 2018-2020, spanned multiple seasons, and covered a broader region (6,982 ha) than the mining lease application (MLA) area for the project (3,819 ha).

Fauna was surveyed at 127 locations. Techniques included pitfall traps, funnel traps, Elliott traps, cage traps, remote-sensory cameras, ultrasonic bat recorders, targeted searches and spotlighting.

Flora was surveyed at 485 locations, allowing the production of a field-verified regional ecosystem map, which corrects errors contained within regulated vegetation mapping, as well as provides a finer scale of information. This revised vegetation map was used in conjunction with known habitat preferences of wildlife (based on published records and field data) to infer the distribution of matters of state and national environmental significance in and near the proposed footprint of Vulcan South.

Field surveys detected 41 species of mammal, 135 species of bird, 36 species of reptile, 14 species of frog and 429 species of vascular plant across the region containing Vulcan South. Species accumulation curves fitted to the data estimated that the surveys successfully detected 88% of the plants, 100% of reptiles, 97% of amphibians, 100% of birds, 92% of non-bat mammals and 100% of the bats present within the survey area that could potentially have been detected using the methodology employed. This represents a thorough knowledge of the region's ecology.

In accordance with best practice, Vulcan South has been strategically positioned to avoid disturbance to as many matters of state and/or national environmental significance as practicable. No protected conservation estates or secured offset areas will be disturbed for the project.

Vulcan South's footprint contains 11 regional ecosystems, including eight least concern, one of concern and two endangered regional ecosystems. Of these, 1,029.8 ha are remnant vegetation and 61.6 ha are regrowth vegetation. The remainder of the project's footprint comprises cleared pastures (665.9 ha).

Twenty-six species of plants and animals listed as threatened species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) were flagged by database searches as being potentially present in the region. The following four matters of national environmental significance (MNES) were detected during surveys of the site, and each is likely to experience significant residual impacts from the project:

- Brigalow (*Acacia harpophylla* dominant and co-dominant) threatened ecological community (endangered) – 120.3 ha will be removed;
- Koala (*Phascolarctos cinereus*) (endangered) – 21.3 ha of high-quality habitat, 559.1 ha of moderate-quality habitat and 443.2 ha of low-quality habitat will be removed;
- Squatter Pigeon *(Geophaps scripta scripta*) (vulnerable) – 671.2 ha of foraging habitat (426.8 ha of which is also breeding habitat) and 692.9 ha of dispersal habitat will be removed; and
- Central Greater Glider (*Petauroides armillatus*) (endangered) – 71.1 ha of habitat will be removed.

Additional impacts on the Ornamental Snake and Northern Quoll are possible but not likely. Neither species was recorded on site, and the habitat present is suboptimal for both species.

It is proposed that environmental offsets are to be provided in accordance with the *EPBC Act Environmental Offsets Policy 2012* for each of the above four matters prior to the commencement of Vulcan South.

Each of the four MNES likely to experience significant residual impacts are also matters of state environmental significance (MSES) protected under the *Nature Conservation Act 1992* (NC Act) or *Vegetatation Management Act 1999.* However, as impacts to these matters are to be assessed under the EPBC Act, the Queensland Government cannot impose additional offset conditions on these matters. Nevertheless, the following vegetation types are MSES that are not also MNES, and as they will be impacted by Vulcan South, will be subject to offsets in accordance with Queensland's *Environmental Offsets Act 2014*:

- 25.6 ha of the of concern regional ecosystem, 11.3.2; and
- 58.3 ha of regional ecosystems 11.3.25, 11.5.3, 11.5.9b, 11.9.2, 11.10.1 and 11.10.3 located within a defined distance from the defining banks of a relevant watercourse.

In addition, minor impacts to the Short-beaked Echidna (*Tachyglossus aculeatus*), Glossy Black-cockatoo (*Calyptorhynchus lathami*) and Common Death Adder (*Acanthophis antarcticus*) (listed as special least concern, vulnerable and vulnerable under the NC Act, respectively) possibly qualify as significant, due to the disturbance of potential feeding and/or breeding sites, which qualify as "ecologically significant locations". These impacts are to be assessed by the Queensland Government to determine whether they are subject to further environmental offsets.

2 INTRODUCTION

Vitrinite Pty Ltd has been investigating the development potential of coal reserves contained within the Exploration Permit Coal (EPC) tenements 1233, 1234 and 1732. As part of its investigations, Vitrinite Pty Ltd engaged Mining and Energy Technical Services Pty Ltd (METServe) to undertake baseline terrestrial ecological surveys across large parts of its three EPC tenements. These surveys spanned the wet and dry seasons of 2018-2019, and the wet season of 2020.

Based on initial investigations, Vitrinite Pty Ltd developed its initial mining project, the Vulcan Coal Mine, located on ML700060. As a result of knowledge gained through additional exploration work and the operation of the Vulcan Coal Mine, Vitrinite Pty Ltd proposes to develop a second small-scale mining project, Vulcan South, on its exploration tenements EPC 1233, EPC 1234 and EPC 1732. Vulcan South will operate independently from Vulcan Coal Mine.

Vulcan South occupies a much smaller area than that surveyed because, at the time ecology surveys commenced, the scale of the project was unknown. Nevertheless, the findings of all surveys—not only those within the project footprint—are presented in this report for two reasons. Firstly, it is valuable to place the ecological values of the project area into a broader regional context. Secondly, species recorded outside the proposed footprint, but in habitats that are also present within the footprint, could be impacted by Vulcan South.

This report presents the findings of ecological surveys across 6,982 hectares (ha) spanning the three tenements. It then assesses the potential impacts of Vulcan South on local environmental values pertaining to terrestrial ecology. Vulcan South will require assessment and approval by the Queensland and Commonwealth Governments, and this report is intended to provide supporting information for a site-specific application for a new environmental authority.

2.1 LOCATION

Throughout this report, the “survey area” refers to the 6,982 ha area in which ecological surveys were undertaken. The “project area” refers to the proposed MLA area containing Vulcan South (3,819 ha). The project area therefore forms a part of the survey area. The 1,757 ha “maximum disturbance footprint” is contained within, and is a subset of, the project area.

The survey area is located midway between Moranbah and Dysart, in the Bowen Basin of central Queensland (**Figure 2-1**). The project falls within the jurisdiction of the Isaac Regional Council. It lies immediately south and west of the Vulcan Coal Mine, and just west of the Peak Downs Mine and Saraji Mine, alongside the Saraji Road. The project area is contained within the following properties:

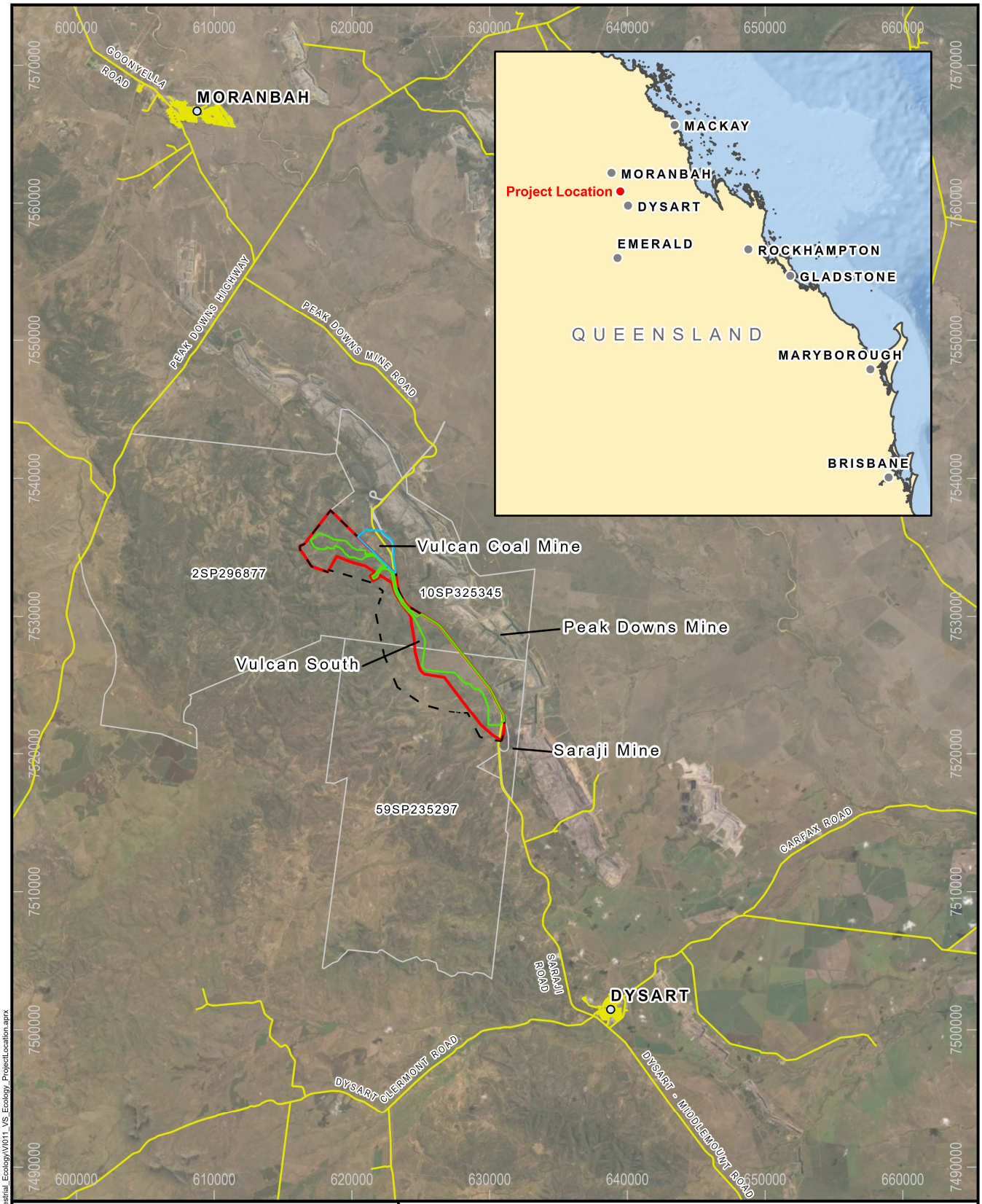
- Lot 2 on Plan SP296877;
- Lot 59 on Plan SP235297;
- Lot 72 on Plan SP137467;
- Lot 26 on Plan CNS125;
- Lot 2 on Plan CNS109; and
- Lot 3 on Plan CNS109.

The survey area also encompasses a portion of Lot 10 on Plan SP208611.

The survey area falls within the Northern Bowen Basin subregion of the Brigalow Belt North bioregion, according to the Interim Biogeographic Regionalisation for Australia.

2.2 EXISTING LAND-USE

The project area is located on predominantly leasehold land that is used primarily for cattle grazing. The project area is bounded to the north and east by proposed and existing coal mining operations. A rail line and sealed highway (Saraji Road) run along the eastern edge of the project area.



Legend

- Town
- Road
- ML 700060
- MLA Area
- Disturbance Footprint
- Survey Area
- Cadastral Boundary

Source: State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Esri, GEBCO, DeLorme, NaturalVue, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_ProjectLocation.aprx

Vulcan South

Project Location

0 3.75 7.5 15

Kilometers

Scale: 1:400,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 2-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

2.3 PROPOSED ACTIVITIES

Vulcan South is a small-scale coal mine that will extract approximately 13.5 Mt of run-of-mine (ROM) coal, consisting predominately of hard coking coal with an incidental thermal secondary product, at a rate of up to 1.95 million tonnes per annum (Mtpa). The project will operate for approximately nine years, including primary rehabilitation works, following a two-year construction period. Coal extraction will occur in three open-cut pits; Vulcan North, Vulcan Main and Vulcan South (**Figure 2-2**). Each pit will be approximately 60 m deep. Truck-and-shovel mining operations will be employed to develop the pits. Coal will be processed by a modular coal handling and preparation plant (CHPP). The proposed CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product for permanent storage within waste rock dumps. No wet tailings wastes or tailings dams are proposed. Coal transportation will occur via a rail loop and load-out facility, located between the Vulcan North and Vulcan Main pits. Coal will be transported on the Goonyella Rail network to coal terminals at either Dalrymple Bay or Gladstone.

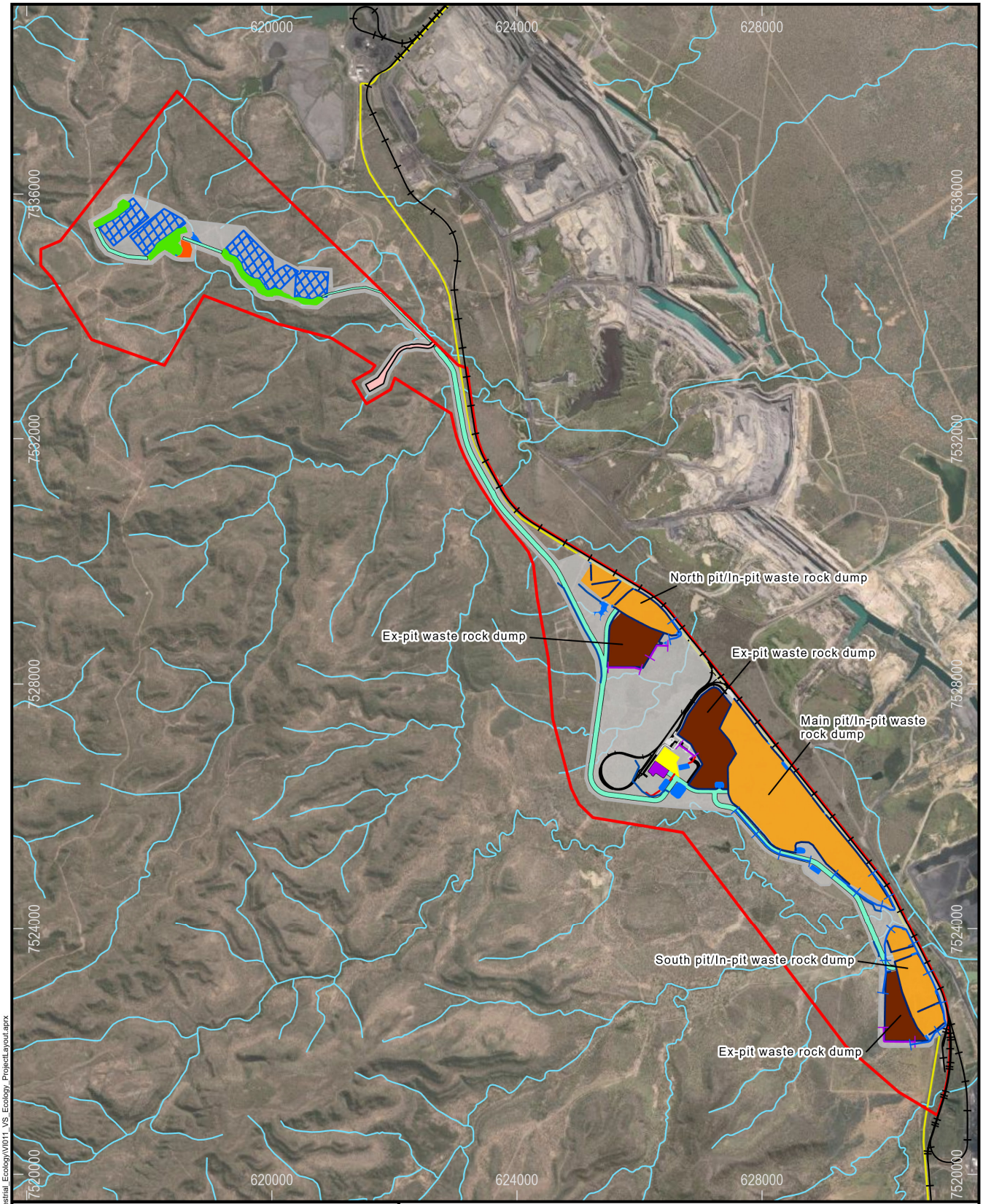
All processing wastes (reject material and dry tailings) will be stored within waste rock dumps. Local waste rock possesses a geochemistry that does not pose a significant risk of generating saline or metalliferous drainage, and no selective handling and treatment measures are proposed. Initial waste rock extracted during the early stages of each pit will be placed in ex-pit dumps to the west of the open pits. Following this initial ex-pit placement and once sufficient pit space has been established, in-pit placement of waste rock will commence. Any voids remaining at the conclusion of mining in each pit will be back-filled with a subset of material stored in ex-pit dumps. The remaining material stored in ex-pit dumps will be rehabilitated in situ. The in-pit dumps will extend up to approximately 60 m above the height of the former ground surface, with batters shaped up to a maximum slope of 15 %. A central plateau will drain to the west to minimise the requirement for significant drainage infrastructure along the eastern toe of the dump (where space is limited).

Ancillary infrastructure will include an access road, ROM pad, offices and a Mine Infrastructure Area (MIA) containing workshops, heavy vehicle parking and storage. Water management infrastructure will be established to divert clean water catchments around operational areas and to manage runoff from disturbed areas. A series of mine water dams will be established to manage raw water supply, pit water and supply water for dust suppression. A series of drains and bunds will be established to direct runoff to sediment control structures. Vulcan South will require up to 1,250 ML/annum of external water to operate. This will come from a mix of an existing pipeline supply, water trucks delivering from off-site sources and, potentially, unallocated groundwater in local non-alluvial aquifers.

In addition to the open-cut operations, Vulcan South will also include a small-scale highwall mining trial in the north of the MLA area. The trial will involve the establishment of four highwall mining benches across three hillsides to allow extraction of coal utilising a CAT HW300 highwall miner, or similar. The highwall mining trial will target up to 750 kt of coal which will be transported by truck to the CHPP via a dedicated haul road within the MLA area. The coal occurs in seams 0.9 to 1.5 m thick beneath 12 to 50 m of overburden. Coal will be extracted using a series of plunges that are 3.5 m wide and up to 400 m long. Minimal infrastructure is required to support the highwall mining trial, including mobile diesel tanks, workshop containers and portable bathroom amenities. Access roads and benches will be constructed in order to provide a stable surface on which to operate the machinery. A small waste rock dump will be built on one of the benches, while will be rehabilitated in situ. Mine-affected water will be contained on each bench and allowed to drain to completed highwall plunges (voids). The trial is scheduled to be completed within the first year of mining operations.

An explosives magazine will be constructed between the highwall trial area and the Vulcan North pit, a safe distance from operational areas and critical infrastructure.

The peak operational workforce is anticipated to comprise 190 positions. On average, less than a third of this workforce would be present on site at any one time due to shift and roster arrangements. The workforce will reside in camps and private facilities in Dysart and/or Moranbah. It is estimated that 80% of the travel to/from site will be undertaken in buses/work vehicles and 20% in private vehicles. There would be two 12-hour shifts per day, with crews operating on a 7-days-on, 7-days-off roster.



Legend

- Drainage Lines
- Railway
- Road
- Mine Access Road
- Rail Loop and Mine Roads
- Surface Water Drain
- Mine Water Drain
- Diversion Bund
- Diversion Drain
- Flood Levee
- CHPP
- Magazine
- MIA
- Dam
- Office
- Haul Road
- Ex-pit Waste Rock Dump
- Open Pit/In-pit Waste Rock Dump
- Highwall Mining Bench
- Highwall Rock Dump
- Highwall Plunge
- VS Maximum Disturbance
- MLA Area

Source: State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_ProjectLayout.aprx

Vulcan South

Proposed Project Layout

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

18/05/2022

Datum: GDA2020
Projection: MGA55

FIGURE 2-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

2.4 RELEVANT LEGISLATION

2.4.1 Queensland

Environmental Protection Act 1994

The *Environmental Protection Act 1994* (EP Act) regulates environmental management and aims to achieve ecologically sustainable development. The EP Act outlines legal obligations and the duty of care all persons have to the environment and directions for preparing environmental protection policies. As the project includes "environmentally relevant activities", an application for an environmental authority will be required under the EP Act.

Nature Conservation Act 1992

The *Nature Conservation Act 1992* (NC Act) regulates native flora, fauna and habitat conservation within Queensland.

Nature Conservation (Wildlife) Regulation 2006

The *Nature Conservation (Wildlife) Regulation 2006* prescribes the conservation status of Queensland wildlife, following provisions of the NC Act.

Vegetation Management Act 1999

The *Vegetation Management Act 1999* (VM Act) provides a planning framework for the management of native vegetation across Queensland. It regulates clearing of vegetation and aims to conserve Queensland's biodiversity through vegetation management.

Environmental Offsets Act 2014

The *Environmental Offsets Act 2014* (EO Act) provides for environmental offsets to counterbalance significant residual impacts of activities on particular matters of state or local environmental significance.

Biosecurity Act 2014

The *Biosecurity Act 2014* lists weeds and pest animals that constitute prohibited or restricted matters, and obligations pertaining to these matters.

2.4.2 Commonwealth

Environmental Protection and Biodiversity Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) provides for the identification and management of Matters of National Environmental Significance, including threatened flora and fauna species, ecological communities, migratory species protected under international treaties, internationally recognised significant wetlands and critical habitat areas. Under the *EPBC Act*, an action will require approval from the Federal Environment Minister if the action has, will have, or is likely to have a significant impact on a Matter of National Environmental Significance.

EPBC Act Environmental Offsets Policy 2012

The *EPBC Act Environmental Offsets Policy* (EOP) provides guidance on how the federal government considers the suitability of a proposed offset, when there are residual impacts of a project on matters of national environmental significance.

3 METHODS

3.1 LITERATURE REVIEW

A desktop-based assessment was undertaken using publicly available databases to determine the ecological values potentially occurring in the vicinity of the project. The following databases were consulted:

1) Queensland Government's Wildlife Online search tool (records within a 20 km buffer from the central point −22.3678, 148.2352);
2) Department of Environment and Energy's Protected Matters Search Tool (records within a 20 km buffer from central point: -22.3678, 148.2352);
3) Atlas of Living Australia;
4) eBird;
5) the Australasian Virtual Herbarium Search tool; and
6) the Department of Environment and Science's regulated vegetation management mapping.

For each species flagged during the literature review, but not recorded on site during field surveys, an assessment of the likelihoods of their presence within the survey area and project area was undertaken based on the reliability and recentness of the record(s) and whether suitable habitat—as described by the Australian Government's Species Profiles and Threats Database, species recovery plans, referral guidelines, and/or primary scientific literature—is present.

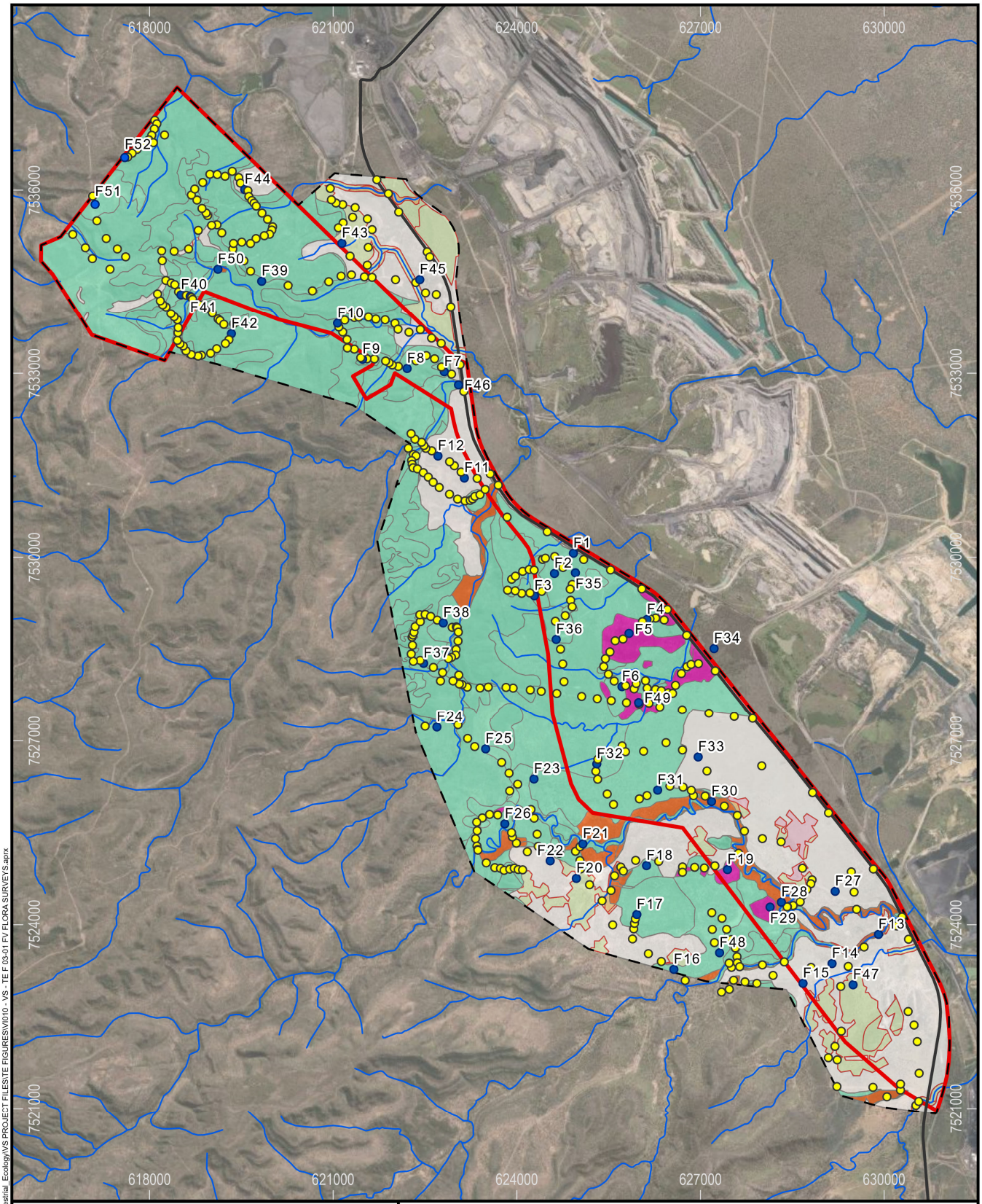
3.2 FIELD SURVEYS

3.2.1 Flora

The principal flora survey was undertaken between 4 February and 15 February 2019 by Dr Chris Wiley (Principal Consultant – Ecology) and Jacob Rolley (Consultant – Ecology). The approach taken followed that prescribed by Neldner *et al*. (2019) in *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland, Version 5.0*. Survey timing coincided with maximum plant growth in the mid- to late-wet season, and was optimal for detecting threatened species as well as describing overall diversity.

Additional surveys for supplementary vegetation mapping were undertaken on 1-2 October 2019 in the far south of the survey area, and between 27 March and 5 April 2020 in the far north-west of the survey area. The former took place in a small area of non-remnant vegetation added to the survey area subsequent to the February 2019 survey. Due to October being a sub-optimal month for flora surveys (dry conditions mean that most grasses and herbs are dormant), this survey aimed primarily to assess the spatial extent of vegetation units rather than comprehensively document the species present within these. The latter took place in a small area added to the north-western survey area subsequent to the October 2019 survey, and was optimal for detecting threatened species, vegetation mapping and recording diversity.

For all flora surveys, the survey area was traversed by car and (mostly) on foot, and routes were pre-selected to maximise coverage of the site and the number of mapped vegetation units visited. The aim of the field surveys was to ground-truth a sufficient sample of sites to enable interpolation of regional ecosystems across the survey area using detailed satellite imagery. In total, 485 sites were ground-truthed across the survey area (**Figure 3-1**). These comprised 433 quaternary sites and 52 secondary sites, as per Neldner *et al*. (2019). Secondary sites are detailed floristic and structural assessments of the vegetation communities present. These were only assessed during optimal conditions in February 2019 and March 2020. Quaternary sites are simple descriptions of the dominant species present and their corresponding regional ecosystem. A small subset (3.5%) of quaternary sites was assessed in October 2019, while the remainder were assessed under optimal conditions in February 2019 and March 2020. Field data were then used in conjunction with satellite imagery to produce a field-verified regional ecosystem map of the entire survey area. This field-verified map corrects numerous errors in certified mapping, as well as provides greater resolution due to its finer scale.



Legend

Certified Regional Ecosystem Mapping

- Category A or B area containing endangered regional ecosystems
- Category A or B area containing of concern regional ecosystems
- Category A or B area that is a least concern regional ecosystem
- Category C or R area containing endangered regional ecosystems
- Category C or R area containing of concern regional ecosystems
- Category C or R area that is a least concern regional ecosystem
- Category X

- Drainage Lines
- Saraji Road
- Survey Area
- MLA Area

Survey Points

- Quaternary
- Secondary

Source: State of Queensland (Department of Resources) 2022, Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VS PROJECT FILES\TE FIGURES\VI010 - VS - TE F 03-01 FV FLORA SURVEYS.aprx

Vulcan South

Locations of Flora Surveys

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 3-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Neldner *et al*. (2019) recommend sampling a minimum of three secondary sites per regional ecosystem. An average of 3.25 secondary sites per regional ecosystem was sampled during field surveys. One quarter of the regional ecosystems present on site were represented by single, small patches less than 10 ha in extent, preventing them being sampled over three sites. The remaining regional ecosystems were sampled at an average of 4.3 secondary sites, surpassing guideline requirements.

In addition to plant lists generated at each secondary site, additional plant species were noted during timed meander searches while walking between sites. These searches had the primary goal of targeting species of conservation significance in accordance with the *Flora Survey Guidelines – Protected Plants version 2.01*. They also allowed for a comprehensive inventory of floral diversity across the survey area.

3.2.2 Fauna

3.2.2.1 Seasonal Conditions

The following fauna surveys were undertaken across the survey area in order to encompass seasonal variation in faunal movements and detectability:

1) 24 October 2018 to 2 November 2018;
2) 4 February 2019 to 15 February 2019 (bird surveys and spotlighting were undertaken during the flora survey);
3) 25 March 2019 to 29 March 2019 (abandoned prematurely due to heavy rain);
4) 8 April 2019 to 17 April 2019;
5) 1 May 2019 to 9 May 2019; and
6) 23 September to 4 October 2019.

All of the above surveys fell within the two seasons recommended by the *Terrestrial Vertebrate Fauna Survey Guidelines for Queensland version 3.0* (Eyre *et al*. 2018) for the Brigalow Belt bioregion.

Heavy rain events (>100 mm within 24 h) occurred during the first and third surveys, leading to flash-flooding of creeks and the filling of temporary pools and gilgais. This provided optimal conditions for the detection of frogs and burrowing snakes. Light rain events (~15 mm) also occurred during the second and fourth surveys, stimulating moderate frog activity. A light shower (<5 mm) during the sixth survey was the first rain received by the site in many months and also stimulated moderate frog activity.

The mean maximum temperature across all surveys was 33.4°C (range = 24.3°C–41.4°C). The mean minimum temperature across all surveyed was 16.8°C (range = 6.6°C–22.9°C). With the possible exception of three nights that fell below 10°C in May 2019, conditions were optimal for detecting ectothermic fauna.

3.2.2.2 General Approach

In accordance with the *Terrestrial Vertebrate Fauna Survey Guidelines for Queensland version 3.0* (Eyre *et al*. 2018), the entire survey area was divided into assessment units based on broad vegetation groups and age (remnant versus regrowth). These guidelines stipulate that each assessment unit is to be sampled at a minimum of three trap sites. This sampling intensity was achieved for most of the broad vegetation groups present on site, and all broad vegetation groups contained within the project area (**Table 3-1**). Two of the broad vegetation groups present on site (7a and 34d) were not amenable to sampling via traps; 7a was too small, rocky and remote, while 34d was primarily open water. These were sampled via targeted searches (day and night), instead. A remote-sensory camera was also installed in broad vegetation group 7a. Where broad vegetation groups were represented on site by both remnant vegetation and high-value regrowth, sampling effort was focused on the former, but the latter was also sampled if it comprised more than 5% of the total area of the broad vegetation group. In total, 34 comprehensive trap sites were sampled. A list of sites and photographs of each are provided in **Appendix A**.

Table 3-1 Summary of sampling effort per broad vegetation group (BVG)

BVG	Constituent regional ecosystems	Short description	Area (hectares)		$N_{trap\ sites}$	
			Remnant	Regrowth	Remnant	Regrowth
10a	11.10.1	*Corymbia citriodora* woodland on hilly terrain.	244.6	0	3	0
12a	11.10.7, 11.10.1x1	Ironbark (*Eucalyptus* spp.) and/or bloodwood (*Corymbia* spp.) woodland on scarps and sandstone tablelands.	836.7	59.6	3	2
16a/9e*	11.3.25/11.3.7	*E. camaldulensis* forest fringing drainage lines/ *Corymbia* spp. woodland on alluvial terraces	147.7/86.1	5.3/0	3	0
17a	11.3.2, 11.5.3	*Eucalyptus populnea* woodland on sandplains or alluvium.	406.4	385.6	3	1
17b	11.9.2	*Eucalyptus orgadophila* woodland on fine-grained sedimentary rocks.	325.5	0	3	0
18b	11.5.9	*Eucalyptus crebra* woodland on flat to undulating plains.	877.7	271.4	3	2
24a	11.10.3	*Acacia shirleyi* or *A. rhodoxylon* open forest on residual surfaces.	1,589.0	68.8	3	1
25a	11.3.1, 11.4.8, 11.4.9	*Acacia harpophylla* woodland to open forest on clay soils	145.2	4.0	3	0
34d	11.3.27c, 11.3.27e	Freshwater swamps and billabongs on floodplains.	8.5	0	0	0
7a	11.10.8	Semi-evergreen vine thicket in sheltered habitats on medium to coarse-grained sedimentary rocks.	1.3	0	0	0
Non-remnant pasture		Cleared pasture, +/- scattered trees or young regrowth	1,519.2		4	

*Broad vegetation groups 16a and 9e occur as parallel, narrow bands along waterways. Due to the narrow width of these vegetation units relative to the area of the standard trapping array, trap sites placed on creek banks invariably spanned both broad vegetation groups. For this reason, they were treated as a single assessment unit.

3.2.2.3 Comprehensive Trap Sites

Each of the 34 comprehensive trap sites was sampled using methodology described in the *Terrestrial Vertebrate Fauna Survey Guidelines for Queensland version 3.0* (Eyre *et al*. 2018). The following traps were installed and monitored twice daily over four days and nights per site:

1) 45 m of 40-cm-high aluminium fly-screen drift fence was installed flush with the ground in a T-arrangement (**Figure 3-2**);
2) four 20-L buckets were installed as pitfall traps beneath this drift fence;
3) three pairs of funnel traps were installed along the drift fence;
4) 20 Elliott traps (baited with an oat-and-peanut-butter mix) were placed at 10-m spacing parallel to the drift fence; and
5) one Reconyx HC550 Hyperfire White Flash remote-sensory camera (baited with an oat-and-peanut-butter mix) was installed approximately 50 m from the drift fence.

The entire trap array spanned approximately 120 m × 50 m. Note that the survey guidelines suggest the use of one cage trap per site, instead of the camera. This recommended approach was adopted during the October 2018 survey, but abandoned in favour of cameras in all other survey rounds. Remote-sensory cameras are able to detect all species potentially caught by a cage trap, but have several advantages. They are (i) easier to transport, (ii) able to 'catch' more than one individual/species per night, and (iii) able to detect a broader range of species that are too large (macropods, dingos, pigs) or small (birds, rodents) to be caught in a cage trap.

In addition to the four days of trapping, each trap site was also subjected to the following targeted surveys:

1) 40 person-minutes of spotlighting;
2) 40 person-minutes of diurnal active searches;
3) 80 minutes of bird surveys (10 minutes during each check of the traps); and
4) one night of recording with an AnaBat Express bat-call detector.

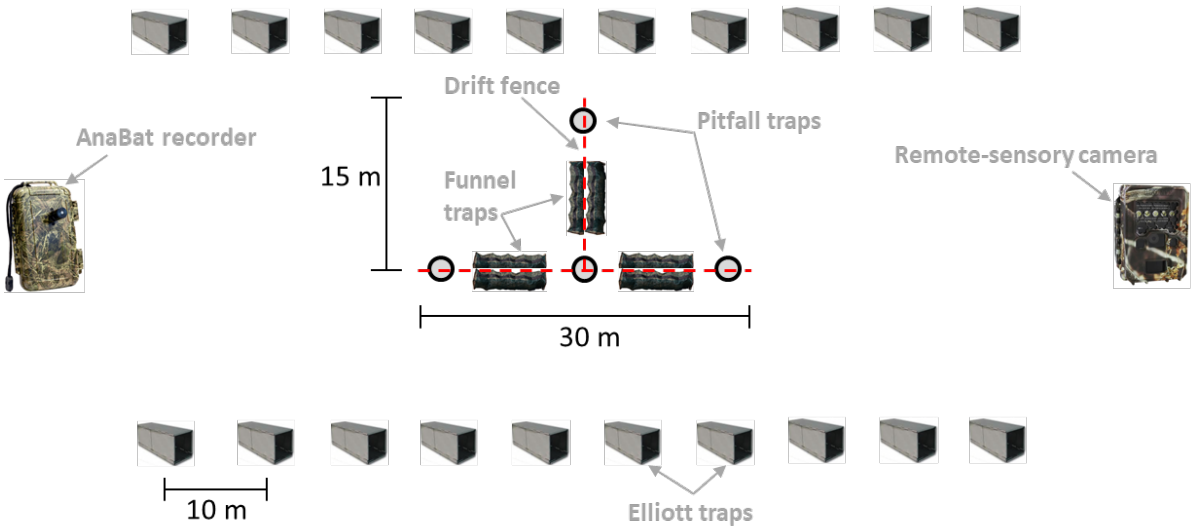


Figure 3-2 Schematic diagram of the trapping array at each comprehensive trap site

3.2.2.4 Supplementary Targeted Surveys

In addition to the sampling at comprehensive trap sites, further targeted searches were undertaken in a range of habitats that are difficult to sample using conventional trapping (e.g., rock outcrops, dams, wetlands, wood piles). Furthermore, targeted searches were undertaken to fill spatial gaps in assessment units that were very extensive and/or spatially heterogenous.

The following surveys were undertaken at additional sites away from the comprehensive trap sites:

1) Diurnal active searches of at least 40 person-minutes' duration were undertaken at 28 sites. This involved turning over logs and rocks, raking through leaf litter, searching for signs of Koalas, and recording all birds seen or heard;
2) Spotlighting for at least 40 person-minutes was undertaken at 28 sites;
3) Bird surveys of at least 20 minutes' duration were undertaken at 24 sites, in addition to diurnal active search sites. All birds heard or seen during flora surveys (10 days of survey effort in February 2019) were also recorded;
4) AnaBat recordings were carried out at 10 sites that represented likely flyways for bats: tracks through forest, creek lines and around dams. Recordings were made across a single night (12 hours) per site; and
5) Remote-sensory cameras were installed at three sites (a total of 12 trap-nights) along creek lines, which are favoured movement pathways for fauna.

3.2.2.5 Total Survey Effort

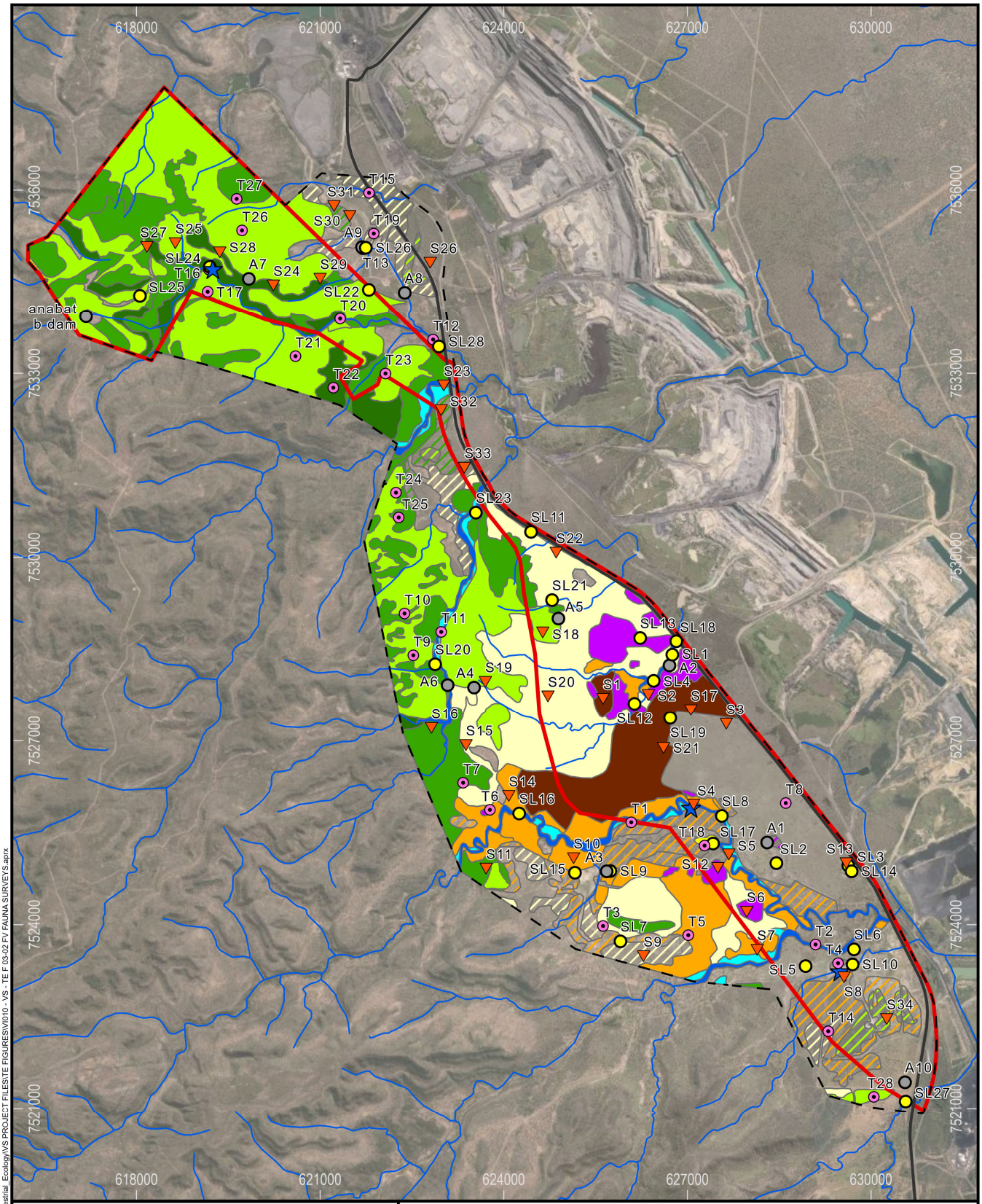
The total amount of survey effort expended for faunal surveys of the survey area is summarised in **Table 3-2** and the locations of surveys are shown on **Figure 3-3**.

Table 3-2 Fauna survey effort across the survey area between October 2018 and October 2019

Survey Method	Targeted Species	Potential EVNT Species*	Total Effort†	Unit
Pitfall trap	Frogs, small reptiles, small mammals	Ornamental Snake, Common Death Adder, Dunmall's Snake, Allan's Lerista	588	Trap-nights
Funnel trap	Lizards, snakes	Ornamental Snake, Common Death Adder, Yakka Skink, Dunmall's Snake, Allan's Lerista	882	Trap-nights
Elliott trap	Small mammals	n/a	2,860	Trap-nights
Cage trap	Medium-sized mammals	Northern Quoll	31	Trap-nights
Remote-sensory camera	Mammals, birds	Short-beaked Echidna, Northern Quoll, Squatter Pigeon	122	Trap-nights
AnaBat	Microchiropteran bats	Ghost Bat, Large Pied Bat	45	AnaBat-nights
Bird survey	Birds	Squatter Pigeon, Red Goshawk, Painted Honeyeater, Australian Painted-snipe, Black-throated Finch, migratory birds	288	Person-hours
Diurnal targeted search	Reptiles, larger mammals	Allan's Lerista, Yakka Skink, Dunmall's Snake, Common Death Adder, Short-beaked Echidna, Koala	45.3	Person-hours
Spotlighting	Frogs, reptiles, mammals, birds	Ornamental Snake, Common Death Adder, Short-beaked Echidna, Central Greater Glider, Koala	52.5	Person-hours

*Potential EVNT species are those listed as endangered, vulnerable, near threatened or special least concern within Queensland and/or nationally that have been historically recorded within the region.

†Note that not all sites were surveyed over four nights, as heavy rain necessitated the early closure of five sites. Four of these were re-surveyed on a later date, resulting in >4 survey nights for these sites.



Legend

- Drainage Lines
- Saraji Road
- Survey Area
- MLA Area

Survey Points

- Trap Site
- Camera
- AnaBat
- Spotlight
- Target

Field-verified Broad Vegetation Group

- 10a
- 12a
- 16a
- 17a
- 17b
- 18b
- 24a
- 25a
- 34d
- 7a
- 9e
- H12a
- H16a
- H17a
- H18b
- H24a
- H25a

Source: Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VS PROJECT FILES\TE FIGURES\VI010 - VS - TE F 03-02 FV FAUNA SURVEYS.aprx

Vulcan South

Locations of Fauna Surveys

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 3-3

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

3.3 GROUNDWATER-DEPENDENT ECOSYSTEMS

The Queensland Government has undertaken mapping of groundwater-dependent ecosystems (GDEs) across most of the State (Department of Science, Information Technology and Innovation 2015). The survey area has, however, not been mapped in the most recent version (version 1.5) of this GDE mapping.

Instead, the *National Atlas of Groundwater Dependent Ecosystems* (BOM 2019) was consulted to identify locations where there is a moderate to high potential for vegetation communities to be dependent on groundwater. This dataset was compared to the field-verified regional ecosystem mapping undertaken as per **Section 3.2.1**. Regional ecosystems present within areas mapped as potentially groundwater-dependent ecosystems were assessed for their likelihood of groundwater dependence by examining:

1) Published literature on the ecology of the dominant tree species in each regional ecosystem;
2) landscape position;
3) water-holding capacity of the soil; and
4) site-specific data on the depth to groundwater (where available).

For regional ecosystems considered likely to be groundwater-dependent, their mapped boundaries were taken from field-verified regional ecosystem mapping, rather than the coarser-scale *National Atlas of Groundwater Dependent Ecosystems.* This integration of GDE mapping with regional ecosystem mapping is a core principle of the Queensland GDE Mapping Project (Department of Science, Information Technology and Innovation 2015).

4 ENVIRONMENTAL VALUES

4.1 OVERVIEW OF THE REGION'S ECOLOGY

4.1.1 Habitat Features

The survey area contains a variety of remnant, regrowth and cleared habitats. The western half of the survey area is dominated by low sandstone ridges and escarpments of the Cherwell/Harrow Range. These escarpments rise 100-170 m above the surrounding plains, and mostly support remnant vegetation. Dominant tree species across the Cherwell/Harrow Range include *Corymbia citriodora, Corymbia aureola, Eucalyptus crebra, Corymbia trachyphloia, Eucalyptus melanophloia* and *Acacia shirleyi.* The sandstone escarpments contain an abundance of boulders and rock outcrops (**Figure 4-1**), which provide shelter for reptiles and rock-wallabies. Rock overhangs and small caves are also present, primarily in the northwest, and these provide potential shelter sites for bats and other fauna.

The eastern half of the survey area predominantly comprises a sand plain supporting woodlands of *Eucalyptus crebra, Eucalyptus melanophloia, Eucalyptus populnea* and/or *Corymbia clarksoniana* (**Figure 4-1**). This plain also contains sections of heavy clay, supporting *Acacia harpophylla, Casuarina cristata* and/or *Eucalyptus cambageana.* These heavier soils have mostly been cleared of their remnant vegetation, although small fragments still remain, especially near Saraji Road. The clay soils support minor gilgai formation. These gilgais tended to be less than 30 cm deep, and held water for less than one month after heavy rain. They provide marginal breeding habitat for frogs, and frog densities tended to be low, even after heavy rain.

A low (~10 m above the surrounding plain) clay rise running northeast-southwest through the southern half of the survey area supported open woodland of *Eucalyptus orgadophila*. The cracking clay soil provided potential shelter for some reptiles and mammals; however, the understorey had been markedly affected by prolonged heavy grazing by livestock. This understorey was dominated by the exotic pasture grass, *Bothriochloa pertusa*, which was grazed to a lawn during dry periods, affording little protection for ground-dwelling fauna.

Heavy grazing pressure was also a notable feature of the sand plains across the survey area. This manifested through the altered composition of the understorey vegetation (Fensham *et al.* 1999; Walker *et al.* 2006). Native perennial grasses, an important food source for a variety of granivorous animals (Lewis 2007; Crowley 2008), were scarce, while introduced pasture grasses (especially *Cenchrus ciliaris, Bothriochloa pertusa, Melinis repens* and *Urochloa mosambicensis*) and native annual species (e.g., *Alloteropsis cimicina, Setaria surgens, Dactyloctenium radulans, Perotis rara*) dominated all remnant and non-remnant habitats away from the sandstone ridges.

The survey area is bisected by numerous first- to fourth-order watercourses that flow in an easterly direction. All of these are tributaries of the Isaac River. All watercourses on site are ephemeral, and sustain flows for short periods (less than one week) following heavy rain. Sub-surface flows (beneath the sandy creek beds) occur for longer periods, and third- and fourth-order watercourses support a dense fringe of *Eucalyptus camaldulensis, Melaleuca leucadendra* and/or *Melaleuca fluviatilis,* trees that can access this water supply. These sandy-bedded watercourses do not provide an important water source for fauna, due to a lack of pools and the short duration of surface flows. The only watercourse on site that retained pooled water for extended periods (i.e., months) after rain was North Creek, but only in its upper reaches. Where it passes through gorges within sandstone escarpments, the boulder-strewn bed of North Creek (**Figure 4-1**) contains numerous small pools, which provide a drinking source for fauna. These pools were dry in the late dry season (September-October).

Other surface water features that provide important water sources for fauna include farm dams and natural wetlands. The latter are represented on site by two billabongs formed in the former channel of Hughes Creek (**Figure 4-1; Figure 4-2**). The western one is a mapped wetland under the *Vegetation Management Act 1999*. Both of these billabongs had heavily grazed margins and supported few waterfowl. Among the farm dams, two areas provided particularly important habitat for waterfowl and other aquatic wildlife: 1) a chain of dams in the far southeast of the survey area (along a

drainage line), and 2) a large dam beside cattle yards in the southwest of the survey area. Both sites supported a diversity of sedges and rushes, providing refuge for waterfowl and other fauna. A smaller, but equally well vegetated dam occurred in the northeast of the survey area, within the Vulcan Coal Mine ML (**Figure 4-1; Figure 4-2**).

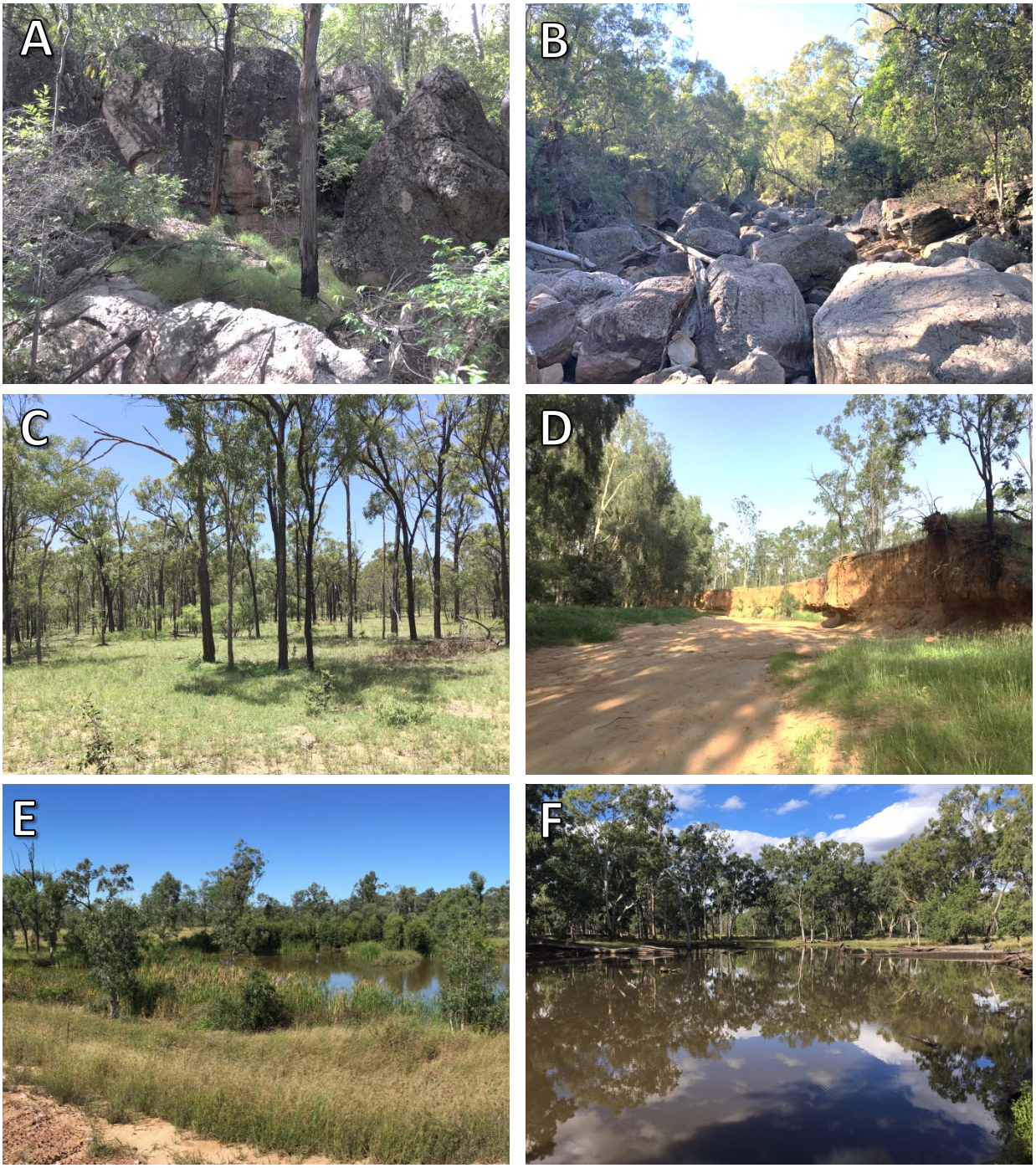
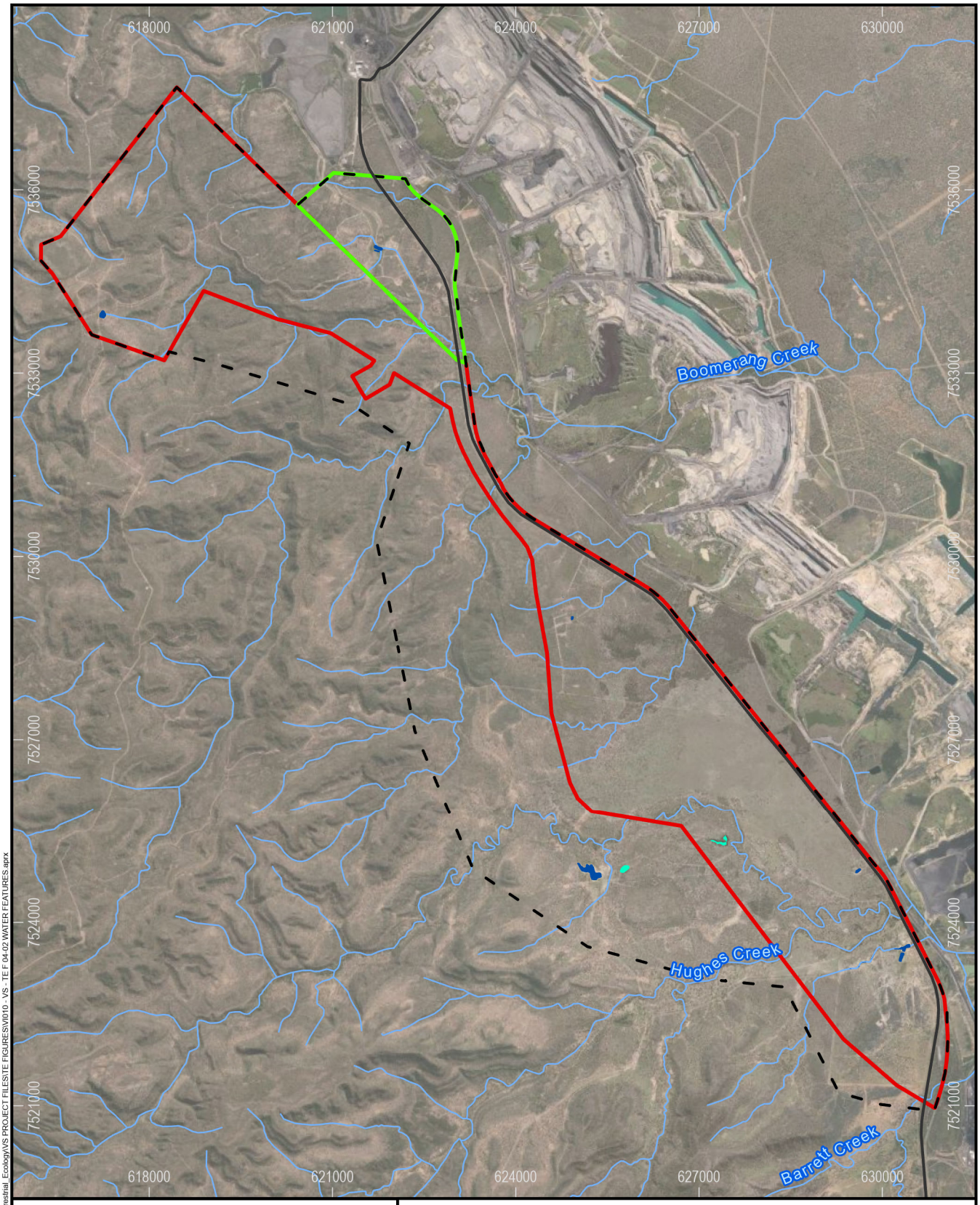


Figure 4-1 **Habitat features of the survey area:** A) sandstone outcrops, B) headwaters of North Creek, C) sand plain woodland dominated by *Eucalyptus crebra* (RE 11.5.9), D) middle reaches of Hughes Creek showing sandy watercourse bed, E) dam in northeast, from which cattle are excluded, and F) natural billabong beside Hughes Creek.



Legend

- Drainage Lines
- Saraji Road
- ML 700060
- MLA Area
- Survey Area
- Dam
- Natural Wetland

Source: Geoscience Australia 2015, State of Queensland (Department of Resources) 2021, Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Vulcan South

Water Features

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-2

VITRINITE BRIGHTER COAL

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4.1.2 Vegetation Communities

Sixteen regional ecosystems were recorded within the survey area (**Table 4-1, Figure 4-3**). Of these, 14 were present within the MLA area. Field surveys revealed widespread errors in the original regulated vegetation map of the site, which has since been updated based on these surveys (for the regulated vegetation map, refer to **Figure 4-16**):

1) A large unit located in the centre of the survey area was erroneously mapped as the endangered regional ecosystem 11.4.8. Field surveys revealed that this entire unit contains the least concern regional ecosystem 11.9.2. This is supported by secondary sites 6, 23 and 31 (**Appendix B**). The regulated vegetation map has been updated accordingly.
2) The dominant unit in the western part of the survey area was mapped as a mixed mosaic containing 11.10.1, 11.10.3 and 11.10.8. While 11.10.3 is widespread in this unit, 11.10.8 is confined to a single, tiny patch (secondary site 50). Regional ecosystem 11.10.1 is represented by two distinctly different subtypes. The classic subtype (dominated by *Corymbia citriodora, Corymbia trachyphloia* and *Eucalyptus crebra*) is limited in extent, primarily occurring in sheltered gorges and south-facing slopes. The more widespread subtype was an open forest dominated by *Corymbia aureola* and *Eucalyptus melanophloia*, which usually grew on plateaux and other exposed sites with shallow, rocky soil. This vegetation unit did not match any of the described regional ecosystems in Queensland, but bore some similarity to 11.10.4a and 11.10.13b (both belong to the broad vegetation group 12a, unlike classical 11.10.1, which belongs to 10a). The Queensland Herbarium has opted to combine both subtypes under 11.10.1 in the updated regulated vegetation map. However, these subunits are mapped separately in this report, in light of their different habitat values to threatened fauna. The subtype dominated by *C. aureola* and *E. melanophloia* is assigned the code 11.10.1x1, as per Nelder *et al.* (2019). Secondary sites assessing 11.10.1x1 include 3, 24, 37 and 44 (**Appendix B**).
3) Large parts of the survey area are mapped as the regional ecosystem 11.5.9b. These areas are better described as 11.5.9, due to the absence of *Eucalyptus tenuipes* and *Lysicarpus angustifolius*, and the frequent dominance of *Eucalyptus melanophloia, Alphitonia excelsa, Acacia* spp. and *Melaleuca nervosa*. This is supported by secondary sites 2, 17, 25 and 32 (**Appendix B**). In some places (e.g., secondary sites 1, 4 and 35), the *Eucalyptus* stratum is missing, resulting in a dense shrub layer of *Melaleuca nervosa, Acacia burdekensis* and/or *Allocasuarina luehmannii*. Presumably this occurs where drainage is impeded by shallow bedrock or texture contrast soils. Such areas may constitute 11.5.2, specifically 11.5.2a where *A. luehmannii* is dominant. However, this designation is not perfect, given the frequent presence of *E. melanophloia,* a species not listed in the description of 11.5.2. Due to a lack of suitable alternatives for these communities, they are retained as subtypes of 11.5.9, despite the localised absence of a *Eucalyptus* stratum.
4) Extensive areas mapped as regional ecosystem 11.5.9b were located on the foot slopes of sandstone outcrops. In many instances, there was substantial outcropping of sandstone present. Based on gully erosion present at some of these sites, the sandy layer was only approximately 0.5 m thick above sandstone. These areas were more appropriately considered 11.10.7, which is the equivalent *E. crebra* and/or *E. melanophloia* community on land zone 10. This is supported by secondary sites 7, 38 and 40 (**Appendix B**).
5) The extent of land zone 3 (alluvium) tended to be over-estimated by certified regional ecosystem mapping. Often, there were relatively flat terraces on the sandstone slopes close to waterways that resembled alluvial plains on aerial imagery. However, field surveys revealed steep boulder-strewn slopes (land zone 10) between these terraces and the banks of the waterway, indicating that these terraces are not alluvial. Furthermore, where land zone 5 (sand plain) abutted waterways, there was often no detectable drop in elevation or change in soil colouration as one approached the waterway, consistent with a shift to land zone 3. In some cases, the terrain actually rose slightly from the neighbouring plain to the banks of the watercourse (with a very steep bank present on one side of the watercourse). Such cases are more appropriately considered land zone 5 up to the watercourse bank.

6) Certified regional ecosystem mapping is undertaken at a broad scale, and contains numerous units composed of a mosaic of multiple regional ecosystems. The fine scale of the field-verified mapping has allowed, in most cases, the re-mapping of each regional ecosystem separately. The updated regulated vegetation map now maps each unit separately.

Table 4-1 Regional ecosystems recorded in the survey and project areas

Regional Ecosystem	BVG*	Short description	VM class†	Biodiv. Status‡	Hectares within survey area		Hectares within project area	
					Remnant	Regrowth	Remnant	Regrowth
11.3.1	25a	*Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains	E	E	1.6	0	0	0
11.3.2	17a	*Eucalyptus populnea* woodland on alluvial plains	OC	OC	127.7	148.2	55.4	63.9
11.3.7	9e	*Corymbia* spp. woodland on alluvial terraces	LC	OC	86.1	0	31.3	0
11.3.25	16a	*E. camaldulensis* forest fringing drainage lines.	LC	OC	147.7	5.3	71.9	2.0
11.3.27c	34d	Mixed sedgeland in freshwater wetland	LC	OC	2.0	0	0	0
11.3.27e	34d	Open water freshwater wetland with fringing trees	LC	OC	6.5	0	6.5	0
11.4.8	25a	*Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* on Cainozoic clay plains.	E	E	127.4	4.0	124.5	4.0
11.4.9	25a	*Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains.	E	E	16.2	0	13.9	0
11.5.3	17a	*Eucalyptus populnea* woodland on Cainozoic sand plains and/or remnant surfaces.	LC	NC	278.7	237.4	33.1	140.1
11.5.9	18b	*Eucalyptus crebra* and other *Eucalyptus* spp. and *Corymbia* spp. woodland on Cainozoic sand plains and/or remnant surfaces.	LC	NC	877.7	271.4	488.6	17.0
11.9.2	17b	*Eucalyptus orgadophila* woodland on fine-grained sedimentary rocks.	LC	NC	325.5	0	267.8	0
11.10.1	10a	*Corymbia citriodora* woodland on coarse-grained sedimentary rocks.	LC	NC	244.6	0	161.0	0
11.10.1x1	12a	*Corymbia aureola* and *Eucalyptus melanophloia* open forest on scarps and sandstone tablelands.	LC	NC	474.0	11.3	227.8	0
11.10.3	24a	*Acacia shirleyi* open forest on coarse-grained sedimentary rocks. Crests and scarps.	LC	NC	1,589.0	68.8	849.9	47.1
11.10.7	12a	*Eucalyptus crebra* woodland on coarse-grained sedimentary rocks.	LC	NC	362.7	48.3	181.9	10.3
11.10.8	7a	Semi-evergreen vine thicket in sheltered habitats on medium to coarse-grained sedimentary rocks.	OC	OC	1.3	0	1.3	0
Non-remnant	-	Cleared pasture, +/- scattered trees or young regrowth	-	-	1,519.2		1,020.0	

*BVG = broad vegetation group

†VM class = classification under the *Vegetation Management Act 1999*: E = endangered, OC = of concern. LC = least concern.

‡Biodiversity status relates to environmentally sensitive areas under the *Environmental Protection Act 1994*: E = endangered, OC = of concern, NC = no concern at present.

618000
621000
624000
627000
630000
7539000
7536000
7533000
7530000
7527000
7524000
7521000

Legend

- Survey Area
- MLA Area

Field-verified RE mapping

- 11.10.1
- 11.10.1x1
- 11.10.3
- 11.10.7
- 11.10.7/11.5.9
- 11.10.8
- 11.3.1
- 11.3.2
- 11.3.2/11.3.7
- 11.3.25
- 11.3.27c
- 11.3.27e
- 11.3.7
- 11.3.7/11.3.2
- 11.4.8
- 11.4.9
- 11.5.3
- 11.5.9
- 11.5.9/11.10.13
- 11.9.2
- HVR 11.10.13
- HVR 11.10.3
- HVR 11.10.7
- HVR 11.10.7/11.10.3
- HVR 11.3.2
- HVR 11.3.25
- HVR 11.4.8
- HVR 11.5.3
- HVR 11.5.3/11.3.2
- HVR 11.5.9

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_FV_RegionalEcosystems.aprx

Vulcan South

Field-verified Regional Ecosystem Map

0 1 2

Kilometers

Scale: 1:60,000 (A3)

16/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-3

VITRINITE BRIGHTER COAL

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4.1.3 Groundwater-dependent Ecosystems

There are three main categories of groundwater-dependent ecosystems (Department of Science, Information Technology and Innovation 2015):

1) vegetation that accesses sub-surface groundwater through its roots;
2) wetlands that receive groundwater discharge (e.g., springs); and
3) subterranean aquatic ecosystems, and marine systems that receive sub-marine discharge of groundwater.

Of these, categories 2 and 3 are aquatic ecosystems assessed elsewhere through an aquatic ecological assessment. Category 1, however, refers to terrestrial ecosystems that are dependent on access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services.

For vegetation to access groundwater in the sub-surface, the roots must be able to reach the capillary zone above the water table and the water quality of groundwater must be adequate. In order to assess and map potential terrestrial groundwater-dependent ecosystems across the survey area, the following data sources were considered:

- *National Atlas of Groundwater Dependent Ecosystems version 2.0* (BOM 2019);
- published literature on root depths and groundwater usage among local vegetation types;
- depth-to-groundwater mapping of part of the project area (provided by hydrogeologist.com.au); and
- groundwater quality (hydrogeologist.com.au 2022).

4.1.3.1 Review of Groundwater Use by Terrestrial Vegetation

There has been much recent worldwide research into groundwater-dependent ecosystems, combining tools such as stable isotope analysis, measurement of pre-dawn leaf water potential, and seasonal tracking of transpiration rates and “greenness” indices. One of the key findings of this research is that the use of groundwater by terrestrial vegetation depends greatly on the depth of this groundwater, and the influence of depth is largely consistent across continents and vegetation communities:

- In arid regions of China, groundwater up to 4–10 m below the surface is used by vegetation (Jin *et al.* 2011; Lv *et al*. 2012; Liu *et al*. 2017).
- In California, groundwater up to a depth of 6–8 m is used by vegetation (McLendon *et al*. 2008).
- Various studies in Australia have identified lower limits to the root extraction of groundwater of 7.5 m (Benyon *et al*. 2006), 5–11 m (O'Grady *et al*. 2006a), 8–10 m (Robinson *et al*. 2006), and 9 m (Zolfaghar *et al*. 2017).

Despite these relatively consistent average patterns, not all tree species access groundwater equally. For example, based on spatial patterns in declining canopy conditions during drought, Kath *et al.* (2014) inferred that *Eucalyptus populnea* (a species native to the survey area) regularly accessed groundwater to a depth of 13 m and, to far lesser extent, up to 26 m. To explore this variation between species in their propensity to access groundwater, published data on local vegetation types were reviewed and summarised in **Table 4-2**. Note that this assessment is limited to regional ecosystems within the project area, as the accuracy of depth-to-groundwater mapping far beyond this is limited by a lack of survey data.

Where data is lacking, it is practical to use the widely adopted rule-of-thumb (e.g., Eamus *et al*. 2006a; Department of Natural Resources, Mines and Energy (DNRME) 2019a), that vegetation is likely to use groundwater where it is up to a depth of 10 m, may possibly use groundwater at depths of 10-20 m, but is unlikely to access water deeper than 20 m.

Table 4-2 Published groundwater usage by local tree species

Regional Ecosystem	Rooting depths of dominant species	Likelihood of groundwater-dependence
11.3.2	*Eucalyptus populnea* accesses groundwater in some situations (Anderson and Hodgkinson 1997) but not others (Fensham and Fairfax 2007). On Brigalow Belt floodplains, *E. populnea* accesses groundwater up to 13 m deep and, to a lesser extent, up to 26 m, but not deeper (Kath *et al.* 2014).	**Moderate:** Possibly uses ground water where groundwater levels are within 13 m, and there may be minimal use of groundwater at sites where the water table is within 25 m of the surface.
11.3.7	*Corymbia tessellaris* accessed groundwater at the only site where it has been studied, where the water table was 4 m deep (O'Grady *et al.* 2006a). As the species is largely confined to terraces along watercourses (where the water table is usually shallow), it is probably often groundwater-dependent. *Corymbia clarksoniana* is highly dependent on groundwater between 6.5 and 10 m deep during the dry season (Cook and O'Grady 2006; O'Grady *et al.* 2006a).	**Moderate:** Possibly utilises groundwater where this is <20 m deep, and likely uses it within 10 m.
11.3.25	*Eucalyptus camaldulensis* is often dependent on shallow aquifers and water courses (Bacon *et al.* 1993). Isotope studies indicate that *E. camaldulensis* accesses groundwater up to a depth of 9.4–11.2 m, but not deeper (Rumman *et al.* 2018). A similar finding—that *E. camaldulensis* commonly accesses groundwater to a depth of 12.5 m—was revealed by studies of tree condition (Kath *et al.* 2014). The latter study revealed that groundwater may also be accessed to a limited extent up to 20 m, but not deeper. *Melaleuca leucadendra* and other riparian *Melaleuca* spp. are reliant on river water and/or shallow groundwater, up to 9 m deep (O'Grady *et al.* 2005, 2006a, 2006b).	**High:** Water tables are within reach of this vegetation, and the constituent species are regularly groundwater-dependent elsewhere.
11.3.27e	This is a vegetated wetland that, to be groundwater-dependent, requires the surface expression of groundwater.	**Nil:** The water table is too low for there to be any surface expression.
11.4.8	Tunstall and Connor (1981) found *Acacia harpophylla* roots to penetrate to at least a depth of 4 m, although high salt content of the soil caused plants to experience strong water deficiencies except immediately after rain. This dependence on rain implied a failure to utilise groundwater. Subsoils beneath *A. harpophylla* communities tend to be heavy, saline and/or sodic, impeding water availability (Tunstall and Connor 1981). *A. harpophylla* tissue is even more resistant to desiccation than that of other shallow-rooted arid-zone *Acacia* spp. (Connor and Tunstall 1968), implying a lack of reliance on groundwater.	**Low:** Unlikely to utilise groundwater.

Regional Ecosystem	Rooting depths of dominant species	Likelihood of groundwater-dependence
11.4.9	Tunstall and Connor (1981) found *Acacia harpophylla* roots to penetrate to at least a depth of 4 m, although high salt content of the soil caused plants to experience strong water deficiencies except immediately after rain. This dependence on rain implies a failure to utilise groundwater. Subsoils beneath *A. harpophylla* communities tend to be heavy, saline and/or sodic, impeding water availability (Tunstall and Connor 1981). *A. harpophylla* tissue is even more resistant to desiccation than that of other shallow-rooted arid-zone *Acacia* spp. (Connor and Tunstall 1968), implying a lack of reliance on groundwater.	**Low:** Unlikely to utilise groundwater.
11.5.3	*Eucalyptus populnea* accesses groundwater in some situations (Anderson and Hodgkinson 1997) but not others (Fensham and Fairfax 2007). On Brigalow Belt floodplains, *E. populnea* accesses groundwater up to 13 m deep and, to a lesser extent, up to 26 m, but not deeper (Kath *et al*. 2014).	**Low-Moderate:** Possibly uses ground water where groundwater level is within 13 m, and there may be minimal use of groundwater elsewhere.
11.5.9	Ironbark species (*Eucalyptus crebra* and *E. melanophloia*) are sensitive to die-back during drought and exhibit xylem flows and root depths consistent with a lack of access to groundwater (Rice *et al*. 2004; Fensham and Fairfax 2007). *Corymbia clarksoniana* is highly dependent on groundwater between 6.5 and 10 m deep during the dry season (Cook and O'Grady 2006; O'Grady *et al*. 2006a). Gow *et al*. (2016) found that *Eucalyptus crebra*, *E. decorticans* and *Corymbia* spp. woodlands on rocky hill slopes exhibited temperature radiation patterns consistent with the use of deep soil water. As the water table was generally between 10 m and 60 m, the authors hypothesised that most of the water used was intercepted while draining through the unsaturated zones of the soil profile, rather than originating from groundwater per se.	**Low-Moderate:** In places where the water table is within 10 m of the ground surface, sub-dominant components of this RE are likely to be groundwater-dependent.
11.9.2	No data has been published on the root structure or groundwater dependence of *Eucalyptus orgadophila*. *Corymbia erythrophloia*, a sub-dominant component of the ecosystem, showed xylem flow patterns consistent with access to some amount of sub-soil water (Rice *et al*. 2004), although whether this reflects use of groundwater is not known.	**Low:** Unlikely to utilise groundwater, due to consistently large depths where this RE occurs.
11.10.1	When *Corymbia citriodora* grew above a shallow water table (i.e., 3.1 m deep), root and evapotranspiration patterns indicated that groundwater was an important water source (Falkiner *et al*. 2006; Benyon *et al*. 2006). No data are published on the use of deeper sources of groundwater by *C. citriodora*. Ironbarks (*Eucalyptus crebra* and *E. melanophloia*) are sensitive to die-back during drought and exhibit xylem flows and root depths consistent with a lack of access to groundwater (Rice *et al*. 2004; Fensham and Fairfax 2007).	**Low:** With the possible exception of the bases of certain gorges, groundwater is too deep within the sandstone ranges to be available to this RE.
11.10.1x1	No data have been published on the groundwater dependence of *Corymbia aureola, Corymbia trachyphloia* or *Eucalyptus exserta.* This vegetation type primarily occupies sandstone plateaux, where groundwater is far beyond the root zone of most trees.	**Low:** Unlikely to utilise groundwater, except when shallow.

Regional Ecosystem	Rooting depths of dominant species	Likelihood of groundwater-dependence
11.10.3	There are no published data on the groundwater-dependence or rooting depths of *Acacia shirleyi* or *Acacia rhodoxylon*. However, other *Acacia* spp. that grow on similar rocky substrates (e.g., *A. aneura, A. aptaneura* and *A. kempeana*) do not access groundwater, but instead have reinforced xylem vessels that are able to cope with strong water deficiencies (Anderson and Hodgkinson 1997; Nolan *et al*. 2017).	**Low:** Dominant species are unlikely to utilise groundwater.
11.10.7	Ironbarks (*Eucalyptus crebra* and *E. melanophloia*) are sensitive to die-back during drought and exhibit xylem flows and root depths consistent with a lack of access to groundwater (Rice *et al*. 2004; Fensham and Fairfax 2007). Gow *et al*. (2016) found that *Eucalyptus crebra*, *E. decorticans* and *Corymbia* spp. woodlands on rocky hill slopes exhibited temperature radiation patterns consistent with the use of deep soil water. As the water table was generally between 10 m and 60 m, the authors hypothesised that most of the water used was intercepted while draining through the unsaturated zones of the soil profile, rather than originating from groundwater per se.	**Low:** Dominant species are unlikely to utilise groundwater and groundwater is likely to be too deep at the locations where this RE occurs (on terraces and slopes).
11.10.8	No data have been published on the root structure or groundwater dependence of local vine thicket trees and shrubs. Most species are semi-deciduous, avoiding drought stress by shedding their leaves and thereby minimising transpiration. Studies of vine thickets across a range of soil types in northern New South Wales found water stress to be ubiquitous during drought periods (Curran *et al*. 2009), implying a lack of access to groundwater during dry periods.	**Low:** Dominant species are unlikely to utilise groundwater.

4.1.3.2 Depth to Groundwater

Hydrogeologist.com.au (2022) developed a calibrated, numerical groundwater model of all relevant aquifers within the vicinity of Vulcan South's proposed pits. This was based on a range of data sources, including an on-site groundwater monitoring network, groundwater assessments from nearby mines, and the *Queensland Groundwater and Surface Water Monitoring* database (DNRME 2019b).

An aquifer is generally defined as a geological unit that can transmit and store significant quantities of groundwater. In the vicinity of the project area, some geological units yield low volumes of groundwater and would not typically be classified as aquifers in most hydrogeological settings. However, as these could provide a small and/or temporary source of groundwater for vegetation, they are referred to as aquifers for the purposes of this assessment.

Groundwater may be stored, even if only temporarily, in three hydro-stratigraphic units present on site:

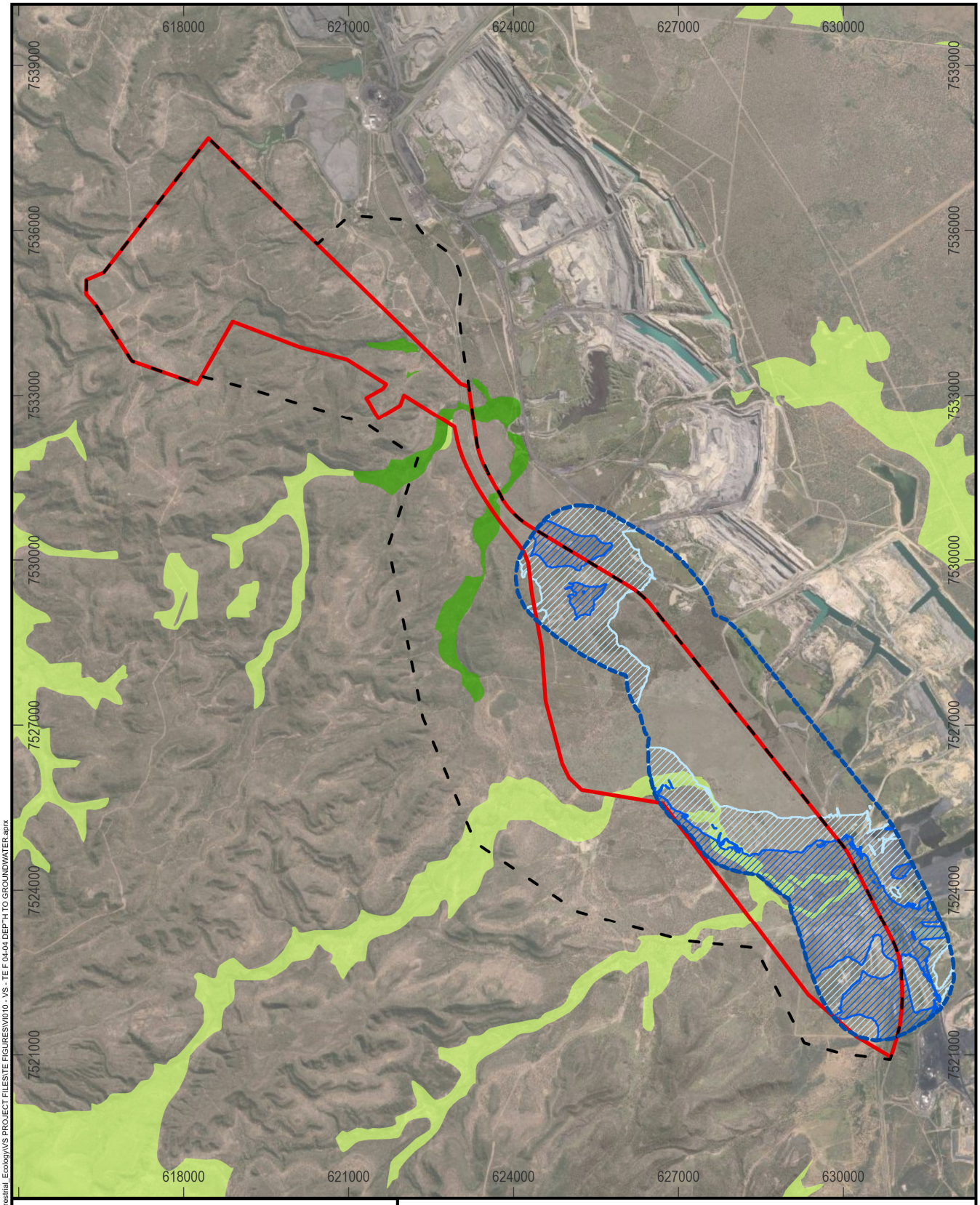
1) Quaternary Alluvium: The silted-up stream channels of ephemeral creeks support small, localised, temporary unconfined "aquifers". The alluvium saturates following flow events within the creeks. As the watercourses are highly ephemeral, some component of sub-surface flow through the alluvium persists after the surface water flow ceases.
2) Tertiary Sediments: This is a mix of Tertiary sediments (lenses of palaeochannel gravels and sands separated by dry, densely compacted sandy silts, sandy clays and clays) and weathered Permian regolith. These aquifers tend to be of limited lateral and vertical extent and consequently have low hydraulic conductivity. This layer was generally unsaturated in the survey area.
3) Permian Coal Measures: The coal seam aquifers are generally confined above and below by the low-permeability inter- and overburden. The coal seam aquifers present on site are regarded as poor aquifers because of their limited thickness and the presence of low-permeability interburden. Across most of the survey area, these aquifers represent the shallowest source of groundwater for vegetation.

Although Quaternary alluvium can provide a temporary source of shallow, fresh groundwater for terrestrial vegetation, this is recharged exclusively via rain and surface flows, and is therefore unaffected by any drawdown that may result from Vulcan South. For most of the survey area, the Permian Coal Measures and, occasionally, the Tertiary sediments contain the uppermost groundwater.

A map of composite groundwater elevation contours, within a buffer of 1 km out from the proposed mining pit edge, was developed by Hydrogeologist.com.au (2022). This was converted to a depth-to-groundwater map based on surface topography obtained from aerial LiDAR data. This map revealed that in some of the project area water tables were within 20 m of the ground surface (**Figure 4-4**), and were therefore potentially within reach of vegetation. In some areas, the groundwater was within 10 m, of the ground surface, where it is likely to be utilised by vegetation. The chief location where this occurs is along Hughes Creek in the south of the project area. Note, the groundwater data provided by Hydrogeologist.com.au (2022) in this report do not include data for the northern half of the survey area (the highwall mining area). However, drilling undertaken in that area has never intercepted groundwater within or above the target coal seams, and highwall mining will therefore not intersect or affect groundwater (Hydrogeologist.com.au 2022).

4.1.3.3 National Atlas of Groundwater Dependent Ecosystems

According to the *National Atlas of Groundwater Dependent Ecosystems*, there is a high potential for terrestrial groundwater-dependent ecosystems along the lower reaches of Boomerang Creek and its larger tributaries, including North Creek (**Figure 4-4**). Riparian vegetation along Hughes Creek and its tributaries is mapped as having a moderate potential of being a terrestrial groundwater-dependent ecosystem (**Figure 4-4**).



Legend

- Survey Area
- MLA Area
- Depth to Groundwater Boundary

Depth to Water

- 0 - 10m
- 10 - 20m

National Groundwater Dependent Ecosystems Atlas

- High Potential Terrestrial GDE
- Moderate Potential Terrestrial GDE

Source: Bureau of Meteorology 2012, Hydrogeologist.com.au 2020, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Depth to Groundwater in Relation to the GDE Atlas

0 2 4

Kilometers

Scale: 1:100,000 (A4)

4/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-4

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VS PROJECT FILES\TE FIGURES\VI010 - VS - TE F 04-04 DEPTH TO GROUNDWATER.aprx

There was reasonable accordance between the *National Atlas of Groundwater Dependent Ecosystems* and depth-to-groundwater mapping. Areas mapped as moderate GDEs along Hughes Creek had a depth to groundwater of less than 20 m, and some of this was shallower than 10 m. However, shallow groundwater was widespread beyond the boundaries of the mapped GDEs (confined to the floodplain of Hughes Creek), suggesting that this national atlas may not include all local GDEs.

While depth-to-groundwater mapping only exists for a subset of the project area, it can be safely assumed that vegetation along Boomerang, Middle and North Creeks are also groundwater-dependent. This is because the depth-to-groundwater mapping closest to these creeks suggests that groundwater is likely to be shallow. Furthermore, the national mapping (which largely accords with depth-to-groundwater mapping along Hughes Creek) indicates a high likelihood of vegetation along these northern creeks being GDEs.

4.1.3.4 Water Quality

All groundwater sampled to date within the project area is saline to highly saline. Electrical conductivity ranges between 5.18 and 22.2 dS/m, with a mean value of 10.9 dS/m (Hydrogeologist. com.au 2022). For context, sea water has an electrical conductivity of approximately 50 dS/m, while drinking water has 0.05–0.5 dS/m. The pH of groundwater on site is generally close to neutral (Hydrogeologist.com.au 2022). Electrical conductivity greater than 3–4 dS/m inhibits the growth of most plants (Katerji *et al.* 2003), although tolerance to salt varies between species. As the water table within the project area is beyond the reach of most local plant communities, the most relevant plant species are those inhabiting regional ecosystems 11.3.2, 11.3.25, 11.3.7, 11.5.3 and 11.5.9.

Some local tree species are known to utilise groundwater with salinity that would preclude its use by most plants. *Eucalyptus camaldulensis*, a dominant tree along local waterways (RE 11.3.25), is one such salt-tolerant species. Salinity comparable to the lower levels recorded onsite impairs the growth of *E. camaldulensis* seedlings, but has no effect on survival (Sun and Dickinson 1995a; Farrell *et al.* 1996). Furthermore, isotope analyses have confirmed that adult trees growing above a 2–3 m deep, highly saline (30–50 dS/m) water table were able to use this groundwater, despite experiencing substantial water stress as a result (Mensforth *et al.* 1994). While saline groundwater can potentially sustain *E. camaldulensis* during dry periods, most growth occurs in response to saturation of the upper soil profile with freshwater during floods. These intermittent flooding events provide half to two-thirds of the water requirements of the species and are vital for maintaining their health (Eamus *et al.* 2006b; Wen *et al.* 2009).

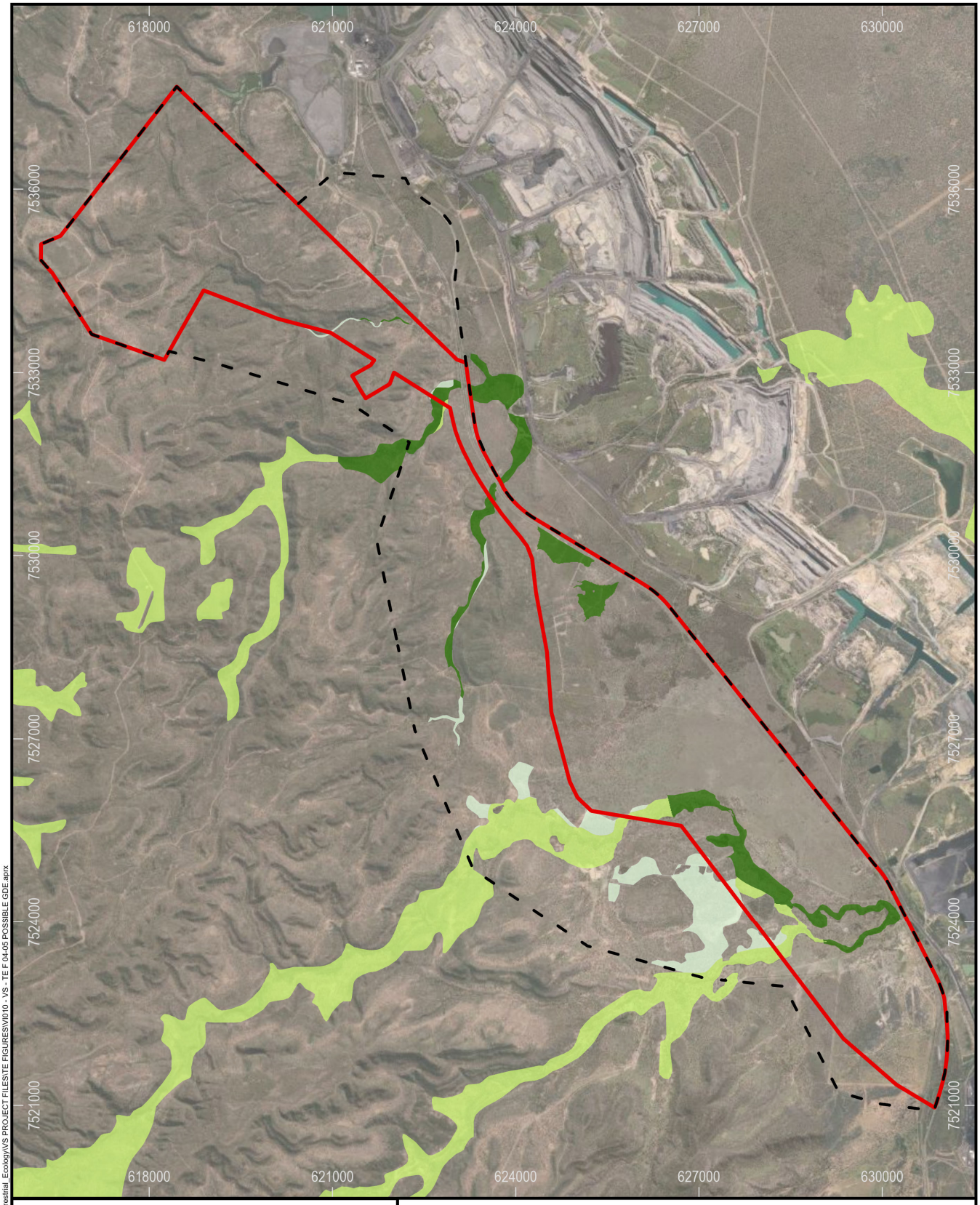
Melaleuca leucadendra, the other dominant riparian species in regional ecosystem 11.3.25 is known to be variously salt-sensitive (van der Moezel *et al.* 1991) to salt-tolerant (Sun and Dickinson 1995a). This species may be able to use groundwater at the lower end of local salinity levels (equivalent to electrical conductivity up to 5 dS/m), even though such concentrations of salt greatly impair growth (Nguyen *et al.* 2009). It is likely that *M. leucadendra* is dependent on shallow, sub-surface flows through Quaternary alluvium along watercourses following rain events, but is not likely to be able to utilise saline groundwater within Tertiary sediment and Permian Coal Measures.

Corymbia tessellaris, a dominant species in RE 11.3.7, is relatively salt-sensitive (Sun and Dickinson 1995b). *Eucalyptus crebra,* a dominant species in RE 11.5.9 and subdominant in RE 11.3.7 and 11.3.25, but more abundant on land zones 5 and 10, has moderate salt tolerance only (Gill and Abrol 1991; Sun and Dickinson 1993; Hoy *et al.* 1994). These species are unlikely to be able to utilise most groundwater on site. *Eucalyptus populnea*, the dominant tree in RE 11.3.2 and 11.5.3, shows a comparable salt-tolerance to *E. camaldulensis* in short-term laboratory trials (Madsen and Mulligan 2006). However, no field studies have examined whether *E. populnea* is able to use saline groundwater.

In summary, most regional ecosystems within the project area are unlikely to be groundwater-dependent. Possible exceptions are regional ecosystems 11.3.25, 11.3.2 and 11.5.3, which may use saline groundwater when this is within the reach of roots (<20 m below the soil surface).

4.1.3.5 Potential Groundwater-dependent Ecosystems

Based on literature reviews (see **Section 4.1.3.1**), depth-to-groundwater data (see **Section 4.1.3.2**), national GDE mapping (see **Section 4.1.3.3**) and water quality data (see **Section 4.1.3.4**), there are likely to be some GDEs contained within the project area. The locations of these likely GDEs closely match that mapped within the *National Atlas of Groundwater Dependent Ecosystems*. Additional partly groundwater-dependent ecosystems may be located in the central and southern parts of the project area, based on depth-to-groundwater data. The location of these GDEs is presented in **Figure 4-5**.



Legend

- Survey Area
- MLA Area

Groundwater Dependent Ecosystems

- High potential GDE
- Moderate potential GDE
- Low potential GDE

Source: Bureau of Meteorology 2012, Hydrogeologist.com.au 2020, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Possible Groundwater Dependent Terrestrial Ecosystems

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

24/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-5

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VS PROJECT FILES\TE FIGURES\VI010 - VS - TE F 04-05 POSSIBLE GDE.aprx

4.1.4 Biodiversity

Field surveys detected 41 species of mammal, 135 species of bird, 36 species of reptile, 14 species of frog and 429 species of vascular plant (**Appendix C**). Not all bat calls could be identified to unique species, and unresolved calls may have arisen from an additional species of bat not included in the above tally (**Appendix D**).

4.1.4.1 Thoroughness of Surveys

The nature of ecological surveys means that it is inevitable that some species present remain undetected. To estimate the extent to which this occurred, species accumulation curves were fitted to the fauna and flora data using EstimateS 9.1.0. The total numbers of species that occur within the survey area were estimated using the Chao2 richness estimator. These analyses suggested that, of the species that could have been detected using the methodology employed, the surveys to date have detected:

1) 88% of the floral diversity;
2) 100% of reptiles;
3) 97% of amphibians;
4) 100% of birds;
5) 92% of non-bat mammals; and
6) 100% of bats.

Note that the above are estimates generated from a statistical analysis of the detection rate per sampling unit (e.g., per trap site). It only takes into account species that *could* be detected by the surveys. Species that were inactive at the time of surveys, or which are visitors that did not occur during the sampling periods are not incorporated into these estimates. Sampling across a broad range of seasons and climatic conditions, as was done for this study, limits the number of species considered undetectable. Nevertheless, it is possible that even for taxonomic groups with total detection, additional species could be detected with additional effort. Still, the number missed is expected to be very low. Overall, the species accumulation curves indicate that the data gathered on the area's ecology is relatively thorough. The incomplete knowledge of mammals reflects the cryptic behaviour (shy, difficult to trap) and low density of many species. The incomplete knowledge of amphibians is due to the highly patchy distribution of populations and the narrow windows of time (immediately after heavy rain) that these are detectable. The incomplete knowledge of plants in part owes to the high diversity present (almost 430 species already recorded), and the observation that many are restricted to patchily distributed micro-habitats within the sandstone ridges and gorges within the survey area.

4.1.4.2 Species at their Distributional Limit

In general, the faunal and floral communities of the survey area were typical of the dry *Acacia* and *Eucalyptus* woodlands of the northern Brigalow Belt.

The location of the project, midway between the mesic environments of coastal regions and the arid interior, results in a mixture of species from wetter and drier environments. The following species widespread in coastal regions reach their western distributional limits in the vicinity of the project: Little Lorikeet (*Glossopsitta pusilla*), Scarlet Honeyeater (*Myzomela sanguinolenta*), Golden Whistler (*Pachycephala pectoralis*), Rufous Fantail (*Rhipidura rufifrons*) and the plants, *Deeringia amaranthoides, Euroschinus falcatus, Aristolochia thozetii, Desmodium rhytidophyllum, Pycnospora lutescens, Trophis scandens, Gossia bidwillii, Lophostemon grandiflorus, Sorghum leiocladum, Persoonia amaliae, Cheilanthes nudiuscula, Cyclophyllum coprosmoides, Pavetta granitica, Acronychia laevis, Flindersia australis, Planchonella pohlmanniana* and *Tetrastigma nitens.* Most of these species were recorded in isolated, sheltered pockets within sandstone gorges.

The project area also represents the eastern distributional limit for the following species typical of more arid environments: Inland Forest Bat (*Vespadelus baverstocki*) and the plants, *Heliotropium cuninghamii, Cleome tetrandra* and *Cyperus betchei.*

Only one species (the plant, *Heliotropium peninsulare*) reaches its southern distributional limit near the project area, and one species (Speckled Warbler, *Pyrrholaemus sagittatus*) is near its northern distributional limit.

None of the above species are threatened or near threatened.

The project lies within the contact zone between two species of near-identical rock-wallabies, the Unadorned Rock-wallaby (*Petrogale inornata*) and Herbert's Rock-wallaby (*Petrogale herberti*).These species are not possible to distinguish in the field without genetic testing or chromosomal analysis. In coastal areas, the Fitzroy River is a dispersal barrier that marks the boundary between the two species. However, it is not known if the two species meet further inland. The project occurs closest to known populations of Unadorned Rock-wallabies, just north of Moranbah. However, the Isaac River lies in between. In contrast, there are no major rivers between the Harrow Range (where Vulcan South is located) and Herbert's Rock-wallaby populations near Clermont. Neither species is listed as threatened and, therefore, the identity of the local rock-wallaby species is inconsequential to assessing the environmental impacts of the project.

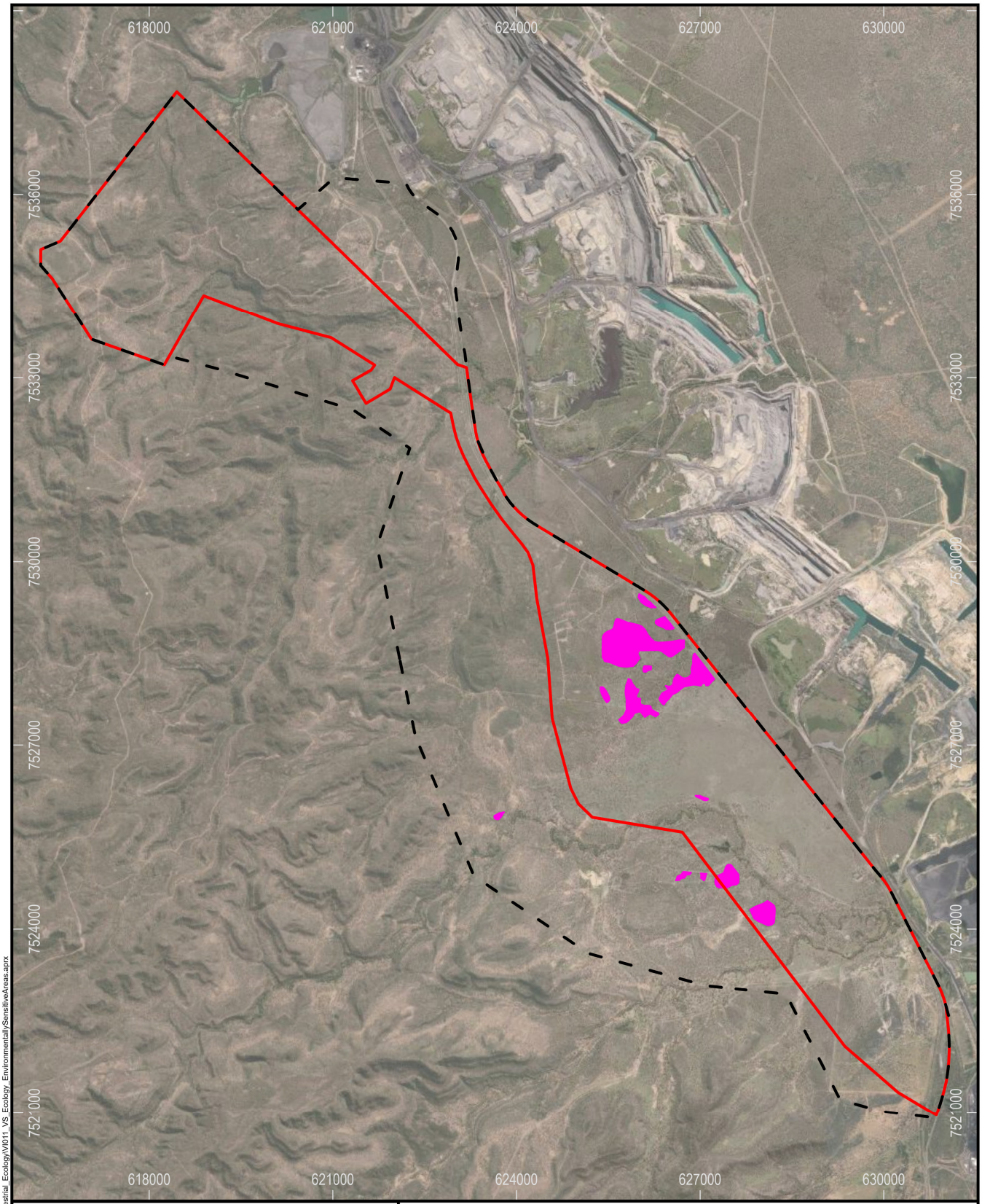
All of the above species occupy relatively broad ranges, and it is unexceptional that a small subset of the 653 species recorded on site occurs near the edge of their distribution. However, one species recorded on site occurs within a very narrow geographic range. The Ornate Velvet Gecko (*Oedura picta*) is a newly described species of reptile (Hoskin 2019) confined to sandstone outcrops within the Cherwell-Harrow Range between Moranbah and Tieri. The project area lies midway along the eastern edge of this very small distribution. The project largely avoids disturbance to the ranges inhabited by this gecko, but small areas of disturbance are expected. Despite its limited range, the Ornate Velvet Gecko is not listed as a threatened or near threatened species.

4.2 ENVIRONMENTALLY SENSITIVE AREAS

Category A and B environmentally sensitive areas are defined under Schedule 12 of the *Environmental Protection Regulation 2008*, while category C environmentally sensitive areas are defined in the *Eligibility Criteria and Standard Conditions for Mining Lease Activities* (Department of Environment and Heritage Protection 2016).

No category A or C environmentally sensitive areas occur in or near the survey area.

The only category B environmentally sensitive areas within the survey area are "endangered regional ecosystems identified in the database known as the 'Regional ecosystem description database'". Field-verified regional ecosystem mapping revealed a total of 145.2 ha of endangered regional ecosystems within the survey area. The locations of these category B environmentally sensitive areas are shown in **Figure 4-6**.



Legend

- Survey Area
- MLA Area

Category B Environmentally Sensitive Areas

- Endangered Regional Ecosystem

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_EnvironmentallySensitiveAreas.aprx

Vulcan South

Environmentally Sensitive Areas

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

2/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-6

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

4.3 MATTERS OF NATIONAL ENVIRONMENTAL SIGNIFICANCE

Matters of national environmental significance (MNES) are those protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). These include:

1. World heritage places;
2. National heritage places;
3. Wetlands of international importance;
4. Listed threatened species and ecological communities;
5. Migratory species protected under international agreements;
6. Commonwealth marine areas;
7. The Great Barrier Reef Marine Park;
8. Nuclear actions; and
9. A water resource, in relation to coal seam gas development and large coal mining development.

The last two matters on the list are not ecological matters, and are assessed elsewhere. Of the remainder, the only MNES present in the vicinity of the project are 4 and 5.

4.3.1 Threatened Ecological Communities

One threatened ecological community was confirmed to be present on site. Two other vegetation communities present on site possessed attributes similar to listed threatened ecological communities, but did not meet the criteria for these listed communities. Each of these three ecological communities is discussed below.

4.3.1.1 Brigalow

A total of 149.2 ha of the threatened ecological community listed as "Brigalow (*Acacia harpophylla* dominant and co-dominant)" are contained within the survey area. This includes remnants and high-quality regrowth of the constituent regional ecosystems, 11.3.1, 11.4.8 and 11.4.9 (see **Figure 4-3**).

4.3.1.2 Poplar Box Woodland on Alluvium

The ecological community listed under the EPBC Act as "Poplar Box Grassy Woodland on Alluvial Plains" broadly corresponds to remnant and high-value regrowth forms of regional ecosystem 11.3.2, among others not found on site. A total of 127.7 ha of remnant 11.3.2 and 148.2 ha of regrowth 11.3.2 occurs within the survey area, mostly along Hughes Creek. Of this, 55.4 ha of remnant 11.3.2 and 63.9 ha of regrowth 11.3.2 occurred within the project area.

According to the draft conservation advice for this ecological community, in order to be considered a MNES, areas of the ecological community must meet key diagnostic characteristics and condition thresholds. One key diagnostic characteristic listed by the draft conservation advice is a "ground layer (<1 m) mostly dominated across a patch by native grasses, other herbs and occasionally chenopods". Dominance is defined as "accounting for more than 50% of the cover". None of the regional ecosystem 11.3.2 within the survey area met this criterion. Weeds (non-native species) comprised 91.8% and 92.9% of the ground layer at the two secondary sites sampled in remnant 11.3.2. These two sites were in the largest, best-quality examples of the community available. This high weed density was typical of ecosystems on alluvial soils in general; weeds also made up an average of 82.2% of the ground layer in 11.3.25.

Within the survey area, *Eucalyptus populnea* (Poplar Box) also formed ecological communities on sand plains. Here, three out of seven secondary sites sampled met the criterion of being dominated by native ground layer species. These sites were on very sandy, leached soils unfavourable for weed establishment. These soil conditions are characteristic of non-alluvial sites, which do not form part of the Poplar Box Grassy Woodland on Alluvial Plains.

Given the dominance of weeds across alluvium within the survey area, none of the *E. populnea* woodlands occurring there qualify as a threatened ecological community under the EPBC Act.

4.3.1.3 Semi-evergreen Vine Thicket

A small area (1.3 ha) of semi-evergreen vine thicket is located in a gorge in the upper reaches of North Creek. Floristically, this resembles the threatened ecological community listed under the EPBC Act as "Semi-evergreen Vine Thickets of the Brigalow Belt (North and South) and Nandewar Bioregions". However, the particular regional ecosystem assigned to this vine thicket (11.10.8) is not included in the listed threatened ecological community, on the grounds that it occurs on coarse-grained sedimentary rock (Department of Climate Change, Energy, the Environment and Water 2022a).

4.3.2 Threatened Species

Twenty-seven species of plants and animals listed as threatened species under the EPBC Act were flagged by database searches as being potentially present in the region. Field surveys confirmed that four of these (Koala, Central Greater Glider, Squatter Pigeon and White-throated Needletail) are present within the survey area (**Figure 4-7**). No threatened species of plants were detected within the survey area.

The likelihoods that the remaining species occur within the survey area were assessed by considering the proximity and recentness of records, as well as availability of potential habitat (**Table 4-3**). An additional 11 species were considered likely or possibly occurring within the vicinity of the project. A detailed description of the habitat requirements of each of the above 15 species is provided in the following subsections.

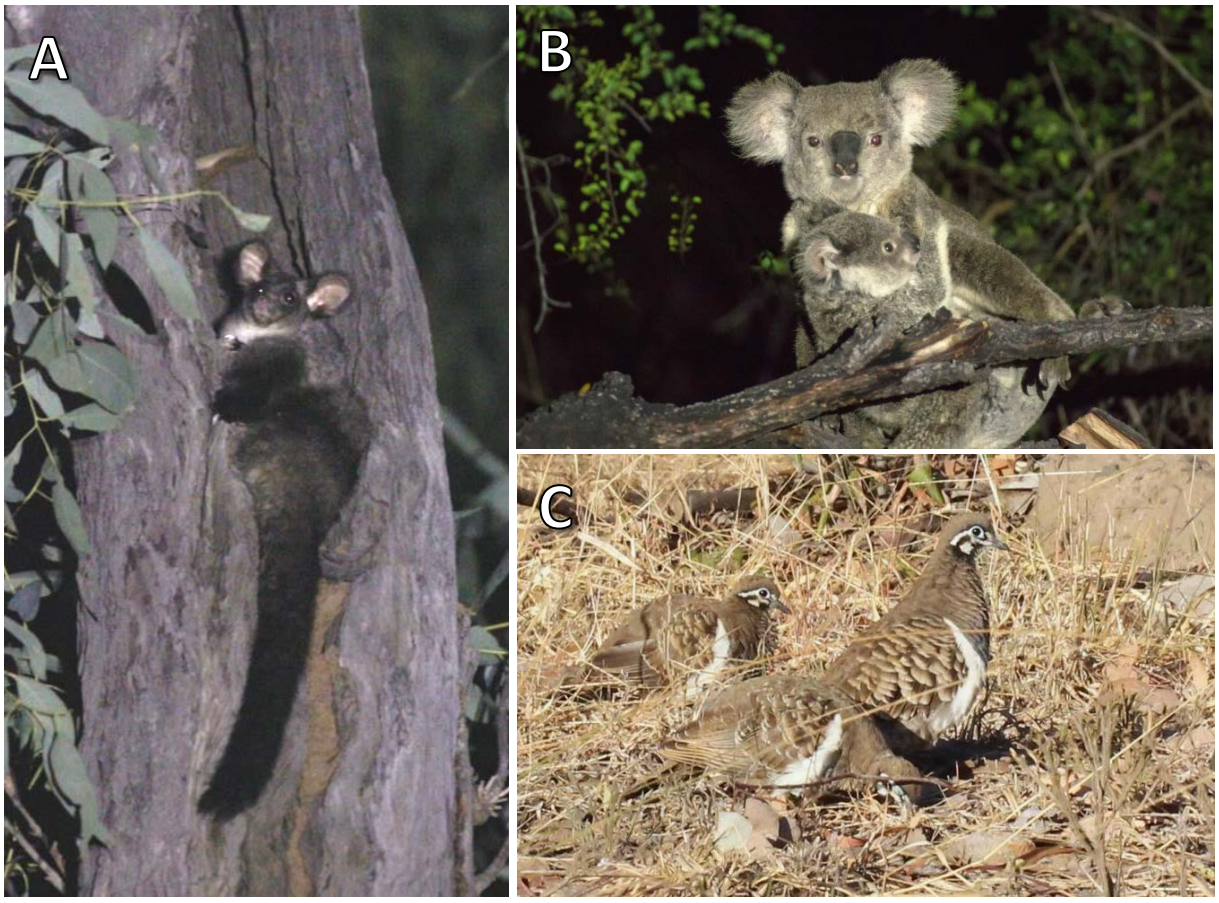


Figure 4-7 **Photographs of threatened wildlife taken during surveys:** A) Central Greater Glider, B) Koala, and C) Squatter Pigeons

Table 4-3 Threatened species of national environmental significance flagged by databases as being potentially present in the local region

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Bird	*Geophaps scripta scripta*	Squatter Pigeon	V	V	Open grassy woodland near water, with areas of bare ground, on land zones 3, 5 and 7.	C	C
Mammal	*Phascolarctos cinereus*	Koala	E	E	Vegetation communities containing food trees (*Eucalyptus* spp.), especially near watercourses.	C	C
Mammal	*Petauroides armillatus*§	Central Greater Glider	E	E	Tall, old-growth eucalypt forest with tree hollows.	C	C
Bird	*Hirundapus caudacutus*	White-throated Needletail	V	V	Airspace containing flying insects, above a diversity of landscapes	C	C
Reptile	*Denisonia maculata*	Ornamental Snake	V	V	Gilgais on heavy clay soil, especially where *Acacia harpophylla* grows.	L	L
Reptile	*Egernia rugosa*	Yakka Skink	V	V	Potentially any vegetated habitat with fallen timber or rocks. There are no nearby records, but habitat is available locally.	P	P
Mammal	*Dasyurus hallucatus*	Northern Quoll	E	LC	Rugged escarpments in wetter forested areas.	P	P
Bird	*Rostratula australis*	Australian Painted-snipe	E	V	Freshwater wetlands with well-vegetated muddy edges.	P	P
Bird	*Erythrotriorchis radiatus*	Red Goshawk	V	E	Large tracts of undisturbed forest, especially near the ecotone between rainforests, melaleuca swamps and open eucalypt woodlands. Within the survey area, it is most likely in densely forested riparian habitats.	P	P
Grass	*Aristida annua*	Annual Wiregrass	V	V	Open eucalypt woodlands and pastures on basalt-derived clay. The survey area lies outside the known distribution of the species; the most northern record is 35 km south.	P	P
Mammal	*Macroderma gigas*	Ghost Bat	V	E	Primarily coastal ranges, where large cave systems occur near extensive forests. The nearest record is 85 km northeast.	P	P
Reptile	*Furina dunmalli*	Dunmall's Snake	V	V	Associated with *Acacia harpophylla* and eucalypt forests. The survey area is outside the known distribution of the species.	P	P
Reptile	*Lerista allanae*	Allan's Lerista	E	E	Inhabits root systems of grass tussocks growing on black clay soils.	P	P
Grass	*Dicanthium queenslandicum*	King Blue-grass	E	V	Grasslands or open woodland on clay soils, with low grazing pressure. Favourable soils within the survey area were subject to high grazing pressure.	P	P
Grass	*Dicanthium setosum*	Hairy Bluegrass	V	LC	Grasslands or open woodland on clay soils, with low grazing pressure.	P	P
Bird	*Calidris ferruginea*	Curlew Sandpiper	CE	E	Primarily coastal mudflats, but occasionally also uses the muddy margins of large freshwater wetlands.	U	U

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Bird	*Grantiella picta*	Painted Honeyeater	V	V	Open woodlands, especially dominated by *Acacia harpophylla* or other *Acacia* species. They are dependent on an abundance of mistletoe, a resource that was scarce in the survey area.	U	U
Bird	*Neochmia ruficauda ruficauda*	Star Finch	E	E	Probably extinct in the Bowen Basin. Formerly inhabited grassy edges of rivers and wetlands.	U	U
Bird	*Poephila cincta cincta*	Southern Black-throated Finch	E	E	Grassy eucalypt forests, especially near water, where the understorey of native perennial grasses has not been compromised by grazing. No records within 100 km.	U	U
Mammal	*Nyctophilus corbeni*	Corben's Long-eared Bat	V	V	Only known from three cave systems, all south of Bundaberg. The survey area lies well outside the known distribution of the species.	U	U
Mammal	*Pteropus poliocephalus*	Grey-headed Flying-fox	V	LC	Rainforests and wet eucalypt forests well south and east of the survey area. No records within 100 km.	U	U
Reptile	*Elseya albagula*	Southern Snapping Turtle	CE	E	Large permanent to semi-permanent river systems. The survey area lies outside the known distribution of the species, and suitable habitat is lacking.	U	U
Reptile	*Rheodytes leukops*	Fitzroy River Turtle	V	V	Inhabits deep pools with fallen timber in rivers with fast-flowing water. Suitable habitat is absent from the survey area.	U	U
Fish	*Maccullochella peelii*	Murray Cod	V	-	Clear, rocky streams, slow-flowing or turbid lowland rivers and billabongs. The survey area lies well outside the natural range of the species.	U	U
Cycad	*Cycas ophiolitica*	Marlborough Blue Cycad	E	E	Grows on steep slopes and hill tops in coastal areas over 100 km east of the survey area.	U	U
Tree	*Cadellia pentastylis*	Ooline	V	V	Edges of sandstone or basalt escarpments within *Acacia harpophylla*, vine-thicket, poplar box and bendee vegetation communities. The survey area lies outside the known distribution of the species. A very small amount of suitable habitat for the species exists on site, and this was thoroughly surveyed.	U	U
Tree	*Samadera bidwillii*	Quassia	V	V	Occurs in lowland rainforest 120 km east of the survey area.	U	U

*Status under the *Environment Protection and Biodiversity Conservation Act 1999*: CE = critically endangered, E = endangered, V = vulnerable, M = migratory.
†Status under the *Nature Conservation Act 1992*: E = endangered, V = vulnerable, LC = least concern, SL = special least concern.
‡Presence within survey area in which the project is contained: C = presence confirmed, L = likely to be present, P = possibly present, U = unlikely to be present.
§Listed under the EPBC Act as *Petauroides volans.*

4.3.2.1 Squatter Pigeon

The southern subspecies of the Squatter Pigeon (*Geophaps scripta scripta*) is listed as vulnerable under the EPBC Act. This species was recorded on numerous occasions throughout the survey area (66 individual records at 28 locations). There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (Threatened Species Scientific Committee 2015a) and the SPRAT profile for the species (Department of Climate Change, Energy, the Environment and Water 2022b).

The Squatter Pigeon is a ground-dwelling bird that feeds on seeds among sparse and low grass, in improved pastures, and beside railway lines and around settlements (Threatened Species Scientific Committee 2015). The Squatter Pigeon inhabits the grassy understorey of open eucalypt woodland, and less often savannas. It is nearly always found near permanent water such as rivers, creeks and waterholes (Threatened Species Scientific Committee 2015). Sandy areas dissected by gravel ridges, which have open and short grass cover, allowing easier movement, are preferred (Threatened Species Scientific Committee 2015). It is less commonly found on heavier soils with dense grass (Threatened Species Scientific Committee 2015). It often occurs in burnt areas and is sometimes found on tracks and roadsides (Threatened Species Scientific Committee 2015).

The species nests on the ground, usually laying two eggs among or under vegetation (Threatened Species Scientific Committee 2015).

Provided land is not overgrazed, Squatter Pigeons coexist readily with cattle grazing; however, the species has largely disappeared from the southern part of its distribution (e.g., New South Wales and southern Queensland), where sheep grazing is widespread and rabbit densities are high (Threatened Species Scientific Committee 2015). Squatter Pigeons often favour thinned habitats where grazing cattle create open patches of ground for foraging. Some introduced pastures also provide a valuable food source for the species (Crome 1976). A moderate amount of land modification probably benefits the species, reflected by long-term population increases (between 1934 and 1999) in grazing properties elsewhere in the Brigalow Belt (Woinarski and Catterall 2004). This is also supported by data comparing undisturbed woodlands near Townsville with areas disturbed by grazing or military activities; the latter two land uses supported ten times more Squatter Pigeons (Woinarski and Ash 2002).

The SPRAT profile defines foraging habitat for the Squatter Pigeon as remnant or regrowth open-forest to sparse, open-woodland or scrub dominated by *Eucalyptus*, *Corymbia*, *Acacia* or *Callitris* species, on sandy or gravelly soils (Queensland land zones 5 and 7), within 3 km of a suitable, permanent or seasonal waterbody (Department of Climate Change, Energy, the Environment and Water 2022b). Breeding habitat occurs on rises occurring on sandy or gravelly soils, within 1 km of a suitable, permanent waterbody (Department of Climate Change, Energy, the Environment and Water 2022b). Typically, the ground-covering vegetation layer in foraging and breeding habitat is considerably patchy, consisting of native, perennial tussock grasses or a mix of perennial tussock grasses and low shrubs or forbs. This patchy, ground layer of vegetation rarely exceeds 33% of the ground area (Department of Climate Change, Energy, the Environment and Water 2022b). The remaining ground comprises bare soil with a light covering of leaf litter (Department of Climate Change, Energy, the Environment and Water 2022b).

Except where this has been cleared, all vegetation within the survey area (with the exception of one small patch of vine-thicket) is dominated by *Eucalyptus, Corymbia* and/or *Acacia* species. Most is located on land zone 5 (sandy plain) favoured by Squatter Pigeons. Here, *Eucalyptus crebra*, *Eucalyptus populnea, Eucalyptus melanophloia* and *Corymbia clarksoniana* are the dominant canopy species. The understorey is usually dominated by the introduced pasture grasses *Bothriochloa pertusa*, *Cenchrus ciliaris* and *Melinis repens*. However, the native grasses *Aristida* spp., *Chrysopogon fallax*, *Eriochloa crebra* and *Alloteropsis cimicina* are occasionally dominant.

Narrow ribbons of land zone 3 (sandy alluvium) occur along creeks, where dense forests of *Eucalyptus camaldulensis* and *Melaleuca leucadendra* grow. Creek terraces support open forests of *Corymbia tessellaris, Eucalyptus populnea, Corymbia dallachiana* and *Corymbia clarksoniana.* In general, land zone 3 contains too thick a grass cover to be favourable for Squatter Pigeons; the mean ground vegetation cover is 58% and four out of five sites sampled exceeded 33% cover. However, most permanent water points (dams and natural wetlands) are located in this land zone, and these provide water resources for Squatter Pigeons. Furthermore, as the ground around these water points is often heavily grazed, patches of suitable foraging habitat exist in an otherwise unfavourable matrix. These "islands" of highly favourable habitat (water with adjacent foraging habitat) were the locations of many Squatter Pigeon sightings (**Table 4-4**).

Land zone 10 (sandstone rises and escarpments) occurs along the western fringe of the MLA area, and more extensively further west. Steep slopes, extensive rock outcropping, no surface water, and a lack of bare ground patches within this land zone make it largely unsuitable for Squatter Pigeons. Of 17 sites sampled, nine were unsuitable for Squatter Pigeons due to having >33% vegetation cover or <10% bare ground. The eight sites classed as suitable based on understorey composition were primarily in regional ecosystems 11.10.7 or 11.10.3 located on the foot slopes. Squatter Pigeon sightings largely mirrored these habitat assessments. Despite comprising 39% of the total survey area, only 3% of individuals sighted were in land zone 10 (all in regional ecosystem 11.10.7), and all were within 300 m of land zone 3 or 5.

The vast majority of sightings (69.7%) were in land zone 5, a finding that strongly accords with habitat preferences presented in the SPRAT profile.

No Squatter Pigeons were recorded on land zones 4 or 9. The heavy clay soils in land zone 9 support an excessively dense grass cover. In remnant 11.9.2, vegetation covers an average of 63% of the ground, and this increases to 85% in areas where 11.9.2 has been cleared. The clay soils in land zone 4 are similarly unsuitable for Squatter Pigeons. Sites surveyed within this land zone fell into one of two categories. In areas where the canopy was open, vegetation covered far greater than 33% of the ground. In areas where the canopy was dense, there was very little grass as a source of seed and/or bare ground on which to forage (one or both categories constituted less than 10% of the total ground cover).

In summary, data gathered on site strongly supports the habitat preferences described in the SPRAT profile, in that land zone 5 constitutes the primary foraging and breeding habitat for Squatter Pigeons within the survey area, land zone 3 is utilised in the vicinity of water, and land zone 10 is mostly not utilised, except for regional ecosystem 11.10.7 on the foot slopes. There is no local evidence that heavy clays on land zones 4 and 9 are utilised by Squatter Pigeons.

Table 4-4 Squatter Pigeon records per habitat type

Land Zone	Vegetation Age	Percentage of Survey Area	Percentage of Squatter Pigeon Records
3: Alluvium	Remnant	5.5%	21.2%*
	Regrowth	2.3%	4.5%*
	Cleared	4.2%	6.1%*
4: Clay plain	Remnant	2.1%	0%
	Regrowth	0.1%	0%
	Cleared	1.6%	0%
5: Sand plain	Remnant	17.1%	15.2%
	Regrowth	7.5%	6.0%
	Cleared	12.2%	48.5%
9: Clay derived from fine-grained	Remnant	4.8%	0%

Land Zone	Vegetation Age	Percentage of Survey Area	Percentage of Squatter Pigeon Records
sedimentary rock	Regrowth	0%	0%
	Cleared	2.8%	0%
10: Sandstone ranges	Remnant	37.5%	3%
	Regrowth	1.7%	0%
	Cleared	0.8%	0%

*Detection rates of Squatter Pigeons in alluvial areas may overestimate the true value of this habitat for the species, as the high grass density within this land zone means that individuals are more likely to forage on tracks, where they are more detectable.

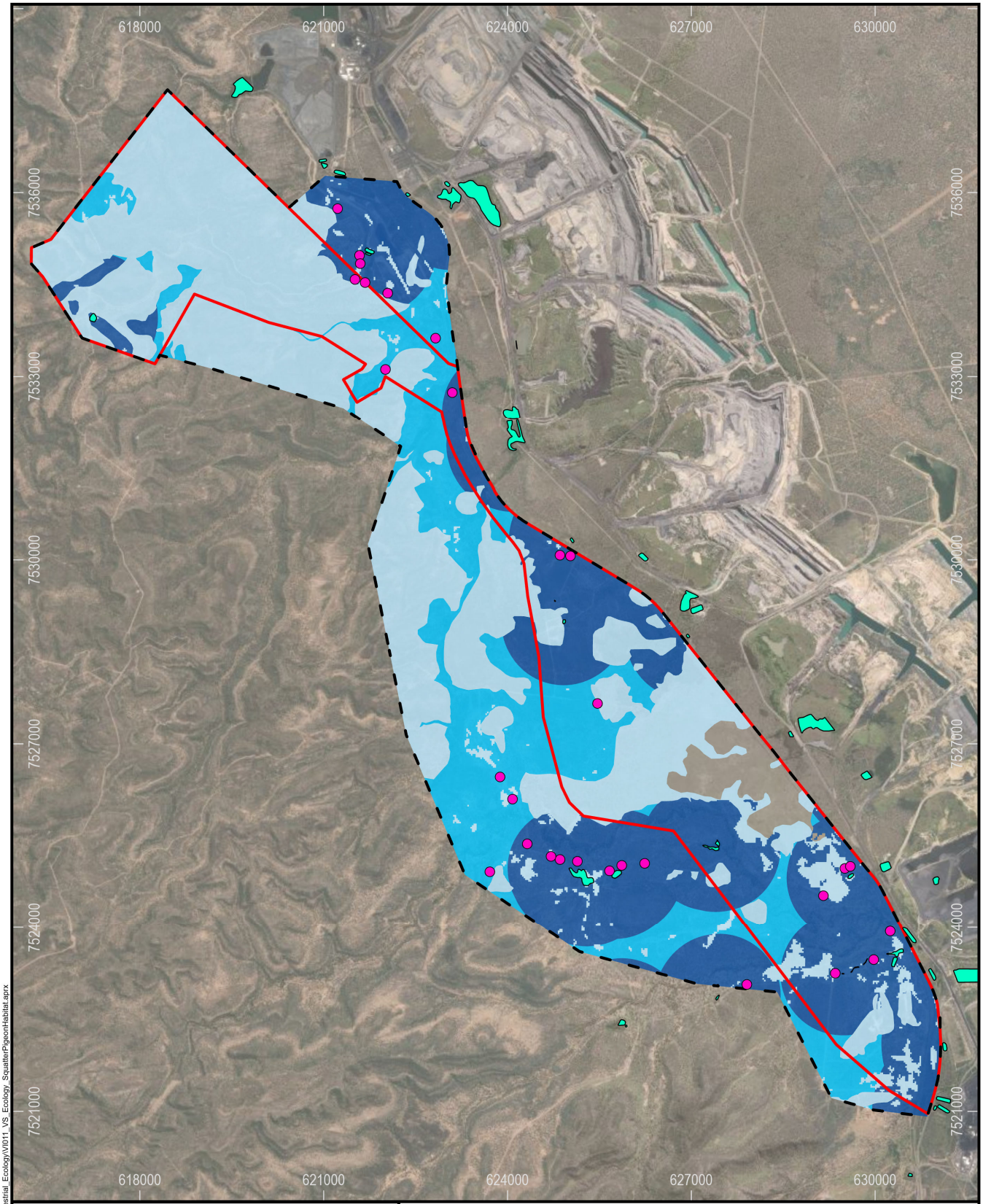
Many cleared patches of vegetation within the survey area had regrown sufficiently, or a sufficient density of trees was retained during clearing, for some cleared areas to qualify as "sparse open-woodland or scrub" used by Squatter Pigeon for foraging and breeding. Accordingly, as can be seen from **Table 4-4**, many Squatter Pigeon records came from cleared vegetation.

There is no single, standard definition of "sparse" vegetation in Australia. The most widely used vegetation classification system (the Specht classification system: Specht 1970) defines "sparse" vegetation classes as possessing 10-30% foliage projection cover or 20-50% canopy cover (the latter includes gaps between leaves within each canopy). However, in its *National Forest and Sparse Woody Vegetation Data* (Department of Industry, Science, Energy and Resources 2020), the Australian Government adopts a more conservative definition of sparse woody vegetation as having 5-19% canopy cover. Given that the definition of Squatter Pigeon habitat as "open-forest to sparse, open-woodland or scrub" was developed by the Australian Government for their SPRAT profile, the Australian Government's definition of "sparse" as >5% canopy cover was adopted for habitat mapping purposes.

Regardless of the status of vegetation under Queensland's VM Act (non-remnant, regrowth or remnant), any parts of land zones 3 or 5 that qualified as "sparse" vegetation according to *National Forest and Sparse Woody Vegetation Data* were considered Squatter Pigeon foraging habitat and/or breeding habitat. Likewise any remnant or former regional ecosystem 11.10.7 was considered habitat if this qualified as "sparse" vegetation. Vegetation with less than 5% cover of woody vegetation, vegetation occurring on land zones 4 or 9, and any vegetation on land zone 10 that is not 11.10.7 were not considered appropriate foraging or breeding habitat.

Most habitats within the survey area that did not qualify as foraging or breeding habitat did qualify as dispersal habitat. Dispersal habitat is defined by the SPRAT profile as any vegetation unit on any land zone where trees are at less 100 m apart. Most of the survey area, including areas that do not qualify as "sparse woody vegetation" have trees that are 100 m or less apart. Satellite imagery was used to identify non-remnant patches where trees were further than 100 m apart. Any vegetation outside these bare patches that were not foraging habitat qualified as dispersal habitat.

The distribution of Squatter Pigeon habitat across the survey area is shown in **Figure 4-8.** In total, the survey area contains 3540.5 ha of foraging habitat (of which 2,146 ha is also breeding habitat) and 3,238.7 ha of dispersal habitat for the Squatter Pigeon. The project area contains 1,626.5 ha of foraging habitat (of which 1,162.2 ha is also breeding habitat) and 1,989.5 ha of dispersal habitat.



Legend

- Squatter Pigeon Sightings
- Survey Area
- MLA Area
- Waterbodies

Squatter Pigeon Habitat

- Breeding and foraging habitat
- Foraging habitat
- Dispersal habitat

Source: Geoscience Australia 2015, Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2019-2022, Earthstar Geographics. Squatter Pigeon habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_SquatterPigeonHabitat.aprx

Vulcan South

Squatter Pigeon Habitat

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

21/07/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-8

VITRINITE BRIGHTER COAL

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4.3.2.2 Koala

Koalas (*Phascolarctos cinereus*) within Queensland, New South Wales and the Australian Capital Territory are listed as endangered under the EPBC Act. This species was recorded 14 times within the survey area, involving at least 12 individuals. It is highly likely that more individuals were present than were detected. The Threatened Species Scientific Committee (2012) suggests an average Koala density of 0.005 Koalas/ha across the Brigalow Belt. Assuming this same density across the survey area, 33 individuals are likely to occur within the survey area. This estimate has low reliability, given the lack of local data on population densities.

The former Australian Government Department of Agriculture, Water and the Environment (2022a) published the *National Recovery Plan for the Koala* Phascolarctos cinereus *(combined populations of Queensland, New South Wales and the Australian Capital Territory)*. The Australian Government has also provided advice about the species' ecology and priority actions to mitigate key threats within the SPRAT profile for the species (Department of Climate Change, Energy, the Environment and Water 2022c) and the conservation advice (Department of Agriculture, Water and the Environment (2022b).

On the western slopes, tablelands and plains in Queensland, Koalas are found in sub-humid *Eucalyptus*-dominated forests and woodlands in riparian and non-riparian environments, and some *Acacia*-dominated forests and woodlands in non-riparian environments (Department of Climate Change, Energy, the Environment and Water 2022c). The main habitat requirement is availability of suitable food trees and, to a lesser extent, shelter trees, which tend to have shadier foliage, be taller and/or be located in sheltered locations in gullies (Crowther *et al.* 2013).

While Koalas have been observed sitting in or eating up to 120 species of eucalypt (Phillips 1990), the diet of individual Koalas is usually limited to one or a few species (Moore and Foley 2000). Preferences also vary between regions or seasons (Moore and Foley 2000). Chemical anti-feedants, soil nutrients and leaf water content in semi-arid areas may limit or prevent Koalas feeding on foliage of individual trees even when the species is considered preferred (Lawler *et al.* 1998; Moore *et al*. 2005). In the northwest of their range in Queensland (including the project area), Koala distribution is limited by heat and water availability, with the highest densities of Koalas occurring along creek lines (Munks *et al.* 1996; Sullivan *et al*. 2003). Variability in leaf nutrition creates patchiness such that species-based assessments of habitat likely overestimate the availability of high-quality habitat (Threatened Species Scientific Committee 2012).

Despite limitations in habitat mapping caused by varying leaf nutrition, a conservative approach to habitat mapping is appropriate, which assumes that any individuals of tree species known to be eaten by Koalas could constitute a potential food tree. Likewise, the SPRAT database defines Koala habitat as "any forest or woodland containing species that are known Koala food trees, or shrubland with emergent food trees" (Department of Climate Change, Energy, the Environment and Water 2022c). This includes remnant, regrowth and modified vegetation communities. Assessment of habitat quality for Koalas therefore relies on the identification of local preferences for species and the quantification of the availability of those species (Department of Climate Change, Energy, the Environment and Water 2022c).

The Australian Koala Foundation (2015) maintains a database of the food trees known to be used by Koalas in each local government area of Australia. This database lists *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* as the primary food trees in the Isaac Regional Council area. Secondary food trees include *Eucalyptus brownii*, *Eucalyptus coolabah*, *Eucalyptus ochrophloia*, *Eucalyptus orgadophila* and *Eucalyptus populnea*. Of these species, *E. camaldulensis*, *E. orgadophila* and *E. populnea* are found within the survey area (**Table 4-5**).

The Australian Koala Foundation (2015) acknowledges that *Eucalyptus crebra* can sometimes constitute an additional secondary food species in localised areas with better soils and nutrient availability. Given that this tree species is eaten by Koalas at nearby sites (Ellis *et al*. 2002; Melzer *et al*. 2014), it is conservatively considered a food tree for the purposes of habitat mapping. This species is widespread across the survey area and surrounding region, being a dominant component of many

of the regional ecosystems occurring on site. Given the low fertility of local sandy soils, it is unlikely that most local *E. crebra* is utilised to a significant extent by Koalas. Indeed, no Koalas were recorded anywhere on land zone 5 (sand plains), where soils are least fertile. However, small numbers were observed on land zone 10 (sandstone) where *E. crebra* was growing. In accordance with the SPRAT definition of Koala habitat (i.e., any forest or woodland containing species that are known Koala food trees), any vegetation containing *E. crebra* is included as potential habitat.

Table 4-5 Distribution of Koala food trees across vegetation units

Regional Ecosystem*	Area (ha)*	Primary Food Trees	Secondary Food Trees	Overall Value to Koalas†	N_{Koalas}/100ha‡
11.3.1	1.6	Absent	Absent	Nil	0
11.3.2	276.2	Absent	*E. populnea* dominant	Moderate	0
11.3.7	86.4	*E. camaldulensis* occasionally present	*E. populnea* and/or *E. crebra* sometimes subdominant	Moderate	0
11.3.25	153.0	*E. camaldulensis* dominant	*E. populnea* and/or *E. crebra* sometimes subdominant	High	7.19
11.3.27c	2.0	Absent	Absent	Nil	0
11.3.27e	6.5	*E. camaldulensis* dominant	*E. populnea* and/or *E. crebra* sometimes subdominant	High	0
11.4.8	131.4	Absent	Absent	Nil	0
11.4.9	16.2	Absent	Absent	Nil	0
11.5.3	517.6	Absent	*E. populnea* dominant	Moderate	0
11.5.9	1,152.5	Absent	*E. crebra* sometimes dominant, but some variants of this RE lack secondary food trees.	Moderate	0
11.9.2	326.4	Absent	*E. orgadophila* dominant	Moderate	0
11.10.1	265.9	Absent	*E. crebra* usually subdominant	Moderate	0.38
11.10.1x1	412.3	Absent	*E. crebra* occasionally present in low densities	Low	0
11.10.3	1,642.1	Absent	*E. crebra* occasionally present as a scattered emergent	Low	0.06
11.10.7	341.6	Absent	*E. crebra* dominant	Moderate	0.29
11.10.8	1.3	Absent	Absent	Nil	0

*Remnant, regrowth and modified forms of regional ecosystems can all constitute habitat, provided non-juvenile food trees (>4 m tall: Queensland Government 2015) are present. Only remnant and regrowth total area is presented in the table, as no Koalas were recorded in cleared vegetation. However, non-remnant habitat that is sufficiently dense to qualify as "sparse woody vegetation" (see **Section 4.3.2.1**) was also considered Koala habitat in **Figure 4-9** and when assessing potential impacts to the species.

†High, moderate and low value habitats all qualify as Koala habitat under the Australian Government's definition (Department of Climate Change, Energy, the Environment and Water 2022c).

‡Refers to the number of Koalas recorded in each regional ecosystem as a function of the total area in hectares of each regional ecosystem within the survey area. Note that this is not the same as population density, as not all Koalas present are likely to have been detected. Nevertheless, it is a useful indicator of relative density.

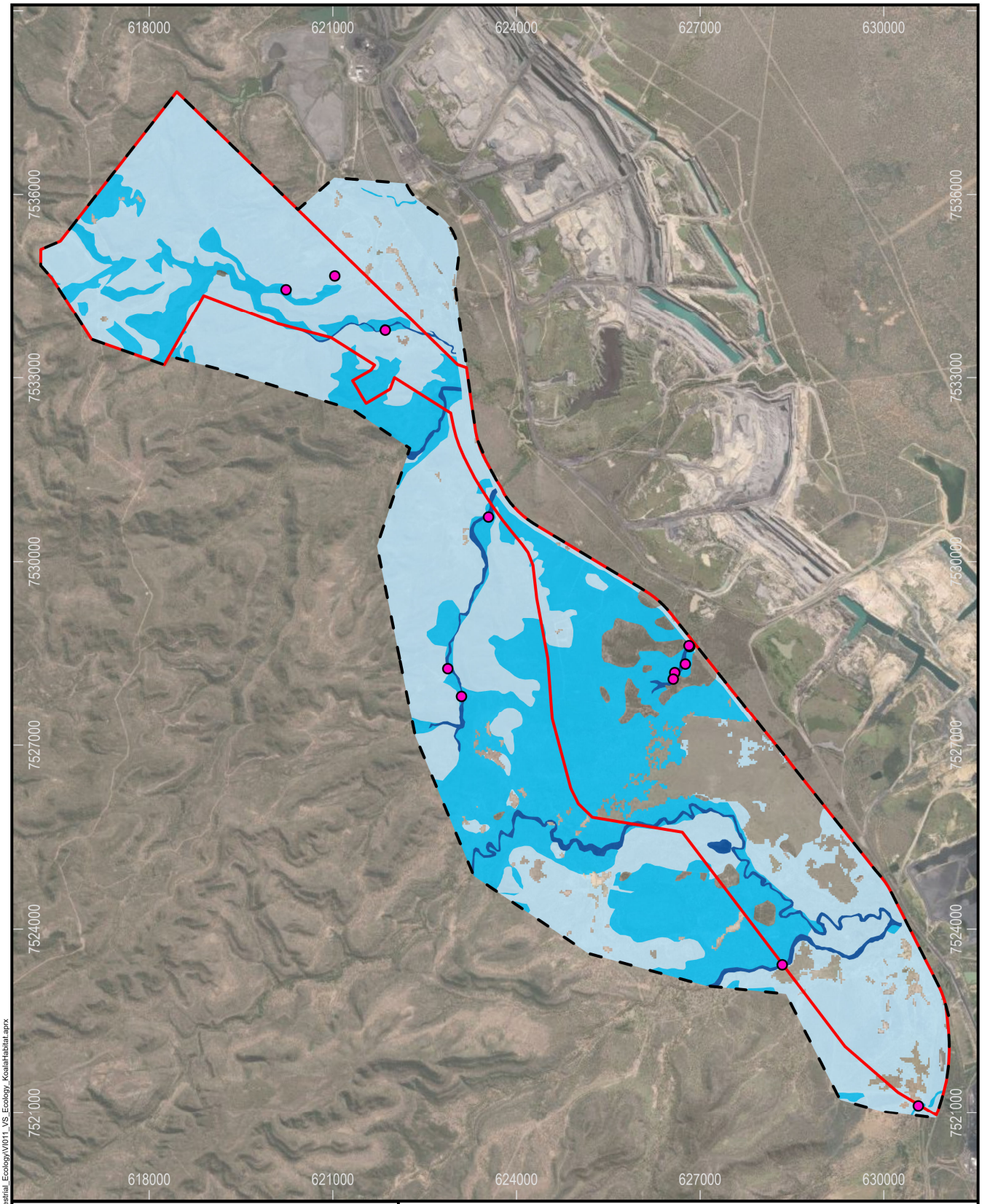
All but one sighting of Koalas occurred in remnant vegetation. The single exception was in regrowth 11.3.25 along Barrett Creek. No Koalas were recorded in cleared vegetation units, despite detectability being higher in smaller trees and open landscapes. This aligns with known preferences of the species for tall trees (Callaghan *et al*. 2011; Smith *et al*. 2013). This finding conflicts with the broad definition of Koala habitat presented in the SPRAT profile (Department of Climate Change, Energy, the Environment and Water 2022c) as any remnant, regrowth and modified vegetation communities containing Koala food trees. As most cleared portions of the survey area contain widely scattered food trees, they therefore qualify as habitat under this definition, despite being of negligible importance to local Koalas. They are therefore mapped as the same low value as remnant units containing low densities of secondary food trees (e.g., 11.10.13 or 11.10.3).

Non-remnant regrowth that had a canopy cover less than 5% is considered “non-woody” vegetation by the *National Forest and Sparse Woody Vegetation Data* (Department of Industry, Science, Energy and Resources 2020) and was accordingly mapped as non-habitat.

The Brigalow Belt bioregion contains the largest population of Koalas within Queensland (Department of Climate Change, Energy, the Environment and Water 2022c), owing to its large size and subhumid climate (other large bioregions are in semi-arid climates with low Koala densities). Habitat connectivity is high across the region surrounding Vulcan South. Habitats containing secondary food trees connect ribbons of important habitat (containing primary food trees) occurring along major watercourses, and provide opportunities for dispersal. The project, however, lies at a habitat edge, as it is bounded to the north and east by existing mining operations that represent an impediment to dispersal. The Koala population present within the survey area is connected to the broader region via extensive tracts of eucalypt forests that cover the Cherwell-Harrow Range, to the west and south.

Habitat clearance and climate change represent the major threats to Koala populations in the Brigalow Belt. The location of primary food trees along watercourses means that they represent important drought refugia. Road-based mortality is another local threat, and multiple fatalities occur along Saraji Road each year. Attacks by domestic dogs, a key threat in densely settled regions of Queensland, is a negligible threat locally, given the low density of houses.

The survey area contains 153.9 ha of high-value habitat, 2,226.6 ha of moderate-value habitat and 3,860.9 ha of low-value habitat for the Koala, while the project area contains 78.4 ha of high-value habitat, 1,152.8 ha of moderate-value habitat and 1,937.8 ha of low-value habitat.



Legend

- Koala Sighting
- Survey Area
- MLA Area

Koala Habitat

- High Quality
- Moderate Quality
- Low Quality

Source: Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2020-2022, Vitrinite 2022, Earthstar Geographics. Koala habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Vulcan South

Koala Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

17/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-9

VITRINITE BRIGHTER COAL

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Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_KoalaHabitat.aprx

4.3.2.3 Central Greater Glider

The Greater Glider (*Petauroides volans*) is listed as an endangered species under the EPBC Act. Recent studies have suggested that this taxon actually comprises three genetically distinct species, with the Central Greater Glider (*P. armillatus*) being present in the survey area (McGregor *et al.* 2020). Its taxonomy under the EPBC Act is yet to be revised in accordance with this recent study.

A total of 20 Central Greater Gliders were recorded within the survey area, with most of these occurring in riparian forests along watercourses. There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (Threatened Species Scientific Committee 2016).

All three species of greater glider feed on the young leaves of *Eucalyptus* and *Corymbia* in a broad range of forests across eastern Australia. They have a preference for tall, montane, moist eucalypt forests with abundant hollows and a diversity of tree species present (Threatened Species Scientific Committee 2016), but also occur in drier lowland forests, provided tall, hollow trees are present.

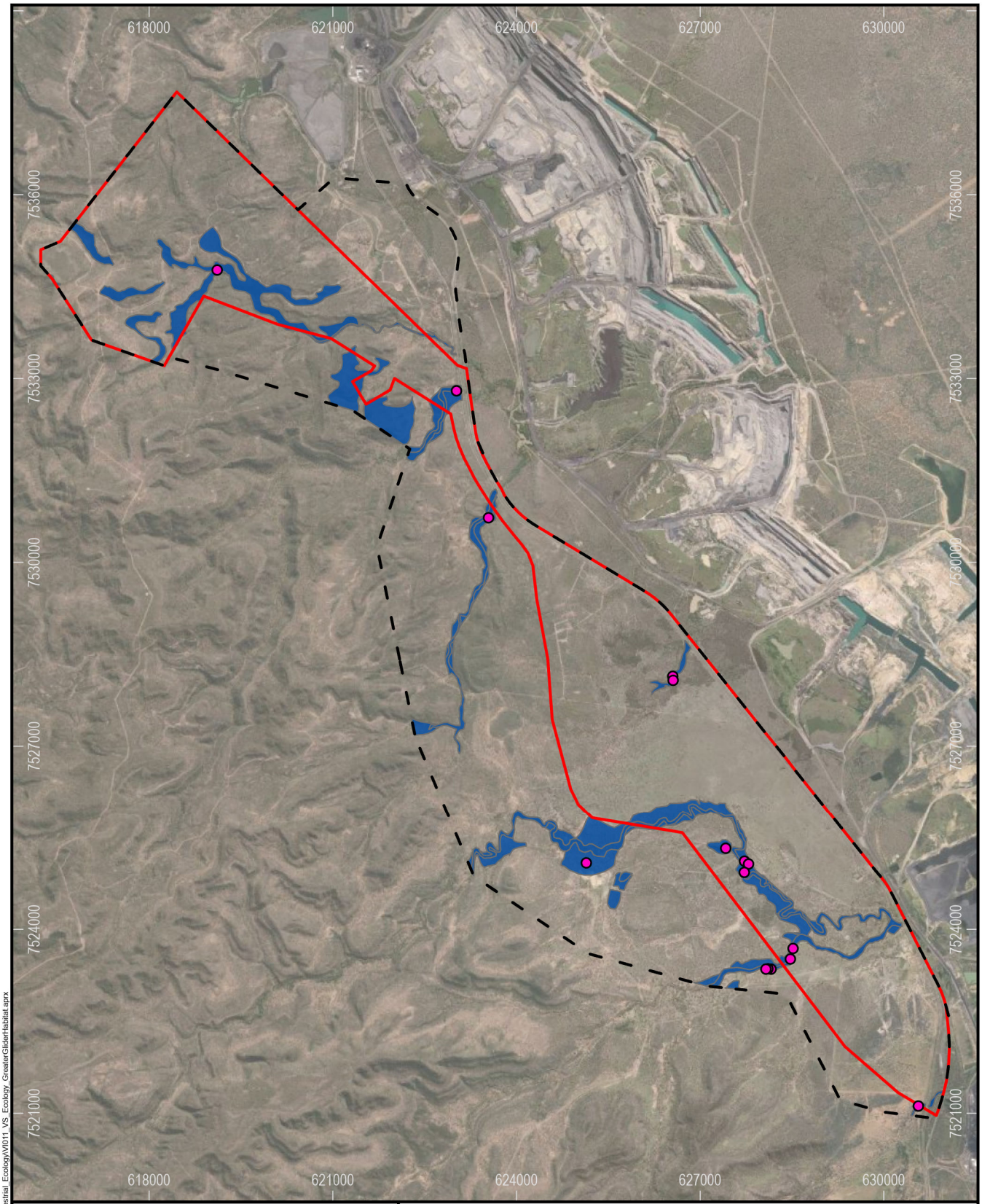
The project lies near the western edge of the distribution of the Central Greater Glider (Kearney *et al.* 2010). Water availability limits the distribution of local populations (Kearney *et al.* 2010). Consequently, local populations are largely restricted to riparian environments, where large, hollow trees are most abundant, and subsoil moisture allows suitable food trees to grow fresh leaves over extended periods of the year.

Each individual requires many large, hollow-bearing trees within its home range of 1-4 ha (Comport *et al*. 1996; Lindenmayer *et al*. 2004). Southern Greater Gliders generally require trees larger than 50 cm (diameter of trunk at breast height) (Kehl and Borsboom 1984), and even larger trees may be required in tropical environments, in order for hollows to be buffered against extreme daytime temperatures (Kearney *et al.* 2010). During ecological surveys of the survey area, high densities of trees of this size were very rarely encountered away from riparian zones. Nevertheless, large, hollow *Corymbia citriodora* occasionally grew in sheltered, south-facing slopes of gorges within the Harrow Range. One Central Greater Glider was recorded within such habitat during surveys. For this reason, regional ecosystem 11.10.1 was also considered potential habitat for Central Greater Gliders within the survey area.

With the exception of the single record in regional ecosystem 11.10.1, all other records were in riparian environments (regional ecosystems 11.3.25, 11.3.7, 11.3.27e and regrowth 11.3.25 with many retained large trees), despite these habitats comprising only 3.7% of the survey area. This is clear evidence for the importance of riparian habitats for local populations of the Central Greater Glider. Local populations are likely to be relatively large, as the species was recorded along all major drainage lines surveyed. Conservatively assuming that each pair occupies 16 ha (the home range in lower productivity forests and more open woodlands: Threatened Species Scientific Committee 2016), there is expected to be at least 58 individuals inhabiting the survey area. This population could be larger than 450 individuals if an average home range of 2 ha is assumed (a more typical size: Threatened Species Scientific Committee 2016). This local population is connected to the broader region via extensive tracts of eucalypt forests that cover the Harrow Range, to the west and south (regional ecosystem 11.10.1 is a subdominant community within this range).

Non-remnant habitats (e.g. regrowth) are unlikely to be utilised by Greater Gliders, due to an absence of hollows for shelter. An exception is where many large, hollow trees were retained during clearing. The only part of the survey area where this was observed was in the far south, along Barrett Creek. Here, a pair of Greater Gliders was observed to emerge from one of the retained hollow dead trees. Riparian vegetation along Barrett Creek was therefore mapped as habitat, while regrowth elsewhere within the survey area was considered to be unsuitable for Greater Gliders.

In total, 617.2 ha of Central Greater Glider habitat are present within the survey area, while the project area contains 328.2 ha of habitat (**Figure 4-10**).



Legend

- Survey Area
- MLA Area
- Central Greater Glider Sighting
- Central Greater Glider Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_GreaterGliderHabitat.aprx

Vulcan South

Central Greater Glider Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-10

VITRINITE BRIGHTER COAL

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4.3.2.4 White-throated Needletail

The White-throated Needletail is an almost exclusively aerial bird that visits eastern Australia when not breeding (the Austral summer). Under the EPBC Act, it is listed both as a threatened species (vulnerable) and a migratory species.

White-throated Needletails feed on flying insects in large, fast-moving flocks that can cover huge distances in a day. In central Queensland, the species is most often recorded in the vicinity of the coast and nearby ranges. It tends to favour forested areas and landforms facilitating updraughts (ranges, cliffs and sand dunes), but can occur over a wide variety of landforms and vegetation types. No White-throated Needletails were recorded in the survey area during the various ecological surveys undertaken on site, despite the species being highly detectable when present. There were also no nearby recent records of the species. However, a flock of approximately 100 White-throated Needletails was observed moving north in airspace above the Vulcan Coal Mine (far northeast of the survey area) during weed monitoring undertaken in March 2022.

White-throated Needletails regularly follow the edges of low pressure systems, and the sighting coincided with unstable storm activity. The timing of the sighting and the direction of travel suggest that the flock was likely on its northward passage to breeding grounds in East Asia. It is possible that the storm cells encouraged the flock to move west of the usual migration route along the coast and sub-coastal ranges.

The survey area is unlikely to be of great importance to the White-throated Needletail. It lies west of the species' usual migration route and the species is rarely recorded in the local region. The survey area is most likely to be used for foraging by flocks that are based in the Clarke Range, but which occasionally follow low pressure systems further west.

4.3.2.5 Ornamental Snake

Ornamental Snakes feed on frogs and favour habitats supporting the temporary pooling of water where frogs breed (Department of Climate Change, Energy, the Environment and Water 2022d). Ornamental Snakes primarily inhabit gilgai (melon-hole) mounds and depressions in land zone 4 (deep-cracking clay plains), but also lake margins and wetlands (Department of Climate Change, Energy, the Environment and Water 2022d). Locally, such habitats tend to support vegetation communities dominated by *Acacia harpophylla* (broad vegetation group 25a). Areas with a diversity of gilgai sizes and depths provide optimal habitat (Department of Climate Change, Energy, the Environment and Water 2022d). An abundance of fallen timber is also important for shelter (Department of Climate Change, Energy, the Environment and Water 2022d). Cleared grasslands may also be utilised, provided that gilgais are present and some debris remains for shelter.

The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* (Department of Sustainability, Environment, Water, Population and Communities 2011) defines suitable habitat for Ornamental Snakes as "open-forests to woodlands associated with gilgai formations and wetlands. These are commonly mapped as QLD REs 11.3.3, 11.4.3, 11.4.6, 11.4.8, 11.4.9, 11.5.16 or mapped as cleared but where the above REs formerly occurred". Important habitat is defined by these guidelines as "gilgai depressions and mounds".

Ornamental Snakes are active, and therefore detectable, only when frogs are active (i.e., following heavy rainfall events). For the remainder of the year, most local frogs (especially the genera *Cyclorana, Platyplectrum* and *Limnodynastes*) remain buried underground, and Ornamental Snakes are similarly inactive. At optimal times of the year, Ornamental Snakes are readily detectable by spotlighting around flooded gilgais where frogs are active, or via funnel and pitfall traps installed in favourable habitats (Department of Climate Change, Energy, the Environment and Water 2022d).

Most of the fauna surveys undertaken on site coincided with ideal conditions for detecting Ornamental Snakes. Heavy rain events occurred midway through the October 2018 and March 2019 surveys, resulting in widespread flash-flooding and the pooling of surface water in gilgais and other depressions. Spotlighting on the nights following these rain events targeted 10 locations potentially

supporting Ornamental Snakes (flooded gilgais, dams and billabongs). A total of 8 person-hours were spent spotlighting in possible habitat under optimal conditions. This represented a disproportionate search effort for this species; it equates to 18.5 % of the total spotlighting effort on site, despite potential Ornamental Snake habitats constituting only 1.8 % of the survey area. In addition, there were three trap sites installed in broad vegetation group 25a, and rain fell midway through the sampling of each of these. Two other trap sites were installed in *Eucalyptus populnea* woodland close to dams with potential to support Ornamental Snakes. Despite all the above search effort, no Ornamental Snakes were recorded on site.

According to the Wildnet database, Ornamental Snakes have been recorded at the adjacent Peak Downs Mine and Saraji Mine (both located immediately east of the survey area) on numerous occasions since 2000. Despite the close proximity, there are several differences between the habitat in the survey area and that present east of Saraji Road. Firstly, certified regional ecosystem mapping indicates that land zone 4 is far more widespread to the east. Within the survey area, it was confined to small, isolated patches mostly less than 5 ha in extent. Secondly, most of land zone 4 within the survey area has very minor to no gilgai development. Where gilgais occurred, these tended to be less than 30 cm deep, and held water for less than one month after heavy rain. Consequently, frog diversity and density was very low in gilgais on site. In contrast, extensive ponds and wetlands (many of which are constructed as part of water management at neighbouring mines) occur to the east of Saraji Road, and many frogs were heard calling from this direction.

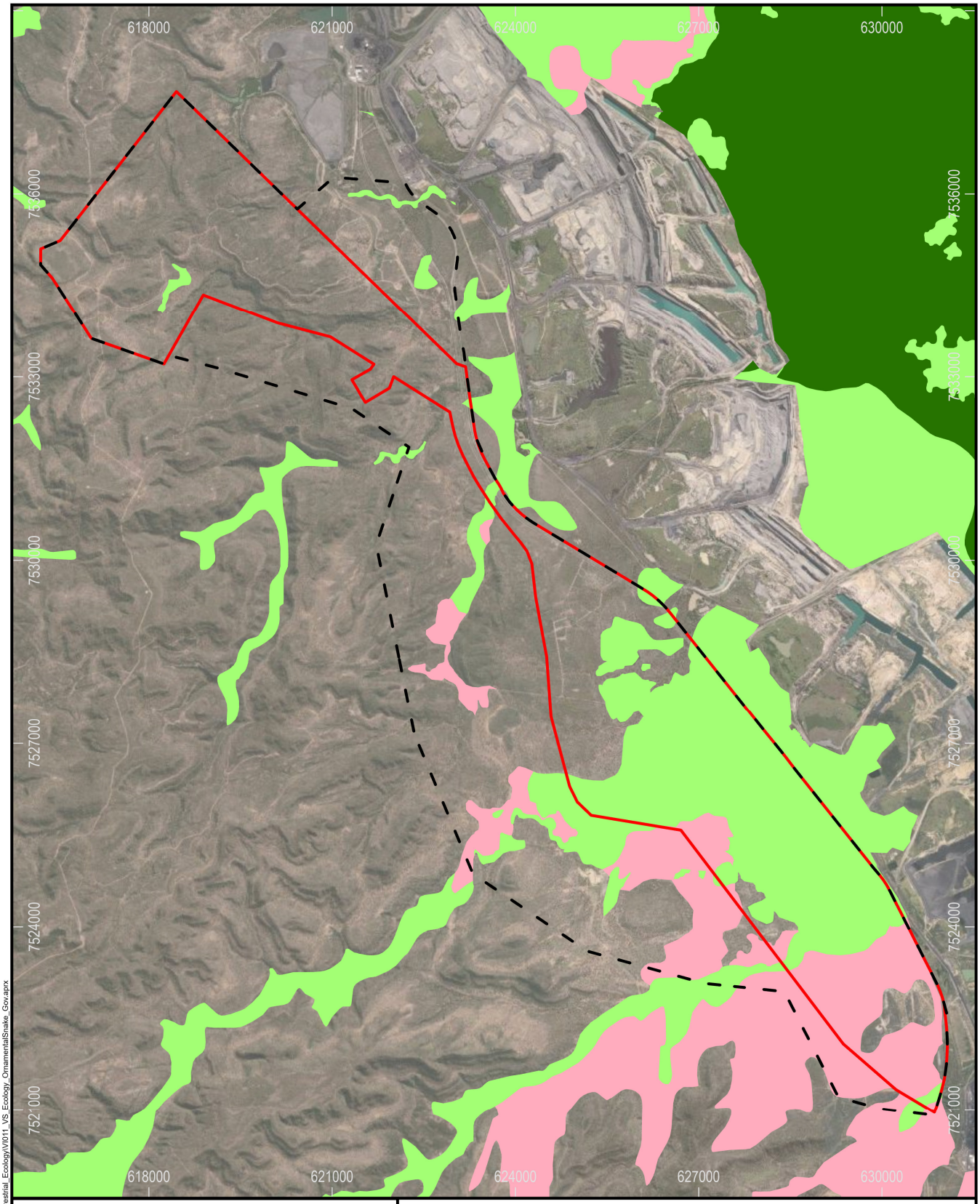
Nevertheless, given that the survey area is adjacent to known populations of Ornamental Snakes, and some potential habitat occurs on site, it is likely that small numbers of Ornamental Snakes utilise the survey area. Failure to detect the species despite optimal survey conditions, combined with the poor quality of habitat present, suggests that the survey area is of marginal importance to the Ornamental Snake.

The Queensland Department of Environment and Science published a habitat suitability model for the Ornamental Snake in January 2019. This model shows extensive areas of habitat in the southern half of the survey area (**Figure 4-11**). However, there are several reasons why the mapping generated by this model was not reliable with respect to the survey area. These include:

1) The model was based on former regional ecosystem mapping, which contained widespread errors with regards to the local distribution of *Acacia harpophylla* communities important to Ornamental Snakes;
2) The model assumed that riparian areas represented non-core habitat; however, all watercourses within the survey area had sandy beds with no surface water pools. No breeding habitat for frogs (and therefore Ornamental Snakes) was present along these watercourses; and
3) Some gilgais and well-vegetated dams occurred in areas mapped as non-remnant, which were excluded from the models. Given the high frog densities recorded at such sites, it is appropriate to include these locations as potential habitat for the Ornamental Snake.

For the above reasons, potential habitat for the Ornamental Snake was re-mapped based on the following principles:

1) Any patches of broad vegetation group 25a (remnant and regrowth forms) were assumed to be primary habitat, unless field surveys confirmed that gilgais were lacking;
2) Any natural wetlands with a dense cover of aquatic vegetation were assumed to be primary habitat;
3) Permanent dams supporting a fringe of aquatic vegetation were considered secondary habitat;
4) Gilgais within cleared pasture were considered secondary habitat; and
5) Dams lacking vegetated margins, and all other locations where surface water did not pool after rain (including all creeks on site), were considered non-habitat.



Legend

- MLA Area
- Survey Area

Ornamental Snake Habitat Value

- Preferred Habitat Known
- Preferred Habitat Possible
- General Habitat Known
- General Habitat Possible

Source: State of Queensland (Department of Environment and Science) 2021, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_OrnamentalSnake_Gov.aprx

Vulcan South

Ornamental Snake Habitat Suitability Model Predictions (Department of Environment and Science)

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

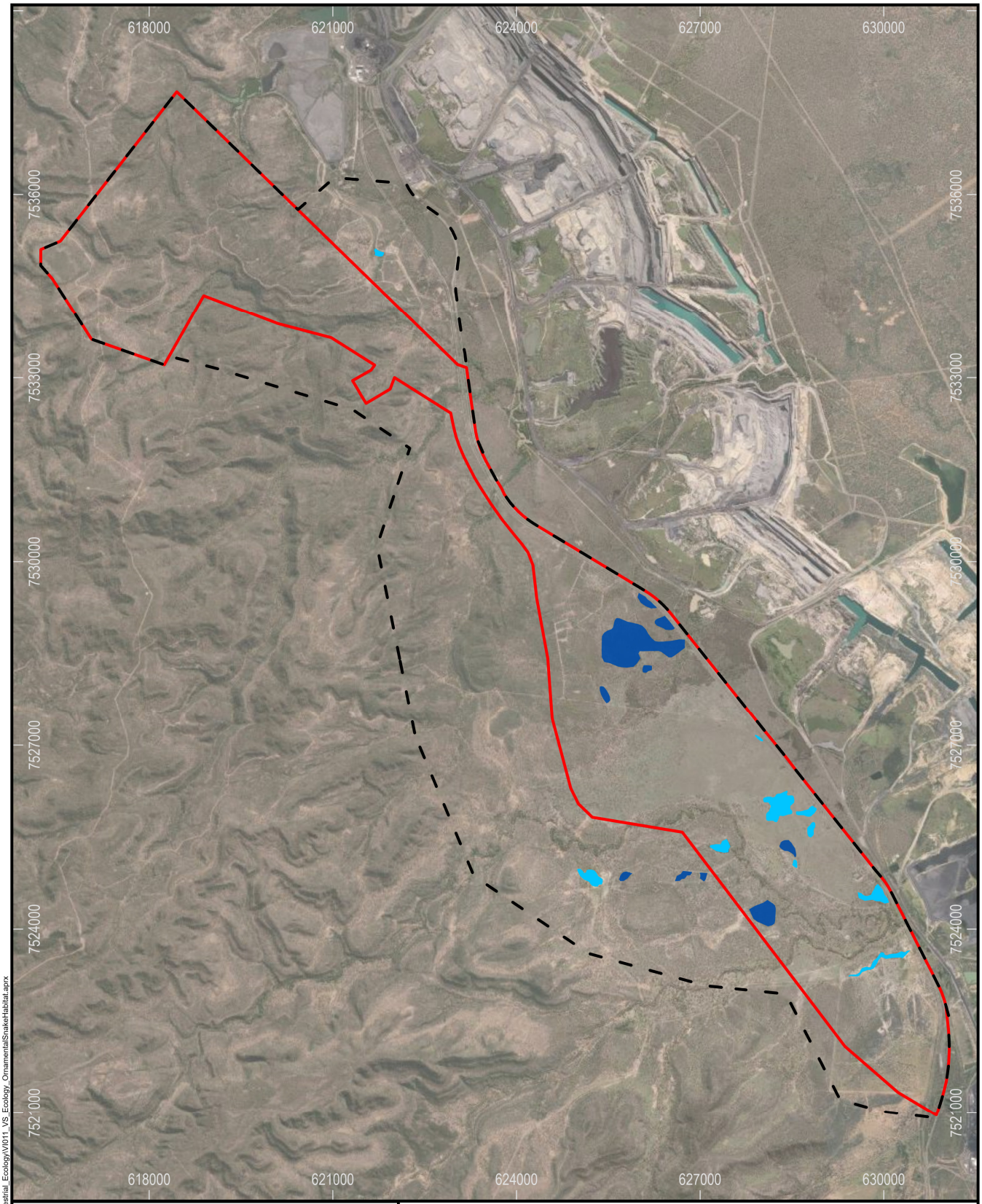
2/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-11

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd



Legend

- MLA Area
- Survey Area

Potential Ornamental Snake Habitat

- Primary
- Secondary

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Vulcan South

Potential Ornamental Snake Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

2/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-12

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_OrnamentalSnakeHabitat.aprx

The resulting habitat map (**Figure 4-12**) revealed 93.1 ha of primary habitat and 48.3 ha of secondary habitat contained within the survey area. Of this, 87.3 ha of primary habitat and 40.2 ha of secondary habitat are contained within the project area.

4.3.2.6 Yakka Skink

Yakka Skinks are large, gregarious lizards that inhabit a broad range of woodland and forest communities across sub-coastal and semi-arid Queensland (Department of Climate Change, Energy, the Environment and Water 2022e). The core habitat of this species is within the Mulga Lands and Brigalow Belt South Bioregions (Department of Climate Change, Energy, the Environment and Water 2022e), and there are few records in the Brigalow Belt North Bioregion (where Vulcan South is located).

Yakka Skinks live in colonies within cavities under and between partly buried rocks, logs or tree stumps, root cavities and abandoned animal burrows (Department of Climate Change, Energy, the Environment and Water 2022e). They remain in close proximity to their burrows, and are only active for brief periods at dawn and dusk (Department of Climate Change, Energy, the Environment and Water 2022e). This, combined with their low density, makes them difficult to detect.

The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* (Department of Sustainability, Environment, Water, Population and Communities 2011) defines suitable habitat for Yakka Skinks as "open-forests to low-woodlands and scrub in QLD RE Land Zones (LZ) 3, 4, 5, 7, 8, 9, 10 and 12 (LZ 8 not considered core habitat; LZ 12 in Wet Tropics bioregion only). Colonies have been found in large hollow logs, cavities or burrows under large fallen trees, tree stumps, logs, stick-raked piles, large rocks and rock piles, dense ground-covering vegetation, and deeply eroded gullies, tunnels and sinkholes". Important habitat is defined as "any contiguous patch of suitable habitat, particularly remnant vegetation, where a colony is known or identified, or any microhabitat where colonies are likely to be found".

The project area lies outside the Yakka Skink's modelled "known/likely to occur" distribution (Department of Sustainability, Environment, Water, Population and Communities 2011). However, the modelled distribution of the Yakka Skink shows that the species "may occur" with the project area (Department of Sustainability, Environment, Water, Population and Communities 2011).

No Yakka Skinks were recorded during surveys on site. Detectability is greatest during warm, humid conditions (Department of Climate Change, Energy, the Environment and Water 2022e), and the surveys were therefore under optimal conditions. Nevertheless, given the large size of the survey area, it was not practical to inspect every possible burrow location within it.

The survey area does not contain habitat connected to known populations of the Yakka Skink. The nearest records (Queensland Museum specimens from 1976 and 2000) of this species are from the vicinity of Blackwater, 130 km to the south. Furthermore, as no colonies have ever been recorded in the northern Bowen Basin, despite extensive ecological surveys undertaken across Dysart-Moranbah-Collinsville for various mining projects, colonies are not "likely to be found" in the vicinity of the Project. Consequently, no "important habitat" is located within the survey area.

Nevertheless, there are scattered records of Yakka Skinks as far north as Cape York, and there remains a slight possibility that the species occurs within the survey area. All remnant and regrowth vegetation within the survey area qualifies as "suitable habitat" for the species, as all contain woody debris and/or rocks that provide structural support for burrows.

4.3.2.7 Northern Quoll

The Northern Quoll inhabits a broad range of habitats across eastern and northern Australia. The *EPBC Act Referral Guideline for the Endangered Northern Quoll* (Department of the Environment 2016) defines critical habitat as "habitat within the modelled distribution of the northern quoll which provides shelter for breeding, and refuge from fire, predation and potential poisoning from Cane Toads". These can include rocky habitats, treed creek lines and structurally diverse forest with large trees, termite mounds and hollow logs (Department of the Environment 2016). The survey area

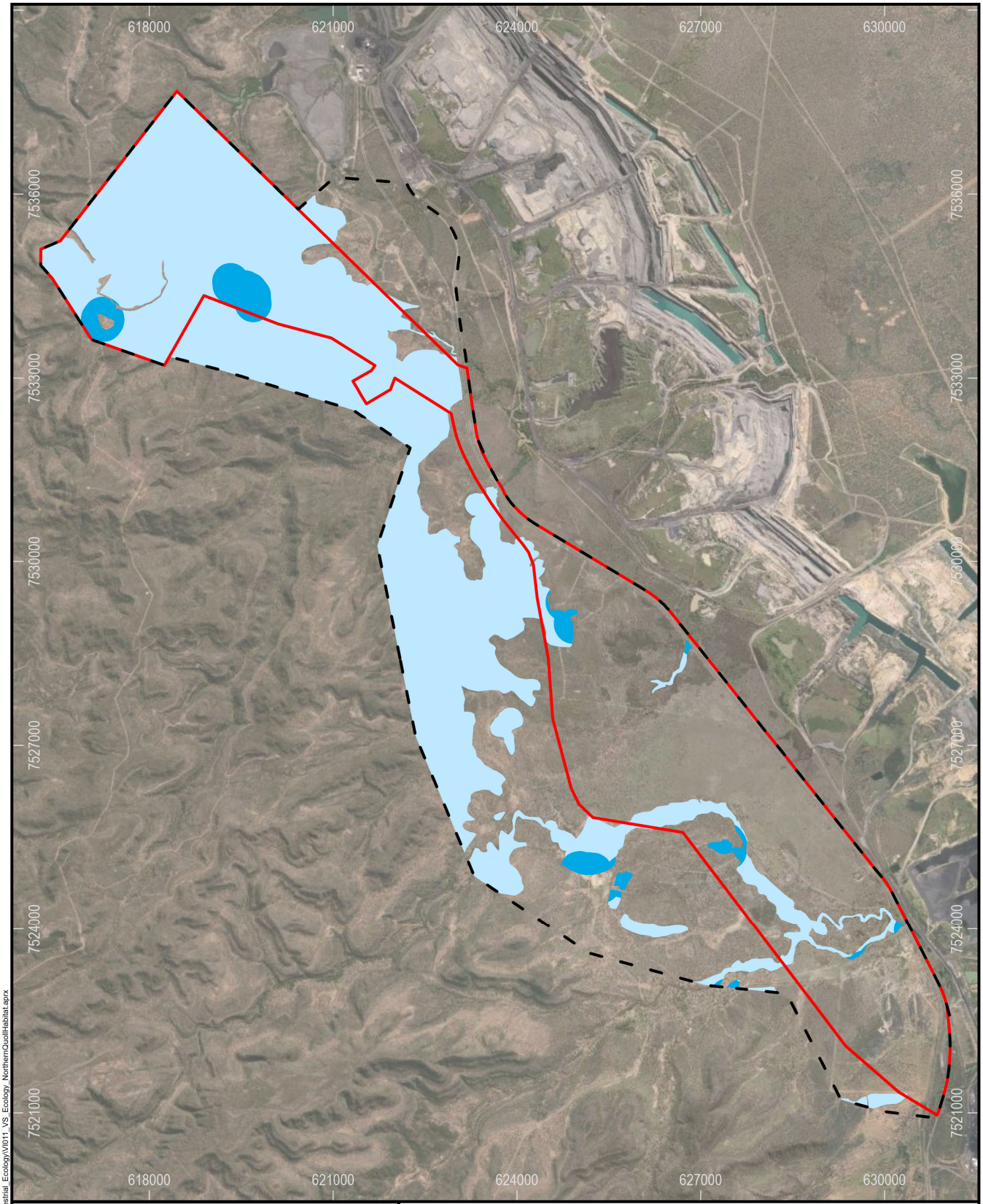
occurs within the modelled distribution of the Northern Quoll (Department of the Environment 2016). Within the survey area, critical habitats were found on land zones 3 and 10 (3,043.2 ha within the survey area). Land zone 10, particularly in the northwest of the survey area, contained boulder-strewn escarpments and gorges, which are potentially important for Northern Quolls (Pollock 1999; Woinarski *et al.* 2008; Hill and Ward 2010). Den sites close to (within 300 m of) permanent fresh water are preferred by the species (Pollock 1999); such sites were very scarce within the survey area (**Figure 4-13**).

The two major threats to Northern Quolls (Feral Cats and Cane Toads: Hill and Ward 2010) were common and widespread across the survey area.

The *EPBC Act Referral Guideline for the Endangered Northern Quoll* (Department of the Environment 2016) recommends a minimum of ten baited remote-sensory cameras to be deployed for four nights each (total of 40 camera-nights). The current survey included 122 camera-nights of sampling, in addition to 31 trap-nights of cage trapping. These surveys failed to detect any Northern Quolls.

In recent decades, the Queensland distribution of the Northern Quoll has contracted towards the most rugged habitats close to the coast (Braithwaite and Griffiths 1994; Woinarski *et al.* 2008). The nearest recent (post-2000) records of the Northern Quoll are from the Clarke Range, 100 km northeast of the survey area. No Northern Quolls have ever been detected at neighbouring mines within the Bowen Basin.

The lack of nearby records despite extensive ecological surveys undertaken in the Moranbah region in recent decades may suggest that the Northern Quoll is extinct in the region. Nevertheless, as the habitat present on site meets the criteria specified in the *EPBC Act Referral Guideline for the Endangered Northern Quoll*, the presence of the species within the survey area remains a possibility. If present, the local population is expected to be of very low density, given the lack of detection, abundance of toads and cats, and the relative paucity of surface water in rocky areas.



Legend

- MLA Area
- Survey Area

Potential Northern Quoll Habitat

- Habitat Within 300m of Water
- Landzone 3 and 10

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_NorthernQuollHabitat.aprx

Vulcan South

Potential Northern Quoll Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

9/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-13

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

4.3.2.8 Australian Painted-snipe

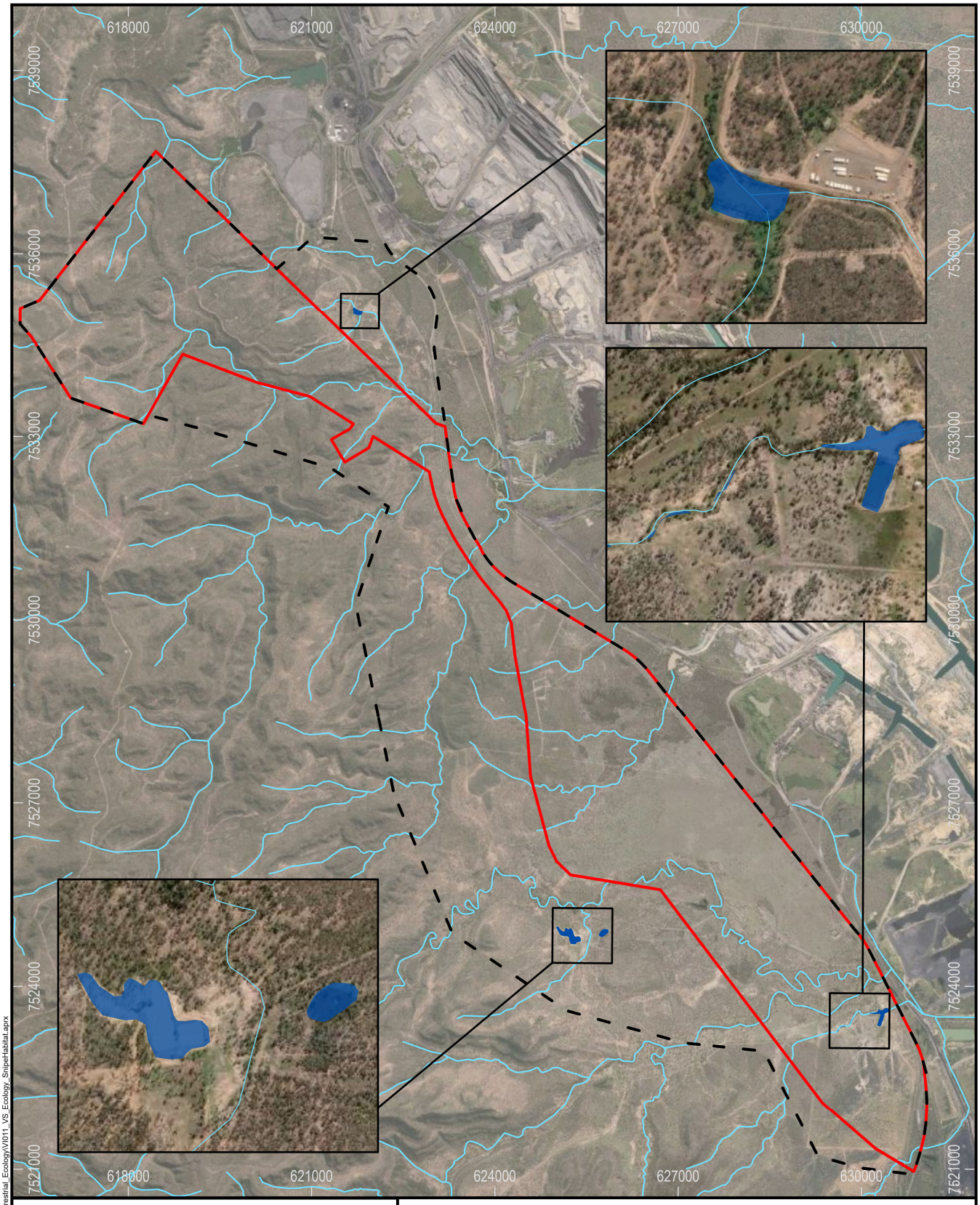
The Australian Painted-snipe is a nomadic shorebird that is an endangered species under the EPBC Act. This species was not recorded within the survey area. There are also very few records of the species from the region, and none of these are recent; it was recorded from near Moranbah on a couple of occasions prior to 1976 (per BirdLife Australia's historical bird atlas). Nevertheless, as this is a secretive, highly mobile species and potential habitat occurs in the vicinity of the project, it is considered a possible visitor to the survey area.

There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (Threatened Species Scientific Committee 2013) and the SPRAT profile for the species (Department of Climate Change, Energy, the Environment and Water 2022f).

The Australian Painted Snipe generally inhabits shallow terrestrial freshwater (occasionally brackish) wetlands, including temporary and permanent lakes, swamps and claypans (Department of Climate Change, Energy, the Environment and Water 2022f). Favoured wetlands have muddy shorelines and margins of rank grass, sedges, rushes, reeds, samphire, lignum (*Muehlenbeckia*), canegrass or sometimes tea-tree (*Melaleuca*) (Department of Climate Change, Energy, the Environment and Water 2022f). The Australian Painted Snipe can use modified habitats, including farm dams; however, they do not necessarily breed in such habitats (Department of Climate Change, Energy, the Environment and Water 2022f). Nest records are all, or nearly all, from or near small islands in freshwater wetlands, provided that these islands are a combination of very shallow water, exposed mud, dense low cover and sometimes some tall dense cover (Department of Climate Change, Energy, the Environment and Water 2022f).

Potential habitat for the Australian Painted Snipe was recorded at natural and artificial (dams) wetlands in the southern third of the survey area (**Figure 4-14**). In addition, a small dam in the northeast of the survey area possessed margins vegetated with suitable sedges and rushes, but the steep banks lacking areas of shallow mud limit the suitability of this habitat for Australian Painted-snipe.

One of the habitats within the survey area contains a small island, which has potential as a nest site for Australian Painted-snipe (inset 3 in **Figure 4-14**). This wetland lies outside the project area. The Australian Painted Snipe is highly mobile and is considered to occur in a single, contiguous breeding population (Department of Climate Change, Energy, the Environment and Water 2022f). Small numbers (singles or small groups) possibly utilise habitat within the project area for short periods during transit through the region.



Legend

- Drainage Lines
- Survey Area
- MLA Area
- Potential Australian Painted-snipe Habitat

Source: Vitrinite 2022, METServe 2020-2022, Maxar, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_SnipeHabitat.aprx

Vulcan South

Potential Habitat for Australian Painted-snipe

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-14

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

4.3.2.9 Red Goshawk

The Red Goshawk is a bird-eating hawk listed as vulnerable under the EPBC Act. There is a recovery plan in place for the species (Department of Environment and Resource Management 2012).

The Red Goshawk formerly had a wide distribution across northern and eastern Australia, occupying a variety of forested environments, but favouring the ecotone between dense forest and open woodland, especially near rivers and wetlands. In partly cleared parts of eastern Queensland it is associated with gorge and escarpment country (Threatened Species Scientific Committee 2015b). Within the last two decades, it has largely disappeared from the southern half of its former distribution. Since 2000, there have been very few (possibly no) confirmed records within New South Wales, where it is listed as critically endangered (NSW Scientific Committee 2008). Likewise, over the past 20 years in Queensland there are very few records of the species south of Townsville. The Birdata database lists a single record (from Main Range, southeast Queensland, in 2000), while the eBird database contains a single record (from Maryborough, in 2005). Neither record is supported by photographic evidence. A total of 10 Queensland records south of Townsville since 2000 are listed within the Wildnet database, without details to assess their validity. Given the propensity for misidentification of the species (Department of Environment and Resource Management 2012), it is likely that many of these records are erroneous. Some of the records (especially those older than ten years) are undoubtedly authentic, given that at least three nests were known in southeast Queensland between 2001 and 2003 (Czechura *et al.* 2010). However, extensive targeted surveys at the same locations between 2013 and 2014 failed to find any Red Goshawks (Seaton 2014).

The survey area occurs within the historical distribution of the Red Goshawk. Potential habitat for the species occurs on site, although it is not of high quality; escarpments and nearby waterways mostly lack surface water, dense forest is lacking, and the surrounding landscape is highly modified through mining and clearing for grazing. The Red Goshawk rarely breeds in areas with fragmented native vegetation (Threatened Species Scientific Committee 2015b), and never more than 1 km from water.

While it is considered possible that dispersing Red Goshawks may occasionally use the survey area, the importance of the site to the species is considered to be low.

4.3.2.10 Annual Wiregrass

The Annual Wiregrass (*Aristida annua*) is thought to be restricted to the black clay soils of central Queensland (Simon 1984), which is where almost all herbarium specimens have been collected. These soils are mostly derived from basalt and support native grasslands or open woodlands dominated by *Eucalyptus orgadophila, Eucalyptus crebra* or *Eucalyptus melanophloia*. One specimen (held at the Queensland Herbarium) was anomalously collected by D. Osten “on a ridge...[with] sandy red loam”. However, according to regional ecosystem mapping, the collection location falls within land zone 8 (clay soil derived from basalt), and the habitat reported is probably erroneous.

No basalt-derived soil exists within the survey area, but black clay soils derived from fine-grained sedimentary rock occur on site and support similar vegetation communities (regional ecosystem 11.9.2). However, these areas were heavily degraded by grazing, with the exotic pasture grass *Bothriochloa pertusa* comprising more than 90% of the vegetation cover. No areas dominated by native grasses were observed on clay soil.

No Annual Wiregrass was recorded during flora surveys. Elsewhere in central Queensland, the species has been collected in flower (when easiest to detect and identify) between February and June. The survey period coincided with the start of this period. Given the early start to the 2018-2019 growing season (e.g., heavy rain commenced in October 2018), and the abundance of flowering annual grasses of other species recorded in February 2019 and March 2020, it is expected that, if present, Annual Wiregrass would have been flowering and readily detectable at the time of survey.

The survey area lies outside the known distribution of Annual Wiregrass, and outside the modelled map of where the “species or species habitat may occur” (Department of Climate Change, Energy, the Environment and Water 2022g). However, the nearest record is only 35 km southwest of the survey

area. Given that potential habitat for this threatened grass exists within the survey area, its occurrence on site is considered possible. However, based on the highly degraded nature of the habitat present, the survey area is likely to be of negligible importance to the species.

4.3.2.11 Ghost Bat

Ghost Bats are large, carnivorous bats whose distribution is primarily limited by suitable roost sites. Ghost bats roost and breed in caves that comprise a small entrance hole and a large chamber, where conditions remain warm and humid year-round (Toop 1985; Armstrong and Anstee 2000). Roost sites are often 30-50 m deep within the cave, where conditions are most stable (Armstrong and Anstee 2000). However, smaller caves may be used transiently (Armstrong and Anstee 2000). Ghost Bats move between a number of caves seasonally or as dictated by weather conditions, and require a range of cave sites. Ghost Bats also colonise disused mines, especially those that are deep and complex, with an isothermal zone (Armstrong and Anstee 2000).

Ghost Bats forage in a wide range of native vegetation types. Foraging areas average 61 ha in size, and are generally within 1-10 km of roost sites (Tideman *et al.* 1985; Diete *et al.* 2016).

Suitable roost sites are scarce across eastern Queensland. There are only two known breeding colonies of Ghost Bats in central eastern Queensland: at Rockhampton and Cape Hillsborough. Genetic studies indicate that these populations are isolated from other populations and each other (Worthington Wilmer *et al*. 1999). This suggests a general lack of suitable breeding habitat elsewhere in central eastern Queensland (Worthington Wilmer *et al*. 1999). Ghost Bats may disperse in winter 20-50 km from the maternity roosts (Toop 1985), and the closest record of a dispersing individual (presumably from Cape Hillsborough) is at the Clarke Range (80 km northeast of the survey area).

The survey area is well outside the known winter dispersal and foraging zones of the two central Queensland populations of Ghost Bats. However, given that the existence of unknown breeding sites is possible, and the proliferation of mining across the Bowen Basin may have inadvertently created new roosting habitats (in disused mines), it is considered possible that the survey area may be used intermittently by Ghost Bats. This use would solely be in a foraging capacity, as none of the sandstone ridges on site supported caves of a size and structure suitable as a roost site. No Ghost Bats were recorded during surveys.

4.3.2.12 Dunmall's Snake

The Dunmall's Snake is poorly known and rarely recorded. The species inhabits a variety of wooded habitats, ranging from *Acacia harpophylla* on cracking clay soil to *Eucalyptus citriodora, Eucalyptus crebra* and *Eucalyptus melanophloia* open forest on sandstone-derived soil (Department of Climate Change, Energy, the Environment and Water 2022h). In the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles*, important habitat for the species is defined as any forest or woodland "within the 'Known/Likely to occur' modelled distribution of the species…and any habitat corridors in between" Department of Sustainability, Environment, Water, Population and Communities 2011). Despite containing potential habitat for the species, the survey area lies outside the known/likely distribution of the Dunmall's Snake, as modelled in the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles*. It is, therefore, not considered "important habitat" for the species. Nevertheless, the survey area lies within the modelled "may occur" zone, and given the difficulty associated with detecting this highly cryptic species, its presence on site is considered possible. No Dunmall's Snakes were detected during surveys. The nearest record is from Clermont, 80 km southwest of the survey area. The species has never been recorded in the Dysart-Moranbah region, despite extensive ecological survey effort at other mine sites. Given the absence of local records despite targeted searches undertaken for Vulcan South and numerous neighbouring mining operations, it is considered unlikely that the species occurs locally.

4.3.2.13 Allan's Lerista

Allan's Lerista is a skink that is confined to black soil downs (undulating plains formed primarily on basalt) in the vicinity of Clermont. It burrows within the upper profile of heavy clay soil under tussocks

of grass (Department of Climate Change, Energy, the Environment and Water 2022i). It is typically recorded from *Eucalyptus orgadophila* and *Corymbia erythrophloia* open woodlands (Department of Climate Change, Energy, the Environment and Water 2022i).

No Allan's Leristas were found during surveys. The nearest known population to the survey area is 30 km west. However, it is separated from the survey area by a 130-km long sandstone range, which likely constitutes an important barrier to dispersal. The species has never been recorded east of this range.

The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* (Department of Sustainability, Environment, Water, Population and Communities 2011) defines suitable habitat for the species as being regional ecosystems 11.8.5 and 11.8.11, both of which are lacking from the survey area. Nevertheless, regional ecosystem 11.9.2 (*E. orgadophila* open woodland on soil derived from fine-grained sedimentary rock) occurs on site, and closely resembles 11.8.5 in its floristics and soil attributes. Furthermore, models within the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* indicate that the species may occur within the survey area, despite the site being outside the modelled "known/likely to occur" zone.

A total of four trap sites were installed in the only patch of potential habitat located within the survey area (three in remnant 11.9.2 and one in cleared 11.9.2), which is twice the sample effort recommended by the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles*.

Taking into account the known distribution of the species and the search effort conducted to date, it is unlikely that Allan's Lerista occurs within the survey area.

4.3.2.14 King Blue-grass

King Blue-grass (*Dicanthium queenslandicum*) inhabits native grasslands and open woodlands on black cracking clay soil derived from basalt. The species also colonises pastures established following the clearance of *Acacia harpophylla* and other dense vegetation communities growing on heavy clay soil. King Blue-grass cannot tolerate continual heavy stocking regimes, and is outcompeted by exotic grass species and weeds, which tend to dominate heavily grazed pastures (Fensham 1999). For this reason, most extant populations are confined to road reserves and other sites semi-protected from grazing livestock.

Heavy clay soils supporting grasses are represented within the survey area by remnant regional ecosystem 11.9.2 and cleared pastures that formerly supported regional ecosystem 11.4.9. Both habitats have been subjected to long periods of heavy grazing. This has led to the almost complete replacement of native perennial grasses with the exotic *Bothriochloa pertusa.* Road verges protected from grazing livestock were dominated by other weed grasses, such as *Cenchrus ciliaris, Megathyrsus maximus, Chloris* spp. and *Hyparrhenia rufa*. Nowhere within the survey area were clay soils observed to support a native grassland community.

The nearest recorded King Blue-grass is in the vicinity of Moranbah Airport, 30 km north of the survey area. While the species possibly once inhabited the survey area, its continued existence is unlikely considering current grazing regimes. The survey area lies just outside the Department of Climate Change, Energy, the Environment and Water's (2022j) modelled "may occur" range of the species.

4.3.2.15 Hairy Bluegrass

Hairy Bluegrass (*Dicanthium setosum*) is associated with heavy basaltic black soils and red-brown loams with clay subsoil (Department of Climate Change, Energy, the Environment and Water 2022k). It is tolerant of a moderate amount of disturbance, but excessive grazing and invasion of exotic grasses threatens the species (Department of Climate Change, Energy, the Environment and Water 2022k). All clay soils within the survey area were dominated by the exotic pasture grass *Bothriochloa pertusa*. No native grass communities were observed on clay within the survey area.

Hairy Bluegrass has a patchy distribution across subcoastal eastern Australia. Based on herbarium records, there appears to be a 280 km gap between known populations at Springsure and Glenden. The survey area occurs within this gap; the nearest known record is 95 km to the north.

The survey area lies just outside the Department of Climate Change, Energy, the Environment and Water's (2022k) modelled "may occur" range of the species. Despite potential habitat occurring on site, the lack of local records and the heavily degraded nature of the available habitat suggest that the survey area is not important for the Hairy Bluegrass.

4.3.3 Migratory Species

Migratory species listed in the following international agreements are protected under the EPBC Act as matters of national environmental significance:

- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention);
- China-Australia Migratory Bird Agreement;
- Japan-Australia Migratory Bird Agreement; and
- Republic of Korea-Australia Migratory Bird Agreement.

Two listed migratory species, the Rufous Fantail and White-throated Needletail, were detected within the survey area. Two additional species (Fork-tailed Swift and Latham's Snipe) are likely visitors, and an additional six species (Sharp-tailed Sandpiper, Oriental Cuckoo, Gull-billed Tern, Black-faced Monarch, Satin Flycatcher, Glossy Ibis) are possible visitors (**Table 4-6**).

The survey area contains important habitat for the Rufous Fantail, Oriental Cuckoo and Satin Flycatcher, according to definitions of the Department of the Environment (2015). However, for no migratory species does the survey area contain "important habitat" that supports an "ecologically significant proportion of the population", as defined by the *Matters of National Environmental Significance: Significant Impact Guidelines 1.1* (Department of the Environment 2013a), *Referral Guidelines for 14 Birds Listed as Migratory Species under the EPBC Act* (Department of the Environment 2015a) and *Industry Guidelines for Avoiding, Assessing and Mitigating Impacts on EPBC Act Listed Migratory Shorebird Species* (Department of Environment and Energy 2017). Each species is discussed further in the following sub-sections.

Table 4-6 Migratory species flagged by database searches as potentially occurring in or near the survey area

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Bird	*Rhipidura rufifrons*	Rufous Fantail	M	SL	Dense woody vegetation, including vine thickets, paperbark forests and rainforest.	C	C
Bird	*Hirundapus caudacutus*	White-throated Needletail	V/M	V	Airspace containing flying insects, above a diversity of landscapes.	C	C
Bird	*Apus pacificus*	Fork-tailed Swift	M	SL	Almost exclusively aerial, foraging on flying insects above all habitat types.	L	L
Bird	*Gallinago hardwickii*	Latham's Snipe	M	SL	Freshwater wetlands with well-vegetated muddy edges.	L	L
Bird	*Cuculus optatus*	Oriental Cuckoo	M	SL	Primarily coastal forest and woodland. Rarely moves inland west of the coastal ranges.	P	P
Bird	*Monarcha melanopsis*	Black-faced Monarch	M	SL	Typically associated with rainforest. Migrating individuals may utilise dense riparian vegetation.	P	P
Bird	*Myiagra cyanoleuca*	Satin Flycatcher	M	SL	Tall wet forests of the coast and nearby ranges. Vagrant individuals may occasionally occur inland, where they are most likely in denser forests (e.g., along waterways).	P	P
Bird	*Plegadis falcinellus*	Glossy Ibis	M	SL	Shallow, marshy edges of large freshwater wetlands.	P	P
Bird	*Calidris acuminata*	Sharp-tailed Sandpiper	M	SL	Estuarine and freshwater wetlands with extensive shallow, muddy margins.	P	P
Bird	*Gelochelidon nilotica*	Gull-billed Tern	M	SL	Primarily a coastal species. Can occur at inland lakes.	P	P
Bird	*Actitis hypoleucos*	Common Sandpiper	M	SL	Inhabits primarily tidal rivers and rocky foreshores. Occasionally uses the edges of inland wetlands.	U	U
Bird	*Calidris ferruginea*	Curlew Sandpiper	CE/M	E	Primarily coastal mudflats, but occasionally also uses the muddy margins of large freshwater wetlands.	U	U
Bird	*Calidris melanotos*	Pectoral Sandpiper	M	SL	Estuarine and freshwater wetlands with extensive shallow, muddy margins.	U	U
Bird	*Motacilla flava*	Yellow Wagtail	M	SL	The shallow, muddy edges of wetlands. Primarily a coastal species.	U	U
Bird	*Pandion haliaetus*	Osprey	M	SL	Restricted to coastlines, estuaries and large inland rivers/lakes.	U	U
Bird	*Phaethon rubricauda*	Red-tailed Tropicbird	M	SL	A marine species that has only been recorded near the survey area following a cyclone.	U	U
Bird	*Tringa nebularia*	Common Greenshank	M	SL	Primarily coastal, but occasionally also uses the muddy margins of large freshwater wetlands.	U	U

Taxon	Species	Common Name	EPBC status*	NC status†	Habitat requirements	Presence in survey area‡	Presence in project area‡
Bird	*Tringa stagnatilis*	Marsh Sandpiper	M	SL	Muddy margins of shallow fresh or brackish water.	U	U

4.3.3.1 Rufous Fantail

Rufous Fantails are migratory birds protected under the Bonn Convention and the EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006*.

Rufous Fantails pass through the project area during transit in spring and autumn. The species lives primarily along the east coast and nearby ranges, in rainforest and wet eucalypt forests with a dense, shrubby midstorey. During migration, they can inhabit drier woodlands further west. Two individuals were recorded on site in September-October 2019: one within vine-thicket and the other within dense *Acacia* regrowth (**Figure 4-15**). The subspecies of these individuals is not known, but given the suboptimal habitat usage, these were likely to be migrants. Therefore, they belonged either to *Rhipidura rufifrons rufifrons* (south-eastern Australian subspecies) or migratory sub-populations of *Rhipidura rufifrons intermedia* (Queensland subspecies).

It is likely that small numbers (5 to 10) pass through the survey area during each northward or southward migration. According to population estimates provided by the *Referral guideline for 14 birds listed as migratory species under the EPBC Act* (Department of the Environment 2015a), this constitutes a tiny fraction (0.001% to 0.002%) of the total population size of the subspecies involved.

Within the survey area, habitats possessing a dense midstorey of *Acacia, Melaleuca* or vine-thicket species are most likely to be used (**Figure 4-15**). In total, 2,453.3 ha of such habitat exist within the survey area. A total of 1,503.3 ha of potential habitat occur within the project area.

The survey area is of marginal significance for the Rufous Fantail, given that most of the population migrates through more coastal habitats further east (based on eBird and Atlas of Living Australia records). Breeding has never been recorded in dry habitats west of the coastal ranges in central Queensland (Barrett *et al.* 2003), and is not likely within the survey area.

4.3.3.2 White-throated Needletail

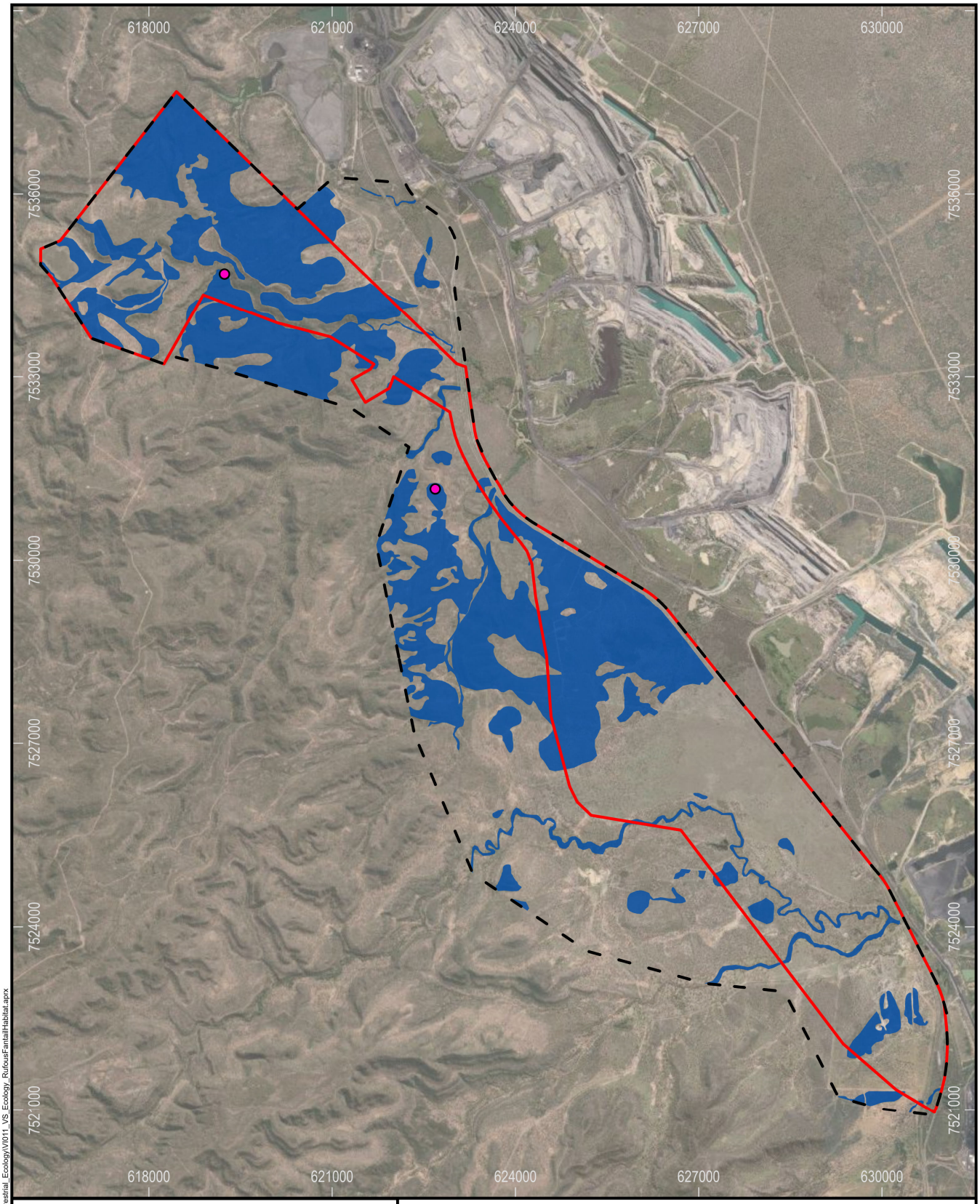
White-throated Needletails are migratory birds protected under the China-Australia Migratory Bird Agreement, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. The species is also protected as a threatened species under the EPBC Act, and is discussed in detail within **Section 4.3.2.4**.

White-throated Needletails were recorded on site on a single occasion. The survey area is likely to be west of their primary migration route, but flocks occasionally feed in the area when drawn west by low pressure systems. The survey area is of no particular importance to the White-throated Needletail on a local or regional scale, and the project will not include any wind turbines, tall buildings, airports or other structures that threaten airspace used by the species for foraging and dispersal.

4.3.3.3 Fork-tailed Swift

Fork-tailed Swifts are migratory birds protected under the China-Australia Migratory Bird Agreement, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Fork-tailed Swifts visit Australia during their non-breeding season (the austral summer). They are exclusively aerial, foraging for flying insects in airspace above most habitats, including cleared farmland. The species is ecologically similar to the White-throated Needletail, and the two species often flock together. The Fork-tailed Swift is the more likely of the two species to forage over inland plains. Flocks of Fork-tailed Swifts are highly mobile and don't remain long in any one location. While no Fork-tailed Swifts were recorded during ecological surveys, it is likely that passing flocks utilise the survey area briefly and intermittently during summer, but possibly not every year. The nearest record is from 45 km north of the survey area.



Legend

- Rufous Fantail Sighting
- Survey Area
- MLA Area
- Rufous Fantail Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_RufousFantailHabitat.aprx

Vulcan South

Rufous Fantail Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-15

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

The survey area is of no particular importance to the Fork-tailed Swift on a local or regional scale, and the project will not include any wind turbines, tall buildings, airports or other structures that threaten airspace used by the species for foraging and dispersal.

4.3.3.4 Latham's Snipe

Latham's Snipe is a shorebird with similar ecological requirements to the Australian Painted-snipe (see **Section 4.3.2.8**). Latham's Snipe are migratory birds protected under the Bonn Convention, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Latham's Snipe inhabit the muddy edges of freshwater and brackish wetlands where there exists abundant low, dense vegetation for shelter. Important habitat for Latham's Snipe is defined in the *Wildlife Conservation Plan for Migratory Shorebirds* (Department of the Environment 2015b) as "areas that have previously been identified as internationally important for the species, or areas that support at least 18 individuals of the species".

The Latham's Snipe was not recorded within the survey area, despite surveys coinciding with seasons when presence is most likely (August-April). Nevertheless, this is a cryptic species and small numbers may have gone undetected. Latham's Snipe commonly utilises relatively small farm dams, provided that its needs for a muddy substrate and vegetated margins are met. There are numerous records of the species within a 100 km radius of the survey area, in many cardinal directions.

Locations of potential habitat are as for the Australian Painted-Snipe (see **Figure 4-14**). None of these habitats are likely to support 18 individuals, and therefore do not qualify as important habitat.

4.3.3.5 Oriental Cuckoo

Oriental Cuckoos are migratory birds protected under the China-Australia Migratory Bird Agreement, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.* No Oriental Cuckoos were recorded within the survey area. The nearest published record is 78 km northeast of the survey area.

Oriental Cuckoos visit Australia when not breeding in the Austral summer (November-April). When in Australia, Oriental Cuckoos typically inhabit monsoonal rainforest, vine thickets, wet sclerophyll forest and open woodlands. They typically favour riparian areas and other ecotones between dense forest and more open habitat.

Most eastern Australian records are along the coast or sub-coastal ranges, with very few sightings further than 100 km from the coast. All inland records listed in eBird are in the vicinity of watercourses, corresponding with the species' preference for denser forests. The survey area lies 135 km from the coast. Occasional individuals may stray to the survey area, where they are most likely to occur along forested watercourses.

A nationally important, ecologically significant proportion of the species' population is described by the former Department of the Environment (2015a) as 1,000 individuals. No more than one or two Oriental Cuckoos are expected to utilise the survey area in any one 12-month period.

4.3.3.6 Black-faced Monarch

Black-faced Monarchs are migratory birds protected under the Bonn Convention and EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Black-faced Monarchs breed in rainforest and wet sclerophyll forest, especially in mountainous areas, sheltered gullies and slopes with a dense understorey of ferns and/or shrubs. In central Queensland, migrating individuals are rarely observed in drier woodlands further than 100 km from the coast. No Black-faced Monarchs were recorded within the survey area, although there is a published record

(from 1999) at the adjacent Peak Downs Mine. As the survey area is west of their primary migration route, it does not contain important habitat for the Black-faced Monarch.

4.3.3.7 Satin Flycatcher

Satin Flycatchers are migratory birds protected under the Bonn Convention and EPBC Act. In Queensland, they are also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Satin Flycatchers breed in tall, wet sclerophyll forest at high altitudes in southeastern Australia and winter at rainforest edges in north Queensland and New Guinea. The survey area lies outside the known breeding and wintering range of the species. Most records of migrating individuals are along the coast and sub-coastal ranges, but occasional records occur in drier woodlands further west. No Satin Flycatchers were recorded within the survey area. The nearest published record is from 63 km southeast of the survey area.

Most inland records listed in eBird occur in September-October or February-March, coinciding with southward and northward migration. While the survey area is west of their primary migration route, small numbers (fewer than five) may pass through annually in a transient capacity. The survey area does not support a nationally important, ecologically significant proportion (defined by the former Department of the Environment (2015a) as 1,700 individuals) of the population at any time.

4.3.3.8 Glossy Ibis

The Glossy Ibis is a migratory bird protected under the Bonn Convention and EPBC Act. In Queensland, it is also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Glossy Ibis inhabit the shallow, muddy edges of lakes, wet, marshy areas, and flooded pastures with short vegetation. The natural wetlands present on site are too small and/or are too heavily treed to provide favourable habitat for the Glossy Ibis. However, two dams constitute marginal habitat that may be used briefly under optimal weather conditions (i.e., when water levels are optimal). Both of these dams are located in the southern half of the survey area, one of which is in the MLA area (refer to inset 2 and 3 on **Figure 4-2**). None of the habitat present within the survey area is considered important for the Glossy Ibis. No Glossy Ibis were recorded within the survey area, but the species has been recorded at the adjacent Peak Downs Mine.

4.3.3.9 Sharp-tailed Sandpiper

The Sharp-tailed Sandpiper is a migratory bird protected under the Bonn Convention, China-Australia Migratory Bird Agreement, Japan-Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement and EPBC Act. In Queensland, it is also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

No Sharp-tailed Sandpipers were recorded within the survey area, but there is a nearby record from Peak Downs Mine in 2001. They are likely to be occasional summer visitors to suitable habitat within the survey area.

Sharp-tailed Sandpipers depend on open wetlands with shallow, muddy margins and often short, damp vegetation. The natural wetlands present on site are too small and/or are too heavily treed to provide favourable habitat for this species. However, two dams constitute marginal habitat that may be used briefly under optimal weather conditions (i.e., when retreating water levels expose muddy banks). Both of these dams are located in the southern half of the survey area (see inset 2 and 3 in **Figure 4-2**), one of which is in the MLA area. None of the habitat present within the survey area is considered important for the Sharp-tailed Sandpiper.

4.3.3.10 Gull-billed Tern

The Gull-billed Tern is a migratory bird protected under the China-Australia Migratory Bird Agreement and EPBC Act. In Queensland, it is also listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006.*

Gull-billed Terns forage over coastal estuaries and large inland lakes and wetlands for fish. All water bodies within the survey area are too small to be favourable for the species, although the two largest dams in the southern part of the survey area (see inset 2 and 3 on **Figure 4-2**) may be used for brief periods by transient individuals. The species has been recorded (in 1999) at the adjacent Peak Downs Mine, which contains larger dams than are present within the survey area. None of the habitat present within the survey area is considered important for the Gull-billed Tern.

4.4 STATE ENVIRONMENTAL SIGNIFICANCE

Matters of state environmental significance are defined in the *State Planning Policy 2017.* Each of these are summarised below, with respect to the project.

4.4.1 Protected Areas

No national parks, conservation parks, resource reserves, special wildlife reserves, nature refuges or coordinated conservation areas are located in or near the survey area.

4.4.2 Marine Matters

No marine parks, marine plants or fish habitat protected under the *Fisheries Act 1994*, *Fisheries Regulation 2008* or the *Marine Parks Act 2004* is contained in the survey area.

4.4.3 Designated Precinct in Strategic Environmental Areas

No strategic environmental areas are listed for the Isaac Regional Council area.

4.4.4 Wetlands and Watercourses

No wetlands or watercourses of high ecological significance are located within the survey area.

4.4.5 Secured Offset Areas

No legally secured offset areas from other projects are located in or near the survey area.

4.4.6 Regulated Vegetation

The following regulated vegetation under the *Vegetation Management Act 1999* (VM Act) is classed as a matter of state environmental significance in the *State Planning Policy 2017*:

(i) category B areas (regional ecosystems) on the regulated vegetation management map that are 'endangered' and 'of concern' regional ecosystems;

(ii) category C areas (regrowth) on the regulated vegetation management map that are 'endangered' and 'of concern' regional ecosystems;

(iii) category R areas (non-remnant vegetation within 50 m of watercourses) on the regulated vegetation management map;

(iv) areas of essential habitat on the essential habitat map for wildlife prescribed as 'endangered wildlife' or 'vulnerable wildlife' under the *Nature Conservation Act 1992*;

(v) category A, B, C or R areas on the regulated vegetation management map that are located within a defined distance from the defining banks of a relevant watercourse identified on the vegetation management watercourse and drainage feature map; and

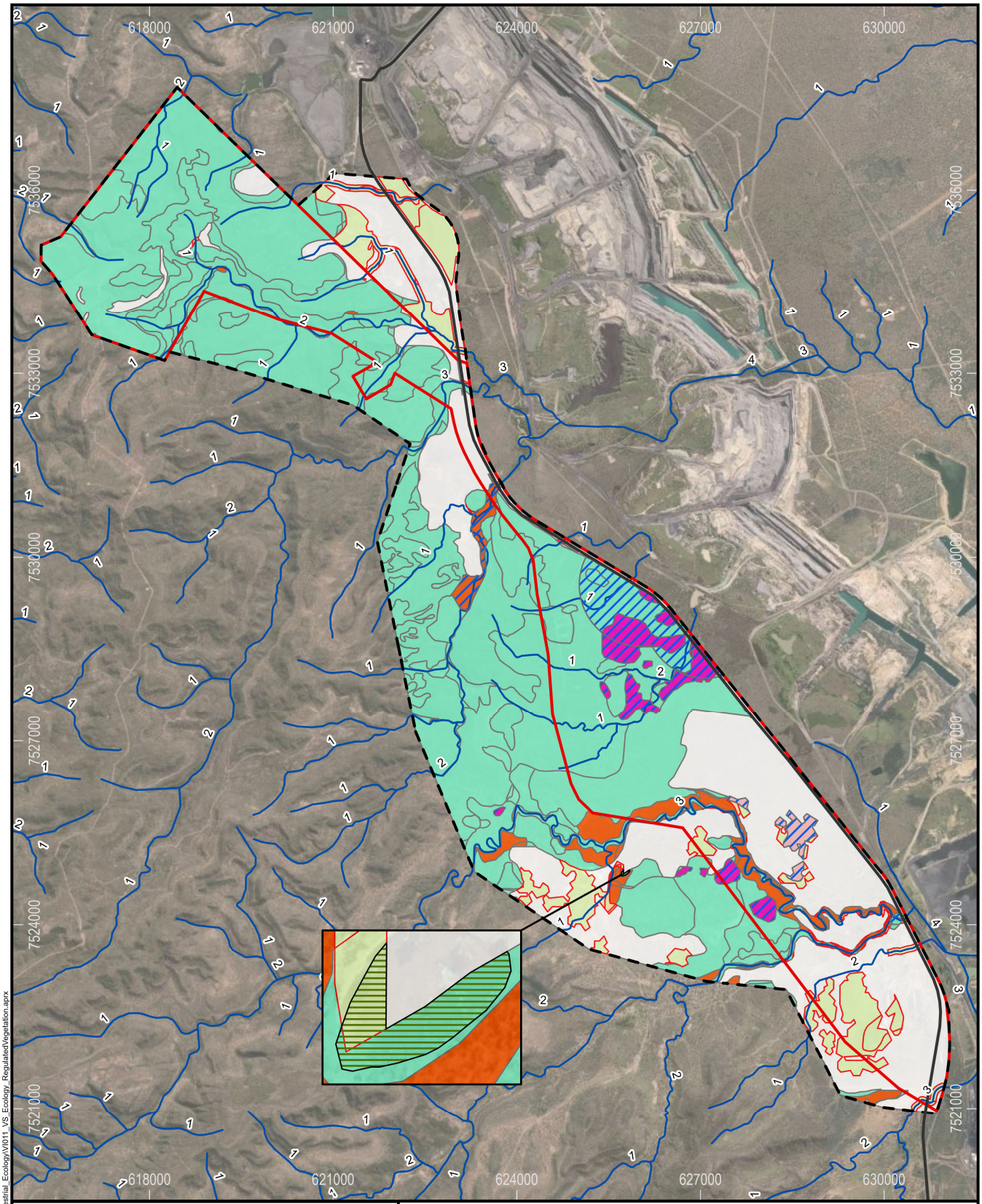
(vi) category A, B, C or R areas on the regulated vegetation management map that are located within a wetland or within 100 metres from the defining bank of a wetland identified on the vegetation management wetlands map.

The regulated vegetation management map, on which the above definitions of regulated vegetation are based (**Figure 4-16**), differs slightly from the field-verified regional ecosystem map. The main differences reflect the extent of regrowth (categories C and R) versus cleared areas (category X). On the regulated vegetation management map, these boundaries are primarily a legacy of an historical property map of assessable vegetation (PMAV). Despite the field-verified regional ecosystem map being a better reflection of what is present on site (hence why it is used for all habitat assessments and calculations for threatened species), the units on the regulated vegetation management map are what is protected under the VM Act. The regulated vegetation contained in the survey area is presented in **Table 4-7**.

Table 4-7 Regulated vegetation constituting MSES

Vegetation Type	Constituent REs	Total Area within the Survey Area	Total Area within the Project Area
Endangered and of concern regional ecosystems (category B)	11.3.2 (of concern) 11.4.8 (endangered) 11.4.9 (endangered) 11.10.8 (of concern) **Total**	177.7 ha 135.8 ha 17.2 ha 2.4 ha **333.0 ha**	95.3 ha 131.3 ha 14.9 ha 1.4 ha **242.9 ha**
Endangered and of concern regrowth (category C)	11.3.2 (of concern) 11.4.9 (endangered) **Total**	9.3 ha 32.3 ha **41.6 ha**	2.0 ha 32.2 ha **34.2 ha**
Non-remnant vegetation along watercourses (Category R)	n/a	54.7 ha	20.7 ha
Essential habitat for threatened wildlife	11.3.2, 11.3.25, 11.4.8, 11.4.9, HVR 11.4.9, 11.5.9	350.3 ha	308.0 ha
Category A, B, C or R areas that occur within 100 m of any wetland	11.3.2 (category B) 11.3.27b (category B) 11.5.3 (category B) HVR 11.3.2 (category C) HVR 11.3.27b (category C) HVR 11.5.3 (category C) Non-remnant (category R) **Total**	3.1 ha 0.9 ha 1.3 ha 0.1 ha 0.4 ha 0.3 ha 0 ha **6.2 ha**	0 ha 0 ha 0 ha 0 ha 0 ha 0 ha 0 ha **0 ha**
Category A, B, C or R areas that are located within a defined distance from the defining banks of a relevant watercourse*	11.3.2 (category B) 11.3.7 (category B) 11.3.25 (category B) 11.3.27b (category B) 11.4.8 (category B) 11.5.3 (category B) 11.5.9b (category B) 11.9.2 (category B) 11.10.1 (category B) 11.10.3 (category B) 11.10.8 (category B) HVR 11.3.2 (category C) HVR 11.3.25 (category C) HVR 11.5.3 (category C) HVR 11.5.9b (category C) HVR11.10.1 (category C) Non-remnant (category R) **Total**	69.1 ha 8.1 ha 88.7 ha 0.2 ha 1.9 ha 23.1 ha 108.6 ha 1.5 ha 55.5 ha 87.5 ha 0.7 ha 1.8 ha 2.4 ha 2.0 ha 15.9 ha 3.1 ha 38.3 ha **508.4 ha**	52.6 ha 1.8 ha 38.4 ha 0.2 ha 1.9 ha 2.6 ha 70.2 ha 1.3 ha 31.3 ha 48.2 ha 0.7 ha 0.2 ha 0 ha 0.3 ha 0.3 ha 0 ha 17.3 ha **267.4 ha**

*The defined distance was listed by Department of Environment and Heritage Protection (2017) as 25 m for a first- or second-order stream and 50 m for a third- or fourth-order stream. The certified vegetation management watercourse map shows the centreline of relevant watercourses, but not the exact locations of their banks. Bank location was estimated based on the average width of watercourses in the survey area. Watercourse widths (distance between banks) were estimated to be 5 m for first-order streams, 10 m for second-order streams, 15 m for third-order streams and 20 m for fourth-order streams. Buffers around the watercourse centreline were enlarged beyond the "defined distance" to account for these stream widths.



Legend

- Road
- Vegetation Management Watercourse/Drainage Feature Map (Stream Order Labelled)
- Survey Area
- MLA Area
- Essential Habitat
- Vegetation Management Wetlands Map

Regulated Vegetation Management Map

- Category A or B area containing endangered regional ecosystems
- Category A or B area containing of concern regional ecosystems
- Category A or B area that is a least concern regional ecosystems
- Category C or R area containing endangered regional ecosystems
- Category C or R area containing of concern regional ecosystems
- Category C or R area that is a least concern regional ecosystems
- Category X area

Source: State of Queensland (Department of Resources) 2022, Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_RegulatedVegetation.aprx

Vulcan South

Regulated Vegetation Management Map

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-16

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

4.4.7 Threatened and Special Least Concern Wildlife

Forty-two species of plants and animals listed as matters of state significance were flagged by database searches as being potentially present in the region. Field surveys confirmed that six of these (Koala, Greater Glider, Squatter Pigeon, Short-beaked Echidna, White-throated Needletail and Rufous Fantail) were present within the survey area. Furthermore, a seventh species (Glossy Black-cockatoo) was recorded on site despite not being flagged as present in the region. No threatened or near threatened species of plants were detected within the survey area.

Most of the species that constitute matters of state significance are also matters of national significance, and were therefore discussed in **Section 4.3.2** and **Section 4.3.3** (see **Table 4-3** and **Table 4-6** for a list of their conservation status under the NC Act).

Only three species that are matters of state environmental significance are not also matters of national significance protected under the EPBC Act. These are the Glossy Black-cockatoo (*Calyptorhynchus lathami*), Short-beaked Echidna (*Tachyglossus aculeatus*) and Common Death Adder (*Acanthophis antarcticus*). The first two species were detected within the survey area and the third is a possible inhabitant. Each is discussed in the following subsections.

4.4.7.1 Glossy Black-cockatoo

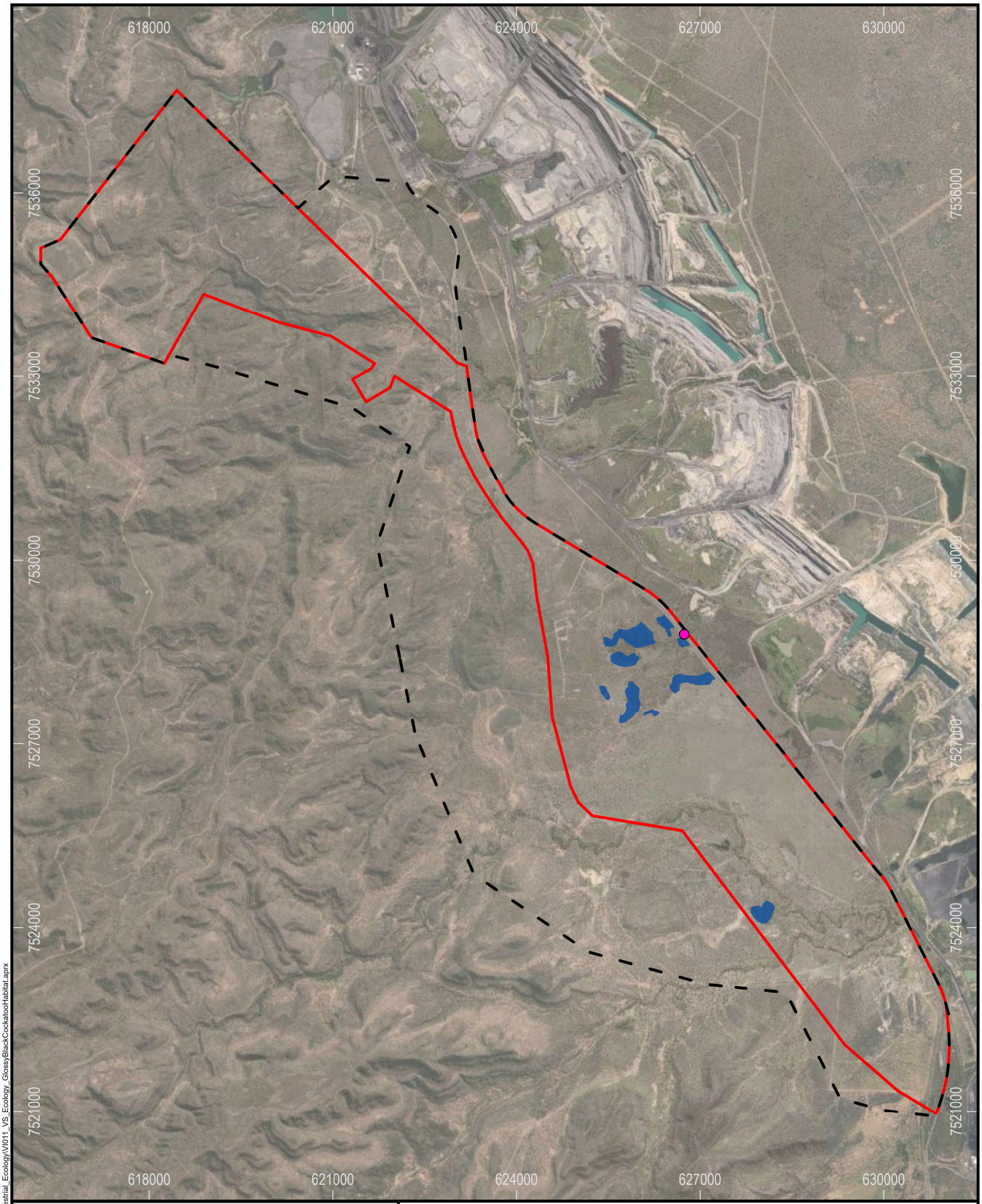
The Glossy Black-cockatoo is listed as Vulnerable under the NC Act. The Glossy Black-cockatoo was not recorded on site during ecology surveys and there were no recent records (from last 50 years) within 100 km of the survey area. Desktop reviews therefore did not flag it as a species that potentially occurred in the vicinity of Vulcan South. Nevertheless, one pair was observed during weed monitoring undertaken within the survey area in March 2022 (**Figure 4-17**).

Glossy Black-cockatoos are dietary specialists, feeding on the seeds of only nine species of *Casuarina* and *Allocasuarina* (Chapman 2007). The cockatoo subspecies found in central Queensland (*C. L. erebus*) is known to feed primarily on *Casuarina cristata, Allocasuarina torulosa* and *Allocasuarina littoralis.* Of these food trees, only *C. cristata* (Belah) occurs within the survey area, where it grows within small patches of Brigalow. The pair of Glossy Black-cockatoos was observed feeding in one of these small groves of Belah. The other food trees are restricted to higher rainfall areas near the coast and nearby ranges.

The occurrence of Glossy Black-cockatoos within the survey area was unusual for several reasons:

- The survey area is far from the closest known permanent populations to the south and east, at Blackdown Tableland, the Clarke Range and the Rockhampton-Shoalwater Bay region.
- The survey area contains multiple small patches of feeding habitat (total of 74.5 ha) isolated from other feeding habitat by extensive tracts of cleared farmland, mines and forest lacking food trees. The small areas of habitat present are almost certainly insufficient to provide a year-round supply of seed. Glossy Black-cockatoos on Kangaroo Island generally require at least 400 ha of feeding habitat within 12 km of nests for successful breeding (Mooney and Pedler 2005).
- The species was not recorded during the extensive fauna surveys undertaken on site, despite particular focus on habitats likely to support the species (i.e., Brigalow areas), due to the potential of this habitat to also harbour Ornamental Snakes and other threatened species.

Taken together, the above evidence suggests that the site provides foraging habitat used occasionally by transient individuals, rather than a locally resident breeding population. The Capricornia region is currently experiencing a severe rainfall deficit. Furthermore, large areas of Glossy Black-cockatoo habitat at Shoalwater Bay experienced bushfires in 2021 (NAFI 2022). These environmental factors may be causing a food shortage within their more usual home ranges, encouraging dispersal to new, suboptimal locations. A similar pattern was observed in southeastern Queensland following the drought and fires of 2019 (Cornell Lab of Ornithology 2022).



Legend

- Glossy Black-Cockatoo Sighting
- Survey Area
- MLA Area
- Glossy Black-Cockatoo Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_GlossyBlackCockatooHabitat.aprx

Vulcan South

Glossy Black-Cockatoo Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-17

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

4.4.7.2 Short-beaked Echidna

The Short-beaked Echidna is the most widespread native mammal in Australia. It is listed as Special Least Concern under the *Nature Conservation (Wildlife) Regulation 2006*. It has no particular habitat requirements other than potential den sites (beneath rocks or fallen timber) and a supply of ants and termites, on which it feeds (Augee 2008). Short-beaked Echidnas, or their scats or excavations, were recorded on seven occasions during ecological surveys. These included within remnant and non-remnant vegetation. As echidnas utilise a broad diversity of natural and modified habitats, and have very large home ranges spanning up to 100 ha (Nichol *et al.* 2011), the entire survey area (6,982.4 ha) comprises potential habitat for the Short-beaked Echidna.

4.4.7.3 Common Death Adder

The Common Death Adder is a snake that inhabits a broad range of habitats across eastern Australia. Its chief habitat requirement is abundant shelter in the form of leaf litter, woody debris and/or rocks. A low density of Cane Toads (*Rhinella marina*) is important, as ingested toads cause lethal poisoning (Phillips *et al.* 2009). Habitats well away from permanent water (where toads congregate and breed) are therefore likely to be most important for the species.

No Common Death Adders were recorded during ecological surveys. However, the species was recently recorded (in 2012) 25 km northeast of the project, and it is possible that populations persist on site despite high densities of Cane Toads. Within the survey area, the sandstone ridges in the western half probably contain the most valuable habitat for the species (**Figure 4-18**). Such habitats have the highest density of shelter sites and lowest densities of toads. There are 2,829.6 ha of remnant and regrowth vegetation on Land zone 10 (sandstone) within the the survey area.

4.5 WEEDS AND PEST ANIMALS

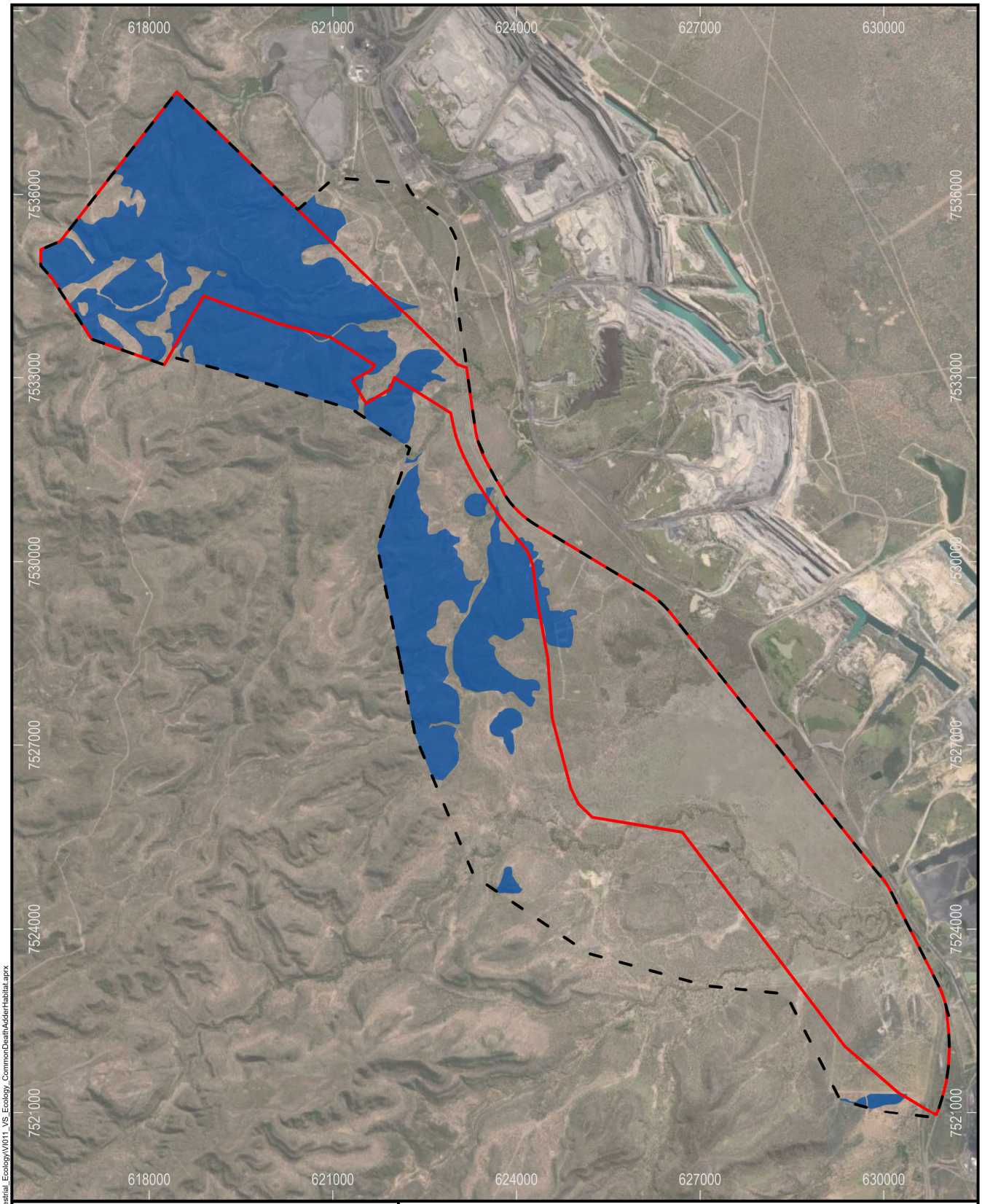
A total of 56 species of non-native plants were recorded within the survey area. Of these, the following weeds were most widespread, occurring at 30% or more of sampling sites:

- *Bothriochloa pertusa* (Indian Couch);
- *Sida spinosa* (Spiked Sida);
- *Cenchrus ciliaris* (Buffel Grass);
- *Melinis repens* (Natal Grass);
- *Portulaca pilosa* (Hairy Portulaca);
- *Stylosanthes scabra* (Shrubby Stylo); and
- *Urochloa mosambicensis* (Sabi Grass).

Seven species of weeds present within the survey area are category 3 restricted matters under the *Biosecurity Act 2014*, which prohibits their sale, trade or spread. These restricted weeds are:

- *Cryptostegia grandiflora* (Rubber Vine);
- *Harrisia martinii* (Harrisia Cactus);
- *Hymenachne amplexicaulis* (Olive Hymenachne);
- *Jatropha gossypiifolia* (Bellyache Bush);
- *Opuntia stricta* (Prickly Pear);
- *Opuntia tomentosa* (Velvet Pear); and
- *Parthenium hysterophorus* (Parthenium).

All of the above, except *H. martini*, are also classed as Weeds of National Significance. While this classification does not introduce additional restrictions, it acts to coordinate management across states.



Legend

- Survey Area
- MLA Area
- Potential Common Death Adder Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_CommonDeathAdderHabitat.aprx

Vulcan South

Potential Habitat for the Common Death Adder

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 4-18

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

The following eight species of non-native animals were recorded within the survey area:

- Feral Cat (*Felis catus*)*;
- Red Fox (*Vulpes vulpes*)*;
- Dingo (*Canis lupus dingo*)*;
- European Rabbit (*Oryctolagus cuniculus*)*;
- House Mouse (*Mus musculus*);
- Feral Pig (*Sus scrofa*)*;
- Cane Toad (*Rhinella marina*); and
- Common Myna (*Acridotheres tristis*).

Species marked with an asterisk are category 3, 4 and 6 restricted matters under the *Biosecurity Act 2014*. The Red Fox, Dingo and European Rabbit are also category 5 restricted matters under the *Biosecurity Act 2014.* Category 3 restricted matters must not be distributed or released, category 4 restricted matters must not be moved, category 5 restricted matters must not be kept, and category 6 restricted matters must not be fed.

5 ECOLOGICAL IMPACTS OF PROPOSED ACTIVITIES

5.1 GENERAL IMPACTS

5.1.1 Clearing

The clearing of vegetation to accommodate the pits, overburden stockpiles and infrastructure is the principal ecological impact of the project. The extent of this impact has been minimised to the greatest extent practicable by:

- utilising in-pit dumping of overburden, to reduce the overall size of the project footprint; and
- the partial use of highwall mining, which produces less waste rock material and disturbs less vegetation than open-cut or other underground methods.

A total of 1,029.7 ha of remnant vegetation (category B regulated vegetation), 61.0 ha of high-value regrowth (category C regulated vegetation) and 665.9 ha of cleared pasture is contained within the project footprint of Vulcan South. The composition of this vegetation is listed in **Table 5-1** and shown in **Figure 5-1**.

Potentially clearing all of this vegetation constitutes the main potential loss of habitat that could result from the project. How this potential habitat loss affects matters of state and national environmental significance is assessed in **Section 5.3**. It is important to note that the project footprint is conservative as it includes both vegetation to be cleared for open-cut mining and associated infrastructure, and vegetation in the highwall mining area. Vegetation above the highwall mining panels (see **Figure 2-2**) is not to be removed, so the clearing footprint of Vulcan South is slightly smaller than the total disturbance footprint.

Table 5-1 Maximum amount of vegetation to be disturbed for Vulcan South

Regional Ecosystem	Description	Maximum amount to be disturbed (includes areas above highwall not cleared) (ha)		Maximum amount to be cleared (excludes highwall footprint) (ha)	
		Field-verified	Regulated Vegetation Map	Field-verified	Regulated Vegetation Map
11.3.2	*Eucalyptus populnea* woodland on alluvial plains.	12.4	25.7	12.4	25.7
11.3.7	*Corymbia* spp. woodland on alluvial terraces.	4.1	0	4.1	0
11.3.25	*Eucalyptus camaldulensis* forest fringing drainage lines.	21.3	6.7	21.3	6.7
11.4.8	*Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* on Cainozoic clay plains.	114.9	121.7	114.9	121.7
11.4.9	*Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains.	1.3	2.3	1.3	2.3
11.5.3	*Eucalyptus populnea* woodland on Cainozoic sand plains and/or remnant surfaces.	20.6	19.7	20.6	19.7
11.5.9	*Eucalyptus crebra* and other *Eucalyptus* spp. and *Corymbia* spp. woodland on Cainozoic sand plains and/or remnant surfaces.	282.9	316.7	282.9	316.7
11.9.2	*Eucalyptus orgadophila* woodland on fine-grained sedimentary rocks.	227.7	226.6	227.7	226.6
11.10.1	*Corymbia citriodora* woodland on coarse-grained sedimentary rocks.	47.9	84.5	33.4	48.6
11.10.1x1	*Corymbia aureola* and *Eucalyptus melanophloia* open	73.8	0	14.5	0

Regional Ecosystem	Description	Maximum amount to be disturbed (includes areas above highwall not cleared) (ha)		Maximum amount to be cleared (excludes highwall footprint) (ha)	
	forest on coarse-grained sedimentary rocks.				
11.10.3	*Acacia shirleyi* open forest on coarse-grained sedimentary rocks. Crests and scarps.	182.3	225.9	71.8	75.0
11.10.7	*Eucalyptus crebra* woodland on coarse-grained sedimentary rocks.	38.1	0	33.0	0
HVR 11.3.2	Regrowth *Eucalyptus populnea* woodland on alluvial plains.	0	1.7	0	1.7
HVR 11.3.25	Regrowth *Eucalyptus camaldulensis* forest fringing drainage lines.	0	0	0	0
HVR 11.10.3	Regrowth *Acacia shirleyi* open forest on coarse-grained sedimentary rocks. Crests and scarps.	30.1	11.4	30.1	11.4
HVR 11.10.7	Regrowth *Eucalyptus crebra* woodland on coarse-grained sedimentary rocks.	5.4	0	5.4	0
HVR 11.4.8	Regrowth *Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* on Cainozoic clay plains.	4.0	0	4.0	0
HVR 11.4.9	Regrowth *Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains.	0	27.5	0	27.5
HVR 11.5.3	Regrowth *Eucalyptus populnea* woodland on Cainozoic sand plains and/or remnant surfaces.	43.6	8.9	43.6	8.9
HVR 11.5.9	Regrowth *Eucalyptus crebra* and other *Eucalyptus* spp. and *Corymbia* spp. woodland on Cainozoic sand plains and/or remnant surfaces.	3.8	1.5	3.8	1.5
Non-remnant	Cleared pasture, +/- scattered trees or young regrowth	642.4	675.9	642.4	673.2
Total project footprint		1,756.7	1,756.7	1,567.2	1,567.2

618000 621000 624000 627000 630000

7539000 7536000 7533000 7530000 7527000 7524000 7521000

Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area

Field-verified RE mapping

- 11.10.1
- 11.10.1x1
- 11.10.3
- 11.10.7
- 11.10.7/11.5.9
- 11.10.8
- 11.3.1
- 11.3.2
- 11.3.2/11.3.7
- 11.3.25
- 11.3.27c
- 11.3.27e
- 11.3.7
- 11.3.7/11.3.2
- 11.4.8
- 11.4.9
- 11.5.3
- 11.5.9
- 11.5.9/11.10.13
- 11.9.2
- HVR 11.10.13
- HVR 11.10.3
- HVR 11.10.7
- HVR 11.10.7/11.10.3
- HVR 11.3.2
- HVR 11.3.25
- HVR 11.4.8
- HVR 11.5.3
- HVR 11.5.3/11.3.2
- HVR 11.5.9

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\V011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\V011_VS_Ecology_FV_RegionalEcosystems.aprx

Vulcan South

Project Footprint Relative to Field-verified Regional Ecosystems

0 1 2

Kilometers

Scale: 1:60,000 (A3)

16/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

The habitats present within the project's footprint are not unique in a local context. All vegetation to be disturbed is represented by areas of remnant vegetation within the broader survey area (see **Table 4-1** and **Figure 4-3**). However, most of REs 11.9.2 and 11.4.8 (70 % and 90 %, respectively) are to be removed.

Three species were recorded within the disturbance footprint but not elsewhere within the survey area:

- The Australasian Pipit (*Anthus novaeseelandiae*) was recorded in open, treeless pastures at fauna site S3 and nearby targeted search locations. These areas will be lost to accommodate the Vulcan Middle pit. Wooded habitats elsewhere within the survey area are largely unsuitable for this bird. Any impacts to the Australasian Pipit will be short term, as this species is one of the fastest colonisers of newly rehabilitated mines in Australia (Gould and Mackey 2015).
- The Yellow-faced Whipsnake (*Demansia psammophis*) was only recorded at two survey locations (S2 and S17), both of which happen to be located within the proposed disturbance footprint. This species has low detectability and is likely to be far more widespread than records indicate. Most wooded habitats within the survey area are likely to be suitable for this snake, and no long-term impacts of Vulcan South are anticipated.
- The Glossy Black-cockatoo (*Calyptorhynchus lathami*) was recorded on a single occasion within the proposed disturbance footprint. Habitat for this species is limited in extent locally and most of the habitat contained within the survey area will be removed for Vulcan South. The impact of this clearing is assessed in **Section 5.3.4.2.**

No locally unique ecological values will be disturbed by the proposed clearing of regrowth and already-cleared pastures.

5.1.2 Habitat Fragmentation

The project is located immediately south and west of existing mines (Peak Downs Mine and Vulcan Coal Mine), which already interrupts west-east movement of wildlife. There is a narrow strip of vegetation between the proposed disturbance footprint and Peak Downs Mine. Any fauna inhabiting this strip could potentially be prevented from dispersing westwards by the proposed open-cut pits. These barriers are only temporary, with the Vulcan North and Vulcan South pits only operationing for three years each, and the Vulcan Main pit operationing for nine years. Once mining is complete in each pit, they are to be refilled with waste rock material and rehabilitated. It is expected that most poorly dispersing terrestrial fauna (e.g., reptiles, frogs) will be able to cross these temporary barriers within 2-3 years after rehabilitation (once a cover of grass and young woody vegetation has established). Fauna dependent on closely spaced trees for dispersal (e.g., Central Greater Gliders) will be affected by the dispersal barriers for far longer (i.e., decades). However, most vegetation between Vulcan South and Peak Downs Mine (within the newly isolated strip) is young regrowth (based on regional ecosystem mapping), and Central Greater Gliders are unlikely to be present there due to an absence of hollow trees in such vegetation.

Overall, habitat fragmentation resulting from Vulcan South will have a relatively limited impact on local wildlife, on account of the limited duration of isolation and the low quality of the isolated habitat.

5.1.3 Subsidence

Highwall mining removes approximately half the target coal seam (average thickness of 1.1 m), leaving regular pillars for structural support. The panels are designed to maintain stability of the overlying strata, such that no subsidence is anticipated. In the unlikely event subsidence was to occur, this would be very limited in scale (less than 1.1 m drop), given the thin seams being removed.

The most important impact of subsidence on vegetation is through changes to surface water runoff patterns and infiltration (Vishwakarma *et al.* 2020). Cracking increases water infiltration and hydrologic associations between aquifers (Vishwakarma *et al.* 2020). However, the vegetation growing

above the proposed highwall panels is on the crest of an already well-drained sandstone ridge. Furthermore, no groundwater occurs within the coal seams or in overlying strata, such that any cracking will not affect groundwater flow.

The minimum depth of the cover above the coal seam is 12 m, which is deeper than almost all tree roots (see **Section 4.1.3.1**). Furthermore, groundwater is too deep to be utilised by vegetation, and highwall mining will hence not damage tap roots accessing groundwater.

Overall, highwall mining is not expected to affect the health of vegetation growing above the panels. The inclusion of these panels within the disturbance footprint is highly conservative.

5.1.4 Removal of Dams

Two stock dams are located within the proposed disturbance footprint, and these will be removed to accommodate the Vulcan Main and Vulcan South pits. These dams provide a water source for Squatter Pigeons and other wildlife. They also provide potential habitat for water birds, frogs and frog-eating snakes. The quality of this habitat for aquatic fauna is low, as each dam's edges are heavily grazed and there is little vegetative cover present at the water's edge. Nevertheless, listed species such as Ornamental Snakes, Sharp-tailed Sandpipers, Gull-billed Terns, Latham's Snipe and Glossy Ibis may occasionally visit these habitats.

Vulcan South will not only remove some existing water sources for wildlife, but will also introduce some new ones, in the form of mine water dams and sediment ponds. As these will not be grazed while in use, they are expected to develop vegetation around their edges, providing potentially superior habitat for aquatic wildlife than the dams being removed. Furthermore, mine dams are proposed to be retained in the final landform, for use as stock dams.

While the net impact of dam removal is expected to be low, this varies between species, and is a consideration within **Section 5.3**, which assesses the residual impacts on each protected matter individually.

5.1.5 Edge Effects

Forest edges are associated with altered microclimate, invasion of weeds and disturbance to wildlife. In the southern half of the project area, edge effects should not increase, as most of it contains a patchy mosaic of remnant, regrowth, cleared areas and roads with a high total edge length. However, parts of the northern half of the project area may increase in edge effects, due to the establishment of a highwall mining haul road through it (See **Figure 2-2**), which could lead to the invasion of weeds. However, there is already an existing track within the project footprint that will be widened to accommodate haul trucks, so additional edge effects are likely to be minimal, if any. Furthermore, the infertile sandstone-derived soil in this area is relatively resistant to weed invasion, with very few weeds recorded at drill pads on this soil type.

The potential increase in weeds is discussed further in **Section 5.1.13.** Other potential edge effects (altered microclimate, disturbance to wildlife) would be short-term; the life of the highwall mining trial is 9-12 months, and the haul road is expected to redevelop vegetation cover within five years of rehabilitation commencing.

5.1.6 Direct Mortality

Nocturnal fauna that shelter during the day (when clearing is undertaken) in hollow trees and under rocks and fallen timber are susceptible to injury or death during the clearing process. Risk of direct mortality is highest for remnant vegetation to be cleared, due to the presence of hollow trees.

5.1.7 Vehicle Collisions

Vulcan South will not introduce any new major roads to the region. Vulcan South will, however, increase road traffic on existing roads, and rail traffic on existing tracks, which could slightly increase the risk of collisions with wildlife crossing roads and/or tracks. The daily commute of workers to/from accommodation in Moranbah and Dysart and the freight of construction materials will increase traffic

on roads by up to 2.8% above baseline level during construction (year 1) and up to 1.2% above baseline conditions in later years (Stantec 2022).

Increases in rail traffic for coal transportation are expected to be nil during the construction phase and insignificant during the operational phase of Vulcan South. The project is located in close proximity to other, much larger, existing coal mining operations currently transporting coal by rail to export terminals on the same line. Considering these much larger operations already utilising the rail tracks, it is expected that any impacts of Vulcan South due to rail transport will be negligible. Impacts of increased traffic (road and rail) will be limited to the life of the mine (nine years). Outside this period, no increases in total traffic over baseline levels are expected.

The establishment of a highwall mining haul road within the northern half of the project footprint will introduce road traffic to habitat that is currently >1 km from a road. This could slightly increase the risk of collisions with wildlife crossing roads. Haul trucks will transport coal from the highwall mining area along this road to the CHPP for 9-12 months, 24 hours per day, at approximately four trucks per hour. Impacts of haulage along this road will be short-term, limited to the highwall mining trial (9-12 months).

5.1.8 Dust

Dust can impact nearby vegetation by blocking photosynthesis and increasing leaf temperature; both impacts can reduce drought tolerance (Farmer 1993). Dust that is severe enough to inhibit plant growth is only likely where vegetation is close to (within 100 m of) the source (roads, operational areas).

Greater Gliders and Koalas both feed on new plant growth. Its possible dust could reduce food availability for these species. However, such effects would only occur close to highly disturbed areas, which these species will most likely avoid for other reasons (noise, light). Therefore, no effects from dust on these species are anticipated.

Any potential effects of dust are expected to be short-term (maximum of nine years), as any effects will cease immediately upon cessation of the adjacent operations.

No threatened plant species are located within the vicinity of Vulcan South. No threatened ecological communities or regional ecosystems occur within 500 m of operational areas that could act as a source of dust.

5.1.9 Groundwater Drawdown

Open-cut mining can lead to the drawdown of groundwater, potentially harming groundwater-dependent ecosystems. Groundwater modelling of the survey area suggests that any drawdown is highly localised and unlikely to affect groundwater-dependent ecosystems. The highwall mining panels do not intercept groundwater and this will have no impact on groundwater-dependent ecosystems. For further details, refer to **Section 5.3.2.**

5.1.10 Noise and Vibration

Noise from traffic and industrial sources can have significant detrimental impacts on fauna (Shannon *et al.* 2016; Cunnington and Fahrig 2010; Barber *et al.* 2010). Vulcan South is located on a busy highway (Saraji Road), immediately west of a large mining operation. The increase in noise resulting from the project is expected to be negligible relative to existing background noise. Nevertheless, there may be localised disturbance from noise where operational areas are close to (e.g., within 200 m of) habitats for threatened fauna (e.g., Greater Gliders, Koalas).

5.1.11 Artificial Lighting

The project will operate 24 hours per day, which will require flood-lighting around operational areas. Artificial lighting can impact fauna through interfering with the navigation of nocturnal species (Howell *et al.* 1954; Salmon *et al.* 1995; Poot *et al.* 2008; Longcore *et al.* 2012), interrupting natural patterns of sleep and cell repair (Ben-Shlomo and Kyriacou 2010), exposing nocturnal prey to elevated

predation risks (Baker and Richardson 2006; Rotics *et al*. 2011; Davies *et al*. 2012), disturbing the timing of daily activities (Miller 2006; Kempenaers *et al*. 2010), and leading to long-term declines in insect populations (Conrad *et al*. 2006). Artificial lighting may also interfere with photosynthesis (Roman *et al*. 2000) and flower development in plants (Wang *et al*. 2003). Vulcan South is located immediately west of a large and strongly lit mining operation. Considering these background light levels, it is expected that any impacts of the project due to lighting will be small and highly localised (to within 500 m of operational areas). Impacts of lighting will be short-term, as most operational sites have a limited age (9-12 months for the highwall areas, 3 years for the Vulcan North and Vulcan South pits, and 9 years for the Vulcan Main pit).

5.1.12 Waste

Waste produced by mining operations (e.g., runoff from stockpiles) can have long-term detrimental effects on the surrounding ecology if allowed to enter waterways. All waste rock on site is chemically benign, and not expected to cause acid or metalliferous drainage. Sediment-collecting infrastructure has been incorporated into the project's design, and no downstream impacts are anticipated. Appropriate storage and disposal of food waste generated by mine workers will prevent feral animals (Black Rats, Feral Cats, Red Foxes) being attracted, which would otherwise indirectly impact threatened wildlife.

5.1.13 Weeds and Pest Animals

Land disturbance and the movement of soils, vehicles and people between areas can promote weed invasion. The risk that Vulcan South could encourage invasion by the seven restricted weeds recorded on site (see **Section 4.5**) is assessed in **Table 5-2**. Controls must be in place to manage the risks posed by Rubber Vine, Harrisia Cactus, Prickly Pear, Velvet Pear and Parthenium in order for Vulcan South to avoid being in violation of the *Biosecurity Act 2014.* While there are no legal obligations to manage non-declared weeds on site, the potential for these to spread and reduce habitat quality for threatened fauna must be considered when assessing the significance of impacts to individual matters. Non-native plants such as Buffel Grass, Indian Couch, Sabi Grass and Natal Grass are already abundant and widespread on site, and have likely already reached the limits of their potential local distribution (limited by soil type and moisture availability).

The project will have negligible effects on pest animal populations. There will be a temporary cessation of current pig- and dingo-hunting in the vicinity of the project during operations. However, this is countered by the deterring effects of lights, noise and vegetation clearance associated with operations. The vast majority of the project footprint already supports high densities of Cane Toads. The removal of existing toad-breeding locations (farm dams) will be counteracted by the construction of other locations (sediment dams, water supply dams), such that Cane Toad densities are expected to remain high throughout the project area.

Table 5-2 Inherent Risk (without controls) that the project could spread restricted weeds

Species	Inherent Risk	Justification
Cryptostegia grandiflora (Rubber Vine)	Moderate	Rubber Vine was confined to creek banks within the project footprint (i.e., Middle and Boomerang Creeks). If not controlled prior to soil disturbance, seeds may be spread to new areas (e.g., soil stockpiles, tracks).
Harrisia martinii (Harrisia Cactus)	High	While not in high density, this cactus was recorded in numerous locations within the project footprint. As it can spread via stem fragments, new infestations could establish in soil stockpiles.
Hymenachne amplexicaulis (Olive Hymenachne)	Low	Olive Hymenachne is an aquatic weed recorded 1.7 km west of the project footprint. Suitable habitat for the species is present within the project footprint.
Jatropha gossypiifolia (Bellyache Bush)	Low	A small infestation (<10 plants) of this weed located 1 km east of the project was the only record of the species across the entire survey area.
Opuntia stricta (Prickly Pear)	Moderate	This cactus was only recorded once within the entire survey area, within the project footprint. If not controlled prior to soil disturbance, fragments may be spread to new areas (e.g., soil stockpiles, tracks).
Opuntia tomentosa (Velvet Pear)	High	This cactus occurred widely, in low densities, across most of the survey area, including within the project footprint. As it can spread via stem fragments, there is a risk that new infestations could establish in soil stockpiles.
Parthenium hysterophorus (Parthenium)	High	Parthenium was abundant on clay soils and alluvial areas (sites with moisture-retentive soil) within the project footprint. If not controlled prior to soil disturbance, seeds may be spread to new areas (e.g., soil stockpiles, tracks).

5.1.14 Cumulative Impacts

Vulcan South adjoins several existing coal mining operations (Peak Downs Mine, Saraji Mine, Vulcan Coal Mine). Environmental impacts of these operations are expected to be additive rather than cumulative or synergistic. Vulcan South will not cause the extent of habitat for any species or ecological community to fall below a threshold at which local populations are likely to become inviable. As the impacts of existing projects have been assessed previously, only the impacts of Vulcan South are assessed.

5.1.15 Summary

The clearance of 1,029.7 ha of remnant vegetation and 61.0 ha of regrowth vegetation will be the principal impact of Vulcan South on ecological matters. Direct mortality, vehicle collisions, artificial lighting and weeds are additional risks that require management.

5.2 RECOMMENDED MITIGATION MEASURES

As part of a site-specific application for a new environmental authority for a resource activity, supporting information must include “strategies for avoiding, mitigating or managing the predicted impacts on the environmental values”. A list of recommended measures for reducing each of the impacts listed in **Section 5.1** is shown in **Table 5-3**.

Table 5-3 Recommended impact mitigation measures

Potential Impact	Recommended mitigation measures
Clearing	1) Vitrinite employees and contractors are to be made aware of environmental obligations and compliance requirements through a site induction program. 2) The edges of the project footprint, and the highwall mining area within it, are to be marked out to prevent unnecessary accidental clearing of the highwall mining area and neighbouring habitats. 3) Overburden is to be mostly returned to the mined pits, to limit the total disturbance footprint of the project. 4) Topsoil removed from each site in preparation for mining is to be stored and managed in accordance with a Progressive Rehabilitation and Closure Plan, to protect a favourable growing medium for vegetation post-mining. 5) Post-mine rehabilitation should aim for a post-mine land use with similar environmental values to those being lost (see the Progressive Rehabilitation and Closure Plan).
Habitat fragmentation	1) Each of the mine pits is to be developed sequentially, so that Vulcan North pit will be rehabilitated prior to Vulcan South pit being developed. This will maintain dispersal corridors for east-west movement through the project area throughout the duration of operations.
Removal of a dam	1) Some mine dams will be retained in the final landform to replace water sources lost due to construction of the open-cut pits.
Edge effects (invasion of weeds)	1) All vehicles that will enter undisturbed parts of the site are to be washed and certified prior to arrival at the project site, to restrict the introduction of new weeds. Weed management activities are to control weeds in high traffic areas. 2) Light vehicles used for commuting between the project area and nearby towns (where they may be exposed to weeds) are to be parked in the visitor carpark. 3) Operational areas and the visitor carpark are to be inspected regularly (at least biannually) to identify new infestations of restricted weeds. These should be treated soon after detection, with follow-up treatment required until populations are eradicated.
Direct mortality	1) Clearing should occur in stages, to allow fauna the opportunity to exit the area. 2) Injured fauna is to be taken to the nearest wildlife carer or veterinarian. 3) Any injury and/or mortality is to be communicated to the Department of Environment and Science within 24 hours. 4) Vitrinite employees and contractors will be made aware of environmental obligations and compliance requirements through the site induction program.
Vehicle collisions	1) Buses are to transport ~80% of workers daily from accommodation to site, to reduce the total number of vehicles using the roads. 2) Trains used to transport coal are to be of the largest size safely driven on the relevant tracks, to reduce the total number of trips required. 3) Haul trucks used to transport coal from the highwall mining area to the CHPP (on site) are to be of the largest size safely driven on the relevant road, to reduce the total number of trips required. 4) On-site speed limits are to be restricted to 60 km/h on all roads through or adjacent to habitat critical to the survival of the koala during dawn and dusk and at night (Department of the Environment 2014). 5) Road signage along the highwall mining haul road is to be installed to alert drivers of koala crossings.
Dust	1) Mitigation measures for managing dust are described elsewhere in the Air Quality Assessment Report. No threatened plant species are located within close proximity to dust-generating operations, and any dust management measures in place for human health will be sufficient for managing risks of dust to environmental values.
Groundwater drawdown	Not applicable.
Noise and vibration	1) Mitigation measures for managing noise and vibration are described elsewhere in the Noise Assessment Report.

Potential Impact	Recommended mitigation measures
Artificial lighting	1) The following lighting designs should be used, where appropriate, in operational areas within 500 m of remnant vegetation: i. Artificial lighting used in operational areas is to be angled away from habitats supporting sensitive species (e.g., riparian areas supporting Koalas and Greater Gliders). ii. Floodlights with "low glare" louvres/attachments are recommended to limit lateral transmission of light. Note that newer LED-type flood lights may have glare-reduction technology built-in. iii. Any street lights used are recommended to be of the "aeroscreen" type (flat glass lenses), to reduce sideways glare. iv. Light fittings should be positioned as close to horizontally as possible.
Waste	1) Food wastes are to be stored in sealed containers and disposed off-site. 2) Mitigation measures for managing mine-affected water are described elsewhere in the Surface Water Assessment Report.
Weeds and pest animals	4) Putrescible waste is to be stored in animal-proof containers and removed from site. 5) All vehicles that will enter undisturbed parts of the site are to be washed and certified prior to arrival at the project site, to restrict the introduction of new weeds. Weed management activities will control weeds in high traffic areas. 6) Light vehicles used for commuting between the project area and nearby towns (where they may be exposed to weeds) are to be parked in the visitor carpark. 7) Operational areas and the visitor carpark are to be inspected regularly (at least biannually) to identify new infestations of restricted weeds. These should be treated soon after detection, with follow-up treatment required until populations are eradicated. 8) Any weeds germinating on topsoil stockpiles should be treated and eradicated to maintain a source of weed-free growing medium for use post-mining. 9) Only native species, or species with low weed risk, are to be included within seed mixes applied to rehabilitated sites.
Cumulative impacts	Not applicable.

5.3 RESIDUAL IMPACTS ON PROTECTED MATTERS

5.3.1 Regulated Vegetation

As it is a resource activity under the *Environmental Protection Act 1994,* section 107, Vulcan South represents exempt clearing work under the *Vegetation Management Act 1999*. Nevertheless, disturbance to some vegetation classed as a matter of state environmental significance may be subject to offsets. The vegetation to be disturbed for Vulcan South is listed in **Table 5-4**.

Table 5-4 Regulated vegetation to be disturbed by Vulcan South

Regulated Vegetation Category	Description	Area to be disturbed (ha)	Total area within survey area (ha)
A	**Declared area, offset area or other protected vegetation*†**	0	0
B	**Remnant vegetation: Endangered*†**	124.0	153.0
	Remnant vegetation: Of Concern*†	25.7	180.1
	Remnant vegetation: Least Concern	880.1	4,319.8
C	**High-value regrowth: Endangered***	27.5	32.3
	High-value regrowth: Of Concern*	1.7	9.3
	High-value regrowth: Least Concern	21.8	375.6

Regulated Vegetation Category	Description	Area to be disturbed (ha)	Total area within survey area (ha)
R	**Non-remnant vegetation within 50 m of a watercourse***	10.1	54.7
X	Already-cleared areas or other exempt areas not regulated by vegetation management laws	665.9	1,857.6
Total		1,756.7	6,982.4

*Vegetation categories in bold are classed as matters of state environmental significance

†Subset of matters of state environmental significance that are "prescribed matters" requiring offsets (Department of Enrivonment and Science 2020)

While the above vegetation categories not shown in bold do not individually constitute matters of state environmental significance, most are classed as significant if they occur "within a defined distance from the defining banks of a relevant watercourse" or "within 100 metres of the defining bank of a wetland identified on the vegetation management wetlands map". Vegetation categories occurring within a defined distance from the defining banks of a relevant watercourse that will be disturbed for Vulcan South are listed in **Table 5-5**. No vegetation within 100 metres of the defining bank of a wetland identified on the vegetation management wetlands map will be disturbed. The wetland identified on the vegetation management wetlands map within the survey area is located well outside of the proposed footprint (1 km) and will not be impacted by Vulcan South.

Table 5-5 Area of each vegetation category contained within a defined distance of the defining banks of relevant watercourses

Regulated Vegetation Category	Description	Area to be disturbed (ha)	Total area within survey area (ha)
A*	Declared area, offset area or other protected vegetation	0	0
B*	Remnant vegetation: Endangered	1.9	1.9
	Remnant vegetation: Of Concern	13.7	69.8
	Remnant vegetation: Least Concern	58.3	373.2
C	High-value regrowth: Endangered	0	0
	High-value regrowth: Of Concern	0.2	1.8
	High-value regrowth: Least Concern	0	23.3
R	Non-remnant vegetation within 50 m of a watercourse	7.1	38.3
Total		**81.1**	**508.4**

*The subset of watercourse vegetation that is subject to offsets

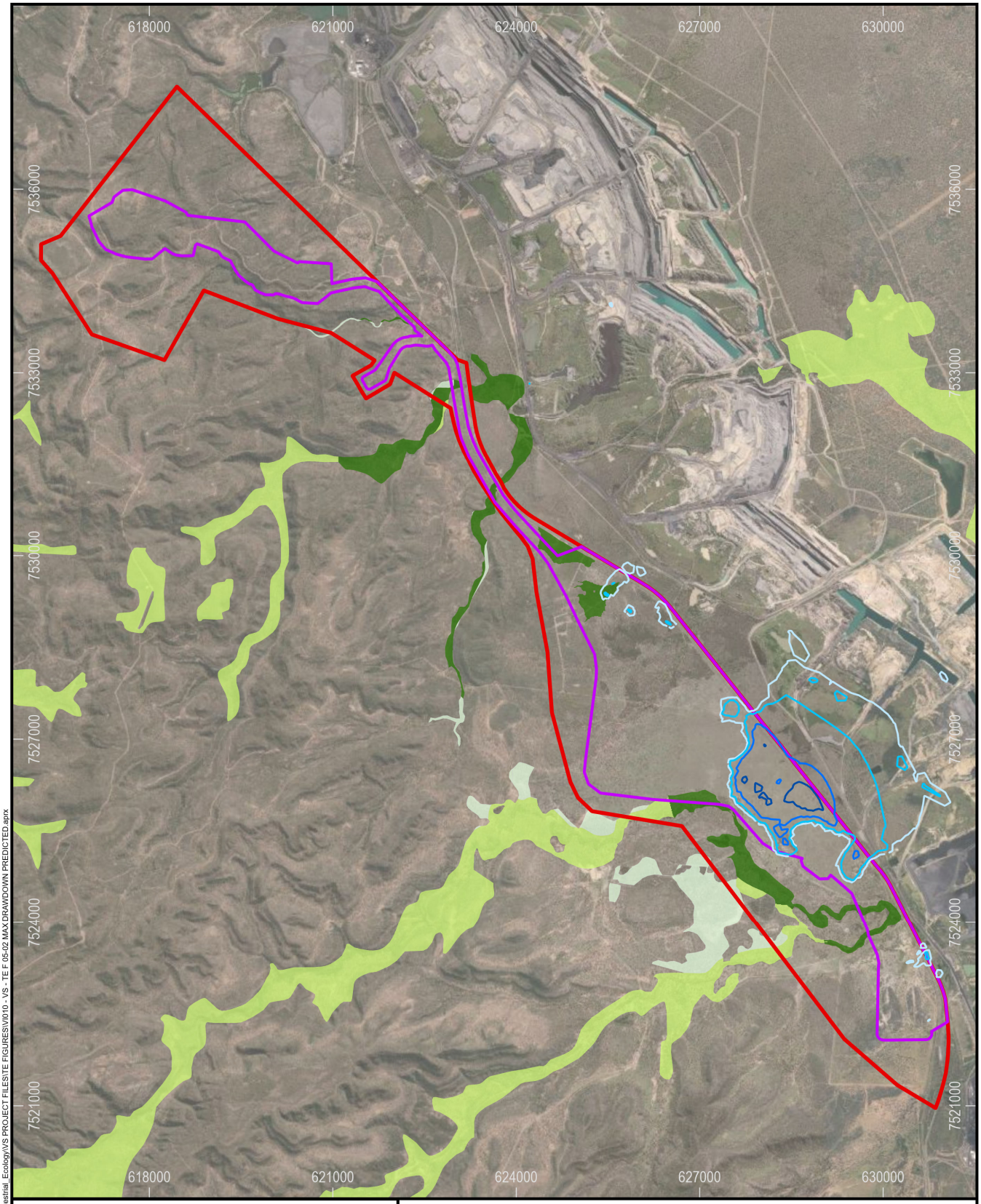
Overall, the regulated vegetation that is a matter of state environmental significance to be disturbed by Vulcan South is 152.1 ha of endangered or of concern category B vegetation, 29.2 ha of endangered or of concern category C vegetation, 10.1 ha of category R vegetation, and 81.1 ha of category B, C or R areas on the regulated vegetation management map that are located within a defined distance from the defining banks of a relevant watercourse.

5.3.2 Groundwater-dependent Ecosystems

Hydrogeologist.com.au (2022) has developed a numerical groundwater flow model of the survey area and broader region to predict the effects of Vulcan South on local groundwater levels. Groundwater flow into the Vulcan South and Vulcan North pits will be negligible, and these pits will be essentially dry. Groundwater flow into the Vulcan Main pit will be up to 43 m^3/day, which will cause localised drawdown in surrounding aquifers. The drawdown predicted from the groundwater flowing into the pits at Vulcan South is limited in geographic extent (up to 2,400 m to the east of the pits toward existing mining) and magnitude (up to 10 m). As the pits will be back-filled, no residual drawdown is expected following the cessation of the project. No remnant vegetation outside the project's clearing footprint is found within the zone of drawdown. Furthermore, any non-remnant vegetation within this zone is highly disturbed by existing mining operations associated with the Peak Downs Mine (**Figure 5-2**).

The groundwater quality is unlikely to be significantly altered by Vulcan South and, in any case, all local potentially groundwater-dependent ecosystems occur upgradient (in terms of the groundwater flow, which mimics the surface water drainage pattern from west to east) of potential effects.

In summary, no impacts to GDEs are predicted to result from Vulcan South, beyond that which will occur due to vegetation clearing.



Legend

- VS Maximum Disturbance
- MLA Area

Groundwater Dependent Ecosystems

- High potential GDE
- Moderate potential GDE
- Low potential GDE

Predicted Drawdown (m)

- 1m
- 2m
- 5m
- 10m

Source: Bureau of Meteorology 2012, Hydrogeologist.com.au 2020, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Maximum Drawdown of Groundwater Predicted

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

8/06/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-2

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VS PROJECT FILES\TE FIGURES\VI010 - VS - TE F 05-02 MAX DRAWDOWN PREDICTED.aprx

5.3.3 Matters of National Environmental Significance

An action that has, will have or is likely to have a significant impact on one or more matters of national environmental significance must be referred and assessed under the EPBC Act. As discussed in detail below, significant residual impacts of Vulcan South are anticipated for one threatened ecological community (Brigalow) and three threatened species (Squatter Pigeon, Koala and Central Greater Glider). A referral is therefore recommended.

5.3.3.1 Brigalow Threatened Ecological Community

Field-verified vegetation mapping reveals that a total of 120.3 ha of the threatened ecological community listed as "Brigalow (*Acacia harpophylla* dominant and co-dominant)" is to be cleared to accommodate the proposed mine and infrastructure (**Figure 5-3**). Of these, 116.3 ha constitute remnant vegetation and the remainder is regrowth that meets the criteria of being older than 15 years, in accordance with the definition of the community within the approved conservation advice (Department of the Environment 2013b).

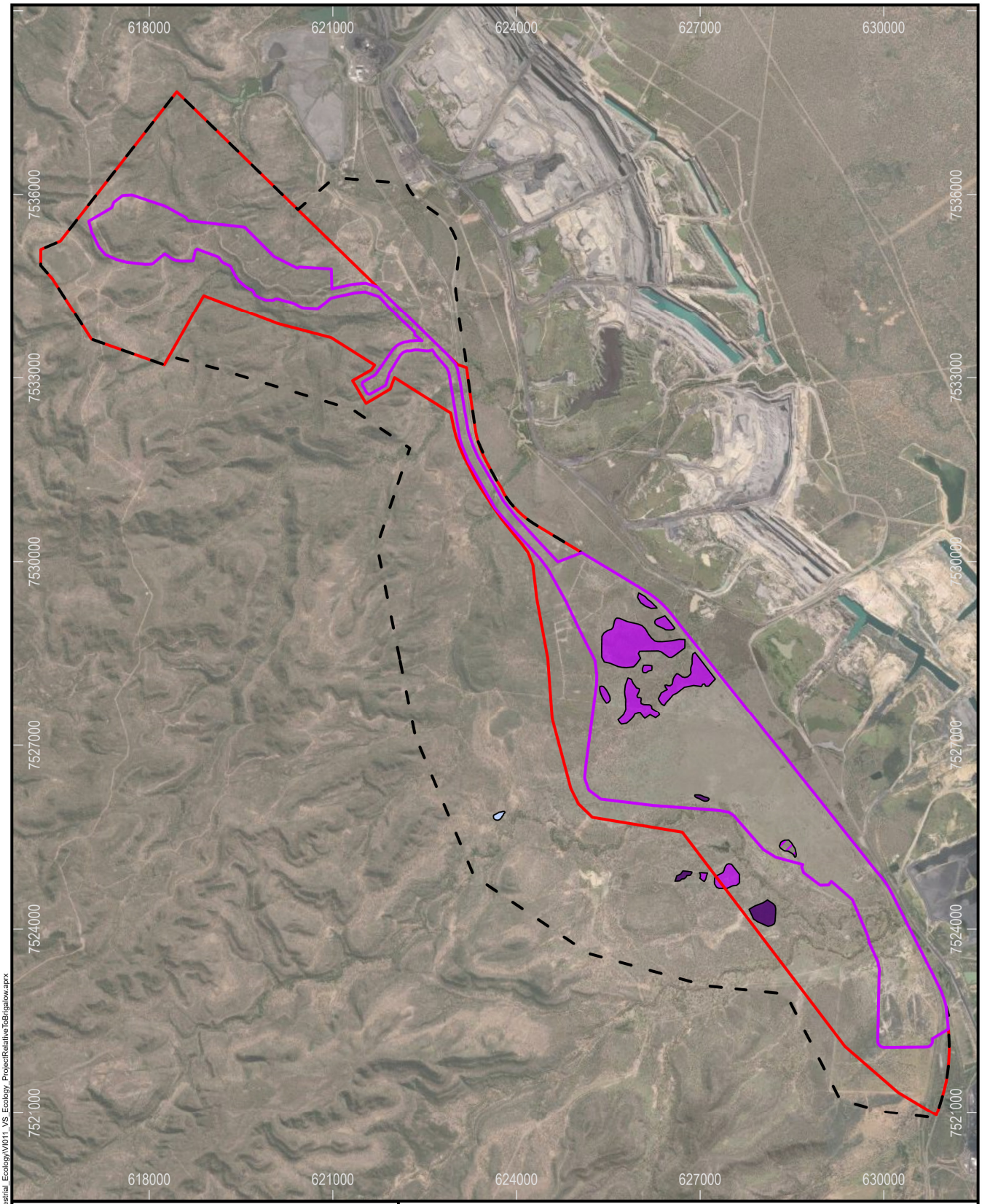
Note that this amount is less than what is indicated by the regulated vegetation map, which includes additional remnant regional ecosystems 11.4.8 and 11.4.9 (constituents of the Brigalow threatened ecological community) over the already-cleared Saraji Road and Norwich Park Branch Railway, along with a patch of regrowth 11.4.9 (which field surveys indicate does not exist) in the vicinity of the Vulcan Main pit.

There is no Brigalow (*Acacia harpophylla* dominant and co-dominant) located within 500 m of the project's footprint boundary. Therefore, no effects of dust and weeds on Brigalow outside the project footprint are anticipated.

According to the *Matters of National Environmental Significance Significant Impact Guidelines 1.1* (Department of the Environment 2013a), an action is likely to have a significant impact on a critically endangered or endangered ecological community if there is a real chance or possibility that it will:

- reduce the extent of an ecological community
- fragment or increase fragmentation of an ecological community, for example by clearing vegetation for roads or transmission lines
- adversely affect habitat critical to the survival of an ecological community
- modify or destroy abiotic (non-living) factors (such as water, nutrients, or soil) necessary for an ecological community's survival, including reduction of groundwater levels, or substantial alteration of surface water drainage patterns
- cause a substantial change in the species composition of an occurrence of an ecological community, including causing a decline or loss of functionally important species, for example through regular burning or flora or fauna harvesting
- cause a substantial reduction in the quality or integrity of an occurrence of an ecological community, including, but not limited to:
  - assisting invasive species, that are harmful to the listed ecological community, to become established, or
  - causing regular mobilisation of fertilisers, herbicides or other chemicals or pollutants into the ecological community that kill or inhibit the growth of species in the ecological community, or
- interfere with the recovery of an ecological community.

Based on the criterion that the extent of the ecological community will be reduced by Vulcan South, the residual impacts to the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community qualify as significant.



Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area

Brigalow

- 11.3.1
- 11.4.8
- 11.4.9
- HVR 11.4.8

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_ProjectRelativeToBrigalow.aprx

Vulcan South

Project Footprint Relative to Brigalow

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

2/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-3

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

5.3.3.2 Squatter Pigeon

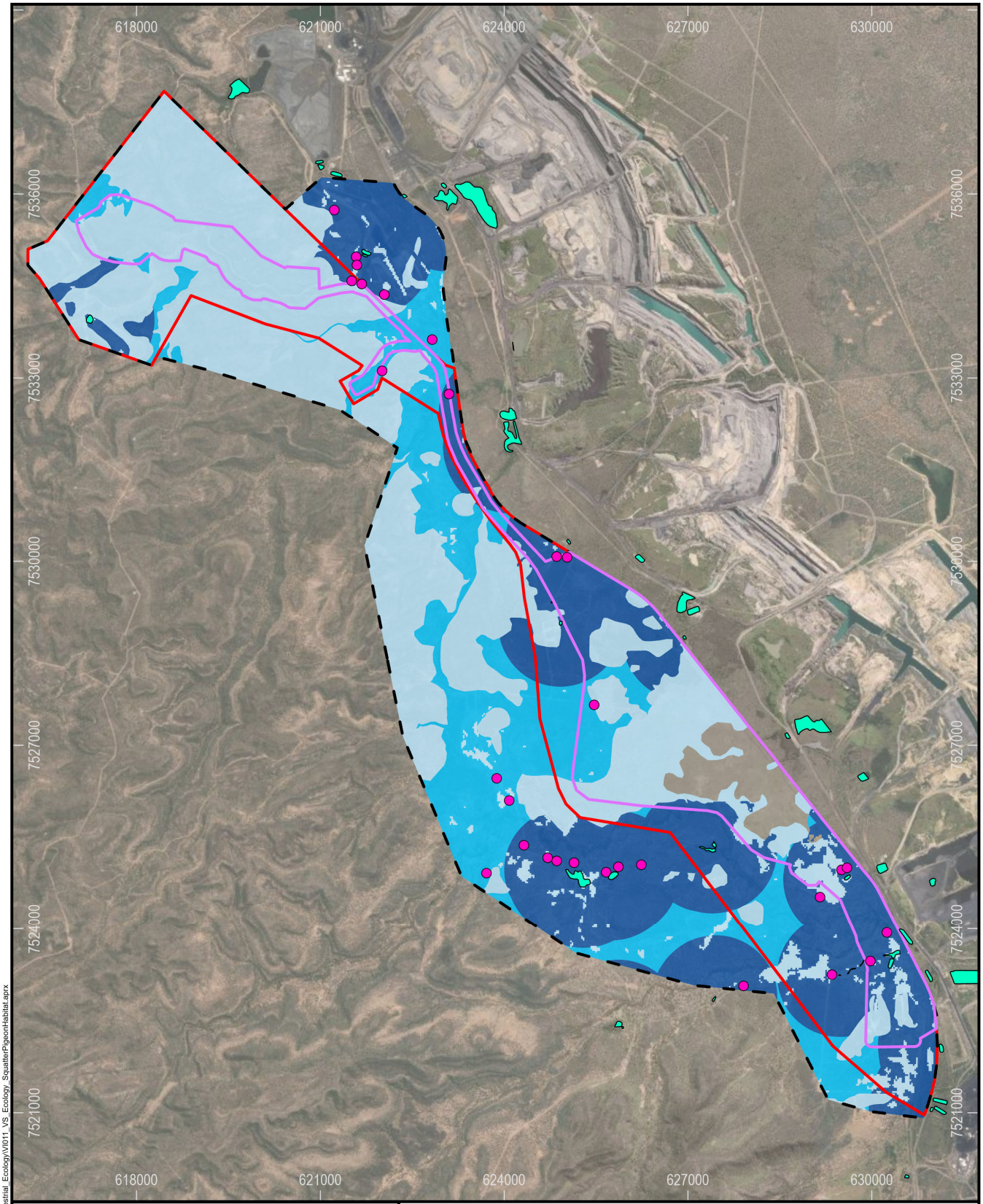
A total of 676.3 ha of foraging habitat (of which 512.2 ha is also breeding habitat) and 877.2 ha of dispersal habitat are contained within the proposed disturbance footprint of Vulcan South (**Figure 5-4**). However, not all of these will be cleared (184.3 ha of dispersal habitat and 5.1 ha of foraging habitat overlies the highwall mining panels and are unlikely to be affected).

Furthermore, two sources of water (dams) used by Squatter Pigeons will be removed for Vulcan South. The removal of these water sources has the potential to reduce the local extent of breeding habitat beyond the boundaries of the disturbance footprint, as breeding habitat is defined by distance to water. However, the addition of new water sources (sediment dams, mine water dams, etc) have the potential to offset some or all of these impacts. In order to assess the net effect of water source removal and addition, Squatter Pigeon breeding habitat was recalculated for the survey area outside the disturbance footprint, based on planned water infrastructure. This analysis revealed that the installation of new water sources will more than make up for the removal of former water sources, and the net gain of breeding habitat outside the clearing footprint will be 85.4 ha (i.e., 85.4 ha of foraging habitat is within 1 km of the new water sources, making this appropriate for breeding). By combining the effects of habitat clearance and water source modifications, the total breeding habitat that will be lost due to Vulcan South is expected to be 426.8 ha.

The size of the average home range of a pair of Squatter Pigeons is not known, but the related Partridge Pigeon (*Geophaps smithii*) is thought to occupy a home range of approximately 8 ha (Fraser *et al.* 2003). Assuming Squatter Pigeons are similar—a likely scenario, given their similar biology—the project could impact up to 54 breeding pairs of Squatter Pigeons. This is very likely to be an over-estimate, and occupancy rates of 50% within potential habitat are more consistent with rates of detection in the field. This implies an expected loss of habitat for up to 27 pairs of Squatter Pigeons.

The net loss of habitat constitutes 20 % of the total breeding habitat and 19 % of the total foraging habitat contained within the survey area. An additional 170 ha of breeding habitat was or is approved to be removed for the neighbouring Vulcan Coal Mine. Assuming habitat from the Vulcan Coal Mine is not rehabilitated prior to the commencement of Vulcan South, breeding habitat for 96 pairs will be retained in the local landscape throughout the project (assuming each pair occupies 8 ha and 50% of available territories are occupied). The estimated size of this retained local population is highly conservative, as it does not include contiguous habitat west and south of the survey area. It is more likely that habitat for several hundred pairs will be retained in the local region, supporting a viable population that will serve as a source of recruitment for rehabilitated land post-mining.

The impacts of habitat clearance will persist at least for the short- to medium-term, until vegetation is re-established on mined land. Being a ground-dwelling bird, they are not dependent on old trees, and rehabilitated sites are expected to meet their requirements for a low, protective tree cover within 15 years post-rehabilitation (Ngugi and Neldner 2015). It is unknown whether the relatively simple understorey vegetation communities that typically establish on rehabilitated sites (Grigg *et al.* 2000; Ngugi and Neldner 2015) will meet the ecological needs of Squatter Pigeons. Their readiness to feed on introduced pasture species such as *Urochloa mosambicensis* and *Stylosanthes* spp. (Crome 1976; C. Wiley pers. obs. 2019) suggests that re-establishing appropriate food plants is likely to be achievable. Consequently, it is estimated that the duration of impacts will be approximately 24 years, although this estimate has low confidence, given the lack of data on the dietary requirements of the species.



Legend

- Squatter Pigeon Sightings
- Survey Area
- VS Maximum Disturbance
- MLA Area
- Waterbodies

Squatter Pigeon Habitat

- Breeding and foraging habitat
- Foraging habitat
- Dispersal habitat

Source: Geoscience Australia 2015, Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2019-2022, Earthstar Geographics. Squatter Pigeon habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_SquatterPigeonHabitat.aprx

Vulcan South

Project Footprint Relative to Existing Squatter Pigeon Habitat

0 1.5 3

Kilometers

Scale: 1:90,000 (A4)

21/07/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-4

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

The significance of impacts to MNES is defined by the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*. An action is likely to have a significant impact on a vulnerable species if there is a real chance or possibility that it will:

1) lead to a long-term decrease in the size of an important population of a species;
2) reduce the area of occupancy of an important population;
3) fragment an existing important population into two or more populations;
4) adversely affect habitat critical to the survival of a species;
5) disrupt the breeding cycle of an important population;
6) modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline;
7) result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat;
8) introduce disease that may cause the species to decline; or
9) interfere substantially with the recovery of the species.

As Vulcan South lies north of the Carnarvon Ranges, the local population of Squatter Pigeons does not qualify as an "important population" according to the Department of Climate Change, Energy, the Environment and Water (2022b), and hence criteria 1, 2, 3 and 5 are not relevant. The scale of habitat loss, relative to the large extent of habitat remaining in the local landscape, means that the project is not likely to jeopardise the viability of local populations (criterion 9 is not triggered).

Nevertheless, this local population is expected to temporarily decline by approximately 132 individuals, which may trigger a significant impact under the sixth criterion listed above. Also, because habitat used for foraging, breeding, roosting and dispersal (qualifies as "habitat critical to the survival of a species" under the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*) is proposed to be removed, criterion 4 is also triggered by the project.

Vulcan South may also lead to localised increases in some weeds, which qualify as invasive species potentially threatening ground-feeding Squatter Pigeons. Weed introduction could potentially occur during the construction, operation and rehabilitation phases of the project. However, these impacts are not likely to extend far beyond Vulcan South's disturbance footprint. As this impact assessment assumes all habitat within this footprint is to be removed, no additional impacts of weeds are anticipated.

Overall, Vulcan South is likely to have a significant residual impact on the Squatter Pigeon under the EPBC Act due to the expectation that it cause the loss of 426.8 ha of breeding and foraging habitat, 244.4 ha of foraging (but not breeding) habitat and 692.9 ha of dispersal habitat to the extent that the population is likely to decline, albeit to a limited extent and only temporarily.

5.3.3.3 Koala

A total of 1,213 ha of Koala habitat are contained within Vulcan South's proposed disturbance footprint, and 1,023.6 ha of this will be cleared. The remainder lies above the highwall mining panels. Little of this (21.3 ha in the clearing footprint) is high-quality habitat (the habitat type in which most records occurred). Of the remainder, 578.7 ha of the disturbance footprint (559.1 ha of the clearing footprint) is moderate-quality habitat and 613 ha of the disturbance footprint (443.2 ha of the clearing footprint) is low-quality habitat (**Figure 5-5**).

Table 5-6 Koala habitat to be cleared

Habitat Class	Vegetation Unit	Food Trees	Area to be removed (ha)	Area above highwall panels (ha)
High quality	11.3.25	**Primary:** *Eucalyptus camaldulensis* dominant **Secondary:** *Eucalyptus populnea* and/or *Eucalyptus crebra* sometimes subdominant	21.3	0
	11.3.27e	**Primary:** *Eucalyptus camaldulensis* dominant **Secondary:** *Eucalyptus populnea* and/or *Eucalyptus crebra* sometimes subdominant	0	0
Moderate quality	11.3.2	**Primary:** absent **Secondary:** *E. populnea* dominant	12.4	0
	11.3.7	**Primary:** *Eucalyptus camaldulensis* occasionally present **Secondary:** *E. populnea* and/or *E. crebra* sometimes subdominant	4.1	0
	11.5.3	**Primary:** absent **Secondary:** *E. populnea* dominant	20.6	0
	11.5.9	**Primary:** absent **Secondary:** *E. crebra* sometimes dominant, but some variants of this RE lack food trees	282.9	0
	11.9.2	**Primary:** absent **Secondary:** *Eucalyptus orgadophila* dominant	174.4	0
	11.10.1	**Primary:** absent **Secondary:** *E. crebra* sometimes subdominant	33.4	14.5
	11.10.7	**Primary:** absent **Secondary:** *E. crebra* dominant	31.4	5.1
Low quality	11.10.3	**Primary:** absent **Secondary:** *E. crebra* occasionally emergent	71.6	110.5
	11.10.1x1	**Primary:** absent **Secondary:** *E. crebra* rarely present	14.5	59.3
	Non-remnant forms of above units		357.0	0

The impact of clearing will last until mature food trees have re-established in rehabilitated areas post-mining. Re-colonisation of rehabilitated sites after six years has been observed in wetter climates in south-east Queensland (Cristescu *et al.* 2013), but a more conservative estimate of 15 years is adopted here due to the drier climate and slower growth rates expected. As the final blocks of disturbed land can only commence rehabilitation at the cessation of mining activities (nine years after the commencement of the project), the duration of disturbance is estimated to be 24 years. Viable populations of Koalas are expected to be maintained in extensive neighbouring habitats (86.1% of the high-quality habitat within the survey area is being retained, and extensive tracts of moderate-quality habitat occur throughout the adjacent Harrow Range) throughout this disturbance period, providing a source of recruitment to rehabilitated areas in the future. Average Koala densities in the Brigalow Belt are thought to be 0.005 Koalas/ha (Threatened Species Conservation Committee 2012). Given that the Cherwell-Harrow Range spans over 170,000 ha, the remaining koala population is expected to exceed 850 individuals.

The location of the proposed disturbance adjacent to existent mining operations, and the progressive staging of Vulcan South (at no time will all three pits be operational) means that no new barriers to dispersal are anticipated to arise as a result of Vulcan South.

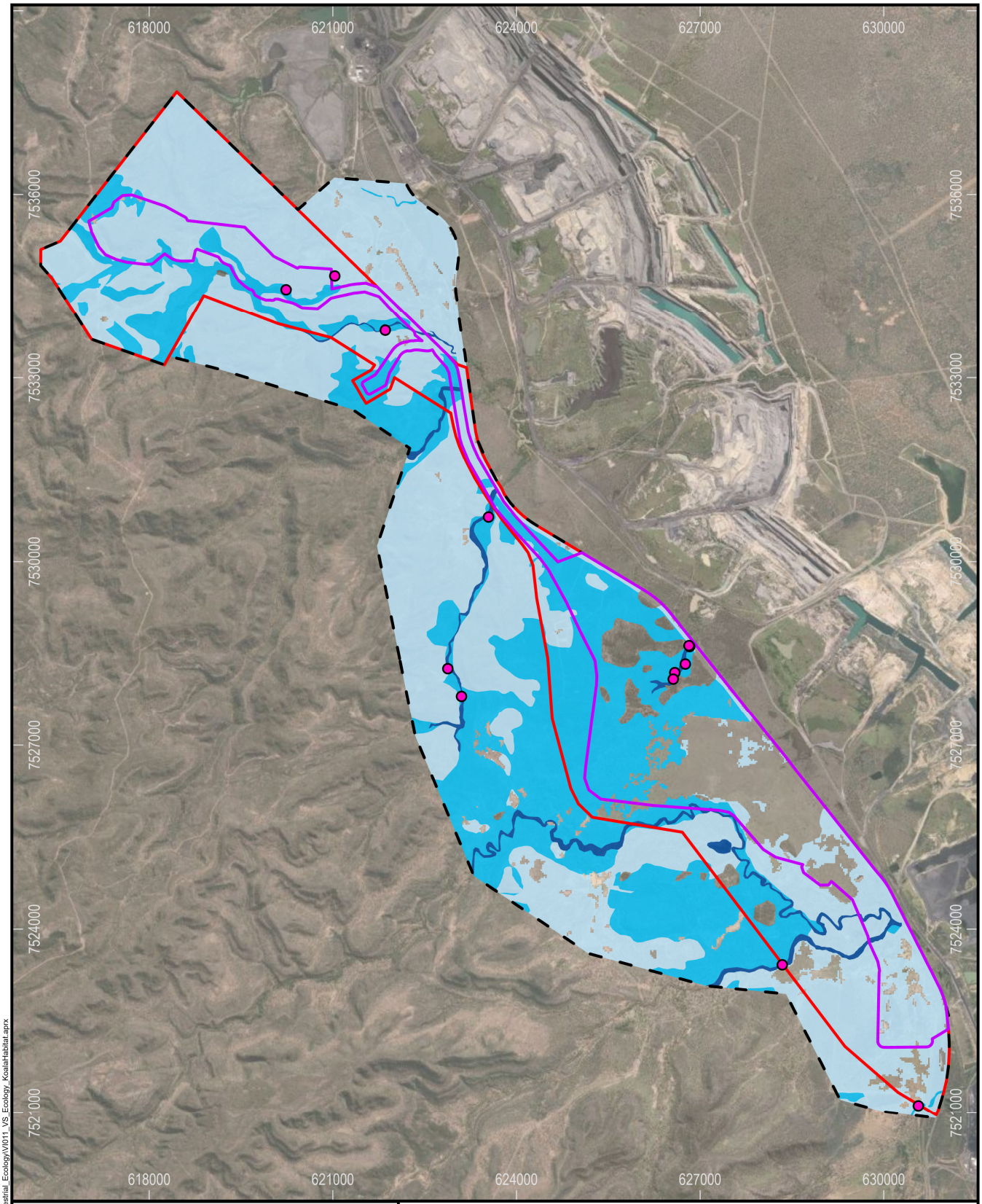
An additional 46.1 ha of high-quality habitat, 499.9 ha of moderate-quality habitat and 1,103.0 ha of low-quality habitat are located within 500 m of the disturbance footprint and therefore may experience some disturbance from lighting, noise and dust. This disturbance is short-term, lasting only for the duration of the adjacent operations (1 to 9 years, depending on location).

Freight of construction materials and daily commute of workers will increase traffic rates on existing roads by up to 2.8 % over baseline levels. This will lead to a negligible increase in risk of vehicles strikes. Due to the short duration and minor magnitude of these impacts, significant long-term impacts on local Koala populations are unlikely.

An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

- lead to a long-term decrease in the size of a population;
- reduce the area of occupancy of the species;
- fragment an existing population into two or more populations;
- adversely affect habitat critical to the survival of a species;
- disrupt the breeding cycle of a population;
- modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline;
- result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat;
- introduce disease that may cause the species to decline; or
- interfere with the recovery of the species.

The *National Recovery Plan for the Koala* defines "area of occupancy" as the area within the extent of occurrence that is occupied by the species using 2 km × 2 km grid cells. Vulcan South will result in one grid cell that is currently occupied by Koalas becoming unoccupied, triggering criterion 2. Furthermore, Vulcan South will adversely affect habitat critical to the survival of the species (habitat used for feeding and resting), and thereby triggers criterion 4. The action therefore qualifies as a significant residual impact under the EPBC Act.



Legend

- Koala Sighting
- Survey Area
- VS Maximum Disturbance
- MLA Area

Koala Habitat

- High Quality
- Moderate Quality
- Low Quality

Source: Australian Government (Department of Industry, Science, Energy and Resources) 2021, METServe 2020-2022, Vitrinite 2022, Earthstar Geographics. Koala habitat derived from the National Forest and Sparse Woody Vegetation dataset (Version 5.0) and field-verified regional ecosystem data.

Vulcan South

Project Footprint Relative to Koala Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-5

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_KoalaHabitat.aprx

5.3.3.4 Central Greater Glider

A total of 85.6 ha of Central Greater Glider habitat is contained within the disturbance footprint, and 71.1 ha of this will be cleared to accommodate Vulcan South (**Figure 5-6**). This represents a loss of 11.5 % of Greater Glider habitat located within the survey area.

This impact will last until tree hollows have been replaced in rehabilitated areas post-mining. It is expected to take 120 years post-planting for trees to be large enough to form natural hollows (Gibbons and Lindenmayer 2002; Smith & Agnew 2002). Re-colonisation of rehabilitated sites after 13 years has been recorded in central Queensland where nest boxes support glider populations in mining rehabilitation sites devoid of natural hollows (Cristescu 2011). However, nest boxes require regular maintenance and replacement (Beyer & Goldingay 2006), and it is doubtful whether such a commitment can be fulfilled over a 120-period, until natural hollows form. For this reason, it is conservatively predicted that the loss of hollow trees within Central Greater Glider habitat constitutes a near-permanent loss. However, where hollows are available nearby, Central Greater Gliders are expected to commence foraging within rehabilitated areas within 15 years. As the majority of the disturbance is for haul roads (see **Figure 2-2**), it is expected that most of this will be usable by Central Greater Gliders within 15 years after rehabilitation, as hollow trees wil be retained nearby.

Viable populations of Greater Gliders are expected to be maintained in extensive neighbouring habitats (88.5 % of Greater Glider habitat is retained in the broader landscape) throughout the disturbance period, providing a source of recruitment to rehabilitated areas in the future. No data on population density is available for Central Greater Gliders within the Brigalow Belt, but the related Greater Glider occurs at average densities of 0.6 to 4 individuals per hectare (Henry 1984; Kehl and Borsboom 1984; van der Ree *et al.* 2004; Nelson *et al.* 2018), while the Northern Greater Glider occurs at a density of 3.3 to 3.8 individuals per hectare at the single site (Taravale) in which they have been studied (Comport *et al.* 1996). With a conservative assumption that densities within the survey area are on the lower end of published data (i.e., 0.6 per hectare), the 546.1 ha of habitat that will remain uncleared within the survey area supports at least 327 individuals. Furthermore, this population is likely to be connected to others throughout the Harrow Range to the west.

The location of this disturbance immediately west of existing mining operations means that no new barriers to dispersal are anticipated to arise as a result of the project. West of the project footprint, continuous tracts of riparian habitat remain connected to forests in sheltered gorges of the Harrow Range.

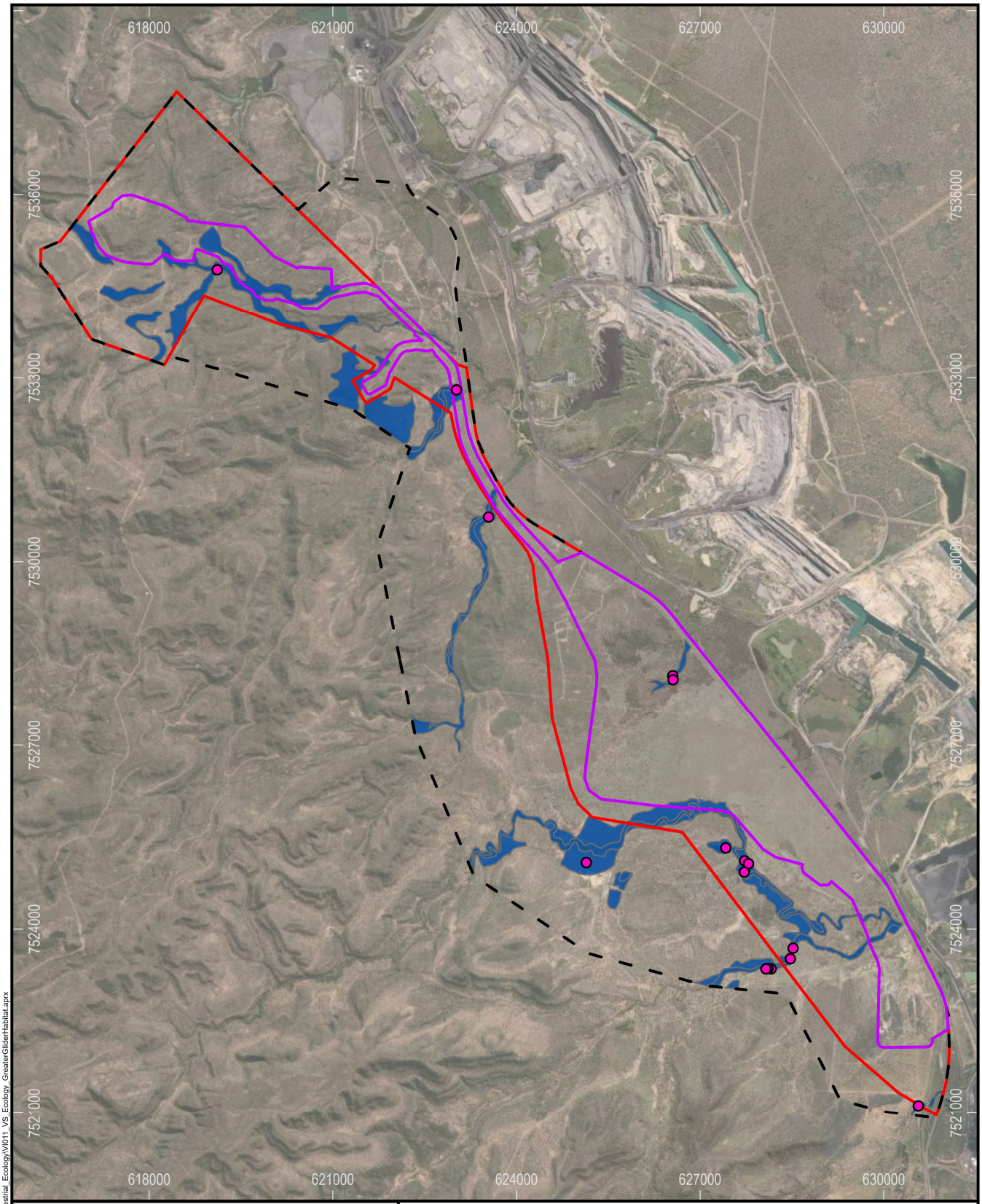
An additional 234.1 ha of habitat for Greater Gliders is located within 500 m of the main operational areas (highwall mining and hauling, mine pit, waste rock dumps and offices) and therefore may experience some disturbance from lighting, noise and dust. This disturbance is short-term, lasting only for the duration of the adjacent operations (1 to 9 years, depending on location).

The significance of impacts to MNES is defined by the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*. An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

- lead to a long-term decrease in the size of a population;
- reduce the area of occupancy of the species;
- fragment an existing population into two or more populations;
- adversely affect habitat critical to the survival of a species;
- disrupt the breeding cycle of a population;
- modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline;
- result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat;
- introduce disease that may cause the species to decline; or
- interfere with the recovery of the species.

On the grounds that the project will reduce the area of occupancy by 71.1 ha and adversely affect habitat critical to the survival of a species (i.e., by removing hollow trees), Vulcan South is likely to significantly impact the Central Greater Glider.

Vulcan South may also lead to localised increases in some weeds, although no local weeds pose a threat to the health and long-term viability of large eucalypts used by Central Greater Gliders.



Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area
- Central Greater Glider Sighting
- Central Greater Glider Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_GreaterGliderHabitat.aprx

Vulcan South

Project Footprint Relative to Central Greater Glider Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-6

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

5.3.3.5 White-throated Needletail

Vulcan South will not introduce any aerial obstacles or hazards to the White-throated Needletail. The clearance of vegetation may result in the temporary reduction of flying insect prey, although this effect will be highly localised and have negligible impact on this fast-moving and wide-ranging bird.

According to the SPRAT profile (Department of Climate Change, Energy, the Environment and Water 2022l), there are few threats to the species in Australia, apart from collisions with overhead wires, lighthouses and windows on tall buildings. These threats will not be elevated by Vulcan South. Vulcan South is not expected to significantly impact the White-throated Needtletail.

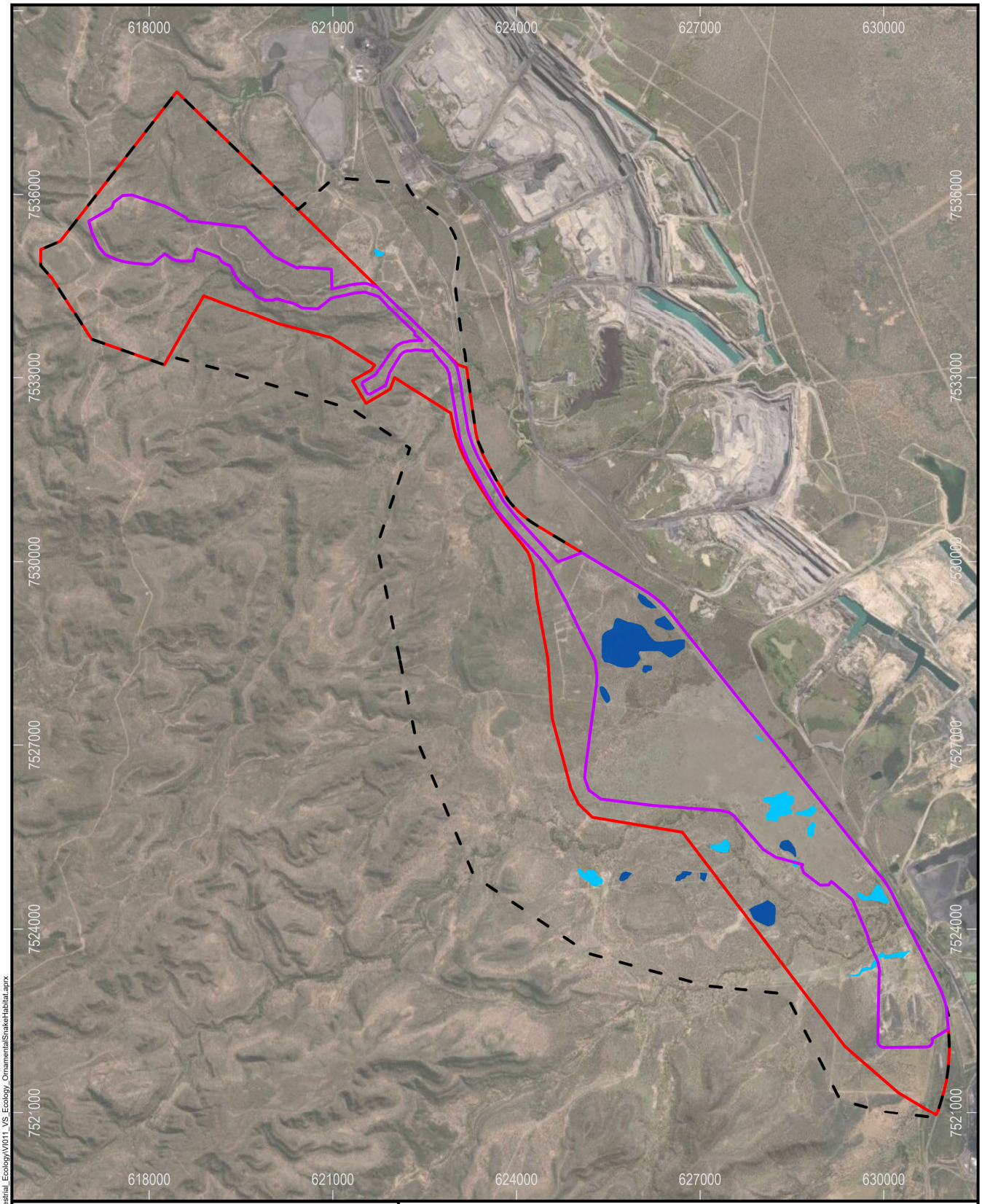
5.3.3.6 Ornamental Snake

The habitats present within the disturbance area are of marginal importance to Ornamental Snakes, given the limited development of gilgais, and small, patchy distribution of potential habitats. Nevertheless, 74.7 ha of potential primary habitat and 32.8 ha of potential secondary habitat will be removed to accommodate the Vulcan North, Main and South pits (**Figure 5-7**). Vulcan South may also increase the isolation of the small, potential habitat patches between the two branches of Hughes Creek (by creating a barrier to dispersal to/from potential habitat to the east of the project), which could reduce the viability of these potential habitat patches for Ornamental Snakes. However, it is more likely that these small, isolated habitat patches are already unoccupied by Ornamental Snakes, as none were recorded there during survey, despite optimal conditions for detection. Furthermore, the closest records of Ornamental Snakes are on the eastern side of the Peak Downs Mine and Saraji Mine. Therefore, those mines already act as a western barrier to this potential habitat, rendering patches within the vicinity of Vulcan South inaccessible. West of the survey area, the Harrow Range acts as natural barrier. Therefore, no impacts on Ornamental Snakes through habitat fragmentation are anticipated.

Overall, the impacts of Vulcan South on the Ornamental Snake are difficult to predict as a result of uncertainty over which, if any, of the small patches of potential local habitat are occupied by the species. It is likely that Vulcan South will have a negligible impact on local populations, given the marginal importance of local habitats for the species. However, in a worst case scenario, up to 141 ha of potential habitat may be lost or rendered inaccessible to Ornamental Snakes. Any impacts could be permanent, given the practical difficulties of recreating gilgai mounds and depressions on a rehabilitated mined surface. In accordance with the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles*, “important habitat” for the Ornamental Snake is to be used as a surrogate for an “important population” when assessing the significance of potential impacts. Important habitat for Brigalow Belt reptiles is defined as:

- habitat where the species has been identified during a survey
- near the limit of the species’ known range;
- large patches of contiguous, suitable habitat and viable landscape corridors (necessary for the purposes of breeding, dispersal or maintaining the genetic diversity of the species over successive generations); or
- a habitat type where the species is identified during a survey, but which was previously thought not to support the species.

No Ornamental Snakes were recorded on site during surveys, despite appropriate search effort during optimal seasonal conditions. The survey area is also not located near the limit of the known range of the Ornamental Snake. Suitable habitat for the species (i.e., gilgais) was very limited in extent, low in quality (gilgais were shallow and held water for short periods only) and very patchily distributed. The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* offer the following comment in specific reference to defining important habitat for the Ornamental Snake: “habitat connectivity between gilgais and other suitable habitats is important”. In light of the poor connectivity and low quality of local habitats on site, in addition to the failure to detect the species on site, impacts to the Ornamental Snake are unlikely to qualify as significant under the EPBC Act.



Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area

Potential Ornamental Snake Habitat

- Primary
- Secondary

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_OrnamentalSnakeHabitat.aprx

Vulcan South

Project Footprint Relative to Potential Ornamental Snake Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-7

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

5.3.3.7 Yakka Skink

Up to 1,027.3 ha of possible habitat for the Yakka Skink (i.e., remnant vegetation as identified by field-verified mapping) is contained within the disturbance footprint of Vulcan South. The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* defines important habitat for the Yakka Skink as "any contiguous patch of suitable habitat, particularly remnant vegetation, where a colony is known or identified…[or] any microhabitat where colonies are likely to be found". The disturbance area does not contain habitat connected to known populations of the Yakka Skink. Furthermore, as no colonies have ever been recorded in the northern Bowen Basin, despite extensive ecological surveys undertaken across Dysart-Moranbah-Collinsville as part of various mining projects, colonies are not "likely to be found" in the vicinity of Vulcan South. Consequently, no "important habitat" is located within the disturbance area, and no significant residual impacts to the Yakka Skink are anticipated.

5.3.3.8 Northern Quoll

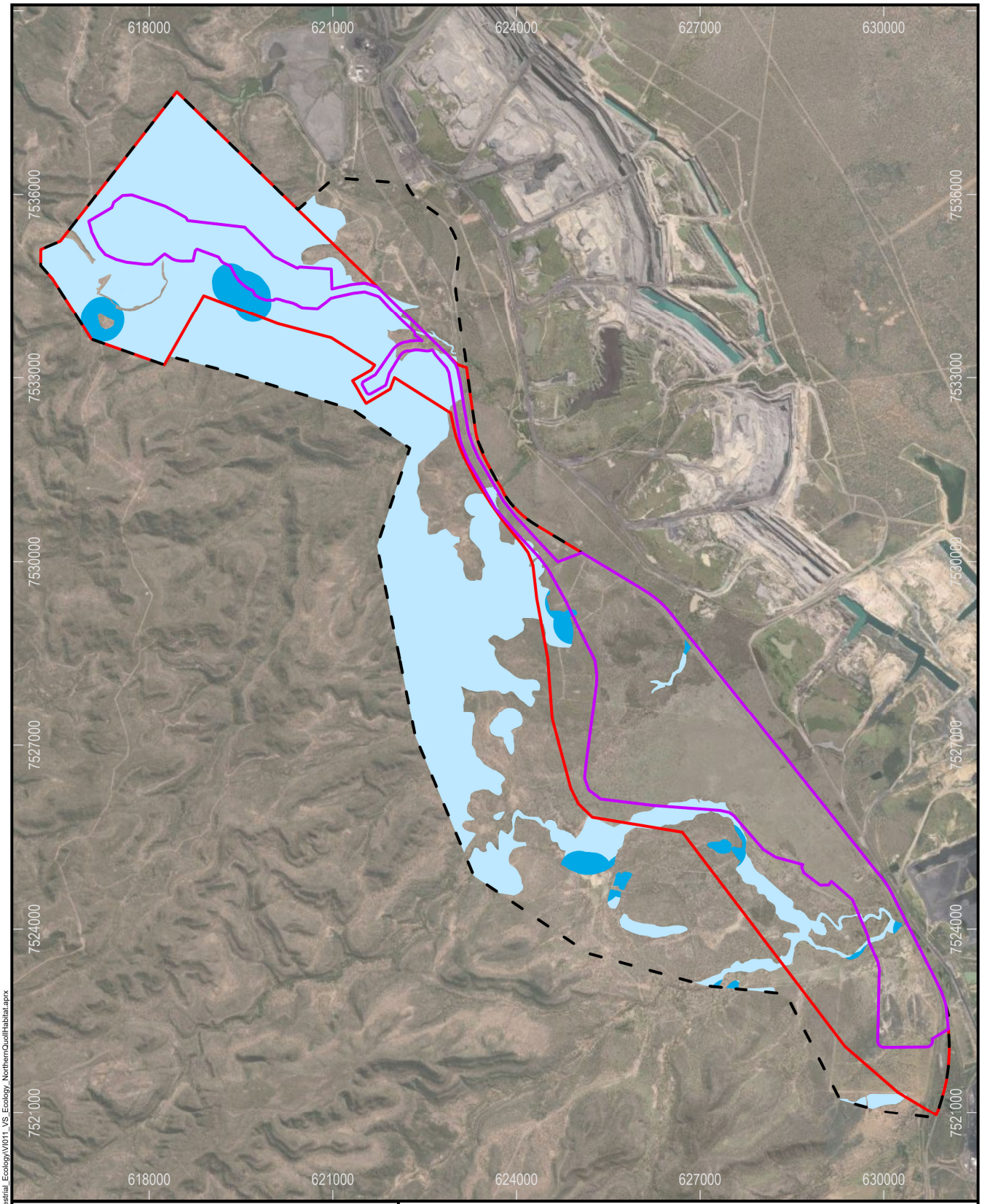
An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

- lead to a long-term decrease in the size of a population;
- reduce the area of occupancy of the species;
- fragment an existing population into two or more populations;
- adversely affect habitat critical to the survival of a species;
- disrupt the breeding cycle of a population;
- modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline;
- result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat;
- introduce disease that may cause the species to decline; or
- interfere with the recovery of the species.

Important habitat for the Northern Quoll is located in "rocky habitats, treed creek lines and structurally diverse forest with large trees, termite mounds and hollow logs" (Department of the Environment 2016), which is locally restricted to the Harrow Range and major watercourses (see **Section 4.3.2.7**). Some of this habitat (up to 190.4 ha; 6.3 % of the total potential Northern Quoll habitat within the survey area) will be removed for Vulcan South (**Figure 5-8**). No Northern Quolls were recorded there. An additional 189.4 ha of habitat occur above the highwall mining panels but are not expected to be affected by the project.

Overall, the impacts of Vulcan South on the Northern Quoll are difficult to predict as a result of uncertainty as to whether any of the potential habitat for Northern Quolls is occupied by the species. Extensive survey efforts, in optimal conditions, failed to detect one within the survey area. There are also no records of the species west of the Clarke Range or Redcliffe Plateau in the past 40 years. It is therefore most likely that the Northern Quoll is absent from the vicinity of Vulcan South, and the project will not affect the species.

However, in the unlikely event that the species does occur on site, Vulcan South may have a significant residual impact on the Northern Quoll under the EPBC Act. The location of the highwall mining trial, in particular, contains sandstone outcrops and gorges that potentially harbour den sites for the species. These actions could therefore adversely affect habitat critical to the survival of the Northern Quoll.



Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area

Potential Northern Quoll Habitat

- Habitat Within 300m of Water
- Landzone 3 and 10

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_NorthernQuollHabitat.aprx

Vulcan South

Project Footprint Relative to Potential Northern Quoll Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-8

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

An additional 958.9 ha of potential habitat for Northern Quolls is located within 500 m of the disturbance footprint and therefore may experience some disturbance from lighting, noise and dust. This disturbance is short-term, lasting only for the duration of the adjacent operations (9 months to 9 years, depending on location; but the vast majority is 9-12 months). The short-term and minor impacts of lighting, noise and dust on the Northern Quoll near Vulcan South do not qualify as an additional significant impact. Vulcan South is also unlikely to lead to an increase in populations of Feral Cats or Cane Toads, invasive species that threaten Northern Quolls.

Overall, it is considered unlikely that Vulcan South will affect the Northern Quoll, but the action should be referred to the Department of Climate Change, Energy, the Environment and Water for a formal assessment in order to decide on whether the anticipated impacts to the Northern Quoll qualify as significant.

5.3.3.9 Australian Painted-snipe

One of the dams to be removed to accommodate the Vulcan South pit contains potential habitat for the Australian Painted-snipe (**Figure 5-9**). This farm dam has an area of 2.2 ha and a shoreline approximately 1.4 km in length. Most of the dam's edges were grazed and lacked aquatic vegetation, although sedges and reeds occupied approximately one-third of the shoreline. Furthermore, the chain of ponds that feeds into this dam has waterside vegetation suitable for Australia Painted-snipe. Whilst none were detected during extensive surveys in optimal conditions, it's possible they could be transient visitors there.

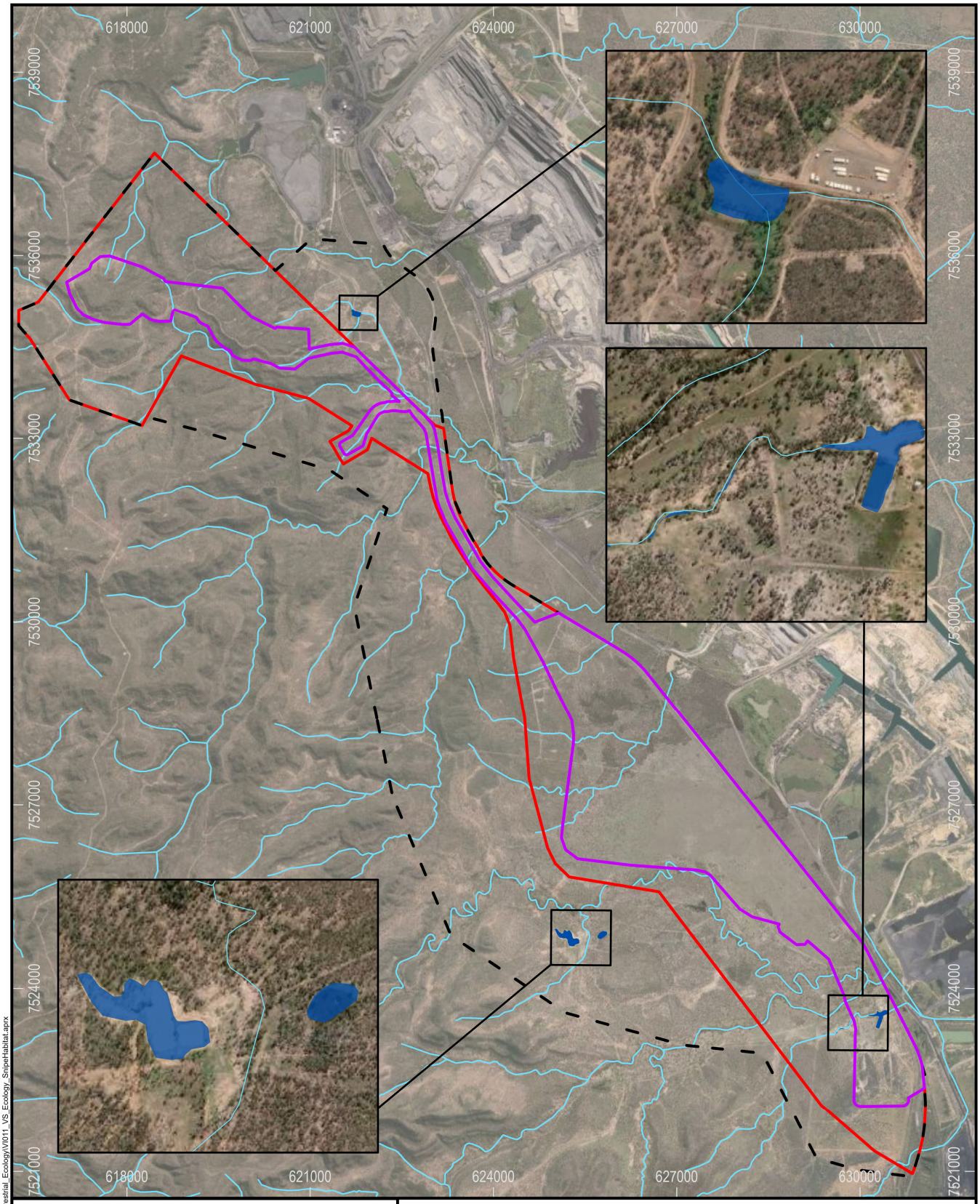
The other dam to be removed lacks any aquatic vegetation on its edges and is therefore highly unlikely to be used by the species.

Within 800 m to the southeast of the dam to be removed are several existing, much larger, water storage dams with densely, vegetated margins on the adjacent Saraji Mine lease. These dams could potentially act as alternative potential habitat for snipe during operations (9 years). It is anticipated these water storage dams at neighbouring mines will be retained for the life of Vulcan South.

The farm dam and chain of ponds to be removed form part of a drainage line that is proposed to be diverted during operations around the northern end of the South pit into Hughes Creek. The drainage line/chain of ponds will be reinstated postmining by constructing a vegetated, drainage corridor through backfilled spoil.

The loss of the farm dam will be permanent, but eventually counteracted by the retention of mine dams constructed for Vulcan South into the final landform as new farm dams. Due to rapidly fluctuating water levels during operations, it is unlikely that mine dams will provide favourable conditions for the establishment of aquatic marginal vegetation (and therefore the Australian Painted-snipe). However, once these have transitioned to farm dams in the final landform, sedges and rushes are expected to establish around the more stable margins.

Overall, the low-quality habitat that will be lost due to Vulcan South is expected to have a negligible impact on the Australian Painted-snipe. The action is unlikely to trigger any of the significant impacts on an endangered species defined by the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*.



Legend

- Drainage Lines
- Survey Area
- VS Maximum Disturbance
- MLA Area
- Potential Australian Painted-snipe Habitat

Source: Vitrinite 2022, METServe 2020-2022, Maxar, Earthstar Geographics.

Vulcan South

Project Footprint Relative to Potential Habitat for Australian Painted-snipe

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-9

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_SnipeHabitat.aprx

5.3.3.10 Red Goshawk

Red Goshawks are probably extinct in the local region. Potential habitat for the species that occurs on site is of poor quality; escarpments and nearby waterways mostly lack surface water, and the surrounding landscape is already highly modified through mining and clearing for grazing. The Red Goshawk rarely breeds in areas with fragmented native vegetation (Threatened Species Scientific Committee 2015b), and never more than 1 km from water. Consequently, the importance of the region to the species is considered to be low. The loss of 1,114 ha of possible local habitat for the species (all remnant and regrowth, as defined on the field-verified vegetation map) is, therefore, considered inconsequential for its long-term conservation. Vulcan South does not trigger any of the significant impacts on vulnerable species defined by the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*.

5.3.3.11 Annual Wiregrass

Only low-quality habitat for Annual Wiregrass is present within the vicinity of Vulcan South; favoured basalt-derived soil is absent, and all the clay soils present support degraded exotic, not native, pasture. Nevertheless, 535.9 ha of this low-quality habitat is to be removed to accommodate the Vulcan Main pit, mine infrastructure area and rail loop. In total, 267.8 ha of this is regional ecosystem 11.9.2 and the remainder is cleared pasture formerly supporting 11.9.2 and/or 11.4.9.

Given that the site lies outside the known distribution of the Annual Wiregrass, and the habitat present is of poor quality, the proposed habitat clearance will likely have a negligible impact on the species. Vulcan South does not trigger any of the significant impacts on vulnerable species defined by the *Matters of National Environmental Significance Significant Impact Guidelines 1.1*.

5.3.3.12 Ghost Bat

Vulcan South will not disturb any roosts for Ghost Bats or remove foraging habitat within 1-10 km of known roost sites. It is unlikely that the project footprint contains important habitat for the species, and no residual impacts on Ghost Bats are anticipated.

5.3.3.13 Dunmall's Snake

The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* defines important habitat for the Dunmall's Snake as any forest or woodland "within the 'Known/Likely to occur' modelled distribution of the species…and any habitat corridors in between" (Department of Sustainability, Environment, Water, Population and Communities 2011). As the disturbance area lies outside the known/likely distribution of the Dunmall's Snake, as modelled in the *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles*, no significant impacts to the species are anticipated.

5.3.3.14 Allan's Lerista

The *Draft Referral Guidelines for the Nationally Listed Brigalow Belt Reptiles* (Department of Sustainability, Environment, Water, Population and Communities 2011) defines important habitat for the species as being "vegetation occurring on mid to dark-brown-coloured, non-cracking clay soils in Queensland regional ecosystems 11.8.5 and 11.8.11/11.8.5 and grassy open-woodland mapped as cleared but where the above regional ecosystems formerly occurred". The disturbance area does not contain important habitat for the species, and no significant residual impacts of Vulcan South are anticipated.

5.3.3.15 King Bluegrass

Potential habitat for King Bluegrass in the vicinity of Vulcan South is highly degraded by grazing and unlikely to support the species. Nevertheless, 539.5 ha of this low-quality habitat is to be removed to accommodate the Vulcan Main pit, mine infrastructure area and rail loop. In total, 267.8 ha of this is regional ecosystem 11.9.2 and the remainder is cleared pasture formerly supporting 11.9.2 and/or 11.4.9. Given the low likelihood that this species occurs onsite, the proposed habitat clearance will likely have a negligible impact on the species.

5.3.3.16 Hairy Bluegrass

Potential habitat for King Bluegrass in the vicinity of Vulcan South is highly degraded by grazing and unlikely to support the species. 539.5 ha of this low-quality habitat is to be removed to accommodate the Vulcan Main pit, mine infrastructure area and rail loop. The survey area lies just outside the Department of Climate Change, Energy, the Environment and Water's (2022k) modelled "may occur" range of the species. The lack of local records and the heavily degraded nature of the available habitat suggest that the survey area is not important for the Hairy Bluegrass. No significant impacts on the species are anticipated.

5.3.3.17 Migratory Species

The Rufous Fantail and White-throated Needletail are migratory species that utilise habitats in the vicinity of the project. The latter is also a vulnerable species (see **Section 5.3.3.5**). The Fork-tailed Swift, Latham's Snipe, Oriental Cuckoo, Black-faced Monarch, Satin Flycatcher, Sharp-tailed Sandpiper, Gull-billed Tern and Glossy Ibis are additional migratory species that possibly utilise habitats in the vicinity of Vulcan South. An action is likely to have a significant impact on a migratory species if there is a real chance or possibility that it will:

- Substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species;
- result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species; or
- seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.

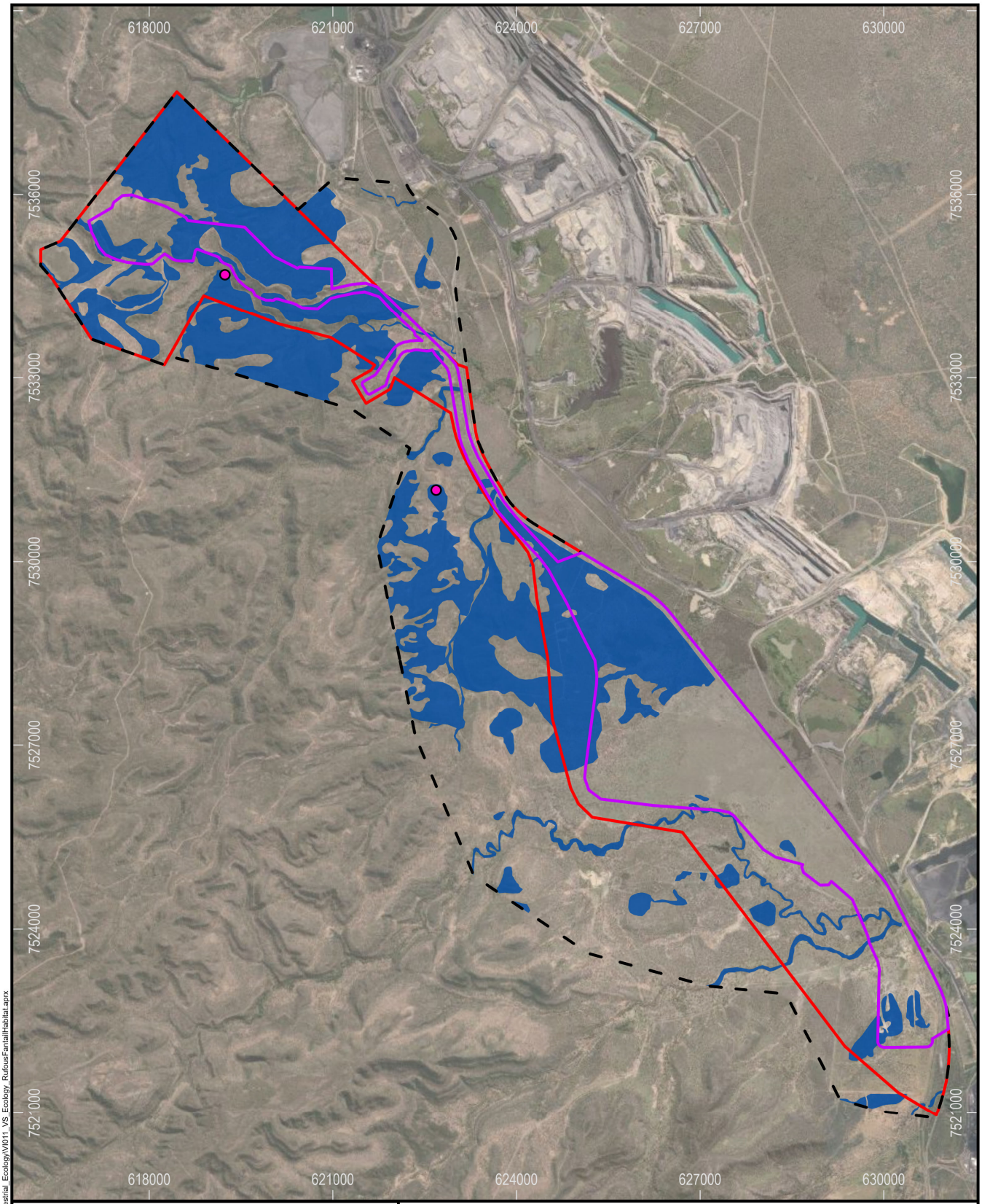
The definitions of "important habitat" for each of these species are defined by the *Referral Guideline for 14 birds Listed as Migratory* (Department of the Environment 2015a), the *Industry Guidelines for Avoiding, Assessing and Mitigating Impacts on EPBC Act listed Migratory Shorebird Species* (Department of Agriculture, Water and the Environment 2017) and the *Revision of the East Asian-Australasian Flyway Population Estimates for 37 Listed Migratory Shorebird Species* (Hansen *et al.* 2017). These are summarised in **Table 5-7**.

Table 5-7 Definitions of "important habitat" and "ecologically significant proportion of the population" for migratory species potentially utilising the Vulcan South area

Species	Important habitat	Invasive species that could be harmful	Ecologically significant proportion of the population	Area of important habitat likely to result in a significant impact if affected
Rufous Fantail	Moist, dense habitats, including mangroves, rainforest, riparian forests and thickets, and wet eucalypt forests with a dense understorey. When on passage a wider range of habitats are used including dry eucalypt forests and woodlands and Brigalow shrublands.	Black Rat *Rattus rattus*, invasive vines of riparian habitat (e.g. rubber vine *Cryptostegia grandiflora*).	1,100 individuals	260 ha
Fork-tailed Swift	Found across a range of habitats, from inland open plains to wooded areas, where it is exclusively aerial.	Unknown	100 individuals	Impacts only considered possible when wind turbines, tall buildings, airports, or other developments interrupt airspace.

Species	Important habitat	Invasive species that could be harmful	Ecologically significant proportion of the population	Area of important habitat likely to result in a significant impact if affected
Latham's Snipe	Areas that have previously been identified as internationally important for the species, or areas that support at least 18 individuals of the species.	Feral Cat, Red Fox	18 individuals	Not prescribed
Oriental Cuckoo	Monsoonal rainforest, vine thickets, wet sclerophyll forest or open *Casuarina*, *Acacia* or *Eucalyptus* woodlands. Frequently at edges or ecotones between habitat types. Riparian forest is favoured habitat in the Kimberley region.	Unknown	1,000 individuals	25,000 ha
Black-faced Monarch	Wet forest specialist, found mainly in rainforest and wet sclerophyll forest, especially in sheltered gullies and slopes with a dense understorey of ferns and/or shrubs.	Black Rat *Rattus rattus*, invasive vines of riparian habitat (e.g. rubber vine *Cryptostegia grandiflora*).	460 individuals	260 ha
Satin Flycatcher	Eucalypt forest and woodlands, at high elevations when breeding. They are particularly common in tall wet sclerophyll forest, often in gullies or along water courses. In woodlands they prefer open, grassy woodland types. During migration, habitat preferences expand, with the species recorded in most wooded habitats except rainforests. Wintering birds in northern Qld will use rainforest/gallery forests interfaces, and birds have been recorded wintering in mangroves and paperbark swamps.	Black Rat *Rattus rattus*, invasive vines of riparian habitat (e.g. rubber vine *Cryptostegia grandiflora*).	1,700 individuals	440 ha
Sharp-tailed Sandpiper	Nationally important habitat for migratory shorebirds is defined as supporting: • 0.1 per cent of the flyway population of a single species of migratory shorebird OR • 2000 migratory shorebirds OR • 15 migratory shorebird species.	Unknown	85 individuals	>0 ha
Gull-billed Tern	Not prescribed			
Glossy Ibis	Not prescribed			

Vulcan South will not disrupt an ecologically significant proportion of any migratory species. The project is also not anticipated to cause the establishment of harmful invasive species. Within the project's footprint, important habitat (as defined by Department of the Environment 2015) exists for the Rufous Fantail, Oriental Cuckoo and Satin Flycatcher. However, the habitats present on site are marginal (more inland, drier and open than is generally preferred) for all three species. It is expected that only one or two Oriental Cuckoos and Satin Flycatchers, and up to 10 Rufous Fantails, pass through the survey area each year. A total of 577.8 ha of potential habitat for transient Rufous Fantails is contained within the maximum disturbance footprint (**Figure 5-10**), along with 99.3 ha of potential habitat for transient Satin Flycatchers and Oriental Cuckoos. It is highly unlikely that the marginal habitats to be disturbed are a limiting factor constraining the migration of any of the migratory bird species listed in **Table 5-7**. For this reason, it is considered unlikely that Vulcan South will result in a significant impact on any migratory species protected under the EPBC Act.



Legend

- Rufous Fantail Sighting
- Survey Area
- VS Maximum Disturbance
- MLA Area
- Rufous Fantail Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_RufousFantailHabitat.aprx

Vulcan South

Project Footprint Relative to Rufous Fantail Habitat

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-10

VITRINITE BRIGHTER COAL

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5.3.4 Species of State Environmental Significance

Most species of State environmental significance are also matters of national significance, and potential impacts to these matters were assessed in **Section 5.3.3**. Nevertheless, the Queensland Government applies different definitions of "significant impacts" under the NC Act to the definitions under the EPBC Act. As the criteria differ for threatened wildlife and special least concern wildlife, these are assessed separately in **Table 5-8** and **Table 5-9**, respectively.

Table 5-8 Assessment of significance of impacts to threatened species of state significance

Threatened Species	Will there be a long-term decrease in the size of a local population?	Will the extent of occurrence of the species be reduced?	Will an existing population be fragmented?	Will it cause genetically distinct populations to form through isolation?	Will it result in harmful invasive species?	Will it introduce disease?	Will it interfere with the recovery of the species?	Will it cause disruption to ecologically significant locations?*
Koala	No	Minor	No	No	No	No	No	Yes
Greater Glider	No	Minor	No	No	No	No	No	Yes
Squatter Pigeon	No	Minor	No	No	No	No	No	Yes
Glossy Black-cockatoo	No	No	No	No	No	No	No	Possibly Minor
White-throated Needletail	No	No	No	No	No	No	No	No
Ornamental Snake	No	Probably No	No	No	No	No	No	Probably No
Australian Painted-snipe	No	No	No	No	No	No	No	No
Common Death Adder	No	Possibly Minor	No	No	No	No	No	Possibly Minor
Red Goshawk	No	No	No	No	No	No	No	No
Yakka Skink	No	No	No	No	No	No	No	No
Annual Wiregrass	No	No	No	No	No	No	No	No
Ghost Bat	No	No	No	No	No	No	No	No
Dunmall's Snake	No	No	No	No	No	No	No	No
Allan's Lerista	No	No	No	No	No	No	No	No
King Blue-grass	No	No	No	No	No	No	No	No

*Ecologically significant locations are defined as breeding, feeding, nesting, migration or resting sites.

Table 5-9 Assessment of significance of impacts to Special Least Concern species of state significance

Special Least Concern Species	Will there be a long-term decrease in the size of a local population?	Will the extent of occurrence of the species be reduced?	Will an existing population be fragmented?	Will gene flow among populations be reduced?	Will ecologically significant locations be disrupted?* (net disruption)
Short-beaked Echidna	No	No	No	No	Minor
Fork-tailed Swift	No	No	No	No	No
Latham's Snipe	No	No	No	No	No
Rufous Fantail	No	No	No	No	No
Sharp-tailed Sandpiper	No	No	No	No	No
Oriental Cuckoo	No	No	No	No	No
Gull-billed Tern	No	No	No	No	No
Black-faced Monarch	No	No	No	No	No
Satin Flycatcher	No	No	No	No	No
Glossy Ibis	No	No	No	No	No

*Ecologically significant locations are defined as breeding, feeding or nesting sites.

The State government can only impose an offset condition in relation to a prescribed activity, if the same, or substantially the same impact and the same, or substantially the same matter has not been subject to assessment under the EPBC Act. As Vulcan South is likely to impact several matters of national environmental significance, it will be referred and assessed under the EPBC Act. Consequently, only two matters of state significance (Common Death Adder and Short-beaked Echidna) will not be assessed under the EPBC Act, and these are therefore discussed in further detail below.

5.3.4.1 Short-beaked Echidna

Short-beaked Echidnas occupy home ranges of 50-100 ha (Nichol *et al*. 2011), and the removal of 1,567.2 ha of potential habitat (23.2 % of that within the survey area outside the approved footprint of the Vulcan Coal Mine) therefore amounts to a loss of 16–31 territories. Given the extensive and continuous matrix of potential habitat to the west and south of the project footprint, these prescribed actions will have a negligible effect on local populations. As the habitat being removed could be used for feeding and breeding, it qualifies as an ecologically significant location according to the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline* (Department of Environment and Heritage Protection 2014). Nevertheless, there are no habitat features of the project footprint that make it locally significant, and extensive tracts of similar habitat will be retained to the west. This retained habitat is of a higher quality than most of the habitat being removed, because much of it is remnant vegetation and thus contains an abundance of fallen timber, important for

denning and providing termites. Sandstone areas to the west also contain an abundance of boulders, which provide den sites.

The main prey of Short-beaked Echidnas (ants and termites) recolonise rehabilitated mine sites almost immediately (i.e., at the time of soil profile reconstruction: Andersen *et al.* 2003; Spain *et al.* 2010). Likewise, Short-beaked Echidnas recolonise rehabilitated mine sites relatively quickly (8 years: Nichols and Grant 2007; 6-10 years: unpublished data from Gove, Northern Teritory). Consequently, any impacts of Vulcan South on the Short-beaked Echidna will be short-term only.

5.3.4.2 Glossy Black-cockatoo

A total of 65 ha of foraging habitat for the Glossy Black-cockatoo will be removed to accommodate the North Pit and associated infrastructure (**Figure 5-11**). This habitat is currently used in a transient capacity by dispersing individuals.

The importance of this habitat to dispersing Glossy Black-cockatoos is probably low. Numerous small patches of *Casuarina cristata* (the local food tree) are scattered widely across the clay plains east of Peak Downs Mine, such that the small patches contained within the disturbance footprint are not the sole source of food in the local landscape. This suggests that Vulcan South is unlikely to lead to a reduction in population size or fragmentation/isolation of populations (by preventing dispersal through the region). Nevertheless, as individuals are known to feed within the disturbance footprint, at least occasionally, this habitat qualifies as an "ecologically significant location" (on the grounds it is used for feeding) according to the *Queensland Environmental Offsets Policy Significant Residual Impact Guidelines.*

5.3.4.3 Common Death Adder

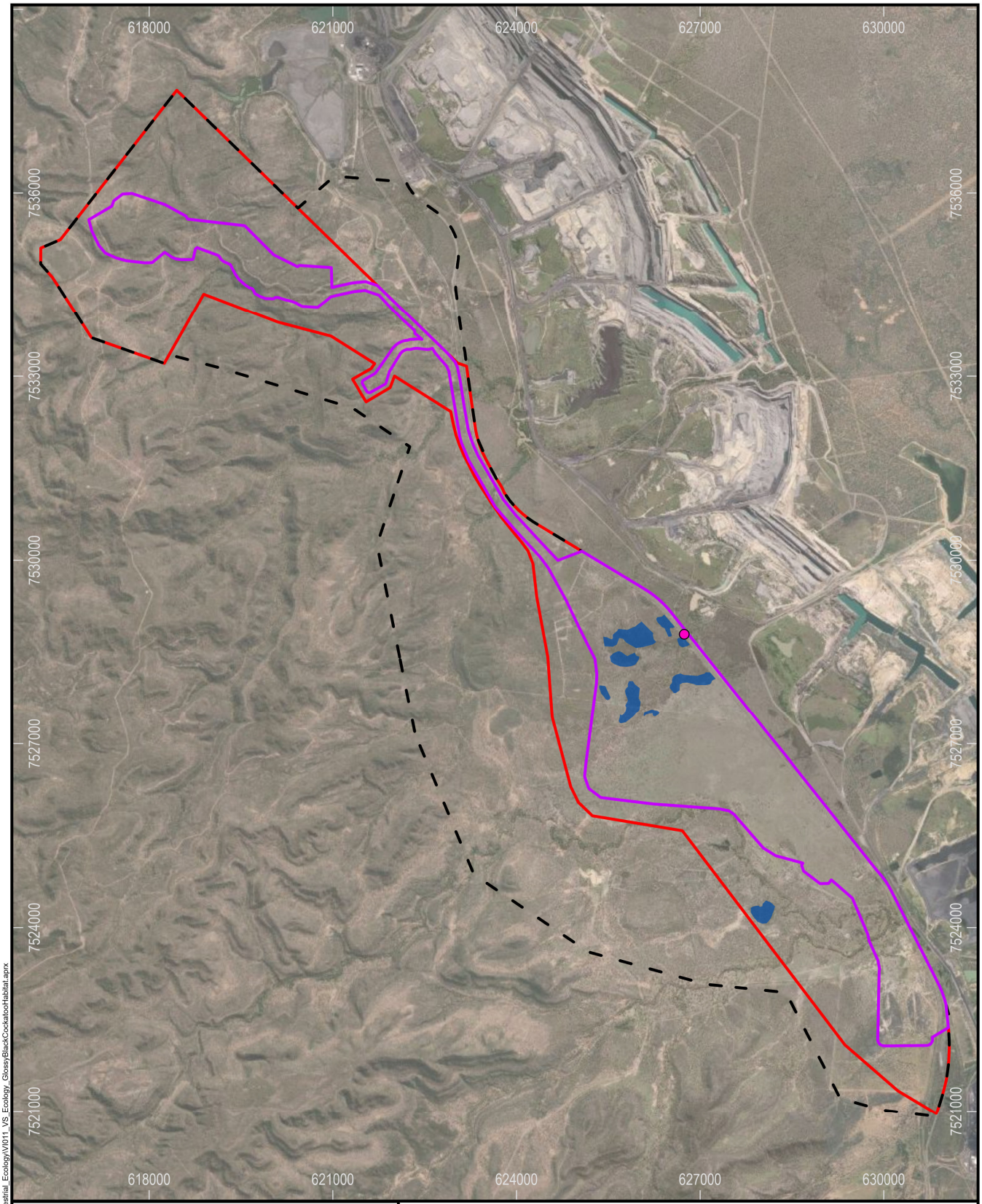
While no Common Death Adders were detected in the survey area, possible habitat for the species occurs on site. Habitat of the highest quality (remnant vegetation with sandstone boulders in elevated areas where Cane Toads are least abundant) occurs throughout the Harrow Range, and up to 377.6 ha of this habitat will be disturbed to accommodate a haul road and associated highwall mining benches and panels within the northern half of Vulcan South (**Figure 5-12**). Note that this estimate is highly conservative, as 189.4 ha of this footprint comprise highwall mining panels, which are not expected to result in the removal of any vegetation.

Potential high-quality habitat for the Common Death Adder is widespread within the survey area (93 % will not be disturbed by Vulcan South) and throughout the rest of the Harrow Range.

Common Death Adders are not confined to sandstone ranges, and could potentially utilise any vegetated habitats (remnant and regrowth) on site. 736.7 ha of these more marginal habitats (lowland areas with an abundance of Cane Toads and few rocks) will also be removed for the proposed mine and associated infrastructure.

The vast majority of the project footprint already supports high densities of Cane Toads, a major threat to Common Death Adders. The removal of existing toad-breeding locations (farm dams) will be counteracted by the construction of other locations nearby (sediment dams, water supply dams), such that Cane Toad densities are expected to remain high throughout the project area. Therefore, the net indirect impact on Common Death Adders via Cane Toad populations is likely to be near neutral.

Overall, the low quality of most habitat, the small scale of disturbance to potentially important habitat corridors (along the Harrow Range), and the fact that no Common Death Adders were detected despite extensive survey effort in optimal conditions, means that Vulcan South will likely have a minor effect on local populations.



Legend

- Glossy Black-Cockatoo Sighting
- Survey Area
- VS Maximum Disturbance
- MLA Area
- Glossy Black-Cockatoo Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_GlossyBlackCockatooHabitat.aprx

Vulcan South

Project Footprint Relative to Habitat for Glossy Black-Cockatoo

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-11

VITRINITE BRIGHTER COAL

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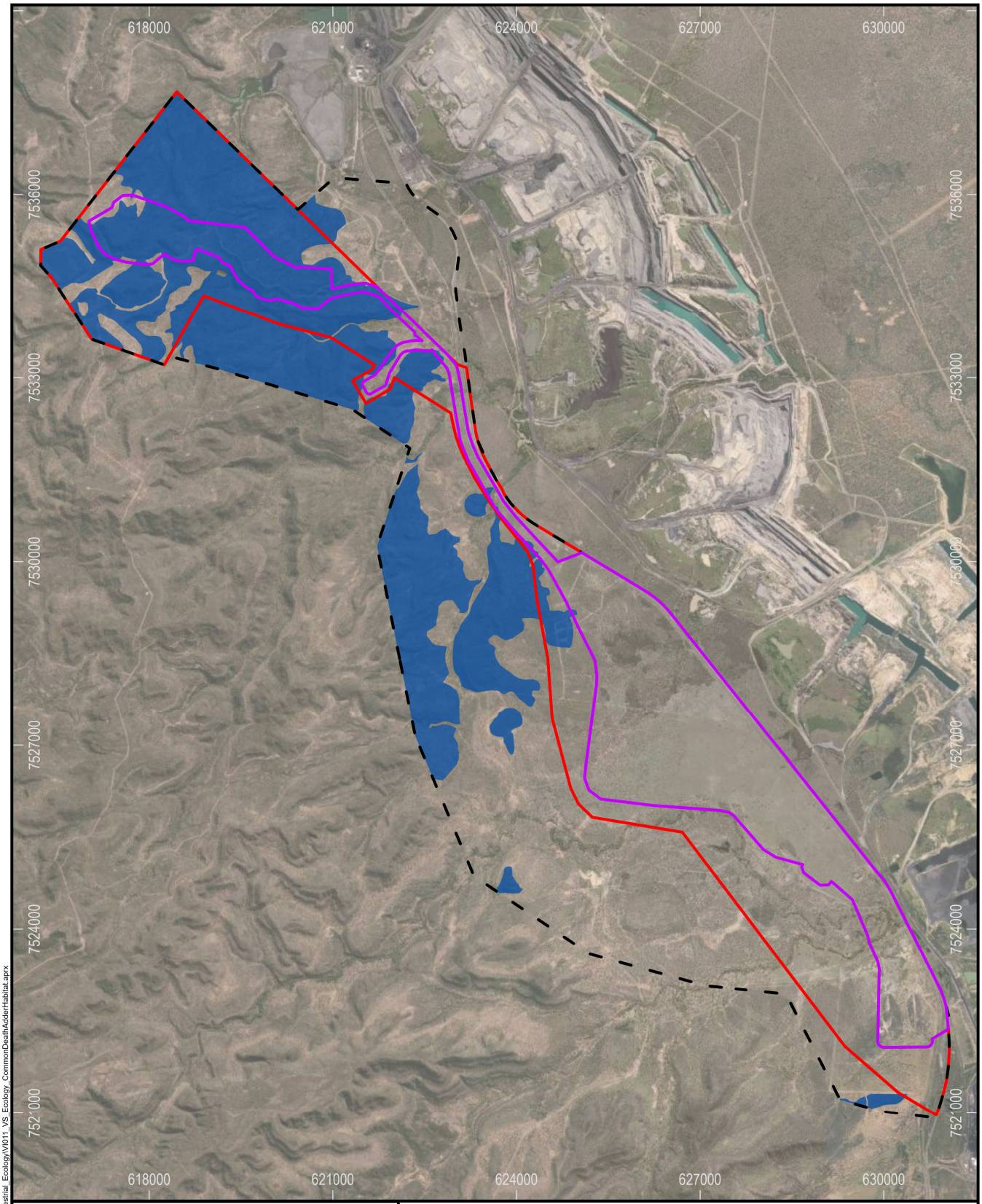

Legend

- Survey Area
- VS Maximum Disturbance
- MLA Area
- Potential Common Death Adder Habitat

Source: Vitrinite 2022, METServe 2020-2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Terrestrial_Ecology\VI011_VS_Ecology_CommonDeathAdderHabitat.aprx

Vulcan South

Project Footprint Relative to Potential Habitat for the Common Death Adder

0 0.75 1.5 3

Kilometers

Scale: 1:90,000 (A4)

23/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 5-12

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

5.4 OFFSET REQUIREMENTS

Offsets are required if the residual impacts to prescribed matters, after avoidance and mitigation measures have been implemented, are considered significant in accordance with the relevant guidelines.

5.4.1 National

Based on the assessment contained in **Section 5.3.3**, the following impacts of Vulcan South on matters of national environmental significance are likely to qualify as significant impacts:

- Removal of 120.3 ha of the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community;
- Removal of 21.3 ha of high-quality habitat, 559.1 ha of moderate-quality habitat and 443.2 ha of low-quality habitat for the Koala;
- Removal of 71.1 ha of habitat for the Central Greater Glider; and
- Removal of 671.2 ha of foraging habitat (426.8 ha of which is also breeding habitat) and 692.9 ha of dispersal habitat for the Squatter Pigeon.

Vulcan South may possibly also affect the Ornamental Snake and Northern Quoll, although neither species was recorded on site, and the habitat present is suboptimal for both species. Due to the likelihood of the above impacts, the project should be referred to the Department of Climate Change, Energy, the Environment and Water for approval under the EPBC Act. It is likely that approval for the project will be conditional on the provision of offsets in accordance with *EPBC Act Environmental Offsets Policy 2012.*

An offset proposal should be developed for all matters likely to experience a significant residual impact.

5.4.2 State

Significant residual impacts to matters of state significance may require offsetting under the *Environmental Offsets Act 2014.* In Queensland, the significance of residual impacts to prescribed matters is defined by the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline* (Department of Environment and Heritage Protection 2014), which is administered under the *Environmental Offsets Act 2014*.

As the matters of state environmental significance that are most likely to experience significant impacts are also matters of national environmental significance (to be assessed under the EPBC Act), duplicate offsets are not required. In accordance with the *Queensland Environmental Offsets Policy 2017*, the Queensland Government can only impose an offset condition in relation to a prescribed activity, if the same, or substantially the same, impact and the same, or substantially the same, matter has not been subject to assessment as a controlled action under the EPBC Act. However, an activity referred to the Commonwealth Government that receives a 'not a controlled action' or a 'not controlled action - particular manner' notice, could still be subject to an offset condition imposed by the Queensland Government. Given that it is likely that Vulcan South will be considered a controlled action, only state matters that are not protected under the EPBC Act may require offsetting under the *Environmental Offsets Act 2014.*

The following vegetation will require offsets under the *Environmental Offsets Act 2014*:

- 25.7 ha of Of Concern regional ecosystem 11.3.2; and
- 58.3 ha of regional ecosystems 11.3.25, 11.5.3, 11.5.9b, 11.9.2, 11.10.1 and 11.10.3 located within a defined distance from the defining banks of a relevant watercourse.

Note that the endangered regional ecosystems 11.4.8 and 11.4.9 do not require separate offsets under the *Environmental Offsets Act 2014,* as they are components of the Brigalow threatened ecological community that will likely require offsetting under the EPBC Act. Likewise, areas mapped as essential habitat under the *Vegetation Management Act 1999* do not require separate offsets, as these areas are contained within the habitat to be offset for threatened species listed under the EPBC Act.

Despite being matters of state environmental significance, Category R vegetation and Category C vegetation are not prescribed matters (defined in Schedule 2 of the *Environmental Offsets Regulation 2014*) and do not require offsetting.

In addition to the above vegetation, impacts to low-quality habitat for the Glossy Black-cockatoo (vulnerable), Short-beaked Echidna (special least concern) and Common Death Adder (vulnerable) possibly qualify as significant, due to the disturbance of potential feeding and/or breeding sites, which qualify as "ecologically significant locations". Nevertheless, not all significant impacts require offsets under the Queensland Environmental Offset Framework; according to the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline* (Department of Environment and Heritage Protection 2014), if residual impacts are significant an offset *may* be required. In light of the small scale of the proposed impacts, the possible absence of Common Death Adders from the site, and the negligible effects Vulcan South is likely to have on local populations of these three species, offsets may not be deemed necessary. This decision ultimately lies with the Department of Environment and Science, who will assess this via the Environmental Authority application process.

As environmental offsets are likely to be required, at least for the regulated vegetation to be disturbed, a Draft Offset Delivery Mechanism report is to be prepared. Following confirmation of this approach via habitat quality assessments of the proposed offset area, an Offset Delivery Plan is then to be developed and submitted to the State Government for approval.

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APPENDIX A

FAUNA TRAP SITE DESCRIPTIONS

Appendix A Fauna trap site descriptions

Site Name: S1 **Description:** Remnant *Eucalyptus orgadophila* open woodland on clay derived from fine-grained sedimentary rock. **BVG:** 17b **Dates:** 24-28/10/2018 **Latitude, Longitude:** -22.3521, 148.2200	
Site Name: S2 **Description:** Remnant *Acacia harpophylla* open forest with emergent *Eucalyptus cambageana.* **BVG:** 25a **Dates:** 25-29/10/2018 **Latitude, Longitude:** -22.3515, 148.2272	
Site Name: S3 **Description:** Cleared pasture with *Carissa ovata* on clay soil **BVG:** n/a **Dates:** 25-29/10/2018 **Latitude, Longitude:** -22.3557, 148.2396	
Site Name: S4 **Description:** Edge of remnant riparian forest dominated by *Eucalyptus camaldulensis.* **BVG:** 16a/9e **Dates**: 25-29/10/2018 **Latitude, Longitude:** -22.3676, 148.2345	

Site Name: S5 **Description:** Ecotone between remnant *Corymbia tessellaris* forest on a sandy alluvial terrace and *Eucalyptus camaldulensis* and *Bauhinia hookeri* along the creek bank. **BVG:** 16a/9e **Dates:** 28/10-1/11/2018 **Latitude, Longitude:** -22.3749, 148.2401	
Site Name: S6 **Description:** Remnant open forest dominated by *Casuarina cristata* and *Acacia harpophylla* on clay soil. **BVG**: 25a **Dates**: 29/10-2/11/2018 **Latitude, Longitude:** -22.3834, 148.2431	
Site Name: S7 **Description:** Remnant *Eucalyptus populnea* open forest on a sand plain. **BVG:** 17a **Dates:** 29/10-2/11/2018 **Latitude, Longitude:** -22.3890, 148.2448	
Site Name: S8 **Description:** High-value regrowth of *Eucalyptus populnea* on a sand plain. **BVG:** 17a (regrowth) **Dates:** 29/10-2/11/2018 **Latitude, Longitude:** -22.3929, 148.2586	

Site Name: S9 **Description:** Heavily thinned *Eucalyptus crebra* and *Corymbia clarksoniana* woodland on a sand plain. **BVG:** 18b (regrowth) **Dates:** 25-28/3/2019 and 8-12/4/2019 **Latitude, Longitude:** -22.3900, 148.2267 Original trapping session was disrupted by heavy rain and had to be repeated at a later date.	
Site Name: S10 **Description:** Remnant *Eucalyptus populnea* open forest, with some *Eucalyptus melanophloia*, on a sandy alluvial terrace. **BVG:** 17a **Dates:** 26-28/3/2019 and 9-13/4/2019 **Latitude, Longitude**: -22.3757, 148.2155 Original trapping session was disrupted by heavy rain and had to be repeated at a later date.	
Site Name: S11 **Description:** Remnant *Corymbia clarksoniana* and *Eucalyptus crebra* open forest at the base of a rocky sandstone scree slope. **BVG:** 12a **Dates:** 26-28/3/2019 and 9-13/4/2019 **Latitude, Longitude:** -22.3773, 148.2017 Original trapping session was disrupted by heavy rain and had to be repeated at a later date.	
Site Name: S12 **Description:** Remnant *Acacia harpophylla* and *Eucalyptus cambageana* woodland on a clay plain. **BVG:** 25a **Dates:** 27-28/3/2019 and 8-12/4/2019 **Latitude, Longitude:** -22.3769, 148.2384 Original trapping session was disrupted by heavy rain and had to be repeated at a later date.	

Site Name: S13 **Description:** Cleared pasture with scattered *Eucalyptus populnea* on a sand plain. **BVG:** n/a **Dates:** 13-17/4/2019 **Latitude, Longitude:** -22.3761, 148.2588	
Site Name: S14 **Description:** Remnant *Eucalyptus populnea* woodland on a sand plain. **BVG:** 17a **Dates:** 9-13/4/2019 **Latitude, Longitude:** -22.3666, 148.2052	
Site Name: S15 **Description:** Partly thinned woodland dominated by *Eucalyptus crebra* on a low sandstone rise. **BVG:** 18b **Dates:** 12-16/4/2019 **Latitude, Longitude:** -22.3592, 148.1983	
Site Name: S16 **Description:** Remnant *Corymbia aureola* and *Eucalyptus melanophloia* open forest with a shrub layer dominated by *Acacia* spp. on sandstone. **BVG:** 12a **Dates:** 12-16/4/2019 **Latitude, Longitude**: -22.3567, 148.1928	

Site Name: S17 **Description:** Remnant *Eucalyptus orgadophila* open woodland on clay derived from fine-grained sedimentary rock. **BVG:** 17b **Dates:** 13-17/4/2019 **Latitude, Longitude:** -22.3537, 148.2339	
Site Name: S18 **Description:** Remnant open forest dominated by *Acacia rhodoxylon* and *Acacia shirleyi* on sandstone. **BVG:** 24a **Dates:** 1-5/5/2019 **Latitude, Longitude:** -22.3424, 148.2103	
Site Name: S19 **Description:** Remnant open forest dominated by *Acacia shirleyi* on sandstone. **BVG:** 24a **Dates:** 1-5/5/2019 **Latitude, Longitude:** -22.3497, 148.2013	
Site Name: S20 **Description:** Remnant woodland dominated by *Eucalyptus crebra* and *Corymbia clarksoniana*, with a shrub layer dominated by *Alphitonia excelsa, Petalostigma pubescens* and *Acacia burdekensis*, on a sand plain. **BVG:** 18b **Dates**: 1-5/5/2019 **Latitude, Longitude**: -22.3518, 148.2112	

Site Name: S21 **Description:** Remnant *Eucalyptus orgadophila* open woodland on heavy clay soil derived from fine-grained sedimentary rock. **BVG:** 17b **Dates:** 30/4-4/5/2019 **Latitude, Longitude:** -22.3593, 148.2296	
Site Name: S22 **Description:** Remnant open forest dominated by *Eucalyptus crebra, Corymbia clarksoniana* and *Eucalyptus melanophloia*, with a dense shrub layer containing *Alphitonia excelsa, Petalostigma pubescens* and *Acacia burdekensis.* **BVG:** 18b **Dates:** 4-8/5/2019 **Latitude, Longitude:** -22.3306, 148.2124	
Site Name: S23 **Description:** Remnant open forest dominated by *Corymbia tessellaris, Corymbia clarksoniana* and *Eucalyptus crebra* beside a creek lined with *Eucalyptus camaldulensis* and *Melaleuca* spp. **BVG:** 16a/9e **Dates:** 5-9/5/2019 **Latitude, Longitude:** -22.3062, 148.1943	
Site Name: S24 **Description:** Remnant open forest dominated by *Corymbia citriodora, Eucalyptus crebra* and *Corymbia trachyphloia,* with a shrub layer containing *Lysicarpus angustifolius* and *Acacia shirleyi.* **BVG:** 10a **Dates:** 5-9/5/2019 **Latitude, Longitude**: -22.2915, 148.1672	

Site Name: S25 **Description:** Remnant *Acacia shirleyi* open forest, but with many dead trees. **BVG:** 12a **Dates:** 5-9/5/2019 **Latitude, Longitude:** -22.2854, 148.1516	
Site Name: S26 **Description:** Non-remnant open woodland dominated by *E. melanophloia, C. clarksoniana* and *Melaleuca viridiflora* on sandy soil. One of the densest examples of non-remnant habitat. **BVG:** Cleared **Dates:** 23-27/09/2019 **Latitude, Longitude:** -22.2880, 148.1920	
Site Name: S27 **Description:** Remnant open forest dominated by *C. citriodora* on coarse-grained sedimentary rocks. **BVG:** 10a **Dates:** 24-28/09/2019 **Latitude, Longitude:** -22.2860, 148.1471	
Site Name: S28 **Description:** Remnant woodland dominated by *C. citriodora* on coarse-grained sedimentary rocks with dense *Acacia shirleyi* midstorey. **BVG:** 10a **Dates:** 24-28/09/2019 **Latitude, Longitude:** -22.2867, 148.1586	

Site Name: S29 **Description:** Remnant *A. shirleyi* open forest on coarse-grained sedimentary rocks. *C. aureola* also present with a sparse, grassy understorey. **BVG:** 24a **Dates:** 25-29/09/2019 **Latitude, Longitude:** -22.2905, 148.1746	
Site Name: S30 **Description:** High-value regrowth with many dead trees and large amounts of fallen debris. Heavily grazed and very open. Canopy dominated by *C. clarksoniana* and *E. crebra.* **BVG:** 12a **Dates:** 27-1/10/2019 **Latitude, Longitude:** -22.2812, 148.1792	
Site Name: S31 **Description:** High-value regrowth, dominated by *Eucalyptus crebra* with a dense midstorey of *A. burdekensis*, on coarse-grained sedimentary rocks. **BVG:** 12a (regrowth) **Dates:** 27-01/10/2019 **Latitude, Longitude:** -22.2797, 148.1767	
Site Name: S32 **Description:** High-value regrowth *E. crebra* and *C. clarksoniana* woodland on coarse-grained sedimentary rocks. **BVG:** 12a (regrowth) **Dates:** 28-02/10/2019 **Latitude, Longitude:** -22.3098, 148.1940	

Site Name: S33 **Description:** High-value regrowth *E. crebra* woodland with dense midstorey of *Acacia* spp. and *Melaleuca viridiflora*. **BVG:** 18b (regrowth) **Dates:** 28-02/10/2019 **Latitude, Longitude:** -22.3182, 148.1980	
Site Name: S34 **Description:** High-value regrowth dominated by *A. rhodoxylon.* Contained large amounts of fallen debris. **BVG:** 24a (regrowth) **Dates:** 29-03/10/2019 **Latitude, Longitude:** -22.3990, 148.2654	

APPENDIX B

VEGETATION DATA FROM SECONDARY SITES

SECONDARY SITE 1 **11.5.9**



Latitude, Longitude: -22.3307, 148.2130

Community description: Low open forest dominated by *Melaleuca nervosa,* with emergent *Alphitonia excelsa*, on a flat sandy plain. The species composition was similar to nearby RE 11.5.9, except for the absence of an upper stratum of *Eucalyptus crebra.* This was therefore considered to be a variation of 11.5.9.

Dominant species per stratum:

E: *Alphitonia excelsa, Melaleuca nervosa.*
T1: *Acacia burdekensis, Melaleuca nervosa.*
S1: *Acacia burdekensis, Melaleuca nervosa.*
S2: *Erythroxylum australe.*
G: *Perotis rara, Setaria surgens, Cheilanthes sieberi.*

Median (and range) canopy height per stratum: E = 9.2 m (9.0–12.4 m), T1 = 5.2 m (4.2–7.4 m), S1 = 2.25 m (2.0–3.0 m), S2 = 1 m (0.4–1.2 m).

% cover of each stratum (vertical projection along 100 m tape): E = 5.5%; T1 = 62.3%; S1 = 5.7%; S2 <0.1%; **total = 65.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Alphitonia excelsa* = 1 m^2/ha **(total = 1 m^2/ha).**
T1: *Melaleuca nervosa* = 4.17 m^2/ha; *Acacia burdekensis* = 0.67 m^2/ha; *Alphitonia excelsa* = 0.67 m^2/ha **(total = 5.51 m^2/ha).**
S1: *Melaleuca nervosa* = 0.5 m^2/ha; *Acacia burdekensis* = 0.17 m^2/ha **(total = 0.67 m^2/ha).**
S2: *Erythroxylum* < 0.15 m^2/ha **(total < 0.15 m^2/ha).**

Landform: Plain **Slope:** 1° E **Soil:** Brown sand

Disturbance: Nil

Ground cover: Rock = 0%, wood = 3%, bare = 30%, litter = 42%, vegetation = 25%.

Species (percent cover): *Acanthospermum hispidum** (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (0.4%), *Alphitonia excelsa* (0.2%), *Aristida holathera* (0.6%), *Bonamia media* (0.1%), *Cheilanthes sieberi* (7%), *Chrysocephalum apiculatum* (0.2%), *Crotalaria medicaginea* (0.1%), *Dactyloctenium radulans* (0.1%), *Desmodium varians* (0.3%), *Emilia sonchifolia** (0.1%), *Eragrostis sororia* (0.1%), *Erythroxylum australe* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.4%), *Heliotropium peninsulare* (0.1%), *Ipomoea polymorpha* (0.7%), *Melaleuca nervosa* (0.2%), *Murdannia graminea* (0.1%), *Perotis rara* (4%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.2%), *Portulaca filifolia* (0.1%), *Richardia brasiliensis** (0.1%), *Setaria surgens* (5%), *Sida cordifolia** (0.8%), *Spermacoce brachystema* (0.1%), *Stylosanthes hamata** (0.3%), *Stylosanthes scabra** (0.1%), *Tephrosia dietrichiae* (0.1%), *Tricoryne elatior* (0.1%), *Urochloa piligera* (3%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 2 **11.5.9**



Latitude, Longitude: -22.3337, 148.2100

Community description: Low woodland dominated by *Eucalyptus melanophloia* on a flat, sandy plain.

Dominant species per stratum:

T1: *Eucalyptus melanophloia.*
T2: *Acacia burdekensis, Eucalyptus melanophloia.*
S1: *Erythroxylum australe, Petalostigma pubescens.*
G: *Alloteropsis cimicina, Aristida calycina* var. *calycina, Eriachne obtusa, Evolvulus alsinoides*

Median (and range) canopy height per stratum: T1 = 6.8 m (5.2–11.4 m), T2 = 4 m (3.2–5 m), S1 = 1.5 m (0.8–2 m).

% cover of each stratum: T1 = 20.2%; T2 = 23.9%; S1 = 5%; **total = 44.6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus melanophloia* = 4.83 m^2/ha; *Acacia burdekensis* = 0.17 m^2/ha **(total = 5 m^2/ha).**
T2: *Acacia burdekensis* = 1.5 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha **(total = 1.67 m^2/ha).**
S1: total <0.17 m^2/ha.

Landform: Plain **Slope:** 1°NE **Soil:** Yellow-brown sand

Disturbance: Lightly grazed

Ground cover: Rock = 0%, wood = 1%, bare = 35%, litter = 40%, vegetation = 24%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (9%), *Alphitonia excelsa* (0.2%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (2%), *Chrysopogon fallax* (0.3%), *Digitaria divaricatissima* (0.1%), *Digitaria* sp. A (0.2%), *Eragrostis lacunaria* (0.2%), *Eragrostis sororia* (0.1%), *Eriachne obtusa* (8%), *Eucalyptus melanophloia* (0.1%), *Evolvulus alsinoides* (0.9%), *Fimbristylis dichotoma* (0.6%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Murdannia graminea* (0.1%), *Paspalidium rarum* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus carpentariae* (0.1%), *Phyllanthus collinus* (0.1%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.1%), *Portulaca pilosa** (0.1%), *Richardia brasiliensis** (0.1%), *Sida hackettiana* (0.1%), *Sida* sp. (Aramac E.J. Thompson+ JER192) (0.2%), *Stylosanthes scabra** (0.2%), *Tephrosia leptoclada* (0.1%), *Urochloa piligera* (0.1%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 3 **11.10.1x1**



Latitude, Longitude: -22.3370, 148.2069

Community description: Low open forest dominated by *Corymbia aureola, Eucalyptus melanophloia* and *Acacia shirleyi* on a low sandstone ridge.

Dominant species per stratum:

T1: *Acacia shirleyi, Corymbia aureola, Eucalyptus melanophloia.*
T2: *Acacia burdekensis.*
S1: *Erythroxylum australe.*
G: *Cleistochloa subjuncea*, *Digitaria diminuta.*

Median (and range) canopy height per stratum: T1 = 9.4 m (8.6–12.4 m), T2 = 5.2 m (3.4–6 m), S1 = 2.4 m (2–2.6 m), S2 = 1 m (0.5–1.5 m).

% cover of each stratum: T1 = 37.6%; T2 = 21.3%; S1 = 6.7%; t**otal = 56.6%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia aureola* = 2.33 m^2/ha; *Acacia shirleyi* = 1.5 m^2/ha; *Eucalyptus melanophloia* = 1.17 m2/ha **(total = 5 m^2/ha).**
T2: *Acacia burdekensis* = 0.17 m^2/ha; *Acacia shirleyi* = 0.5 m^2/ha; *Alphitonia excelsa* = 0.17 m^2/ha; *Corymbia aureola* = 0.17 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha **(total = 1.18 m^2/ha).**
S1: *Erythroxylum australe* = 0.33 m^2/ha **(total = 0.33 m^2/ha).**

Landform: Low rocky rise **Slope:** 3°NNE **Soil:** Grey sand

Disturbance: none

Ground cover: Rock = 45%, wood = 7%, bare = 10%, litter = 23%, vegetation = 15%.

Species (percent cover): *Acacia bancroftiorum* (0.1%), *Acacia shirleyi* (0.1%), *Achyranthes aspera* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis imicina* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida benthamii* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (0.1%), *Cleistochloa subjuncea* (7%), *Corymbia aureola* (0.1%), *Cyanthillium cinereum* (0.1%), *Desmodium macrocarpum* (0.1%), *Digitaria diminuta* (3.6%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (0.1%), *Eriochloa pseudoacrotricha* (0.1%), *Erythroxylum australe* (0.2%), *Eucalyptus melanophloia* (0.1%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Hibiscus meraukensis* (0.1%), *Ipomoea brownii* (0.2%), *Marsdenia microlepis* (0.1%), *Melinis repens* (0.1%), *Panicum effusum* (0.1%), *Paspalidium gracile* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus carpentariae* (0.1%), *Pseuderanthemum variabile* (0.1%), *Scleria brownii* (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Spermacoce brachystema* (0.1%), *Stylosanthes scabra** (0.2%), *Tephrosia juncea* (0.1%), *Themeda triandra* (0.1%), *Ventilago viminalis* (0.1%), *Xenostegia tridentata* (0.1%).

SECONDARY SITE 4 **11.5.9**



Latitude, Longitude: -22.3403, 148.2247

Community description: Low woodland dominated by *Allocasuarina leuhmannii* on a sand plain. It is best considered a variant of 11.5.9 lacking a *Eucalyptus* upper stratum.

Dominant species per stratum:

T1: *Allocasuarina luehmannii.*
T2: *Acacia burdekensis, Allocasuarina luehmannii, Grevillea striata.*
S1: *Allocasuarina luehmannii.*
G: *Eragrostis sororia*, *Chrysopogon fallax*, *Eriachne obtusa*.

Median (and range) canopy height per stratum: T1 = 9.4 (8–11.6 m), T2 = 5 m (4.2–5.6 m), S1 = 2.8 m (1.6–3 m).

% cover of each stratum: T1 = 31.3%, T2 = 20.8%; S1 = 11%; **total = 55.2%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Allocasuarina luehmannii* = 3.83 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha **(total = 4 m^2/ha).**
T2: *Allocasuarina luehmannii* = 4.5 m^2/ha **(total = 4.5 m^2/ha).**
S1: < 0.17 m^2/ha.

Landform: Slight rise on a sandy plain **Slope:** 2°E **Soil:** Yellow-brown sand

Disturbance: Nil

Ground cover: Rock = 0%, wood = 2%, bare = 34%, litter = 45%, vegetation = 19%.

Species (percent cover): *Allocasuarina luehmannii* (0.4%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida holathera* (0.1%), *Brunoniella australis* (0.1%), *Carissa ovata* (0.1%), *Cheilanthes sieberi* (0.3%), *Chrysopogon fallax* (3.1%), *Commelina lanceolata* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (5%), *Eremochloa bimaculata* (0.1%), *Eriachne obtusa* (7%), *Evolvulus alsinoides* (0.8%), *Fimbristylis dichotoma* (0.1%), *Grevillea striata* (0.1%), *Murdannia graminea* (0.4%), *Oldenlandia mitrasacmoides* subsp. *trachymenoides* (0.1%), *Panicum effusum* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus collinus* (0.1%), *Polycarpaea corymbosa* (0.1%), *Portulaca pilosa** (0.1%), *Sida hackettiana* (0.1%), *Sphaeromorphaea australis* (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia leptoclada* (0.1%).

SECONDARY SITE 5 **11.4.8**



Latitude, Longitude: -22.3424, 148.2219

Community description: Low open forest dominated by *Casuarina cristata* and *Acacia harpophylla* (subdominant), with emergent *Eucalyptus cambageana*, on clay plain.

Dominant species per stratum:

E: *Eucalyptus cambageana.*
T1: *Acacia harpophylla, Casuarina cristata.*
T2: *Acacia harpophylla, Terminalia oblongata.*
S1: *Carissa ovata*.
G: *Ancistrachne uncinata, Paspalidium constrictum*, *Chloris divaricata*, *Cyperus gracilis*.

Median (and range) canopy height per stratum: E = 16 (14.4–16.4 m) T1 = 9.2 m (7.2–11.6 m), T2 = 3.5 m (3.0–4.0 m), S1 = 2 m (1.0–2.5 m).

% cover of each stratum: E = 19%; T1 = 67.1%; T2 = 13.1%; S1 = 4.3%; **total = 78.8%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Eucalyptus cambageana* = 2.17 **(total = 2.17 m^2/ha).**
T1: *Casuarina cristata* = 5.83 m^2/ha; *Acacia harpophylla* = 1.33 m^2/ha; *Eucalyptus cambageana* = 0.83 m^2/ha; *Terminalia oblongata* = 0.33 m^2/ha. **(total = 8.32 m^2/ha).**
T2: *Acacia harpophylla* =0.33 m^2/ha **(total = 0.33 m^2/ha).**
S1: <0.17 m^2/ha.

Landform: Slight rise on a plain **Slope:** 1°E **Soil:** Reddish-brown sand, but probably texture contrast, with a clay subsoil.

Disturbance: Nil

Ground cover: Rock = 0%, wood = 8%, bare = 4%, litter = 75%, vegetation = 13%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Acacia harpophylla* (0.1%), *Alectryon diversifolius* (0.1%), *Ancistrachne uncinata* (1.2%), *Apowollastonia spilanthoides* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa pertusa** (0.1%), *Brunoniella australis* (0.1%), *Bursaria incana* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (5.5%), *Casuarina cristata* (0.2%), *Cheilanthes sieberi* (0.1%), *Chloris divaricata* (0.9%), *Cymbidium canaliculatum* (0.1%), *Cymbopogon refractus* (0.1%), *Cynanchum viminale* (0.1%), *Cyperus gracilis* (0.7%), *Desmodium varians* (0.1%), *Einadia nutans* (0.1%), *Enchylaena tomentosa* var. *tomentosa* (0.1%), *Enneapogon lindleyanus* (0.1%), *Eremophila mitchellii* (0.1%), *Erythroxylum australe* (0.1%), *Evolvulus alsinoides* (0.1%), *Geijera parviflora* (0.1%), *Grewia retusifolia* (0.1%), *Hibiscus brachysiphonius* (0.1%), *Hibiscus sturtii* (0.1%), *Jasminum didymum* subsp. *lineare* (0.1%), *Nyssanthes erecta* (0.1%), *Parsonsia lanceolata* (0.1%), *Paspalidium constricutum* (0.9%), *Phyllanthus collinus* (0.1%), *Pseuderanthemum variabile* (0.1%), *Sida corrugata* (0.2%), *Solanum ellipticum* (0.1%), *Solanum parvifolium* (0.1%), *Sporobolus scabridus* (0.1%), *Themeda avenacea* (0.1%), *Vachellia bidwillii* (0.1%).

SECONDARY SITE 6 **11.9.2**



Latitude, Longitude: -22.3503, 148.2209

Community description: Woodland dominated by *Eucalyptus orgadophila* and *Corymbia erythrophloia* on clay soil derived from fine-grained sedimentary rock.

Dominant species per stratum:

T1: *Eucalyptus orgadophila.*
T2: *Corymbia erythrophloia*, *Eucalyptus orgadophila.*
S1: *Bursaria incana, Denhamia cunninghamii, Atalaya hemiglauca.*
S2: *Carissa ovata.*
U: *Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: T1 = 12.8 m (10.4–17.6 m), T2 = 5.2 m (4.0–7.0 m), S1 = 1.7 m (1.5–2.1 m), S2 = 0.9 m (0.5–1.2 m).

% cover of each stratum: T1 = 15.6%; T2 = 11.2% S1 = 0.5%, S2 = 3%; **total = 26.9%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia erythrophloia* = 1.33 m^2/ha; *Eucalyptus crebra* = 0.33 m^2/ha; *Eucalyptus orgadophila* = 0.5 m^2/ha **(total = 4.08 m^2/ha).**
T2: *Corymbia erythrophloia* = 1 m^2/ha **(total = 1 m^2/ha).**
S1: <0.17 m^2/ha).
S2: < 0.17 m^2/ha.

Landform: Low rise **Slope:** 1°N **Soil:** Dark-brown clay

Disturbance: Heavily grazed

Ground cover: Rock = 0%, wood = 0.5%, bare = 10%, litter = 4.2%, vegetation = 85.3%.

Species (percent cover): *Abildgaardia ovata* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Alloteropsis semialata* (0.1%), *Aristida gracilipes* (0.1%), *Atalaya hemiglauca* (0.1%), *Bothriochloa ewartiana* (0.2%), *Bothriochloa pertusa** (78.9%), *Brunoniella australis* (0.1%), *Carissa ovata* (3%), *Cenchrus ciliaris** (0.1%), *Chrysopogon fallax* (0.1%), *Corymbia erythrophloia* (0.1%), *Cyanthillium cinereum* (0.1%), *Denhamia cunninghamii* (0.1%), *Desmodium varians* (0.1%), *Enneapogon* sp. A (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Grewia latifolia* (0.1%), *Heliotropium peninsulare* (0.1%), *Indigofera linifolia* (0.1%), *Indigofera linnaei* (0.1%), *Melhania oblongifolia* (0.1%), *Neptunia gracilis* (0.1%), *Phyllanthus fuernrohrii* (0.1%), *Rhynchosia minima* (0.1%), *Rostellularia adscendens* (0.1%), *Scleria brownii* (0.1%), *Sida hackettiana* (0.1%), *Stylosanthes scabra** (0.3%), *Tephrosia filipes* subsp. *filipes* (0.1%), *Themeda triandra* (0.1%).

SECONDARY SITE 7 **11.10.7**



Latitude, Longitude: -22.3041, 148.1923

Community description: Low woodland dominated by *Corymbia clarksoniana* on a low sandstone rise. The community does not closely match any of the described regional ecosystems, but is closest to 11.10.1 and 11.10.7. Nearby areas of the ridge had *Eucalyptus crebra* and/or *Eucalyptus melanophloia* growing alongside *C. clarksoniana*, so 11.10.7 was considered the best fit for the community.

Dominant species per stratum:

T1: *Corymbia clarksoniana.*
T2: *Acacia flavescens, Acacia burdekensis, Alphitonia excelsa, Petalostigma pubescens.*
S1: *Erythroxylum australe, Leptospermum lamellatum, Petalostigma pubescens.*
G: *Melinis repens*, Digitaria eriantha*, Aristida calycina* var. *calycina.*

Median (and range) canopy height per stratum: T1 = 9.6 m (9.6–10.6 m), T2 = 6.4 m (4.6–6.8 m), S1 = 2.5 m (1–3 m)

% cover of each stratum: T1 = 22.1%; T2 = 13.6%; S1 = 6%; S2 = 11%; **total = 52.4%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia clarksoniana* = 1.83 m^2/ha **(total = 1.83 m^2/ha).**
T2: *Petalostigma pubescens* = 0.33 m^2/ha; *Corymbia clarksoniana* = 0.33 m^2/ha; *Terminalia porphyrocarpa* = 0.33 m^2/ha; *Alphitonia excelsa* = 0.17 m^2/ha; *Acacia burdekensis* = 0.17 m^2/ha **(total = 1.33 m^2/ha).**
S1: *Erythoxylum australe* = 0.67 m^2/ha **(total = 0.67 m^2/ha).**

Landform: Crest of low sandstone rise **Slope:** 4°NE **Soil:** Light grey-pink sand

Disturbance: Heavily grazed

Ground cover: Rock = 59%, wood = 1%, bare = 15%, litter = 15%, vegetation = 10%.

Species (percent cover): *Acacia flavescens* (0.2%), *Achyranthes aspera* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (0.5%), *Alphitonia excelsa* (0.1%), *Amaranthus interruptus* (0.1%), *Aristida benthamii* (0.1%), *Aristida calycina* var. *calycina* (1.7%), *Aristida holathera* (0.1%), *Bidens bipinnata** (0.1%), *Bidens pilosa** (0.1%), *Bonamia media* (0.1%), *Chamaecrista rotundifolia** (0.1%), *Cheilanthes sieberi* (0.1%), *Cleome viscosa* (0.1%), *Commelina lanceolata* (0.1%), *Cyperus betchei* (0.1%), *Digitaria eriantha** (3.7%), *Digitaria ramularis* (0.5%), *Dinebra decipiens* var. *decipiens* (0.1%), *Eragrostis spartinoides* (0.2%), *Eriachne mucronata* (0.5%), *Erythroxylum australe* (0.1%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Gomphrena celosioides** (0.1%), *Ipomoea brownii* (0.1%), *Larsenaikia ochreata* (0.1%), *Marsdenia microlepis* (0.1%), *Melinis repens** (2.7%), *Pandorea pandorana* (0.1%), *Paspalidium gracile* (0.1%), *Pavetta granitica* (0.3%), *Perotis rara* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus carpentariae* (0.1%), *Phyllanthus collinus* (0.1%), *Planchonella pohlmanniana* (0.1%), *Polycarpaea corymbosa* (0.1%), *Portulaca bicolor* (0.1%), *Portulaca oleracea** (0.1%), *Portulaca pilosa** (0.1%), *Pseuderanthemum variabile* (0.1%), *Setaria surgens* (0.1%), *Sida hackettiana* (0.3%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia filipes* subsp. *filipes* (0.1%), *Urochloa mosambicensis** (0.1%), *Xenostegia tridentata* (0.1%), *Zornia* sp. (0.1%).

SECONDARY SITE 8 **11.10.3**



Latitude, Longitude: -22.3037, 148.1864

Community description: Woodland dominated by *Acacia shirleyi* on sandstone crest.

Dominant species per stratum:

T1: *Acacia shirleyi, Alphitonia excelsa* (subdominant) *Corymbia clarksoniana* (subdominant).
S1: *Erythroxylum australe.*
G: *Alloteropsis cimicina*, *Cleistochloa subjuncea, Urochloa piligera.*

Median (and range) canopy height per stratum: T1 = 11.4 m (9.2–11.4 m), S1 = 3.5 (3.0–4.0 m).

% cover of each stratum: T1 = 36%; S1 = 27%; **total = 60.6%**.

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Acacia shirleyi* = 8.67 m^2/ha; *Corymbia clarksoniana* = 0.83 m^2/ha; *Alphitonia excelsa* = 0.5 m^2/ha **(total = 10.25 m^2/ha).**
S1: *Erythroxylum australe* = 0.5 m^2/ha **(total = 0.33 m^2/ha).**

Landform: Crest of sandstone ridge **Slope:** 1°N **Soil:** Grey sand

Disturbance: Heavily grazed; burn marks indicate a relatively recent fire.

Ground cover: Rock = 38%, wood = 2%, bare = 14%, litter = 32%, vegetation = 14%.

Species (percent cover): *Achyranthes aspera* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (6%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida enthamii* (0.5%), *Aristida calycina* var. *calycina* (0.1%), *Bidens bipinnata** (0.1%), *Chamaecrista absus* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (0.8%), *Cyanthillium cinereum* (0.1%), *Cyperus betchei* (0.1%), *Digitaria diminuta* (0.1%), *Eragrostis lacunaria* (0.1%), *Erythroxylum australe* (0.5%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Hibiscus meraukensis* (0.1%), *Ipomoea brownii* (0.1%), *Marsdenia microlepis* (0.1%), *Melinis repens* (0.2%), *Perotis rara* (0.1%), *Phyllanthus carpentariae* (0.1%), *Portulaca bicolor* (0.1%), *Portulaca pilosa** (0.1%), *Pseuderanthemum variabile* (0.1%), *Ptilotus polystachyus* (0.1%), *Scleria sphacelata* (0.1%), *Sida aprica* (0.1%), *Sida atherophora* (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Spermacoce brachystema* (0.1%), *Tinospora smilacina* (0.1%), *Urochloa piligera* (2.6%), *Wrightia saligna* (0.1%), *Xenostegia tridentata* (0.1%).

SECONDARY SITE 9 **11.10.3**



Latitude, Longitude: -22.3024, 148.1793

Community description: Low open forest dominated by *Acacia shirleyi*, with emergent *Corymbia citriodora*, on sandstone hillside.

Dominant species per stratum:

E: *Corymbia citriodora.*
T1: *Acacia shirleyi.*
S1: *Acacia shirleyi, Erythroxylum australe.*
G: *Cleistochloa subjuncea.*

Median (and range) canopy height per stratum: T1 = 9.8 m (7.6–9.8 m), S1 = (2.5–3.0 m).

% cover of each stratum: T1 = 52.7; S1 = 6.7; **total = 52.8%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Corymbia citriodora* = 0.17 m^2/ha **(total = 0.17 m^2/ha).**
T1: *Acacia shirleyi* = 7.5 m^2/ha; *Corymbia clarksoniana* = 0.17 m^2/ha **(total = 7.67 m^2/ha).**
S1: *Acacia shirleyi* <0.17 m^2/ha; *Erythroxylum australe* <0.17 m^2/ha **(total <0.17 m^2/ha).**

Landform: Rocky hillside **Slope:** 20°E **Soil:** Brown sandy-loam with sandstone boulders

Disturbance: Fire scars to 3 m high on tree trunks; lightly grazed.

Ground cover: Rock = 20%, wood = 4.5%, bare = 5%, litter = 10%, vegetation = 61.5%.

Species (percent cover): *Acacia shirleyi* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida benthamii* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (60%), *Cyanthillium cinereum* (0.1%), *Digitaria diminuta* (0.1%), *Erythroxylum australe* (0.1%), *Goodenia* sp. (Mt Castletower M.D. Crisp 2753) (0.1%), *Marsdenia microlepis* (0.1%), *Paspalidium gracile* (0.1%), *Persoonia falcata* (0.1%), *Phyllanthus collinus* (0.1%), *Scleria sphacelata* (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Solanum parvifolium* (0.1%).

SECONDARY SITE 10 **11.10.1**



Latitude, Longitude: -22.2971, 148.1753

Community description: Open forest dominated by *Corymbia citriodora* on sandstone.

Dominant species per stratum:

T1: *Corymbia citriodora, Corymbia trachyphloia.*
T2: *Acacia shirleyi, Lysicarpus angustifolius.*
S1: *Alphitonia excelsa, Dodonaea lanceolata.*
G: *Cleistochloa subjuncea, Melinis repens*, Scleria sphacelata.*

Median (and range) canopy height per stratum: T1 = 25.6 m (19–28.8 m), T2 = 10 m (9.2–11.8 m), S1 = 1.5 m (1.2–1.5 m).

% cover of each stratum: T1 = 51%; T2 = 45.6%; S1 = 3.6%; **total = 74.3%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia citriodora* = 2.83 m^2/ha **(total = 2.83 m^2/ha)**
T2: *Lysicarpus angustifolius* = 1.83 m^2/ha; *Acacia shirleyi* = 1 m^2/ha; *Eucalyptus crebra* = 1 m^2/ha; *Bursaria incana* = 0.33 m^2/ha; *Larsenaikia ochreata* = 0.17 m^2/ha; *Corymbia trachyphloia* = 0.17 m^2/ha **(total = 4.5 m^2/ha)**
S1: *Alphitonia excelsa* = 0.17 m^2/ha **(total = 0.17 m^2/ha)**

Landform: Steep foot slope of rocky hill **Slope:** 30°SE **Soil:** Sandy

Disturbance: Nil

Ground cover: Rock = 55%, wood = 1%, bare = 1%, litter = 25%, vegetation = 18%.

Species (percent cover): *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida benthamii* (0.2%), *Aristida calycina var. calycina* (0.1%), *Breynia oblongifolia* (0.1%), *Bursaria incana* (0.1%), *Capparis canescens* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (9%), *Corymbia citriodora subsp. citriodora* (0.1%), *Corymbia trachyphloia* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyclophyllum coprosmoides* (0.3%), *Cymbopogon obtectus* (0.1%), *Cymbopogon refractus* (0.2%), *Desmodium macrocarpum* (0.1%), *Dodonaea lanceolata* (0.1%), *Eragrostis spartinoides* (0.1%), *Erythroxylum australe* (0.1%), *Euphorbia drummondii* (0.1%), *Euphorbia tannensis* (0.1%), *Evolvulus alsinoides* (0.1%), *Gahnia aspera* (0.1%), *Galactia tenuiflora* (0.1%), *Goodenia* sp. (Mt Castletower M.D. Crisp 2753) (0.1%), *Hovea tholiformis* (0.1%), *Larsenaikia ochreata* (0.1%), *Leptospermum lamellatum* (0.1%), *Lomandra multiflora* (0.1%), *Marsdenia microlepis* (0.1%), *Melinis repens** (2%), *Murdannia graminea* (0.1%), *Oxalis corniculata* (0.1%), *Panicum effusum* (0.1%), *Persoonia amaliae* (0.1%), *Persoonia falcata* (0.1%), *Phyllanthus carpentariae* (0.1%), *Phyllanthus virgatus* (0.1%), *Pseuderanthemum variabile* (0.1%), *Rostellularia adscendens* (0.1%), *Scleria sphacelata* (2.2%), *Sida* sp. (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Solanum ellipticum* (0.1%), *Themeda triandra* (0.2%).

SECONDARY SITE 11 **HVR 11.5.9**



Latitude, Longitude: -22.3198, 148.1956

Community description: Open forest dominated by *Eucalyptus crebra* on sand plain.

Dominant species per stratum:

T1: *Eucalyptus crebra, Eucalyptus melanophloia* (subdominant).
S1: *Erythroxylum australe, Petalostigma pubescens.*
G: *Chrysopogon fallax*, *Bothriochloa pertusa**.

Median (and range) canopy height per stratum: T1 =12 m (10–14 m), S1 = 3 m (0.5–3 m).

% cover of each stratum: T1 = 54.7%; **total = 54.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 8 m^2/ha; *Eucalyptus melanophloia* = 0.5 m^2/ha; *Corymbia dallachiana* = 0.17 m^2/ha; *Corymbia clarksoniana* = 0.17 m^2/ha **(total = 8.84 m^2/ha)**
S1: *Erythroxylum australe* <0.15 m^2/ha; *Petalostigma pubescens* <0.15 m^2/ha **(total <0.15 m^2/ha)**

Landform: Gently sloping plain **Slope:** 2°S **Soil:** Yellow-grey sand

Disturbance: Previously cleared; regular fire has maintained an open understorey.

Ground cover: Rock = 0%, wood = 1.5%, bare = 40%, litter = 35%, vegetation = 23.5%.

Species: *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Bothriochloa decipiens* var. *cloncurrensis* (0.3%), *Bothriochloa pertusa** (20%), *Brunoniella australis* (0.1%), *Cenchrus ciliaris** (0.1%), *Chamaecrista absus* (0.1%), *Chloris divaricate* (0.1%), *Chrysopogon fallax* (5%), *Cyanthillium cinereum* (0.1%), *Cyperus fulvus* (0.1%), *Digitaria divaricatissima* (0.1%), *Digitaria* sp. A (0.1%), *Eragrostis sororia* (0.1%), *Eulalia aurea* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Glycine tomentella* (0.1%), *Gomphrena celosioides** (0.1%), *Grewia latifolia* (0.1%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Melhania oblongifolia* (0.1%), *Murdannia graminea* (0.1%), *Phyllanthus carpentariae* (0.8%), *Phyllanthus collinus* (0.1%), *Portulaca pilosa** (0.1%), *Rostellularia adscendens* (0.1%), *Scoparia dulcis** (0.1%), *Sida hackettiana* (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Sida spinosa** (0.2%), *Stylosanthes scabra** (0.1%), *Urochloa piligera* (0.1%), *Zornia areolata* (0.1%), *Zornia muriculata* subsp. *angustata* (0.1%).

SECONDARY SITE 12 **HVR 11.10.3**



Latitude, longitude: -22.3166, 148.1914

Community description: Low open forest dominated by *Acacia shirleyi*, with emergent *Eucalyptus crebra* and *Eucalyptus exserta*, on a sandstone ridge.

Dominant species per stratum:

E: *Eucalyptus crebra, Eucalyptus exserta.*
T1: *Acacia shirleyi.*
S1: *Erythroxylum australe.*
G: *Cleistochloa subjuncea, Paspalidium caespitosum.*

Median (and range) canopy height per stratum: T1 = 8.2 m (7–9.8 m), S1 = (1.5–4 m).

% cover of each stratum: T1 = 66.8%; S1 = 10%; **total 73.3%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: <0.17 m^2/ha)
T1: *Acacia shirleyi* =5.83 m^2/ha; *Eucalyptus exserta* = 1.3 m^2/ha; *Eucalyptus crebra* = 0.67 m^2/ha **(total = 7.8 m^2/ha)**
S1: *Erythroxylum australe* = 0.5 m^2/ha **(total = 0.5 m^2/ha)**

Landform: Ridge top **Slope:** 3°E **Soil:** Grey-brown silty sand

Disturbance: Burnt and probably previously cleared. Mapped as non-remnant.

Ground cover: Rock = 1%, wood = 6%, bare = 31%, litter = 42%, vegetation = 20%.

Species (percent cover): *Acacia shirleyi* (0.1%), *Alloteropsis cimicina* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.8%), *Calotis cuneifolia* (0.1%), *Cenchrus ciliaris** (0.1%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (0.1%), *Cleistochloa subjuncea* (8%), *Dianella nervosa* (0.1%), *Digitaria diminuta* (0.1%), *Eragrostis lacunaria* (0.2%), *Eriachne obtusa* (0.1%), *Erythroxylum australe* (0.1%), *Eucalyptus crebra* (0.1%), *Evolvulus alsinoides* (0.1%), *Jasminum didymum* subsp. *lineare* (0.1%), *Larsenaikia ochreata* (0.1%), *Marsdenia microlepis* (0.1%), *Opuntia tomentosa** (0.1%), *Panicum effusum* (0.1%), *Paspalidium caespitosum* (5%), *Paspalidium gracile* (0.4%), *Pseuderanthemum variabile* (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (1%), *Stylosanthes scabra** (0.4%), *Thyridolepis xerophila* (0.1%), *Urochloa mosambicensis** (0.2%).

SECONDARY SITE 13 **11.3.25**



Latitude, Longitude: -22.3866, 148.2619

Community description: Closed forest dominated by *Eucalyptus camaldulensis* and *Melaleuca fluviatilis* along an ephemeral watercourse.

Dominant species per stratum:

T1: *Eucalyptus camaldulensis, Melaleuca fluviatilis.*
T2: *Bauhinia hookeri.*
G: *Megathyrsus maximus* var. *pubiglumis *, Sida rhombifolia*, Bothriochloa pertusa*, Acanthospermum hispidum*, Urochloa mosambicensis*.*

Median (and range) canopy height per stratum: T1 = 24.8 m (15.6–55.8 m), T2 = 5 m.

% cover of each stratum: T1 = 86.9%; T2 = 0.5%; **total = 86.9 %**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus camaldulensis* = 5.67 m^2/ha; *Melaleuca fluviatilis* = 6 m^2/ha; *Corymbia tessellaris* = 0.3 m^2/ha **(total = 11.97 m^2/ha)**
T2: *Bauhinia hookeri* = 0.3 m^2/ha **(total = 0.3 m^2/ha)**

Landform: Creek bank **Slope:** 0° **Soil:** Brown clay

Disturbance: Grazed and with very high weed densities.

Ground cover: Rock = 0%, wood = 1%, bare = 5%, litter = 7%, vegetation = 87%.

Species (percent cover): *Acanthospermum hispidum** (8%), *Achyranthes aspera* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (0.1%), *Bauhinia hookeri* (0.1%), *Bidens bipinnata** (0.1%), *Bothriochloa pertusa** (30%), *Calyptocarpus vialis** (0.1%), *Carissa ovata* (0.1%), *Cenchrus ciliaris** (0.1%), *Chloris virgata** (0.1%), *Commelina diffusa* (0.1%), *Crinum arenarium* (0.1%), *Cynodon dactylon** (3%), *Datura leichhardtii** (0.1%), *Digitaria eriantha** (2%), *Echinochloa colona** (1%), *Eragrostis elongata* (0.1%), *Eucalyptus camaldulensis* (0.1%), *Ficus opposita* (0.1%), *Gomphrena celosioides** (0.1%), *Ipomoea plebia* (0.1%), *Malvastrum coromandelianum** (0.1%), *Megathyrsus maximus* var. *pubiglumis** (4%), *Melinis repens** (0.1%), *Parthenium hysterophorus** (0.2%), *Perotis rara* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca pilosa** (0.1%), *Scoparia dulcis** (0.1%), *Senna occidentalis** (0.1%), *Sida cordifolia** (0.3%), *Sida rhombifolia** (8%), *Sida spinosa** (0.1%), *Solanum ellipticum* (0.1%), *Stachytarpheta jamaicensis** (0.1%), *Stylosanthes hamata** (0.1%), *Urochloa mosambicensis** (20%), *Verbesina encelioides** (0.1%), *Xanthium occidentale** (0.2%), *Zornia muriculata* subsp. *angustata* (0.1%).

SECONDARY SITE 14 **Non-remnant**



Latitude, Longitude: -22.3909, 148.2546

Community description: Open pasture derived from cleared *Eucalyptus populnea* dominated woodland.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
S1: *Atalaya hemiglauca, Carissa ovata, Eucalyptus populnea.*
G: *Cenchrus ciliaris, Bothriochloa pertusa, Urochloa mosambicensis*

Median (and range) canopy height per stratum: T1 = 10 m (8–15.2 m), S1 = 2.5 m (1.5–4 m).

% cover of each stratum: T1 < 0.1%; S1 = 1.9%; **total = 1.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Persoonia falcata* = 0.75 m^2/ha; *Eucalyptus populnea* = 0.5 m^2/ha **(total = 1.25 m^2/ha)**
S1: *Atalaya hemiglauca* <0.15 m^2/ha, *Carissa ovata* <0.15 m^2/ha, *Eucalyptus populnea* <0.15 m^2/ha **(total = <0.15 m^2/ha)**

Landform: Plain **Slope:** 0° **Soil:** Dark-brown silt

Disturbance: Cleared, weed-infested and heavily grazed.

Ground cover: Rock = 0%, wood = 0.2%, bare = 10%, litter = 1%, vegetation = 88.8%.

Species: *Alternanthera nana* (0.1%), *Apowollastonia spilanthoides* (0.1%), *Atalaya hemiglauca* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa ewartiana* (0.1%), *Bothriochloa pertusa** (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (0.2%), *Cenchrus ciliaris** (65%), *Chrysopogon fallax* (0.1%), *Crotalaria juncea** (0.1%), *Cyanthillium cinereum* (0.1%), *Digitaria eriantha** (0.1%), *Enteropogon ramosus* (0.1%), *Eucalyptus populnea* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Gomphrena celosioides** (0.1%), *Grewia retusifolia* (0.1%), *Indigofera colutea* (0.1%), *Indigofera linnaei* (0.1%), *Neptunia gracilis* (0.1%), *Panicum effusum* (0.1%), *Parsonsia lanceolata* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca pilosa** (0.1%), *Rhynchosia minima* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Sphaeromorphaea australis* (0.1%), *Sporobolus caroli* (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes humilis** (0.1%), *Stylosanthes scabra** (0.1%), *Urochloa mosambicensis** (10%).

SECONDARY SITE 15 **Regrowth 11.5.3**



Latitude, Longitude: -22.3939, 148.25

Community description: Low open forest dominated by *Eucalyptus populnea* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus populnea*.
T2: *Eucalyptus populnea*.
S1: *Carissa ovata*.
G: *Bothriochloa pertusa*, Sida hackettiana*

Median (and range) canopy height per stratum: T1 = 9.8 m (9.6–12 m), S1 = 1.6 m (1.4–2.5 m).

% cover of each stratum: T1 = 62.9%; S1 = 7%; **total = 66.2%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 8.17 m^2/ha; *Corymbia clarksoniana* = 0.33 m^2/ha; *Persoonia falcata* = 0.16 m^2/ha **(total = 8.66 m^2/ha)**
T2: *Eucalyptus populnea* <0.17 m^2/ha **(total <0.17 m^2/ha)**
S1: *Carissa ovata* <0.17 m^2/ha **(total < 0.17 m^2/ha)**

Landform: Plain **Slope:** 1°SW **Soil:** Yellow-brown loam.

Disturbance: Previously cleared and not quite old enough to qualify as high-value regrowth?; heavily grazed.

Ground cover: Rock = 0%, wood = 1%, bare = 53%, litter = 32%, vegetation = 14%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Alternanthera denticulata* (0.1%), *Alternanthera nana* (0.1%), *Apowollastonia spilanthoides* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa pertusa** (8.6%), *Brunoniella australis* (0.1%), *Carissa ovata* (0.1%), *Cenchrus ciliaris** (0.1%), *Chrysopogon fallax* (0.1%), *Cyperus gracilis* (0.1%), *Enteropogon ramosus* (0.1%), *Eremophila debilis* (0.1%), *Eucalyptus populnea* (0.1%), *Evolvulus alsinoides* (0.1%), *Glycine* sp. (Mackay S.B. Andrews+ 43) (0.1%), *Gomphrena celosioides** (0.1%), *Grewia latifolia* (0.1%), *Grewia retusifolia* (0.6%), *Owenia acidula* (0.1%), *Phyllanthus collinus* (0.1%), *Portulaca oleracea** (0.1%), *Rhynchosia minima* (0.1%), *Sida hackettiana* (1.4%), *Sida spinosa** (0.1%), *Solanum ellipticum* (0.1%), *Sporobolus caroli* (0.1%), *Stylosanthes scabra** (0.1%), *Urochloa mosambicensis** (0.8%).

SECONDARY SITE 16 **11.5.3**



Latitude, Longitude: -22.3920, 148.2295

Community description: Open forest dominated by *Eucalyptus populnea* on sandy soils.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
T2: *Corymbia clarksoniana, Eucalyptus populnea.*
G: *Cenchrus ciliaris*.*

Median (and range) canopy height per stratum: T1 = 14.2 m (13.4–18 m), T2 = 7.2 m (0.4–7.2 m), S1 = 3 m (2.0–4.0 m).

% cover of each stratum: T1 = 52.2%; T2 = 45.6%; **total = 72%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 5.17 m^2/ha **(total = 5.17 m^2/ha)**
T2: *Eucalyptus populnea* = 4.25 m^2/ha; *Corymbia clarksoniana* = 0.5 m^2/ha **(total = 4.75 m^2/ha)**

Landform: Plain on low rise **Slope:** 2°S **Soil:** Yellow-brown sand

Disturbance: Grazed and dominated by weed understorey.

Ground cover: Rock = 0%, wood = 1.5%, bare = 20%, litter = 30%, vegetation = 48.5%.

Species (percent cover): *Acanthospermum hispidum** (0.1%), *Achyranthes aspera* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Archidendropsis basaltica* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida holathera* (0.1%), *Aristolochia thozetii* (0.1%), *Boerhavia pubescens* (0.1%), *Bonamia media* (0.5%), *Bothriochloa pertusa** (0.5%), *Breynia oblongifolia* (0.1%), *Brunoniella australis* (0.1%), *Calotis cuneifolia* (0.1%), *Capparis canescens* (0.1%), *Capparis lasiantha* (0.1%), *Cenchrus ciliaris** (42%), *Chrysopogon fallax* (0.1%), *Clerodendrum tomentosum* (0.1%), *Cyanthillium cinereum* (0.1%), *Dactyloctenium radulans* (0.1%), *Dysphania melanocarpa* forma *melanocarpa* (0.1%), *Enneapogon lindleyanus* (0.1%), *Enteropogon ramosus* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Glycine* sp. (Mackay S.B. Andrews+ 43) (0.1%), *Glycine tomentella* (0.1%), *Gomphrena celosioides** (0.1%), *Grewia retusifolia* (0.1%), *Ipomoea polymorpha* (0.1%), *Parsonsia lanceolata* (0.1%), *Phyllanthus collinus* (0.1%), *Portulaca filifolia* (0.1%), *Rostellularia adscendens* (0.1%), *Setaria surgens* (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes humilis** (0.1%), *Urochloa mosambicensis** (1%), *Ventilago viminalis* (0.1%), *Zornia areolata* (0.1%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 17 **11.5.9**



Latitude, Longitude: -22.3839, 148.2236

Community description: Low open woodland dominated by *Corymbia clarksoniana*. Despite the absence of *Eucalyptus crebra*, it otherwise resembles regional ecosystem 11.5.9 in structure and floristics of the lower strata. A small number of sandstone boulders suggests that it might be 11.10.7 instead of 11.5.2, but the land form was otherwise a sandy plain.

Dominant species per stratum:

T1: *Corymbia clarksoniana.*
T2: *Acacia burdekensis, Alphitonia excelsa.*
S1: *Melaleuca nervosa.*
G: *Melinis repens*, Perostis rara, Alloteropsis cimicina, Aristida calycina* var. *calycina.*

Median (and range) canopy height per stratum: T1 =9.6 m (8.6–12.2 m), T2 = 6.4 m (5.4–7 m), S1 = 3.0 m (2.0–4.0 m).

% cover of each stratum: T1 = 3.7%; T2 = 14.3%; S1 = 10.7%; t**otal = 26.6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia clarksoniana* = 1.5 m^2/ha **(total = 1.5 m^2/ha)**
T2: *Acacia burdekensis* = 0.83 m^2/ha; *Alphitonia excelsa* = 0.33 m^2/ha; *Petalostigma pubescens* = 0.17 m^2/ha; *Bursaria incana* = 0.17 m^2/ha **(total = 1.5 m^2/ha)**
S1: *Melaleuca nervosa* = 1.5 m^2/ha **(total = 1.5 m^2/ha)**

Landform: Low sandy plateau **Slope:** 2°N **Soil:** Yellow-brown coarse sand with scattered sandstone boulders.

Disturbance: Lightly grazed.

Ground cover: Rock = 1%, wood = 2%, bare = 45%, litter = 22%, vegetation = 30%.

Species: *Acacia burdekensis* (0.1%), *Acanthospermum hispidum** (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (2%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (3%), *Bonamia media* (0.1%), *Chamaecrista absus* (0.1%), *Chrysopogon fallax* (0.1%), *Cleome tetrandra* var. *tetrandra* (0.1%), *Cyanthillium cinereum* (0.1%), *Dactyloctenium radulans* (0.9%), *Digitaria eriantha** (0.6%), *Dysphania melanocarpa* forma *melanocarpa* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (0.1%), *Erythroxylum australe* (0.1%), *Fimbristylis dichotoma* (0.1%), *Glycine tomentella* (0.1%), *Goodenia glabra* (0.1%), *Heliotropium peninsulare* (0.1%), *Indigofera colutea* (0.1%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Melinis repens** (9%), *Paspalidium rarum* (0.1%), *Perotis rara* (3.7%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.1%), *Portulaca bicolor* (0.2%), *Psydrax oleifolia* (0.1%), *Setaria surgens* (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (1.3%), *Spermacoce brachystema* (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes scabra** (0.4%), *Tribulopis angustifolia* (0.1%), *Urochloa mosambicensis** (1%), *Urochloa piligera* (5%), *Zornia* sp. (0.1%).

SECONDARY SITE 18 **11.5.3**



Latitude, Longitude: -22.3767, 148.2250

Community description: Woodland dominated by *Eucalyptus populnea* on a sand plain.

Dominant species per stratum:

T1: *Corymbia dallachiana.*
T2: *Alphitonia excelsa, Acacia burdekensis, Eucalyptus populnea, Melaleuca nervosa.*
S1: *Erythroxylum australe.*
G: *Alloteropsis cimicina, Chrysopogon fallax, Eragrostis speciosa*, *Perotis rara, Sida hackettiana, Urochloa piligera.*

Median (and range) canopy height per stratum: T1 = 16.6 m (12.8–17.2 m), T2 = 6.4 m (6.0–7.2 m), S1 = 1.8 m (1.0–2.0 m).

% cover of each stratum: T1 = 2%; T2 = 45.4%; S1 = 4.4%; **total = 51.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Acacia burdekensis* = 2.33 m^2/ha; *Eucalyptus populnea* = 1.67 m^2/ha; *Corymbia dallachiana* = 0.3 m^2/ha; *Corymbia clarksoniana* = 0.17 m^2/ha **(total = 4.47 m^2/ha)**
T2: *Melaleuca nervosa* = 4.83 m^2/ha; *Alphitonia excelsa* = 0.67 m^2/ha; **(total = 5.5 m^2/ha)**
S1: *Erythroxylum australe* <0.15 m^2/ha **(total <0.15 m^2/ha)**

Landform: Low sandy plateau. **Slope:** 2°N **Soil:** Yellow-brown sand with scattered boulders.

Disturbance: Light grazing.

Ground cover: Rock = 0.5%, wood = 2%, bare = 40%, litter = 23%, vegetation = 33.5%.

Species (percent cover): *Acanthospermum hispidum** (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (7.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (8.1%), *Cyanthillium cinereum* (0.1%), *Desmodium filiforme* (0.1%), *Digitaria minima* (0.1%), *Eragrostis spartinoides* (0.1%), *Eragrostis speciosa* (2.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Murdannia graminea* (0.1%), *Perotis rara* (8%), *Phyllanthus collinus* (0.1%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.1%), *Portulaca filifolia* (1.2%), *Portulaca pilosa** (0.1%), *Setaria surgens* (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (2.1%), *Sida spinosa** (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia leptoclada* (0.1%), *Tribulopis angustifolia,* (0.1%), *Urochloa piligera* (2.2%), *Zornia* sp. (0.1%).

SECONDARY SITE 19 **11.4.8**



Latitude, Longitude: -22.3772, 148.2379

Community description: Woodland dominated by *Acacia harpophylla* and *Eucalyptus cambageana* on a clay plain.

Dominant species per stratum:

T1: *Acacia harpophylla, Eucalyptus cambageana.*
S1: *Eremophila mitchellii, Ventilago viminalis.*
S2: *Carissa ovata.*
G: *Cenchrus ciliaris*, Chloris ventricosa, Urochloa mosambicensis*.*

Median (and range) canopy height per stratum: T1 = 11.6 m (10.6–14.6 m), S1 = 5.5 m (5.0–6.0 m), S2 = 1 m (0.5–1.6 m).

% cover of each stratum: T1 = 27.7%; S1 = 5.4%; S2 = 33.2%; **total = 53.8%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Acacia harpophylla* = 5.67 m^2/ha; *Eucalyptus cambageana* = 1.67 m^2/ha **(total = 7.34 m^2/ha)**
S1: *Eremophila mitchellii* = 0.3 m^2/ha; *Flindersia dissosperma* = 0.17 m^2/ha **(total = 0.47 m^2/ha)**
S2: *Carissa ovata* <0.15 m^2/ha **(total <0.15 m^2/ha)**

Landform: Plain **Slope:** 1°E **Soil:** Grey-brown sandy-clay, possibly heavier subsoil. No gilgais.

Disturbance: Grazed; numerous dead trees.

Ground cover: Rock = 0%, wood = 1%, bare = 20%, litter = 20%, vegetation = 59%.

Species (percent cover): *Abutilon oxycarpum* var. *incanum* (0.3%), *Acacia harpophylla* (0.6%), *Achyranthes aspera* (0.1%), *Alternanthera nana* (0.8%), *Ancistrachne uncinata* (0.1%), *Aristida gracilipes* (0.5%), *Atalaya hemiglauca* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa pertusa** (0.5%), *Brunoniella australis* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (37%), *Cassia brewsteri* (0.1%), *Cenchrus ciliaris** (5%), *Cheilanthes sieberi* (0.1%), *Chloris divaricata* (6%), *Desmodium varians* (0.1%), *Ehretia membranifolia* (0.1%), *Einadia nutans* (0.1%), *Einadia nutans* subsp. *linifolia* (0.1%), *Eragrostis lacunaria* (1%), *Eremophila mitchellii* (0.1%), *Evolvulus alsinoides* (0.1%), *Grewia latifolia* (0.1%), *Harrisia martinii** (0.1%), *Jacquemontia paniculata* (0.1%), *Maireana microphylla* (0.1%), *Melhania oblongifolia* (0.1%), *Nyssanthes erecta* (0.1%), *Opuntia tomentosa** (0.1%), *Owenia acidula* (0.1%), *Parsonsia lanceolata* (0.1%), *Parthenium hysterophorus** (0.5%), *Paspalidium caespitosum* (0.1%), *Paspalidium distans* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca oleracea** (0.1%), *Portulaca pilosa** (0.1%), *Pseuderanthemum variabile* (0.1%), *Salsola australis* (0.1%), *Sida hackettiana* (0.1%), *Sida rohlenae* (0.1%), *Sporobolus caroli* (0.4%), *Urochloa mosambicensis** (3%), *Urochloa piligera* (0.1%), *Ventilago viminalis* (0.1%).

SECONDARY SITE 20 **HVR 11.5.3**



Latitude, Longitude: -22.3787, 148.2139

Community description: Open forest dominated by *Eucalyptus populnea* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
T2: *Eucalyptus populnea.*
S1: *Eucalyptus populnea, Erythroxylum australe.*
G: *Bothriochloa pertusa*, Aristida calycina* var. *calycina, Fimbristylis dichotoma.*

Median (and range) canopy height per stratum: T1 = 14.8 m (10.0–15.6 m), T2 = 3.0 m (2.5–4.0 m), S1 = 1.0 m (0.5–1.5 m).

% cover of each stratum: T1 = 58.4%; T2 = 2.1%; S1 = 1.6%; **total = 60.5%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 12.17 m^2/ha **(total = 12.17 m^2/ha)**
T2: *Eucalyptus populnea* < 0.17 **(total < 0.17 m^2/ha)**
S1: *Erythroxylum australe* < 0.17 **(total < 0.17 m^2/ha)**

Landform: Plain **Slope:** 1°NE **Soil:** Yellow-brown sand

Disturbance: Previously cleared; heavily grazed.

Ground cover: Rock = 0%, wood = 2%, bare = 40%, litter = 20%, vegetation = 38%.

Species (percent cover): *Alloteropsis cimicina* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera denticulata* (0.1%), *Alternanthera nana* (0.1%), *Apowollastonia spilanthoides* (0.1%), *Aristida calycina* var. *calycina* (1%), *Boerhavia pubescens* (0.1%), *Bothriochloa pertusa** (26.6%), *Carissa ovata* (0.1%), *Cenchrus ciliaris** (0.3%), *Cheilanthes sieberi* (0.1%), *Chloris divaricata* (3%), *Chloris virgata** (0.1%), *Chrysopogon fallax* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyperus fulvus* (0.1%), *Digitaria longiflora* (0.1%), *Enneapogon lindleyanus* (0.1%), *Eragrostis lacunaria* (1%), *Eragrostis leptostachya* (0.1%), *Eragrostis sororia* (0.1%), *Eremophila debilis* (0.1%), *Erythroxylum australe* (0.1%), *Eucalyptus populnea* (0.1%), *Euphorbia drummondii* (0.1%), *Fimbristylis dichotoma* (2%), *Gomphrena celosioides** (0.1%), *Grewia latifolia* (0.1%), *Ipomoea polymorpha* (0.1%), *Melhania oblongifolia* (0.1%), *Murdannia graminea* (0.1%), *Opuntia tomentosa** (0.1%), *Panicum effusum* (0.1%), *Phyllanthus collinus* (0.1%), *Phyllanthus* sp. (Myra Vale J.J. BruhlJ.J. Bruhl+ 1810) (0.1%), *Portulaca filifolia* (0.1%), *Portulaca pilosa** (0.1%), *Rhynchosia minima* (0.1%), *Rostellularia adscendens* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%), *Urochloa mosambicensis** (0.1%), *Vittadinia pustulata* (0.1%), *Zornia areolata* (0.1%).

SECONDARY SITE 21 **11.3.25**



Latitude, Longitude: -22.3736, 148.2149

Community description: Open forest dominated by *Corymbia tessellaris, Melaleuca fluviatilis, Eucalyptus camaldulensis* and *Casuarina cunninghamiana* on the banks of an ephemeral watercourse.

Dominant species per stratum:

T1: *Casuarina cunninghamiana, Corymbia tessellaris, Eucalyptus camaldulensis, Melaleuca fluviatilis.*
S1: *Bauhinia hookeri, Lophostemon grandiflorus.*
G: *Megathyrsus maximus* var. *pubiglumis*, Bothriochloa ewartiana.*

Median (and range) canopy height per stratum: T1 = 24.2 m (21.8–24.4 m), S1 = 5.0 m (3.0–9.6 m).

% cover of each stratum: T1 = 62.4%; S1 = 46.9%; **total = 95.5%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia tessellaris* = 4.33 m^2/ha; *Melaleuca fluviatilis* = 3.17 m^2/ha; *Casuarina cunninghamiana* = 1.17 m^2/ha; *Eucalyptus camaldulensis* = 1.17 m^2/ha; *Cassia brewsteri* = 0.17 m^2/ha **(total = 10.01 m^2/ha).**
S1: *Bauhinia hookeri* = 0.67 m^2/ha; *Casuarina cunninghamiana* = 0.17 m^2/ha; *Lophostemon grandiflorus* = 0.17 m^2/ha; *Melaleuca fluviatilis* = 0.17 m^2/ha **(total = 1.18 m^2/ha).**

Landform: Creek bank **Slope:** 40°N **Soil:** Yellow sand

Disturbance: High weed densities.

Ground cover: Rock = 0%, wood = 1%, bare = 3%, litter = 30%, vegetation = 66%.

Species (percent cover): *Abutilon guineense** (0.1%), *Acacia salicina* (0.1%), *Acanthospermum hispidum** (0.1%), *Achyranthes aspera* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Ageratum conyzoides** (0.1%), *Ajuga australis* (0.1%), *Alloteropsis cimicina* (0.1%), *Bauhinia hookeri* (0.1%), *Bidens pilosa** (0.1%), *Bothriochloa ewartiana* (7%), *Bothriochloa pertusa** (0.2%), *Calyptocarpus vialis* (0.1%), *Cenchrus ciliaris** (0.1%), *Chamaecrista absus* (0.1%), *Cheilanthes sieberi* (0.1%), *Chloris virgata** (0.1%), *Clematicissus opaca* (0.1%), *Clerodendrum floribundum* (0.1%), *Commelina diffusa* (0.7%), *Crotalaria mitchellii* (0.1%), *Cyanthillium cinereum* (0.2%), *Cynodon dactylon** (0.1%), *Cyperus gracilis* (0.1%), *Cyperus leiocaulon* (0.1%), *Digitaria ammophila* (0.1%), *Digitaria eriantha** (0.2%), *Dysphania melanocarpa* forma *melanocarpa* (0.1%), *Emilia sonchifolia** (0.1%), *Euphorbia hirta** (0.1%), *Ficus opposita* (0.1%), *Glycine tomentella* (0.7%), *Grewia retusifolia* (0.1%), *Heteropogon contortus* (0.1%), *Ipomoea plebia* (0.1%), *Lomandra longifolia* (0.1%), *Megathyrsus maximus* var. *pubiglumis** (52%), *Melaleuca fluviatilis* (0.1%), *Oxalis corniculata* (0.1%), *Parthenium hysterophorus** (0.1%), *Pimelea sericostachya* (0.3%), *Rostellularia adscendens* (0.1%), *Senna occidentalis** (0.1%), *Setaria surgens* (0.1%), *Sida cordifolia** (0.1%), *Sida rhombifolia* (0.1%), *Stephania japonica* (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes humilis** (0.1%), *Tinospora smilacina* (0.1%), *Tridax procumbens** (0.1%), *Urochloa foliosa* (0.1%), *Urochloa mosambicensis** (0.1%), *Xanthium occidentale** (0.1%).

SECONDARY SITE 22 **HVR 11.5.9**



Latitude, Longitude: -22.3761, 148.2097

Community description: Woodland dominated by *Eucalyptus melanophloia* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus melanophloia.*
T2: *Melaleuca nervosa.*
S1: *Melaleuca nervosa.*
G: *Chrysopogon fallax, Bothriochloa pertusa*, Perotis rara, Alloteropsis cimicina.*

Median (and range) canopy height per stratum: T1 = 10.2 m (8.0–11.8 m), T2 = 5.2 m (4.6–5.6 m), S1 = 1.6 m (1.0–2.4 m).

% cover of each stratum: T1 = 37%; T2 < 0.1%; S1 < 0.1%; **total = 37%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus melanophloia* = 9.83 m^2/ha **(total = 9.83 m^2/ha)**
T2: *Melaleuca nervosa* = 0.83 m^2/ha **(total = 0.83 m^2/ha)**
S1: total < 0.17 m^2/ha

Landform: Slight rise. **Slope:** 3°N **Soil:** Yellow sand.

Disturbance: Previously cleared but probably very old regrowth; heavily grazed.

Ground cover: Rock = 0%, wood = 1%, bare = 30%, litter = 18%, vegetation = 51%.

Species (percent cover): *Acanthospermum hispidum** (0.1%), *Alloteropsis cimicina* (8%), *Aristida inaequiglumis* (0.1%), *Bonamia media* (0.1%), *Bothriochloa pertusa** (28%), *Chrysopogon fallax* (8%), *Dactyloctenium radulans* (0.1%), *Digitaria longiflora* (0.1%), *Eragrostis sororia* (0.1%), *Eragrostis speciosa* (0.1%), *Eucalyptus melanophloia* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Heliotropium peninsulare* (0.1%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Paspalidium rarum* (0.1%), *Perotis rara* (1%), *Phyllanthus* sp. (Myra Vale.J. Bruhl+ 1810) (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca pilosa** (0.1%), *Setaria surgens* (0.2%), *Sida hackettiana* (0.2%), *Stylosanthes hamata** (3.5%), *Stylosanthes scabra** (0.1%), *Tribulopis angustifolia* (0.1%), *Urochloa piligera* (0.1%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 23 **11.9.2**



Latitude, Longitude: -22.3641, 148.2071

Community description: Open forest dominated by *Eucalyptus orgadophila* on clay soil derived from fine-grained sedimentary rock.

Dominant species per stratum:

T1: *Eucalyptus orgadophila.*
T2: *Acacia excelsa, Corymbia erythrophloia.*
S1: *Erythroxylum australe, Ventilago viminalis.*
G: *Bothriochloa pertusa*, Enneapogon* sp., *Jaquemontia paniculata*, *Melhania oblongifolia*

Median (and range) canopy height per stratum: T1 = 17.6 m (12.4–18.2 m), T2 = 7.6 m (6.8–8.6 m), S1 = 2.3 m (2.0–3.0 m).

% cover of each stratum: T1 = 69.6%; T2 = 5%; S1 = 4.9%; **total = 75.1%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus orgadophila* = 6.5 m^2/ha; *Acacia excelsa* = 2.5 m^2/ha **(total = 9 m^2/ha)**
T2: *Bursaria incana* = 0.17 m^2/ha; *Corymbia erythrophloia* = 0.33 m^2/ha **(total = 0.5 m^2/ha)**
S1: total < 0.17 m^2/ha

Landform: Low rise. **Slope:** 12°S **Soil:** Dark-brown clay-loam imbedded sandstone.

Disturbance: Lightly grazed

Ground cover: Rock = 0.1%, wood = 0.7%, bare = 25%, litter = 55%, vegetation = 19.2%.

Species (percent cover): *Acacia excelsa* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Aristida gracilipes* (0.5%), *Aristida holathera* (0.1%), *Atalaya hemiglauca* (0.1%), *Bothriochloa ewartiana* (0.4%), *Bothriochloa pertusa** (9%), *Brunoniella australis* (0.1%), *Bursaria incana* (0.1%), *Carissa ovata* (0.4%), *Cassytha filiformis* (0.4%), *Cenchrus ciliaris** (0.3%), *Enneapogon* sp. A (2%), *Eucalyptus orgadophila* (0.1%), *Euphorbia drummondii* (0.1%), *Eustrephus latifolius* (0.1%), *Glycine tomentella* (0.1%), *Heteropogon contortus* (0.1%), *Indigofera linifolia* (0.1%), *Indigofera linnaei* (0.1%), *Jacquemontia paniculata* (1%), *Lomandra multiflora* (0.1%), *Melhania oblongifolia* (1.6%), *Melinis repens* (0.1%), *Ocimum caryophyllinum* (0.6%), *Peripleura hispidula* var. *setosa* (0.1%), *Phyllanthus maderaspatensis* (0.1%), *Psydrax oleifolia* (0.1%), *Rostellularia adscendens* (0.4%), *Scleria brownii* (0.1%), *Sida hackettiana* (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes scabra** (0.1%), *Themeda triandra* (0.1%), *Urochloa foliosa* (0.1%), *Vachellia bidwillii* (0.1%), *Ventilago viminalis* (0.1%).

SECONDARY SITE 24 **11.10.1x1**



Latitude, Longitude: -22.3566, 148.1916

Community description: Woodland dominated by *Corymbia aureola* on a low sandstone rise.

Dominant species per stratum:

T1: *Corymbia aureola, Eucalyptus crebra, Eucalyptus melanophloia.*
T2: *Acacia curvinervia, Acacia burdekensis.*
S1: *Erythroxylum australe.*
G: *Alloteropsis cimicina, Melinis repens*.*

Median (and range) canopy height per stratum: T1 = 13.8 m (10.8–15.2 m), T2 = 5.6 m (4.0–6.0 m), S1 = 2.5 m (1.0–3.0 m).

% cover of each stratum: T1 = 33.6%; T2 = 62%; S1 = 15.1%; **total = 84.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia aureola* = 2.83 m^2/ha; *Alphitonia excelsa* = 1 m^2/ha; *Acacia burdekensis* = 0.5 m^2/ha; *Eucalyptus crebra* = 0.33 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha; *Petalostigma pubescens* = 0.17 m^2/ha; **(total = 5 m^2/ha)**
T2: *Acacia curvinervia* = 3 m^2/ha; *Corymbia aureola* = 1 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha; **(total = 4.17 m^2/ha)**
S1: *Erythroxylum australe* = 1 m^2/ha **(total = 1 m^2/ha)**

Landform: Rocky hillside. **Slope:** 9°NE **Soil:** Yellow-grey sand

Disturbance: Grazed

Ground cover: Rock = 28%, wood = 1.5%, bare = 33%, litter = 20%, vegetation = 17.5%.

Species (percent cover): *Acacia bancroftiorum* (0.1%), *Acacia curvinervia* (0.1%), *Acacia dietrichiana* (0.1%), *Alloteropsis cimicina* (8%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Bonamia media* (0.1%), *Chamaecrista absus* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (0.1%), *Corymbia aureola* (0.1%), *Eragrostis lacunaria* (0.1%), *Erythroxylum australe* (0.1%), *Euphorbia bifida* (0.1%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Heliotropium peninsulare* (0.1%), *Hibiscus meraukensis* (0.1%), *Ipomoea brownii* (0.1%), *Ipomoea plebia* (0.1%), *Larsenaikia ochreata* (0.1%), *Melinis repens** (1.5%), *Phyllanthus carpentariae* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Spermacoce brachystema* (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia filipes* subsp. *filipes* (0.1%), *Tinospora smilacina* (0.1%), *Urochloa piligera* (5.1%), *Xenostegia tridentata* (0.1%).

SECONDARY SITE 25 **Non-remnant**



Latitude, Longitude: -22.3597, 148.1994

Community description: Pasture with scattered *Eucalyptus crebra* on sand plain. Area was likely to formerly have been regional ecosystem 11.5.9.

Dominant species per stratum:

T1: *Eucalyptus crebra, Grevillea striata.*
S1: *Archidendropsis basaltica, Atalaya hemiglauca.*
G: *Urochloa mosambicensis*, Chloris barbata*.*

Median (and range) canopy height per stratum: T1 = 14.8 m (12.4–19 m), S1 = 2.0 m (0.5–4.0 m).

% cover of each stratum: T1 < 0.1%, S1 = 3.4; **total = 3.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 3 m^2/ha **(total = 3 m^2/ha).**
S2: *Archidendropsis basaltica* = 0.17 m^2/ha; *Atalaya hemiglauca* = 0.17 m^2/ha **(total = 0.34 m^2/ha).**

Landform: Low rise on sand plain **Slope:** 2°SSE **Soil:** Yellow-sand

Disturbance: Previously cleared, and probably thinned since; heavily grazed.

Ground cover: Rock = 0%, wood = 0.2%, bare = 49.8%, litter = 18%, vegetation = 32%.

Species (percent cover): *Acanthospermum hispidum** (0.1%), *Alloteropsis cimicina* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Archidendropsis basaltica* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Bothriochloa pertusa** (0.9%), *Brunoniella australis* (0.1%), *Cenchrus ciliaris** (0.4%), *Chamaecrista absus* (0.1%), *Cheilanthes sieberi* (0.1%), *Chloris barbata** (6.1%), *Chrysopogon fallax* (0.1%), *Cyanthillium cinereum* (0.1%), *Dactyloctenium radulans* (0.1%), *Digitaria ciliaris* (0.1%), *Dysphania melanocarpa* forma *melanocarpa* (0.1%), *Einadia nutans* (0.1%), *Enteropogon ramosus* (0.1%), *Eragrostis lacunaria* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.8%), *Gomphrena celosioides** (0.1%), *Indigofera colutea* (0.1%), *Ipomoea polymorpha* (0.1%), *Murdannia graminea* (0.1%), *Perotis rara* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus* sp. (Myra Vale.J. Bruhl+ 1810) (0.1%), *Portulaca pilosa** (0.1%), *Sida cordifolia** (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (1%), *Urochloa mosambicensis** (20%).

SECONDARY SITE 26 **11.5.3**



Latitude, Longitude: -22.3707, 148.2025

Community description: Open forest dominated by *Eucalyptus populnea* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
T2: *Acacia excelsa, Eremophila mitchellii, Ventilago viminalis.*
S1: *Carissa ovata, Erythroxylum australe.*
G: *Bothriochloa pertusa*, Aristida gracilipes*, *Cyperus gracilis.*

Median (and range) canopy height per stratum: T1 = 15.6 m (11–16.6 m), T2 = 7.2 m (5.2–9.0 m), S1 = 1.8 m (1.4–2.5 m).

% cover of each stratum: T1 = 53.3%; T2 = 17%; S1 = 49.5%; **total = 88.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 8.67 m^2/ha; *Acacia excelsa* = 0.33 m^2/ha **(total = 9 m^2/ha)**
T2: *Eremophila mitchellii* = 3.33 m^2/ha; *Ventilago viminalis* = 2.33 m^2/ha; *Alphitonia excelsa* = 0.17 m^2/ha **(total = 5.83 m^2/ha)**
S1: *Erythroxylum australe* = 0.17 m^2/ha **(total = 0.17 m^2/ha)**

Landform: Plain. Supposed to be land zone 3, but there was no noticeable terrace. It was a high bank from the creek up to the plain.

Slope: 0° **Soil:** Fine yellow-grey sand

Disturbance: Grazed

Ground cover: Rock = 0%, wood = 2%, bare = 31%, litter = 52%, vegetation = 15%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Abutilon oxycarpum* var. *incanum* (0.1%), *Acacia excelsa* (0.1%), *Achyranthes aspera* (0.1%), *Alternanthera denticulata* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida gracilipes* (4%), *Atalaya hemiglauca* (0.1%), *Boerhavia pubescens* (0.2%), *Bonamia media* (0.1%), *Bothriochloa pertusa** (3.7%), *Breynia oblongifolia* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (1%), *Cassia brewsteri* (0.1%), *Cenchrus ciliaris** (0.2%), *Chloris divaricata* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyperus gracilis* (1.7%), *Einadia nutans* (0.2%), *Enneapogon lindleyanus* (0.1%), *Eragrostis lacunaria* (0.2%), *Eremophila mitchellii* (0.1%), *Erythroxylum australe* (0.1%), *Eucalyptus populnea* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Gomphrena celosioides** (0.1%), *Grewia retusifolia* (0.1%), *Malvastrum americanum** (0.1%), *Melhania oblongifolia* (0.2%), *Nyssanthes erecta* (0.1%), *Parsonsia lanceolata* (0.3%), *Phyllanthus collinus* (0.1%), *Portulaca oleracea** (0.1%), *Salsola australis* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.2%), *Sporobolus caroli* (0.1%), *Tribulus terrestris** (0.1%), *Ventilago viminalis* (0.1%).

SECONDARY SITE 27 **Non-remnant**



Latitude, Longitude: -22.3803, 148.2550

Community description: Open pasture with scattered *Eucalyptus populnea*

Dominant species per stratum:

T1: *Eucalyptus populnea.*
S1: *Cassia brewsteri.*
G: *Bothriochloa pertusa*, Urochloa mosambicensis*, Fimbristylis dichotoma.*

Median (and range) canopy height per stratum: T1 = 9.1 m (7.2–24.6 m), S1 = 1.5 m (1.0–4.0 m).

% cover of each stratum: T1 = 8.2%; S1 = 2.1%; **total = 10.3%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* =1.17 m^2/ha **(total = 1.17 m^2/ha)**.
S1: *Corymbia tessellaris* = 0.17 m^2/ha **(total = 0.17 m^2/ha)**.

Landform: Plain **Slope:** 1°S **Soil:** Dark-brown clay with sand

Disturbance: Cleared and heavily grazed; high weed density.

Ground cover: Rock = 0%, wood = 0.5%, bare = 10%, litter = 5%, vegetation = 84.5%.

Species (percent cover): *Aristida calycina* var. *calycina* (0.1%), *Bothriochloa pertusa** (76%), *Cassia brewsteri* (0.1%), *Cenchrus ciliaris** (1.1%), *Chrysopogon fallax* (0.1%), *Crinum arenarium* (0.1%), *Dactyloctenium radulans* (0.1%), *Digitaria diminuta* (0.1%), *Eragrostis sororia* (0.1%), *Fimbristylis dichotoma* (2%), *Gomphrena celosioides** (0.1%), *Grewia retusifolia* (0.1%), *Heteropogon contortus* (0.5%), *Indigofera colutea* (0.1%), *Ipomoea polymorpha* (0.1%), *Murdannia graminea* (0.1%), *Neptunia gracilis* (0.1%), *Owenia acidula* (0.1%), *Oxalis corniculata* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca pilosa** (0.1%), *Salsola australis* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Sphaeromorphaea australis* (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes scabra** (0.5%), *Urochloa mosambicensis** (2%), *Zornia muriculata* subsp. *angustata* (0.1%), *Zornia* sp. (0.1%).

SECONDARY SITE 28 **11.3.2**



Latitude, Longitude: -22.3819, 148.2465

Community description: Woodland dominated by *Eucalyptus populnea* on alluvial flats beside a watercourse.

Dominant species per stratum:

T1: *Eucalyptus populnea, Eucalyptus melanophloia* (subdominant).
T2: *Cassia brewsteri.*
S1: *Carissa ovata.*
G: *Cenchrus ciliaris*, Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: T1 =22 m (15–24 m), T2 = 7.0 m (6.4–9.0 m), S1 = 1.5 m (0.5–2.5 m).

% cover of each stratum: T1 = 30.2%; T2 = 6.4%; S1 = 8.8%; **total = 38.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 3.83 m^2/ha; *Eucalyptus camaldulensis* = 0.33 m^2/ha; *Acacia excelsa* = 0.67 m^2/ha; *Eucalyptus melanophloia* = 0.83 **(total = 5.66 m^2/ha).**
T2: *Eucalyptus populnea* = 0.5 m^2/ha; *Cassia brewsteri* = 1 m^2/ha; *Ventilago viminalis* = 0.5 m^2/ha; *Corymbia erythrophloia* = 0.17 m^2/ha; *Bauhinia hookeri* = 0.33 m^2/ha; *Eucalyptus melanophloia* = 0.5 m^2/ha **(total = 3 m^2/ha)**.
S1 < 0.17 m^2/ha

Landform: Plain **Slope:** 1°SW **Soil:** Brown sand.

Disturbance: Grazed; very high weed cover.

Ground cover: Rock = 0%, wood = 1%, bare = 20%, litter = 8%, vegetation = 71%.

Species (percent cover): *Afrohybanthus enneaspermus* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina var. calycina* (0.1%), *Aristida gracilipes* (0.1%), *Atalaya hemiglauca* (0.1%), *Bothriochloa ewartiana* (0.1%), *Bothriochloa pertusa** (9%), *Capparis lasiantha* (0.1%), *Carissa ovata* (0.5%), *Cenchrus ciliaris** (55%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (0.5%), *Cymbidium canaliculatum* (0.1%), *Cyperus fulvus* (0.1%), *Cyperus gracilis* (0.1%), *Desmodium macrocarpum* (0.1%), *Eragrostis sororia* (0.1%), *Eucalyptus melanophloia* (0.1%), *Eucalyptus populnea* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (2%), *Grewia retusifolia* (0.1%), *Harrisia martinii** (0.1%), *Heteropogon contortus* (0.1%), *Jacquemontia paniculata* (0.1%), *Melhania oblongifolia* (0.1%), *Opuntia tomentosa** (0.1%), *Oxalis corniculata* (0.1%), *Panicum effusum* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca pilosa** (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.6%), *Urochloa mosambicensis** (0.1%), *Zornia muriculata* subsp. *angustata* (0.4%).

SECONDARY SITE 29 **11.4.9**



Latitude, Longitude: -22.3827, 148.2447

Community description: Woodland dominated by *Acacia harpophylla* and *Casuarina cristata* on a clay plain.

Dominant species per stratum:

T1: *Acacia harpophylla, Casuarina cristata.*
T2: *Bauhinia hookeri, Eremophila mitchellii, Terminalia oblongata.*
S1: *Acacia harpophylla, Bauhinia hookeri, Carissa ovata.*
G: *Cenchrus ciliaris*.*

Median (and range) canopy height per stratum: T1 =16.4 m (15.2–16.8 m), T2 = 6.2 m (5.0–10.6 m), S1 = 1.0 m (0.5–2.0 m).

% cover of each stratum: T1 = 40.6%; T2 = 26.2%; S1 = 58.8%; **total = 72.8%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Acacia harpophylla* = 2.83 m^2/ha; *Bauhinia carroniii* = 0.33 m^2/ha **(total = 3.16 m^2/ha)**.
T2: *Eremophila mitchellii* = 1.33 m^2/ha; *Bauhinia carronii* = 0.83 m^2/ha; *Casuarina cristata* = 0.5 m^2/ha; *Ventilago viminalis* = 0.83 m^2/ha **(total = 3.49 m^2/ha)**.
S1: *Bauhinia carronii* = 1 m^2/ha; *Casuarina cristata* = 0.5 m^2/ha **(total = 1.5 m^2/ha)**.

Landform: Plain **Slope:** 1°S **Soil:** Dark-brown clay with thin surface covering of sand; shallow gilgais.

Disturbance: Minimal.

Ground cover: Rock = 0%, wood = 7%, bare = 12%, litter = 50%, vegetation = 31%.

Species (percent cover): *Abutilon oxycarpum* var. *incanum* (0.2%), *Alectryon diversifolius* (0.1%), *Alternanthera denticulata* (0.1%), *Amaranthus interruptus* (0.1%), *Amaranthus viridis** (0.1%), *Apophyllum anomalum* (0.1%), *Bauhinia hookeri* (0.1%), *Boerhavia pubescens* (0.1%), *Brunoniella australis* (0.1%), *Carissa ovata* (19.5%), *Cenchrus ciliaris** (8%), *Cheilanthes sieberi* (0.1%), *Cyperus concinnus* (0.1%), *Cyperus gracilis* (0.1%), *Cyperus perangustus* (0.1%), *Dactyloctenium radulans* (0.1%), *Echinochloa colona** (0.1%), *Ehretia membranifolia* (0.1%), *Eragrostis pilosa** (0.1%), *Eriochloa crebra* (0.1%), *Geijera parviflora* (0.1%), *Ipomoea plebia* (0.1%), *Malvastrum americanum** (0.1%), *Marsdenia viridiflora* subsp. *viridiflora* (0.1%), *Owenia acidula* (0.1%), *Parsonsia lanceolata* (0.1%), *Parthenium hysterophorus** (0.1%), *Plumbago zeylanica* (0.1%), *Portulaca oleracea** (0.1%), *Salsola australis* (0.1%), *Senna coronilloides* (0.1%), *Sporobolus caroli* (0.1%), *Sporobolus scabridus* (0.1%), *Tribulus terrestris** (0.1%), *Urochloa foliosa* (0.1%), *Ventilago viminalis* (0.1%).

SECONDARY SITE 30 **11.3.2**



Latitude, Longitude: -22.3672, 148.2353

Community description: Open woodland dominated by *Eucalyptus populnea* on sandy alluvial flat.

Dominant species per stratum:

T1: *Corymbia tessellaris, Eucalyptus populnea.*
T2: *Acacia salicina, Cassia brewsteri.*
S1: *Capparis canescens, Eucalyptus populnea.*
G: *Cenchrus ciliaris*.*

Median (and range) canopy height per stratum: T1 =11.6 m (11.0–19.2 m), T2 = 7.4 m (6.4–8.4 m), S1 = 1.5 m (1.0–3.0 m).

% cover of each stratum: T1 = 15%; T2 = 20.1%; S1 = 2.9%; **total = 32.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 6.33 m^2/ha; *Corymbia dallachiana* = 0.33 m^2/ha **(total = 6.66 m^2/ha)**.
T2: *Eucalyptus populnea* = 1.33 m^2/ha; *Corymbia dallachiana* = 0.17 m^2/ha; *Corymbia tessellaris* = 0.5 m^2/ha; *Acacia salicina* = 0.33 m^2/ha; *Cassia brewsteri* = 0.5 m^2/ha **(total = 2.83 m^2/ha).**

Landform: Plain **Slope:** 0° **Soil:** Yellow-brown sand.

Disturbance: Grazed; high weed densities.

Ground cover: Rock = 0%, wood = 1%, bare = 30%, litter = 25%, vegetation = 44%.

Species (percent cover): *Acacia salicina* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida gracilipes* (0.1%), *Boerhavia pubescens* (0.1%), *Bonamia media* (0.1%), *Bothriochloa ewartiana* (0.1%), *Bothriochloa pertusa** (0.1%), *Capparis canescens* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (0.1%), *Cassia brewsteri* (0.1%), *Cenchrus ciliaris** (40.3%), *Chrysopogon fallax* (0.1%), *Crinum arenarium* (0.1%), *Cyanthillium cinereum* (0.1%), *Eremophila mitchellii* (0.1%), *Eucalyptus populnea* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Glycine tomentella* (0.1%), *Gomphrena celosioides** (0.1%), *Grewia retusifolia* (0.1%), *Harrisia martinii** (0.1%), *Hibiscus sturtii* (0.1%), *Indigofera colutea* (0.1%), *Indigofera linnaei* (0.1%), *Melhania oblongifolia* (0.1%), *Oxalis corniculata* (0.1%), *Parsonsia lanceolata* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca filifolia* (0.1%), *Rostellularia adscendens* (0.1%), *Sida hackettiana* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes humilis** (0.1%), *Stylosanthes scabra** (0.1%).

SECONDARY SITE 31 **11.9.2**



Latitude, Longitude: -22.3656, 148.2267

Community description: Open woodland dominated by *Eucalyptus orgadophila* on a clay plain derived from fine-grained sedimentary rock.

Dominant species per stratum:

T1: *Eucalyptus orgadophila.*
T2: *Cassia brewsteri, Vachellia bidwillii, Ventilago viminalis.*
S1: *Carissa ovata.*
G: *Cenchrus ciliaris*, Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: T1 =13.4 m (9.4–15 m), T2 = 6.2 m (5.2–6.6 m), S1 = 1.5 m (0.5–2.5 m).

% cover of each stratum: T1 = 6%; T2 < 0.1%, S1 < 0.1%; **total = 6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus orgadophila* = 2 m^2/ha **(total = 2 m^2/ha)**.
T2: *Vachellia bidwillii* = 0.33 m^2/ha; *Atalaya hemiglauca* = 0.17 m^2/ha; *Acacia salicina* = 0.17 m^2/ha **(total = 0.67 m^2/ha)**.
S1: < 0.17 m^2/ha

Landform: Plain **Slope:** 2°S **Soil:** Spongy, dark-brown clay-loam.

Disturbance: Many dead trees; heavily grazed; high weed densities.

Ground cover: Rock = 0%, wood = 0%, bare = 10%, litter = 7%, vegetation = 83%.

Species (percent cover): *Acacia salicina* (0.1%), *Atalaya hemiglauca* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa ewartiana* (0.1%), *Bothriochloa pertusa** (76.8%), *Camptacra barbata* (0.3%), *Cenchrus ciliaris** (2%), *Cleome viscosa* (0.1%), *Cyperus rotundus** (0.1%), *Datura leichhardtii** (0.1%), *Digitaria eriantha** (0.1%), *Euphorbia bifida* (0.1%), *Glycine* sp. (Mackay S.B.Andrews+ 43) (0.1%), *Indigofera linifolia* (0.1%), *Lomandra multiflora* (0.1%), *Malvastrum americanum** (0.1%), *Neptunia gracilis* (0.4%), *Parthenium hysterophorus** (0.1%), *Phyllanthus maderaspatensis* (0.1%), *Polymeria pusilla* (0.1%), *Portulaca oleracea** (0.1%), *Rhynchosia minima* (0.1%), *Sida pleiantha* (0.1%), *Sida spinosa** (0.3%), *Stylosanthes scabra** (0.1%), *Tephrosia* sp. B (0.1%), *Tribulus terrestris** (0.1%), *Urochloa mosambicensis** (1%).

SECONDARY SITE 32 **11.5.9**



Latitude, Longitude: -22.3618, 148.217

Community description: Open woodland dominated by *Eucalyptus crebra* and *Corymbia dallachiana* (subdominant) on a sand plain. A small number of sandstone rocks were present, but otherwise the landform was a sand plain.

Dominant species per stratum:

T1: *Corymbia dallachiana, Eucalyptus crebra.*
S1: *Melaleuca nervosa.*
G: *Chrysopogon fallax, Bothriochloa pertusa, Bothriochloa bladhii*

Median (and range) canopy height per stratum: T1 = 13.8 m (12.0–14.4 m), S1 = 0.6 m (0.5–2.5 m).

% cover of each stratum: T1 = 7.8%; S1 = 6.7%; **total = 14.5%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 3 m^2/ha; *Corymbia dallachiana* = 1.67 m^2/ha; *Grevillea striata* = 0.17 m^2/ha **(total = 4.84 m^2/ha)**
S1: <0.17 m^2/ha)

Landform: Low rise on plain. **Slope:** 3°W **Soil:** Dark, yellow-brown sand.

Disturbance: Minimal.

Ground cover: Rock = 0.2%, wood = 0%, bare = 40%, litter = 18%, vegetation = 41.8%.

Species: *Alloteropsis cimicina* (0.4%), *Apowollastonia spilanthoides* (0.1%), *Aristida benthamii* (0.1%), *Aristida calycina* var. *calycina* (0.4%), *Aristida holathera* (0.1%), *Bonamia media* (0.1%), *Bothriochloa pertusa** (30%), *Brunoniella australis* (0.1%), *Cenchrus ciliaris** (0.1%), *Chamaecrista absus* (0.1%), *Chrysopogon fallax* (5%), *Corymbia dallachiana* (0.1%), *Dactyloctenium radulans* (0.1%), *Digitaria divaricatissima* (0.1%), *Eragrostis sororia* (0.1%), *Eriachne mucronata* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Glycine tomentella* (0.1%), *Grewia retusifolia* (0.1%), *Heteropogon contortus* (2%), *Indigofera linnaei* (0.1%), *Ipomoea polymorpha* (0.1%), *Melaleuca nervosa* (0.1%), *Melhania oblongifolia* (0.1%), *Murdannia graminea* (0.3%), *Parthenium hysterophorus** (0.1%), *Perotis rara* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus collinus* (0.1%), *Portulaca pilosa** (0.1%), *Sida hackettiana* (0.1%), *Spermacoce brachystema* (0.1%), *Stylosanthes scabra** (0.7%), *Tephrosia leptoclada* (0.1%), *Urochloa mosambicensis** (0.1%), *Urochloa piligera* (0.1%).

SECONDARY SITE 33 **Non-remnant**



Latitude, Longitude: -22.3607, 148.2331

Community description: Open cleared pasture in what was formerly open *Eucalyptus orgadophila* woodland (regional ecosystem 11.9.2).

Dominant species per stratum:

T1: *Corymbia erythrophloia, Eucalyptus orgadophila.*
S1: *Cassia brewsteri.*
G: *Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: E = 6.8 m (6.8 – 7.8 m), T1 = 1.5 m (0.5 – 2.5 m).

% cover of each stratum: T1 = 1%; S1 = 11.9%; **total = 12.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia erythrophloia* = 0.33 m^2/ha; *Eucalyptus orgadophila* = 0.17 m^2/ha **(total = 0.5 m^2/ha)**
S1: <0.15 m^2/ha

Landform: Low rise. **Slope:** 3°SE **Soil:** Dark brown clay-loam.

Disturbance: Cleared and heavily grazed.

Ground cover: Rock = 0%, wood = 0.1%, bare = 10%, litter = 5%, vegetation = 84.9%.

Species (percent cover): *Abutilon guineense** (0.1%), *Acacia salicina* (0.1%), *Archidendropsis basaltica* (0.2%), *Bothriochloa pertusa** (82%), *Brunoniella australis* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (0.6%), *Cassia brewsteri* (0.1%), *Cenchrus ciliaris** (0.1%), *Clerodendrum floribundum* (0.1%), *Dactyloctenium radulans* (0.1%), *Digitaria eriantha** (0.1%), *Eulalia aurea* (0.1%), *Euphorbia bifida* (0.1%), *Eustrephus latifolius* (0.1%), *Galactia tenuiflora* (0.1%), *Glycine tomentella* (0.1%), *Heliotropium cunninghamii* (0.1%), *Indigofera linifolia* (0.2%), *Indigofera linnaei* (0.1%), *Ipomoea plebia* (0.1%), *Macroptilium atropurpureum** (0.1%), *Neptunia gracilis* (0.1%), *Parthenium hysterophorus** (0.1%), *Phyllanthus maderaspatensis* (0.1%), *Polymeria pusilla* (0.1%), *Portulaca filifolia* (0.1%), *Psydrax oleifolia* (0.1%), *Rhynchosia minima* (0.1%), *Sida hackettiana* (0.1%), *Sida pleiantha* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%), *Tragus australianus* (0.1%), *Urochloa mosambicensis** (0.1%), *Urochloa piligera* (0.1%).

SECONDARY SITE 34 **11.4.8**



Latitude, Longitude: -22.3446, 148.2355

Community description: Tall shrubland dominated by *Acacia harpophylla*, with scattered emergent *Acacia harpophylla* and *Eucalyptus cambageana*.

Dominant species per stratum:

E: *Acacia harpophylla, Eucalyptus cambageana.*
T1: *Acacia harpophylla.*
S1: *Acacia harpophylla, Carissa ovata.*
G: *Cenchrus ciliaris*.*

Median (and range) canopy height per stratum: E = 12 m (11.2–13.2 m), T1 = 4.0 m (3.0–5.4 m), S1 = 1.0 m (0.5–1.5 m).

% cover of each stratum: E = 4%; T1 = 41.1%; S1 = 26.5%; **total = 53.5%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Acacia harpophylla* = 0.3 m^2/ha; *Eucalyptus cambageana* = 0.3 m^2/ha; *Bauhinia carronii* = 0.3 m^2/ha **(total = 1 m^2/ha)**.
T1: *Acacia harpophylla* = 5.33 m^2/ha **(total = 5.33 m^2/ha)**.
S1: <0.17 m^2/ha.

Landform: Plain **Slope:** 0° **Soil:** Dark brown clay-loam; no gilgais; some surface pebbles.

Disturbance: Very few large trees and these were mostly dead. Most of the living vegetation was relatively young regrowth (DBH < 5 cm).

Ground cover: Rock = 0.1%, wood = 1%, bare = 30%, litter = 48.9%, vegetation = 20%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Abutilon oxycarpum* var. *incanum* (0.1%), *Acacia harpophylla* (2%), *Apophyllum anomalum* (0.1%), *Boerhavia pubescens* (0.1%), *Brunoniella australis* (0.1%), *Capparis lasiantha* (0.1%), *Carissa ovata* (8%), *Cenchrus ciliaris** (8%), *Cheilanthes sieberi* (0.1%), *Chloris divaricata* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyperus gracilis* (0.1%), *Enchylaena tomentosa* var. *tomentosa* (0.1%), *Eragrostis lacunaria* (0.1%), *Evolvulus alsinoides* (0.1%), *Harrisia martinii** (0.1%), *Paspalidium distans* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca filifolia* (0.1%), *Portulaca oleracea** (0.1%), *Solanum esuriale* (0.1%), *Terminalia oblongata* (0.1%).

SECONDARY SITE 35 **11.5.9**



Latitude, Longitude: -22.3336, 148.2134

Community description: Closed scrub dominated by *Melaleuca nervosa* and *Acacia burdekensis,* with emergent *Corymbia clarksoniana*, on a sand plain. Resembles regional ecosystem 11.5.9 but with a very dense mid-storey. Presumably drainage is impeded by texture contrast soil or shallow bedrock.

Dominant species per stratum:

E: *Corymbia clarksoniana.*
T1: *Acacia burdekensis, Melaleuca nervosa.*
S1: *Alphitonia excelsa, Melaleuca nervosa.*
G: *Eriochloa crebra, Perotis rara, Sida hackettiana, Setaria surgens, Alloteropsis cimicina.*

Median (and range) canopy height per stratum: E = 15.2 m (13.8–16.8 m), T1 = 4.0 m (3.5–4.8 m), S1 = 2.0 m (1.0–2.5 m).

% cover of each stratum: E < 0.1%; T1 = 84.3%; S1 = 16.6%; **total = 90.6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Corymbia clarksoniana* = 0.17 m^2/ha **(total = 0.17 m^2/ha)**.
T1: *Melaleuca nervosa* = 6.67 m^2/ha; *Acacia burdekensis* = 6.3 m^2/ha; *Alphitonia excelsa* = 0.67 m^2/ha **(total = 13.64 m^2/ha)**.
S1: *Acacia burdekensis* = 0.33 m^2/ha; *Melaleuca nervosa* =0.33 m^2/ha **(total = 0.66 m^2/ha)**.

Landform: Plain. **Slope:** 1°N **Soil:** Grey sand.

Disturbance: Nil.

Ground cover: Rock = 0%, wood = 2%, bare = 10%, litter = 50%, vegetation = 38%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (4%), *Alphitonia excelsa* (0.3%), *Bidens pilosa** (0.1%), *Bonamia media* (0.1%), *Cassytha filiformis* (0.1%), *Cheilanthes sieberi* (0.1%), *Chrysocephalum apiculatum* (0.1%), *Cleome tetrandra* var. *tetrandra* (0.1%), *Crotalaria medicaginea* (0.1%), *Dactyloctenium radulans* (0.1%), *Desmodium filiforme* (0.1%), *Dysphania melanocarpa* forma *melanocarpa* (0.1%), *Emilia sonchifolia** (0.1%), *Eriochloa crebra* (9%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Glycine tomentella* (0.1%), *Indigofera colutea* (0.1%), *Ipomoea polymorpha* (0.4%), *Melaleuca nervosa* (0.1%), *Perotis rara* (3%), *Petalostigma pubescens* (0.1%), *Portulaca pilosa** (0.1%), *Richardia brasiliensis** (0.1%), *Setaria surgens* (9%), *Sida cordifolia** (0.3%), *Sida hackettiana* (1.6%), *Spermacoce brachystema* (0.1%), *Tribulopis angustifolia* (0.1%), *Urochloa piligera* (8%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 36 **11.10.3**



Latitude, Longitude: -22.3434, 148.2104

Community description: Low open forest dominated by *Acacia shirleyi* and *Acacia rhodoxylon*, with emergent *Corymbia clarksoniana*, on the crest of a sandstone rise.

Dominant species per stratum:

E: *Corymbia clarksoniana.*
T1: *Acacia rhodoxylon, Acacia shirleyi.*
S1: *Erythroxylum australe.*
G: *Cleistochloa subjuncea, Alloteropsis cimicina, Thyridolepis xerophila.*

Median (and range) canopy height per stratum: E = 15.2 m (12.2–15.6 m), T1= 5.6 m (5.2–5.6 m), S1 = 2.0 m (1.5–3.5 m).

% cover of each stratum: E = 21.1%; T1 = 58.6%; S1 = 4.3%; **total = 68.5%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Corymbia clarksoniana* = 1.33 m^2/ha **(total = 1.33 m^2/ha)**.
T1: *Acacia shirleyi* = 6 m^2/ha; *Acacia rhodoxylon* = 2.5 m^2/ha; *Lysicarpus angustifolius* = 0.17 m^2/ha; *Corymbia clarksoniana* = 0.17 m^2/ha; *Alphitonia excelsa* = 0.17 m^2/ha **(total = 9.0 m^2/ha)**.
S1: <0.17 m^2/ha.

Landform: Crest **Slope:** 2°NE **Soil:** Yellow-grey sand.

Disturbance: Nil.

Ground cover: Rock = 0%, wood = 4%, bare = 20%, litter = 65%, vegetation = 11%.

Species (percent cover): *Acacia rhodoxylon* (0.1%), *Acacia shirleyi* (0.2%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (1.5%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Cheilanthes sieberi* (0.6%), *Cleistochloa subjuncea* (2%), *Digitaria diminuta* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (0.1%), *Larsenaikia ochreata* (0.1%), *Lysicarpus angustifolius* (0.1%), *Murdannia graminea* (0.1%), *Sida hackettiana* (0.1%), Sida sp. (Musselbrook M.B. Thomas+ MRS437) (0.1%), *Stylosanthes scabra** (0.1%), *Thyridolepis xerophila* (5.3%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 37 **11.10.1x1**



Latitude, Longitude: -22.3471, 148.1894

Community description: Woodland dominated by *Corymbia aureola* on a low sandstone rise.

Dominant species per stratum:

T1: *Corymbia aureola*
T2: *Alphitonia excelsa, Acacia flavescens.*
S1: *Erythroxylum australe.*
G: *Melinis repens, Alloteropsis cimicina.*

Median (and range) canopy height per stratum: T1 = 13 m (10.2–14.8 m), T2 = 3.8 m (3.4–5 m), S1 = 1.5 m (0.5–2.5 m).

% cover of each stratum: T1 = 32.8%; T2 = 19.5%; S1 = 3.6%; **total = 45.3%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia aureola* = 4.33 m^2/ha; *Eucalyptus melanophloia* = 0.33 m^2/ha; *Corymbia clarksoniana* = 0.17 m^2/ha; *Larsenaikia ochreata* = 0.17 m^2/ha **(total = 5 m^2/ha)**
T2: *Alphitonia excelsa* = 1.33 m^2/ha; *Acacia flavescens* = 1.33 m^2/ha; *Acacia burdekensis* = 0.33 m^2/ha; **(total = 2.99 m^2/ha)**
S1: <0.15 m^2/ha

Landform: Low rise **Slope:** 3°S **Soil:** Yellow-grey sand with large sandstone boulders.

Disturbance: Grazed.

Ground cover: Rock = 9%, wood = 4%, bare = 33%, litter = 19%, vegetation = 35%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alloteropsis cimicina* (2%), *Alphitonia excelsa* (0.4%), *Aristida calycina* var. *calycina* (0.1%), *Aristida holathera* (0.1%), *Bidens bipinnata** (0.1%), *Bonamia media* (0.1%), *Breynia oblongifolia* (0.1%), *Chamaecrista absus* (0.6%), *Commelina lanceolata* (0.1%), *Corymbia aureola* (0.1%), *Cyperus betchei* (0.1%), *Digitaria longiflora* (0.1%), *Eragrostis sororia* (0.1%), *Eriochloa crebra* (2%), *Erythroxylum australe* (0.1%), *Evolvulus alsinoides* (0.1%), *Glycine tomentella* (0.1%), *Hibiscus meraukensis* (0.1%), *Ipomoea brownii* (0.1%), *Ipomoea plebia* (0.1%), *Ipomoea polymorpha* (0.1%), *Larsenaikia ochreata* (0.1%), *Lomandra longifolia* (1%), *Melinis repens* (20%), *Oxalis corniculata* (0.1%), *Phyllanthus virgatus* (0.1%), *Portulaca filifolia* (0.1%), *Setaria surgens* (0.1%), *Sida hackettiana* (0.8%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia filipes* subsp. *filipes* (0.1%), *Tinospora smilacina* (0.1%), *Trema tomentosa* (0.5%), *Tribulopis angustifolia* (0.1%), *Urochloa piligera* (4%), *Xanthorrhoea johnsonii* (0.7%), *Xenostegia tridentata* (0.1%).

SECONDARY SITE 38 **11.10.7**



Latitude, Longitude: -22.3411, 148.1925

Community description: Open forest dominated by *Eucalyptus crebra* on a flat terrace of a sandstone slope.

Dominant species per stratum:

T1: *Eucalyptus crebra, Corymbia clarksoniana* (subdominant), *Corymbia dallachiana* (subdominant).
T2: *Acacia burdekensis, Alphitonia excelsa, Petalostigma pubescens.*
S1: *Petalostigma pubescens.*
G: *Chrysopogon fallax, Aristida calycina* var. *calycina, Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: T1 = 15 m (13.6–22 m), T2 = 8.0 m (3.6–9.2 m), S1 = 1.5 m (0.5–1.5 m).

% cover of each stratum: T1 = 75.2%; T2 = 11.5%; S1 = 7.7%; **total = 77.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 5.5 m^2/ha; *Corymbia clarksoniana* = 0.33 m^2/ha; *Corymbia dallachiana* = 0.33 m^2/ha; *Acacia burdekensis* = 0.17 m^2/ha. **(total = 6.33 m^2/ha)**
T2: *Petalostigma pubescens* = 0.33 m^2/ha; *Eucalyptus crebra* = 0.17 m^2/ha; *Corymbia dallachiana* = 0.17 m^2/ha; *Alphitonia excelsa* = 0.17 m^2/ha; **(total =0.84 m^2/ha)**
S1: <0.15 m^2/ha

Landform: Terrace of sandstone slope. **Slope:** 3°E **Soil:** Yellow-grey sand with no rocks.

Disturbance: Numerous dead trees.

Ground cover: Rock = 0%, wood = 0.5%, bare = 35%, litter = 30%, vegetation = 34.5%.

Species (percent cover): *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (4%), *Bothriochloa pertusa** (19%), *Breynia oblongifolia* (0.1%), *Cenchrus ciliaris** (0.4%), *Chamaecrista absus* (0.1%), *Chrysopogon fallax* (8%), *Cyperus fulvus* (0.1%), *Digitaria divaricatissima* (0.1%), *Eragrostis sororia* (0.1%), *Eriochloa crebra* (0.1%), *Eucalyptus crebra* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Glycine sp.* (Mackay S.B.Andrews+ 43) (0.1%), *Grewia retusifolia* (0.3%), *Heliotropium peninsulare* (0.1%), *Marsdenia microlepis* (0.1%), *Panicum effusum* (0.4%), *Petalostigma pubescens* (0.1%), *Phyllanthus carpentariae* (0.1%), *Phyllanthus collinus* (0.1%), *Pseuderanthemum variabile* (0.1%), *Scoparia dulcis** (0.1%), *Sida hackettiana* (0.3%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%).

SECONDARY SITE 39 **11.10.1**



Latitude, Longitude: -22.2909, 148.1633

Community description: Open forest dominated by *Corymbia citriodora, Corymbia trachyphloia* and *Lysicarpus angustifolius* on a steep, sandstone hillside.

Dominant species per stratum:

T1: *Corymbia citriodora, Corymbia trachyphloia, Lysicarpus angustifolius.*
T2: *Lysicarpus angustifolius, Corymbia trachyphloia*
S1: *Acacia dietrichiana, Lysicarpus angustifolius.*
G: *Cleistochloa subjuncea, Scleria sphacelata, Digitaria diminuta, Goodenia* sp. (Mt Castletower M.D. Crisp 2753).

Median (and range) canopy height per stratum: T1 =11.8 m (10.4–18.2 m), T2 = 4.0 m (3.0–5.2 m), S1 = 1.5 m (0.5 – 2.0 m).

% cover of each stratum: T1 = 49.8%; T2 = 8.8%; S1 = 5.2%; **total = 56.6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Lysicarpus angustifolius* = 4.67 m^2/ha; *Corymbia trachyphloia* = 1.67 m^2/ha; *Acacia shirleyi* = 1.5 m^2/ha; *Corymbia citriodora* = 0.83 m^2/ha; *Eucalyptus crebra* = 0.33 m^2/ha **(total = 9 m^2/ha)**.
T2: *Corymbia trachyphloia* = 0.33 m^2/ha; *Lysicarpus angustifolius* = 0.17 m^2/ha; *Larsenaikia ochreata* = 0.17 m^2/ha **(total = 0.67 m^2/ha)**.
S1: <0.15 m^2/ha.

Landform: Steep rocky slope. **Slope:** 38°S **Soil:** Grey sand with abundant sandstone.

Disturbance: Regular but not recent fire.

Ground cover: Rock = 30%, wood = 0.5%, bare = 1%, litter = 40%, vegetation = 28.5%.

Species (percent cover): *Acacia dietrichiana* (0.1%), *Acacia flavescens* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida gracilipes* (0.1%), *Calotis cuneifolia* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (13.5%), *Coelospermum reticulatum* (0.1%), *Commelina lanceolata* (0.1%), *Coronidium oxylepis* (0.1%), *Corymbia trachyphloia* (0.4%), *Cyanthillium cinereum* (0.1%), *Cymbopogon obtectus* (0.5%), *Cyperus betchei* (0.1%), *Daviesia filipes* (0.1%), *Desmodium rhytidophyllum* (0.1%), *Digitaria diminuta* (3%), *Eragrostis spartinoides* (0.1%), *Eriachne obtusa* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Goodenia* sp. (Mt Castletower M.D. Crisp 2753) (4%), *Hovea tholiformis* (0.1%), *Larsenaikia ochreata* (0.1%), *Lysicarpus angustifolius* (0.9%), *Oxalis corniculata* (0.1%), *Panicum effusum* (0.3%), *Persoonia falcata* (0.1%), *Phyllanthus collinus* (0.1%), *Pomax umbellata* (0.1%), *Scleria sphacelata* (2%), *Setaria surgens* (0.1%), *Sorghum leiocladum* (0.1%), *Tephrosia* sp. A (0.1%), *Xanthorrhoea johnsonii* (1%), *Zornia* sp. (0.1%).

SECONDARY SITE 40 **11.10.7**



Latitude, Longitude: -22.2930, 148.1505

Community description: Woodland dominated by *Eucalyptus crebra* and *Eucalyptus melanophloia* growing on a low terrace on a sandstone slope.

Dominant species per stratum:

T1: *Eucalyptus crebra, Eucalyptus melanophloia, Acacia shirleyi.*
T2: *Petalostigma pubescens, Acacia burdekensis.*
S1: *Eucalyptus crebra*
G: *Aristida calycina* var. *calycina, Chrysopogon fallax, Eriochloa crebra.*

Median (and range) canopy height per stratum: T1 = 12.8 m (9.2–14.6 m), T2 = 5.6 m (4.0–7.0 m), S1 = 2 m (0.5–3.0 m).

% cover of each stratum: T1 = 23%; T2 = 8.7%; S1 = 5.1%; **total = 33.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 2.67 m^2/ha; *Eucalyptus melanophloia* = 1.83 m^2/ha; *Acacia shirleyi* = 0.5 m^2/ha; *Corymbia dallachiana* = 0.17 m^2/ha **(total = 5.17 m^2/ha)**
T2: *Petalostigma pubescens* = 1 m^2/ha; *Acacia burdekensis* = 0.5 m^2/ha **(total = 1.5 m^2/ha)**
S1: < 0.17 m^2/ha

Landform: Ledge on foot slope of sandstone ridge. **Slope:** 6°ESE **Soil:** Grey-brown sand with no outcropping rock.

Disturbance: Lightly grazed.

Ground cover: Rock = 0%, wood = 1%, bare = 59%, litter = 20%, vegetation = 20%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (4%), *Cenchrus ciliaris** (0.1%), *Chamaecrista absus* (0.1%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (6.5%), *Corymbia dallachiana* (0.1%), *Cyanthillium cinereum* (0.1%), *Digitaria brownii* (0.1%), *Digitaria diminuta* (0.1%), *Digitaria* sp. A (0.4%), *Eragrostis leptostachya* (0.1%), *Eragrostis sororia* (0.5%), *Eriochloa crebra* (5%), *Erythroxylum australe* (0.1%), *Eucalyptus crebra* (0.1%), *Eucalyptus melanophloia* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Lobelia purpurascens* (0.1%), *Melinis repens** (0.1%), *Murdannia graminea* (0.1%), *Panicum effusum* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus collinus* (0.1%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.1%), *Rostellularia adscendens* (0.1%), *Sida cordifolia** (0.1%), *Sida hackettiana* (0.2%), *Sida spinosa** (0.3%), *Stylosanthes scabra** (0.2%), *Themeda triandra* (0.1%), *Urochloa mosambicensis** (0.1%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 41 **11.10.1**



Latitude, Longitude: -22.2933, 148.1519

Community description: Open forest dominated by *Corymbia citriodora* on a rocky sandstone foot slope.

Dominant species per stratum:

T1: *Corymbia citriodora, Eucalyptus crebra* (subdominant).
T2: *Corymbia citriodora, Corymbia trachyphloia, Eucalyptus crebra.*
S1: *Acacia flavescens, Acacia burdekensis.*
G: *Cymbopogon refractus, Themeda triandra, Melinis repens*.*

Median (and range) canopy height per stratum: T1 = 24.4 m (23–25.8 m), T2 = 11 m (8.4–13 m), S1 = 2.5 m (0.6–4 m).

% cover of each stratum: T1 = 46.2%; T2 = 30.2%; S1 = 14.1%; **total = 69.6%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia citriodora* = 3.17 m^2/ha; *Eucalyptus crebra* = 0.67 m^2/ha **(total = 3.84 m^2/ha)**.
T2: *Eucalyptus crebra* = 4.67 m^2/ha; *Corymbia trachyphloia* = 0.33 m^2/ha **(total = 5 m^2/ha)**.
S1: < 0.17 m^2/ha

Landform: Rocky foot slope next to gully **Slope:** 18°E **Soil:** Grey-brown sand with sandstone boulders

Disturbance: Few weeds and light grazing.

Ground cover: Rock = 35%, wood = 0.5%, bare = 10%, litter = 31.5%, vegetation = 23%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Acacia macradenia* (0.2%), *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.3%), *Aristida benthamii* (0.1%), *Aristida spuria* (0.1%), *Breynia oblongifolia* (0.1%), *Brunoniella australis* (0.1%), *Capparis canescens* (0.1%), *Cenchrus ciliaris** (0.2%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (0.1%), *Coelospermum reticulatum* (0.1%), *Corymbia citriodora* subsp. *citriodora* (0.1%), *Crotalaria montana* (0.1%), *Cyanthillium cinereum* (0.1%), *Cymbopogon refractus* (8.4%), *Dichanthium sericeum* (0.1%), *Enneapogon lindleyanus* (0.1%), *Eriochloa pseudoacrotricha* (0.1%), *Erythroxylum australe* (0.1%), *Eucalyptus crebra* (0.1%), *Eucalyptus melanophloia* (0.1%), *Eustrephus latifolius* (0.1%), *Glycine tomentella* (0.1%), *Grewia latifolia* (0.1%), *Hakea lorea* (0.1%), *Indigofera australis* (0.1%), *Larsenaikia ochreata* (0.1%), *Marsdenia microlepis* (0.1%), *Melhania oblongifolia* (0.1%), *Melinis repens** (2%), *Panicum effusum* (0.1%), *Persoonia falcata* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus virgatus* (0.1%), *Pterocaulon ciliosum* (0.1%), *Pycnospora lutescens* (0.1%), *Rostellularia adscendens* (0.1%), *Scleria sphacelata* (0.1%), *Sida spinosa** (0.1%), *Solanum ellipticum* (0.1%), *Stylosanthes scabra** (0.1%), *Tephrosia juncea* (0.1%), *Themeda triandra* (8%).

SECONDARY SITE 42 **11.10.3**



Latitude, Longitude: -22.2988, 148.1585

Community description: Low open forest dominated by *Acacia shirleyi*, with emergent *Corymbia aureola*, on a terrace of a sandstone ridge.

Dominant species per stratum:

E: *Corymbia aureola.*
T1: *Acacia shirleyi.*
S1: *Alphitonia excelsa, Erythroxylum australe.*
G: *Cleistochloa subjuncea, Eriachne obtusa, Thyridolepis xerophila*

Median (and range) canopy height per stratum: E = 13.2 m (11.8–13.6 m), T1 = 9.8 m (5.6–10.4 m), S1 = 1.5 m (1.0–1.5 m).

% cover of each stratum: E = 21.5%; T1 = 58.2%; S1 = 1.4%; t**otal = 70.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Acacia shirleyi* = 0.5 m^2/ha; *Corymbia aureola* = 0.83 m^2/ha **(total = 1.33 m^2/ha)**.
T1: *Acacia shirleyi* = 5.83 m^2/ha **(total = 5.83 m^2/ha)**.
S1: <0.15 m^2/ha.

Landform: Ledge of sandstone ridge. **Slope:** 8°N **Soil:** Pink-grey sand with many small rocks.

Disturbance: Recent fire seems to have resulted in many large dead *A. shirleyi*.

Ground cover: Rock = 5%, wood = 8%, bare = 28%, litter = 35%, vegetation = 24%.

Species (percent cover): *Acacia shirleyi* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida gracilipes* (0.1%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (17.7%), *Digitaria diminuta* (0.1%), *Eragrostis sororia* (0.1%), *Eriachne obtusa* (4%), *Marsdenia microlepis* (0.1%), *Pseuderanthemum variabile* (0.1%), *Scleria sphacelata* (0.1%), *Solanum parvifolium* (0.1%), *Thyridolepis xerophila* (1%), *Wrightia saligna* (0.1%).

SECONDARY SITE 43 **HVR 11.5.9**



Latitude, Longitude: -22.2852, 148.1759

Community description: Woodland dominated by *Eucalyptus crebra* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus crebra.*
T2: *Ventilago viminalis, Grevillea parallela, Acacia excelsa.*
S1: *Erythroxylum australe.*
G: *Cenchrus ciliaris*, Bothriochloa pertusa*.*

Median (and range) canopy height per stratum: T1 = 14.8 m (11.2–17.4 m), T2 = 7.8 m (7.4–9.2 m), S1 = 2.0 m (1.0–3.0 m).

% cover of each stratum: T1 = 22.5%; T2 = 16.9%; S1 = 16%; **total = 43.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 3.33 m^2/ha; *Grevillea striata* = 0.17 m^2/ha; *Acacia excelsa* = 0.17 m^2/ha **(total = 3.67 m^2/ha)**.
T2: *Ventilago viminalis* = 1.67 m^2/ha *Corymbia dallachiana* = 1.33 m^2/ha; *Corymbia clarksoniana* = 1.17 m^2/ha; **(total = 4.17 m^2/ha)**.
S1: <0.15 m^2/ha.

Landform: Sandy foot slope **Slope:** 2°N **Soil:** Yellow sand

Disturbance: Heavily grazed; evidence of heavy thinning of vegetation; probably previously cleared.

Ground cover: Rock = 0%, wood = 0.5%, bare = 45%, litter = 30%, vegetation = 24.5%.

Species (percent cover): *Acacia excelsa* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Boerhavia pubescens* (0.1%), *Bothriochloa pertusa** (2%), *Capparis canescens* (0.1%), *Cenchrus ciliaris** (18.5%), *Chamaecrista absus* (0.1%), *Chrysopogon fallax* (0.1%), *Clerodendrum floribundum* (0.1%), *Commelina lanceolata* (0.1%), *Dianella nervosa* (0.1%), *Digitaria longiflora* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis spartinoides* (0.1%), *Erythroxylum australe* (0.3%), *Eucalyptus crebra* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Flindersia dissosperma* (0.1%), *Galactia tenuiflora* (0.1%), *Harrisia martinii** (0.1%), *Jacquemontia paniculata* (0.1%), *Melhania oblongifolia* (0.1%), *Murdannia graminea* (0.1%), *Parsonsia lanceolata* (0.4%), *Phyllanthus collinus* (0.1%), *Portulaca oleracea** (0.1%), *Portulaca pilosa** (0.1%), *Pseuderanthemum variabile* (0.1%), *Rostellularia adscendens* (0.1%), *Sida spinosa** (0.1%), *Stylosanthes scabra** (0.1%), *Urochloa mosambicensis** (0.1%), *Ventilago viminalis* (0.1%), *Vittadinia pustulata* (0.1%).

SECONDARY SITE 44 **11.10.1x1**



Latitude, Longitude: -22.2774, 148.1604

Community description: Low woodland dominated by *Corymbia aureola* on a sandstone plateau. Mapped as high-value regrowth, but is probably remnant and naturally stunted by the lack of topsoil. It is improbable that it would have been cleared considering the difficult terrain.

Dominant species per stratum:

T1: *Corymbia aureola.*
S1: *Acacia bancroftiorum, Acacia flavescens, Acacia burdekensis.*
G: *Cleistochloa subjuncea, Melinis repens*

Median (and range) canopy height per stratum: T1 = 9.6 m (6.4–10.4 m), S1 = 2.5 m (0.5–3.5 m).

% cover of each stratum: T1 = 26.2%; S1 = 40.7%; **total = 62.1%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia aureola* = 5 m^2/ha; *Terminalia porphyrocarpa* = 0.17 m^2/ha **(total = 5.17 m^2/ha)**.
S1: *Acacia shirleyi* = 0.17 m^2/ha; *Acacia flavescens* = 0.17 m^2/ha **(total = 0.34 m^2/ha)**.

Landform: Rocky plateau. **Slope:** 12°W **Soil:** Quartz/white sand.

Disturbance: Lightly grazed; many large dead trees appear to have been killed by a severe historical fire. This may be why the site appeared to be non-remnant from aerial imagery.

Ground cover: Rock = 35%, wood = 0.5%, bare = 5%, litter = 43%, vegetation = 17%.

Species (percent cover): *Acacia bancroftiorum* (0.1%), *Acacia burdekensis* (0.2%), *Acacia dietrichiana* (0.1%), *Acacia flavescens* (0.3%), *Acacia shirleyi* (0.2%), *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Aristida benthamii* (0.8%), *Cheilanthes sieberi* (0.1%), *Cleistochloa subjuncea* (12%), *Corymbia aureola* (0.1%), *Digitaria diminuta* (0.2%), *Eragrostis spartinoides* (0.1%), *Eriachne obtusa* (0.1%), *Erythroxylum australe* (0.4%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Hovea tholiformis* (0.3%), *Larsenaikia ochreata* (0.1%), *Lomandra longifolia* (0.1%), *Melinis repens* (1%), *Panicum effusum* (0.1%), *Solanum ellipticum* (0.1%), *Urochloa piligera* (0.1%).

SECONDARY SITE 45 **HVR 11.10.3**



Latitude, Longitude: -22.2905, 148.1883

Community description: Open forest dominated by *Acacia shirleyi*, with emergent *Eucalyptus crebra* and *Corymbia clarksoniana*, on a low sandstone ridge.

Dominant species per stratum:

E: *Eucalyptus crebra, Corymbia clarksoniana.*
T1: *Acacia shirleyi.*
S1: *Erythroxylum australe***.**
G: *Alloteropsis cimicina, Melinis repens*.*

Median (and range) canopy height per stratum: E = 12.8 m; T1 = 10.6 m (7.4–11.6 m), S1 = 3.0 m (1.0–4.0 m).

% cover of each stratum: E < 0.1%; T1 = 74.2%; S1 = 12%; **total = 76.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Corymbia clarksoniana* = 0.17 m^2/ha **(total = 0.17 m^2/ha)**.
T1: *Acacia shirleyi* = 14.67 m^2/ha **(total = 14.67 m^2/ha)**.
S1: <0.15 m^2/ha.

Landform: Low ridge. **Slope:** 15°S **Soil:** Pink-grey sand with lots of gravel.

Disturbance: Previously cleared; much dumped rubbish.

Ground cover: Rock = 5%, wood = 1%, bare = 20%, litter = 67%, vegetation = 7%.

Species (percent cover): *Acacia shirleyi* (0.1%), *Alloteropsis cimicina* (3.9%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Calotis cuneifolia* (0.1%), *Capparis canescens* (0.1%), *Cheilanthes sieberi* (0.1%), *Cyanthillium cinereum* (0.1%), *Digitaria diminuta* (0.1%), *Eragrostis lacunaria* (0.1%), *Erythroxylum australe* (0.1%), *Harrisia martinii** (0.1%), *Melinis repens* (1%), *Paspalidium gracile* (0.1%), *Portulaca filifolia* (0.1%), *Portulaca oleracea** (0.1%), *Pseuderanthemum variabile* (0.1%), *Ptilotus polystachyus* (0.1%), *Sida* sp. (Musselbrook M.B. Thomas+ MRS437) (0.4%), *Urochloa mosambicensis** (0.1%).

SECONDARY SITE 46 **11.3.25**



Latitude, Longitude: -22.3061, 148.1946

Community description: Closed forest dominated by *Eucalyptus camaldulensis* and *Melaleuca leucadendra* on the bank of an ephemeral watercourse.

Dominant species per stratum:

T1: *Eucalyptus camaldulensis, Melaleuca leucadendra.*
T2: *Alphitonia excelsa.*
S1: *Ficus opposita.*
G: *Bidens pilosa*, Megathyrsus maximus* var. *pubiglumis*, Acanthospermum hispidum*, Richardia brasiliensis*.*

Median (and range) canopy height per stratum: T1 = 21 m (18.4–21.2 m), T2 = 10.8 m (9.2–11 m), S1 = 2.5 m (1.0–4.0 m).

% cover of each stratum: T1 = 87.3%; T2 = 18.8%; S1 = 30.7%; **total = 87.7%**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Melaleuca leucadendra* = 9.83 m^2/ha; *Eucalyptus camaldulensis* = 8 m^2/ha; *Corymbia clarksoniana* = 0.5 m^2/ha **(total = 18.5 m^2/ha)**.
T2: *Alphitonia excelsa* = 0.33 m^2/ha; *Flindersia australis* =0.17 m^2/ha **(total = 0.5 m^2/ha)**.
S1: *Acacia macradenia* = 0.17 m^2/ha; *Ficus opposita* = 0.17 m^2/ha **(total = 0.33 m^2/ha)**.

Landform: Creek bank. **Slope:** 0° **Soil:** Sand.

Disturbance: Very high weed densities.

Ground cover: Rock = 0%, wood = 1%, bare = 15%, litter = 60%, vegetation = 24%.

Species (percent cover): *Acacia macradenia* (0.1%), *Acanthospermum hispidum** (3%), *Ageratum conyzoides** (0.4%), *Albizia canescens* (0.1%), *Alternanthera nana* (0.1%), *Aristolochia thozetii* (0.1%), *Bidens pilosa** (7%), *Bothriochloa pertusa** (0.6%), *Cenchrus ciliaris** (0.1%), *Clerodendrum floribundum* (0.1%), *Commelina diffusa* (0.1%), *Crinum arenarium* (0.1%), *Crotalaria mitchellii* (0.1%), *Crotalaria pallida** (0.1%), *Cryptostegia grandiflora** (0.1%), *Cyanthillium cinereum* (0.1%), *Cyperus gracilis* (0.1%), *Dactyloctenium radulans* (0.1%), *Desmodium filiforme* (0.1%), *Digitaria brownii* (0.1%), *Digitaria eriantha** (0.2%), *Echinochloa colona** (0.1%), *Emilia sonchifolia** (0.2%), *Erythrina vespertilio* (0.1%), *Eucalyptus camaldulensis* (0.1%), *Ficus opposita* (3%), *Ipomoea plebia* (0.1%), *Juncus usitatus* (0.1%), *Lomandra longifolia* (0.1%), *Macroptilium atropurpureum** (0.1%), *Megathyrsus maximus* var. *pubiglumis** (1.4%), *Parthenium hysterophorus** (0.1%), *Passiflora foetida** (0.7%), *Richardia brasiliensis** (3%), *Scoparia dulcis** (0.1%), *Senna occidentalis** (0.1%), *Sida cordifolia** (1%), *Sida hackettiana* (0.1%), *Sida rhombifolia* (0.2%), *Urochloa mosambicensis** (0.5%), *Xanthium occidentale** (0.1%).

SECONDARY SITE 47 **HVR 11.5.3**



Latitude, Longitude: -22.3940, 148.2580

Community description: Woodland dominated by *Eucalyptus populnea* on sand plain. A very small amount of sandstone present at the surface, but otherwise is land zone 5.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
T2: *Alphitonia excelsa, Cassia brewsteri, Melaleuca nervosa.*
S1: *Erythroxylum australe.*
G: *Alloteropsis cimicina, Eriochloa crebra, Sida hackettiana, Stylosanthes scabra*.*

Median (and range) canopy height per stratum: T1 = 15.2 m (11.6–16 m), T2 = 6.6 m (6.2–8.6 m), S1 = 2.5 m (1.0–4.2 m).

% cover of each stratum: T1 = 31.1%; T2 = 16.4%; S1 = 0.6; **total = 44.9%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 6.83 m^2/ha **(total = 6.83 m^2/ha)**.
T2: *Cassia brewsteri* = 0.5 m^2/ha; *Alphitonia excelsa* = 1.67 m^2/ha **(total = 2.17 m^2/ha)**.
S1: <0.15 m^2/ha.

Landform: Plain **Slope:** 1°N **Soil:** Yellow-grey sand.

Disturbance: Previously cleared; grazed.

Ground cover: Rock = 0.1%, wood =0.5%, bare = 45%, litter = 25%, vegetation = 29.4%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Acacia salicina* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Alloteropsis cimicina* (13%), *Alphitonia excelsa* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Aristida holathera* (0.9%), *Bonamia media* (0.1%), *Carissa ovata* (0.1%), *Cenchrus ciliaris** (0.4%), *Cheilanthes sieberi* (0.1%), *Chrysopogon fallax* (0.3%), *Desmodium filiforme* (0.1%), *Digitaria divaricatissima* (0.2%), *Digitaria eriantha** (0.1%), *Diospyros humilis* (0.1%), *Eragrostis lacunaria* (0.1%), *Eragrostis sororia* (0.2%), *Eragrostis speciosa* (0.1%), *Eriachne mucronata* (0.1%), *Eriochloa crebra* (6%), *Erythroxylum australe* (0.3%), *Eucalyptus populnea* (0.1%), *Euphorbia bifida* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (0.1%), *Ipomoea polymorpha* (0.1%), *Melinis repens* (0.1%), *Perotis rara* (0.2%), *Phyllanthus collinus* (0.2%), *Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 1810) (0.2%), *Phyllanthus virgatus* (0.1%), *Portulaca filifolia* (0.1%), *Portulaca oleracea** (0.1%), *Sida hackettiana* (2%), *Sida spinosa** (0.1%), *Stylosanthes hamata** (0.1%), *Stylosanthes scabra** (2%), *Tephrosia leptoclada* (0.2%), *Urochloa mosambicensis** (0.1%), *Zornia* sp. (0.7%)**.**

SECONDARY SITE 48 **11.5.3**



Latitude, Longitude: -22.3895, 148.2367

Community description: Woodland dominated by *Eucalyptus populnea* on a sand plain.

Dominant species per stratum:

T1: *Eucalyptus populnea.*
T2: *Vachellia bidwillii, Eucalyptus populnea.*
S1: *Carissa ovata.*
G: *Scoparia dulcis*, Heteropogon contortus, Fimbristylis dichotoma, Bothriochloa pertusa*, Cenchrus ciliaris*, Urochloa mosambicensis*.*

Median (and range) canopy height per stratum: T1 = 16.8 m (11.6–19.8 m), T2 = 4.2 m (2.8–6.8 m), S1 = 1.0 m (0.5–1.5 m).

% cover of each stratum: T1 = 44.2%; T2 = 3%; S1 = 12.7%; **total = 45.3%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus populnea* = 14.67 m^2/ha; *Corymbia clarksoniana* = 0.33 m^2/ha; *Eucalyptus crebra* = 0.17 m^2/ha; *Eucalyptus melanophloia* = 0.17 m^2/ha **(total = 15.34 m^2/ha)**
T2: *Corymbia dallachiana* = 0.17 m^2/ha; *Cassia brewsteri* = 0.17 m^2/ha; *Vachellia bidwillii* = 0.17 m^2/ha **(total = 0.51 m^2/ha)**
S1: < 0.15 m^2/ha

Landform: Plain. **Slope:** 0° **Soil:** Fine grey-brown sand.

Disturbance: Grazed.

Ground cover: Rock = 0%, wood =0.8%, bare = 25%, litter = 35%, vegetation = 39.2%.

Species (percent cover): *Achyranthes aspera* (0.1%), *Afrohybanthus enneaspermus* (0.1%), *Afrohybanthus stellarioides* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.4%), *Boerhavia pubescens* (0.1%), *Bothriochloa ewartiana* (0.2%), *Bothriochloa pertusa** (4%), *Carissa ovata* (2%), *Cenchrus ciliaris** (5%), *Chamaecrista absus* (0.1%), *Chrysopogon fallax* (0.8%), *Crotalaria juncea** (0.1%), *Cyanthillium cinereum* (0.1%), *Cynodon dactylon** (0.1%), *Cyperus fulvus* (0.1%), *Cyperus gracilis* (0.1%), *Desmodium filiforme* (0.1%), *Enteropogon ramosus* (0.2%), *Eragrostis sororia* (0.1%), *Eriochloa crebra* (0.3%), *Eucalyptus populnea* (0.1%), *Euphorbia drummondii* (0.1%), *Evolvulus alsinoides* (0.1%), *Fimbristylis dichotoma* (3%), *Glycine tomentella* (0.1%), *Grewia retusifolia* (0.2%), *Heteropogon contortus* (3%), *Indigofera colutea* (0.1%), *Ipomoea plebia* (0.1%), *Malvastrum americanum** (0.1%), *Melinis repens* (0.5%), *Phyllanthus collinus* (0.1%), *Polygala triflora* (0.1%), *Scoparia dulcis** (5%), *Sida hackettiana* (0.2%), *Sida spinosa** (0.8%), *Spermacoce brachystema* (0.1%), *Stylosanthes scabra** (2%), *Urochloa mosambicensis** (9%), *Vachellia bidwillii* (0.1%), *Zornia areolata* (0.1%).

SECONDARY SITE 49 **11.4.8**



Latitude, Longitude: -22.3526, 148.2236

Community description: Open forest dominated by *Acacia harpophylla* and *Casuarina cristata*, with emergent *Eucalyptus cambageana*, on a clay plain.

Dominant species per stratum:

E: *Eucalyptus cambageana*.
T1: *Acacia harpophylla*, *Casuarina cristata*, *Terminalia oblongata.*
T2: *Acacia harpophylla*, *Terminalia oblongata.*
S1: *Carissa ovata, Terminalia oblongata.*
G: *Paspalidium caespitosum*, *Eragrostis lacunaria*.

Median (and range) canopy height per stratum: E = 20.4 m (18.4–24.6 m); T1 = 12.8 m (12.2–16.6 m), T2 = 5.0 m (4.8–5.8 m), S1 = 1.5 m (0.5–3.0 m).

% cover of each stratum: E = 10.6%; T1 = 56.5%; T2 = 12%; S1 = 43.1%; **total = 83.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Eucalyptus cambageana* = 0.5 m^2/ha **(total = 0.5 m^2/ha)**.
T1: *Casuarina cristata* = 4.67 m^2/ha; *Acacia harpophylla* = 4.5 m^2/ha; *Terminalia oblongata* = 3 m^2/ha; *Eucalyptus cambageana* = 0.67 m^2/ha; *Ventilago viminalis* = 0.17 m^2/ha **(total = 13.01 m^2/ha)**.
T2: <0.17 m^2/ha.
S1: <0.17 m^2/ha.

Landform: Plain. **Slope:** 2°NE **Soil:** Brown clay loam with some surface pebbles. No obvious gilgais.

Disturbance: Grazed.

Ground cover: Rock = 0.1%, wood = 1%, bare = 24%, litter = 38%, vegetation = 36.9%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Bothriochloa pertusa** (0.1%), *Brunoniella australis* (0.1%), *Carissa ovata* (0.1%), *Casuarina cristata* (31.4%), *Cenchrus ciliaris** (0.1%), *Chloris divaricata* (0.1%), *Chrysopogon fallax* (0.1%), *Cymbopogon refractus* (0.1%), *Cynanchum viminale* (0.1%), *Desmodium varians* (0.1%), *Enneapogon* sp. A (0.1%), *Eragrostis lacunaria* (0.4%), *Eremophila mitchellii, Erythroxylum australe, Evolvulus alsinoides, Flindersia dissosperma, Glycine* sp. (Mackay S.B. Andrews+ 43), *Grewia latifolia* (0.1%), *Hibiscus sturtii* (0.1%), *Jacquemontia paniculata* (0.1%), *Jasminum didymum* subsp. *lineare* (0.1%), *Melhania oblongifolia* (0.1%), *Ocimum caryophyllinum* (0.1%), *Paspalidium caespitosum* (0.1%), *Phyllanthus virgatus* (0.1%), *Rhynchosia minima* (0.1%), *Scleria brownii* (0.2%), *Terminalia oblongata* (2%).

SECONDARY SITE 50 **11.10.8**



Latitude, Longitude: -22.2892, 148.1563.
Community description: Low closed forest (semi-evergreen microphyll vine-thicket) dominated by *Planchonella pubescens*, *Geijera salicifolia*, *Gossia bidwillii* and *Hovea longipes* in a sheltered sandstone gorge.

Dominant species per stratum:

E: *Acacia shirleyi, Lophostemon suaveolens, Euroschinus falcatus.*
T1: *Planchonella pubescens, Geijera salicifolia, Drypetes deplanchei, Acronychia laevis, Psydrax odorata.*
S1: *Hovea longipes, Alyxia ruscifolia, Gossia bidwillii.*
G: *Ancistrachne uncinata.*

Median (and range) canopy height per stratum: E =11 m (10–13 m); T1 = 5 m (4–6 m); S1 = 1.5 m (1–2 m).

% cover of each stratum: E = 46.8%; T1 =64.7%; S1 = 30.4%; **total = 92.4%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

E: *Acacia shirleyi* = 0.83 m^2/ha; *Alectryon connatus* = 0.17 m^2/ha; *Bursaria incana* = 0.33 m^2/ha; *Euroschinus falcata* = 0.5 m^2/ha; *Ficus rubiginosa* = 0.17 m^2/ha; *Pleiogynium timoriense* **=** 0.33 m^2/ha; (**total = 2.33 m^2/ha)**.
T1: *Planchonella pubescens* = 3.17 m^2/ha; *Geijera salicifolia* = 2.67 m^2/ha; *Gossia bidwillii* = 1.5 m^2/ha; *Ehretia membranifolia* = 0.5 m^2/ha; *Exocarpos latifolius* = 0.67 m^2/ha; *Drypetes deplanchei* = 0.17 m^2/ha; *Psydrax odorata* subsp. *buxifolia* = 0.17 m^2/ha; **(total = 8.85 m^2/ha)**.
S1: *Hovea longipes* = 1.33 m^2/ha; *Psydrax odorata* subsp. *buxifolia* = 0.67 m^2/ha **(total = 2 m^2/ha)**.

Landform: Rocky gorge. **Slope:** 45°ESE **Soil:** Abundant sandstone boulders.

Disturbance: nil.

Ground cover: Rock = 70%, bare = 2%, litter = 20%, vegetation = 8%.

Species (percent cover): *Abutilon oxycarpum* (0.1%), *Acacia burdekensis* (0.1%), *Acacia shirleyi* (0.1%), *Acronychia laevis* (0.1%), *Alectryon connatus* (0.1%), *Alphitonia excelsa* (0.1%), *Alyxia ruscifolia* (0.7%), *Amyema conspicua* (0.1%), *Ancistrachne uncinata* (0.5%), *Bidens bipinnata** (0.1%), *Bursaria incana* (0.1%), *Capparis lasiantha* (0.1%), *Cassytha filiformis* (0.1%), *Cheilanthes nudiuscula* (0.2%), *Cissus oblonga* (0.1%), *Cleistochloa subjuncea* (0.7%), *Commelina diffusa* (0.2%), *Cyanthillium cinereum* (0.2%), *Deeringia amaranthoides* (0.1%), *Dinebra decipiens* var. *decipiens* (0.1%), *Diospyros humilis* (0.1%), *Drypetes deplanchei* (0.3%), *Ehretia membranifolia* (0.1%), *Exocarpos latifolius* (0.3%), *Ficus rubiginosa* (0.1%), *Gahnia aspera* (0.1%), *Geijera salicifolia* (0.1%), *Gossia bidwillii* (0.2%), *Harrisia martinii** (0.1%), *Hovea longipes* (0.3%), *Jasminum didymum* subsp. *racemosum* (0.1%), *Jasminum simplicifolium* subsp. *australiense* (0.1%), *Larsenaikia ochreata* (0.2%), *Lophostemon suaveolens* (0.1%), *Myrsine variabilis* (0.1%), *Parsonsia lanceolata* (0.1%), *Pavetta granitica* (0.1%), *Planchonella pubescens* (0.1%), *Plectranthus parviflorus* (0.2%), *Pleiogynium timoriense* (0.1%), *Psydrax odorata* subsp. *buxifolia* (0.1%), *Richardia brasiliensis** (0.1%), *Scleria brownii* (0.1%), *Scleria sphacelata* (0.1%), *Scoparia dulcis** (0.1%), *Secamone elliptica* (0.1%), *Setaria surgens* (0.1%), *Sida hackettiana* (0.1%), *Solanum ellipticum* (0.1%), *Tetrastigma nitens* (0.1%), *Trema tomentosa* (0.1%), *Trophis scandens* (0.1%).

SECONDARY SITE 51 **11.10.7**



Date: 1 April 2020

Latitude, Longitude: -22.2798, 148.1368

Community description: *Eucalyptus crebra* open woodland situated on a terrace of a sandstone slope.

Dominant species per stratum:

T1: *Eucalyptus crebra, Eucalyptus melanophloia* (sub-dominant).
S1: *Acacia burdekensis.*
G: *Bothriochloa pertusa*, Chrysopogon fallax*

Median (and range) canopy height per stratum: T1 = 15.8 m (12.3-16 m), S1 = 2.6 m (2.1-8.2 m).

% cover of each stratum (vertical projection along 100 m tape): T1 = 15.2 %, S1 < 0.1%; **total = 15.2%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Eucalyptus crebra* = 3.33 m^2/ha **(total = 3.33 m^2/ha).**

Landform: Terrace of a sandstone slope. **Slope:** 1°W **Soil:** Grey-brown sandy clay.

Disturbance: Many dead trees; high weed density.

Ground cover: rock = 1.5%, litter = 20.5%, bare = 18%, vegetation = 60%.

Species (percent cover): *Acacia burdekensis* (0.1%), *Alloteropsis cimicina* (0.1%), *Alphitonia excelsa* (0.1%), *Alternanthera nana* (0.1%), *Aristida calycina* var. *calycina* (0.1%), *Bothriochloa bladhii* (0.1%), *Bothriochloa decipiens* var. *decipiens* (2%), *Bothriochloa pertusa** (48%), *Brunoniella australis* (0.1%), *Cenchrus ciliaris** (0.1%), *Chrysopogon fallax* (5.5%), *Crotalaria juncea* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyperus fulvus* (0.1%), *Dactyloctenium radulans* (0.1%), *Dichanthium sericeum* (0.1%), *Digitaria ammophila* (0.1%), *Digitaria papposa* (0.5%), *Enteropogon acicularis* (0.1%), *Eragrostis sororia* (0.1%), *Eucalyptus crebra* (0.1%), *Eulalia aurea* (0.1%), *Fimbristylis dichotoma* (0.1%), *Galactia tenuiflora* (0.1%), *Ipomoea polymorpha* (0.1%), *Lobelia concolor* (0.1%), *Marsdenia microlepis* (0.1%), *Melhania oblongifolia* (0.1%), *Melinis repens** (0.1%), *Panicum effusum* (0.1%), *Parthenium hysterphorus** (0.1%), *Phyllanthus virgatus* (0.1%), *Rhynchosia minima* (0.1%), *Sida hackettiana* (0.3%), *Sida rohlenae* subsp. *rohlenae* (0.1%), *Sporobolus caroli* (0.1%), *Stylosanthes scabra** (0.1%), *Themeda triandra* (0.2%), *Tragus australianus* (0.1%), *Urochloa mosambicensis** (0.1%), *Zornia muelleriana* subsp. *muelleriana* (0.1%).

SECONDARY SITE 52 **11.10.1**



Date: 2 April 2020

Latitude, Longitude: -22.2728, 148.1414

Community description: Open forest dominated by *Corymbia citriodora* on sandstone.

Dominant species per stratum:

T1: *Corymbia citriodora, Eucalyptus crebra* (sub-dominant).
T2: *Acacia shirleyi, Alphitonia excelsa, Corymbia citriodora.*
S1: *Acacia bancroftiorum, Acacia flavescens, Erythroxylum australe.*
G: *Cleistochloa subjuncea, Scleria sphacelata.*

Median (and range) canopy height per stratum: T1 = 18.8 m (16.8-21.6 m), T2 = 8.8 m (6.8-10.2 m), S1 = 2 m (1.1-3.6 m).

% cover of each stratum (vertical projection along 100 m tape): T1 = 42.1%, T2 =18.1%, S1 = 23.8%; **total = 73.7%.**

Basal area (using a Bitterlich gauge, measured at three points along the transect)**:**

T1: *Corymbia aureola* = 0.17 m^2/ha; *Corymbia citriodora* = 5.67 m^2/ha **(total = 5.83 m^2/ha).**
T2: *Acacia shirleyi* = 0.83 m^2/ha; *Euroschinus falcata* = 0.17 m^2/ha **(total = 1 m^2/ha).**
S1: *Erythroxylum australe* **=** 0.17 m^2/ha; **(total = 0.17 m^2/ha).**

Landform: Crest of hill slope. **Slope:** 20°S **Soil:** Coarse sand.

Disturbance: Minimal.

Ground cover: rock = 61.8%, litter = 18%, bare = 0.5%, vegetation = 19.7%.

Species (percent cover): *Acacia bancroftiorum* (0.1%), *Acacia flavescens* (0.1%), *Amyema congener* (0.1%), *Blumea axillaris* (0.1%), *Breynia oblongifolia* (0.1%), *Bursaria incana* (0.1%), *Cassytha filiformis* (0.1%), *Cleistochloa subjuncea* (13%), *Clerodendrum floribundum* (0.1%), *Corymbia citriodora* subsp. *citriodora* (0.1%), *Cyanthillium cinereum* (0.1%), *Cyclophyllum coprosmoides* (0.3%), *Cymbopogon obtectus* (0.1%), *Desmodium rhytidophyllum* (0.1%), *Digitaria ramularis* (0.1%), *Dinebra decipiens* var. *decipiens* (0.1%), *Erythroxylum australe* (0.1%), *Euphorbia bifida* (0.1%), *Euphorbia tannensis* (0.1%), *Evolvulus alsinoides* (0.1%), *Galactia tenuiflora* (0.1%), *Goodenia* sp. (Mt Castletower M.D. Crisp 2753) (0.1%), *Hibiscus meraukensis* (0.1%), *Indigofera pratensis* (0.1%), *Ipomoea brownii* (0.1%), *Jasminum didymum* subsp. *lineare* (0.1%), *Marsdenia microlepis* (0.1%), *Melinis repens** (0.1%), *Oxalis corniculata* (0.1%), *Pandorea pandorana* (0.1%), *Parsonsia lanceolata* (0.1%), *Persoonia falcata* (0.1%), *Petalostigma pubescens* (0.1%), *Phyllanthus carpentariae* (0.1%), *Phyllanthus virgatus* (0.1%), *Scleria sphacelata* (3%), *Setaria surgens* (0.1%).

APPENDIX C

FLORA AND FAUNA RECORDED DURING SURVEYS

Appendix C1 Flora recorded during field surveys

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Acanthaceae	*Brunoniella australis*	Blue Trumpet	0	0	100	100	29	33	67	33	0	0	0	0	50
Acanthaceae	*Pseuderanthemum variabile*	Pastel Flower; Love Flower	0	0	50	0	0	11	0	33	80	67	0	20	0
Acanthaceae	*Rostellularia adscendens*	Pink Tongues	50	33	0	0	29	22	67	67	0	33	0	0	0
Aizoaceae	*Portulaca bicolor*		0	0	0	0	0	11	0	0	20	33	0	0	0
Aizoaceae	*Portulaca filifolia*		50	0	25	0	57	11	0	0	20	0	0	20	25
Aizoaceae	*Portulaca oleracea**	Common Purslane	0	0	50	100	43	11	33	0	20	33	0	0	0
Aizoaceae	*Portulaca pilosa**	Pink Purslane	50	33	25	0	29	78	0	0	20	33	0	0	75
Aizoaceae	*Trianthema portulacastrum**	Black Pigweed	0	0	0	0	0	0	0	0	0	0	0	0	0
Amaranthaceae	*Achyranthes aspera*	Devil's Horsewhip; Chaff Flower	0	67	25	0	43	0	0	0	20	33	0	20	0
Amaranthaceae	*Alternanthera denticulata*	Lesser Joyweed	0	0	0	100	43	0	0	0	0	0	0	0	0
Amaranthaceae	*Alternanthera nana*	Hairy Joyweed	50	33	25	0	86	44	0	33	40	0	0	0	50
Amaranthaceae	*Alternanthera pungens**	Khaki Weed	0	0	0	0	0	0	0	0	0	0	0	0	0
Amaranthaceae	*Amaranthus interruptus*		0	0	0	100	0	0	0	0	0	33	0	0	0
Amaranthaceae	*Amaranthus viridis**	Green Amaranth	0	0	0	100	0	0	0	0	0	0	0	0	0
Amaranthaceae	*Deeringia amaranthoides*	Redberry; Shrubby Deeringia	0	0	0	0	0	0	0	0	0	0	100	0	0
Amaranthaceae	*Gomphrena celosioides**	Gomphrena Weed	50	33	0	0	57	11	0	0	0	33	0	0	75
Amaranthaceae	*Nyssanthes erecta*		0	0	50	0	14	0	0	0	0	0	0	0	0
Amaranthaceae	*Ptilotus polystachyus*		0	0	0	0	0	0	0	0	40	0	0	0	0
Amaryllidaceae	*Crinum arenarium*	Field Lily	50	67	0	0	0	0	0	0	0	0	0	0	25
Anacardiaceae	*Euroschinus falcata*	Ribbonwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Anacardiaceae	*Pleiogynium timoriense*	Burdekin Plum	0	0	0	0	0	0	0	0	0	0	100	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Apiaceae	*Platysace valida*		0	0	0	0	0	0	0	0	0	0	0	0	0
Apocynaceae	*Alstonia constricta*	Bitter Bark; Quinine Bush	0	0	0	0	0	0	0	0	0	0	0	0	0
Apocynaceae	*Alyxia ruscifolia*	Chain Fruit	0	0	0	0	0	0	0	0	0	0	100	0	0
Apocynaceae	*Carissa ovata*	Conkerberry; Currant Bush	100	33	100	100	71	11	67	0	0	0	0	0	50
Apocynaceae	*Cryptostegia grandiflora**	Rubber Vine	0	33	0	0	0	0	0	0	0	0	0	0	0
Apocynaceae	*Cynanchum viminale*	Caustic Vine	0	0	50	0	0	0	0	0	0	0	0	0	0
Apocynaceae	*Marsdenia microlepis*		0	0	0	0	0	0	0	67	80	67	0	20	0
Apocynaceae	*Marsdenia viridiflora* subsp. *viridiflora*	Native Pear	0	0	0	100	0	0	0	0	0	0	0	0	0
Apocynaceae	*Parsonsia lanceolata*	Rough Silkpod	50	0	50	100	29	11	0	0	0	0	100	0	25
Apocynaceae	*Secamone elliptica*	Corky Milk Vine	0	0	0	0	0	0	0	0	0	0	100	0	0
Apocynaceae	*Wrightia saligna*	Milk Wood	0	0	0	0	0	0	0	0	40	0	0	0	0
Aristolochiaceae	*Aristolochia thozetii*	Australian Native Dutchman's Pipe	0	33	0	0	14	0	0	0	0	0	0	0	0
Asteraceae	*Acanthospermum hispidum**	Bristly Star Bur; Goat's Head	0	100	0	0	29	33	0	0	0	0	0	0	25
Asteraceae	*Ageratum conyzoides**	Billygoat Weed	0	67	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Apowollastonia spilanthoides*		0	0	25	0	29	11	0	0	0	0	0	0	25
Asteraceae	*Bidens bipinnata**	Bipinnate Cobbler's Pegs	0	33	0	0	0	0	0	0	20	33	100	20	0
Asteraceae	*Bidens pilosa**	Cobbler's Pegs	0	67	0	0	0	11	0	0	0	33	0	0	0
Asteraceae	*Calotis cuneifolia*	Purple Burr-daisy	0	0	0	0	14	0	0	33	40	0	0	0	0
Asteraceae	*Calyptocarpus vialis*	Creeping Cinderella Weed	0	67	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Camptacra barbata*		0	0	0	0	0	0	33	0	0	0	0	0	0
Asteraceae	*Centipeda minima*	Spreading Sneezeweed	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Chrysocephalum apiculatum*	Billy Buttons	0	0	0	0	0	22	0	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Asteraceae	*Coronidium oxylepis*	Pointed Everlasting Daisy	0	0	0	0	0	0	0	33	0	0	0	0	0
Asteraceae	*Cyanthillium cinereum*	Vernonia	50	67	25	0	71	22	33	100	60	33	100	20	50
Asteraceae	*Eclipta prostrata**	False Daisy; Eclipta	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Emilia sonchifolia**	Tassel Flower; Emilia	0	67	0	0	0	22	0	0	0	0	0	0	0
Asteraceae	*Parthenium hysterophorus**	Parthenium Weed	0	100	25	100	0	11	33	0	0	0	0	0	25
Asteraceae	*Peripleura hispidula* var. *setosa*		0	0	0	0	0	0	33	0	0	0	0	0	0
Asteraceae	*Pterocaulon ciliosum*		0	0	0	0	0	0	0	33	0	0	0	0	0
Asteraceae	*Sonchus oleraceus**	Common Sowthistle	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Sphaeromorphaea australis*	Spreading Nut-heads	0	0	0	0	0	11	0	0	0	0	0	0	50
Asteraceae	*Tridax procumbens**	Tridax Daisy	0	33	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Verbesina encelioides**	Golden Crownbeard; Butter Daisy	0	33	0	0	0	0	0	0	0	0	0	0	0
Asteraceae	*Vittadinia pustulata*		0	0	0	0	14	11	0	0	0	0	0	0	0
Asteraceae	*Xanthium occidentale**	Noogoora Burr	0	100	0	0	0	0	0	0	0	0	0	0	0
Bignoniaceae	*Pandorea pandorana*	Wonga Vine	0	0	0	0	0	0	0	0	0	33	0	0	0
Boraginaceae	*Ehretia membranifolia*	Peach Bush; Weeping Koda	0	0	25	100	0	0	0	0	0	0	100	0	0
Boraginaceae	*Heliotropium cunninghamii*		0	0	0	0	0	0	0	0	0	0	0	0	25
Boraginaceae	*Heliotropium peninsulare*		0	0	0	0	0	33	33	0	0	33	0	20	0
Brassicaceae	*Cardamine hirsuta**	Hairy Bittercress	0	0	0	0	0	0	0	0	0	0	0	0	0
Byttneriaceae	*Hannafordia shanesii*		0	0	0	0	0	0	0	0	0	0	0	0	0
Cactaceae	*Harrisia martinii**	Harrisia Cactus	100	0	50	0	0	11	0	0	20	0	100	0	0
Cactaceae	*Opuntia stricta**	Prickly Pear	0	0	0	0	0	0	0	0	0	0	0	0	0
Cactaceae	*Opuntia tomentosa **	Velvet Pear; Wooly Pear	50	0	25	0	14	0	0	0	20	0	0	0	0

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			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Caesalpiniaceae	*Bauhinia hookeri*	White Bauhinia	0	67	0	100	0	0	0	0	0	0	0	0	0
Caesalpiniaceae	*Cassia brewsteri*	Brewster's Cassia	50	0	25	0	14	0	0	0	0	0	0	0	50
Caesalpiniaceae	*Chamaecrista absus*	Pig's ear; Sensitive Pea	0	33	0	0	14	44	0	0	20	67	0	40	25
Caesalpiniaceae	*Chamaecrista nomame*		0	0	0	0	0	0	0	0	0	0	0	0	0
Caesalpiniaceae	*Chamaecrista rotundifolia**	Round-leaf Sensitive Pea	0	0	0	0	0	0	0	0	0	33	0	0	0
Caesalpiniaceae	*Petalostylis labicheoides*	Butterfly Bush	0	0	0	0	0	0	0	0	0	0	0	0	0
Caesalpiniaceae	*Senna coronilloides*	Brigalow Senna	0	0	0	100	0	0	0	0	0	0	0	0	0
Caesalpiniaceae	*Senna occidentalis**	Coffee Senna	0	100	0	0	0	0	0	0	0	0	0	0	0
Campanulaceae	*Lobelia purpurascens*	White Root	0	0	0	0	0	0	0	0	0	33	0	0	0
Campanulaceae	*Wahlenbergia gracilis*	Blue Bell	0	0	0	0	0	0	0	0	0	0	0	0	0
Capparaceae	*Apophyllum anomalum*	Warrior Bush; Broom Bush	0	0	25	100	0	0	0	0	0	0	0	0	0
Capparaceae	*Capparis canescens*	Bumble Bush; Wild Orange	50	0	0	0	14	11	0	67	20	0	0	0	0
Capparaceae	*Capparis lasiantha*	Wyjeelah; Nepine	100	0	75	0	29	0	0	0	0	0	100	0	50
Caryophyllaceae	*Polycarpaea corymbosa*		0	0	0	0	0	11	0	0	0	33	0	0	0
Casuarinaceae	*Allocasuarina luehmannii*	Bull Oak	0	0	0	0	0	11	0	0	0	0	0	0	0
Casuarinaceae	*Casuarina cristata*	Belah	0	0	50	0	0	0	0	0	0	0	0	0	0
Celastraceae	*Denhamia cunninghamii*	Yellow-berry Bush	0	0	0	0	0	0	33	0	0	0	0	0	0
Celastraceae	*Denhamia oleaster*		0	0	0	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	*Dysphania melanocarpa* forma *melanocarpa*	Black Crumbweed	0	33	0	0	14	22	0	0	0	0	0	0	25
Chenopodiaceae	*Einadia nutans* subsp. *nutans*	Climbing Saltbush	0	0	50	0	14	0	0	0	0	0	0	0	25
Chenopodiaceae	*Einadia nutans* subsp. *linifolia*	Narrow Climbing Saltbush	0	0	25	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	*Enchylaena tomentosa* var.	Ruby Saltbush	0	0	50	0	0	0	0	0	0	0	0	0	0

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	tomentosa														
Chenopodiaceae	*Maireana microphylla*	Small-leaf Bluebush	0	0	25	0	0	0	0	0	0	0	0	0	0
Chenopodiaceae	*Salsola australis*	Roly-Poly	0	0	25	100	14	0	0	0	0	0	0	0	25
Chenopodiaceae	*Sclerolaena birchii*	Galvanised Burr	0	0	0	0	0	0	0	0	0	0	0	0	0
Cleomaceae	*Cleome tetrandra* var. *tetrandra*		0	0	0	0	0	22	0	0	0	0	0	0	0
Cleomaceae	*Cleome viscosa*	Tick Weed	0	0	0	0	0	0	33	0	0	33	0	0	0
Combretaceae	*Terminalia oblongata*	Yellow-wood	0	0	50	0	0	0	0	0	0	0	0	0	0
Commelinaceae	*Commelina diffusa*	Climbing Dayflower	0	100	0	0	0	0	0	0	0	0	100	0	0
Commelinaceae	*Commelina lanceolata*		0	0	0	0	0	22	0	33	0	33	0	20	0
Commelinaceae	*Murdannia graminea*	Grass Lily	0	0	0	0	29	67	0	33	0	33	0	20	50
Convolvulaceae	*Bonamia media*		50	0	0	0	43	56	0	0	0	33	0	40	0
Convolvulaceae	*Evolvulus alsinoides*	Dwarf Morning Glory	100	0	100	0	86	67	33	67	40	100	0	80	25
Convolvulaceae	*Ipomoea brownii*		0	0	0	0	0	0	0	0	20	33	0	60	0
Convolvulaceae	*Ipomoea plebia*	Bell Vine	0	100	0	100	14	0	0	0	0	0	0	40	25
Convolvulaceae	*Ipomoea polymorpha*		0	0	0	0	57	78	0	0	0	0	0	20	50
Convolvulaceae	*Jacquemontia paniculata*		50	0	50	0	0	11	33	0	0	0	0	0	0
Convolvulaceae	*Polymeria pusilla*		0	0	0	0	0	0	33	0	0	0	0	0	25
Convolvulaceae	*Xenostegia tridentata*		0	0	0	0	0	0	0	0	20	33	0	60	0
Cyperaceae	*Abildgaardia ovata*		0	0	0	0	0	0	33	0	0	0	0	0	0
Cyperaceae	*Bulbostylis barbata*		0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus betchei*		0	0	0	0	0	0	0	33	20	33	0	20	0
Cyperaceae	*Cyperus concinnus*		0	0	0	100	0	0	0	0	0	0	0	0	0

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Cyperaceae	*Cyperus conicus* var. *conicus*		0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus difformis*	Variable Flatsedge	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus fulvus*	Sticky Sedge	50	0	0	0	29	11	0	0	0	33	0	0	0
Cyperaceae	*Cyperus gracilis*	Slender Flat-sedge	50	67	50	100	43	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus leiocaulon*		0	33	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus perangustus*		0	0	0	100	0	0	0	0	0	0	0	0	0
Cyperaceae	*Cyperus rotundus**	Purple Nutsedge	0	0	0	0	0	0	33	0	0	0	0	0	0
Cyperaceae	*Eleocharis acuta*	Common Spikerush	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	*Fimbristylis dichotoma*	Common Fringe-sedge	100	0	0	0	71	100	33	33	0	67	0	20	75
Cyperaceae	*Gahnia aspera*	Rough Saw-sedge	0	0	0	0	0	0	0	33	0	0	100	0	0
Cyperaceae	*Scleria brownii*		0	0	25	0	0	0	67	0	0	0	100	20	0
Cyperaceae	*Scleria sphacelata*		0	0	0	0	0	0	0	100	60	0	100	0	0
Ebenaceae	*Diospyros humilis*	Small-leaved Ebony	0	0	0	0	14	0	0	0	0	0	100	0	0
Erythroxylaceae	*Erythroxylum australe*	Australian Cocaine Bush; Dogwood	0	0	50	0	43	33	0	67	80	67	0	80	0
Euphorbiaceae	*Acalypha eremorum*	Soft Acalypha	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	*Euphorbia bifida*		0	0	0	0	14	0	33	0	0	0	0	20	25
Euphorbiaceae	*Euphorbia drummondii*	Caustic Weed	0	0	0	0	29	0	33	33	20	33	0	60	0
Euphorbiaceae	*Euphorbia hirta**	Asthma Weed	0	33	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	*Euphorbia tannensis*	Desert Spurge	0	0	0	0	0	0	0	33	0	0	0	0	0
Euphorbiaceae	*Jatropha gossypiifolia**	Bellyache Bush	0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Aeschynomene brevifolia*		0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Aeschynomene indica*	Indian Jointvetch	0	0	0	0	0	0	0	0	0	0	0	0	0

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Fabaceae	*Bossiaea carinalis*		0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Crotalaria juncea**	Brown Hemp	0	0	0	0	14	0	0	0	0	0	0	0	25
Fabaceae	*Crotalaria medicaginea*	Trefoil Rattlepod	0	0	0	0	0	22	0	0	0	0	0	0	0
Fabaceae	*Crotalaria mitchellii*	Yellow Rattlepod	0	67	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Crotalaria montana*		0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Crotalaria pallida**	Smooth Rattlepod	0	33	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Daviesia filipes*		0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Desmodium filiforme*		0	33	0	0	43	11	0	0	0	0	0	0	0
Fabaceae	*Desmodium macrocarpum*	Large-podded Trefoil	50	0	0	0	0	0	0	33	0	0	0	20	0
Fabaceae	*Desmodium rhytidophyllum*	Hairy Trefoil	0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Desmodium varians*	Slender Tick-trefoil	0	0	75	0	0	11	33	0	0	0	0	0	0
Fabaceae	*Erythrina vespertilio*	Bat's Wing Coral Tree	0	33	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Galactia tenuiflora*		0	0	0	0	29	44	33	33	20	33	0	60	50
Fabaceae	*Glycine* sp. (Mackay S.B. Andrews+ 43)		0	0	25	0	29	0	33	0	0	33	0	0	0
Fabaceae	*Glycine tomentella*	Woolly Glycine	50	33	0	0	29	44	33	33	0	0	0	20	25
Fabaceae	*Hovea longipes*	Brush Hovea	0	0	0	0	0	0	0	0	0	0	100	0	0
Fabaceae	*Hovea tholiformis*		0	0	0	0	0	0	0	67	0	0	0	20	0
Fabaceae	*Indigofera australis*	Australian Indigo	0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Indigofera colutea*	Sticky Indigo	50	0	0	0	14	22	0	0	0	0	0	0	75
Fabaceae	*Indigofera hirsuta*	Hairy Indigo	0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Indigofera linifolia*	Narrow-leafed Indigo	0	0	0	0	0	0	100	0	0	0	0	0	25
Fabaceae	*Indigofera linnaei*	Birdsville indigo	50	0	0	0	0	11	67	0	0	0	0	0	50

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Fabaceae	*Indigofera* sp. A		0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Macroptilium atropurpureum**	Siratro	0	33	0	0	0	0	0	0	0	0	0	0	25
Fabaceae	*Pycnospora lutescens*	Pycnospora	0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Rhynchosia minima*	Least Snout-bean	0	0	25	0	29	0	67	0	0	0	0	0	50
Fabaceae	*Sesbania cannabina*	Sesbania Pea	0	0	0	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Stylosanthes hamata**	Caribbean Stylo	0	67	0	0	43	33	33	0	0	0	0	0	50
Fabaceae	*Stylosanthes humilis**	Townsville Stylo	50	33	0	0	14	0	0	0	0	0	0	0	25
Fabaceae	*Stylosanthes scabra**	Shrubby Stylo	100	0	0	0	71	89	100	33	20	100	0	80	100
Fabaceae	*Tephrosia dietrichiae*		0	0	0	0	0	11	0	0	0	0	0	0	0
Fabaceae	*Tephrosia filipes* subsp. *filipes*		0	0	0	0	0	0	33	0	0	33	0	40	0
Fabaceae	*Tephrosia juncea*		0	0	0	0	0	0	0	33	0	0	0	20	0
Fabaceae	*Tephrosia leptoclada*		0	0	0	0	29	33	0	0	0	0	0	0	0
Fabaceae	*Tephrosia* sp. A		0	0	0	0	0	0	0	33	0	0	0	0	0
Fabaceae	*Tephrosia* sp. B		0	0	0	0	0	0	33	0	0	0	0	0	0
Fabaceae	*Zornia areolata*		0	0	0	0	43	11	0	0	0	0	0	0	0
Fabaceae	*Zornia muelleriana subsp. muelleriana*		0	0	0	0	14	44	0	0	0	33	0	20	0
Fabaceae	*Zornia muriculata subsp. angustata*		50	33	0	0	0	11	0	0	0	0	0	0	25
Fabaceae	*Zornia* sp.		0	0	0	0	29	11	0	33	0	33	0	0	25
Goodeniaceae	*Goodenia glabra*	Smooth Goodenia	0	0	0	0	0	11	0	0	0	0	0	0	0
Goodeniaceae	*Goodenia grandiflora*	Large-flowered Goodenia	0	0	0	0	0	0	0	0	0	0	0	0	0
Goodeniaceae	*Goodenia* sp. (Mt Castletower M.D. Crisp 2753)		0	0	0	0	0	0	0	67	20	0	0	0	0

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Hemerocallidaceae	*Dianella nervosa*	Flax Lily	0	0	0	0	0	11	0	0	20	0	0	0	0
Johnsoniaceae	*Tricoryne elatior*	Yellow Autumn-lily	0	0	0	0	0	11	0	0	0	0	0	0	0
Juncaceae	*Juncus polyanthemus*	Australian Grey Rush	0	0	0	0	0	0	0	0	0	0	0	0	0
Juncaceae	*Juncus usitatus*	Common Rush	0	33	0	0	0	0	0	0	0	0	0	0	0
Lamiaceae	*Ajuga australis*	Australian Bugle	0	33	0	0	0	0	0	0	0	0	0	0	0
Lamiaceae	*Anisomeles malabarica*	Catmint	0	0	0	0	0	0	0	0	0	0	0	0	0
Lamiaceae	*Clerodendrum floribundum*	Lolly Bush	0	67	0	0	0	11	0	0	0	0	0	0	25
Lamiaceae	*Clerodendrum tomentosum*	Hairy Lolly Bush	0	0	0	0	14	0	0	0	0	0	0	0	0
Lamiaceae	*Ocimum caryophyllinum*	Holy Basil	0	0	25	0	0	0	33	0	0	0	0	0	0
Lamiaceae	*Plectranthus parviflorus*	Little Spurflower	0	0	0	0	0	0	0	0	0	0	100	0	0
Lauraceae	*Cassytha filiformis*	Love Vine; Dodder Laurel	0	0	0	0	0	11	33	0	0	0	100	0	0
Laxmanniaceae	*Eustrephus latifolius*	Wombat Berry	0	0	0	0	0	0	33	33	0	0	0	0	25
Laxmanniaceae	*Lomandra longifolia*	Spiny-head Mat-rush	0	67	0	0	0	0	0	0	0	0	0	40	0
Laxmanniaceae	*Lomandra multiflora*	Many-flowered Mat-rush	0	0	0	0	0	0	67	33	0	0	0	0	0
Loranthaceae	*Amyema congener*	Variable Mistletoe	0	0	0	0	0	0	0	0	0	0	0	0	0
Loranthaceae	*Amyema conspicua*	Alphitonia Mistletoe	0	0	0	0	0	0	0	0	0	0	100	0	0
Malvaceae	*Abutilon guineense**	Chinese Lantern	0	33	0	0	0	0	0	0	0	0	0	0	25
Malvaceae	*Abutilon oxycarpum*	Lantern Bush	0	0	75	0	29	0	0	0	0	0	100	0	0
Malvaceae	*Abutilon oxycarpum* var. *incanum*	Lantern Bush	0	0	50	100	14	0	0	0	0	0	0	0	0
Malvaceae	*Gossypium australe*	Australian Cotton	0	0	0	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Hibiscus brachysiphonius*	Low Hibiscus	0	0	25	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Hibiscus meraukensis*	Merauke Hibiscus	0	0	0	0	0	11	0	0	20	0	0	60	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Malvaceae	*Hibiscus sturtii*	Hill Hibiscus	50	0	50	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Malvastrum americanum**	Spiked Malvastrum	0	0	0	100	29	0	33	0	0	0	0	0	0
Malvaceae	*Malvastrum coromandelianum**	Prickly Malvastrum	0	33	0	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Sida aprica*		0	0	0	0	0	0	0	0	20	0	0	0	0
Malvaceae	*Sida atherophora*		0	0	0	0	0	0	0	0	20	0	0	0	0
Malvaceae	*Sida cordifolia**	Flannel Weed	50	100	0	0	29	33	0	0	20	33	0	0	25
Malvaceae	*Sida corrugata*	Variable Sida	0	0	25	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Sida hackettiana*	Golden Rod; Spiked Sida	100	33	25	0	100	78	67	0	20	100	100	60	75
Malvaceae	*Sida pleiantha*		0	0	0	0	0	0	33	0	0	0	0	0	25
Malvaceae	*Sida rhombifolia*	Paddy's Lucerne	0	100	0	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Sida rohlenae*	Shrub Sida	0	0	25	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Sida* sp.		0	0	0	0	0	0	0	33	0	0	0	0	0
Malvaceae	*Sida* sp. (Aramac E.J. Thompson+ JER192)		0	0	0	0	0	11	0	0	0	0	0	0	0
Malvaceae	*Sida* sp. (Musselbrook M.B. Thomas+ MRS437)		0	0	0	0	0	11	0	33	60	33	0	40	0
Malvaceae	*Sida spinosa**	Spiny Sida	100	33	0	0	100	22	33	33	20	100	0	40	100
Marsileaceae	*Marsilea sp.*	Nardoo	0	0	0	0	0	0	0	0	0	0	0	0	0
Meliaceae	*Owenia acidula*	Emu Apple	0	0	25	100	14	0	0	0	0	0	0	0	25
Menispermaceae	*Stephania japonica*	Snake Vine	0	33	0	0	0	0	0	0	0	0	0	0	0
Menispermaceae	*Tinospora smilacina*	Heart Vine	0	33	0	0	0	0	0	0	20	0	0	40	0
Menyanthaceae	*Nymphoides* sp.	Water Snowflake	0	0	0	0	0	0	0	0	0	0	0	0	0
Mimosaceae	*Vachellia bidwillii*	Corkwood Wattle	0	0	25	0	14	0	33	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Mimosaceae	*Acacia bancroftiorum*	Bancroft Wattle	0	0	0	0	0	0	0	0	0	0	0	60	0
Mimosaceae	*Acacia burdekensis*	Burdekin Wattle	0	0	0	0	14	33	0	33	0	33	100	40	0
Mimosaceae	*Acacia curvinervia*		0	0	0	0	0	0	0	0	0	0	0	20	0
Mimosaceae	*Acacia dietrichiana*	Dietrich Wattle	0	0	0	0	0	0	0	33	0	0	0	40	0
Mimosaceae	*Acacia excelsa*	Ironwood Wattle	0	0	0	0	14	11	33	0	0	0	0	0	0
Mimosaceae	*Acacia flavescens*	Red Wattle	0	0	0	0	0	0	0	33	0	33	0	20	0
Mimosaceae	*Acacia harpophylla*	Brigalow	0	0	75	0	0	0	0	0	0	0	0	0	0
Mimosaceae	*Acacia julifera* subsp. *julifera*		0	0	0	0	0	0	0	0	0	0	0	0	0
Mimosaceae	*Acacia macradenia*	Zig-Zag Wattle	0	33	0	0	0	0	0	33	0	0	0	0	0
Mimosaceae	*Acacia rhodoxylon*	Ringy Rosewood	0	0	0	0	0	0	0	0	0	0	0	20	0
Mimosaceae	*Acacia salicina*	Sally Wattle; Willow Wattle	50	33	0	0	14	0	33	0	0	0	0	0	25
Mimosaceae	*Acacia shirleyi*	Lancewood	0	0	0	0	0	0	0	0	80	0	100	60	0
Mimosaceae	*Albizia canescens*	Belmont Siris	0	33	0	0	0	0	0	0	0	0	0	0	0
Mimosaceae	*Archidendropsis basaltica*	Dead Finish	0	0	0	0	14	0	0	0	0	0	0	0	50
Mimosaceae	*Leucaena leucocephala**	Leucaena	0	0	0	0	0	0	0	0	0	0	0	0	0
Mimosaceae	*Neptunia gracilis*	Native Sensitive Plant	0	0	0	0	0	0	67	0	0	0	0	0	75
Molluginaceae	*Glinus lotoides*	Hairy Carpet-weed	0	0	0	0	0	0	0	0	0	0	0	0	0
Moraceae	*Ficus opposita*	Sandpaper Fig	0	100	0	0	0	0	0	0	0	0	0	0	0
Moraceae	*Ficus rubiginosa*	Rock Fig	0	0	0	0	0	0	0	0	0	0	100	0	0
Moraceae	*Trophis scandens*	Burny Vine	0	0	0	0	0	0	0	0	0	0	100	0	0
Myrsinaceae	*Myrsine variabilis*	Muttonwood	0	0	0	0	0	0	0	0	0	0	100	0	0
Myrtaceae	*Corymbia aureola*	Yellowjacket	0	0	0	0	0	0	0	0	0	0	0	80	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Myrtaceae	*Corymbia citriodora* subsp. *citriodora*	Lemon-scented Gum	0	0	0	0	0	0	0	67	0	0	0	0	0
Myrtaceae	*Corymbia clarksoniana*	Clarkson's Bloodwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Corymbia dallachiana*	Ghost Gum	0	0	0	0	0	11	0	0	0	33	0	0	0
Myrtaceae	*Corymbia erythrophloia*	Variable-barked Bloodwood	0	0	0	0	0	0	33	0	0	0	0	0	0
Myrtaceae	*Corymbia tessellaris*	Carbeen; Blackbutt	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Corymbia trachyphloia*	Brown Bloodwood	0	0	0	0	0	0	0	67	0	0	0	0	0
Myrtaceae	*Eucalyptus camaldulensis*	River Red Gum	0	67	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Eucalyptus crebra*	Narrow-Leaved Ironbark	0	0	0	0	0	11	0	33	20	67	0	0	0
Myrtaceae	*Eucalyptus melanophloia*	Silver-leaved Ironbark	50	0	0	0	0	22	0	33	0	33	0	20	0
Myrtaceae	*Eucalyptus orgadophila*	Mountain Coolibah	0	0	0	0	0	0	33	0	0	0	0	0	0
Myrtaceae	*Eucalyptus populnea*	Poplar Box	100	0	0	0	71	0	0	0	0	0	0	0	25
Myrtaceae	*Gossia bidwillii*	Python Tree	0	0	0	0	0	0	0	0	0	0	100	0	0
Myrtaceae	*Leptospermum lamellatum*	Weeping Tea-tree	0	0	0	0	0	0	0	33	0	0	0	0	0
Myrtaceae	*Lophostemon grandiflorus*	Northern Swamp Mahogany	0	33	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Lophostemon suaveolens*	Swamp Mahogany	0	0	0	0	0	0	0	0	0	0	100	0	0
Myrtaceae	*Lysicarpus angustifolius*	Budgeroo	0	0	0	0	0	0	0	33	0	0	0	20	0
Myrtaceae	*Melaleuca fluviatilis*	Weeping Paperbark	0	33	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Melaleuca leucadendra*	Paperbark	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	*Melaleuca nervosa*	Broad-leaved Paperbark	0	0	0	0	14	78	0	0	0	0	0	0	0
Nyctaginaceae	*Boerhavia pubescens*		50	0	75	100	71	11	33	0	0	0	0	0	25
Olacaceae	*Ximenia americana**	Tallow Wood; Yellow Plum	0	0	0	0	0	0	0	0	0	0	0	0	0
Oleaceae	*Jasminum didymum* subsp. *lineare*	Desert Jasmine	0	0	50	0	0	0	0	0	20	0	0	0	0

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			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Oleaceae	*Jasminum didymum* subsp. *racemosum*	Native Jasmine	0	0	0	0	0	0	0	0	0	0	100	0	0
Oleaceae	*Jasminum simplicifolium* subsp. *australiense*	Stiff Jasmine	0	0	0	0	0	0	0	0	0	0	100	0	0
Orchidaceae	*Cymbidium canaliculatum*	Black Orchid	50	0	25	0	0	0	0	0	0	0	0	0	0
Oxalidaceae	*Oxalis corniculata*	Creeping Woodsorrel	100	33	0	0	0	0	0	67	0	0	0	20	25
Passifloraceae	*Passiflora foetida**	Stinking Passionflower	0	33	0	0	0	0	0	0	0	0	0	0	0
Pentapetaceae	*Melhania oblongifolia*		100	0	50	0	29	33	67	33	0	0	0	0	0
Phyllanthaceae	*Breynia oblongifolia*	Coffee Bush	0	0	0	0	29	0	0	67	0	33	0	20	0
Phyllanthaceae	*Phyllanthus carpentariae*		0	0	0	0	0	22	0	33	20	67	0	40	0
Phyllanthaceae	*Phyllanthus collinus*		0	0	25	0	100	56	0	33	20	100	0	0	0
Phyllanthaceae	*Phyllanthus fuernrohrii*	Sand Spurge	0	0	0	0	0	0	33	0	0	0	0	0	0
Phyllanthaceae	*Phyllanthus maderaspatensis*		0	0	0	0	0	0	67	0	0	0	0	0	25
Phyllanthaceae	*Phyllanthus* sp. (Myra Vale J.J. Bruhl+ 181)		0	0	0	0	43	44	0	0	0	33	0	0	25
Phyllanthaceae	*Phyllanthus virgatus*	Creeping Phyllanthus	100	33	75	0	14	11	0	67	0	0	0	20	50
Picrodendraceae	*Petalostigma pubescens*	Quinine Tree	0	0	0	0	0	44	0	33	0	100	0	20	25
Pittosporaceae	*Bursaria incana*	Prickly Pine	0	0	25	0	0	0	33	33	0	0	100	0	0
Plantaginaceae	*Scoparia dulcis**	Licorice Weed	0	67	0	0	14	11	0	0	0	33	100	0	0
Plumbaginaceae	*Plumbago zeylanica*	Wild Plumbago	0	0	0	100	0	0	0	0	0	0	0	0	0
Poaceae	*Alloteropsis cimicina*	Summer Grass	0	67	0	0	43	67	0	0	60	33	0	80	25
Poaceae	*Alloteropsis semialata*	Cockatoo Grass	0	0	0	0	0	0	33	0	0	0	0	0	0
Poaceae	*Ancistrachne uncinata*	Hooky Grass	0	0	50	0	0	0	0	0	0	0	100	0	0
Poaceae	*Aristida benthamii*	Bentham's Wiregrass	0	0	0	0	0	11	0	67	40	33	0	40	0

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			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Poaceae	*Aristida calycina var. calycina*	Dark Wiregrass	100	0	25	0	100	67	0	67	80	100	0	80	50
Poaceae	*Aristida gracilipes*		100	0	50	0	14	0	67	33	20	0	0	0	0
Poaceae	*Aristida holathera*	Tall Kerosene Grass	0	0	0	0	29	44	33	0	0	33	0	20	0
Poaceae	*Aristida inaequiglumis*	Unequal Wiregrass	0	0	0	0	0	11	0	0	0	0	0	0	0
Poaceae	*Aristida spuria*		0	0	0	0	0	0	0	33	0	0	0	0	0
Poaceae	*Arundinella nepalensis*	Reedgrass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Bothriochloa decipiens var. cloncurrensis*	Pitted Bluegrass	0	0	0	0	0	11	0	0	0	0	0	0	0
Poaceae	*Bothriochloa ewartiana*	Desert Bluegrass	100	33	0	0	14	0	100	0	0	0	0	0	25
Poaceae	*Bothriochloa pertusa**	Indian Couch	100	100	75	0	71	44	100	0	0	33	0	0	100
Poaceae	*Capillipedium parviflorum*	Scented-top Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Cenchrus ciliaris**	Buffel Grass	100	100	75	100	86	33	100	33	20	67	0	0	100
Poaceae	*Chloris barbata**	Purpletop Chloris	0	0	0	0	0	0	0	0	0	0	0	0	25
Poaceae	*Chloris divaricata*	Slender Chloris	0	0	100	0	29	11	0	0	0	0	0	0	0
Poaceae	*Chloris virgata**	Feathertop Rhodes Grass	0	67	0	0	14	0	0	0	0	0	0	0	0
Poaceae	*Chrysopogon fallax*	Golden Beard Grass	100	0	25	0	86	78	33	33	20	67	0	20	75
Poaceae	*Cleistochloa subjuncea*		0	0	0	0	0	0	0	67	80	0	100	80	0
Poaceae	*Cymbopogon obtectus*	Silkyheads	0	0	0	0	0	0	0	67	0	0	0	0	0
Poaceae	*Cymbopogon refractus*	Barbed Wire Grass	0	0	50	0	0	0	0	67	0	0	0	0	0
Poaceae	*Cynodon dactylon**	Bermuda Grass; Green Couch	0	67	0	0	14	0	0	0	0	0	0	0	0
Poaceae	*Dactyloctenium radulans*	Button Grass	0	33	0	100	14	56	0	0	0	0	0	0	75
Poaceae	*Dichanthium sericeum*	Queensland Bluegrass	0	0	0	0	0	0	0	33	0	0	0	0	0
Poaceae	*Digitaria ammophila*	Silky Umbrella Grass	0	33	0	0	0	0	0	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Poaceae	*Digitaria brownii*	Cotton Panic Grass	0	33	0	0	0	0	0	0	0	33	0	0	0
Poaceae	*Digitaria ciliaris*	Summer Grass	0	0	0	0	0	0	0	0	0	0	0	0	25
Poaceae	*Digitaria diminuta*		0	0	0	0	0	0	0	33	100	33	0	60	25
Poaceae	*Digitaria divaricatissima*	Umbrella Grass	0	0	0	0	14	33	0	0	0	33	0	0	0
Poaceae	*Digitaria eriantha**		0	100	0	0	14	11	33	0	0	33	0	0	50
Poaceae	*Digitaria longiflora*		0	0	0	0	14	22	0	0	0	0	0	20	0
Poaceae	*Digitaria minima*		0	0	0	0	14	0	0	0	0	0	0	0	0
Poaceae	*Digitaria ramularis*		0	0	0	0	0	0	0	0	0	33	0	0	0
Poaceae	*Digitaria* sp. A		0	0	0	0	0	22	0	0	0	33	0	0	0
Poaceae	*Dinebra decipiens* var. *decipiens*	Slender Cane Grass	0	0	0	0	0	0	0	0	0	33	100	0	0
Poaceae	*Dinebra ligulata*		0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Echinochloa colona**	Awnless Barnyard Grass	0	67	0	100	0	0	0	0	0	0	0	0	0
Poaceae	*Eleusine indica**	Indian Crowfoot Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Enneapogon lindleyanus*	Conetop Nineawn	0	0	25	0	43	0	0	33	0	0	0	0	0
Poaceae	*Enneapogon* sp. A		0	0	25	0	0	0	67	0	0	0	0	0	0
Poaceae	*Enteropogon ramosus*	Curly Windmill Grass	0	0	0	0	43	0	0	0	0	0	0	0	50
Poaceae	*Eragrostis elongata*	Clustered Lovegrass	0	33	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Eragrostis lacunaria*	Purple Lovegrass	0	0	75	0	57	44	0	0	60	0	0	60	25
Poaceae	*Eragrostis leptostachya*	Paddock Lovegrass	0	0	0	0	14	0	0	0	0	33	0	0	0
Poaceae	*Eragrostis parviflora*	Weeping Lovegrass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Eragrostis pilosa**	Soft Lovegrass	0	0	0	100	0	0	0	0	0	0	0	0	0
Poaceae	*Eragrostis sororia*		50	0	0	0	57	78	0	0	20	67	0	60	25

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			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Poaceae	*Eragrostis spartinoides*		0	0	0	0	14	11	0	67	0	33	0	20	0
Poaceae	*Eragrostis speciosa*	Hansome Lovegrass	0	0	0	0	29	11	0	0	0	0	0	0	0
Poaceae	*Eremochloa bimaculata*	Poverty Grass	0	0	0	0	0	11	0	0	0	0	0	0	0
Poaceae	*Eriachne mucronata*	Mountain Wanderrie Grass	0	0	0	0	14	11	0	0	0	33	0	0	0
Poaceae	*Eriachne obtusa*	Northern Wanderrie Grass	0	0	0	0	0	22	0	33	40	0	0	20	0
Poaceae	*Eriochloa crebra*	Cup Grass	0	0	0	100	29	11	0	0	0	67	0	20	0
Poaceae	*Eriochloa pseudoacrotricha*	Early Spring Grass	0	0	0	0	0	0	0	33	0	0	0	20	0
Poaceae	*Eulalia aurea*	Silky Browntop	0	0	0	0	0	11	0	0	0	0	0	0	25
Poaceae	*Heteropogon contortus*	Black Speargrass	50	33	0	0	14	11	33	0	0	0	0	0	25
Poaceae	*Hymenachne amplexicaulis*	Olive Hymenachne	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Hyparrhenia rufa*	Thatch Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Megathyrsus maximus* var. *maximus*	Guinea Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Megathyrsus maximus* var. *pubiglumis*	Green Panic	0	100	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Melinis repens*	Red Natal Grass	0	33	0	0	29	11	33	67	40	67	0	80	0
Poaceae	*Panicum effusum*	Hairy Panic	50	0	0	0	14	11	0	100	20	67	0	40	25
Poaceae	*Paspalidium caespitosum*	Brigalow Grass	0	0	50	0	0	0	0	0	20	0	0	0	0
Poaceae	*Paspalidium constricutum*	Knottybutt Grass	0	0	25	0	0	0	0	0	0	0	0	0	0
Poaceae	*Paspalidium distans*		0	0	50	0	0	0	0	0	0	0	0	0	0
Poaceae	*Paspalidium gracile*	Slender Panic	0	0	0	0	0	0	0	0	60	33	0	20	0
Poaceae	*Paspalidium rarum*	Rare Paspalidium	0	0	0	0	0	33	0	0	0	0	0	0	0
Poaceae	*Perotis rara*	Comet Grass	0	33	0	0	29	56	0	0	20	33	0	0	25

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			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Poaceae	*Schizachyrium fragile*	Firegrass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Setaria surgens*		0	33	0	0	29	44	0	33	0	33	100	20	0
Poaceae	*Sorghum leiocladum*	Wild Sorghum	0	0	0	0	0	0	0	33	0	0	0	0	0
Poaceae	*Sporobolus caroli*	Fairy Grass	0	0	25	100	29	0	0	0	0	0	0	0	25
Poaceae	*Sporobolus scabridus*		0	0	25	100	0	0	0	0	0	0	0	0	0
Poaceae	*Thellungia advena*	Coolibah Grass	0	0	0	0	0	0	33	0	0	0	0	0	0
Poaceae	*Themeda avenacea*	Native Oatgrass	0	0	25	0	0	0	0	0	0	0	0	0	0
Poaceae	*Themeda triandra*	Kangaroo Grass	0	0	0	0	0	0	67	67	0	33	0	20	0
Poaceae	*Thyridolepis xerophila*		0	0	0	0	0	0	0	0	40	0	0	20	0
Poaceae	*Tragus australianus*	Small Burrgrass	0	0	0	0	0	0	0	0	0	0	0	0	25
Poaceae	*Tripogon loliiformis*	Five-minute Grass	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae	*Urochloa foliosa*	Leafy Panic	0	33	0	100	0	0	33	0	0	0	0	0	0
Poaceae	*Urochloa mosambicensis**	Sabi Grass	50	100	25	0	71	33	33	0	40	67	0	0	100
Poaceae	*Urochloa piligera*	Hairy Armgrass	0	0	25	0	14	78	0	0	20	0	0	60	25
Polygalaceae	*Polygala triflora*		0	0	0	0	14	0	0	0	0	0	0	0	0
Polygonaceae	*Persicaria attenuata*	White Smartweed	0	0	0	0	0	0	0	0	0	0	0	0	0
Pontederiaceae	*Monochoria cyanea*	Native Water Hyacinth	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	*Grevillea decora*		0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	*Grevillea parallela*	Silver Oak; Beefwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	*Grevillea pteridifolia*	Golden Parrot Tree; Fern-leaved Grevillea	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	*Grevillea sessilis*		0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	*Grevillea striata*	Beefwood	0	0	0	0	0	11	0	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Proteaceae	*Hakea lorea*	Corkwood; Bootlace Oak	0	0	0	0	0	0	0	33	0	0	0	0	0
Proteaceae	*Persoonia amaliae*		0	0	0	0	0	0	0	33	0	0	0	0	0
Proteaceae	*Persoonia falcata*	Wild Pear; Geebung	0	0	0	0	0	0	0	100	20	0	0	0	0
Pteridaceae	*Cheilanthes sieberi*	Poison Rock Fern	50	33	75	100	43	33	0	100	100	67	0	80	25
Pteridaceae	*Cheilanthes nudiuscula*		0	0	0	0	0	0	0	0	0	0	100	0	0
Putranjivaceae	*Drypetes deplanchei*	Yellow Tulip; Grey Boxwood	0	0	0	0	0	0	0	0	0	0	100	0	0
Rhamnaceae	*Alphitonia excelsa*	Red Ash; Soap Tree	50	0	0	0	71	67	0	67	100	100	100	100	25
Rhamnaceae	*Ventilago viminalis*	Vine Tree	0	0	25	100	29	11	33	0	0	0	0	20	0
Rubiaceae	*Coelospermum reticulatum*	Medicine Bush	0	0	0	0	0	0	0	67	0	0	0	0	0
Rubiaceae	*Cyclophyllum coprosmoides*	Coast Canthium; Sweet Susie	0	0	0	0	0	0	0	33	0	0	0	0	0
Rubiaceae	*Larsenaikia ochreata*	Native Gardenia	0	0	0	0	0	0	0	100	20	33	100	80	0
Rubiaceae	*Oldenlandia mitrasacmoides* subsp. *trachymenoides*		0	0	0	0	0	11	0	0	0	0	0	0	0
Rubiaceae	*Pavetta granitica*		0	0	0	0	0	0	0	0	0	33	100	0	0
Rubiaceae	*Pomax umbellata*	Pomax	0	0	0	0	0	0	0	33	0	0	0	0	0
Rubiaceae	*Psydrax odorata* subsp. *buxifolia*	Shiny-leaved Canthium	0	0	0	0	0	0	0	0	0	0	100	0	0
Rubiaceae	*Psydrax oleifolia*	Wild Lemon; Myrtle	0	0	0	0	0	11	33	0	0	0	0	0	25
Rubiaceae	*Richardia brasiliensis**	White Eye; Mexican Clover	0	33	0	0	0	33	0	0	0	0	100	0	0
Rubiaceae	*Spermacoce brachystema*	Stiff-leafed Spermacoce	0	0	0	0	14	44	0	0	20	0	0	40	0
Rutaceae	*Acronychia laevis*	Hard Aspen	0	0	0	0	0	0	0	0	0	0	100	0	0
Rutaceae	*Flindersia australis*	Crow's Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Rutaceae	*Flindersia dissosperma*	Scrub Leopardwood	0	0	25	0	0	11	0	0	0	0	0	0	0
Rutaceae	*Geijera parviflora*	Wilga	0	0	25	100	0	0	0	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Rutaceae	*Geijera salicifolia*	Scrub Wilga; Green Satinheart	0	0	0	0	0	0	0	0	0	0	100	0	0
Santalaceae	*Exocarpos latifolius*	Broad-leaved Ballart; Scrub Cherry	0	0	0	0	0	0	0	0	0	0	100	0	0
Santalaceae	*Santalum lanceolatum*	Northern Sandalwood	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapindaceae	*Alectryon connatus*	Grey Bird's-eye	0	0	0	0	0	0	0	0	0	0	100	0	0
Sapindaceae	*Alectryon diversifolius*	Scrub Boonaree	0	0	25	100	0	0	0	0	0	0	0	0	0
Sapindaceae	*Atalaya hemiglauca*	Whitewood	50	0	25	0	14	0	100	0	0	0	0	0	25
Sapindaceae	*Dodonaea lanceolata*	Hop Bush	0	0	0	0	0	0	0	33	0	0	0	0	0
Sapindaceae	*Dodonaea stenophylla*		0	0	0	0	0	0	0	0	0	0	0	0	0
Sapotaceae	*Planchonella pohlmanniana*	Yellow Boxwood	0	0	0	0	0	0	0	0	0	33	0	0	0
Sapotaceae	*Planchonella pubescens*		0	0	0	0	0	0	0	0	0	0	100	0	0
Scrophulariaceae	*Eremophila debilis*	Winter Apple	0	0	0	0	29	0	0	0	0	0	0	0	0
Scrophulariaceae	*Eremophila mitchellii*	False Sandalwood	50	0	75	0	14	0	0	0	0	0	0	0	0
Scrophulariaceae	*Myoporum montanum*	Western Boobialla	0	0	0	0	0	0	0	0	0	0	0	0	0
Solanaceae	*Datura leichhardtii**	Thornapple	0	33	0	0	0	0	33	0	0	0	0	0	0
Solanaceae	*Pimelea sericostachya*		0	33	0	0	0	0	0	0	0	0	0	0	0
Solanaceae	*Solanum ellipticum*	Potato Bush	0	33	25	0	14	0	0	67	0	0	100	20	0
Solanaceae	*Solanum esuriale*	Quena	0	0	25	0	0	0	0	0	0	0	0	0	0
Solanaceae	*Solanum parvifolium*		0	0	25	0	0	0	0	0	40	0	0	0	0
Sparrmanniaceae	*Corchorus trilocularis*	Wild Jute	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparrmanniaceae	*Grewia latifolia*	Dysentery Plant; Dog's Balls	0	0	50	0	29	11	33	33	0	0	0	0	0
Sparrmanniaceae	*Grewia retusifolia*	Dysentery Bush; Emu Berry	100	33	25	0	57	11	0	0	0	33	0	0	50
Stylidiaceae	*Stylidium eglandulosum*	Woolly-stemmed Triggerplant	0	0	0	0	0	0	0	0	0	0	0	0	0

Family	Scientific Name	Common Name	Percentage of secondary sites in each regional ecosystem containing the species												
			11.3.2	11.3.25	11.4.8	11.4.9	11.5.3	11.5.9	11.9.2	11.10.1	11.10.3	11.10.7	11.10.8	11.10.13	Non-remnant
Typhaceae	*Typha* sp.	Bulrush	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulmaceae	*Trema tomentosa*	Poison Peach	0	0	0	0	0	0	0	0	0	0	100	20	0
Verbenaceae	*Stachytarpheta jamaicensis**	Snake weed	0	33	0	0	0	0	0	0	0	0	0	0	0
Violaceae	*Pigea enneasperma*	Purple Spade Flower	100	33	0	0	57	11	67	0	0	33	0	0	0
Violaceae	*Pigea stellarioides*	Orange Spade Flower	0	33	0	0	29	56	0	100	40	100	0	80	0
Vitaceae	*Cissus oblonga*	Smooth Water Vine	0	0	0	0	0	0	0	0	0	0	100	0	0
Vitaceae	*Clematicissus opaca*	Pepper Vine	0	33	0	0	0	0	0	0	0	0	0	0	0
Vitaceae	*Tetrastigma nitens*	Native Grape; Three-leaf Water Vine	0	0	0	0	0	0	0	0	0	0	100	0	0
Xanthorrhoeaceae	*Xanthorrhoea johnsonii*	Johnson's Grass Tree	0	0	0	0	0	0	0	33	0	0	0	20	0
Zygophyllaceae	*Tribulopis angustifolia*		0	0	0	0	14	33	0	0	0	0	0	20	0
Zygophyllaceae	*Tribulus terrestris**	Goat's Head; Bullhead; Small Caltrop	0	0	0	100	14	0	33	0	0	0	0	0	0

Appendix C2 Fauna recorded during field surveys

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
MAMMALS												
Short-beaked Echidna	*Tachyglossus aculeatus*	++		+	+				++	+		+
Eastern Grey Kangaroo	*Macropus giganteus*				++		+	++	+		+	++
Common Wallaroo	*Macropus robustus*		++	++					+++			
Unadorned/Herbert's Rock-wallaby	*Petrogale inornata/herberti*	+++										

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Swamp Wallaby	*Wallabia bicolor*		++	+	+				+++	+		
Rufous Bettong	*Aepyprymnus rufescens*			+		+		++				++
Narrow-nosed Planigale	*Planigale tenuirostris*						+			++		+
Common Planigale	*Planigale maculata*							+				+
Koala	*Phascolarctos cinereus*		+	+	+++	+			+			
Common Brush-tailed Possum	*Trichosurus vulpecula*	+		++	+++	+++	+	++				
Krefft's Glider	*Petaurus notatus*						+			+		
Squirrel Glider	*Petaurus norfolcensis*				++			+				
Central Greater Glider	*Petauroides armillatus*	+	++		+++	++					++	
House Mouse	*Mus musculus*		+	+				+	++			
Delicate Mouse	*Pseudomys delicatulus*		+					++				+
Eastern Pebble Mouse	*Pseudomys patrius*			++				++				
Lakeland Downs Mouse	*Leggadina lakedownensis*		++	++				+				
Water Rat	*Hydromys chrysogaster*											+
European Rabbit	*Oryctolagus cuniculus*		+		++	++	+++	+	+	++		+
Little Red Flying-fox	*Pteropus scapulatus*				++							++
Feral Pig	*Sus scrofa*				+							+
Feral Cat	*Felis catus*			+	+		+	+	+	+		++
Dingo	*Canis lupus dingo*			++	++			++				
Red Fox	*Vulpes vulpes*							+				
Bats												
Gould's Wattle Bat	*Chalinolobus gouldii*		+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Chocolate Wattle Bat	*Chalinolobus morio*		++	++		+	+	++	+++			+++

Common Name	Scientific Name	Abundance per Broad Vegetation Group*									
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Hoary Wattle Bat	*Chalinolobus nigrogriseus*				++	+				+		
Little Pied Bat	*Chalinolobus picatus*		+++	++	+	-	+	+++	+++	-	+++	+++
Long-eared Bat	*Nyctophilus* sp.			+++	+	++	+	+	+	++		+
Western Broad-nosed Bat	*Scotorepens balstoni*		-	+	++	+++	-	+++	+++	+++	-	+++
Little Broad-nosed bat	*Scotorepens greyii*		+++	+++	+++	+++	+	+++	+++	+++	+++	+++
Inland Forest Bat	*Vespadelus baverstocki*		+	+++	-	-	-	+	++	-		+++
Eastern Cave Bat	*Vespadelus troughtoni*		+	+++		+++	+	+++	+++			+
Eastern Bentwing Bat	*Miniopterus orianae oceanensis*		+++	++	++	+	+	+++	+++		-	
White-striped Freetail-bat	*Austronomus australis*			+								
Greater Northern Freetail-bat	*Chaerephon jobensis*		+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Northern Freetail Bat	*Ozimops lumsdenae*		+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Eastern Freetail Bat	*Ozimops ridei*		++	+++	+++	+++	+++	+++	+++	+++	-	+++
Bristle-faced Freetail Bat	*Setriostris eleryi*		-	-					-			++
Yellow-bellied Sheathtail-bat	*Saccolaimus flaviventris*		-	+++	+++	+++	+	+++	+++	+++	+++	+++
Troughton's Sheathtail-bat	*Taphozous troughtoni*		-	-	-		-	-	-	-		-
BIRDS												
Emu	*Dromaius novaehollandiae*			+					+		+	
Magpie Goose	*Anseranas semipalmata*											++
Plumed Whistling-duck	*Dendrocygna eytoni*				+							++
Australian Wood Duck	*Chenonetta jubata*											++
Pacific Black Duck	*Anas superciliosa*										++	++
Grey Teal	*Anas gracilis*										++	

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Hardhead	*Aythya australis*											+
Brown Quail	*Synoicus ypsilophorus*			++							+	++
Stubble Quail	*Coturnix pectoralis*											+
Australasian Grebe	*Tachybaptus novaehollandiae*											+
Common Bronzewing	*Phaps chalcoptera*					++			+			
Crested Pigeon	*Ocyphaps lophotes*			+		++	+++	++				++
Squatter Pigeon	*Geophaps scripta*			++		++		+				++
Bar-shouldered Dove	*Geopelia humeralis*				+			++	+			
Diamond Dove	*Geopelia cuneata*			+				+				
Peaceful Dove	*Geopelia placida*			+++	+++	++		+++	+++	++		+++
Australian Bustard	*Ardeotis australis*							++				+
Pheasant Coucal	*Centropus phasianinus*		+	++	++	++	+	++		++		
Channel-billed Cuckoo	*Scythrops novaehollandiae*			+	++		++	++	+	+		+
Horsfield's Bronze-cuckoo	*Chrysococcyx basalis*					+						
Shining Bronze-cuckoo	*Chrysococcyx lucidus*		++						++			
Little Bronze-cuckoo	*Chrysococcyx minutillus*				+							+
Pallid Cuckoo	*Cacomantis pallidus*					+			+			++
Fan-tailed Cuckoo	*Cacomantis flabelliformis*								+			
Pacific Koel	*Eudynamys orientalis*				++	++	+					
Tawny Frogmouth	*Podargus strigoides*	+		+	++			++	+			
Australian Owlet-nightjar	*Aegotheles cristatus*		++	+				+				
White-throated Nightjar	*Eurostopodus mystacalis*	+		+						++		+
White-throated Needletail	*Hirundapus caudacutus*											++

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Eurasian Coot	*Fulica atra*											+
Brolga	*Antigone rubicunda*											++
Bush Stone-curlew	*Burhinus grallarius*				+				+			
Pied Stilt	*Himantopus himantopus*									+		+
Masked Lapwing	*Vanellus miles*					++						++
Black-fronted Dotterel	*Elseyornis melanops*											++
Painted Buttonquail	*Turnix varius*		++	++				++				++
Little Black Cormorant	*Phalacrocorax sulcirostris*											++
Australasian Darter	*Anhinga novaehollandiae*											+
Australian Pelican	*Pelecanus conspicillatus*											+
Eastern Great Egret	*Ardea alba modesta*				+							+
Intermediate Egret	*Ardea intermedia*											+
White-necked Heron	*Ardea pacifica*											+
Cattle Egret	*Bubulcus ibis*											+
White-faced heron	*Egretta novaehollandiae*											++
Nankeen Night-heron	*Nycticorax caledonicus*											++
Straw-necked Ibis	*Threskiornis spinicollis*											++
Royal Spoonbill	*Platalea regia*											+
Black-shouldered Kite	*Elanus axillaris*									+		
Wedge-tailed Eagle	*Aquila audax*		++	++	+							++
Pacific Baza	*Aviceda subcristata*		+							+		
Brown Goshawk	*Accipiter fasciatus*			+				+				
Black Kite	*Milvus migrans*							++		+		++

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Whistling Kite	*Haliastur sphenurus*			+++	+++	+++	+	+++	++	++	+	+++
Southern Boobook	*Ninox novaeseelandiae*	+	+	++	++	+++	+	++	+	++		++
Laughing Kookaburra	*Dacelo novaeguineae*		++	+++	+++	+++	+++	+++	+++	+++		+++
Blue-winged Kookaburra	*Dacelo leachii*				++	+	+	++		+++		
Red-backed Kingfisher	*Todiramphus pryrrhopygius*											+
Forest Kingfisher	*Todiramphus macleayii*				+	++			+	+++		
Sacred Kingfisher	*Todiramphus sanctus*		+							+++		
Rainbow Bee-eater	*Merops ornatus*		+	+++	++	++		++	+++	++		++
Dollarbird	*Eurystomus orientalis*				+++	+++				+++		
Nankeen Kestrel	*Falco cenchroides*				+	++						++
Peregrine Falcon	*Falco peregrinus*			+			+					
Brown Falcon	*Falco berigora*		+									
Sulphur-crested Cockatoo	*Cacatua galerita*	+++	+++	+++	+++	+++	++	+++	+++	+++	++	++
Glossy Black-cockatoo	*Calyptorhynchus lathami*									+		
Galah	*Eolophus roseicapilla*			++	++	++	+	++				++
Cockatiel	*Nymphicus hollandicus*						++					+
Red-winged Parrot	*Aprosmictus erythropterus*		++	+++	+++	+++	+++	+++	++	+++		+++
Pale-headed Rosella	*Platycercus adscitus*		++	+++	+++	+++	+++	+++	+++	++	++	++
Budgerigar	*Melopsittacus undulatus*		++	++				+				++
Little Lorikeet	*Glossopsitta pusilla*					+						
Rainbow Lorikeet	*Trichoglossus haematodus*	++	+++	+++	+++	+++	++	+++	+++	+++		++
Scaly-breasted Lorikeet	*Trichoglossus chlorolepidotus*			++								
Spotted Bowerbird	*Chlamydera maculata*			+	++	+++	++	+	+			

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Red-backed Fairywren	*Malurus melanocephalus*		++	++	++	+++	+++	++	++	+++	+	+++
Purple-backed Fairywren	*Malurus assimilis*				+			++		++		
Noisy Miner	*Manorina melanocephala*		+++	++	+++	+++	++	++	++	+++	++	++
Yellow-throated Miner	*Manorina flavigula*			++		++	+++	++	++			++
Singing Honeyeater	*Gavicalis virescens*			+			+			+		
Scarlet Honeyeater	*Myzomela sanguinolenta*									+		
Brown Honeyeater	*Lichmera indistincta*	+		++	++			+++	+			++
Blue-faced Honeyeater	*Entomyzon cyanotis*		++	+++	+++	+++		+++	++		++	++
White-throated Honeyeater	*Melithreptus albogularis*	+	+++	+++	+++	++	+	+++	++	+	+	
Striped Honeyeater	*Plectorhyncha lanceolata*			++	+			++	+++			
Little Friarbird	*Philemon citreogularis*		+++	+++	+++	++	+++	++	+++	+++	+	++
Noisy Friarbird	*Philemon corniculatus*		+++	+++	+++	+++	++	+++	+++	+++	+	+++
Striated Pardalote	*Pardalotus striatus*		+++	+++	+++	+++	+++	+++	+++	+++	++	+++
Yellow Thornbill	*Acanthiza nana*		++						+++			
Buff-rumped Thornbill	*Acanthiza reguloides*		+++					++	+++	++		
Speckled Warbler	*Pyrrholaemus sagittatus*			+				+				
Weebill	*Smicrornis brevirostris*		+++	+++	+++	+++	+	+++	+++	+++	++	++
White-throated Gerygone	*Gerygone olivacea*	+		+++	++	++		+++	+++	+++		+
Grey-crowned Babbler	*Pomatostomus temporalis*		+++	+++	++	++		+++	+++	+++		
Golden-headed Cisticola	*Cisticola exilis*											+
Silvereye	*Zosterops lateralis*	++								++		
Masked Woodswallow	*Artamus personatus*											++
White-browed Woodswallow	*Artamus superciliosus*				++				++			++

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Black-faced Woodswallow	*Artamus cinereus*							+				
White-breasted Woodswallow	*Artamus leucorynchus*				++							
Grey Butcherbird	*Cracticus torquatus*		+++	++	+++	++		++	+++	+	+	
Pied Butcherbird	*Cracticus nigrogularis*		++	+++	+++	+++	+++	+++	+++	+++	+	+++
Australian Magpie	*Gymnorhina tibicen*		+++	+++	+++	+++	+++	+++	+++	+++		+++
Pied Currawong	*Strepera graculina*	+++	+++	+++	++	++		+++	+++	+		+
Black-faced Cuckooshrike	*Coracina novaehollandiae*		+++	+++	++	++	+++	+++	+++	+++		+++
White-bellied Cuckooshrike	*Coracina papuensis*			++	+	+	++					
White-winged Triller	*Lalage tricolor*					+		++				
Common Cicadabird	*Edolisoma tenuirostre*								+			
Varied Sitella	*Daphoenositta chrysoptera*		+++		++				++			
Grey Shrikethrush	*Colluricincla harmonica*		+++		++			++	+++			+
Golden Whistler	*Pachycephala pectoralis*	+										
Rufous Whistler	*Pachycephala rufiventris*		++	+++	++	+++	+	+++	+++	+++	+	++
Olive-backed Oriole	*Oriolus sagittatus*		+++	++	++	+	+	+++	++			
Australasian Figbird	*Sphecotheres vieilloti*			++	++	++						
Spangled Drongo	*Dicrurus bracteatus*				+					++		
Grey Fantail	*Rhipidura albiscapa*	+	++	++	++			+++	+++			++
Rufous Fantail	*Rhipidura rufifrons*	+						+				
Willie Wagtail	*Rhipidura leucophrys*		+	+	++	+	+	++	+	++	+	++
Magpie-lark	*Grallina cyanoleuca*			+		+++		++				+++
Leaden Flycatcher	*Myiagra rubecula*	+	+++	+	++		++	++	++	++		
Australian Raven	*Corvus coronoides*			++	+	+						

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Torresian Crow	*Corvus orru*		+++	+++	+++	+++	+++	+++	+++	+++		+++
White-winged Chough	*Corcorax melanorhamphos*			++	++	+			+			
Apostlebird	*Struthidea cinerea*	+	++	+++	++	+++		++	++		++	++
Jacky Winter	*Microeca fascinans*			+								
Eastern Yellow Robin	*Eopsaltria australis*								+			
Australasian Reed Warbler	*Acrocephalus australis*											+
Brown Songlark	*Megalurus cruralis*											+
Rufous Songlark	*Megalurus mathewsi*						+++		+	+		++
Common Myna	*Acridotheres tristis*											++
Mistletoebird	*Dicaeum hirundinaceum*	+	+	+	+			+	+++		+	
Australasian Pipit	*Anthus novaeseelandiae*											++
Chestnut-breasted Mannikin	*Lonchura castaneothorax*			++								++
Plum-headed Finch	*Neochmia modesta*			++								
Double-barred Finch	*Taeniopygia bichenovii*	+	++	+++	+			+++	++		+	
REPTILES												
Robust Blind Snake	*Anilios ligatus*				+							
Small-headed Blind Snake	*Anilios affinis*					+		+	+			
Spotted Python	*Antaresia maculosa*			+								
Black-headed Python	*Aspidites melanocephalus*									+		
Brown Tree Snake	*Boiga irregularis*				+							
Green Tree Snake	*Dendrelaphis punctulatus*											+
Eastern Brown Snake	*Pseudonaja textilis*											+
Coral Snake	*Brachyurophis australis*			+								

Common Name	Scientific Name	Abundance per Broad Vegetation Group*									
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Yellow-faced Whipsnake	*Demansia psammophis*						+			+		
Curl Snake	*Suta suta*			+								
Burton's Legless Lizard	*Lialis burtonis*		+		+				+			
Eastern Striped Skink	*Ctenotus robustus/spaldingi*		+++	++		+	+	+	++			++
Eastern Barred Wedgesnout Ctenotus	*Ctenotus strauchii*							++		++		
Eastern Mulch-slider	*Lerista fragilis*		+++	++		+		+	+++	+		+
Common Dwarf Skink	*Menetia greyii*			++								
Dwarf Litter-skink	*Pygmaeascincus timlowi*			+	++	++						++
Iridescent Litter-skink	*Lygisaurus foliorum*		+++		++				+++			
Shaded-litter Rainbow-skink	*Carlia munda*			++	++	++		++		+		++
Open-litter Rainbow-skink	*Carlia pectoralis*	+++		++	+++	+++		++	+++			
Robust Rainbow-skink	*Carlia schmeltzii*			+	+		+		+			
Tussock Rainbow-skink	*Carlia vivax*				++					++		
Elegant Snake-eyed Skink	*Cryptoblepharus pulcher*		++	++	++	+	+	++				
Fire-tailed Skink	*Morethia taeniopleura*		+++	+++	++	++	+	+	+++			+
Bearded Dragon	*Pogona barbata*			+				+				
Tommy Roundhead	*Diporiphora australis*		++	+++				++	++			
Black-headed Monitor	*Varanus tristis*					+		++				+
Dubious Dtella	*Gehyra dubia*	+		+++	++		+++	++	+++	++		+
Chain-backed Dtella	*Gehyra catenata*				++		+		++	+++		
Bynoe's Gecko	*Heteronotia binoei*	+++	+++	+++	+++	+++	++	+++	+++	+++		+++
Spiny Knob-tail Gecko	*Nephrurus asper*								+			
Box-patterned Gecko	*Lucasium steindachneri*		++	+++		++	++	+++		++		

Common Name	Scientific Name	Abundance per Broad Vegetation Group*										
		7a	10a	12a	16a/9e	17a	17b	18b	24a	25a	34d	NR†
Eastern Fat-tailed Gecko	*Diplodactylus platyurus*			++		+++			+			
Wood Gecko	*Diplodactylus vittatus*		+						+++			
Ocellated Velvet Gecko	*Oedura monilis*							+	+	+++		
Ornate Velvet Gecko	*Oedura picta*			++								
Eastern Spiny-tailed Gecko	*Strophurus williamsi*			++			+			+		+
AMPHIBIANS												
Cane Toad	*Rhinella marina*	+		+++	+++	+++	++	+++	+++	++	+++	+++
Spotted Grass Frog	*Limnodynastes tasmaniensis*			+		++	++	+		+		++
Scarlet sided Pobblebonk	*Limnodynastes terraereginae*				++	++					++	
Green Tree-Frog	*Litoria caerulea*			+					++	+	++	
Desert Tree-Frog	*Litoria rubella*							+		++	+++	++
Roth's Tree Frog	*Litoria rothii*										++	
Bumpy Rocket Frog	*Litoria inerma*					++					++	+++
Broad-palmed Frog	*Litoria latopalmata*											+
Ornate Burrowing Frog	*Platyplectrum ornatum*		+	++	+++	+++	++	+++	++	+++	+++	+++
Short-footed Frog	*Cyclorana brevipes*					++	+	++	+	+		
New Holland Frog	*Cyclorana novaehollandiae*					++					+++	++
Green-stripe Frog	*Cyclorana albogutata*										+	++
Wrinkled Toadlet	*Uperoleia rugosa*							+				+
Major Toadlet	*Pseudophryne major*										++	

*Abundance: + = only one individual recorded; ++ = more than one individual but present in fewer than half the sites surveyed; +++ = present in the majority of sites surveyed.
†NR = non-remnant pasture.

APPENDIX D

ANABAT RESULTS

Microbat Call Interpretation Report

Prepared for ("Client"):	METSERVE
Survey location/project name:	Saraji West
Survey dates:	25 October – 3 November 2018
Client project reference:	
Job no.:	MET-1802
Report date:	14 December 2018

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Methods

Data received & post-processing

Balance! Environmental received 14 ZCA data files and associated log files, recorded using two Anabat Express detectors (Titley Scientific, Brisbane) over seven consecutive nights (25th October – 2nd November 2018).

The ZCA files were processed with *AnalookW* (Corben 2018) to extract individual Anabat ZC call-sequence files for analysis. This process yielded some 33,000 ZC files; however, when a generic noise filter was applied in *AnalookW*, fewer than 3000 ZC files were found to contain identifiable bat-calls. Most of the noise files were generated from Anabat B (Meserve).

Call analysis and identification

All ZC files that passed the noise filter were analysed in *AnalookW*, with species identification achieved manually by comparing call spectrograms and derived metrics with those of reference calls from central and northern Queensland and/or with published call descriptions (e.g. Reinhold et al. 2001). Consideration was also given to the probability of species' occurrence based on published distribution information (e.g. Churchill 2008; van Dyck *et al.* 2013) and on-line database records (e.g. http://www.ala.org.au).

Reporting standard

The format and content of this report follows Australasian Bat Society standards for the interpretation and reporting of bat call data (Reardon 2003), available on-line at http://www.ausbats.org.au/.

Species nomenclature follows Jackson & Groves (2015), which elevates the sub-genus names proposed by Reardon *et al.* (2014) for the *Mormopterus* free-tailed bats to genus level; hence *Ozimops lumsdenae* (syn. *M.* beccarii) and *O. ridei* (syn. *M. ridei* and *M.* 'species 2') are used herein.

Results & Discussion

A total of 2469 individual bat calls were identified in this data set, with 82% (2031) of those recorded by Anabat B (Metserve) and the remainder (438 calls) recorded by Anabat ECO1019.

Reliable identification was achieved on 2191 calls (89% of total), which were attributed to seven unique species and two species pairs, the members of which cannot be differentiated based on call characteristics. The positively-identified species included the following:

- *Chalinolobus gouldii;*
- *Nyctophilus geoffroyi / N. gouldi;*
- *Scotorepens balstoni;*
- *Scotorepens greyii / S. sanborni;*
- *Vespadelus troughtoni;*
- *Chaerephon jobensis;*
- *Ozimops lumsdenae;*
- *Ozimops ridei;* and
- *Saccolaimus flaviventris.*

Eighteen percent (278) of the calls could not be reliably identified due to similarities in call characteristics shared by several species that are likely to occur in the study area. These unresolved calls were allocated to one of the following species groups:

- *Chalinolobus gouldii / Ozimops ridei;*
- *C. gouldii / Scotorepens balstoni;*
- *Scotorepens greyii / Chalinolobus nigrogriseus;*
- *Saccolaimus flaviventris / Chaerephon jobensis;* and
- *S. flaviventris / Ozimops lumsdenae.*

Of these unresolved groups, only one potentially represents an additional species (*i.e. Chalinolobus nigrogriseus*), with the others all containing species that were otherwise positively identified form more typical calls.

Table 1 provides a summary of species' presence on each detector-night throughout the survey. Where unresolved calls were identified, all members of the relevant group are listed as "possible" unless positive identification was achieved on other calls.

Sample spectrograms of each recorded call type are shown at Appendix 1.

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Reardon, T. B., McKenzie, N. L., Cooper, S. J. B., Appleton, B., Carthew, S. and Adams, M. (2014). A molecular and morphological investigation of species boundaries and phylogenetic relationships in Australian free-tailed bats *Mormopterus* (Chiroptera : Molossidae). *Australian Journal of Zoology* **62**, 109–136.

Reinhold, L., Law, B., Ford, G. and Pennay, M. (2001). *Key to the bat calls of south-east Queensland and north-east New South Wales*. Department of Natural Resources and Mines, Brisbane.

van Dyck, S., Gynther, I. and Baker, A. (ed.) (2013). *Field Companion to the Mammals of Australia*. New Holland; Sydney.

Table 1. Microbat species recorded during the Saraji West survey, 25 October – 2 November 2018.

♦ = 'definite' - at least one call was attributed unequivocally to the species

□ = 'possible' - calls similar to those of the species were recorded, but were not reliably identified

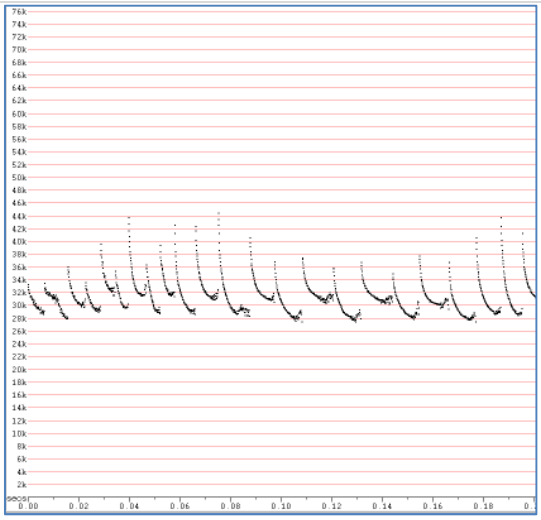
Detector:	Anabat B Metserve							Anabat ECO1019				
Date:	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct	1-Nov	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct
Chalinolobus gouldii	♦	♦	♦	♦	♦	♦	♦	♦		♦	♦	♦
Chalinolobus nigrogriseus	□	□	□			□	□			□		
Nyctophilus species						♦						
Scotorepens balstoni	♦	♦	♦	□	□	♦	♦					♦
Scotorepens greyii / S. sanborni		♦	♦	♦	♦	♦	♦				♦	♦
Vespadelus troughtoni							♦					♦
Chaerephon jobensis	□	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	
Ozimops lumsdenae		♦	♦	♦	♦	♦	♦	♦		♦	♦	♦
Ozimops ridei	□	♦	♦	□	□	♦	♦	♦		♦	□	□
Saccolaimus flaviventris	♦	♦	♦		♦	♦	♦		♦	♦	♦	♦

Glossary

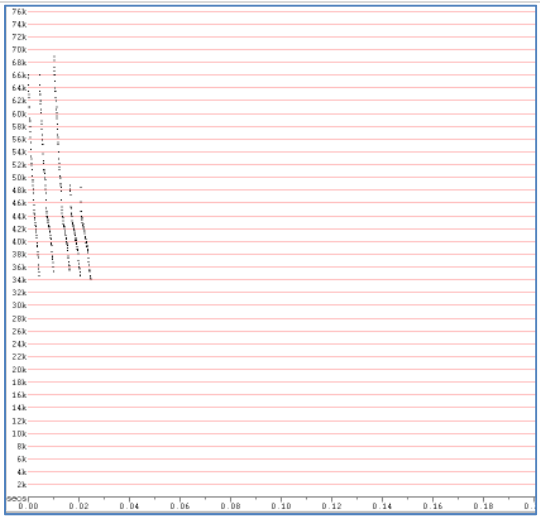
Technical terms used in this report are described in the following table.

Approach phase	The part of a bat *call* emitted as the bat starts to home in on a detected prey item; a transitional series of *pulses* between the *search phase* and *feeding buzz*, that become progressively steeper and shorter in duration.
Call	Refers to a single bat call, made up of a series of individual sound *pulses* in one or more *phases* (*search, approach, feeding buzz*).
CF (=Constant Frequency)	A type of *pulse* in which the dominant component consists of a more-or-less 'pure tone' of sound at a Constant Frequency; with *shape* appearing flat on the sonogram. Often also contains a brief *FM* component at the beginning and/or end of the CF component (*viz.* FM-CF-FM).
Characteristic frequency (Fc)	The frequency of the flattest part of a *pulse*; usually the lowest frequency reached in the *qCF* component of a pulse. This is often the primary diagnostic feature for species identification.
Duration	The time period from the beginning of a *pulse* to the end of the pulse.
Feeding buzz	The terminal part of a *call*, following the *approach phase*, emitted as the bat catches a prey item; a distinctive, rapid series of very steep, very short-duration pulses.
FM (=Frequency Modulated)	A type of *pulse* in which there is substantial change in frequency from beginning to end; *shape* ranges from almost vertical and linear through varying degrees of curvature.
FC range	Refers to the range of frequencies occupied by the *characteristic frequency* section of *pulses* within a call or set of calls.
Frequency sweep or "band-width"	The range of frequencies through which a *pulse* sweeps from beginning to end; Maximum frequency (Fmax) – minimum frequency (Fmin).
Knee	The transitional part of a *pulse* between the initial (usually steeper) frequency sweep and the *characteristic frequency* section (usually flatter); time to knee (Tk) and frequency of knee (Fk) can be diagnostic for some species.
Pulse	An individual pulse of sound within a bat *call*; the *shape*, *duration* and *characteristic frequency* of a pulse are the key diagnostic features used to differentiate species.
Pulse body	The part of the *pulse* between the *knee* and *tail* and containing the *characteristic frequency* section.
Pulse shape	The general appearance of a *pulse* on the sonogram, described using relative terms related to features such as slope and degree of curvature. See also *CF, qCF* and *FM*.
qCF (=quasi Constant Frequency)	A type of *pulse* in which there is very little change in frequency from beginning to end; *shape* appears to be almost flat. Some pulses also contain an *FM* component at the beginning and/or end of the qCF component (*viz.* FM-qCF).
Search phase	The part of a bat *call* generally required for reliable species diagnosis. A consistent series of *pulses* emitted by a bat that is searching for prey or and/or navigating through its habitat. Search phase pulses generally have longer duration, flatter slope and more consistent shape than *approach phase* and *feeding buzz* pulses.
Sequence	Literally, a sequence of *pulses* that may be from one or more bats; but generally refers to a *call* or part (e.g. *phase*) of a call.
Tail	The final component of a *pulse*, following the *characteristic frequency* section; may consist of a short or long sweep of frequencies either upward or downward from the Fc; or may be absent.

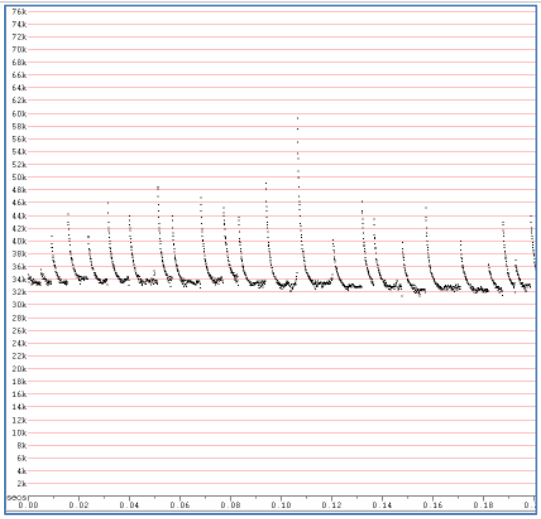
Appendix 1 Representative call sequences from the Saraji West survey, October 2018.
AnalookW spectrograms with time between pulses removed pulses



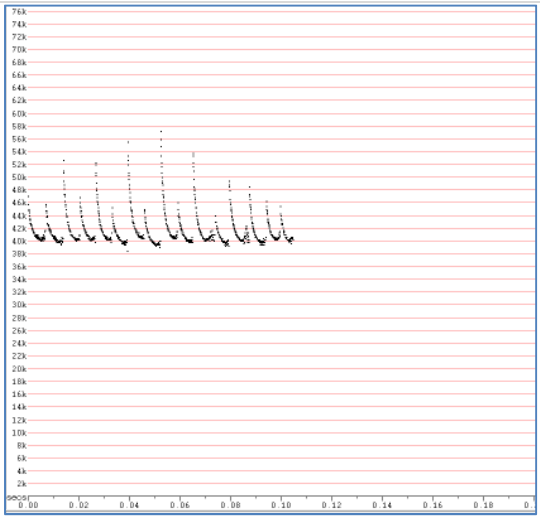
Chalinolobus gouldii



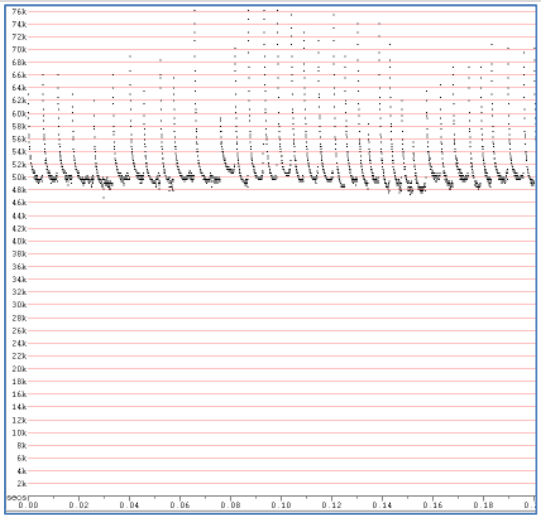
Nyctophilus species



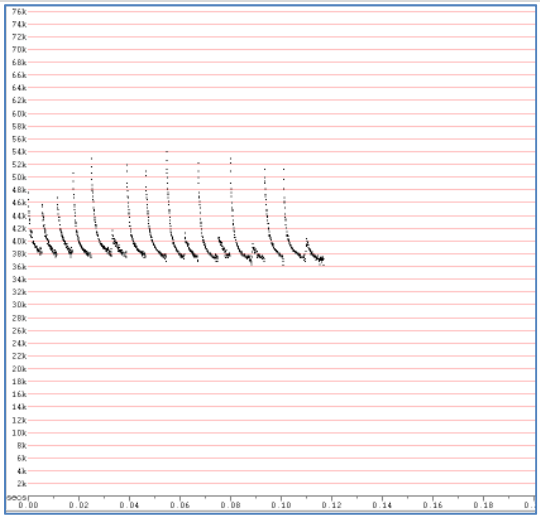
Scotorepens balstoni



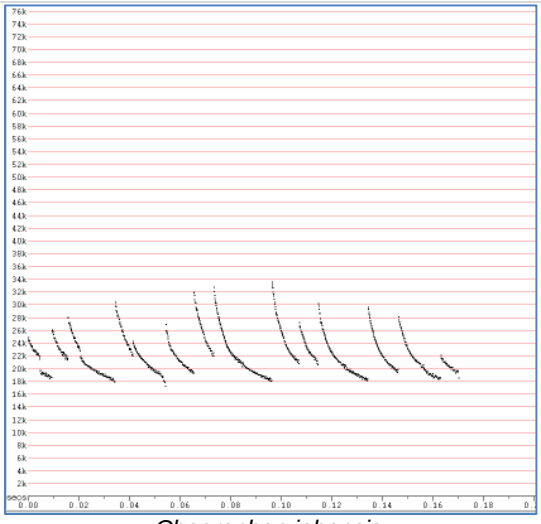
Scotorepens greyii / S. sanborni



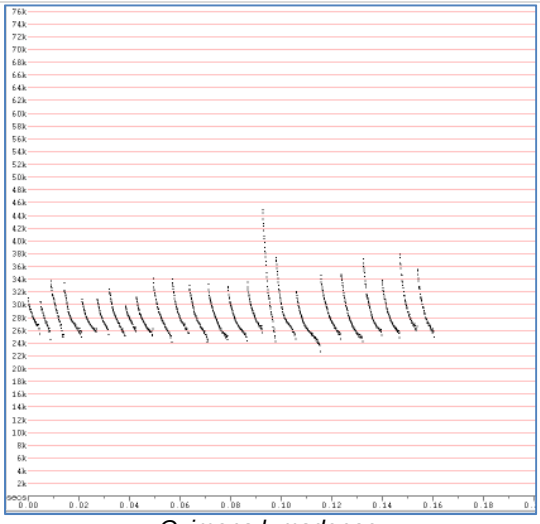
Vespadelus troughtoni



Scotorepens spp. or *Chalinolobus nigrogriseus*



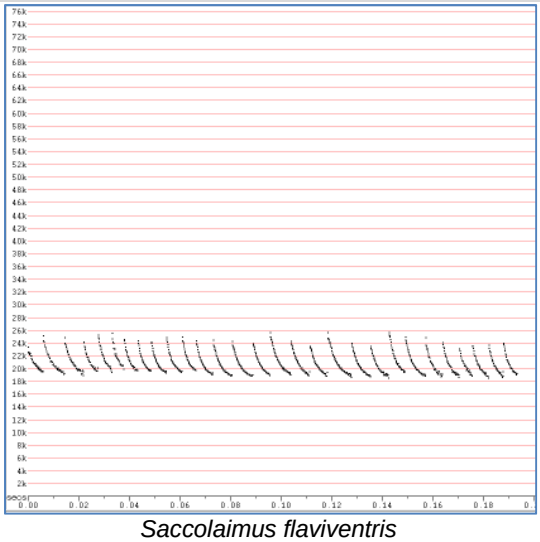
Chaerephon jobensis



Ozimops lumsdenae



Ozimops ridei



Saccolaimus flaviventris

Microbat Call Interpretation Report

Prepared for ("Client"):	METSERVE
Survey location/project name:	Saraji West
Survey dates:	26 March – 7 May 2019
Client project reference:	
Job no.:	MET-1901
Report date:	19 August 2019

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Methods

Data received & post-processing

Balance! Environmental received 30 ZCA data files and associated log files, recorded using two Anabat Express detectors (Titley Scientific, Brisbane) over three survey periods: 26-28 March; 8-15 April; and 30 April – 7 May 2019.

Deployment locations for the two detectors were extracted from the included LOG files. These are plotted on the map at **Figure 1**, with the GPS data extract for each detector listed in **Appendix 1**.

The ZCA files were processed with *Anabat Insight* (version 1.8.9; Titley Scientific) to extract individual Anabat ZC call-sequence files for analysis. This process yielded 37,660 ZC files; however, 33,931 of those files were discarded by the application of a noise filter to remove those files containing only non-bat sounds (e.g. from insects, wind, etc.).

Call analysis and identification

All ZC files that passed the noise filter were analysed in *Anabat Insight*. First-pass call identification was achieved using a Decision Tree analysis to group and label similar calls based primarily on frequency characteristics. Species identities within each group were then verified and/or altered manually by reviewing call spectrograms and derived metrics and comparing them with those of reference calls from central and northern Queensland and/or with published call descriptions (e.g. Reinhold et al. 2001). Consideration was also given to the probability of species' occurrence based on published distribution information (e.g. Churchill 2008; van Dyck *et al.* 2013) and on-line database records (e.g. http://www.ala.org.au).

Reporting standard

The format and content of this report follows Australasian Bat Society standards for the interpretation and reporting of bat call data (Reardon 2003), available on-line at http://www.ausbats.org.au/.

Species nomenclature follows Jackson & Groves (2015).



Figure 1 Bat detector deployment locations – Saraji West surveys, March, April and May 2019.

Results & Discussion

Detector A recorded no bat-call data on the nights of 28th March and 10th April; and Detector B failed to record any bat calls on the nights of 27th March and 10th April. A total of 3737 individual bat calls were identified across the remaining detector-nights.

Reliable identification was achieved on 1636 calls (44% of total detected calls), which were attributed to the following 11 unique species and two indistinguishable species pairs:

- *Chalinolobus gouldii;*
- *Chalinolobus morio;*
- *Chalinolobus picatus;*
- *Nyctophilus geoffroyi / N. gouldi;*
- *Scotorepens balstoni;*
- *Scotorepens greyii / S. sanborni;*
- *Vespadelus troughtoni;*
- *Miniopterus orianae oceanensis;*
- *Austronomus australis;*
- *Chaerephon jobensis;*
- *Ozimops lumsdenae;*
- *Ozimops ridei;* and
- *Saccolaimus flaviventris.*

Fifty-six percent (2101) of the calls could not be reliably identified due to similarities in call characteristics shared by several species that are likely to occur in the study area. These unresolved calls were allocated to one of several multi-species groups, including:

- *C. gouldii / O. ridei;*
- *C. gouldii / S. balstoni;*
- *C. morio / V. troughtoni;*
- *C. picatus / M. o. oceanensis;*
- *C. picatus / S. greyii / S. sanborni;*
- *C. picatus / Vespadelus baverstocki;*
- *S. flaviventris / C. jobensis;*
- *S. flaviventris / O. lumsdenae;* and
- *O. lumsdenae / Taphozous troughtoni.*

Two of these unresolved groups represent potential additional species (*i.e. C. picatus* / ***V. baverstocki*** and *O. lumsdenae* / ***T. troughtoni***); however, it is considered unlikely that *V. baverstocki* would occur in the study area. The latter species, *T. troughtoni*, may be present if suitable subterranean roost sites exist in the broader study area.

Table 1 provides a summary of species' presence on each detector-night throughout the survey. Where unresolved calls were identified, all members of the relevant group are listed as "possible" unless positive identification was achieved on other calls.

Sample spectrograms of each recorded call type are shown at **Appendix 2**.

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Table 1-A. Microbat species recorded during the Saraji West survey, March-May 2019 – **Detector A**.

♦ = 'definite' - at least one call was attributed unequivocally to the species

□ = 'possible' - calls similar to those of the species were recorded, but were not reliably identified

Detector - serial number:	**A - SN318011**														
Detector-night:	26/3	27/3	28/3	08/4	09/4	10/4	11/4	12/4	13/4	15/4	30/4	01/5	03/5	06/5	07/5
Chalinolobus gouldii	♦	♦		♦	♦		♦		♦	♦	♦	♦	□	♦	□
Chalinolobus morio	♦				□					□	□	♦			
Chalinolobus picatus	□				□		♦		□	□	♦	♦	♦		♦
Nyctophilus sp.	♦				♦				♦				♦		
Scotorepens balstoni	♦			♦	□		□				□	♦			♦
Scotorepens greyii	♦				♦		♦		♦	♦	□	♦	♦		□
Vespadelus baverstocki	□				□				□	□	□		□		
Vespadelus troughtoni	♦				♦				♦	□	□	♦		♦	♦
Miniopterus orianae oceanensis	♦						□			♦		♦	♦		♦
Austronomus australis								♦							
Chaerephon jobensis	♦	♦		♦	♦		♦	♦	♦	♦	♦	♦	♦	♦	♦
Ozimops lumsdenae	♦	□		♦	♦		♦	♦	♦	♦	♦	♦		♦	
Ozimops ridei	♦	□		□	□		□		□	♦	♦	□	□	♦	□
Saccolaimus flaviventris	♦	□		♦	♦		♦	□	□		□	□	□	♦	
Taphozous troughtoni												□	□		

Table 1-B. Microbat species recorded during the Saraji West survey, March-May 2019 – **Detector B**.

♦ = 'definite' - at least one call was attributed unequivocally to the species

□ = 'possible' - calls similar to those of the species were recorded, but were not reliably identified

Detector - serial number:	**B - SN324680**														
Detector-night:	26/3	27/3	28/3	08/4	09/4	10/4	11/4	12/4	13/4	15/4	30/4	01/5	03/5	06/5	07/5
Chalinolobus gouldii	♦		♦	♦	♦		♦	♦	♦	♦	□	♦	♦	♦	♦
Chalinolobus morio								□	□	♦	□	♦	♦	□	
Chalinolobus picatus	□			□			□	□	□	□	□	♦	♦	♦	□
Nyctophilus sp.			♦	♦					♦			♦		♦	
Scotorepens balstoni	□		□	□	□							♦	□		
Scotorepens greyii	□			♦			□	♦	♦	♦	□	♦	♦	♦	□
Vespadelus baverstocki				□				□	□			□	□		
Vespadelus troughtoni								♦	♦	♦	□		♦	♦	
Miniopterus orianae oceanensis			♦					♦	♦	♦	♦	♦	♦	♦	♦
Austronomus australis															
Chaerephon jobensis	♦		♦	♦	♦		♦	♦	♦	♦	♦	♦	♦	♦	♦
Ozimops lumsdenae	♦		♦	♦	♦		♦		♦	♦	♦	♦	♦		♦
Ozimops ridei	♦		♦	♦	♦		♦	♦	♦	♦	♦	♦	♦	□	□
Saccolaimus flaviventris			♦	♦			♦	♦	♦	♦	□	♦	♦	□	□
Taphozous troughtoni				□						□			□		□

Glossary

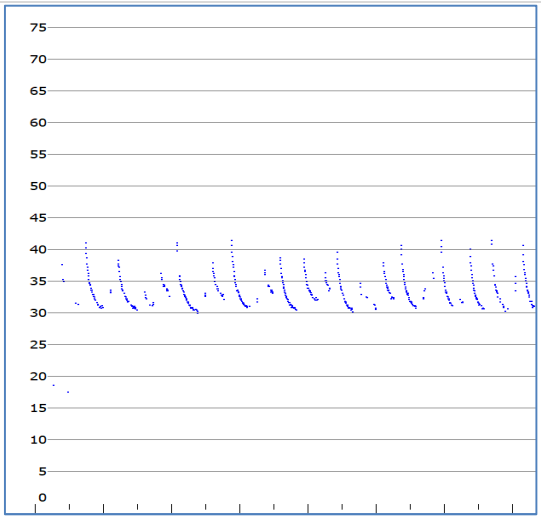
Technical terms used in this report are described in the following table.

Approach phase	The part of a bat *call* emitted as the bat starts to home in on a detected prey item; a transitional series of *pulses* between the *search phase* and *feeding buzz*, that become progressively steeper and shorter in duration.
Call	Refers to a single bat call, made up of a series of individual sound *pulses* in one or more *phases* (*search, approach, feeding buzz*).
CF (=Constant Frequency)	A type of *pulse* in which the dominant component consists of a more-or-less 'pure tone' of sound at a Constant Frequency; with *shape* appearing flat on the sonogram. Often also contains a brief *FM* component at the beginning and/or end of the CF component (*viz.* FM-CF-FM).
Characteristic frequency (Fc)	The frequency of the flattest part of a *pulse*; usually the lowest frequency reached in the *qCF* component of a pulse. This is often the primary diagnostic feature for species identification.
Duration	The time period from the beginning of a *pulse* to the end of the pulse.
Feeding buzz	The terminal part of a *call*, following the *approach phase*, emitted as the bat catches a prey item; a distinctive, rapid series of very steep, very short-duration pulses.
FM (=Frequency Modulated)	A type of *pulse* in which there is substantial change in frequency from beginning to end; *shape* ranges from almost vertical and linear through varying degrees of curvature.
FC range	Refers to the range of frequencies occupied by the *characteristic frequency* section of *pulses* within a call or set of calls.
Frequency sweep or "band-width"	The range of frequencies through which a *pulse* sweeps from beginning to end; Maximum frequency (Fmax) – minimum frequency (Fmin).
Knee	The transitional part of a *pulse* between the initial (usually steeper) frequency sweep and the *characteristic frequency* section (usually flatter); time to knee (Tk) and frequency of knee (Fk) can be diagnostic for some species.
Pulse	An individual pulse of sound within a bat *call*; the *shape*, *duration* and *characteristic frequency* of a pulse are the key diagnostic features used to differentiate species.
Pulse body	The part of the *pulse* between the *knee* and *tail* and containing the *characteristic frequency* section.
Pulse shape	The general appearance of a *pulse* on the sonogram, described using relative terms related to features such as slope and degree of curvature. See also *CF, qCF* and *FM*.
qCF (=quasi Constant Frequency)	A type of *pulse* in which there is very little change in frequency from beginning to end; *shape* appears to be almost flat. Some pulses also contain an *FM* component at the beginning and/or end of the qCF component (*viz.* FM-qCF).
Search phase	The part of a bat *call* generally required for reliable species diagnosis. A consistent series of *pulses* emitted by a bat that is searching for prey or and/or navigating through its habitat. Search phase pulses generally have longer duration, flatter slope and more consistent shape than *approach phase* and *feeding buzz* pulses.
Sequence	Literally, a sequence of *pulses* that may be from one or more bats; but generally refers to a *call* or part (e.g. *phase*) of a call.
Tail	The final component of a *pulse*, following the *characteristic frequency* section; may consist of a short or long sweep of frequencies either upward or downward from the Fc; or may be absent.

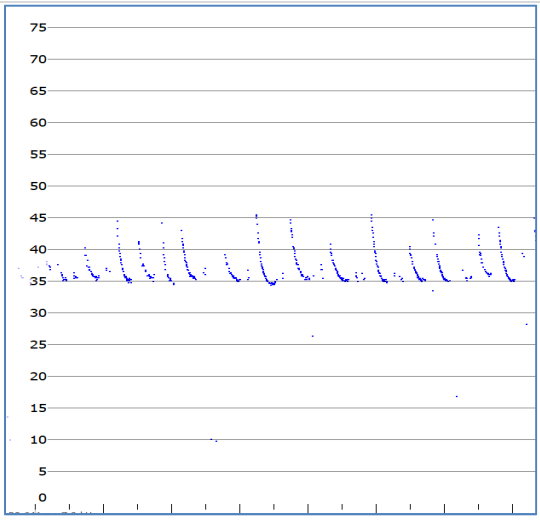
Appendix 1 GPS coordinates derived from detector LOG files.

Detector name	Serial Number	Date	Latitude	Longitude
A	SN318011	26/03/2019	-22.37716	148.21459
		27/03/2019	-22.37623	148.23676
		28/03/2019	-22.37618	148.23673
		8/04/2019	-22.39008	148.22679
		9/04/2019	-22.3665	148.20516
		10/04/2019	-22.39518	148.23804
		11/04/2019	-22.37769	148.22077
		12/04/2019	-22.35665	148.19285
		13/04/2019	-22.37584	148.25864
		15/04/2019	-22.35043	148.19961
		30/04/2019	-22.35911	148.2297
		1/05/2019	-22.34987	148.20114
		3/05/2019	-22.35026	148.19531
		6/05/2019	-22.28541	148.15191
		7/05/2019	-22.30574	148.19387
B	SN324680	26/03/2019	-22.3904	148.22627
		27/03/2019	-22.37693	148.20079
		28/03/2019	-22.37695	148.20086
		8/04/2019	-22.37699	148.20077
		9/04/2019	-22.37691	148.20069
		10/04/2019	-22.37602	148.2143
		11/04/2019	-22.37597	148.21452
		12/04/2019	-22.35903	148.1982
		13/04/2019	-22.35358	148.23393
		15/04/2019	-22.3537	148.23395
		30/04/2019	-22.35166	148.21131
		1/05/2019	-22.34241	148.21047
		3/05/2019	-22.34033	148.21277
		6/05/2019	-22.29084	148.16613
		7/05/2019	-22.33003	148.21279

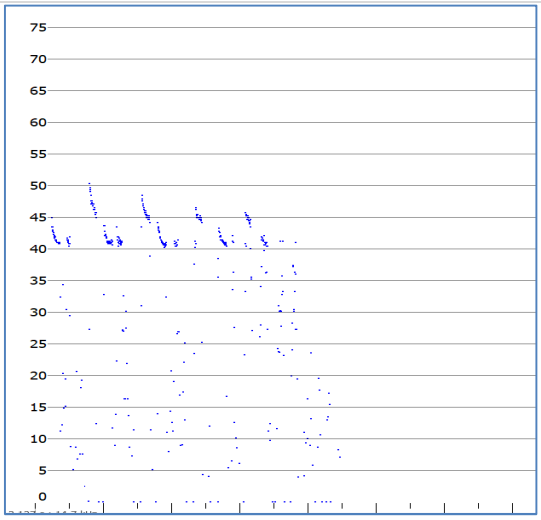
Appendix 2 Representative call sequences from the Saraji West surveys, March-May 2019.
AnalookW spectrograms with time between pulses removed pulses



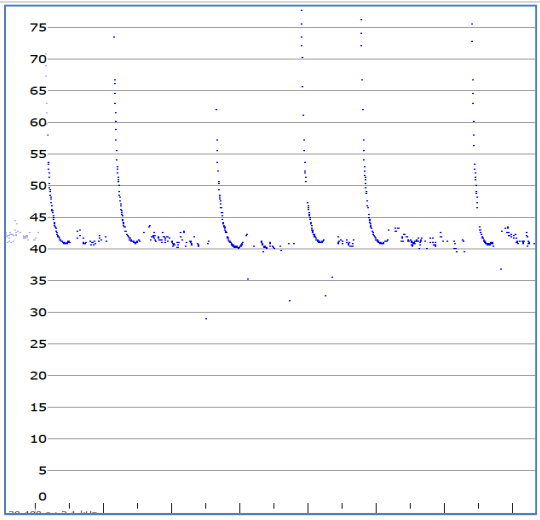
Chalinolobus gouldii



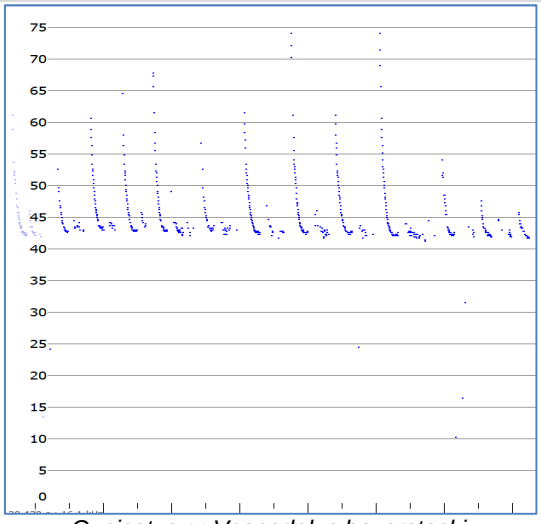
Scotorepens balstoni



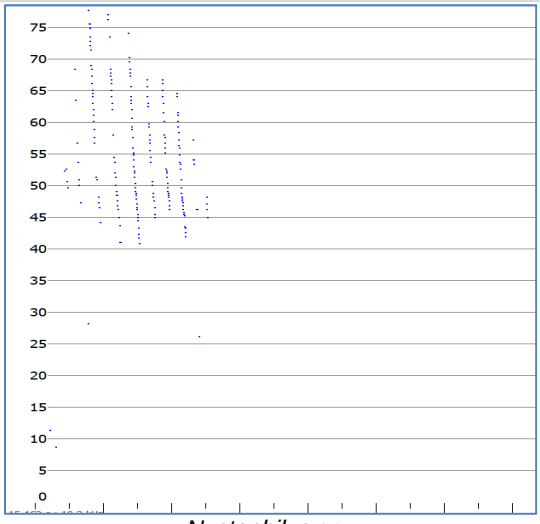
Chalinolobus picatus



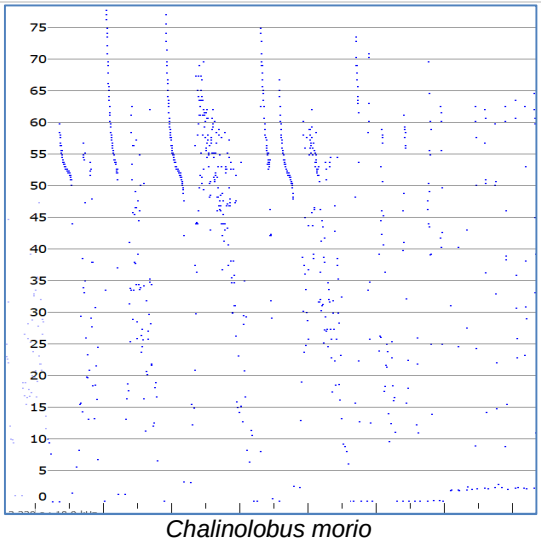
Scotorepens greyii / S. sanborni



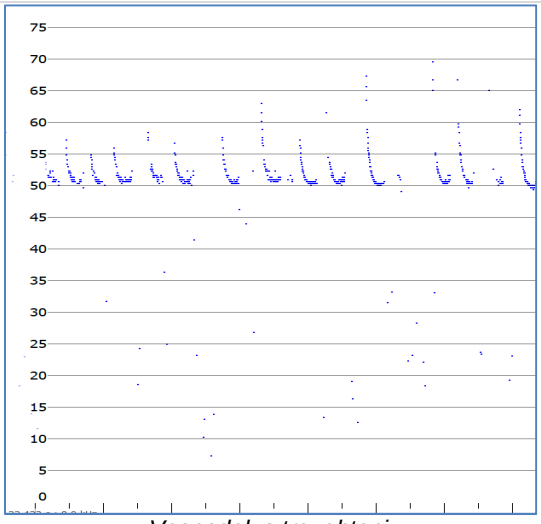
C. picatus or *Vespadelus baverstocki*



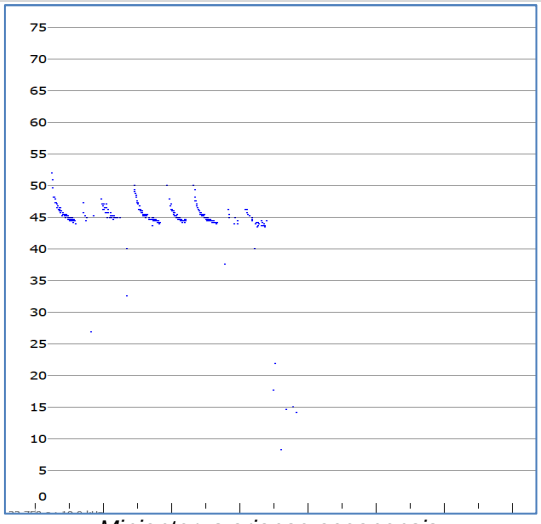
Nyctophilus sp.



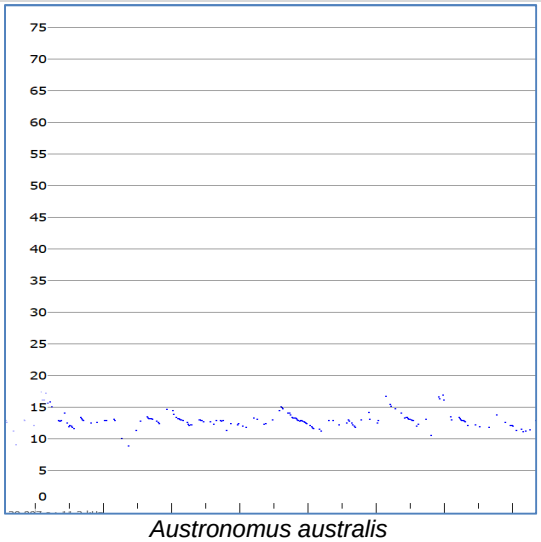
Chalinolobus morio



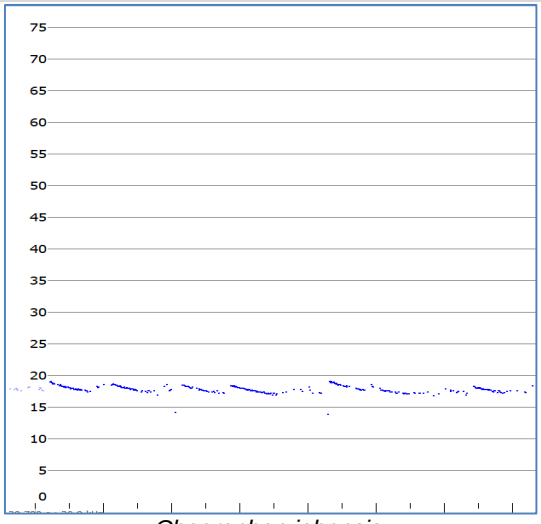
Vespadelus troughtoni



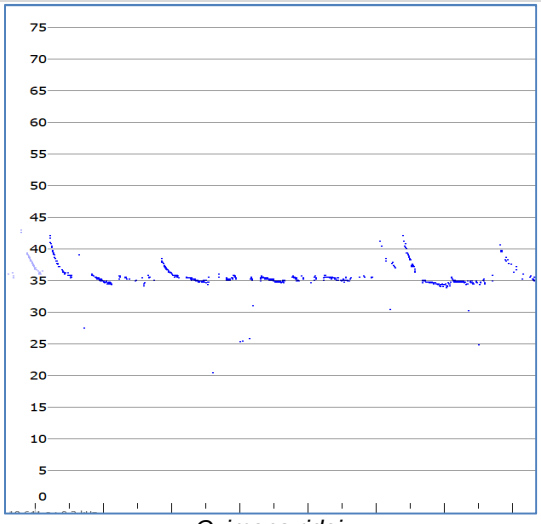
Miniopterus orianae oceanensis



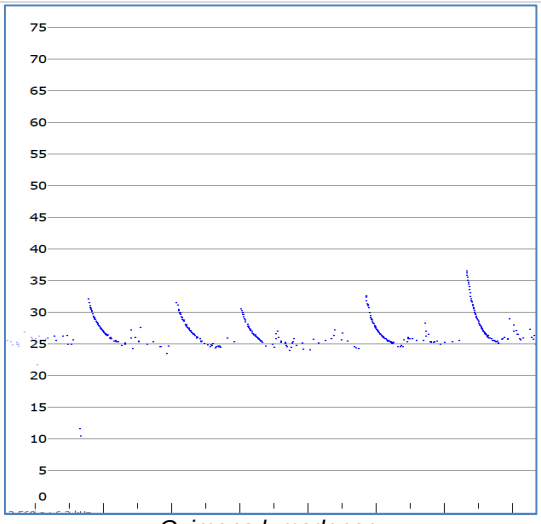
Austronomus australis



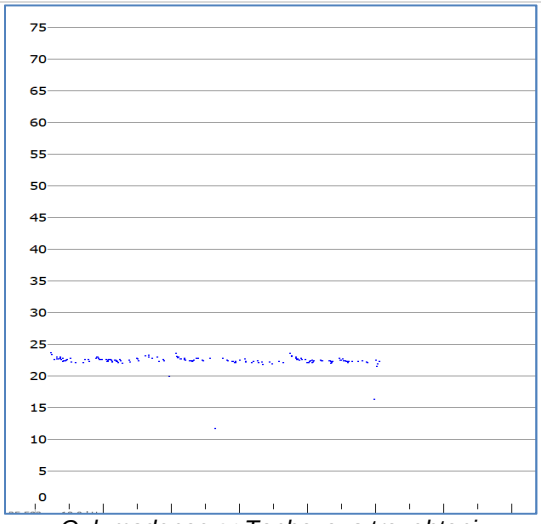
Chaerephon jobensis



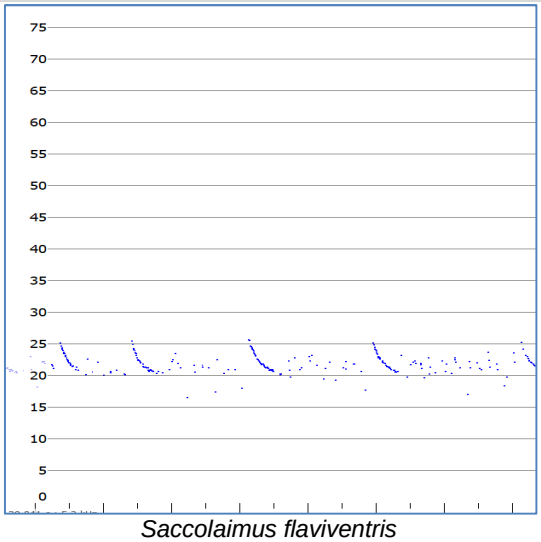
Ozimops ridei



Ozimops lumsdenae



O. lumsdenae or *Taphozous troughtoni*



Saccolaimus flaviventris

Microbat Call Interpretation Report

Prepared for ("Client"):	METSERVE
Survey location/project name:	Dysart area
Survey dates:	23-30 September 2019
Client project reference:	
Job no.:	MET-1902
Report date:	4 December 2019

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Methods

Data received & post-processing

Balance! Environmental received 13 ZCA data files and associated log files, recorded using two Anabat Express detectors (Titley Scientific, Brisbane) deployed over eight consecutive nights (23-30 September 2019). The raw data files were named according to the site numbers at which each detector was deployed. These deployment details are summarised in **Table 1**.

The ZCA files were processed with *Anabat Insight* (version 1.9.1; Titley Scientific) to extract individual Anabat ZC call-sequence files for analysis. This process yielded 23,231 ZC files; however, 19,620 of those files were discarded by the application of a noise filter to remove files containing only non-bat sounds (e.g. from insects, wind, etc.).

Call analysis and identification

All ZC files that passed the noise filter were analysed in *Anabat Insight*. First-pass call identification was achieved using a Decision Tree analysis to group and label similar calls based primarily on frequency characteristics. Species identities within each group were then verified and/or altered manually by reviewing call spectrograms and derived metrics and comparing them with those of reference calls from central and northern Queensland and/or with published call descriptions (e.g. Reinhold et al. 2001). Consideration was also given to the probability of species' occurrence based on published distribution information (e.g. Churchill 2008; van Dyck *et al.* 2013) and on-line database records (e.g. http://www.ala.org.au).

Reporting standard

The format and content of this report follows Australasian Bat Society standards for the interpretation and reporting of bat call data (Reardon 2003), available on-line at http://www.ausbats.org.au/.

Species nomenclature follows Jackson & Groves (2015).

Table 1 Bat detector deployment details extracted from the data files.

Detector:	Anabat A - SN318011						Anabat B - SN324680						
Date:	24/9	25/9	26/9	27/9	28/9	29/9	23/9	24/9	25/9	27/9	28/9	29/9	30/9
Site:	S27	A7	A8	A9	S32	S34	S26	S28	S29	S31	S30	S33	A10

Results & Discussion

Of the 3,611 ZC files passed the noise filter, 913 were found to contain only brief and/or weak and/or highly-fragmented bat calls that were of no use for species identification. From the 2,698 files that remained a total of 2881 bat calls were identified.

Reliable identification was achieved on 2184 calls (76% of total), which were attributed to 12 unique species and two indistinguishable species pairs. These positively identified species included:

- *Chalinolobus gouldii;*
- *Chalinolobus morio;*
- *Chalinolobus picatus;*
- *Nyctophilus geoffroyi / N. gouldi;*
- *Scotorepens balstoni;*
- *Scotorepens greyii / S. sanborni;*
- *Vespadelus baverstocki;*
- *Vespadelus troughtoni;*
- *Miniopterus orianae oceanensis;*
- *Chaerephon jobensis;*
- *Ozimops lumsdenae;*
- *Ozimops ridei;*
- *Setirostris eleryi;* and
- *Saccolaimus flaviventris*.

The other 697 calls could not be reliably identified due to similarities in call characteristics shared by several species. These unresolved calls were allocated to one of the following multi-species groups:

- *C. gouldii / O. ridei / S. balstoni;*
- *C. morio / V. troughtoni;*
- *C. picatus / S. greyii / S. sanborni;*
- *S. greyii / S. eleryi;*
- *S. flaviventris / C. jobensis;*
- *S. flaviventris / O. lumsdenae;* and
- *O. lumsdenae / Taphozous troughtoni.*

The above groups mostly represent species that were also identified positively from more typical calls. The last group potentially represents an additional species for this survey. *Taphozous troughtoni* is likely present in the study area, but it's calls can be difficult to distinguish from those of *O. lumsdenae*. Calls allocated to the group had shorter duration, more uniform pulses than those allocated positively to *O. lumsdenae*, but it was still not possible to reliably attribute them to *T. troughtoni*.

Table 2 provides a summary of species' presence per site. Where unresolved calls were identified, all members of the relevant group are listed as "possible" unless positive identification was achieved on other calls. Sample spectrograms of each recorded call type are shown at **Appendix 1**.

References

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Table 2. Microbat species recorded during the Dysart surveys, 23-30 September 2019.

♦ = 'definite' - at least one call was attributed unequivocally to the species

□ = 'possible' - calls similar to those of the species were recorded, but were not reliably identified

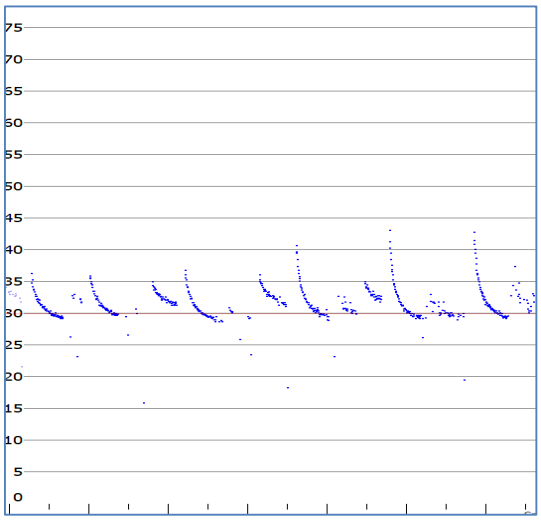
Site:	A7	A8	A9	A10	S26	S27	S28	S29	S30	S31	S32	S33	S34
Chalinolobus gouldii	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	□
Chalinolobus morio		♦	♦	♦	♦	□	♦		□	♦	♦	♦	□
Chalinolobus picatus	♦	♦	♦	♦	□	□	□	□	♦	♦	□	♦	□
Nyctophilus sp.			♦			♦				♦	♦	♦	
Scotorepens balstoni	□	♦	♦	♦		□	□	♦			♦	♦	♦
Scotorepens greyii	♦	♦	♦	♦	□	♦	♦	♦	♦	♦	♦	♦	♦
Vespadelus baverstocki		♦		♦	♦	♦		♦	♦	♦	♦	♦	
Vespadelus troughtoni			♦	□		□			□	♦	♦	♦	♦
Miniopterus orianae oceanensis	♦								♦	□			□
Chaerephon jobensis	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Ozimops lumsdenae	♦		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Ozimops ridei	□	♦	♦	♦	♦	□	♦	♦	♦	□	□	♦	♦
Setirostris eleryi		□	♦	□	□	□		□	□	□	□		□
Saccolaimus flaviventris		♦	♦	♦	♦	□		♦	♦	♦	♦	♦	♦
Taphozous troughtoni	□		□			□	□		□	□	□	□	□

Glossary

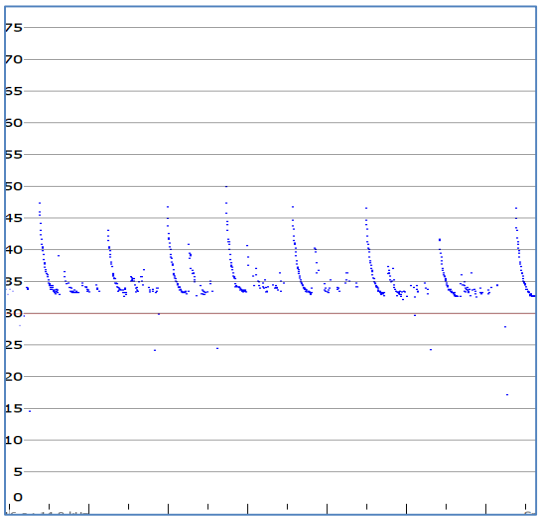
Technical terms used in this report are described in the following table.

Approach phase	The part of a bat *call* emitted as the bat starts to home in on a detected prey item; a transitional series of *pulses* between the *search phase* and *feeding buzz*, that become progressively steeper and shorter in duration.
Call	Refers to a single bat call, made up of a series of individual sound *pulses* in one or more *phases* (*search, approach, feeding buzz*).
CF (=Constant Frequency)	A type of *pulse* in which the dominant component consists of a more-or-less 'pure tone' of sound at a Constant Frequency; with *shape* appearing flat on the sonogram. Often also contains a brief *FM* component at the beginning and/or end of the CF component (*viz.* FM-CF-FM).
Characteristic frequency (Fc)	The frequency of the flattest part of a *pulse*; usually the lowest frequency reached in the *qCF* component of a pulse. This is often the primary diagnostic feature for species identification.
Duration	The time period from the beginning of a *pulse* to the end of the pulse.
Feeding buzz	The terminal part of a *call*, following the *approach phase*, emitted as the bat catches a prey item; a distinctive, rapid series of very steep, very short-duration pulses.
FM (=Frequency Modulated)	A type of *pulse* in which there is substantial change in frequency from beginning to end; *shape* ranges from almost vertical and linear through varying degrees of curvature.
FC range	Refers to the range of frequencies occupied by the *characteristic frequency* section of *pulses* within a call or set of calls.
Frequency sweep or "band-width"	The range of frequencies through which a *pulse* sweeps from beginning to end; Maximum frequency (Fmax) – minimum frequency (Fmin).
Knee	The transitional part of a *pulse* between the initial (usually steeper) frequency sweep and the *characteristic frequency* section (usually flatter); time to knee (Tk) and frequency of knee (Fk) can be diagnostic for some species.
Pulse	An individual pulse of sound within a bat *call*; the *shape*, *duration* and *characteristic frequency* of a pulse are the key diagnostic features used to differentiate species.
Pulse body	The part of the *pulse* between the *knee* and *tail* and containing the *characteristic frequency* section.
Pulse shape	The general appearance of a *pulse* on the sonogram, described using relative terms related to features such as slope and degree of curvature. See also *CF, qCF* and *FM*.
qCF (=quasi Constant Frequency)	A type of *pulse* in which there is very little change in frequency from beginning to end; *shape* appears to be almost flat. Some pulses also contain an *FM* component at the beginning and/or end of the qCF component (*viz.* FM-qCF).
Search phase	The part of a bat *call* generally required for reliable species diagnosis. A consistent series of *pulses* emitted by a bat that is searching for prey or and/or navigating through its habitat. Search phase pulses generally have longer duration, flatter slope and more consistent shape than *approach phase* and *feeding buzz* pulses.
Sequence	Literally, a sequence of *pulses* that may be from one or more bats; but generally refers to a *call* or part (e.g. *phase*) of a call.
Tail	The final component of a *pulse*, following the *characteristic frequency* section; may consist of a short or long sweep of frequencies either upward or downward from the Fc; or may be absent.

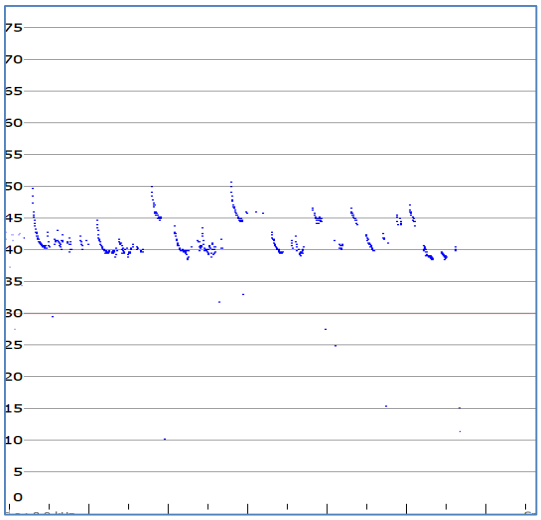
Appendix 1 Representative call sequences from the Dysart survey, 23-30 September 2019.
Time scale (*x*-axis) = 10ms per tick; time between pulses removed



Chalinolobus gouldii



Scotorepens balstoni



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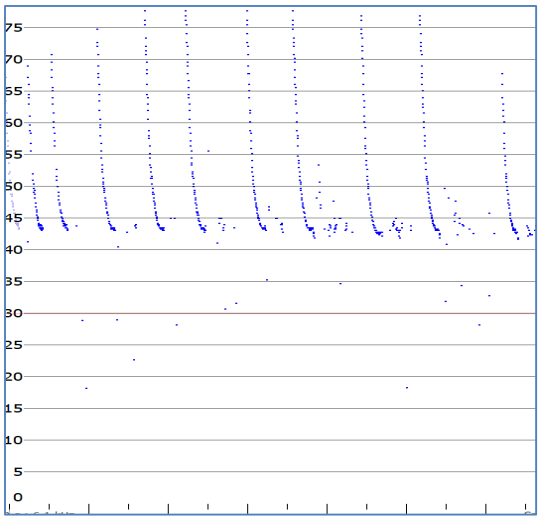
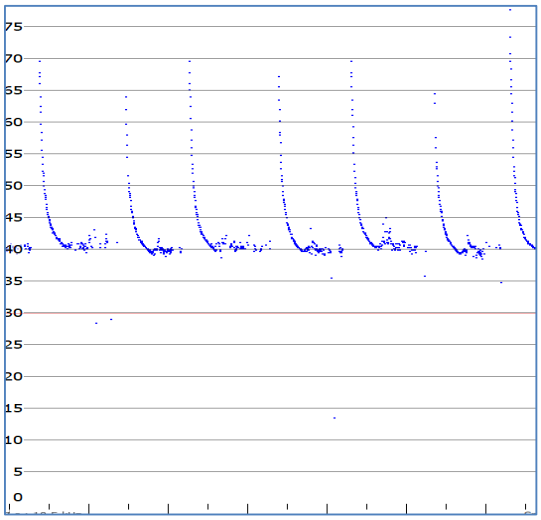
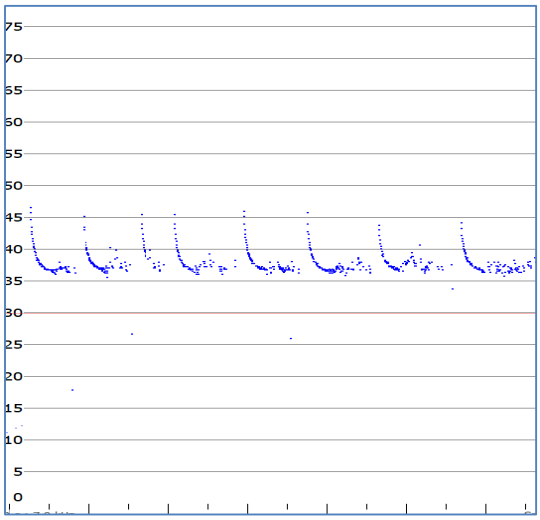


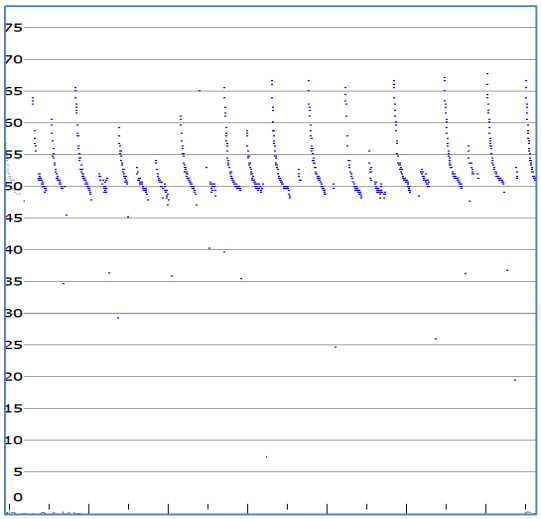
Vespadelus baverstocki



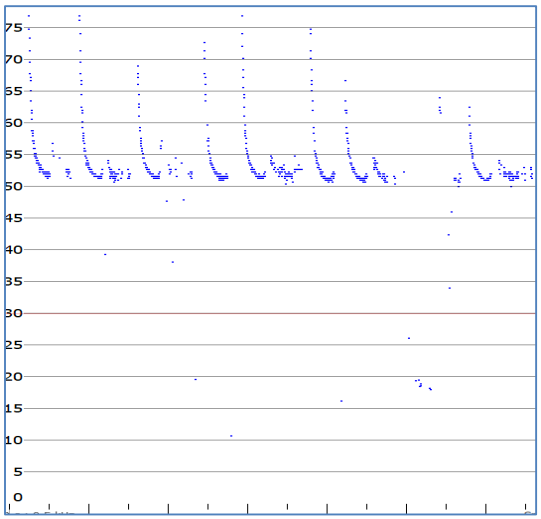
Scotorepens greyii / S. sanborni



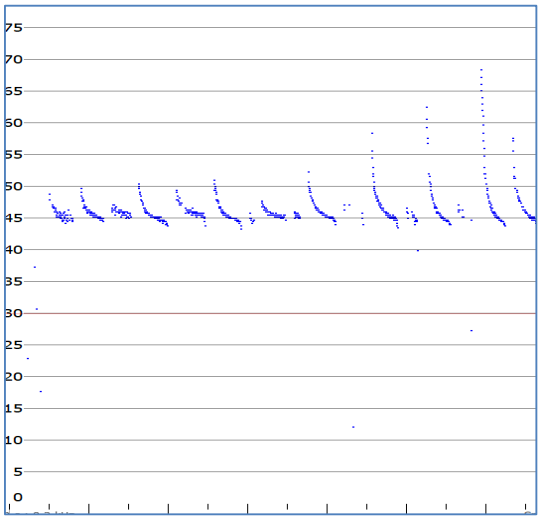
Setirostris eleryi



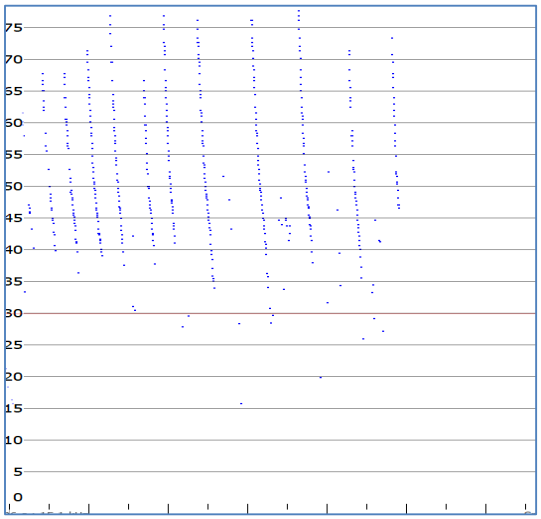
Chalinolobus morio



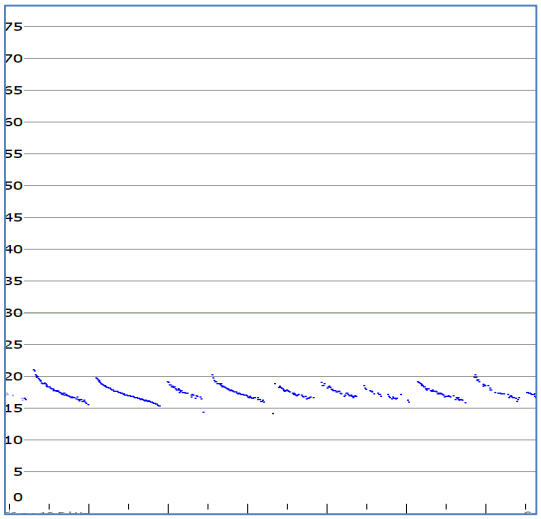
Vespadelus troughtoni



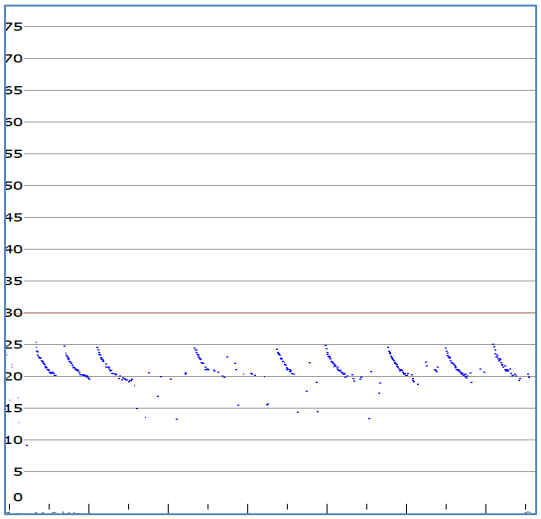
Miniopterus orianae oceanensis



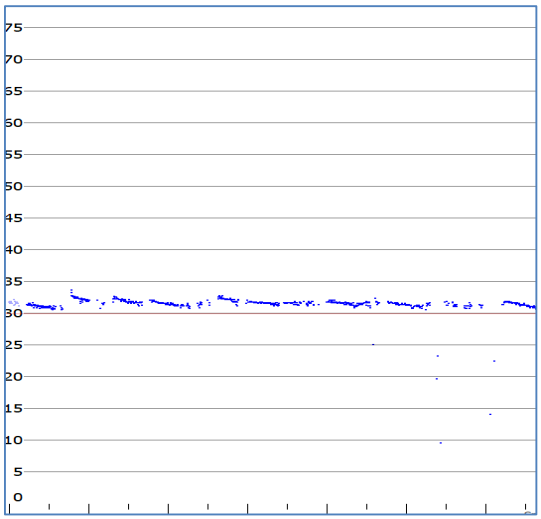
Nyctophilus sp.



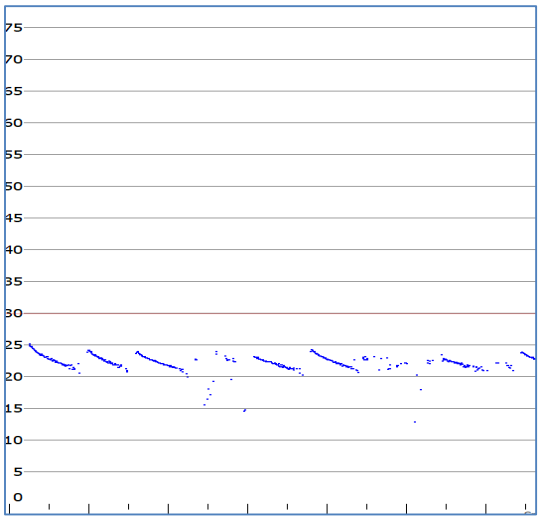
Chaerephon jobensis



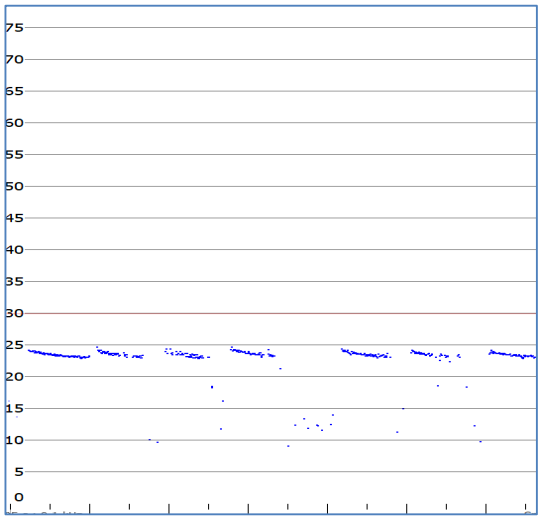
Saccolaimus flaviventris



Ozimops ridei



Ozimops lumsdenae



O. lumsdenae / Taphozous troughtoni

Appendix E – Stakeholder Engagement Plan



VITRINITE
BRIGHTER COAL

METSERVE
Mining & Energy Technical Services Pty Ltd

Stakeholder Engagement Plan

for Vulcan South

May 2022

This report has been prepared solely for the benefit of Vitrinite Pty Ltd. Mining and Energy Technical Services Pty Ltd (METServe) accepts no liability for the use or interpretation of any information contained in this report for any other purpose other than intended, or for its use by any party other than the above named Client.

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1.1.2 Project Timing and Development Stages 2
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Appendix A Stakeholder Register ..... A

1 INTRODUCTION

Mining and Energy Technical Services Pty Ltd (METServe) has been engaged by Vitrinite Pty Ltd (Vitrinite) to manage the environmental approvals process for Vulcan South (the Project). As part of the Project, Vitrinite will require a Stakeholder Engagement Plan (SEP) to be developed to ensure that relevant stakeholders are consulted about the Project, and stakeholder feedback is appropriately recorded, documented and considered throughout the Project planning process.

1.1 PROJECT OVERVIEW

The Project is located north of Dysart and approximately 35 km south of Moranbah in Queensland's Bowen Basin (**Figure 1**). The Project lies to the immediate west of several established mining operations, including BHP's Peak Downs and Saraji mines.

The Project is located immediately to the south of Vitrinite's initial mining Project, the Vulcan Coal Mine (VCM), located on ML700060. The Project mining lease application area abuts ML700060 however proposed activities will be largely implemented separately.

The Vulcan hard coking coal target has been defined and selected for open cut development via 3 separate open cut pits that form the primary mining focus of the Project. The Project will operate for approximately nine years, including primary rehabilitation works, following a two year construction period and will extract approximately 13.5 Mt of Run of Mine (ROM) coal consisting predominately of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 Mtpa. The Project will target the Alex and multiple Dysart Lower coal seams. Truck and shovel mining operations will be employed to develop the pits. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO) at a location between the northern and central pits. The CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product for permanent storage within active waste rock dumps. No wet tailings wastes are proposed and therefore no tailings dams are required.

At each of the three pits, out-of-pit waste rock dumps will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. Ancillary infrastructure, including a ROM pad, offices, roads and surface water management infrastructure will be established to support the operation.

A realignment of the existing Saraji Road and services infrastructure to the eastern boundary of the proposed Mining Lease Application (MLA) area, adjacent to the existing rail easement, is also proposed in a number of locations. The re-alignment will occur within the MLA area.

In-pit dumping will fill the majority of the pit volumes during operations with the remaining final voids to be backfilled upon cessation of mining, resulting in the establishment of low waste rock dump landforms over the former pit areas. Following backfill of the final voids, the remaining material stored in the initial out-of-pit waste rock dumps will be rehabilitated in-situ.

The Project includes a small-scale highwall mining trial program in the north of the MLA. The trial will involve the establishment of 4 highwall mining benches across a number of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner, or similar. The highwall mining trial will target up to 750 kt of coal which will be transported by truck to the Project CHPP via a dedicated haul road within the MLA area. The trial is scheduled to be completed within the first year of mining operations.

A Progressive Rehabilitation and Closure Plan (PRCP) has been prepared to meet obligations under the *Environmental Protection Act, 1994* as amended by the *Mineral Resources and Energy (Financial Provisioning) Act 2018 Act*. The PRCP describes the proposed final landform, post-mine land uses, rehabilitation planning information and a schedule of progressive rehabilitation activities.

1.1.1 Proponent

Queensland Coking Coal Pty Ltd is owned by Vitrinite Pty Ltd. Queensland Coking Coal Pty Ltd is the Environmental Authority and Mining Lease applicant. Vitrinite is the proponent and will appoint a statutory operator.

1.1.2 Project Timing and Development Stages

The Project is a small scale mining operation, with coal extraction planned for approximately eight years, followed by completion of primary rehabilitation activities in year nine. Construction of infrastructure associated with the mining operation, including the CHPP and the rail loop, is expected to be completed within 2 years. Realignment of sections of Saraji Road sections will occur as required while the project progresses.

1.1.3 Workforce and Accommodation

The Project is anticipated to require a workforce of 190 personnel (both permanent employees and contractors). As such, it is classified as a "large resource project" under the *Strong and Sustainable Resource Communities Act 2017 (*SSRC Act*)*. It is anticipated that less than approximately one third of this workforce would be present on site at any one time due to shift and roster arrangements and the inclusion of off-site haulage positions in this total. The Project's workforce will be primarily sourced from the regional area (i.e. Isaac and Mackay regions) and make use of the existing accommodation camp facilities and private housing at Moranbah and Dysart. Whilst sourcing of local people will be prioritised, it is anticipated that a combination of regional workforce solutions (Drive-in / Drive-out (DIDO) from Mackay and Fly-in / Fly-out (FIFO) from Moranbah Airport) will be required.

For the purposes of this plan, it is assumed the workforce will reside in a mixture of accommodation facilities from camp (80%) to private residences (20%). It is assumed there will be a 50% / 50% split between Dysart and Moranbah. Travel to site from Dysart and Moranbah will be 80% bus/work vehicles and 20% private vehicles (approx.). There would be two 12 hour shifts per day, with crews operating on a 7 days on / 7 days off roster.

The following indicative workforce breakdown is anticipated:

- Staff – 30; and
- Mining contractors – 160

The Project will require a mining lease (ML) as well as environmental approvals under Queensland and Commonwealth legislation. A site specific Environmental Authority (EA) application will need to be submitted for approval in accordance with the Queensland *Environmental Protection Act 1994* (EP Act). It is anticipated that this will not trigger the requirement for a supporting Environmental Impact Statement (EIS).

The Project will also be referred to the Commonwealth Department of the Environment and Energy (DoEE) for approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

1.1.4 Existing Land Use and Tenure

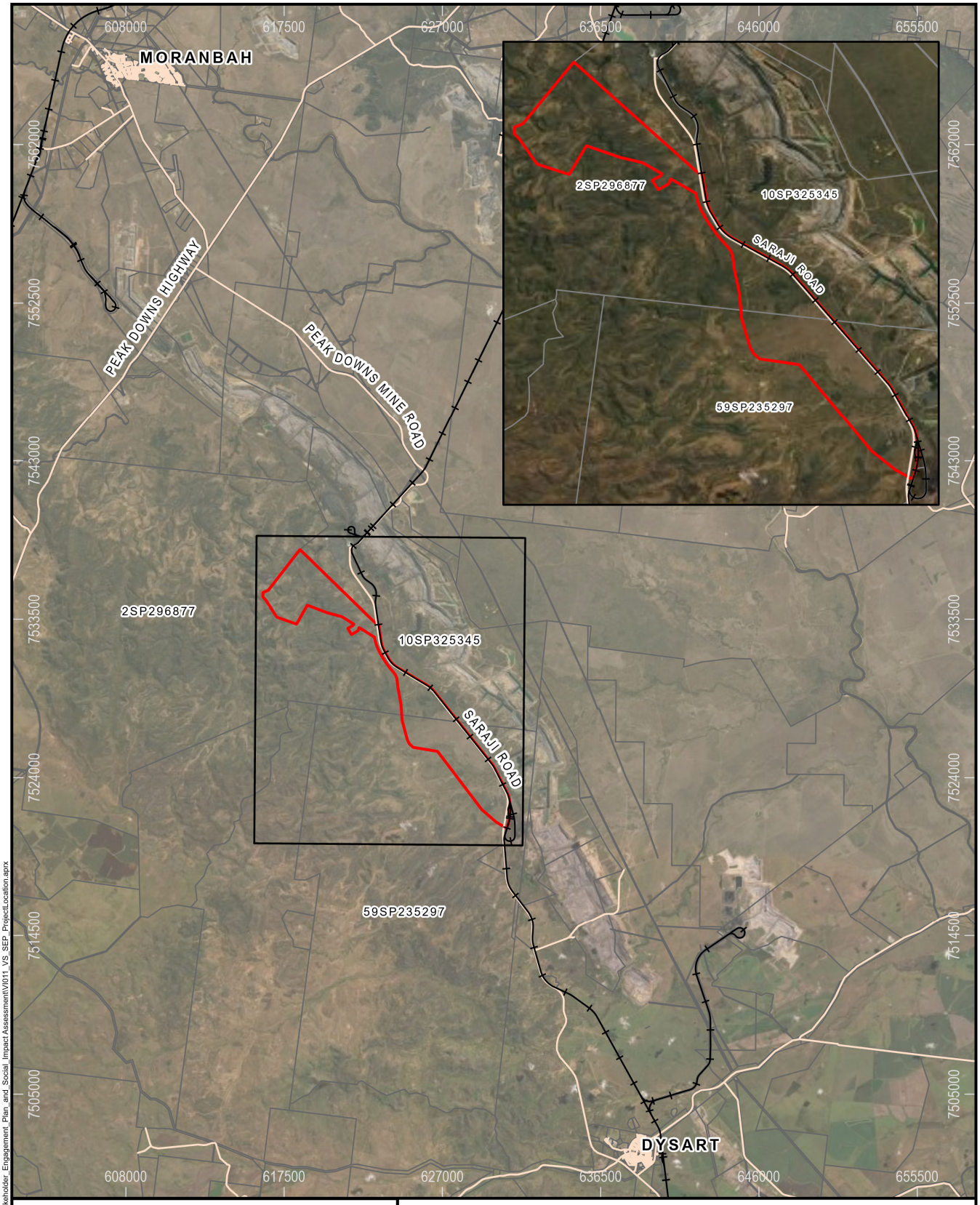
The Project MLA covers an area of approximately 3800 hectares (ha) and is situated over multiple underlying tenures (MDL 3039, EPC 1732 and 1234). The MLA area overlies adjacent portions of existing Exploration Permit Coal (EPC) 1732 and 1234 tenements (held by Qld Coal Aust No.1 Pty Ltd and Queensland Coking Coal Pty Ltd, respectively). Both companies hold an equal 50% share of the Mineral Development Licence (MDL). The Project disturbance footprint is 1756.7 ha.

A list of the properties', tenure, usage and owners/managers within the Project area are outlined in **Table 1**.

Table 1 Land Tenure and Real Property Descriptions for the Project

Lot/Plan	Tenure	Usage	Owner
2/SP296877	Lands Lease	Pastoral	O'Sullivan
59/SP235297	Lands Lease	Pastoral	O'Sullivan
72/SP137467	Reserve	Railway	Aurizon
Saraji Road	Road Licence	Road for public use	Isaac Regional Council
26/CNS125	Lands Lease	Norwich Park Branch Railway	Aurizon
2/CNS109	Lands Lease	Norwich Park Branch Railway	Aurizon
3/CNS109	Lands Lease	Saraji Mine Balloon Loop Railway	Aurizon

The Project falls within the Isaac Regional Council local government area. The region has a distinct mining influence with multiple significant coal mining operations in the immediate vicinity of the Project. A majority of the land within the MLA has been previously disturbed by agriculture and mining related activities. There are a small number of rural or residential dwellings located within 5 km of the southern extent of the Project activities.



Legend

- Railway
- Road
- MLA Boundary
- Cadastral Boundary

Source: State of Queensland (Department of Resources) 2021-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Stakeholder_Engagement_Plan_and_Social_Impact Assessment\VI011_VS_SEP_ProjectLocation.aprx

Vulcan South

Project Location

0 3 6 12

Kilometers

Scale: 1:330,000 (A4)

11/03/2022

Datum: GDA2020
Projection: MGA55

FIGURE 1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

1.2 PURPOSE AND SCOPE OF THE STAKEHOLDER ENGAGEMENT PLAN

The purpose of the Project SEP is to assist in the planning, management and review of stakeholder engagement activities. Through the SEP, Vitrinite aims to:

- Build and maintain effective relationships with its stakeholders; and
- Maintain its social license to operate.

The Project SEP is a live and iterative document that:

- Identifies relevant stakeholders across the life of the Project; initially during the approvals phase but also during post approval operations and rehabilitation and closure phases;
- Identifies appropriate engagement approaches, activities and timeframes for these activities, both during the approvals phase and post approval phases; and
- Details the requirements for recording, tracking and analysing consultation activities for reporting in the approval application, and for managing stakeholder concerns.

1.3 OBJECTIVES

The SEP aims to provide Vitrinite with a practical and ongoing management tool for effective stakeholder engagement and to assist in building and maintaining relationships, trust and credibility with the relevant groups.

The objectives of the SEP include:

- Identify and record key stakeholders;
- Identify challenges and opportunities;
- Establish and implement communication and consultation practices that promote an ongoing relationship with stakeholders;
- Provide timely and accurate information to stakeholders;
- Provide convenient and identifiable avenues for feedback from stakeholders;
- Record and respond to any complaints in a timely manner; and
- Facilitate consultation feedback and input into mine rehabilitation and closure plans.

2 STAKEHOLDER ENGAGEMENT PLANNING

This SEP outlines how stakeholder engagement will be planned, managed and reviewed. It has been developed based on the identification and assessment of stakeholders, issues, opportunities, risks, concerns and interests within the Project's area of influence and impact.

2.1 IDENTIFICATION AND ASSESSMENT

Identification of stakeholders that have an interest and influence in the Project's approval, construction, operation and eventual rehabilitation and closure is based on their proximity, dependency, representation, responsibility and strategic intent and includes relevant Government and non-Government development organisations. The process includes:

- Identify and assess issues, opportunities and associated risks, including access to resources;
- Identify stakeholder concerns and interest gathered through a variety of mechanisms including direct consultation; and
- Assess the impact of the Project's activities within the area of influence, including the social aspect of site closure.

2.2 STAKEHOLDER IDENTIFICATION

The identification of stakeholders is significant to the Project's longevity and sustainability. It is also practical to be able to identify and analyse the role and involvement that particular stakeholders will have throughout the life of the Project. As such, stakeholders have been classified into two categories (as defined under section 38 and section 41 of the EP Act) depending on the predicted level of Project impact, perceived level of stakeholder involvement on site activities, and the perceived level of interest in site activities or the outcomes of decisions. These two categories (and corresponding EP Act definitions) include:

1. **Affected Stakeholder:** Under section 38 of the EP Act this includes:
    - A person mentioned in subsection (2) for the operational land or any land joining it. This includes (amongst others) the registered proprietor/s of any freehold land, the registered holder/s of any land that is held from the State, any holder/s or applicant/s of mining tenures or other resource related tenures, trustees of any land under the *Nature Conservation Act 1992* or *Land Act 1994*, and holders of any unallocated State land, State forests or Conservation parks or State Controlled Roads;
    - Registered native title body corporates, claimants or representative Aboriginal/Torres Strait Islander body; or
    - A relevant local government.

2. **Interested Stakeholder:** Under section 41(3)(b) of the EP Act this includes an unincorporated community or environmental body with a financial or non-financial interest in the local government area that the operational land is in.

Categorising stakeholders as above allows for targeted planning, assessment and reviewing of stakeholder consultation practices, feedback, schedules and timing.

Table 2 below lists relevant stakeholders according to the definitions under section 38 and section 41 of the EP Act, as well as a summary of perceived potential interests in the Project. **Appendix A** presents a register of completed engagement activities, including those for other components of the Vitrinite's projects in the area, the VCM and the Bulk Sample Project (BSP).

Table 2 Stakeholder list by category and potential concerns

Stakeholder Group	Potential Interests
Affected Stakeholders	
Underlying Landholders	• Lawful management of the land • Lawful operation of the project • Management of offsite impacts (particularly surface waters and groundwater) • Land rehabilitation and post-mine land uses • Weed control • Site access • Unauthorised access controls
Adjacent Landholders	• Noise and dust emissions • Blasting overpressure and vibration • Management of offsite impacts (particularly surface waters and groundwater) • Quality of mine rehabilitation • Offsite impacts on land capability • Lighting emissions • Work opportunities • Land acquisition process • Transport and road impacts • Fences and gates
Traditional Owners	• Disturbance of cultural heritage sites and artefacts • Management of cultural heritage sites and artefacts • Access to land for cultural purposes • Employment opportunities
Local Council	• Compliance with development and planning conditions • Re-alignment of IRC road infrastructure and associated approval processes • Support for community and local business • Engagement with stakeholders • Impact of mine closure • Information on significant variations to Project • Worker and contractor accommodation impacts • Social infrastructure impacts
Stakeholders with infrastructure within the Proposed MLA	• Interaction with and effects on infrastructure • Possible relocation requirements • Continuity of service
Stakeholders with commercial operations within the proposed MLA	• Interaction with and effects on infrastructure and operations • Possible relocation requirements • Continuity of operations
Interested Stakeholders	
Queensland Department of Environment and Science (DES)	• EA application and PRCP • Environmental assessments and mitigation measures • Environmental management plans • Mine rehabilitation
Queensland Department of Natural Resources, Mines and Energy (DNRME)	• Mining Lease application • Water supply and water infrastructure • Compliance with operational plans and safety • Mine closure

Stakeholder Group	Potential Interests
Queensland Department of Transport and Main Roads (DTMR)	• Transport and road impacts • Transport Impact Assessment (TIA) • Pavement Impact Assessment (PIA) • Associated contributions • Road Use Management Plan
Commonwealth Department of the Environment and Energy (DoEE)	• EPBC Act referral • Assessment of MNES, values, impacts and mitigation measures
Downstream water users (BMA)	• Impacts on local and regional surface and groundwater • Potential flooding impacts and impacts on critical infrastructure

The Project is a small scale, short term coal project located within a well-established coal mining region of Queensland. It is proposed on disturbed land immediately adjacent to a number of well-established large scale coal mining Projects. Based on this and limited social impacts determined to be associated with the Project, the need for broad community engagement has been determined not to be required. Representative bodies for the community (IRC, government agencies) will and have been consulted and the general public will have the opportunity to comment on the EA application and PRCP as part of the EA application assessment process. Vitrinite consider this to be an appropriate level of engagement.

2.2.1 Landholders

Underlying landholders are described in **Table 3.**

Table 3 Landholders / Reserves by Lot / Plan and Property Name

Lot / Plan	Landholder / Reserve	Property Name
Underlying Landholders/ Reserves		
• 26 CNS125	Aurizon Holdings Limited	Norwich Park Branch Railway
• Saraji Road	Isaac Regional Council	Saraji Road Reserve
• 2 SP296877	Robert A & Raye M O'Sullivan	Saraji Station

2.2.2 Traditional Owners

The Barada Barna People (QUD380/08), represented by the Barada Barna Aboriginal Corporation RNTBC ICN 8343 (BBAC), are the native title holders for the broader project area, and the 'Aboriginal party' for the Project under the Aboriginal Cultural Heritage Act 2003 (Qld).

2.2.3 Local Councils

The relevant local council is the Isaac Regional Council.

2.2.4 Organisations with Infrastructure on the MLA

The following organisations presently own and / or operate infrastructure on the proposed MLA:

- Aurizon;
- IRC;
- Telstra;
- Dyno Nobel Asia Pacific Ltd;

- Kalari Pty Ltd;
- Saraji Station; and
- BHP Billiton Mitsubishi Alliance (BMA) Pty Ltd.

2.2.5 Nearby Businesses

Businesses in close proximity to the proposed Project presently include:

- Dyno Nobel Asia Pacific Ltd;
- Kalari Pty Ltd;
- BHP Billiton Mitsubishi Alliance (BMA) Pty Ltd; and
- Saraji Station.

2.2.6 State and Federal Regulators

Relevant State and Federal regulatory agencies include:

- Queensland Department of Environment and Science (DES);
- Queensland Department of Natural Resources, Mines and Energy (DNRME);
- Queensland Department of Transport and Main Roads (DTMR); and
- Commonwealth Department of the Environment and Energy (DoEE).

2.2.7 Neighbouring Mining Operations

BMA own the neighbouring Peak Downs and Saraji coal mines.

3 STAKEHOLDER ENGAGEMENT ACTIVITIES

Stakeholder engagement activities (including frequency of engagement) have been identified for the various stakeholders discussed above, and once executed, are included in the Project's Stakeholder Register (refer **Appendix A**).

The level of stakeholder engagement will:

- Be based on the goals / objectives of the engagement program and effectiveness of the technique in reaching the target audience; and
- May vary considerably depending on the level of interest and impact the stakeholder has.

The methods of stakeholder engagement that have been considered include:

- Face to face meetings;
- Scheduled and routine conferences (monthly, quarterly, annual, etc.);
- Telephone meetings;
- Workshops; and / or
- Newsletters and email correspondence.

Regardless of the stakeholder group or method of engagement, all engagement will apply the following principles:

- Transparent – Open and honest in engagement activities, setting expectations;
- Realistic – Set clear objectives and understanding of what is to be achieved out of the engagement;
- Inclusive – Identify stakeholders and provide meaningful opportunities for them to engage;
- Respectful – Listen and acknowledge the needs of stakeholders, different opinions and perspectives; and
- Responsive – Consider and respond to issues and concerns, providing feedback to stakeholders.

3.1.1 Landholders

Underlying and adjacent landholders have been identified as Affected Project stakeholders.

Project Engagement activities will involve the following:

- Initial telephone contact between the Project Manager and the landholder;
- Round 1 - individual face-to-face meetings to discuss:
    - Draft Project description;
    - Environmental approvals and tenure processes and scheduling;
    - Environmental baseline surveys and monitoring undertaken to date and baseline results;
    - Approach to impact assessment and management of noise, dust, weed management, property disturbance etc.;
    - Approach to progressive rehabilitation and closure planning; and
    - Future communications protocol.
- Round 2 - individual face-to-face meetings to discuss:
    - Final Project description proposed for approval;
    - Results of impact assessment - particularly management of noise, dust and weeds, and closure impacts;
    - Proposed project rehabilitation and final landform / land use; and
    - Further information on the environmental approvals process and opportunities to comment during the public notification process.

3.1.2 Traditional Owners

The Proponent and the BBAC have entered into an indigenous land use agreement (body corporate agreement) (ILUA) in respect of the Vulcan Project, which is in the process of being registered with the National Native Title Tribunal. The ILUA also contemplates the management of Aboriginal cultural heritage under the Aboriginal Cultural Heritage Act 2003 (Qld). Engagement will continue in accordance with the ILUA.

3.1.3 Local Council

The Project is located within the Isaac Regional Council and engagement will focus on the Project's potential impacts to the surrounding region (including infrastructure and transport impacts). IRC data has been interrogated as part of the social impact assessment, and impacts to local businesses, community groups, worker accommodation in Dysart and Moranbah, social infrastructure (health, education and emergency services) are considered to be limited.

Consultation with Isaac Regional Council directly in relation to the proposed realignment of IRC's Saraji Road and provision of regular Project updates has been ongoing and is documented in **Appendix A**. This includes approval applications requirements for the off-lease component of the road realignment to the north of the proposed MLA.

3.1.4 Organisations with Infrastructure on the MLA

Direct consultation will occur with each organisation that operates infrastructure on the proposed MLA. Each party will be engaged separately via e-mail, phone and face-to-face meetings to discuss current infrastructure operations, interactions with the project, realignment requirements and ongoing management requirements.

3.1.5 Nearby Businesses

Direct consultation will occur with each organisation that operates businesses on or adjacent to the proposed MLA. Each party will be engaged separately via e-mail, phone and face-to-face meetings to discuss current business operations, interactions with the project, potential relocation requirements and ongoing management requirements.

3.1.6 State and Federal Regulators

Engagement with State and Federal regulators will occur throughout the Project planning assessment and execution phases. Engagement will be via e-mail, phone and face-to-face meetings (including presentations of Project information). Engagement will typically be focussed around a number of approval process stages including:

- Introduction of proponent and project concept (including clarification of approval processes and assessment / application requirements);
- Discussion of baseline assessment findings;
- Discussion of impact assessment findings and management and mitigation proposals;
- Application pre-lodgement;
- Application assessment consultation, information requests, notification processes; and
- Compliance and reporting.

3.1.7 Neighbouring Operations

BMA operates the Peak Downs mine immediately to the east of the Project MLA. BMA will be engaged via e-mail, phone and face-to-face meetings.

3.1.8 Statutory Public Notification

Prescribed statutory public notification periods form part of the ML, EA and EPBC referral application and approvals process. During these periods, approval application material will be advertised in various newspapers, made available on the Vitrinite website and on the DES and DoEE websites for the public to respond to by way of written submissions to the regulators.

3.2 COMMUNICATION CHANNELS

A Vitrinite channel of communication will be established linking Project staff / management to external stakeholders who wish to comment on (or ask questions about) the Projects various components and / or impacts. Information will also be included on the Vitrinite website and updated as necessary along with instructions on how external stakeholders can make a submission to DoEE, DNMRE, DES and / or Vitrinite during the public notification process.

Vitrinite will distribute information to stakeholders as required and in consideration of confidentiality requirements as well as releasing information as required in accordance with its public notification obligations.

Two-way communication is fundamental to engagement with stakeholders. Engagement and feedback opportunities will be actively sought to ensure that stakeholders are comfortable with the level of Project knowledge and so that any management of enquiries, complaints or issues can be handled efficiently. Feedback from Project consultation activities will be met within appropriate timeframes as follows:

- Telephone or face-to-face enquiries about current Project activities will aim to be responded to by the next business day;
- Telephone or face-to-face enquiries about non-current (i.e. proposed) Project activities will aim to be responded to within three business days; and
- Email and letter enquires within five business days from date of receipt of correspondence.

Virtinite's neighbouring VCM has a proposed a complaint process based on the one currently in place for Vitrinite's approved Bulk Sample Project (BSP) as conditioned by the environmental authority (EA). This system will be applied to the full Project, of which the BSP and VCM are smaller components. It will document criticism or concern over perceived environmental issues and will be available for consultation by the relevant stakeholders. The complaints register will record:

1. name, address and contact number of the complainants;
2. time and date of the complaint;
3. reasons for the complaint;
4. investigations undertaken;
5. conclusions formed;
6. actions taken to resolve the complaint;
7. any abatement measures implemented; and
8. person responsible for resolving the complaint.

Should the Project be required to have any further or different complaint procedures through conditions from an administering authority, they will of course take precedence to ensure compliance of the project.

4 ONGOING ENGAGEMENT

Stakeholders will continue to be engaged during the project construction, operations and closure phases. Specific consultation in relation to the Progressive Rehabilitation and Closure Plan (PRCP) is discussed in **Section 7.**

Affected stakeholders will be advised of any relevant Project changes that are proposed to occur throughout the Project execution. Relevant Project changes are considered to be those that significantly change the information, decisions and agreements that had been discussed in prior engagement or approval notification activities.

5 RECORDKEEPING, REPORTING AND REVIEW

A record of all stakeholder engagement (past, ongoing or prospective) will be maintained in order to verify stakeholder engagement conducted, address stakeholder concerns in a timely manner and manage the Project approval process to acknowledge and (where feasible) incorporate stakeholder feedback.

Appendix A provides relevant engagement records documented to date (at time of publication). This document details the consultation that has occurred though the previous components of Vitrinite's projects in the area, the VCM and the BSP.

5.1 RECORDKEEPING

The Vitrinite Project Manager and / or personnel responsible for stakeholder engagement, as well as any staff responsible for holding a Project email and / or telephone number, will be accountable for implementing Vitrinite's record keeping process, including:

- Direct data entry into records; and
- Advising any other supporting staff responsible for inputting stakeholder engagement data into formal records.

5.2 REPORTING

For each stakeholder engagement record generated, the following will be reported:

- Consultation date(s);
- The stakeholders consulted;
- Consultation type (face-to-face meeting, community forum, workshop, quarterly meetings, etc.);
- Information provided;
- Topics of discussion; and
- Outcomes and ongoing commitments.

5.3 ANNUAL REVIEW

This SEP (including the Stakeholder Register) will be reviewed annually (post Project approval) and updated accordingly to ensure that:

- Any updated legislation, standards and other reference information is incorporated into the SEP and any supporting Vitrinite management systems; and
- Vitrinite's engagement process throughout the Project's operations and rehabilitation and closure phases remains efficient, informative and fit for purpose in accordance with accepted industry standards and legislative requirements.

6 ROLES AND RESPONSIBILITIES

The Vitrinite Project Manager is primarily responsible for the planning and implementation of stakeholder engagement activities for the Project. Where applicable, engagement will build on existing engagement between stakeholders and Vitrinite personnel. Accordingly, those involved with existing engagement tasks will play an ongoing role in the implementation of the SEP. Other Vitrinite personnel involved in stakeholder engagement are identified in the Stakeholder Register (**Appendix A**).

7 REHABILITATION AND CLOSURE

7.1 ENGAGEMENT AND CLOSURE PLANNING

A PRCP is required to be developed for the Project in accordance with the Queensland Government's Mined Land Rehabilitation Policy. The PRCP must be submitted as part of the site-specific EA application for a new mining activity and is required to comply with requirements as set out in DES' *Progressive Rehabilitation and Closure Plans Guideline (PRCP Guideline)* (effective as at 1 November 2019).

As part of the PRCP planning process, and in accordance with section 126C(1)(c)(iii) and (iv) of the EP Act as well as DES' PRCP Guideline, Vitrinite must demonstrate that sufficient effort has been made in engaging stakeholders in the preparation of the PRCP. The following three components will be considered:

- The identification of relevant stakeholders;
- Identification of a Stakeholder Engagement Register identifying the engagement carried out in developing the PRCP (it may refer to the Stakeholder Engagement Register appended to this document); and
- A description of ongoing (rehabilitation related) engagement proposed during Project operations and closure activities (note discussion of this in **Section 7.2** below).

The above PRCP planning requirements have been considered in the development of this SEP, with rehabilitation and closure planning forming a component of the Project's stakeholder engagement process. **Appendix A** provides relevant engagement records documented to date.

7.2 ONGOING PRCP ENGAGEMENT

The *Progressive Rehabilitation and Closure Plans Guideline* (PRCP Guideline), requires ongoing engagement with relevant stakeholders to determine any changes in stakeholder perspectives and to communicate any relevant closure related changes proposed by Vitrinite. Given the short duration of the proposed Project (eight years of coal extraction), it is considered unlikely that significant changes to the proposed rehabilitation activities will occur. Similarly, it is considered that stakeholder perspectives on rehabilitation are unlikely to change, particularly if the proposed rehabilitation activities are implemented successfully.

Nonetheless, Vitrinite commits to providing relevant stakeholders with copies of annual rehabilitation progress reporting and will utilise this mechanism for communication of any proposed changes to the PRCP and to obtain feedback from stakeholders for consideration in ongoing planning and activities. Should significant amendment of the PRCP be proposed, stakeholders will be engaged as part of the amendment process.

APPENDIX A

STAKEHOLDER REGISTER

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
20 March 2019	Meeting	O'Sullivans (Saraji and Cherwell)	Cherwell Station	Mike Cavanaugh, O'sullivan family	Planned location of water bores	Groundwater bores	Ongoing discussions around borehole conversion if suitable
30 April 2019	Meeting	DES	DES Office Emerald	Allison Sinclair, Mick Callan, Dave Moss, Heath Carney,	Vulcan Bulk Sample Project and Vitrinite introduction, VCP introduction	Bulk Sample Project Description, Vulcan Project introduction	BSP EA application planning to continue. Prelodgement meeting to be held in a few months prior to EA application submission
16 May 2019	Meeting	Barada Barna People	Vitrinite Office, Brisbane	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	Project update and preliminary ILUA discussions	Ongoing dialogue towards ILUA execution
21 May 2019	Meeting	DNRME (Coal Hub)	Rockhampton	Mick Callan, Nick Williams, DNMRE representatives	Project overview presentation	Project update	Ongoing consultation regarding project development
18 June 2019	Meeting	Barada Barna People	McCullough Robertson Lawyers	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	ILUA meetings, Info sessions, execution meeting	Ongoing dialogue towards ILUA execution

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
11 July 2019	Meeting	DNRME	DNRME Offices Rockhampton	Alex Grundy, Deb Toon, Mick Callan, Dave Moss	Overview of Bulk Sample Project, introduction to VCP	MDL Application requirements discussed and agreed. VCP and future opportunities broadly discussed	BSP EA and MDL application submissions to proceed as planned, Further updates on VCP to be provided.
31 July 2019	Meeting	Dyno Nobel	Vitrinite Office, Brisbane	John Stevens and Simon Masters (Dyno) Mick Callan, Nick Williams, Ryan Welker	Detailed project update	project interactions, update on project development	ongoing consultation
10 September 2019	Meeting	Barada Barna People	McCullough Robertson Lawyers	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	ILUA meetings, Info sessions, execution meeting	Ongoing dialogue towards Ilua execution
11 September 2019	Meeting	DES	DES Office - Gladstone	Chris Loveday, Nicholas Williams, Mick Callan, Dave Moss	VCP overview, values and impacts, approach to PRCP	Vulcan Project approval strategy, phases, discussed likelihood of EIS and proposal to submit well informed EA application, identified environmental values and impacts. Approach to PRCP	Ongoing consultation around submission

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
11 September 2019	Meeting	RG Tanner	RG Tanner Gladstone	RG Tanner, Nicholas Williams, Mick Callan, Dave Moss	VCP overview	Port operations and allocations	Ongoing consultation
24 October 2019	Meeting	Landholder - O'Sullivans (Saraji and Cherwell)	Saraji Station			Land purchase options / Project Update	Ongoing consultation
30 October 2019	Teleconference	DES	Teleconference Brisbane-Emerald	Allison Sinclair, Gillian Naylor, Jessica Edgar, Dave Moss	PRCP approach	PRCP approach, confirmation of submission requirements, query guideline availability - timing, scope of supporting assessments	Ongoing consultation once guideline available and understood.
4 November 2019	Meeting	BMA/BHP	BHP Office, Brisbane	Mick Callan, Dave Moss, Alan Hocking	Provided surface water modelling and flood assessment	Water supply, data sharing, project update, flood modelling	BHP to review and provide comment
7 November 2019	Meeting	Landholder - O'Sullivans (Saraji and Cherwell)	Cherwell Station	Mick Callan, Nick Williams, O'Sullivan Family	Project update, discuss land owner plans for property	Land purchase options / Project update	Ongoing negotiation
20 November 2019	Meeting	Isaac Regional Council	Moranbah	Mick Callan, Rob Machill, Sean Robinson	Project update and draft road relocation plans	Road relocation discussions and approval process	IRC to provide draft compensation agreement for road relocation

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
17 December 2019	Meeting	BMA	BMA offices Brisbane	Alan Hocking, James Zhan, Julian Orth, Mick Callan, Dave Moss	Project Overview, water supply options	Discussed water supply options, VCP flood mapping and potential for use of mine affected water	Ongoing consultation and water supply discussion, provision of VCP project flood mapping for BMA incorporation and consideration against critical infrastructure.
13 January 2020	Meeting	Barada Barna	McCullough Robertson Lawyers	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	ILUA meetings, Info sessions, execution meeting	Ongoing dialogue towards ILUA execution
28 January 2020	Meeting	Barada Barna	Chermside Bowls Club, 468 Rode Road, Chermside	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	ILUA meetings, Info sessions, execution meeting	Ongoing dialogue towards ILUA execution
29 January 2020	Meeting	Barada Barna	Ipswich Best Western Hotel, 51/55 Warwick Street, Ipswich	Nick Williams, Ryan Welker, Directors and members of Barada Barna Aboriginal Corporation, legal representatives	Project update presentation	ILUA meetings, Info sessions, execution meeting	Ongoing dialogue towards ILUA execution

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
04 February 2020	Meeting	Mines Inspectorate	Dysart	Nick Williams, Ryan Welker, Mick Callan, Mike Cavanaugh, James Richardson, large contingent of QLD mines inspectors	Powerpoint presentation outlining the Vulcan project, development plans and SHMS development plans	Project update, initial consultation on SHMS development	Presentation well received by inspectors, Vitrinite committed to maintaining open dialogue as the project develops
13 February 2020	Meeting	Aurizon	Vitrinite office, Brisbane	Mick Callan, James Richardson, Nick Remmelt, Tiffany Bruce	Project presentation, draft rail protection plan	Project update and discuss rail interactions	Aurizon to provide feedback on management plan and arrange follow up meetings
17 February 2020	Meeting	BMA	BMA offices Brisbane	Alan Hocking, James Zhan, Mick Callan, Dave Moss	VCP Overview, water supply options	Discussed water supply options, confirmation of no BMA concern on impacts of VCP flood modelling on critical infrastructure at BMA operations	Ongoing consultation and water supply discussion
20 February 2020	Meeting	IRC	IRC Office Moranbah	Steve Voke, IRC personnel, Mick Callan, James Richardson, Dave Moss	Vulcan Project update, Saraji Road alignment	compensation agreements, Road Use Management Plan, approval mechanisms under the Land Act. Opportunities to present to Council	Ongoing consultation

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
21 February 2020	Meeting	DES	DES Emerald Office	Jessica Edgar, Gillian Naylor, Barbara van der Pol	Project update and approval process discussion	Vulcan project changes, Vulcan South, PRC Plan/Environmental Authority application	Ongoing consultation
30 March 2020	Teleconference	DES	N/A	Tenille Nielsen, Emma Burgess, Keeley Hartzer	Project updates and amendments	Vulcan project proposal discussion	Ongoing consultation
2 June 2020	e-mail correspondence	DES	N/A	Chris Loveday/ Dave Moss/ Mick Callan/ Kate Bennink	Vulcan Project broad approval strategy incorporating Vulcan South	Vulcan project phasing and approvals approach	Ongoing consultation
5 June 2020	Meeting	DES	DES Office Gladstone	Chris Loveday/Dave Moss/Mick Callan	Vulcan Project broad approval strategy	Preliminary project discussion	Ongoing consultation
23 June 2020	e-mail correspondence	DES	N/A	Chris Loveday/ Dave Moss/ Mick Callan/ Kate Bennink	Vulcan Project broad approval strategy – response from DES	Brief commentary on proposed approach and commitment to further consultation	Ongoing consultation
February - November 2021	e-mail correspondence	DES	N/A	Chris Loveday/Aiyisha McLean/Pauline Gregory/ Kathleen Ahern/Kate Bennink	Vulcan South preliminary assessment and EIS decision application	Vulcan South EIS decision application	Ongoing consultation

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
11 February 2021	Teleconference	DES	N/A	Chris Loveday/Dave Moss	EIS decision application	EIS decision application	Ongoing consultation
19 August 2021	Meeting	Landholder - O'Sullivans (Saraji and Cherwell)	Vulcan Mine Site	Kerry O'Sullivan, Mick Callan, Nick Williams, Tom O'Malley	Vulcan South mine and rehabilitation	Vulcan South water storage options	Ongoing consultation
January 2022 to Current	Monthly meetings	BMA	Video Conference	BMA – Matt Ray, Tracey Drever, Vitrinite – Ben Dunlop	Updates on site and advancement of Vulcan south ML and EA applications	Interactions between companies, updates on progress, ML application	Ongoing consultation
24 March 2022	Meeting / Pre-lodgement presentation	DES	Vulcan Mine Site	DES personnel (Emma Burgess, Marijke Schuurs, Chelsea Engel, Jade Caldwell, Connor Shelton)/Dave Moss/Ben Dunlop	Project presentations, pre-lodgement overview of Vulcan South. Site visit.	Bulk Sample, BSP, CHPP + Rail, site tour, Vulcan South Project Pre-lodgement presentation.	Ongoing consultation

Consultation date	Consultation type	Stakeholder	Location	Attendees	Information Provided	Topics of discussion	Outcomes/ ongoing commitments
April – May 2022	Pre-lodgement consultation and application reviews	Department of Resources	Phone and e-mail	Mel Veti, Deborah Toon	Pre-lodgement discussion and ML application review	Vulcan South ML application	Application finalisation, submission and ongoing consultation

Appendix F – Landform Evolution Modelling

Vulcan South LEM Report

Landform Evolution Modelling Study

Vitrinite Pty Ltd
1571-21-C3, 13 March 2023

Report Title	Vulcan South LEM Report, Landform Evolution Modelling Study
Client	Vitrinite Pty Ltd
Report Number	1571-21-C3

Revision Number	Report Date	Report Author	Reviewer
0 [DRAFT]	17 January 2023	RN	JO/GR
1	31 January 2023	RN	JO/GR
2	2 February 2023	RN	JO/GR
3	13 March 2023	RN	JO/GR

For and on behalf of WRM Water & Environment Pty Ltd
Level 9, 135 Wickham Tce, Spring Hill
PO Box 10703 Brisbane Adelaide St Qld 4000
Tel 07 3225 0200

Greg Roads

Senior Principal Engineer

NOTE: This report has been prepared on the assumption that all information, data and reports provided to us by our client, on behalf of our client, or by third parties (e.g. government agencies) is complete and accurate and on the basis that such other assumptions we have identified (whether or not those assumptions have been identified in this advice) are correct. You must inform us if any of the assumptions are not complete or accurate. We retain ownership of all copyright in this report. Except where you obtain our prior written consent, this report may only be used by our client for the purpose for which it has been provided by us.

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1 Introduction

1.1 OVERVIEW

Vulcan South (the Project), which is managed by Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), is a proposed open pit and highwall mining operation located to the southeast of Moranbah, in Central Queensland. The Project is located immediately south and west of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM), located on Mining Lease (ML) 700060. The location of the Exploration Permits (Coal) (EPCs) and the Project ML area are shown in Figure 1.1.

A Progressive Rehabilitation and Closure Plan (Draft PRCP) (METServe, 2022) for the Project has been prepared to meet the requirements of section 126C and 126D of the Environmental Protection Act 1994 (EP Act) and the *Guideline – Progressive rehabilitation and closure plans* (PRCP guideline) (DES, 2021). Section 3.6.1 of the PRCP guideline (DES, 2021) outlines that final landform design is a key component of rehabilitation and closure planning. The Draft PRCP provides rehabilitation goals and the methodology proposed to meet these goals including the proposed cover designs for the six waste rock dump (WRD) landforms proposed for the post-closure mining land use (PMLU).

WRM Water & Environment Pty Ltd (WRM) has been engaged to undertake landform evolution modelling (LEM) for the six WRD's to provide supporting information for the PRCP to:

- determine the long-term stability of the PMLU rehabilitated landforms and the level of potential environmental risk of emplacing rejects materials in the waste rock dumps (WRD); and
- analyse the future stability of the proposed landform cover designs and justify the reasonability of the targeted landform design objectives as outlined in the PRCP.

The WRD's assessed for the Project are shown in Figure 1.2 to Figure 1.4 and defined as Rehabilitation Area 1 (RA1) and Rehabilitation Area 2 (RA2) in the Draft PRCP and include the:

- Ex-pit WRD's (RA1):
  - Vulcan North ex-pit WRD;
  - Vulcan Main ex-pit WRD; and
  - Vulcan South ex-pit WRD.
- In Pit WRD's (RA2):
  - Vulcan North in-pit WRD;
  - Vulcan Main in-pit WRD; and
  - Vulcan South in-pit WRD.

The LEM assessment undertaken as part of this report tests the adequacy of the proposed WRD embankment slope and cover design detailed in the Draft PRCP. The results of the assessment can be used to inform landform rehabilitation design, demonstrate how the results support the current targeted landform rehabilitation objectives and demonstrate the requirements for long-term stability of the landforms.

1.2 REPORT STRUCTURE

The report has been structured as follows:

- Section 2 presents the methodology used to undertake the LEM assessment;
- Section 3 summarises the findings of the assessment;
- Section 4 discusses recommendations as an outcome of the study; and
- Section 5 is a list of references.

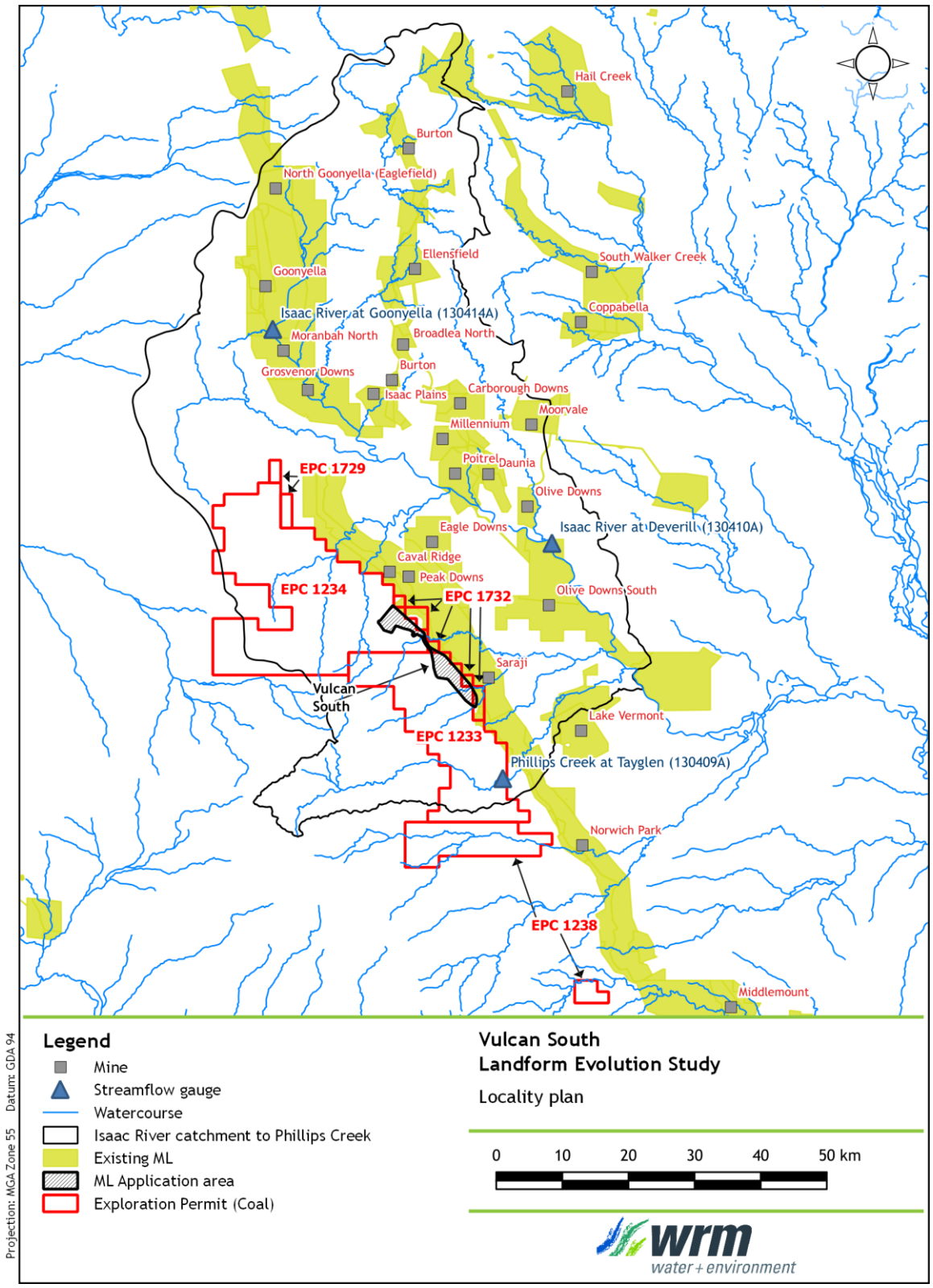

Figure 1.1 – Locality

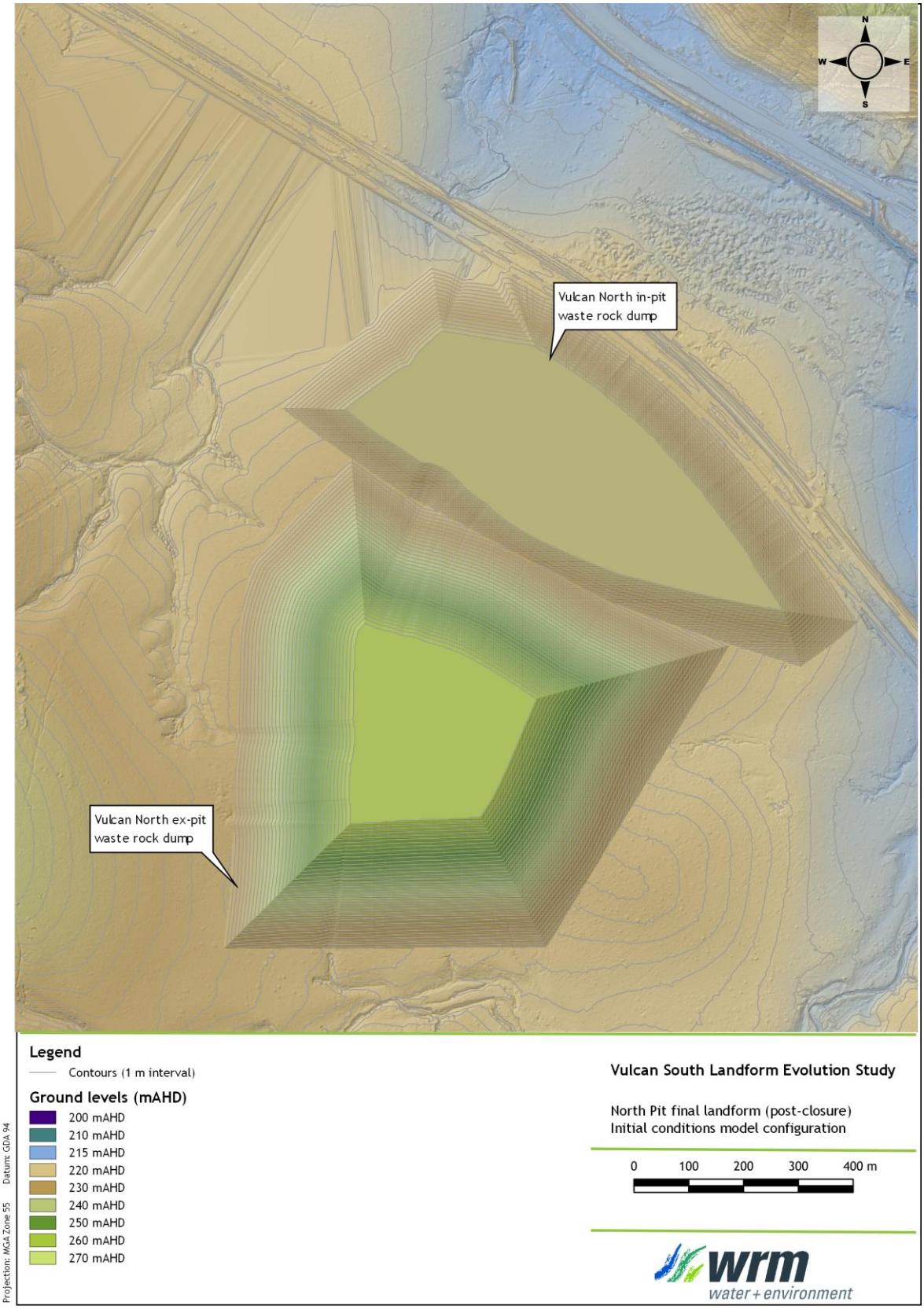

Figure 1.2 – Vulcan South final landform and rehabilitation areas – Vulcan North pit

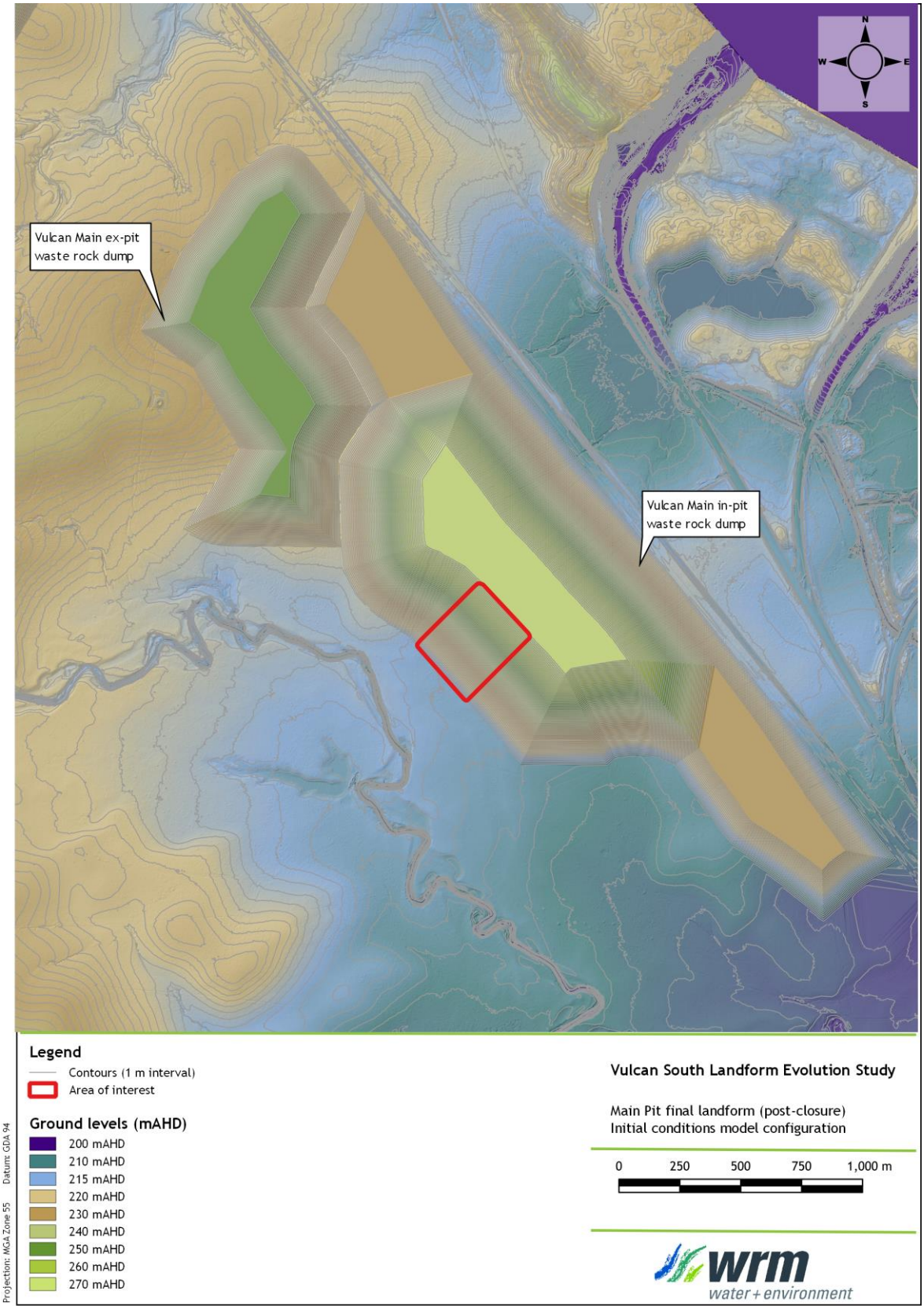

Figure 1.3 – Vulcan South final landform and rehabilitation areas – Vulcan Main pit

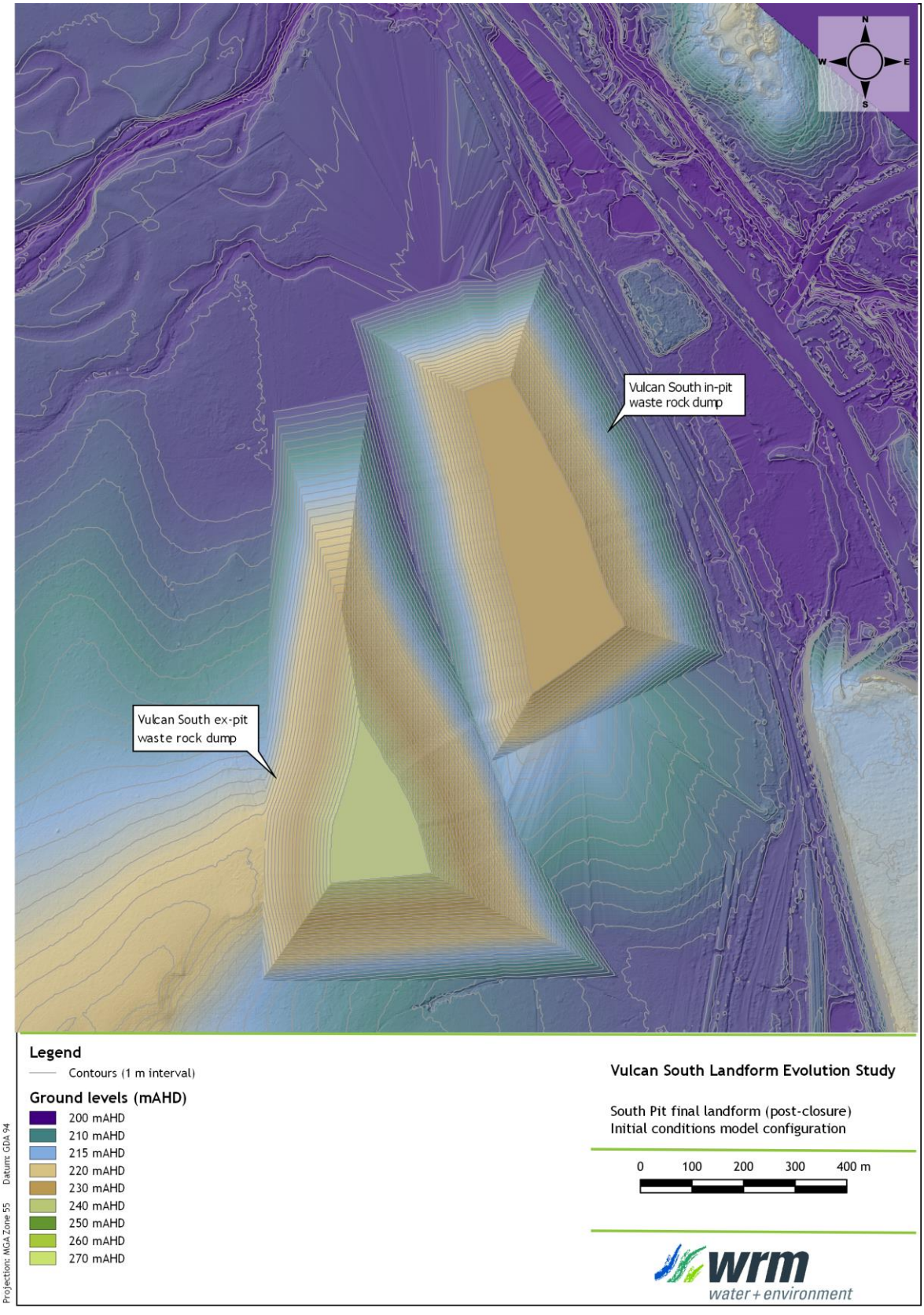

Figure 1.4 – Vulcan South final landform and rehabilitation areas – Vulcan South pit

2 Methodology

2.1 OVERVIEW

This section of the report describes the methodology used to undertake the LEM assessment. Construction of the final landform including the cover, final slope and drainage has not yet been completed and detailed designs of the landforms have not been developed. To provide the supporting information for the PRCP, the LEM assessment has focussed on the design of the embankment slope and cover.

Figure 1.2 to Figure 1.4 shows conceptual digital elevation models (DEM) of the proposed final landforms at the Project. The six WRDs incorporate batter slopes of 15% with a relatively flat plateau. The six landforms were assessed to determine the longest batter slopes. The longest batter slope lengths for each landform were:

- up to 105 m for the Vulcan North in-pit WRD;
- up to 250 m for the Vulcan North ex-pit WRD;
- up to 380 m for the Vulcan Main in-pit WRD;
- up to 220 m for the Vulcan Main ex-pit WRD;
- up to 205 m for the Vulcan South in-pit WRD; and
- up to 210 m for the Vulcan South ex-pit WRD.

The longest batter slope on the six landforms (excluding proposed batter drainage) is located on the Vulcan Main in-pit WRD at the area of interest shown in Figure 1.3. This batter slope is 380 m long from the crest to the toe.

The assessment has therefore focussed on the Vulcan Main in-pit WRD batter slope, which is called the **representative batter slope** in this report. If this batter slope is shown to be acceptable, it can be inferred that the other batter slopes would be acceptable because they have the same slope and cover design.

The following rehabilitation scenarios, obtained from the Draft PRCP, were assessed using the LEM:

- Scenario 1: Bare earth/unvegetated landform slope representing a failed vegetative establishment phase during early years of rehabilitation;
- Scenario 2: Rock mulched landform (30% rock mulching) prior to vegetation establishment;
- Scenario 3: Rock mulched landform (30% rock mulching) with 30% grass/vegetation cover;
- Scenario 4: Rock mulched landform (30% rock mulching) with 50% grass/vegetation cover; and
- Scenario 5: Rock mulched landform (30% rock mulching) with 70% grass/vegetation cover representing successful rehabilitation of the landform.

The assessment provides information on the ability of different cover management scenarios to resist erosion assuming no drainage works are undertaken. The proposed drainage would potentially reduce the batter slopes, at least in the short term to further assist in the management of erosion of the batter.

2.2 MODELLING APPROACH

The LEM tool SIBERIA within the CAESAR-lisflood (CAESAR) platform was used for the assessment. SIBERIA is a geomorphological / landscape evolution model that simulates catchment erosion and depositions for time scales from hours to 1000's of years. SIBERIA models soil erosion and deposition of the landforms by assessing rainfall-runoff drainage directions

which are used to determine the area contributing/flowing through grid cells of the model. The model then calculates continuity equations for flow and sediment transport which determines erosion rates/depths output by the model.

The model parameters were first validated against the predicted soil loss rates provided in the Draft PRCP which are based on localised parameters (local rainfall erosivity, Limpopo soil erodibility, etc.). The validated parameters were then used to assess the erosion potential of the representative batter slope. The above rehabilitation scenarios for the representative batter slope were assessed for two timescales including:

- The first 10 years post mining to represent the establishment phase of site rehabilitation; and
- A period of 100 years post mining.

The LEM assessment was then undertaken for all six WRD's to provide an indication of what the landforms would look like after 100 years.

2.3 AVAILABLE DATA

The key input parameters to SIBERIA include:

- The proposed landform design in .DXF file format (see Section 2.3.1);
- Sediment and particle distribution information and sediment transport information representative of the materials proposed to be used for rehabilitation of the landform (see Section 2.3.2);
- Geotechnical data of the rehabilitated WRDs (see Section 2.3.3); and
- Geochemistry of the waste rock material (see Section 2.3.4)
- The surface water assessment (see Section 2.3.5).

2.3.1 Topography

Figure 1.2 to Figure 1.4 shows concept DEMs of the proposed final landforms provided by Vitrinite dated 11 March 2022.

The DEMs were processed using 12D and QGIS software prior to input to the CAESAR model. The input resolution to CAESAR was a 2 m grid cell size.

The concept DEMs do not include the suite of drainage measures that are proposed for the WRD plateau and embankments. Therefore, model results using the concept DEMs are slightly conservative as the inclusion of these drainage measures would reduce erosion risks.

2.3.2 Soil and land suitability

AARC prepared the *Vulcan South Soil and Land Suitability Assessment* (AARC, 2022) report for the Project, herein referred to as the soils report. The soils report documents the characteristics of the existing material available for use for the rehabilitation of the WRDs.

The soils report (AARC, 2022) notes that the surface soils across the Project area mainly consist of the Limpopo soil management unit (SMU) and these soils are proposed to be used for the rehabilitation of the WRD's. The topsoil is dominated by sand (79%) with 8% silt, 10% clay and 3% gravel. The sandy surface soils are non-sodic and not likely to be vulnerable to dispersion. However, clay subsoils (below 0.5 m) are sodic and susceptible to dispersion.

The soils report derived the erosion rates specific to the Limpopo SMU using the Revised Universal Soil Loss Equation (RUSLE). RUSLE is calculated using rainfall erosivity (for local conditions), soil erodibility, slope-length gradients, cover and management, and conservation/support practice factors. Table 2.1 summarises the predicted erosion rates for the proposed cover management strategies using the Limpopo SMU.

Table 2.1 – Predicted soil erosion rates of the Limpopo SMU as a factor of slope and cover from the Draft PRCP

Scenario	Cover management	C	Gradient (%)	A (t/ha.y)
1	Bare ground (pre-vegetation)	1.000	15	306.4
2	30% rock mulch (pre-vegetation)	0.325	15	99.58
3	30% rock mulch with 30% grass cover	0.100	15	30.64
4	30% rock mulch with 50% grass cover	0.050	15	15.32
5	30% rock mulch with 70% grass cover	0.018	15	5.52

2.3.3 Geotechnical assessment

Blackrock Mining Solutions Pty Ltd (Blackrock) prepared the geotechnical assessment memorandum *Vulcan Complex – Jupiter Final Landform Slope Stability Assessment* (Blackrock, 2020), herein referred to as the geotechnical report. The geotechnical report assessed the stability of the proposed WRD embankment design used for the Vulcan Coal Mine project. Blackrock concluded that the generally accepted Factor of Safety (FoS) criteria for long-term slopes should be greater than 1.5, and should be adopted for the Vulcan South project WRD embankment design.

2.3.4 Geochemistry assessment

RGS Mine Waste and Water Management prepared the *Geochemical Assessment of Waste Rock, Coal Reject and Coal* (RGS, 2022) for the Project, herein referred to as the geochemistry report. The geochemistry report documents the characteristics of the waste rock material proposed to be emplaced to form the post-mining Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms. A summary of the conclusions of the geochemistry report on the waste rock material are as follows:

- *The overwhelming majority of the waste rock materials have low sulfide content, excess acid neutralising capacity (ANC), and are classified as non-acid forming (NAF) (Barren). These materials have a very low risk of acid generation and a high factor of safety with respect to potential for generation of acidity.*
- *Coal reject materials have relatively low sulfide content and excess ANC. As a bulk mixed material, it is expected that coal reject will be classified as NAF and have a relatively low risk of generating acidic drainage. Co-disposal of reject materials in waste rock dumps is likely to have a beneficial impact on the quality of the reject leachate.*
- *Coal is likely to have similar geochemical characteristics to coal reject materials and will be temporarily stockpiled at the ROM area prior to being transferred to the CHPP. As is standard practice at coal mining operations in the Bowen Basin, any surface runoff and seepage from the ROM coal stockpile will be monitored for quality and managed in the mine water management system as part of the Water Management Plan.*
- *Initial and ongoing surface runoff and seepage from mining waste materials is expected to be pH neutral to slightly alkaline and have a low level of salinity.*
- *There is no significant metal/metalloid enrichment in mining waste materials compared to applied guideline values and median crustal abundance in un-mineralised soils.*
- *Most metals/metalloids are sparingly soluble at the neutral to slightly alkaline pH of leachate expected from bulk NAF mining waste materials. Dissolved metal/metalloid concentrations in surface runoff and leachate from bulk NAF mining waste materials are expected to be low and unlikely to pose a significant risk to the quality of surface and groundwater resources at relevant storage facilities.*

- *NAF waste rock materials should be amenable to revegetation as part of rehabilitation activities, although, gypsum and fertiliser addition may need to be considered for sodic materials to limit dispersion and erosion and to provide a reasonable growth medium for revegetation and rehabilitation.*

2.3.5 Surface water assessment

The surface water assessment (WRM, 2022) presents the proposed conceptual drainage design of the six post-closure landforms. The proposed drainage design of the six final landform WRDs (to be confirmed during detailed design) include indicative alignments for surface water drains, plateau drains, contour banks and drop structures. These drainage control structures decrease erosion risk ratings once implemented during detailed design of the landforms. The surface water assessment also provides mapping of the post-closure landform within the floodplain extent. The landforms are generally located out of areas of high velocities and depths (i.e. along or adjacent to major creeks and drainage lines).

2.4 REHABILITATION CRITERIA

Figure 2.1 shows the recommended cover design to optimise plant growth for rehabilitation of the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms, obtained from the Draft PRCP. The topsoil layer is proposed to allow a suitable vegetative cover to establish to prevent erodibility of the landform. Where required, gypsum, organic matter and fertilizer will be mixed with the waste rock materials to reduce the sodicity and reduce the potential for dispersion and erosion (RGS, 2022).

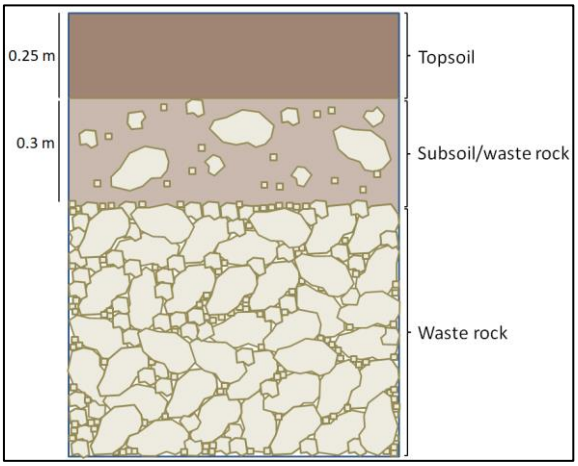

Figure 2.1 – Cover design to optimise plant growth

The Draft PRCP also provides defined rehabilitation goals for each PMLU. The criteria of relevance to this assessment are summarised in Table 2.2. The following is of note from the Draft PRCP:

- *Despite no need for a cover that protects waste rock from oxidation, waste rock will be placed in such a way to facilitate vegetation re-establishment. Following the return of waste rock to the open cut pit, at least 300 mm of subsoil (removed from the pits prior to mining and stockpiled) is to be spread over the rock. This will enhance the water-holding capacity of the soil and provide a more favourable growing environment for vegetation. Given the vulnerability of local subsoils to dispersion, some waste rock will be mixed with the subsoil (approximate ratio of rock to subsoil of 1:3), to provide protection from erosion, in the unexpected event that that rock mulch cover and developing grass cover doesn't provide adequate protection, and the overlying topsoil becomes eroded in places.*
- *Topsoil will be spread over the subsoil/rock mix at a depth of 250 mm to provide a favourable medium for plant establishment. Note that this cover design varies slightly between rehabilitation areas due to material availability and rehabilitation*

requirements. In addition, a number of topsoil and subsoil ameliorative measures will be implemented, wherever required, to ameliorate poor soil structure, low moisture retention and low nutrient concentrations that may be encountered with the Limpopo SMU.

- *Amelioration measures that can be utilised where required, include the application of organic matter, fertiliser, rapid establishing cover crops, and hydro mulching.*

Table 2.2 – Rehabilitation objectives, indicators and completion criteria outlined in the Draft PRCP (METServe, 2022)

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
PMLU A: Low-intensity cattle grazing					
A1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll et al. 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2021). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2020).
A2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal.	Prior to the commencement of topsoil placement.	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2 but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a hydrocarbon spill).
		Water quality at permanent monitoring locations downstream of the Project.	Annually, following rain events.	Surface water in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.
		Groundwater quality within permanent monitoring bores.	Quarterly.	Groundwater in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
A3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA are incorporated into the completion criteria.
A4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
A5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).
A6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).
PMLU B: Low-intensity cattle grazing with Habitat for Threatened Species					

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies.	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll *et al.* 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2022). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2022).
B2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal	Prior to the commencement of landform development	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2, but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a vehicle accident leading to hydrocarbon spills)
		Water quality at permanent monitoring locations downstream of the Project	Annually, following rain events	Surface water in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site specific surface water quality triggers will be established over time and present the most accurate measure of effect on water quality.
		Groundwater quality within permanent monitoring bores	Quarterly	Groundwater in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site specific groundwater quality triggers will be established over time and present the most accurate measure of effect on water quality.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA are incorporated into the completion criteria.
B4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
B5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).
B6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B7	Koala food trees are to have a similar dominance within rehabilitated vegetation communities as they did in vegetation present on site prior to mining	Proportion of the total basal area of woody vegetation at the site that comprises *Eucalyptus crebra*, *Eucalyptus populnea* or *Eucalyptus camaldulensis*.	Sites are to be monitored six and ten years after planting.	*Eucalyptus crebra* and/or *Eucalyptus populnea* are to constitute 21% of the total basal area of woody vegetation on sand plains. **AND** *Eucalyptus camaldulensis* is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7.	Relative dominance of Koala food trees is based on secondary site data gathered from nine sand plain reference sites and three riparian reference sites (METServe, 2022).
B8	Trees are to be sufficiently tall to be used by Koalas and to escape browsing by cattle (except RA1).	Mean height of the tallest ten trees per hectare	Sites are to be monitored six and ten years after planting.	The mean height of the tallest ten trees per hectare is ≥4 m.	The Queensland Environmental Offsets Policy defines non-juvenile Koala habitat trees to be those with a height greater than 4 m (DES 2020). Such trees are also beyond the reach of cattle.
B9	Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons	The mean Normalised Difference Vegetation Index (NDVI) calculated using Landsat imagery captured following at least two months without rain (e.g., late dry season)	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	Rehabilitated areas are to have a mean NDVI between 0.1240 and 0.1778	Ecological surveys of the local region found that Squatter Pigeons are confined to vegetation with a density that falls within the range of NDVI values used as the completion criterion (METServe, 2022).
B10	Availability of food for the Glossy Black-cockatoo is restored to pre-mining levels	Basal area of the food tree Casuarina cristata	Sites are to be monitored six and ten years after planting.	Rehabilitated areas where the ground is level and soil management unit "Orange" has been used as topsoil are to have a minimum basal area of 0.5 m^2/ha stems of Casuarina cristata per ha.	Casuarina cristata was mostly restricted to Orange soil units pre-mining. Where present, C. cristata had a basal area of 0.5 to 5.83 m^2/ha (based on three reference sites).
B11	Diversity of food for the Greater Glider is restored to pre-mining levels	Species richness of Eucalyptus and Corymbia species in a 10 m × 50 m plot.	Sites are to be monitored six and ten years after planting.	Rehabilitated areas on the Zambezi soil management unit are to contain Eucalyptus camaldulensis and at least one other species of Corymbia or Eucalyptus.	Three secondary sites sampled in riparian reference sites all contained E. camaldulensis and one other Eucalyptus or Corymbia sp.

2.5 SIBERIA MODEL PARAMETERS

Table 2.3 shows the SIBERIA model parameters that are used to define the landform evolution and mean annual erosion. The Beta1 parameter represents the different cover types, which was derived iteratively to match the predicted erosion rates given in the draft PRCP for each cover type. Table 2.4 shows adopted parameters for each cover management scenario.

Table 2.3 – SIBERIA model parameters

Parameter	Description
Beta1	*Coefficient b1 in the fluvial sediment transport formula*
Beta3	*Coefficient between discharge and area in the sediment transport formula*
m1	*Exponent on the discharge m1 in the sediment transport formula*
m3	*Exponent on the area in discharge used in the sediment transport*
n1	*Exponent on this slope n1 in the sediment transport formula*

Source: User Manual for SIBERIA (Version 8.30) (Wilgoose, G., 2005)

Table 2.4 – Adopted SIBERIA model parameters

Scenario (see Section 2)	Parameter				
	Beta1	Beta3	m1	m3	n1
1	*0.01780*	*1*	*1.5*	*1*	*2*
2	*0.00560*	*1*	*1.5*	*1*	*2*
3	*0.00164*	*1*	*1.5*	*1*	*2*
4	*0.00082*	*1*	*1.5*	*1*	*2*
5	*0.00030*	*1*	*1.5*	*1*	*2*

2.6 MODEL CALIBRATION

Table 2.5 compares the average erosion rates in tonnes per hectare per year predicted by the SIBERIA model and those given in the Draft PRCP and shown in Table 2.1 for the five proposed landform cover management scenarios. To be consistent with the values given in the Draft PRCP, the SIBERIA model results are provided for the average erosion rate for the 15% landform slope after 100 m of slope travel across 100 m. The average erosion rate was calculated using a cross sectional average of erosion depths across the landform embankment (at 100 m) over a 10-year simulation.

Overall, the adopted SIBERIA model parameters shown in Table 2.4 produces erosion rates similar to the values estimated in the Draft PRCP (using the RUSLE) for the five proposed landform surfaces. Note that the predicted erosion rates are based on theoretical assessments and are not derived from field observed erosion data, meaning they are only suitable for comparative purposes only. The erosion rates within the model were scaled to match theoretical calculations for predicted soil losses and therefore predictions produced by the model are somewhat predetermined.

The approach used for this assessment should be validated once the post-mining landform is established. This can be undertaken once data has been collected from the rehabilitated landform by comparing observed rill/deposition depths over cross-sectional areas of the landform to the calculated rates.

Table 2.5 – Representative slope calibration results

Scenario	Average erosion rate (t/ha.y)		Difference
	RUSLE[a]	Siberia Model	
1 – Bare earth (pre-vegetation)	306.40	306.95	0.2%
2 - 30% rock mulch (pre-vegetation)	99.58	98.70	-0.9%
3 - 30% rock mulch with 30% grass cover	30.64	30.74	0.3%
4 - 30% rock mulch with 50% grass cover	15.32	15.32	0.0%
5 - 30% rock mulch with 70% grass cover	5.52	5.58	1.1%

[a] Values adopted from the Draft PRCP

2.7 EROSION RISK ASSESSMENT CRITERIA

For this assessment, erosion depth has been used as the erosion risk assessment criteria as given in Table 2.6. Erosion risk assessment criteria was derived from the rehabilitation criteria (see Section 2.4) for the landforms and the milestones outlined in the Draft PRCP. It was deemed that erosion model outcomes which achieved a very low erosion risk would satisfy the rehabilitation criteria and the landform cover design could be considered stable.

Table 2.6 – Erosion risk assessment criteria

Erosion risk	Erosion depth (m)	Observations
Very Low	< 0.15	• Erosion depth only affecting uppermost topsoil layer. • Land is stable, only minor active rills or gully erosion no deeper than 0.15 m. • Negligible effects on receiving environment. • Vegetative cover established and effective.
Low	0.15 – 0.25	• Erosion depth affecting up to the topsoil layer. • Land is stable, only minor active rills or gully erosion no deeper than 0.25 m. • Minor risk of sedimentation to downstream waterways. • Reduced ability for topsoil layer to restore cover over time.
Moderate	0.25 – 0.55	• Erosion depth affecting topsoil layer and subsoil layers in some areas of the landform. • Increased sedimentation of downstream waterways. • Exposure of subsoil/waste rock material to runoff (however classified NAF and unlikely to generate saline runoff).
High	> 0.55	• Erosion depth greater than topsoil layer and rehabilitative cover has failed. • Great risk of sedimentation of downstream waterways. • Exposure of compacted waste rock material to runoff (however classified NAF and unlikely to generate saline runoff). • Rehabilitation works required to restore cover.

Note: Erosion risk criteria was derived based on rehabilitation objectives outlined in the Draft PRCP

3 Findings

3.1 REPRESENTATIVE SLOPE ASSESSMENT

Table 3.1 summarises the erosion risk assessment results for the full length of the representative batter slope for the five proposed cover management scenarios. Results are provided for the maximum erosion depths across the representative slope of 380 m. This is the longest slope length on any of the landforms proposed across the Vulcan North, Vulcan Main and Vulcan South proposed final landforms. To minimise error caused by boundary effects, the maximum erosion depth along the slope was assessed above the end of the batter slope and landform toe drain as the drainage configuration along the toe of the landforms are yet to be finalised and will likely include some form of works to prevent erosion.

Table 3.1 – Erosion risk assessment results

Scenario	Maximum erosion depth (m)	
	10-year model simulation	100-year model simulation
1 – Bare earth (pre-vegetation)	1.20	N/A
2 - 30% rock mulch (pre-vegetation)	0.60	2.50
3 - 30% rock mulch with 30% grass cover	0.35	1.10
4 - 30% rock mulch with 50% grass cover	0.20	0.80
5 - 30% rock mulch with 70% grass cover	0.10	0.50

N/A – Bare earth 100 year simulation could not be processed with SIBERIA as limits of erosion were too high

Figure 3.1 to Figure 3.5 show figures of the final landform along the representative batter slope for the five rehabilitation scenarios after 100 years. The following is of note:

- Scenario 1 – Bare earth (pre-vegetation) has a high erosion risk for both the 10-year and 100-year simulations. For the 100-year simulation (shown in Figure 3.1):
  - The embankment is predicted to fail completely after 35 years of simulation time. Within the 35 year simulation time, rilling and gully erosion exceeds high erosion risk criteria along the full length of the embankment. Erosion depth greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 20 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - Failure of rehabilitative cover and entire embankment slope and will require remediation works to re-establish cover;
  - Subsoil layer and compacted waste rock material layers would be exposed to environment; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 2 – 30% rock mulch (pre-vegetation) has a high erosion risk for both the 10-year and 100-year simulations. For the 100-year simulation (shown in Figure 3.2):
  - Rilling and gully erosion exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depths greater than topsoil/subsoil layers;

- Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 30 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
- Majority of the rehabilitative cover and embankment slope would fail and will require remediation works to re-establish cover;
- Subsoil layer and compacted waste rock material layers exposed to environment; and
- Great risk of sediment loads transported to downstream receiving waters.

- Scenario 3 – 30% rock mulch and 30% grass cover has a moderate erosion risk for the 10-year and high erosion risk for the 100-year simulations. For the 100-year simulation (shown in Figure 3.3):
  - Rilling and gullying exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depths greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 40 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - Embankment fails the design criteria less than 100 m down the face of the slope;
  - Subsoil/waste rock material layer exposed to environment; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 4 – 30% rock mulch and 50% grass cover has a low erosion risk for the 10-year and high erosion risk for the 100-year simulations (shown in Figure 3.4):
  - Rilling and gullying exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depth greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 60 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - The upper slopes are relatively stable but rills exceed rehabilitation criteria depths along the lower slope for the 100-year simulations;
  - Some of the embankment may require remediation to ensure cover remains suitable; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 5 - 30% rock mulch and 70% grass cover has a very low erosion risk for the 10-year and moderate erosion risk for the 100-year simulations. For the 100-year simulation (shown in Figure 3.5):
  - Rilling/gullying exceeds the moderate erosion risk criteria along the majority of the length of the embankment slope. Erosion depth affecting topsoil layer and subsoil layers in some areas of the landform;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) are recommended to reduce slope lengths to a maximum spacing of 100 m intervals as per the soils report (AARC, 2022) to mitigate erosion risk via rilling and gully erosion;
  - The upper slopes are suitably stable, vegetative cover is established and effective; and
  - Increased risk of sediment loads transported to downstream receiving waters.

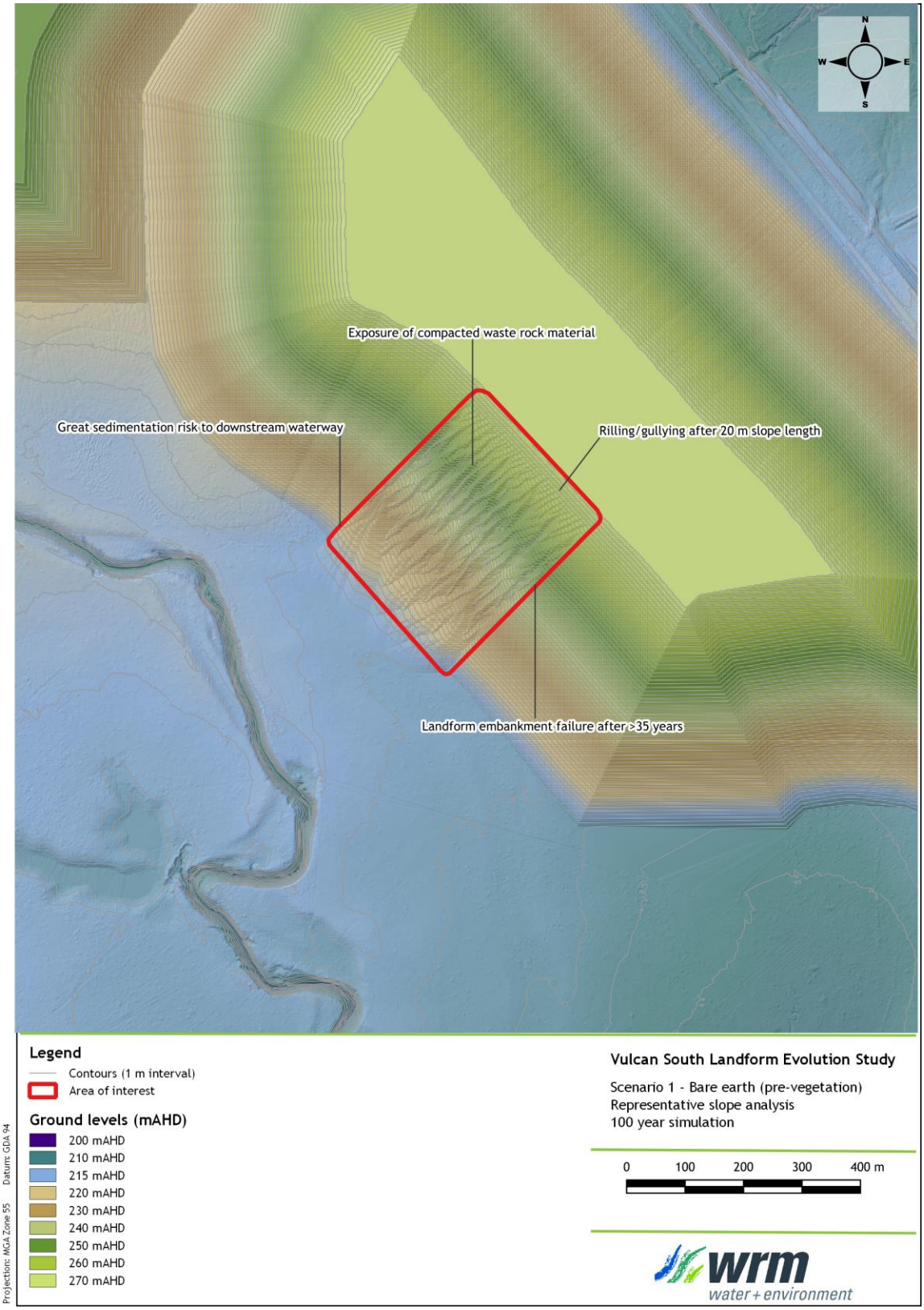

Figure 3.1 – Predicted rill/gully erosion for Scenario 1 – Bare earth (pre-vegetation) for the representative batter slope, 100 year simulation

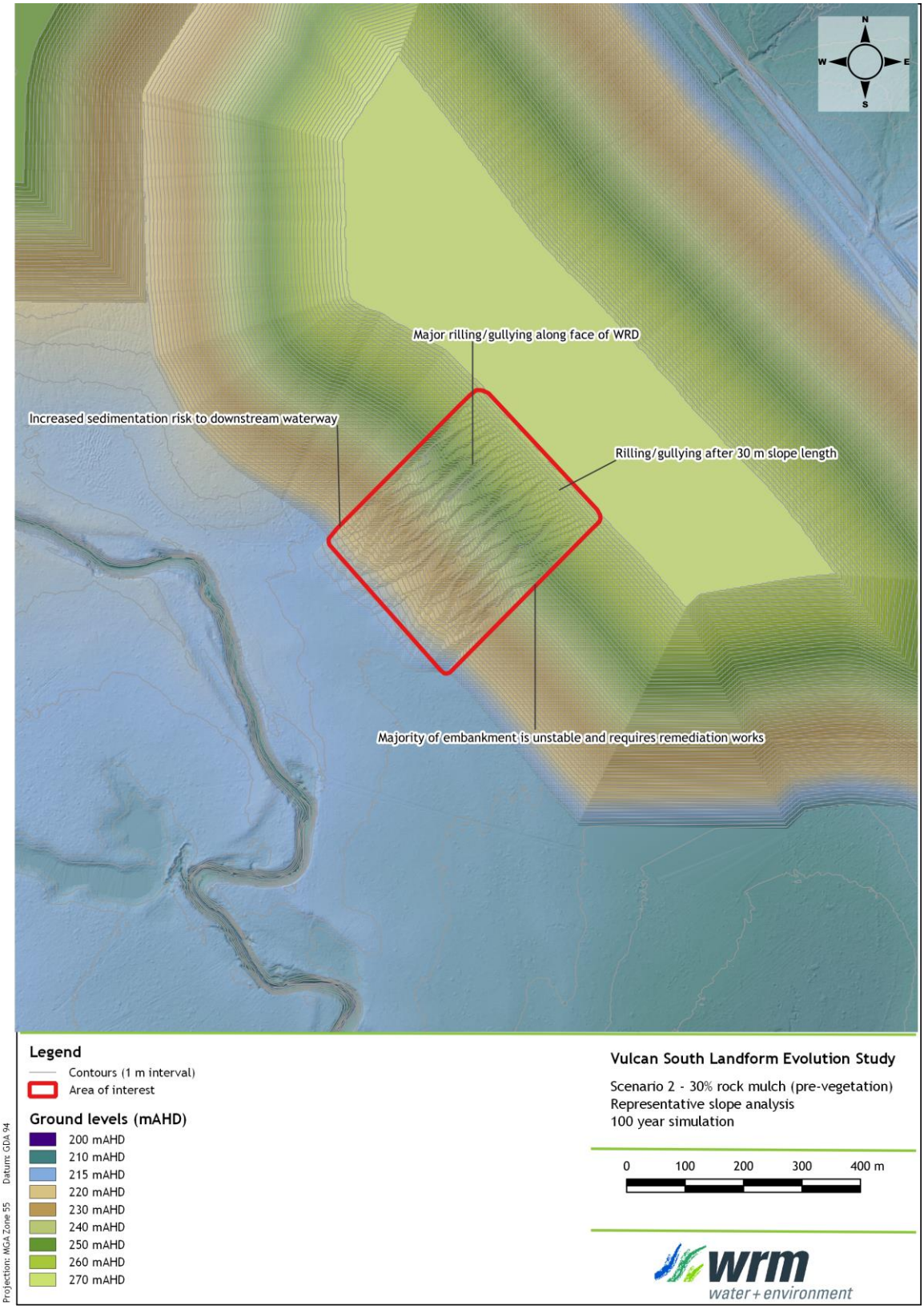

Figure 3.2 – Predicted rill/gully erosion for Scenario 2 – 30% rock mulch (pre-vegetation) for the representative batter slope, 100 year simulation

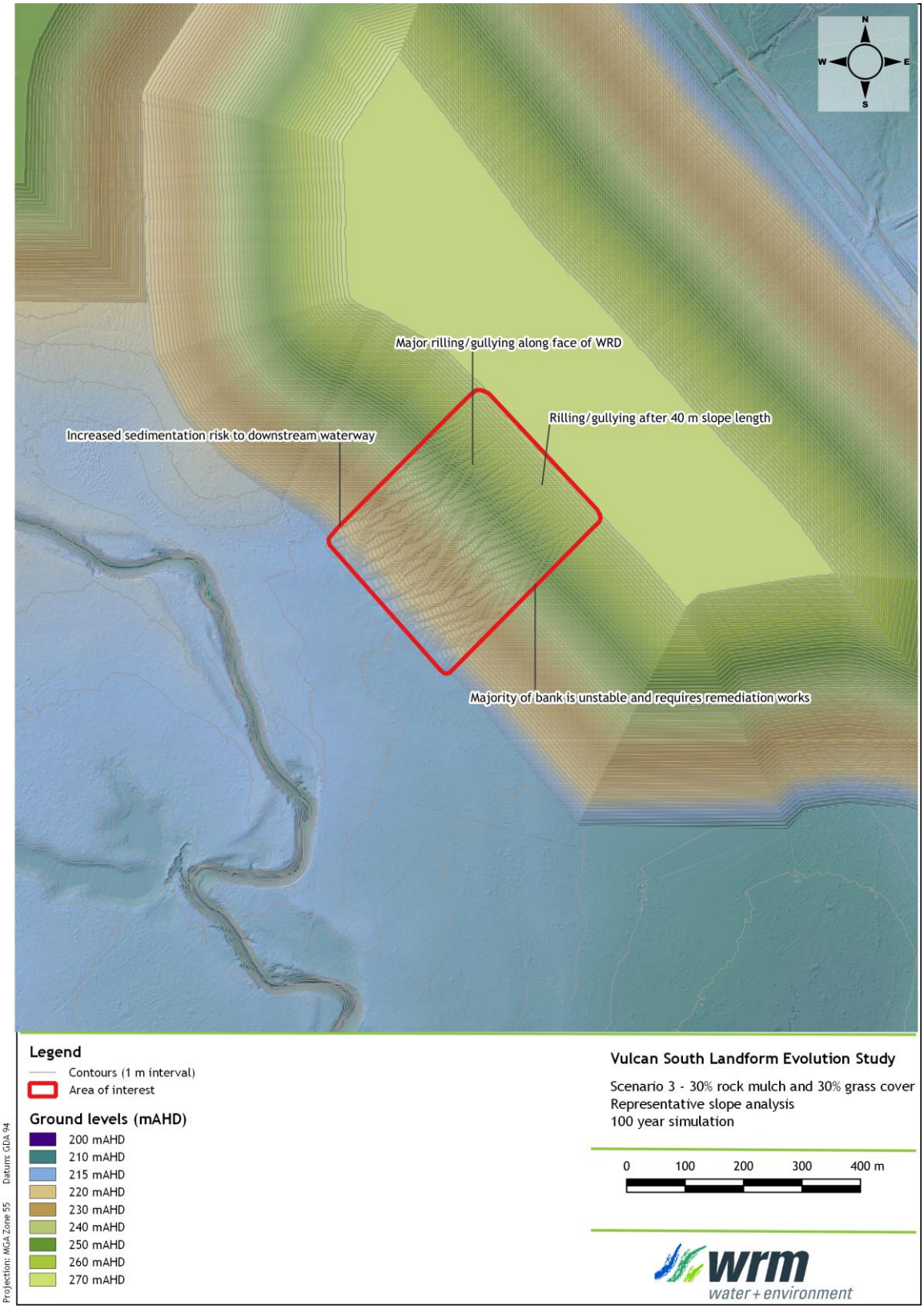

Figure 3.3 – Predicted rill/gully erosion for Scenario 3 – 30% rock mulch and 30% grass cover for the representative batter slope, 100 year simulation

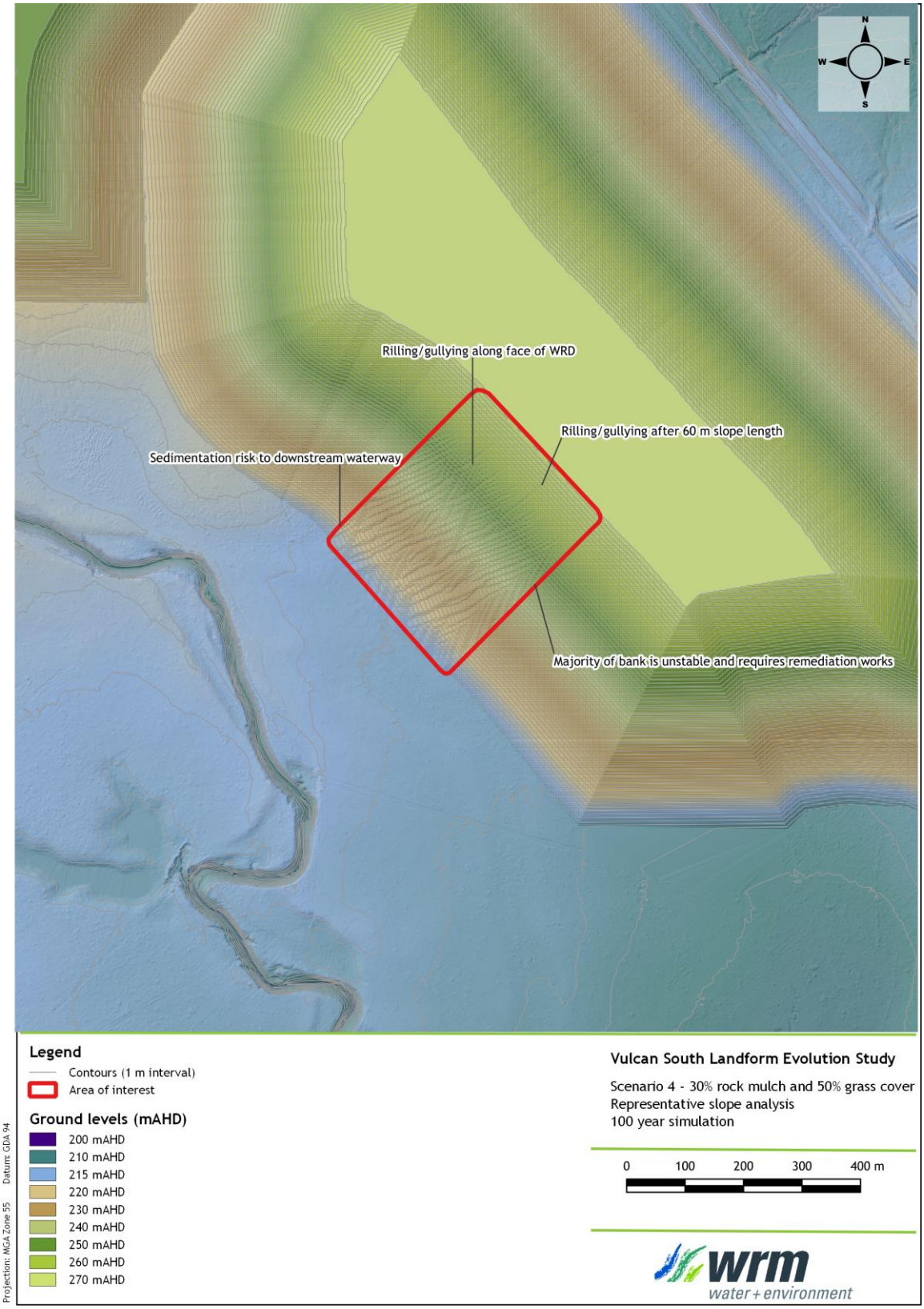

Figure 3.4 – Predicted rill/gully erosion for Scenario 4 – 30% rock mulch and 50% grass cover for the representative batter slope, 100 year simulation

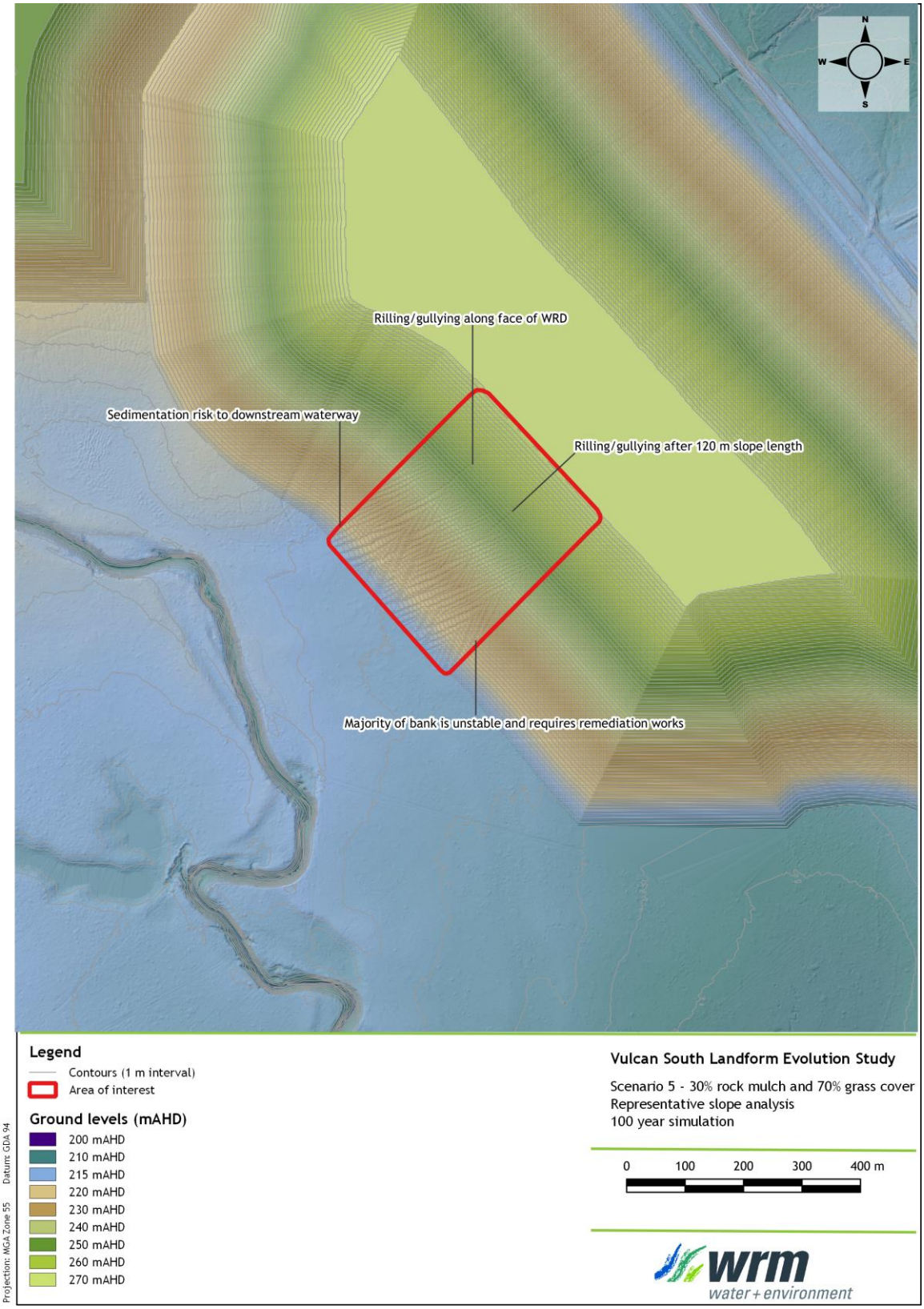

Figure 3.5 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for representative slope, 100 year simulation

3.2 APPLICATION TO PROPOSED LANDFORMS

3.2.1 General

The representative slope assessment shows that slope lengths up to 380 m with fully established Scenario 5 vegetative cover achieves a 'moderate' erosion risk. However, the results show that slope lengths up to 120 m with fully established Scenario 5 vegetative cover would achieve a 'very low' erosion risk. With drainage control structures implemented during detailed design of the six landforms as recommended in the soils report (AARC, 2022) at a maximum spacing of 100 m, the six landforms should be considered as suitably stable against long-term erosion. On this basis, all batter slopes on the site would achieve a 'very low' erosion risk criteria with drainage control structures implemented because they have the same slope and cover design.

The adopted model parameters used for the representative slope assessment were used to highlight the potential erosion risk locations (areas of concern) for the full concept landform designs for the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms. The model was run for the 100 year timeframe assuming Scenario 5 (30% rock mulch with 70% grass cover) rehabilitative cover management for the assessment. General observations of the stability/erosion risk assessment are:

- Concave (valley) sections of the proposed concept landform designs are subject to higher erosion risk as runoff naturally converges to these points along the landforms. With the implementation of rock chutes during detailed design of the landforms, erosion risks would decrease;
- Coarse sediment is predicted to accumulate along the toe drains of the proposed in-pit and ex-pit WRDs to reduce the downstream impacts;
- The upper slopes of the landforms would generally be considered stable in the long-term and have low risk of rilling and gully erosion; and
- Slope lengths of 100 m or less under Scenario 5 vegetative cover achieves a 'very low' erosion risk rating indicating that detailed design of the proposed WRD landforms implementing drainage control structures would be suitably stable in the long-term.

3.2.2 Vulcan North waste rock dumps

Figure 3.6 shows the predicted areas of concern for the concept Vulcan North in-pit and ex-pit WRD designs under the Scenario 5 vegetative cover. The maximum slope length for the Vulcan North in-pit and ex-pit WRDs is approximately 105 m and 250 m, respectively. The following is of note regarding the stability/erosion risk assessment:

- The Vulcan North in-pit WRD is predicted to have significantly less rilling and gully erosion across the landform because the maximum slope length of the landform is shorter than the representative batter slope length of 380 m. The majority of the landform would be considered stable in the long-term and have low risk of rilling / gully erosion.
- The Vulcan North ex-pit WRD is also predicted to have less rilling and gully erosion because the slope length is marginally shorter than the representative slope length of 380 m. Drainage control structures will be required to reduce erosion risks.

3.2.3 Vulcan Main waste rock dumps

Figure 3.7 shows the predicted areas of concern for the concept Vulcan Main in-pit and ex-pit WRD designs. The maximum slope length for the Vulcan Main in-pit and ex-pit WRDs is approximately 380 m and 220 m, respectively. The following is of note regarding the stability/erosion risk assessment:

- The southwest and northeast face of the Vulcan Main in-pit WRD both have maximum slope lengths of 380 m. The results show that these sections of the WRD are prone to the highest risk of rilling / gully erosion without drainage controls. Erosion risks at the benched areas

(northern and southern sections) of the Vulcan Main in-pit WRD are significantly lower as slope lengths are shorter than the representative slope length at the benched areas.

- The Vulcan Main ex-pit WRD is predicted to have less rilling and gully erosion because the slope length is marginally shorter than the representative slope length of 380 m. Drainage control structures will be required reduce erosion risks.

3.2.4 Vulcan South waste rock dumps

Figure 3.8 shows the predicted areas of concern for the concept Vulcan South in-pit and ex-pit WRD designs. The maximum slope length for the Vulcan South in-pit and ex-pit WRDs is approximately 205 m and 210 m, respectively. The Vulcan South in-pit and ex-pit WRD are predicted to have less rilling and gully erosion because the slope lengths are shorter than the representative slope length of 380 m. Drainage control structures will be required reduce erosion risks.

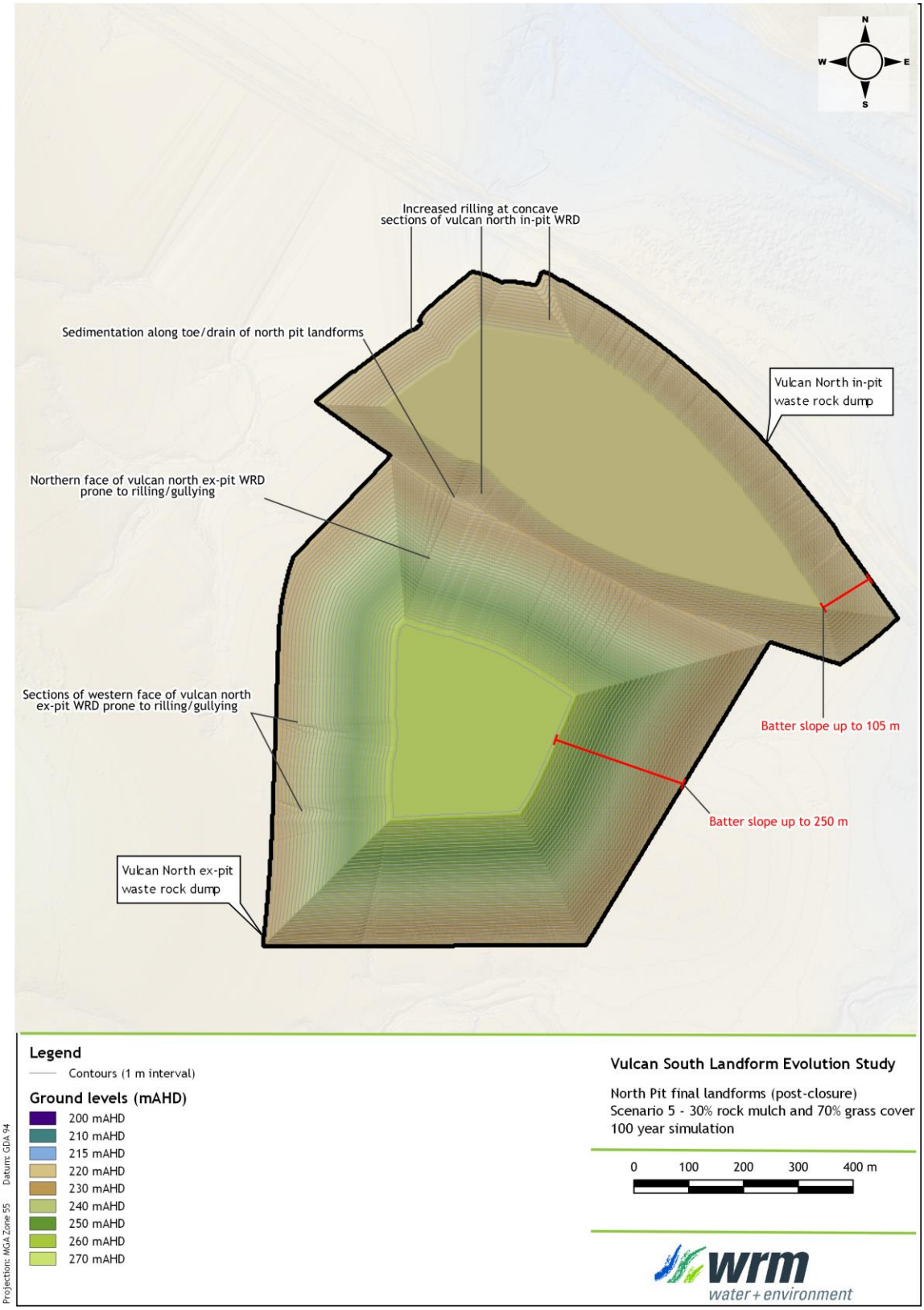

Figure 3.6 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan North Pit waste rock dumps, 100 year simulation

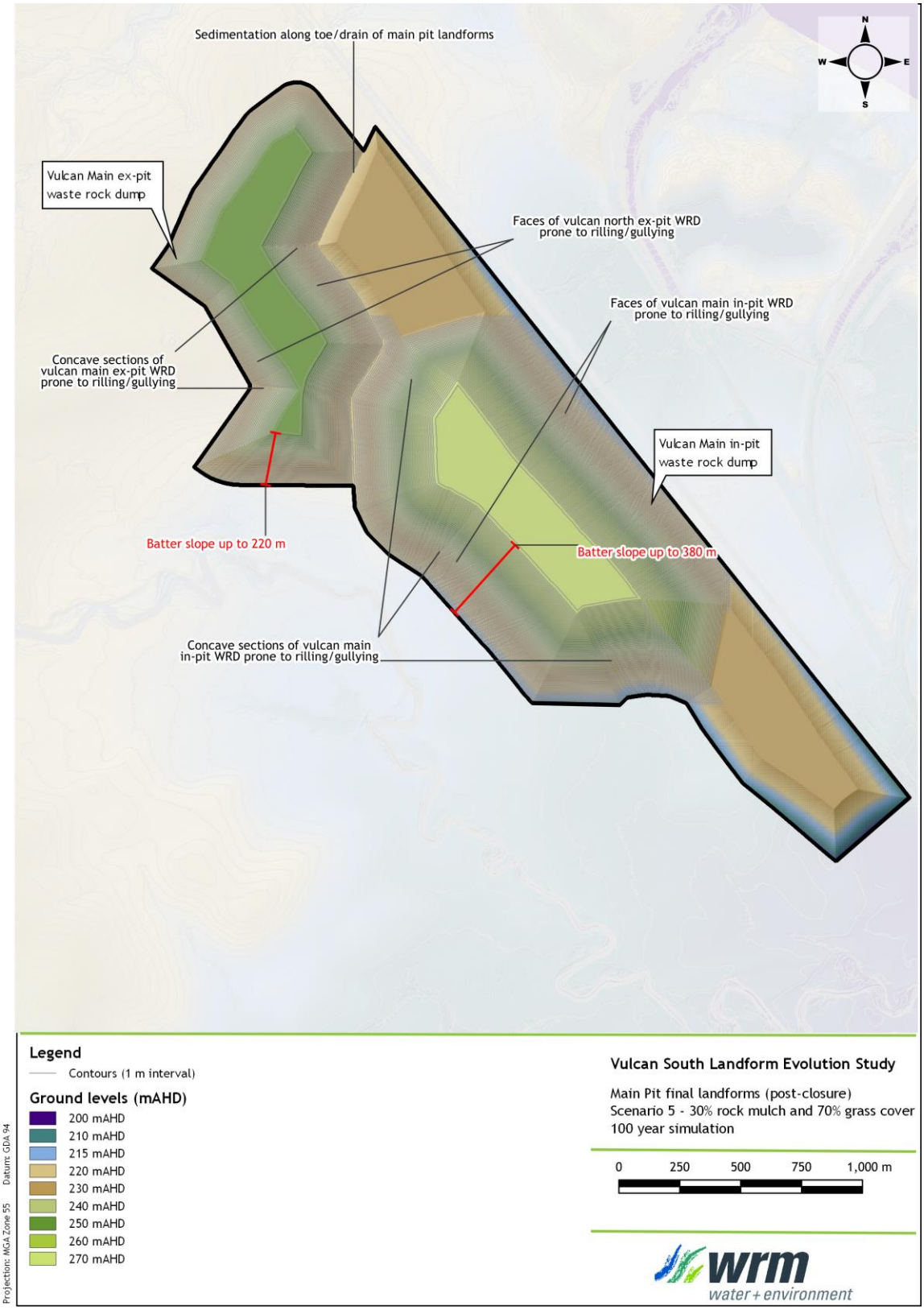

Figure 3.7 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan Main pit waste rock dumps, 100 year simulation

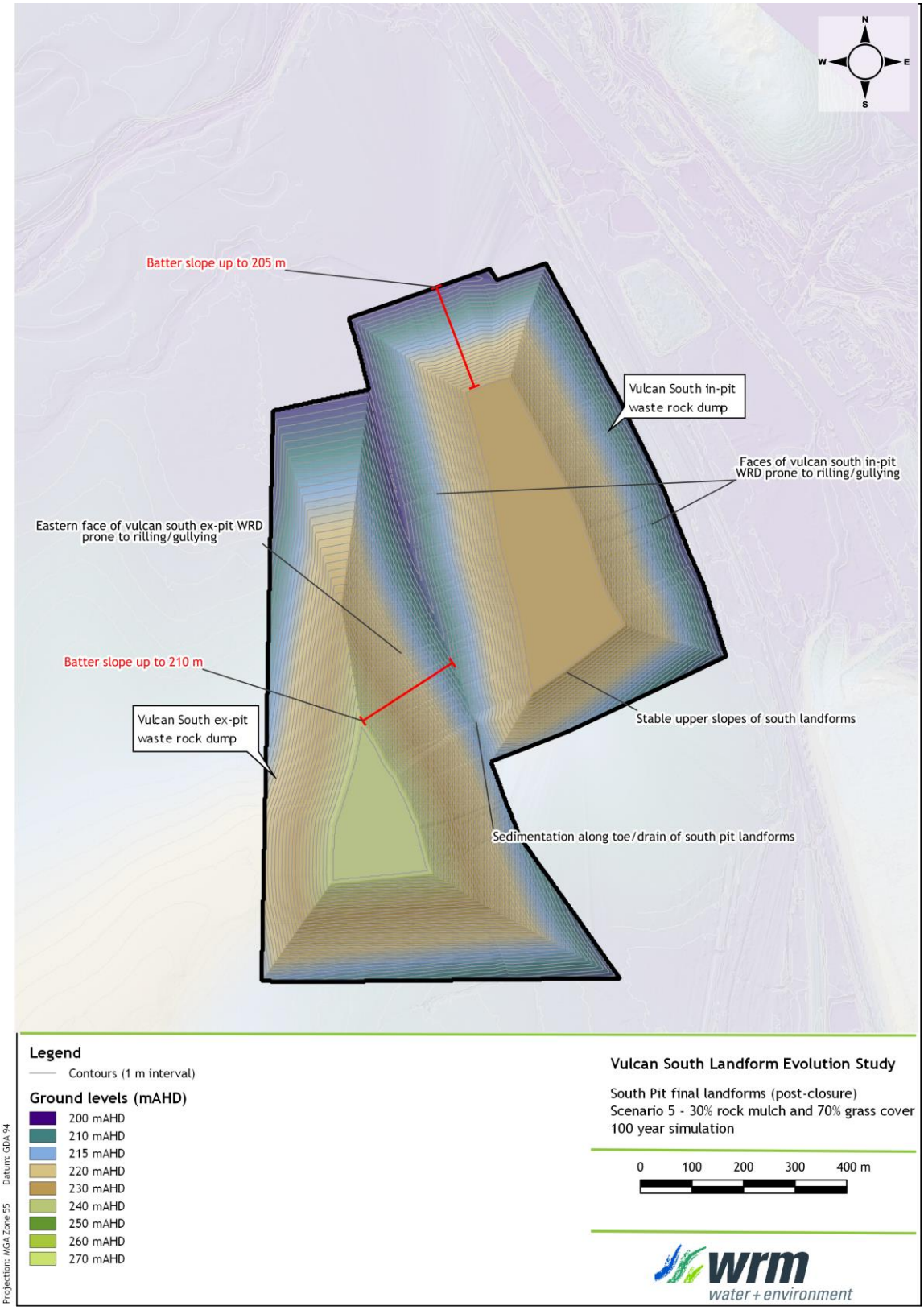

Figure 3.8 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan South pit waste rock dumps, 100 year simulation

4 Summary and recommendations

4.1 LANDFORM ASSESSMENT

Table 4.1 summarises the erosion risk for the modelled scenarios against the erosion risk criteria. The LEM results show that the erosion of the landforms under Scenario 5 achieves a 'very low' erosion risk rating in the first 10 year vegetation establishment period. Over a 100 year timeframe, the erosion risk prior to the implementation of drainage control structures has a 'moderate' erosion risk rating. Under Scenario 5 with the implementation of drainage control structures at a maximum spacing of 100 m intervals, the LEM results show that a 'very low' erosion risk rating is achieved over the 100 year timeframe. The erosion objectives achieved include:

- Erosion depth only affecting uppermost topsoil layer;
- Land is stable, only minor active rills or gully erosion no deeper than 0.15 m;
- Negligible sedimentation effects on downstream waterways; and
- Vegetative cover is considered widely established and effective however may have reduced ability to recover in some areas.

The Scenario 5 vegetation cover would achieve the rehabilitation criteria objective for the Project with drainage control structures in place, as outlined in the Draft PRCP. Once the Scenario 5 rehabilitation cover management has been established across RA1 and RA2, rilling and gully erosion risk decreases. If the detailed design of the proposed landforms includes contour banks to reduce slope lengths along the WRDs, it is likely that erosion risk ratings would be reduced even further.

Table 4.1 – Summary of erosion risk

Scenario	10-year model simulation	100-year model simulation
1 – Bare earth (pre-vegetation)	High	High
2 - 30% rock mulch (pre-vegetation)	High	High
3 - 30% rock mulch with 30% grass cover	Moderate	High
4 - 30% rock mulch with 50% grass cover	Low	High
5 - 30% rock mulch with 70% grass cover	Very Low	Moderate

During the vegetation establishment 10-year timeframe, the cover management scenario likely to be in place is Scenario 2 which includes the rock mulch (30% cover) and limited vegetation, however, it is of note that some vegetation is likely to have established after a one-to-two-year period, as such the erosion risk rating results are conservative. Scenario 2 achieves a 'high' erosion risk rating over the 10-year timeframe, characterised as follows:

- Erosion depth affecting topsoil layer and subsoil layers of the landform;
- Great risk of sedimentation of downstream waterways; and
- Exposure of subsoil/waste rock material to runoff (however classified NAF and unlikely to generate saline runoff).
- The model results show that during the 10-year vegetation establishment period, contour banks would be required to reduce slope lengths and erosion rates.

Overall, the SIBERIA erosion modelling indicates that the rehabilitation areas RA1 and RA2

(Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms) would achieve the long-term rehabilitation criteria objectives outlined in the Draft PRCP once the Scenario 5 vegetative cover is established and drainage control structures are implemented to reduce slope lengths. The likelihood that the underlying waste rock material will be exposed is low.

4.2 RECOMMENDATIONS

It is recommended that the proposed rehabilitation areas (RA1 and RA2) are monitored up until the Scenario 5 rehabilitation cover management scenario has been fully established, and any rilling or gully erosion up until the target vegetative cover is established is remediated to the proposed landform designs for the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRDs.

If it is found that Scenario 5 vegetative cover is difficult to achieve or the slope lengths between drainage control structures exceed 100 m, it is likely that erosion risk would be greater for the proposed concept WRD designs.

4.3 LIMITATIONS

The erosion results are representative of the nominated 10-year and 100-year post mining timeframes. The modelling does not evaluate timeframes longer than 100-years. The LEM assessment erosion rates would continue and erosion rill depths will increase when longer timeframes are considered as the erosion modelling does not consider vegetative growth or soil replenishment over the model simulation period.

Although the soil report and geotechnical report provide information on soil characteristics and slope stability, once detailed design of the landforms are available, field observations should be undertaken to monitor and gather site specific erosion data with proposed landform cover in place to compare against the predicted erosion rates, which are based on theoretical assessments and only suitable for comparative purposes only. The erosion rates within the model were scaled to match theoretical calculations for predicted soil losses and therefore predictions produced by the model are somewhat predetermined. The potential effects of climate change have also not been considered.

5 References

AARC, 2022	*'Vulcan South Soil and Land Suitability Assessment'* Version 4.1, prepared for METServe by AARC Environmental Solutions Pty Ltd, March 2022.
Blackrock, 2020	*'Vulcan Complex – Jupiter Final Landform Slope Stability Assessment'*, prepared for Vitrinite Pty Ltd by Blackrock Mining Solutions Pty Ltd, March 2020.
DES, 2021	*'Guideline – Progressive rehabilitation and closure plans (PRC plans)'*, Department of Environment and Science, Queensland Government, March 2021.
METServe, 2022	*'Progressive Rehabilitation and Closure Plan – Vulcan South'*, Draft PRCP prepared for Vitrinite Pty Ltd by METServe, 2022.
RGS, 2022	*'01_2022014_Geochemical Assessment of Waste Rock, Coal Reject and Coal_Rev 01'*, prepared for METServe by RGS Environmental Consultants Pty Ltd, March 2022.
Tongway and Hindley, 2004	*'Landscape Function Analysis: Procedures for monitoring and assessing landscapes – with special reference to minesites and rangelands'*, Tongway, D.J. and N.L. Hindley, CSIRO Sustainable Ecosystems, Canberra, 2004.
Willgoose, 2005	*'User Manual for SIBERIA (Version 8.30)'*, Professor Gary Willgoose, Telluric Research, July 2005.

Appendix G –Geotechnical Assessment Memorandum

MEMORANDUM

To:	Mining & Energy Technical Services Pty Ltd
Attention:	Damien Plucknett
Prepared By:	Ty Grantham
Reviewed By:	Tom Sullivan
Date:	16th March 2022
Memo Ref:	BMS-P22010C-VIT-VUL-M-1-V0.2
Subject:	Vulcan South Project – Final Landform Geotechnical Assessment **DRAFT**

1 INTRODUCTION

This memorandum presents the results of a geotechnical assessment for the Vulcan South Project (VSP) final landforms, i.e., rehabilitated in-pit and ex-pit spoil dumps. Two-dimensional (2D) limit equilibrium analyses were performed to determine the overall slope stability in terms of a Factor of Safety (FoS) as part of mine closure requirements.

The assessment was carried out by Blackrock Mining Solutions Pty Ltd (Blackrock) at the request of Mining and Energy Technical Services Pty Ltd (MET Serve) as part of their Progressive Rehabilitation and Closure Plan (PRCP).

2 SLOPE STABILITY ANALYSIS

2.1 Material Properties and Assumptions

The current assessment is based on the Mohr-Coulomb shear strength parameters and material types specified in Blackrock's Vulcan Complex Geotechnical Assessment Report (BMS Report No. BMS-VIT-VUL-201910-01-V4.0), as summarised in Table 2-1.

As indicated by Mining & Energy Technical Services Pty Ltd (MET Serve), dry tailings would be co-disposed with the spoil. Therefore, a reduction of the spoil shear strength parameters from Category 2.5 to Category 2 (Simmons & McManus, 2004) was applied to the analyses. A basal saturated spoil layer of approximately 5 m thickness was assumed for the ex-pit spoil dumps.

Table 2-1: Mohr-Coulomb Shear Strength Parameters

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface	Hu Type
Tertiary and Weathered Permian		23	Mohr-Coulomb	50	30	Water Surface	Automatically Calculated
Fresh Permian		24	Mohr-Coulomb	450	42	Water Surface	Automatically Calculated
Cat 2.0 (U)		18	Mohr-Coulomb	30	28	Water Surface	Automatically Calculated
Cat 2.0 (S)		20	Mohr-Coulomb	15	23	Water Surface	Automatically Calculated

2.2 Design Geometry

Final landform designs were provided to Blackrock by METServe on 23 February 2022. Rehabilitated dump slopes were designed to approximately 9° (1V:6H) in accordance with Queensland Government's regulations, as shown in Figure 2-1 to Figure 2-3.

In-pit spoil dumps would be backfilled to natural ground level and then surcharged with additional spoil to final landform specifications.

Figure 2-4 and Figure 2-5 shows the sectional geometries of the in-pit and ex-pit spoil dumps.

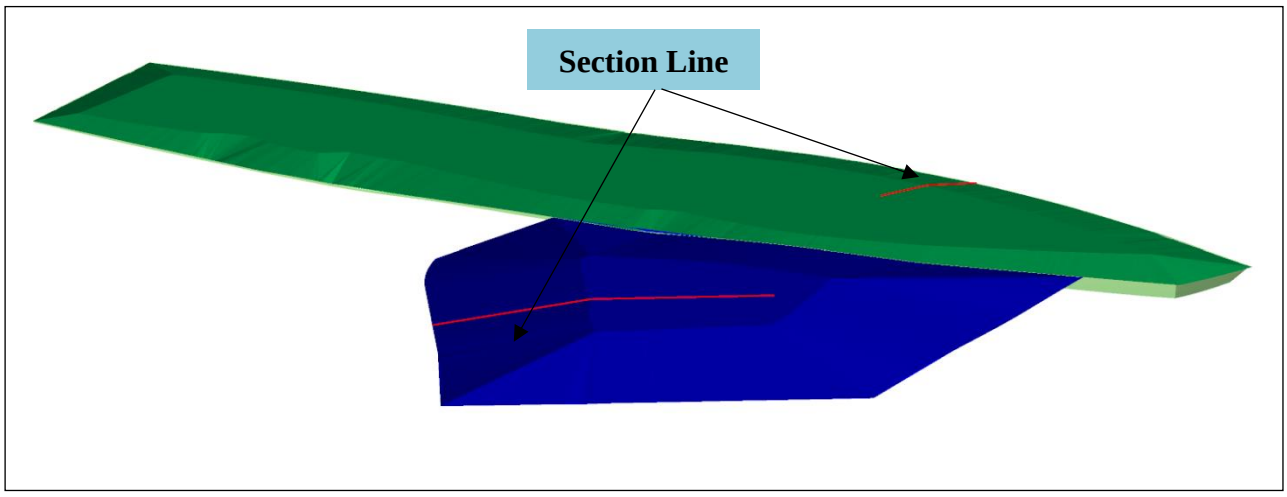

Figure 2-1: Vulcan North Pit Final Landform Design – North Facing View Showing In-Pit Dump (Green) and Ex-Pit Dump (Blue) Footprints

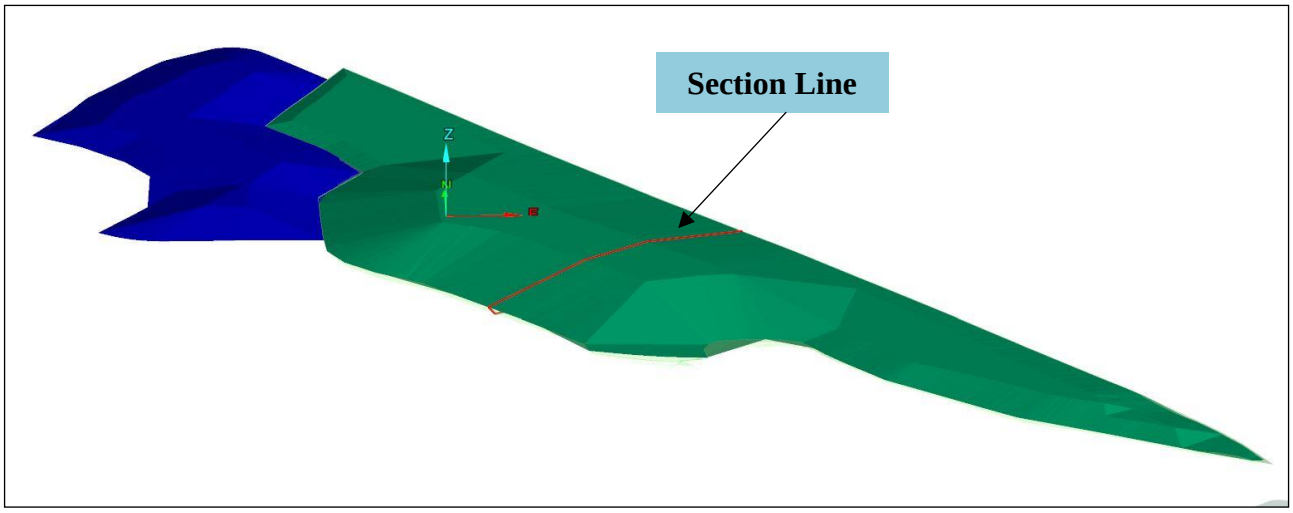

Figure 2-2: Vulcan Main Pit Final Landform Design – North Facing View Showing In-Pit Dump (Green) and Ex-Pit Dump (Blue) Footprints

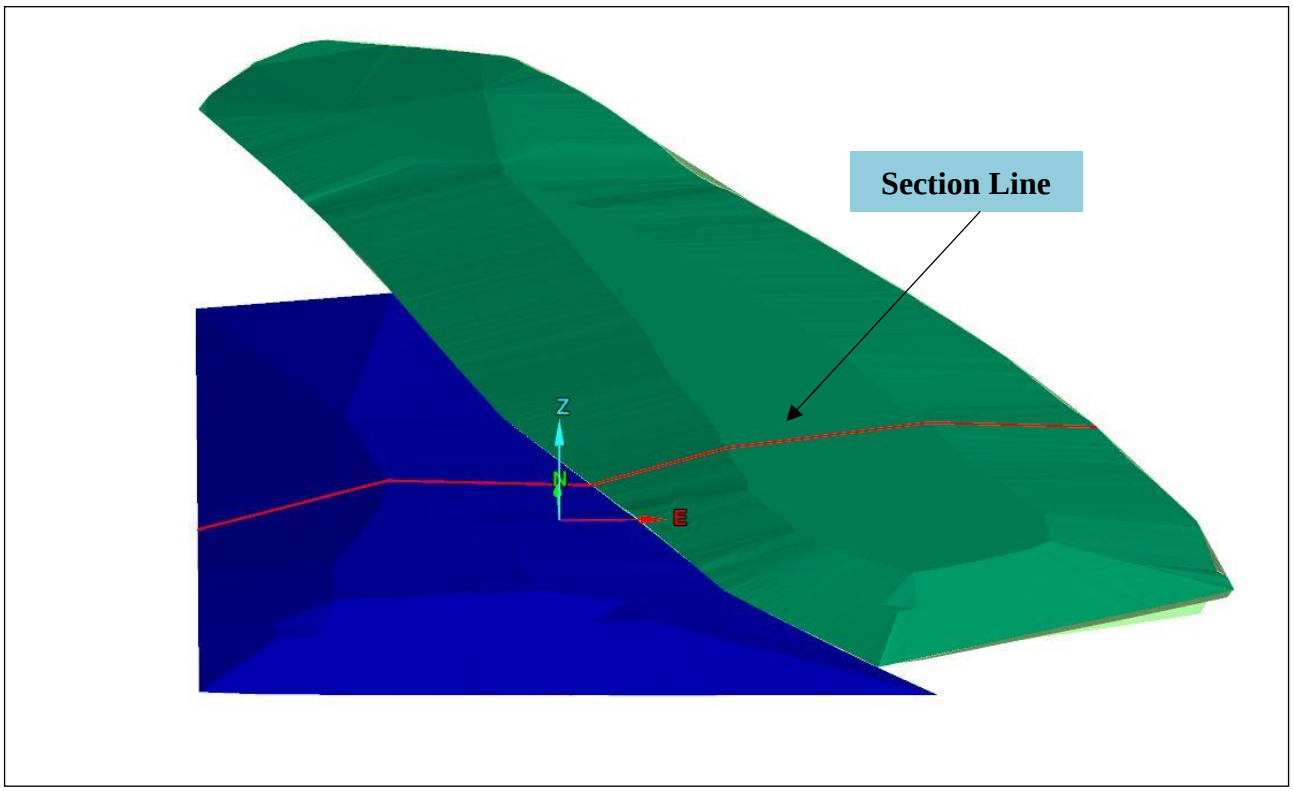

Figure 2-3: Vulcan South Pit Final Landform Design – North Facing View Showing In-Pit Dump (Green) and Ex-Pit Dump (Blue) Footprints

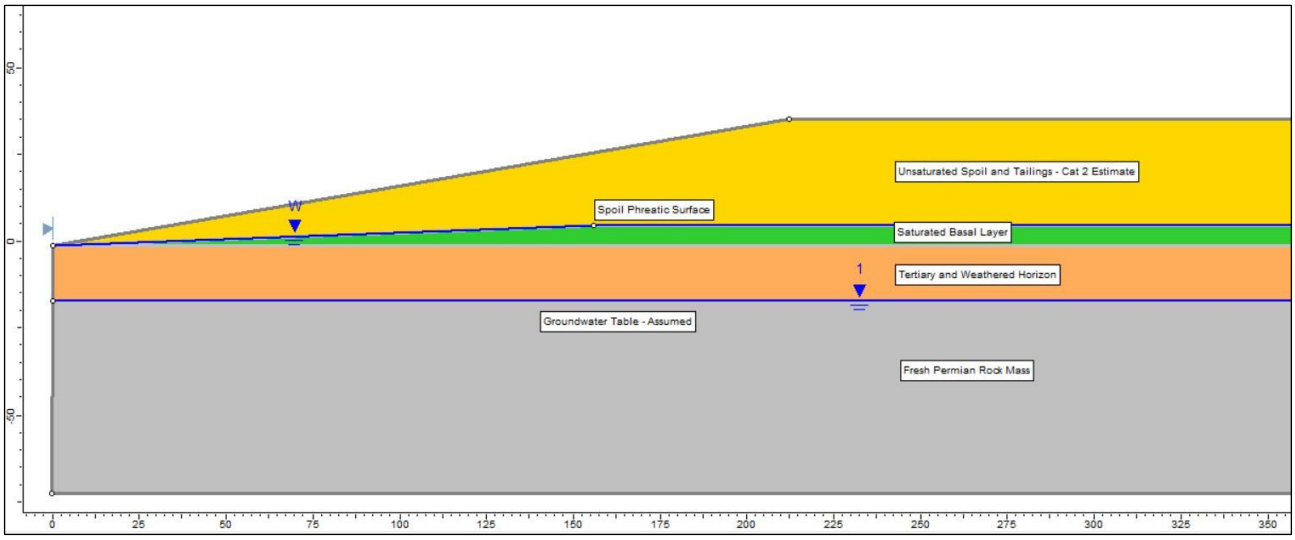

Figure 2-4: Ex-Pit Spoil Dump Geometry

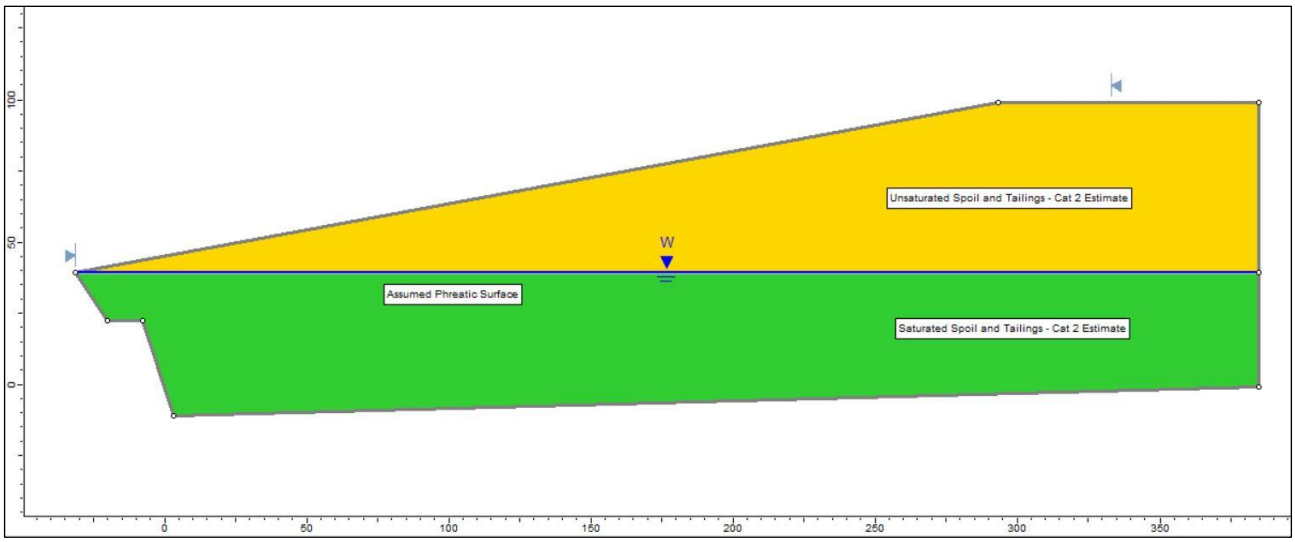

Figure 2-5: In-Pit Spoil Dump Geometry

2.3 Limit Equilibrium Analysis & Results

Two-dimensional limit equilibrium analyses were assessed in terms of a circular failure mechanism acting through the unsaturated and saturated Category 2 spoil material for the in-pit and ex-pit spoil dumps, respectively.

The Category 2 material parameters are derived from the coal spoil shear strength framework developed by Simmons & McManus (2004). In this case, the estimated spoil category used for the analysis was Category 2, which generally comprises fine-grained, low plasticity spoil with larger clasts.

Analyses were made for representative cross-sections of the final landform (i.e., in-pit and ex-pit spoil dumps), as shown in Figure 2-1 to Figure 2-3(Section 2.2). Analyses were carried out using industry-standard 2D limit equilibrium methods in Slide2 (V9.020) developed by Rocscience.

The accepted Factor of Safety (FoS) criterion for final landform slopes is ≥1.5. The FoS is a measure of driving forces versus resisting forces in a system, where a FoS of 1 equates to a 50% probability that failure will occur. FoS values >1 generally indicate that a system is likely to be geotechnically stable.

The analyses indicated critical FoS values between 2.56 and 4.03 for the in-pit and ex-pit dumps, respectively, using the General Limit Equilibrium/Morgenstern-Price (GLE/M-P) method. These results are considered satisfactory in terms of meeting final landform design acceptance and long-term geotechnical stability criteria.

The results of the limit equilibrium analyses are summarised in Table 2-2, and presented in Figure 2-6 to Figure 2-11, for in-pit and ex-pit dump final landforms from Vulcan North Pit to Vulcan South Pit.

Table 2-2: VSP Final Landform Slope Stability Analysis Results

Final Landform	Failure Surface	Search Method	FoS
Vulcan North - Ex-Pit Dump	Circular	Auto-Refine	**3.48**
Vulcan North - In-Pit Dump			**3.01**
Vulcan Main - In-Pit Dump			**2.56**
Vulcan Main - Ex-Pit Dump			**3.99**
Vulcan South - In-Pit Dump			**3.14**
Vulcan South - Ex-Pit Dump			**4.03**

GLE/M-P FoS reported

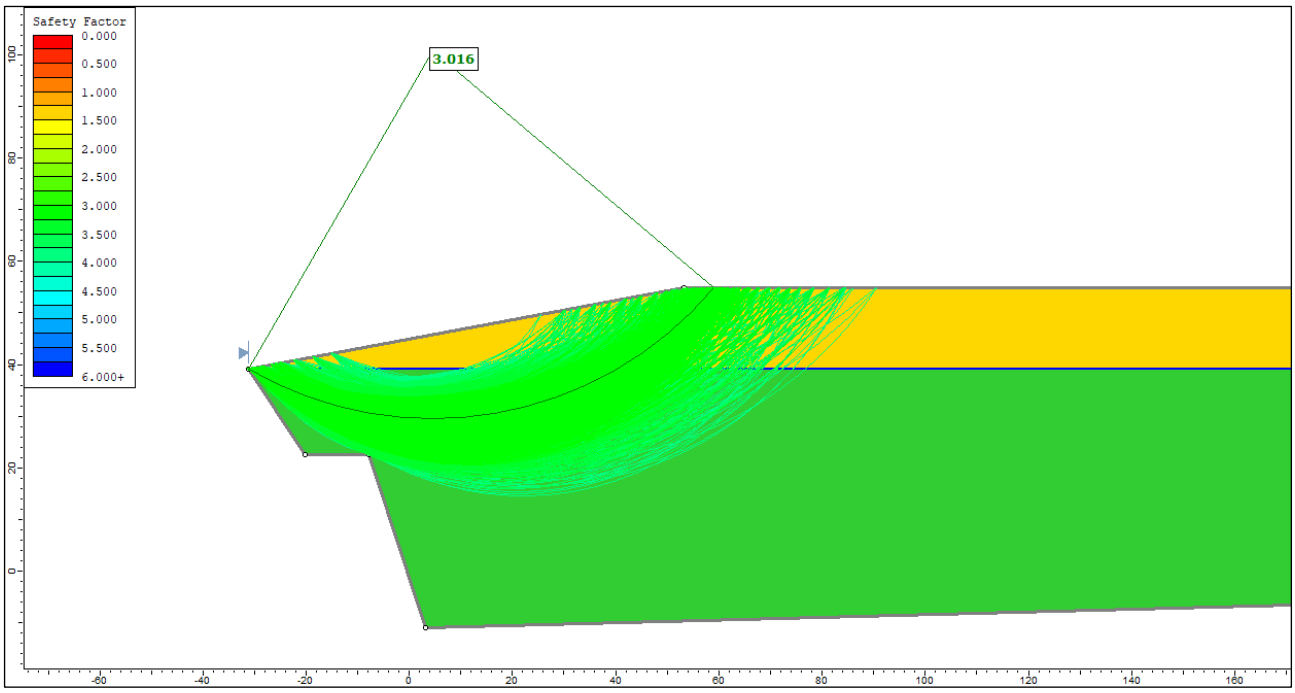

Figure 2-6: Vulcan North Pit – In-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 3.01 (GLE/M-P)

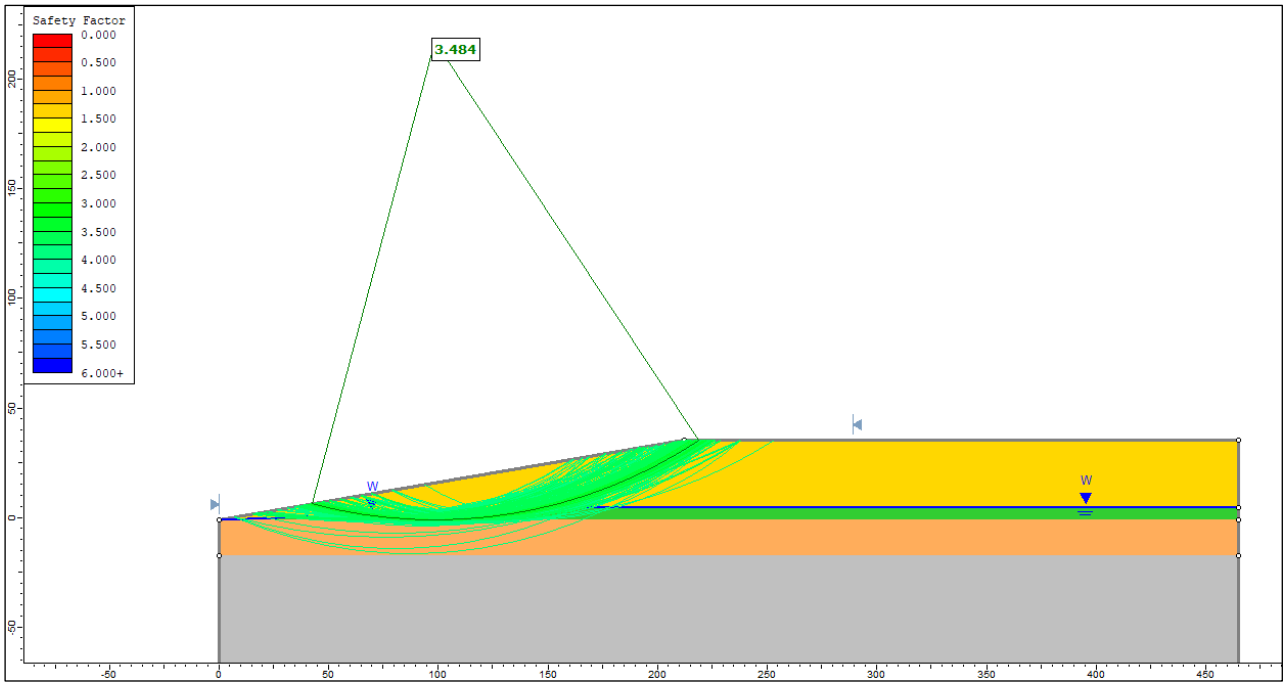

Figure 2-7: Vulcan North Pit – Ex-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 3.48 (GLE/M-P)

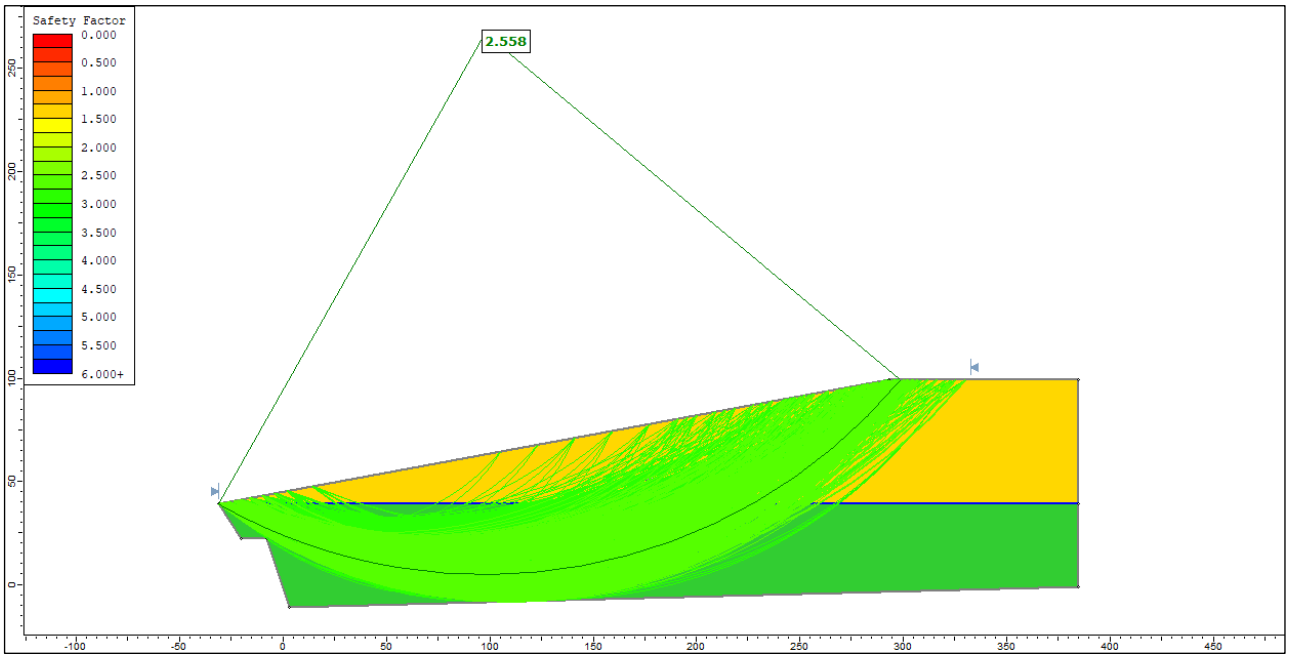

Figure 2-8: Vulcan Main Pit – In-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 2.56 (GLE/M-P)

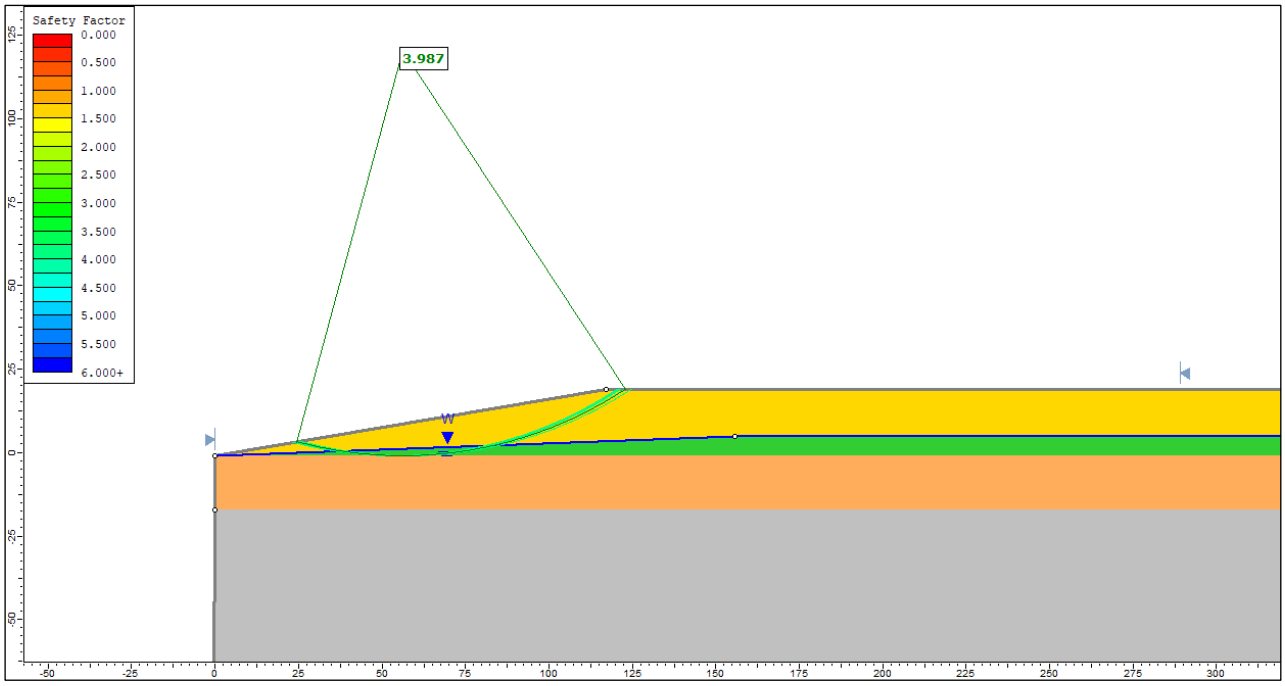

Figure 2-9: Vulcan Main Pit – In-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 3.99 (GLE/M-P)

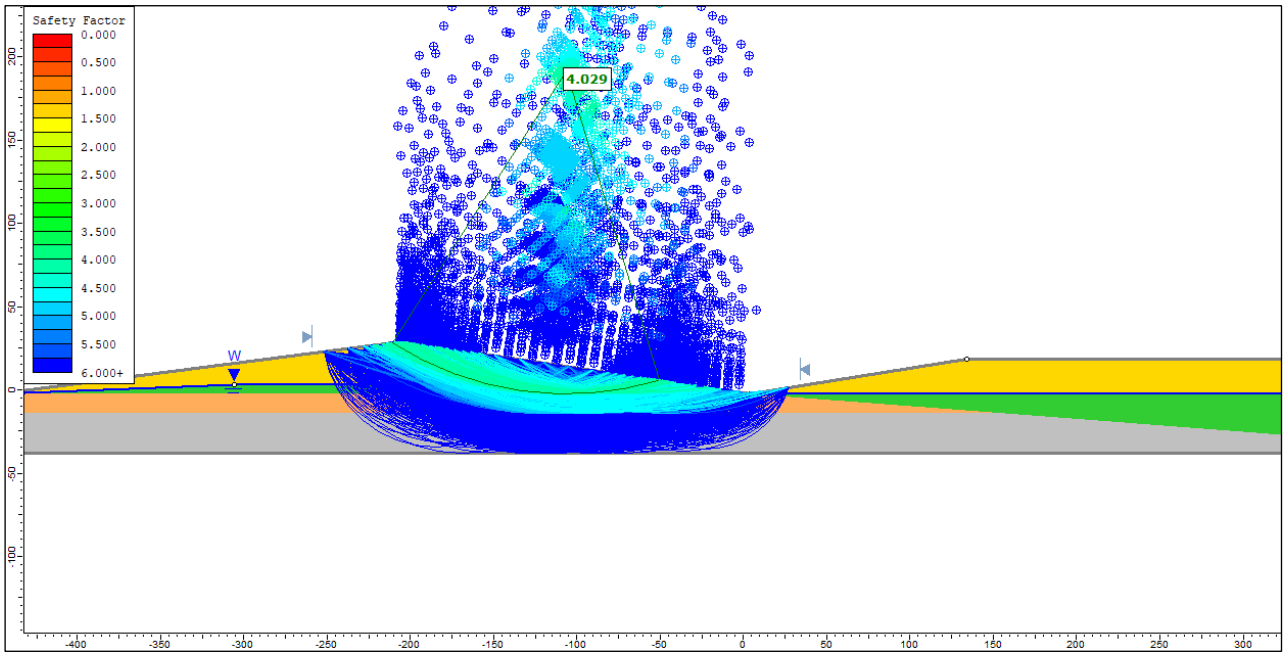

Figure 2-10: Vulcan South Pit – Ex-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 4.03 (GLE/M-P)

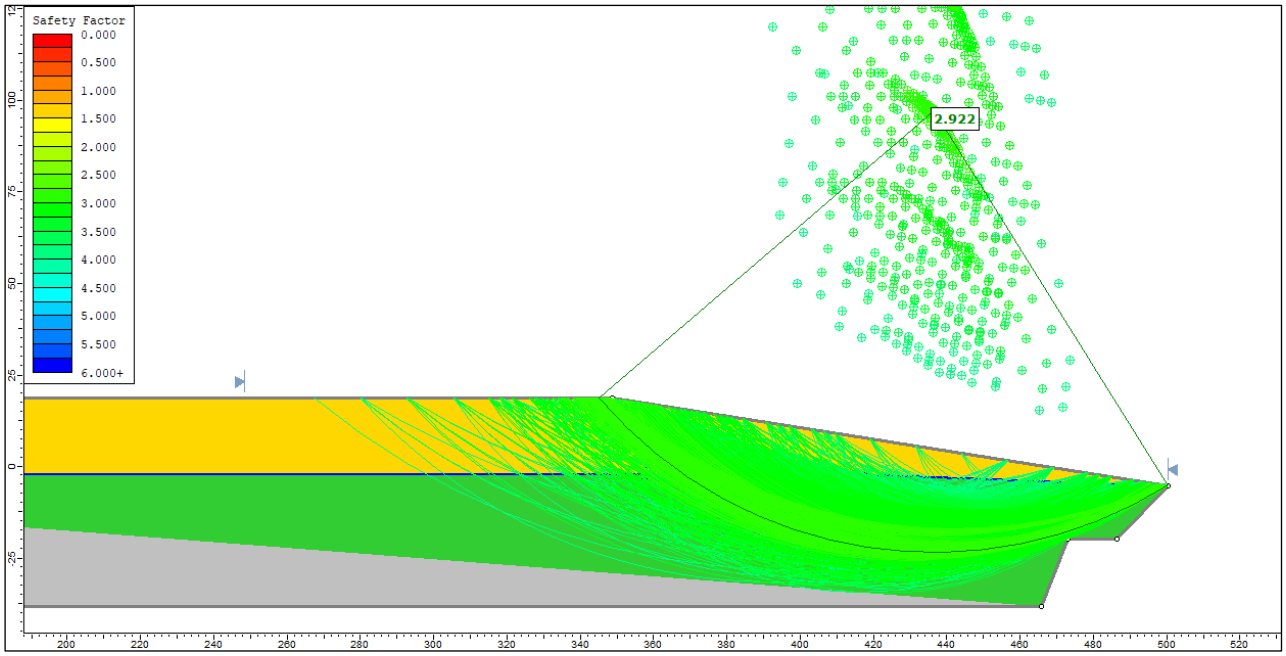

Figure 2-11: Vulcan South Pit – In-Pit Dump – Final Landform – Circular Failure (Auto-Refine) – FoS 3.14 (GLE/M-P)

3 CONCLUSIONS

It can be concluded from the 2D limit equilibrium analyses that:

- In-pit and external spoil dumps were assessed to be geotechnically stable, based on the assumptions and final landform designs provided by METServe; and
- The proposed final landform design exceeds the minimum FoS of 1.5 for long-term stability, based on the assumptions, and is therefore acceptable from a geotechnical perspective.

4 REFERENCES

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Appendix H – Geochemical Assessment

TECHNICAL REPORT

Geochemical Assessment of Waste Rock, Coal Reject and Coal

Vulcan South

Prepared for: **Vitrinite Pty Ltd**

RGS

MINE WASTE AND WATER MANAGEMENT

TECHNICAL REPORT

Geochemical Assessment of Waste Rock, Coal Reject and Coal

Vulcan South

Prepared for: Vitrinite Pty Ltd

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This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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1 INTRODUCTION

1.1 Project Overview

Vitrinite Pty Ltd (Vitrinite) is the proponent of Vulcan South (the Project), located north of Dysart and approximately 33 km south-east of Moranbah in Queensland's Bowen Basin (**Figure 1-1**). The Project lies to the immediate west of several established mining operations including BHP's Peak Downs and Saraji mines.

The Project is located immediately to the south of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM), located on ML700060. The Vulcan South mining lease application area abuts ML700060, however proposed activities will be implemented separately.

The Vulcan hard coking coal target has been defined and selected for open cut development via three separate open cut pits that form the primary mining focus of the Project. The Project includes primary rehabilitation works, following a two-year construction period and will operate for approximately nine years. The Project will extract approximately 13.5 Mt of run of mine (ROM) coal consisting predominately of hard coking coal with an incidental thermal secondary product at a rate of up to 1.95 Mtpa. The Project will target the Alex and multiple Dysart Lower coal seams. Truck and shovel mining operations will be employed to develop the pits. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility at a location between the northern and central pits. The CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product (along with a reject product) for permanent storage within active waste rock dumps.

Out-of-pit waste rock dumps will be established prior to commencing in-pit dumping activities that will continue for the life of the operation. Ancillary infrastructure, including a ROM pad, offices, roads and surface water management infrastructure will be established to support the operation.

A realignment of the existing Saraji Road and services infrastructure to the eastern boundary of the proposed Mining Lease Application (MLA) area, adjacent to the existing rail easement, is also proposed in a number of locations. The re-alignment will occur within the MLA area.

In-pit dumping will fill the majority of the pit volumes during operations with the remaining final voids to be backfilled upon cessation of mining, resulting in the establishment of waste rock dump landforms above the former pit areas. Following backfill of the final voids, the remaining material stored in the initial out-of-pit waste rock dumps will be rehabilitated in-situ.

The Project includes a small-scale highwall mining trial program in the north of the MLA. The trial will involve the establishment of four highwall mining benches across a number of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner or similar. The highwall mining trial will target up to 750 kt of coal which will be transported by truck to the Project CHPP via a dedicated haul road within the MLA area. The trial is scheduled to be completed within the first year of mining operations.

The Project is a small-scale mining operation, with coal extraction planned for approximately eight years, followed by completion of primary rehabilitation activities in year nine. Construction of infrastructure associated with the mining operation, including the CHPP and the rail loop, is expected to be completed within 2 years. Construction of the realigned Saraji Road sections will be completed intermittently as the project progresses, as required. Ongoing establishment of internal road networks, surface water management infrastructure and other ancillary infrastructure will continue to be developed as the pits and in-pit dumps advance.

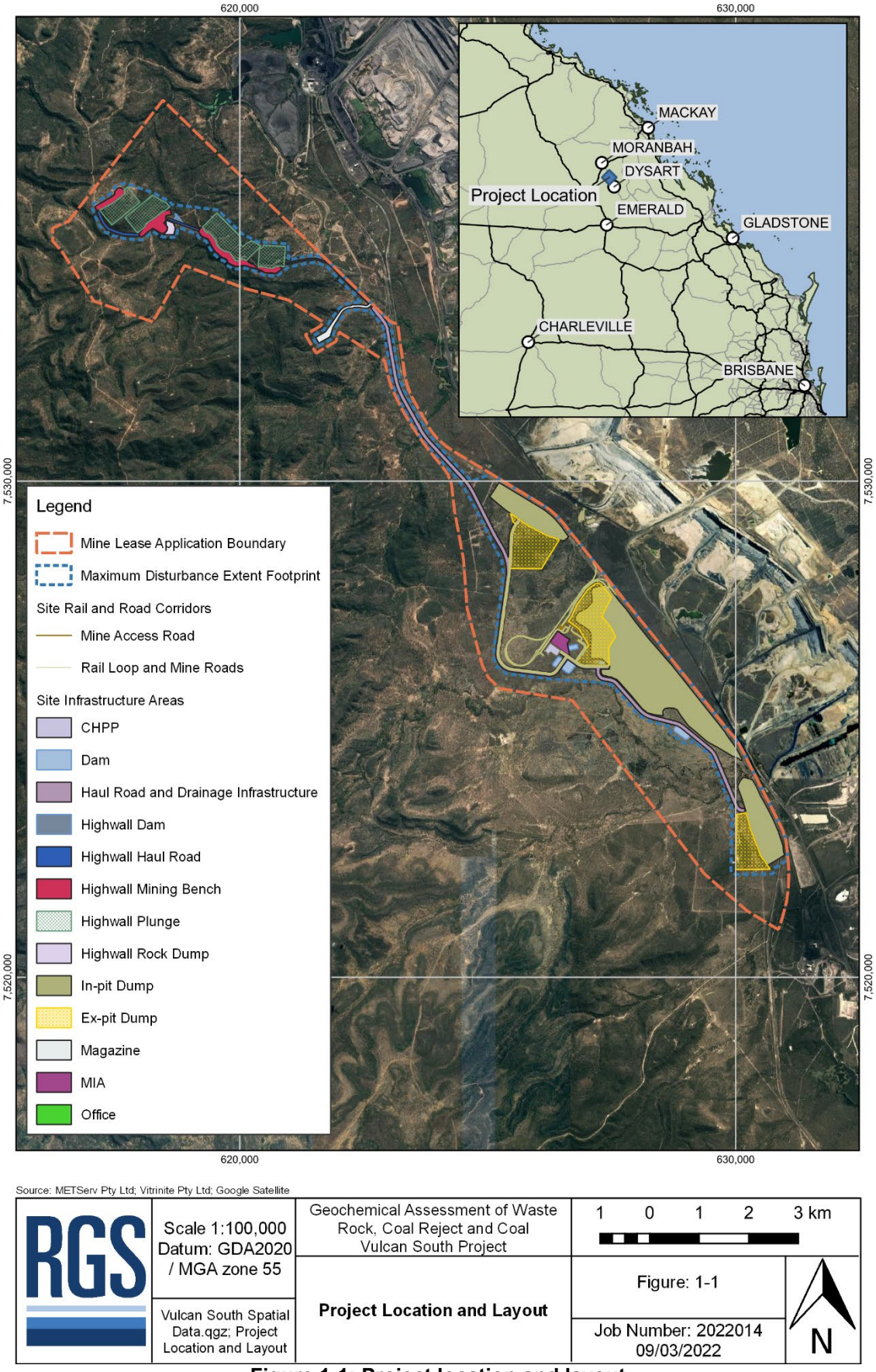


Figure 1-1: Project location and layout

1.2 Open Cut Mining Activities

1.2.1 Overview

The three open cut pits will extend to a depth of approximately 60 metres (m), following the seams as they dip eastwards. The footprints of the proposed open cut pits are provided in **Table 1-1**.

Table 1-1: Open cut pit characteristics

Open Cut Pit	Approximate Footprint (ha)	Mining Direction	Target Seams
Vulcan North	66	North to south	Alex and multiple Dysart Lower
Vulcan Main	334	North to south	Alex and multiple Dysart Lower
Vulcan South	77	North to south	Alex and multiple Dysart Lower

1.2.2 Waste rock removal and placement

Initial waste rock extracted during the early stages of each open pit will be placed in out-of-pit dumps to the west of the open pits. Following this initial out-of-pit placement and once sufficient pit space has been established, in-pit placement of waste rock will commence. This will continue for the life of each pit as it is developed. The in-pit dumps will extend up to approximately 60 m above the surrounding ground level, with batters shaped up to a maximum slope of 15 %. A central plateau will drain to the west to minimise the requirement for significant drainage infrastructure along the eastern toe of the dump (where space is limited).

An assessment of waste rock geochemistry has concluded that the waste rock does not propose a significant risk of generating acid, saline or metalliferous drainage. Therefore, no selective handling and treatment measures are proposed. Furthermore, low permeability capping over the dump surface is considered not to be required.

1.2.3 Coal extraction

Once waste rock has been removed to expose the coal seam, coal will be extracted via truck and shovel. The coal will be hauled to the ROM pad. Crushing and screening will be completed as part of the CHPP raw coal handling circuit.

1.3 High Wall Mining Trial

The Project includes a small-scale highwall mining trial program in the north of the MLA. The trial will involve the establishment of four highwall mining benches across a series of hillsides to facilitate extraction of coal utilising a CAT HW300 highwall miner or similar and will target up to 750 kt of coal within the first year of mining operations. Mined coal will be loaded by front-end-loader and transported by truck to the Project CHPP via a dedicated haul road within the MLA. Whilst common in other coal mining regions, the trial will test the proposed highwall mining equipment in local conditions to assist Vitrinite decision making on the methodology's suitability for other assets held within the region.

The target areas for the trial present competent roof and floor materials and target seams that are relatively flat dipping and non-undulating. The coal seams are of a thickness that is appropriate for highwall mining (0.9 to 1.5 m) and the coal itself is of reasonable strength whilst still being easily cut with a highwall continuous miner. The depth of cover ranges between 12 and 50 m.

Minimal infrastructure will be required to support the highwall mining trial. This will include mobile diesel fuel tanks, workshop containers and portable bathroom amenities. Earthmoving equipment will be required for the development of benches for the highwall miner to operate on as well as road construction and maintenance equipment to build and maintain the haul road to the CHPP/ROM stockpile area. For the trial, the benches will form part of the haul road and will be connected by sections of linking haul road.

ROM coal will be loaded from the discharge conveyor of the highwall miner onto a stacker belt for stockpiling on the active bench. Loaders will manage the stockpile and load B-triple trucks for haulage to the Project CHPP facilities. Waste rock from the benches will be temporarily stockpiled during highwall mining activities, prior to being back-filled into the bench areas during progressive rehabilitation.

One of the benches will require establishment of a small waste rock dump that will be rehabilitated in situ.

Mine affected water will be contained on each bench and allowed to drain to completed highwall plunges (voids). Following rehabilitation earthworks, runoff will be managed by erosion and sediment control structures before being allowed to flow to the receiving environment at an acceptable quality.

1.4 Production Rate

The Project will commence operations at the Vulcan North and Vulcan Main pits in close succession. Operations at the Vulcan Main pit will continue for the full 8-year mine life. Mining activities at the Vulcan North pit are anticipated to be completed after three years. Activities at the Vulcan South pit will commence in Year 6 of operations and will conclude three years later in Year 8.

Throughout the Project life, the average annual ROM coal production rate is less than 1.7 Mtpa. During peak production periods, the Project will produce up to 1.95 Mtpa.

1.5 Coal Processing

The Project will include a modular CHPP to process ROM coal into a number of marketable products (coking coal and thermal coal). In summary, the CHPP will include:

- a raw coal handling circuit to size ROM coal for further processing and remove incidental reject wastes;
- a raw coal bypass conveyor to provide the option to direct appropriate quality raw coal to the product stockpile;
- three CHPP circuits (coarse, secondary coarse and mid-sized) for coal beneficiation, producing a single product stream;
- a tailings thickener to thicken ultrafine reject material; and
- tailings dewatering technology to dewater tailings to a solid cake for disposal in active waste rock dumps.

The CHPP will produce dual products at any one time with different products produced in campaigns via control of different ROM feed materials.

1.5.1 Processing wastes

All processing wastes, including reject material and dry process tailings, will be stored within active waste rock dumps, removing the requirement for a tailings storage facility at the site. Priority will be given to disposal of processing wastes within in-pit dumps at depth; however, scheduling constraints may necessitate storage of some material in ex-pit waste rock dumps.

Wastewater will be recycled within the CHPP circuit to minimise raw water demand and storage and disposal requirements.

1.6 Product Handling

A single CHPP product conveyor will deliver product coal to a radial product stacker. The system will be able to deliver different products to two different stockpiles. Each of the stockpiles will have a capacity of 200,000 tonnes.

The train load out facility will link the product stockpiles with the proposed rail loop and will utilise a two-coal valve reclaim system to load at a rate of 3,500 tph. The train load out facility will be managed via a fully

automated system, including overload protection and load veneering. The facility will be positioned over the rail line and will incorporate a suitable under rail spillage pit.

1.6.1 Product Rail

Product coal will be railed from the Project rail loop onto the Goonyella Rail network. Export options include Dalrymple Bay to the north and RG Tanna, in Gladstone, to the south.

1.7 Progressive Rehabilitation

A Progressive Rehabilitation and Closure Plan (PRCP) has been prepared to support the Environmental Authority Application and to meet Vitrinite's obligations under the *Environmental Protection Act, 1994* as amended by the *Mineral Resources and Energy (Financial Provisioning) Act 2018 Act*. In summary, the PRCP describes the proposed final landform, post-mine land uses, rehabilitation planning information and a schedule of progressive rehabilitation activities.

1.8 Ancillary Infrastructure

The ancillary infrastructure required to support mining operations will be progressively established as the pits, dumps and highwall trial progress.

A new mine access road will be established from Saraji Road in the centre of the MLA, between the rail loop and the northern extent of the Vulcan Main pit. This will lead to the site offices and administration and on to the MIA. The MIA will include heavy vehicle workshops and park-up, equipment laydown areas and Project offices and facilities.

An explosives magazine will be established to the west of the Vulcan north pit, a suitable distance from operational areas and critical infrastructure.

Surface water management infrastructure will be established progressively to divert clean water catchments around operational areas and to manage runoff from disturbed areas. A series of mine water dams will be established to manage raw water supply, pit water and supply water for dust suppression. A series of drains and bunds will be established to direct runoff to sediment control structures.

Linking roads, tracks and pipelines will be established around site as required. Similarly, temporary stockpiles of useful materials (e.g., topsoil, subsoil, gravels) will be established as required in available and appropriate locations. To facilitate flexible establishment of such infrastructure, a conservative disturbance footprint has been proposed and assessed.

1.9 Scope of Work

RGS has completed a Geochemical Assessment of waste rock, coal reject and coal for the Project in accordance with relevant legislation, guidelines, and policies[1,2,3,4]. RGS has produced this technical report for inclusion in the Project baseline studies and approvals process. The study was completed to address the following items:

- Review of available geochemical and geological data and existing drill hole database (including plans, drill hole logs and drill core photographs) associated with the Project;
- Coordination of the material sampling and geochemical characterisation programs;

[1] COA (2016). Commonwealth of Australia. Leading Practice Sustainable Development Program for the Mining Industry. Preventing Acid and Metalliferous Drainage. September, Canberra ACT.
[2] DEHP (2013). Application Requirements for Activities with Impacts to Land Guideline. Queensland Department of Environment and Heritage Protection.
[3] DME (199). Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland, Technical Guideline – Assessment and Management of Acid Drainage and Saline/Sodic Wastes. Queensland Department of Minerals and Energy (DME).
[4] INAP (2022). Global Acid Rock Drainage Guide (GARD Guide). Document prepared by Golder Associates on behalf of the International Network on Acid Prevention (INAP). June 2022 (http://www.inap.com.au/).

- Refinement of any necessary environmental management measures related to waste rock and coal reject emplacement and rehabilitation and ROM coal stockpile management; and
- Preparation of a Geochemical Assessment Report (this report) largely based on existing information that will be supplemented by additional geochemical information on samples from the Project, when available. The Geochemical Assessment Report has assessed the potential for any Acid and Metalliferous Drainage (AMD) or other salinity/erosion/ dispersion issues related to waste rock, coal reject and coal at the Project.

2 GEOLOGY, MINING ACTIVITIES AND REHABILITATION

The Project is located north of Dysart to the immediate west of several established mining operations including Peak Downs and Saraji coal mines.

2.1 Geology and Stratigraphy

The Project will target the Alex and multiple Dysart Lower coal seams within the Permian-aged Moranbah Coal Measures. A surficial Tertiary waste rock (overburden) sequence is present in the Project area, consisting of unconsolidated soils and sands. Underlying this is Permian-aged waste rock (overburden), which is comprised of sandstone and siltstone.

The Permian waste rock (interburden) materials at the Project generally comprise sandstone, siltstone, claystone and coal, that were deposited in a fluvial flood plain environment within the Bowen Basin. Significant mesa hills formed by highly resistant sandstones have provided target coal seams throughout the centre of the study area. The typical stratigraphic profile encountered at the Project is provided in **Figure 4**.

The Alex seam is generally quite shallow and occurs just below the base of weathering in the stratigraphic profile. The Dysart Lower Seam comprises several plys with the waste rock (interburden/parting) in between generally consisting of fine-grained sedimentary units, such as siltstone, mudstone and claystone, with the occasional carbonaceous or coaly unit.

The May Seam (consisting of carbonaceous claystone) and Matilda Seam (consisting of interbedded coal and siltstone) underlie the Dysart seam, but are not considered economic.

2.2 Mining Activities

2.2.1 Overview

The open cuts will extend to a depth of approximately 60 m, following the seams as they dip eastwards. The total footprint of the proposed open cuts is approximately 477 ha (**Table 1-1**). Development of the open cuts will progress from the west of the pits mining from north to south, toward the eastern boundary of the proposed MLA. Truck and shovel mining methods and blasting will be employed to extract waste rock and coal from the pit.

2.2.2 Waste rock removal and placement

Initial waste rock extracted during the early stages of the development of the open cut pits will be placed in an out-of-pit dump to the west of the pits. Following this initial out of pit placement and once sufficient pit space has been established, in-pit placement of waste rock will commence. This will continue for the life of the project as the pits advance. The in-pit dumps will extend approximately 60 m above the surrounding ground level, with batters shaped at a maximum of 15 %. A central plateau will drain to the west to minimise the requirement for significant drainage infrastructure along the eastern toe of the dump (where space is limited).

Assessment of waste rock geochemistry (RGS, 2019; 2020) showed that the waste rock does not pose a significant risk of generating acid, saline or metalliferous drainage. Therefore, no selective handling and treatment measures are proposed and low permeability capping over the dump is unlikely to be required.

2.2.3 Coal extraction

Once waste rock has been removed to expose the coal seams, coal will be extracted via truck and shovel. The coal will be hauled to the ROM pad. Crushing and screening will be completed as part of the CHPP raw coal handling circuit. Depending on mining and market conditions, ROM coal may be trucked to the Vulcan Coal Mine CHPP located on ML700060 to the north of the project. If this is the case, haulage would be via private haul road and would not need to utilise public roadways.

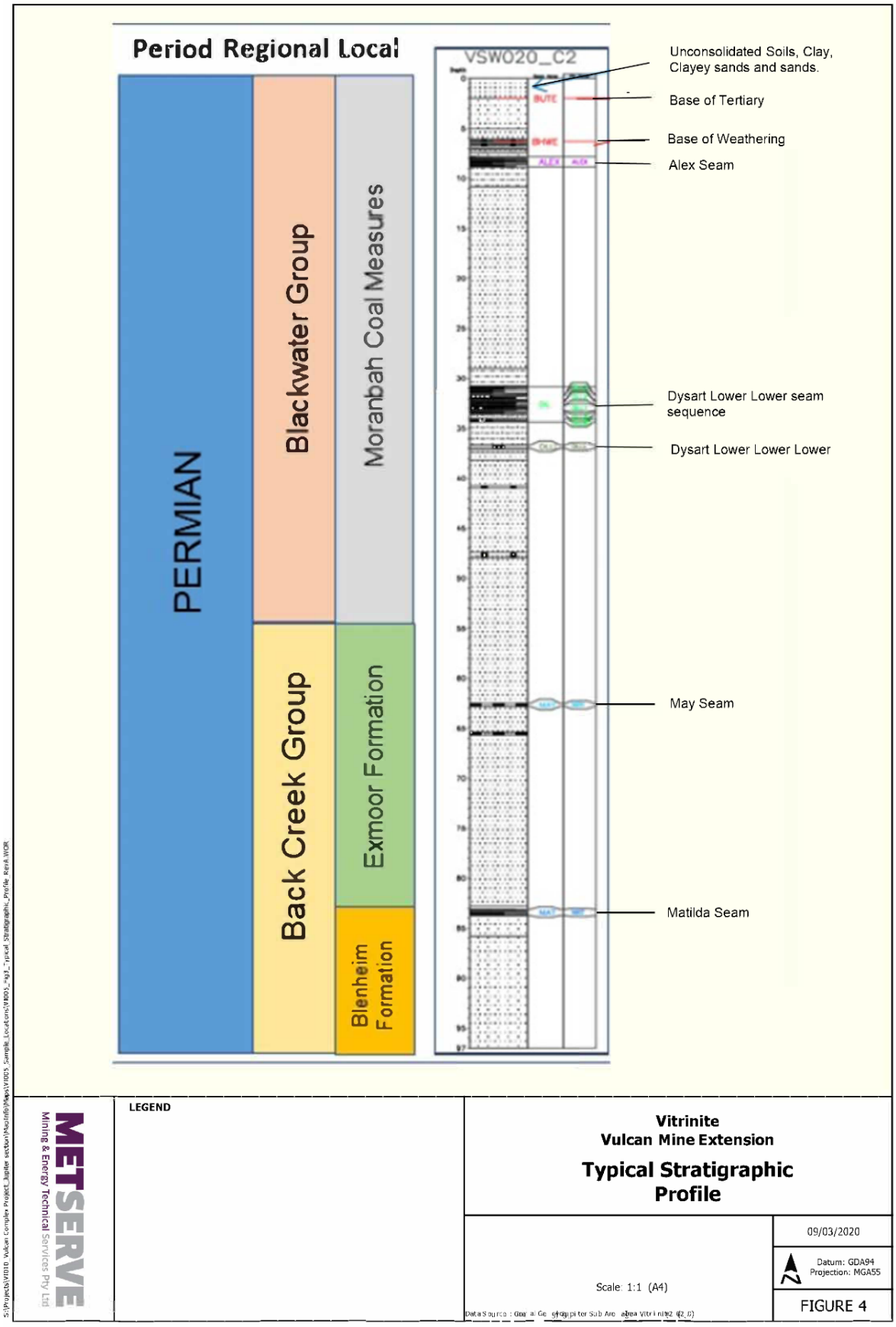


Figure 2-1: Typical stratigraphic profile

2.2.4 Production rate and schedule

An indicative annual mining schedule is provided in **Table 2-1**. Product coal will be railed from the Project rail loop onto the Goonyella Rail network. Export options include Dalrymple Bay to the north and RG Tanna in southern Gladstone.

Table 2-1: Indicative mining schedule

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	
	2023	2024	2025	2026	2027	2028	2029	2030	Total (t)
Highwall Mining									
Topsoil (t)	622,557								**622,557**
Waste Rock (t)	6,246,343								**6,246,343**
ROM Coal (t)	750,000								**750,000**
Vulcan North Pit									
Topsoil (t)	58,734	313,019	40,004						**411,757**
Waste Rock (t)	4,001,234	24,117,467	1,616,789						**29,735,489**
ROM Coal (t)	26,137	1,202,385	585,592						**1,814,114**
Vulcan Main Pit									
Topsoil (t)	35,686	298,486	298,079	305,290	389,958	183,329	257,856	141,396	**1,910,079**
Waste Rock (t)	1,261,637	17,067,931	38,929,456	40,431,863	40,855,127	33,106,442	23,798,147	11,652,257	**207,102,860**
ROM Coal (t)		687,965	1,223,774	1,841,120	1,728,933	1,560,844	1,304,554	1,027,403	**9,374,594**
Vulcan South Pit									
Topsoil (t)						142,196	198,534	131,741	**472,471**
Waste Rock (t)						8,100,351	17,179,435	13,883,816	**39,163,602**
ROM Coal (t)						249,607	647,113	451,034	**1,347,754**
Annual total									
Topsoil (t)	716,977	611,505	338,083	305,290	389,958	325,525	456,390	273,137	**3,416,865**
Waste Rock (t)	11,509,214	41,185,398	40,546,244	40,431,863	40,855,127	41,206,793	40,977,582	25,536,073	**282,248,294**
ROM Coal (t)	776,137	1,890,350	1,809,366	1,841,120	1,728,933	1,810,451	1,949,667	1,488,437	**13,294,461**

2.2.5 Ancillary Infrastructure

A new mine access road will be established from Saraji Road in the centre of the MLA, between the rail loop and the northern extent of the Vulcan Main pit. This will lead to the site offices and administration and then on to the Mine Infrastructure Are (MIA).The MIA will include heavy vehicle workshops and park-up, equipment laydown areas, project offices and facilities. An explosives magazine will be established to the west of the Vulcan North pit, away from operational areas and critical infrastructure.

Surface water management infrastructure will be established progressively to divert clean water catchments around operational areas and to manage runoff from disturbed areas. A series of mine water dams will be established to manage raw water supply, pit water and supply water for dust suppression. A series of drains and bunds will be established to direct runoff to sediment control structures.

Linking roads, tracks and pipelines will be established around site as required. Similarly, temporary stockpiles of useful materials (e.g., topsoil, subsoil and gravels) will be established as required in available and appropriate locations. To facilitate flexible establishment of such infrastructure, a conservative disturbance footprint has been proposed and assessed.

2.3 Progressive Rehabilitation

A Progressive Rehabilitation and Closure Plan (PRCP) has been prepared to support the Environmental Authority Application and to meet Vitrinite's obligations under the *Environmental Protection Act, 1994* as amended by the *Mineral and Energy Resources (Financial Provisioning) Act 2018*. In summary, the PRCP describes the proposed final landform, post-mine land uses, rehabilitation planning information and a schedule of progressive rehabilitation activities.

3 METHODOLOGY

RGS personnel worked closely with Vitrinite (geological) personnel to develop an appropriate sampling and geochemical testing plan, which was used to obtain representative samples of waste rock (overburden and interburden) and coal reject materials associated with the VCM and Vulcan South. This was supplemented with total sulfur data for a range of coal samples from the VCM/Vulcan South target seams (Alex and Dysart Lower).

3.1 Sample Selection and Preparation

The sampling methodology used to obtain representative samples of waste rock and coal reject materials for the Project was undertaken in accordance with relevant technical guideline documents. While there are no specific regulatory guidelines regarding the number of samples required, existing risk-based technical guidelines for the geochemical assessment of mining waste materials in Australia (AMIRA, 2002; COA, 2016c) and worldwide (INAP, 2022) were used by RGS as a framework for the sampling program.

3.1.1 Waste Rock (Overburden and Interburden)

Representative samples of waste rock (overburden and interburden) materials were identified and collected as drill chips from the 2018-2019 exploration drilling program. A total of 138 waste rock samples were collected from 21 drill holes at the Project. Seven of these holes were drilled within the Jupiter target area and 14 within the Vulcan target area. The locations of the Jupiter and Vulcan drill holes with respect to the Project are shown in **Figure 3-1**.

The samples represented the waste rock (overburden and interburden; including roof, floor and parting materials, i.e., potential coal reject material) expected to be encountered during development activities, from the surface to a depth of approximately 45 m. This covers the entire stratigraphic profile that is currently under consideration for mining at the Project. **Table 3-1** provides the number of samples of each type of material collected from the Jupiter and Vulcan targets and used in the geochemical assessment. Further information on the identity of the 138 individual waste rock samples is provided in **Table B1** (**Attachment B**). The number of samples was selected to provide a good statistical representation of the amount and type of mined material expected to be encountered at the Project, considering the risk profile indicated from the geology and geochemical information from nearby coal projects.

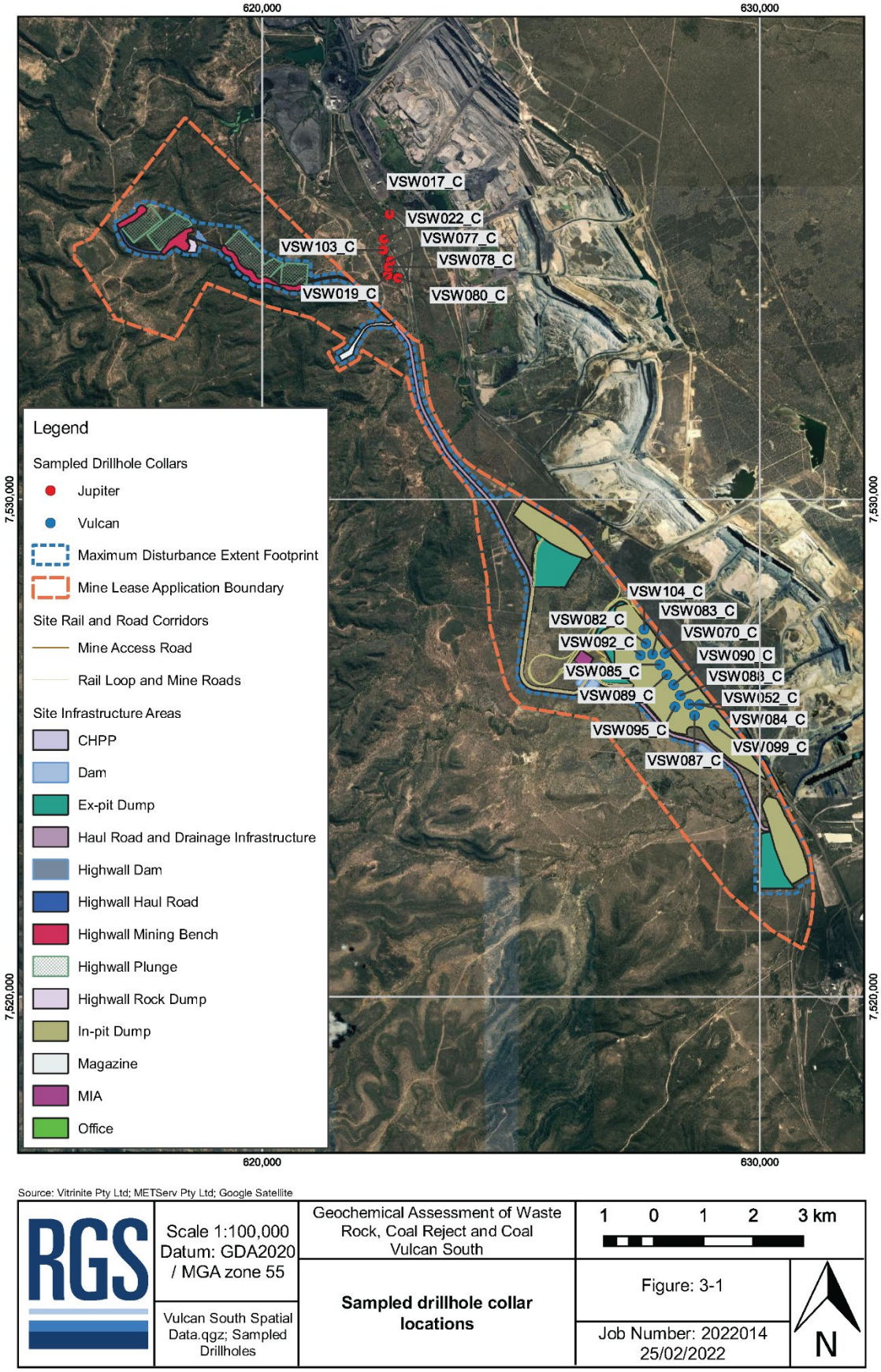


Figure 3-1: Sampled drillhole collar locations

3.1.2 Coal Reject

Two size fractions (coarse: Wash 2, <50 to >2 mm; and fine: Wash 3 & fines, <2 to >0.25 mm & <0.25 to >0 mm) of coal reject materials were selected to best represent the two coal reject streams that will be produced from coal washing on site. Coal core from a total of six holes was collected by Vitrinite personnel and delivered to the ALS coal quality laboratory in Richlands, Queensland. This core was composited into 11 samples of coarse and fine reject material (four from Jupiter and seven from Vulcan) and sent to ALS Environmental Laboratory (ALS) in Stafford, Queensland for geochemical testing.

Table 3-1: Sample materials used for geochemical testing

Sample Description	Sample Type	Number of samples	
		Vulcan Target	Jupiter Target
Waste Rock and Potential Coal Reject			
Soil, clay, sandstone, siltstone, claystone and conglomerate	Overburden	83	17
Sandstone, siltstone and claystone	Interburden	12	1
Sandstone, siltstone and claystone; carbonaceous sandstone, siltstone, claystone and coal	Roof, floor and parting	20	5
	Total	**115**	**23**
Coal Reject		Coarse	Fine
Coarse and fine reject	Coal Reject	5	6
	Total	**5**	**6**

3.1.3 Sample Preparation

Once received, the waste rock and coal reject samples were prepared by crushing and pulverising to less than 75 µm size, where necessary. This method of sample preparation results in a homogenous sample, but also generates a large sample surface area in contact with the assay solution. This provides a greater potential for dissolution and reaction and represents an assumed initial 'worst case' scenario for these materials. A list describing the source of all of the 149 waste rock and coal reject samples included in this study is provided in **Table B1** (**Attachment B**).

3.2 Geochemical Test Program

A series of geochemical and physical tests were completed on the 149 waste rock and coal reject samples described in detail in **Section 3.1**. The test program was designed to assess the degree of risk from the presence and potential oxidation of sulfides, as well as the generation and the presence/leaching of soluble metals/metalloids and salts. The assessment also included characterisation of standard soil parameters including salinity, sodicity, cation exchange capacity, exchangeable sodium percentage and major metal concentrations.

A detailed summary of the parameters involved in completing a static and kinetic geochemical characterisation and assessment of mining waste materials is provided in **Attachment A**.

3.2.1 Static Tests

Static geochemical tests provide a 'snapshot' of the characteristics of a sample material at a single point in time. These tests were staged to screen individual samples before selecting either individual and/or composite samples for more detailed static test work.

The Acid Base Account method was used as a screening procedure whereby the acid-neutralising and acid-generating characteristics of a material were assessed. All 149 samples were screened using the Acid Base Account method, which included static geochemical testing for the following parameters:

- pH [1:5 w:v. sample:deionised water];

- Electrical conductivity (EC) [1:5 w:v. sample:deionised water];
- Total sulfur [LECO analyser]; and
- Acid neutralising capacity (ANC) [AMIRA, 2002 method].

The results of the ABA screening tests are discussed in **Section 4.1**. After the results of the screening tests were received and interpreted, two waste rock (interburden) samples and 11 coal reject samples were also tested for sulfide sulfur, using the chromium reducible sulfur (Scr), Australian Standard (AS 4969.7, 2008) method.

From the total sulfur value (or Scr value, where available), maximum potential acidity (MPA) values were calculated. Scr data was preferentially used where available, as it provides a more accurate representation of the potential MPA, as acid generation primarily forms from the oxidation of reactive sulfide measured by this method.

After the results of the initial static geochemical tests were received and reviewed, 122 of the original 149 samples were used to create six composite samples for waste rock and four composite samples for coal reject materials. For the Vulcan target, soil, sandstone, clay and claystone composites were prepared; while sandstone and siltstone composites were prepared for the Jupiter target. All ten composite samples were sent for whole rock multi-element testing at ALS Stafford laboratory. The composite samples were tested for:

- Paste pH and EC [1:5 w:v. sample: deionised water];
- Major cations (Ca, Mg, K, Na) [HCl and HNO3 acid digest followed by ICP-AES/MS];
- Major anions (Cl, SO_4, F) [ICP-AES/MS and PC Titrator (1:5 w:v water extracts)];
- Acidity and alkalinity as $CaCO_3$ mg/L [PC Titrator (1:5 w:v water extracts)];
- Total metals (Ag, Al, As, B, Cd, Cr, Co, Cu, F, Fe, Hg, Pb, Mn, Mo, Ni, Sb, Se, U, V and Zn) [HCl and HNO_3 acid digest followed by FIMS and/or ICP-AES/MS]; and
- Soluble metals (Ag, Al, As, B, Cd, Cr, Co, Cu, F, Fe, Hg, Pb, Mn, Mo, Ni, Sb, Se, U, V and Zn) [ICPAES/MS and FIMS (1:5 w:v water extracts)].

The six composite waste rock samples were also tested for exchangeable cations (Ca, Mg, Na and K) [ICP-AES], and results were used to calculate the cation exchange capacity (CEC) and exchangeable sodium percentage (ESP). Summary geochemical results tables for the static geochemical test program are provided in **Attachment B**. The ALS laboratory certificates of analysis are provided in **Attachment D**.

3.2.2 Kinetic Tests

Following receipt and interpretation of the static geochemical test results, six kinetic leach column (KLC) tests were set up at the RGS 'in-house' laboratory using composite waste rock and coal reject materials from the Vulcan and Jupiter targets. The KLC tests for waste rock were completed from June to December 2019 and from December 2019 to June 2020 for coal reject materials. A summarised description of the material represented by each KLC test is shown below in **Table 3-2**. The identities of the specific individual samples included in composite samples used for the KLC test program are detailed in **Table B7** (**Attachment B**).

Table 3-2: KLC material description

KLC Sample #	Description
KLC1	Mainly Sandstone waste rock (Vulcan target)
KLC2	Mainly Claystone waste rock (Vulcan target)
KLC3	Mainly Sandstone waste rock (Jupiter target)
KLC4	Mainly Siltstone waste rock (Jupiter target)
KLC 5	Coarse Reject (Jupiter/Vulcan Target)
KLC 6	Fine Reject (Jupiter/Vulcan Target)

Approximately 2 kg of each composite sample was weighed and used in each of the KLC tests. Heat lamps were used daily to simulate sunshine and ensure that the KLC test materials were unsaturated and subject to oxidising conditions between leaching events (this is essentially an assumed “worst case” scenario for sulfide oxidation and potential acid/salt generation). Further details and a schematic of the KLC test arrangement are provided in **Attachment A**.

All leachate samples collected from the KLC tests were assayed at ALS Stafford laboratory for:

- pH, EC, Acidity and alkalinity [PC Titrator and pH/ EC probes];
- Dissolved metals/metalloids (Al, As, B, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, V and Zn) [ICP-AES/MS];
- Dissolved major cations (Ca, Mg, Na and K) [ICP-AES/MS]; and
- Dissolved major anions (Cl, SO_4) and F [ICP-AES/MS].

Summary results tables and trends for the KLC tests are provided in **Attachment C**. The raw ALS laboratory test results received for the KLC test program are provided in **Attachment D**.

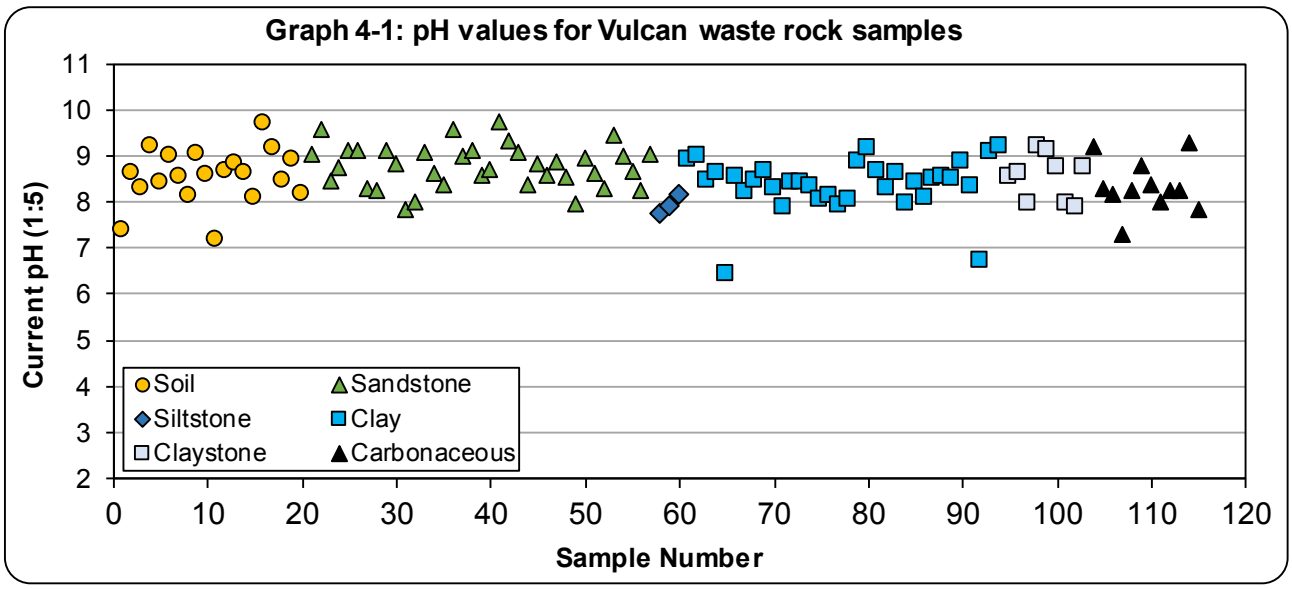
4 GEOCHEMICAL AND PHYSICAL CHARACTERISATION RESULTS

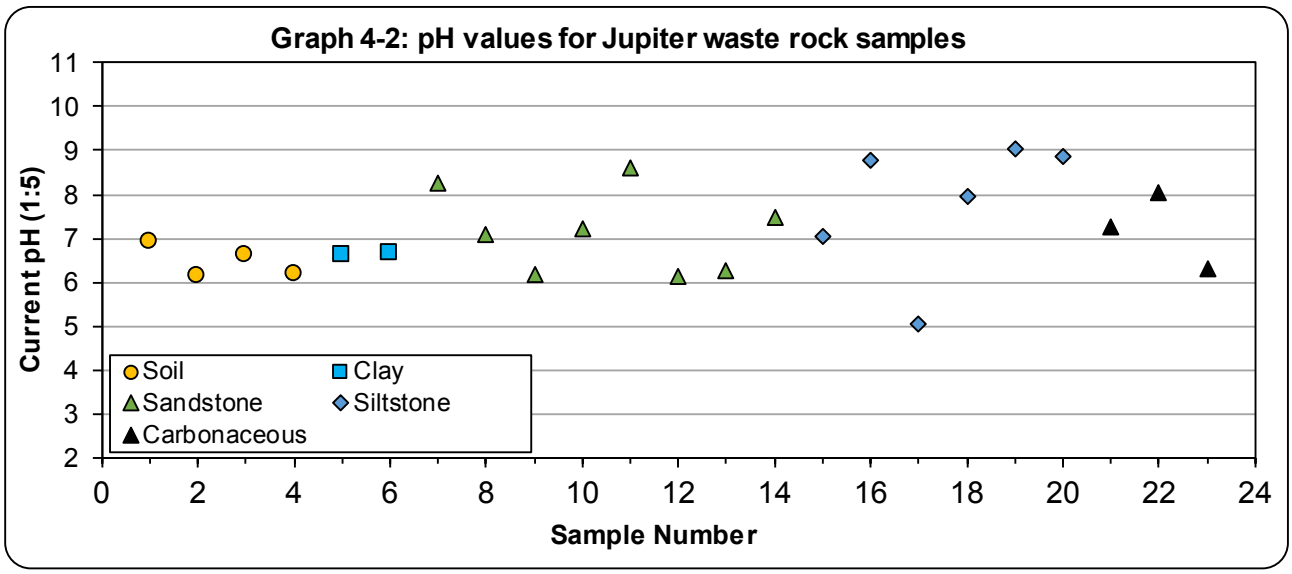
4.1 Acid Base Account

4.1.1 Overburden/Interburden

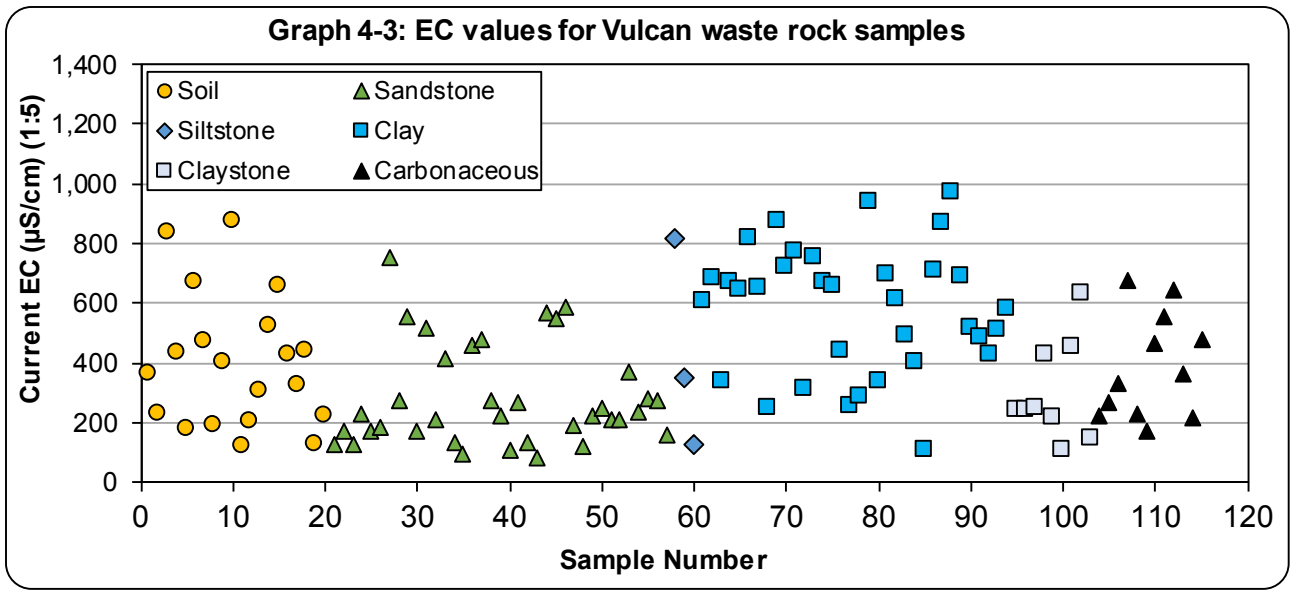
Acid Base Account results for the 138 waste rock (overburden/interburden) samples (115 from the Vulcan target; 23 from the Jupiter target) are presented in **Table B2** (**Attachment B**) and summarised below. The results are shown by target and lithology to facilitate interpretation.

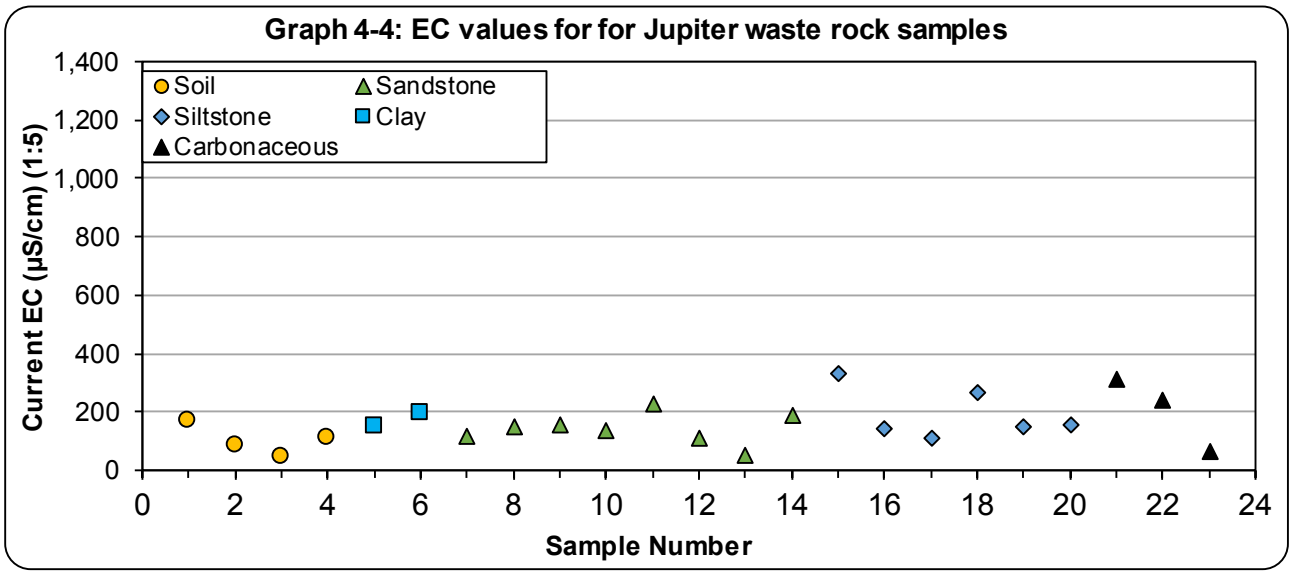
- **pH:** The $pH_{(1:5)}$ of the 115 samples from the Vulcan target ranges from 6.4 to 9.7, with a median pH value of 8.6 (**Graph 4-1**). The $pH_{(1:5)}$ of the 23 samples from the Jupiter target ranges from 5.1 to 9.0, with a median value of 7.0 (**Graph 4-2**). The pH results indicate that waste rock material at the Vulcan and Jupiter targets will add some alkalinity to any contact water as the pH of deionised water used in the pH tests is typically in the pH range of 5.0 to 6.5.





- **EC:** The current $EC_{(1:5)}$ of the Vulcan target samples ranges from 85 to 972 µS/cm, with a median value of 365 µS/cm (**Graph 4-3**). The current $EC_{(1:5)}$ of the Jupiter target samples ranges from 43 to 331 µS/cm, with a median value of 152 µS/cm (**Graph 4-4**). The highest EC values tend to be associated with some of the soil and clay materials at the Vulcan target.





To provide additional context, the $pH_{(1:5)}$ and $EC_{(1:5)}$ results for waste rock (overburden and interburden) are classified against pH and salinity criteria for mining waste materials, as defined by the Queensland DME (1995) technical guidelines for the environmental management of exploration and mining in Queensland (**Table 4-1**).

Based on the median pH and EC values, the waste rock (overburden/interburden) samples tested are generally regarded as having a 'Medium' to 'High' soil pH and 'Low' salinity characteristics, as indicated by the distribution of samples corresponding to each pH and salinity class. Samples from the Jupiter target have a slightly lower (neutral) median pH value than samples from the Vulcan target.

Table 4-1: Salinity and pH criteria for assessment of waste rock samples

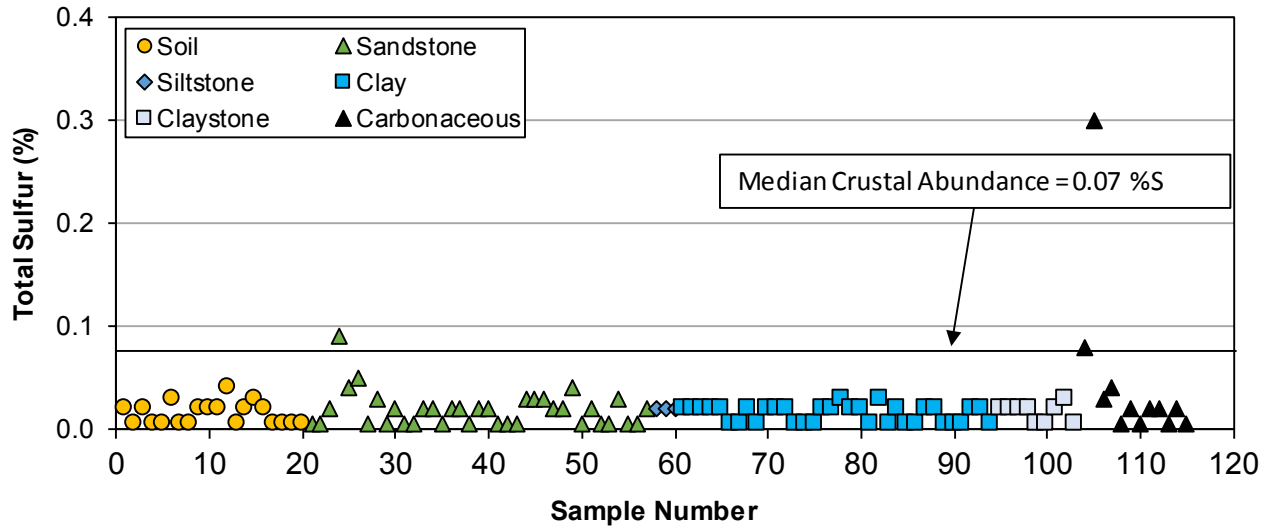
Vulcan Target	Very Low	Low	Medium	High	Very High
$pH_{1:5}$	< 4.5	4.5 – 5.5	5.5 – 7.0	7.0 – 9.0 (Median – 8.6)	> 9.0
$EC_{1:5}$ (µS/cm)	< 150	150 – 450 (Median – 365)	450 – 900	900 – 2,000	> 2,000
Jupiter Target	**Very Low**	**Low**	**Medium**	**High**	**Very High**
$pH_{1:5}$	< 4.5	4.5 – 5.5	5.5 – 7.0 (Median 7.0)	7.0 – 9.0	> 9.0
$EC_{1:5}$ (µS/cm)	< 150	150 – 450 (Median – 152)	450 – 900	900 – 2,000	> 2,000

Note: Adapted from DME, 1995. Highlighted cells show the category corresponding to the median pH and EC values (orange shading) for the waste rock (overburden/interburden) samples.

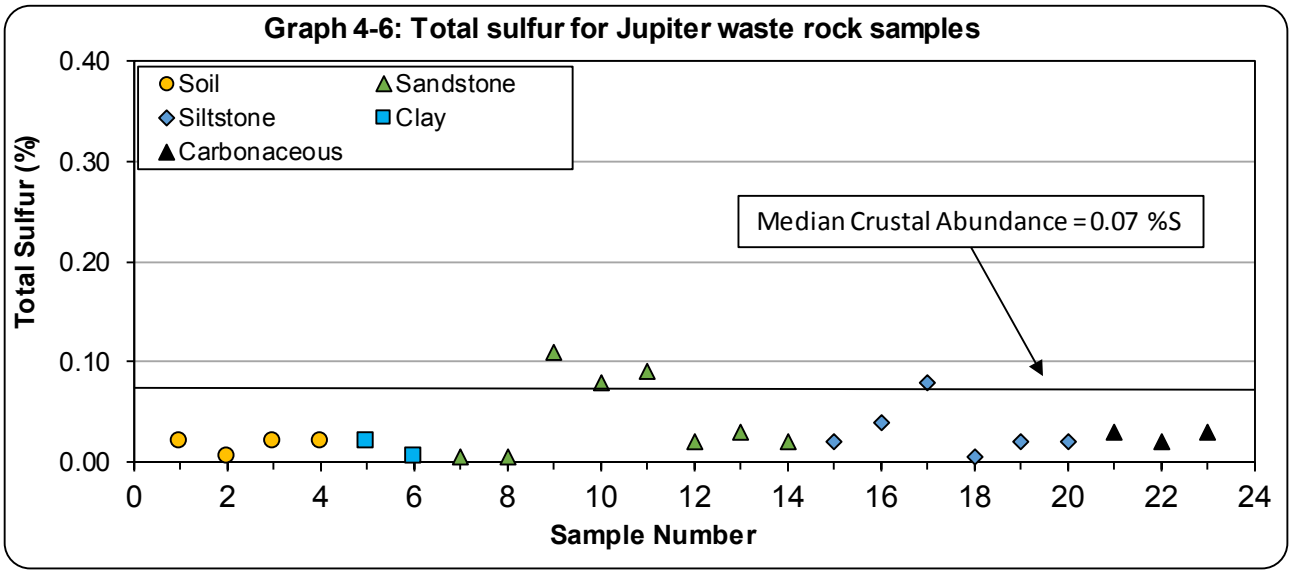
The pH and EC tests were completed on pulverised samples (≤ 75 µm) with a large surface area in contact with the leaching solution, thereby providing greater potential for dissolution and reaction, and represent an assumed 'worst case' scenario. It is also expected that the salinity of leachate from low sulfur mining waste materials will diminish with time as salts are flushed from the rock matrix and a state of equilibrium develops. At that point, the salinity of seepage/runoff should stabilise at a lower asymptotic concentration relative to the weathering/erosion of the materials.

- **Sulfur:** The total sulfur content of the samples from the two targets ranges from below the laboratory limit of reporting (LoR) to 0.30 %S and has a very low median value of 0.02 %S, compared with the median crustal abundance value of 0.07% S in unmineralised soils (Bowen, 1979; INAP, 2022). Materials with a total sulfur content less than or equal to 0.1 %S are essentially barren of sulfur, generally represent background concentrations, and have negligible capacity to generate acidity[5]. **Graphs 4-5 and 4-6** illustrate the total sulfur content of the sample materials from the Vulcan and Jupiter targets, respectively. The results demonstrate that most samples have a total sulfur concentration well below median crustal abundance.

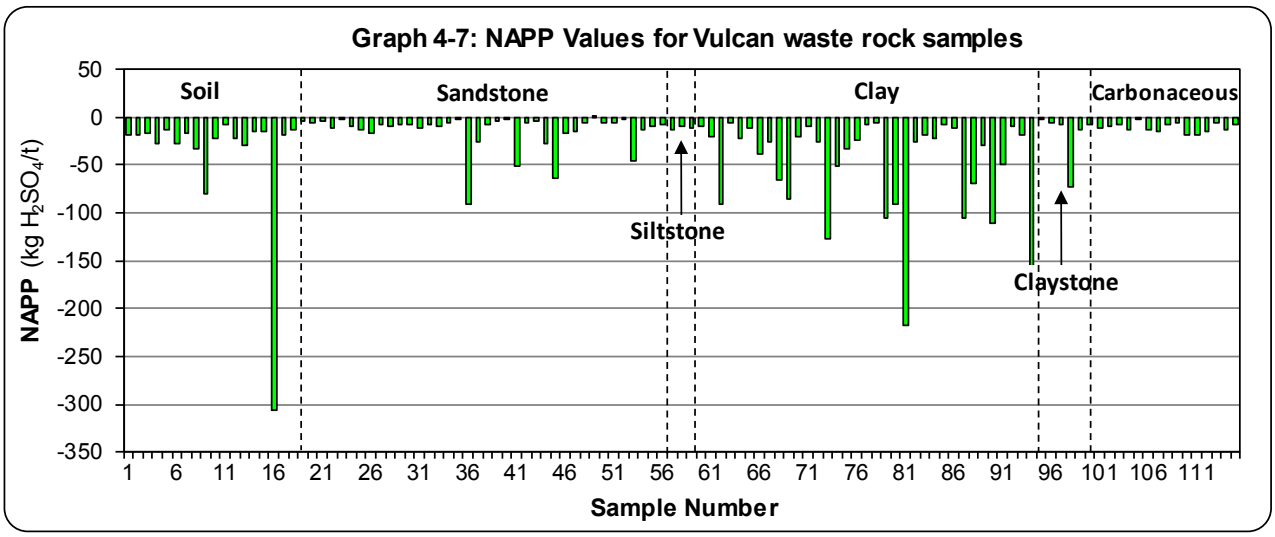
Graph 4-5: Total sulfur for Vulcan waste rock samples

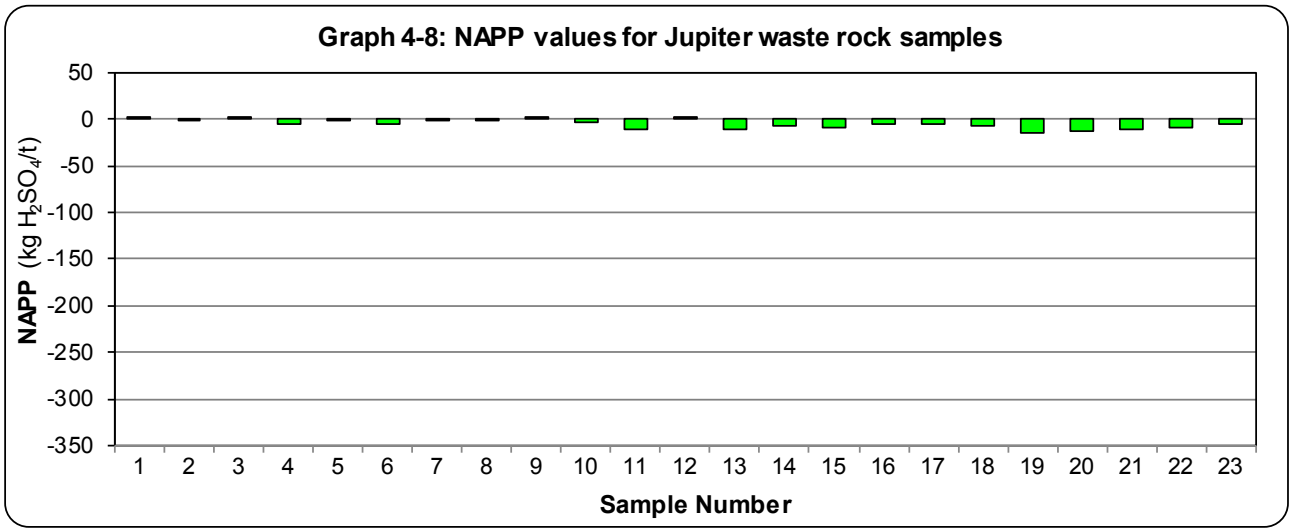


[5] The median crustal abundance of sulfur (0.07% S) has been rounded up to 0.1% (INAP, 2022).



- **Sulfide sulfur:** Due to the very low total sulfur content of most of the waste rock (overburden/interburden) samples, only two samples (a weathered coal sample from the Alex coal seam at Vulcan and a sandstone sample from Jupiter) were tested for sulfide sulfur using the Scr method. The test results show that only the weathered coal sample from Vulcan contains any appreciable sulfide sulfur and approximately half of the total sulfur content is likely to be present as organic sulfur which does not generate acidity.
- **MPA:** Based on the total sulfur content (and sulfide sulfur content, where available), the MPA that could be generated by the Vulcan and Jupiter waste rock samples ranges from below the laboratory LoR to 4.7 kg H_2SO_4/t, and has a very low median value of 0.6 kg H_2SO_4/t.
- **ANC:** The ANC for the 138 samples ranges from 0.25 to 307 kg H_2SO_4/t and has a median value of 13.6 kg H_2SO_4/t, which is approximately 20 times the median MPA.
- **ANC:MPA ratio:** The ANC:MPA ratio of the 138 samples ranges from 0.2 to 1,423.7, with a median value of 36.1. In simplistic terms, this means that on average, the overburden and interburden sample materials have more than an order of magnitude excess ANC over MPA.
- **NAPP:** The calculated Net Acid Producing Potential (NAPP) values range from -306.4 to 1.0 kg H_2SO_4/t, with a negative median value of -12.7 kg H_2SO_4/t. The NAPP data is presented in **Graphs 4-7 and 4-8**.

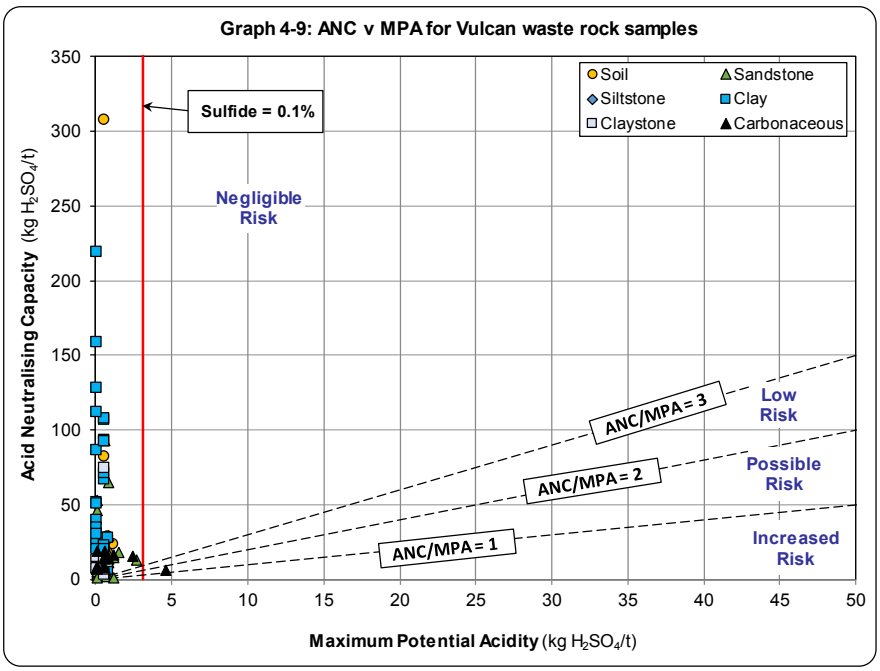




Given the very low sulfur content of the waste rock tested and the generally negative NAPP values, the risk of generating any significant amounts of acidity from these materials is considered to be negligible.

Graphs 4-9 and **4-10** show plots of ANC versus MPA for the waste rock samples tested by material type from the Vulcan and Jupiter targets, respectively. ANC:MPA ratio lines have been plotted on the figures to illustrate the factor of safety associated with the samples in terms of potential for generation of acidity. Generally, those samples with an ANC:MPA ratio of greater than 2 and a sulfide content of <0.1% S are considered to represent material with a high factor of safety and a very low risk of generating acidity (COA, 2016c; INAP, 2022).

The Acid Base Account results show that all but one sample (a weathered coal sample from the Alex seam at Vulcan) plots in the negligible risk domain shown in the figures and therefore the overwhelming majority of samples tested represent waste rock materials that have a high factor of safety and a very low risk of generating acidity. If economic, it is likely that the Alex seam will be mined and report as coal to the ROM pad. As can be seen in **Figure 3**, the Alex seam covers a depth interval of only 1 m and therefore is expected to represent a small fraction (up to 2%) of waste rock materials at the Vulcan target if found to be uneconomic and reports as waste rock.



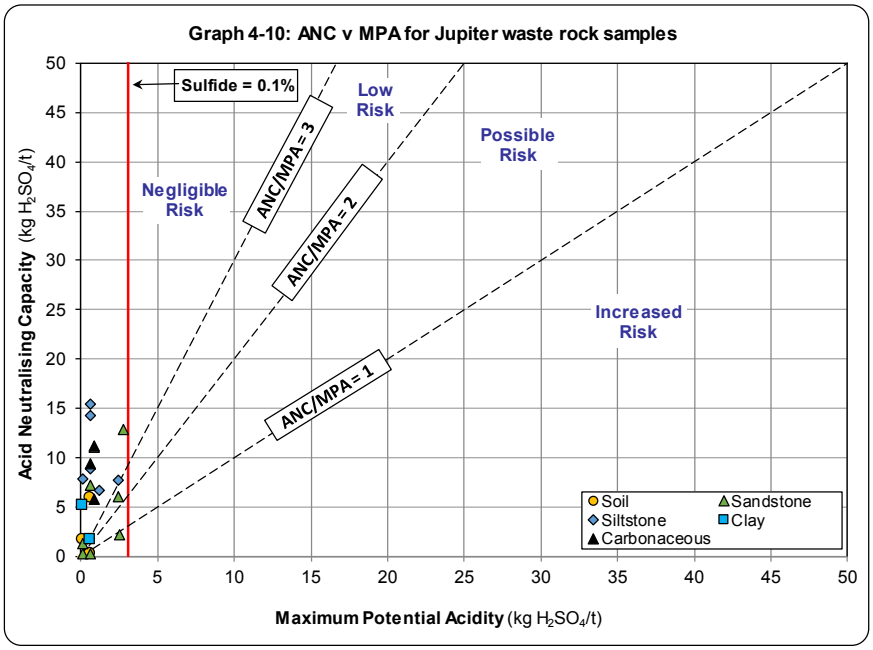


Table 4-2 provides a summary of the geochemical classification criteria used by RGS to classify the acid forming nature of the waste rock and a breakdown of the number of samples in each classification category. The classification criteria reflect Australian (COA, 2016c) and international (INAP, 2022) guidelines for the classification of mining waste materials.

The Acid Base Account test data presented in **Table C2 (Attachment C)** and discussed in this section have been used to classify the acid forming nature of the 138 waste rock samples. The results in **Table 4-2** demonstrate that of the 138 samples tested, 137 samples (~99.3%) are classified as Non-Acid Forming (NAF) (Barren) and one sample (~1%) is classified as Uncertain. None of the samples are classified as Potentially Acid Forming (PAF).

Table 4-2: Geochemical classification criteria for waste rock materials

Geochemical Classification	Total Sulfur[1] (%)	NAPP (kg H_2SO_4/t)	ANC:MPA Ratio	No. Samples (n = 138)
Non-Acid Forming (Barren)[2]	≤ 0.1	-	-	137
Non-Acid Forming	> 0.1	≤ -5	≥ 2	0
Uncertain	> 0.1	> -5 and ≤ +5	< 2	1
Potentially Acid Forming	> 0.1	> +5	< 2	0

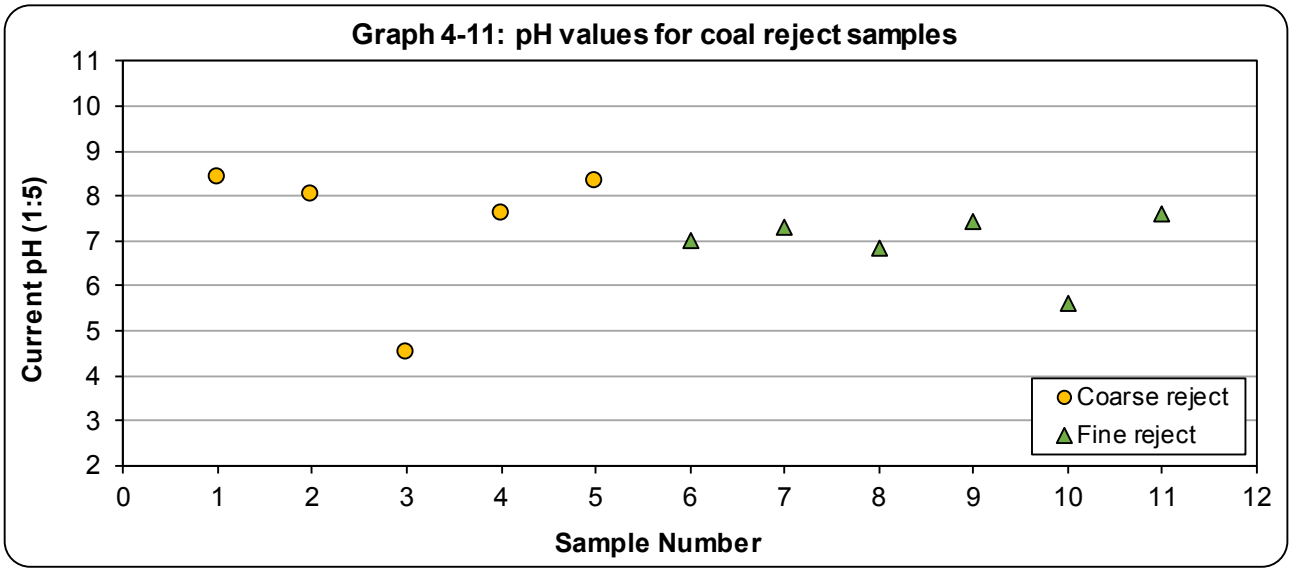
Notes:
1. If total sulfur is less than or equal to 0.1% S, the NAPP and ANC:MPA ratio are not required for material classification as the sample is essentially barren of oxidisable sulfur.
2. A sample classified as NAF can be further described as 'barren' if the total sulfur and/or sulfide sulfur content is less than or equal to 0.1% S, as the sample essentially has negligible acid generating capacity.

Overall, the Acid Base Account results confirm that the overwhelming majority of the waste rock materials represented by the samples tested have low sulfur content, excess ANC, and are classified as NAF. These materials have a high factor of safety and a very low risk of generating acidic drainage. One carbonaceous (weathered coal) sample has a slightly elevated sulfur content, however, as a bulk material, waste rock is likely to have excess ANC and be classified as NAF.

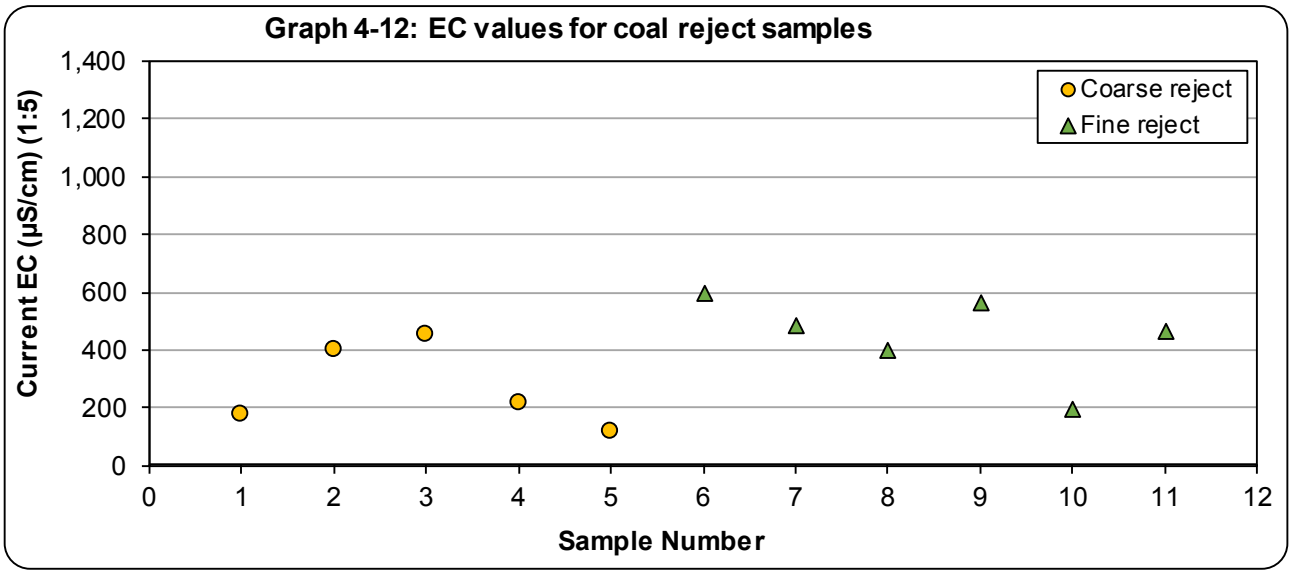
4.1.2 Coal Reject

Acid Base Account results for the 11 coal reject samples from the Project (five coarse reject and six fine reject samples) are presented in **Table B3** (**Attachment B**) and summarised below. The results are shown by material type to facilitate interpretation.

- **pH:** The $pH_{(1:5)}$ of the 11 coal reject samples ranges from 4.5 to 8.4 and has a median pH value of 7.4 (**Graph 4-11**). The pH results indicate that bulk coal reject material generated at the Project will most likely add some alkalinity to any contact water as the pH of deionised water used in the pH tests is typically in the pH range of 5.0 to 6.5. The lowest pH value was obtained for one of the coarse reject samples however the remaining four coarse reject samples have a neutral to slightly alkaline pH value. On the basis of these results, it is expected that leachate from bulk coal reject materials will be pH neutral.



- **EC:** The current $EC_{(1:5)}$ of the coal reject samples ranges from 116 to 595 µS/cm and has a median value of 401 µS/cm (**Graph 4-12**). The highest EC is measured for the fine reject materials.



To provide additional context, the $EC_{(1:5)}$ and $pH_{(1:5)}$ results for coal reject are classified against pH and salinity criteria for mining waste materials, as defined by the Queensland DME (1995) technical guidelines for the environmental management of exploration and mining in Queensland (see **Table 4-3**).

Table 4-3: Salinity and pH criteria for assessment of coal reject samples

Coal Reject	Very Low	Low	Medium	High	Very High
$pH_{1:5}$	< 4.5	4.5 – 5.5	5.5 – 7.0	7.0 – 9.0 (Median – 7.4)	> 9.0
$EC_{1:5}$ (µS/cm)	< 150	150 – 450 (Median – 401)	450 – 900	900 – 2,000	> 2,000

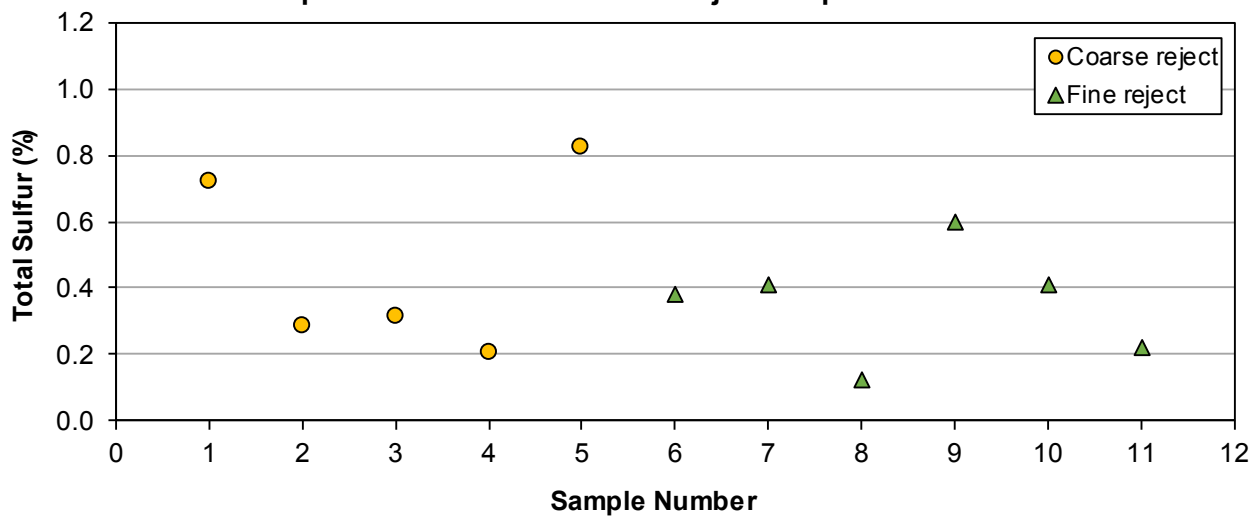
Note: Adapted from DME, 1995. Highlighted cells show the category corresponding to the median pH and EC values (orange shading) for the coal reject samples.

Based on the median pH and EC values, the coal reject samples tested are generally regarded as having a slightly 'High' soil pH and 'Low' salinity characteristics, as indicated by the distribution of samples corresponding to each pH and salinity class.

The pH and EC tests were completed on pulverised samples (≤ 75 µm) with a large surface area in contact with the leaching solution, thereby providing greater potential for dissolution and reaction, and represent an initial 'worst case' scenario. While sulfide oxidation in some coal reject materials may contribute to increases in the salinity of leachate in the short term, it is expected that in the longer term the salinity from bulk coal reject materials will stabilise and potentially diminish over time at a concentration relative to the weathering/erosion of the materials as salts are flushed from the material matrix and a state of equilibrium develops.

Sulfur: The total sulfur content of the 11 coal reject samples ranges from 0.12 to 0.82% S and has an elevated median value of 0.38% S, compared with the median crustal abundance value of 0.07% S in unmineralised soils (Bowen, 1979; INAP, 2022). **Graph 4-13** illustrates the total sulfur content of the coal reject materials. The results demonstrate that most samples have a total sulfur concentration greater than median crustal abundance.

Graph 4-13: Total sulfur for coal reject samples



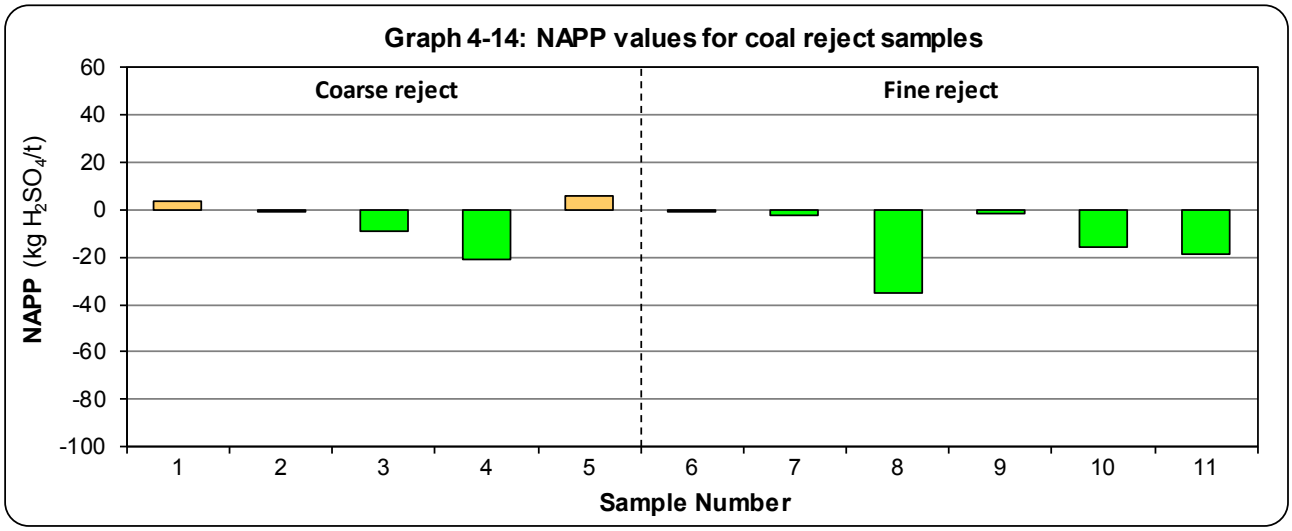
Sulfide sulfur: Due to the elevated total sulfur content of most of the coal reject samples, all of the samples were tested for sulfide using the Scr method. The test results show that on average, approximately 40% of the total sulfur is present as sulfide and the remainder of the total sulfur is likely to be present as organic sulfur or sulfate.

MPA: Based on the sulfide content, the MPA that could be generated by the 11 coal reject samples ranges from 0.6 to 17.4 kg H_2SO_4/t, and has a moderate median value of 4.7 kg H_2SO_4/t.

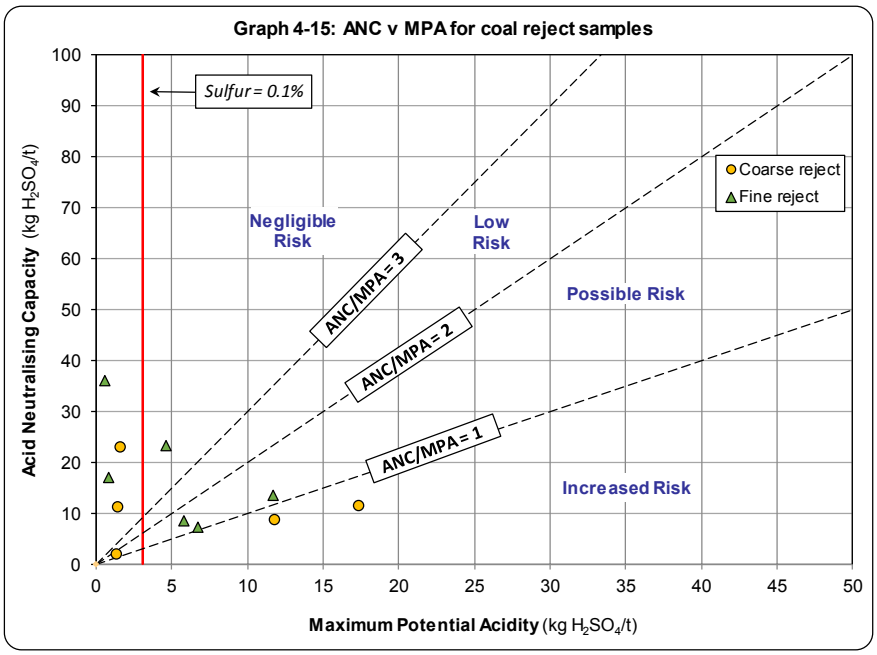
ANC: The ANC for the 11 coal reject samples ranges from 1.8 to 36 kg H_2SO_4/t and has a median value of 11.3 kg H_2SO_4/t, which is over twice the median MPA.

ANC:MPA ratio: The ANC:MPA ratio of the 11 coal reject samples ranges from 0.6 to 65.3 (median of 1.5). In simplistic terms, this means that most coal reject materials have excess ANC over MPA.

NAPP: The calculated NAPP values range from -35.4 to +6.1 kg H_2SO_4/t, with a negative median value of -2.7 kg H_2SO_4/t. The NAPP data is presented in **Graph 4-14** and shows that while most of the coal reject samples have negative NAPP value or a value that is close to zero, two coarse reject samples have a slightly positive NAPP value. Overall, as a bulk mixed material, the risk of generating any significant amounts of acidity from these materials is considered to be low.



Graph 4-15 shows a plot of ANC versus MPA for the 11 samples tested by material type from the Vulcan and Jupiter targets, respectively. ANC:MPA ratio lines have been plotted on the figures to illustrate the factor of safety associated with the samples in terms of potential for generation of acidity. Those samples with an ANC:MPA ratio of greater than 2 and a sulfide content of <0.1% S are considered to represent material with a high factor of safety and a very low risk of generating acidity (COA, 2016c; INAP, 2022).



The Acid Base Account result show that six coal reject samples plot in the negligible to low-risk domains, three samples plot in the possible risk domain (i.e., the ANC:MPA ratio is between 1 and 2) and two (coarse reject) samples plot in the increased risk domain (i.e., the ANC:MPA ratio is less than 1). Overall, as a bulk mixed material it is expected that the coal reject materials will have a relatively low risk of generating acid.

Coal rejects produced at the Project will be co-disposed with waste rock material. From a geochemistry viewpoint, co-disposal of any coarse and fine reject materials would be beneficial. Coal reject materials typically remain moist and any oxidation will only occur at surface (i.e., the fine reject will fill the gaps between the coarse reject particles and generally limit oxygen ingress). Similarly, disposal of a small amount of mixed coarse and fine reject materials within waste rock cells would be beneficial as waste rock typically has very low sulfur content and excess ANC. This approach to coal reject management has been successfully used at a number of existing coal mining operations in the Bowen Basin including Middlemount Coal Mine (RGS, 2013).

Table 4-4 provides a summary of the geochemical classification criteria used by RGS to classify the acid forming nature of the coal reject samples, and a breakdown of the number of samples in each classification category.

Table 4-4: Geochemical classification criteria for coal reject materials

Geochemical Classification	Total Sulfur[1] (%)	NAPP (kg H_2SO_4/t)	ANC:MPA Ratio	No. Samples (n = 11)
Non-Acid Forming (Barren)[2]	≤ 0.1	-	-	5
Non-Acid Forming	> 0.1	≤ -5	≥ 2	1
Uncertain	> 0.1	> -5 and ≤ +5	< 2	4
Potentially Acid Forming	> 0.1	> +5	< 2	1

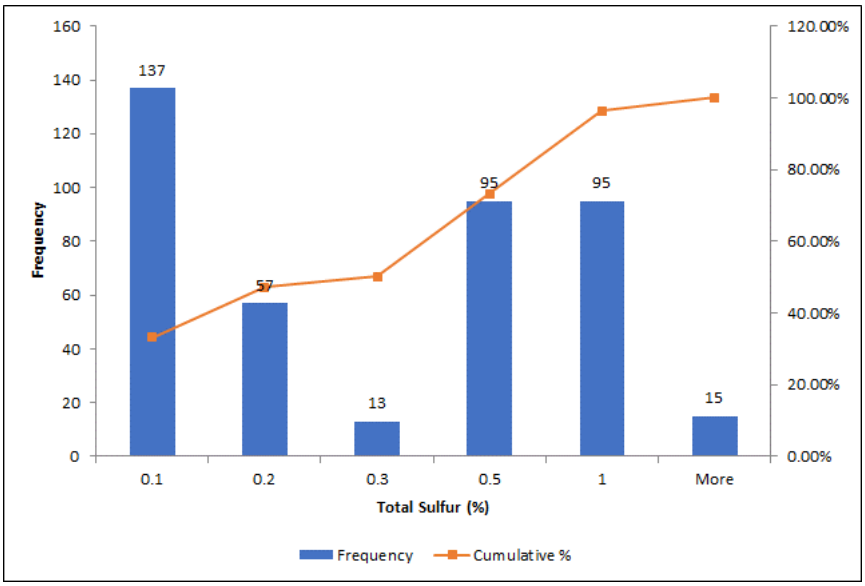
Notes:
1. If total sulfur is less than or equal to 0.1% S, the NAPP and ANC:MPA ratio are not required for material classification as the sample is essentially barren of oxidisable sulfur.
2. A sample classified as NAF can be further described as 'barren' if the total sulfur and/or sulfide sulfur content is less than or equal to 0.1% S, as the sample essentially has negligible acid generating capacity.

The Acid Base Account test data presented in **Table B3 (Attachment B)** and discussed in this section have been used to classify the acid forming nature of the 11 coal reject samples tested. The results in **Table 4-4** demonstrate that of the 11 samples tested, five samples are classified as NAF (Barren), one sample is classified as NAF, four samples are classified as Uncertain and one sample is classified as PAF. The classification criteria reflect Australian (COA, 2016c) and international (INAP, 2022) guidelines for the classification of mining waste materials.

Overall, the Acid Base Account results confirm that most of the coal reject materials represented by the samples tested have relatively low sulfide content, excess ANC, and are classified as NAF. As a bulk mixed material, it is expected that coal reject will have a relatively low risk of generating acidic drainage. Co-disposal of coarse and fine reject materials and subsequent disposal with waste rock materials is likely to be beneficial and eliminate any residual risk.

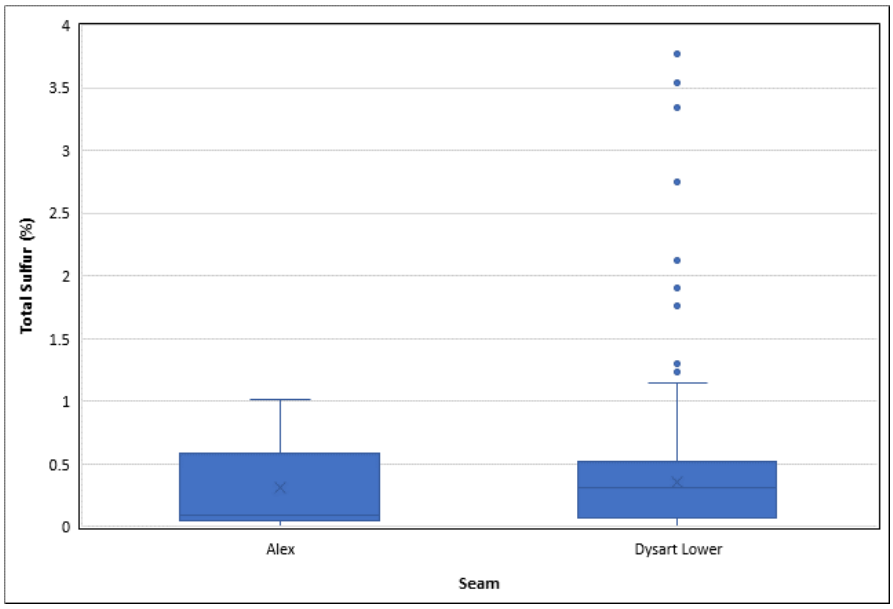
4.1.3 Coal

Seepage may occur from mined coal temporarily stockpiled at the ROM area prior to processing at the CHPP. Based on the total sulfur content of a range of coal samples from the target seams (Alex and Dysart Lower) (412 samples) it is likely that the coal materials will have similar geochemical characteristics to the coal reject materials described in **Section 4.1.2**. **Graph 4-16** shows the total sulfur distribution in raw coal materials for the target coal seams. The results demonstrate that approximately 75% of the raw coal material represented by the samples tested has a relatively low total sulfur content <0.5% S. It should also be noted that approximately half of the total sulfur content is likely to be present as organic sulfur which has negligible capacity to generate acid.



Graph 4-16: Total sulfur distribution for raw coal samples

Graph 4-17 shows a "box and whisker" total sulfur plot for the target Alex and Dysart Lower coal seams using the same dataset (412 samples) used to generate **Graph 4-16**. The results show that the mean, median and 75th percentile total sulfur values in coal are low and generally at or below 0.5% S. While a small number of higher total sulfur outliers occur for the Dysart Lower seam most samples have lower total sulfur content, Available sulfur speciation indicates that approximately half of the total sulfur will be present as organic sulfur, which has negligible capacity to generate acid.



Graph 4-17: Total sulfur "box and whisker" plot for raw coal samples

In terms of potential impacts from the ROM coal stockpile, it is expected that the quality of any leachate will be similar to that of coal reject materials described in **Section 4.1.2**. As is standard practice at coal mining operations in the Bowen Basin, any surface runoff and seepage from the ROM coal stockpile will be monitored for quality and managed in the mine water management system as part of the Water Management Plan.

4.2 Multi-Element Concentration in Solids

Multi-element scans were carried out on 10 mining waste samples (i.e., six composite samples of waste rock and four composite samples of coal reject materials) as described in **Section 3.2.1** to identify any elements (metals/metalloids) present at concentrations that may be of environmental concern with respect to materials handling, storage, revegetation and water quality.

To provide relevant context, RGS has compared the total metal/metalloid concentration in samples to National Environmental Protection Council (NEPC) Health-based Investigation Levels (HIL(C)) for soils in public open spaces (NEPC, 2013).

The results from multi-element testing (total metals/metalloids) of the 10 selected mining waste samples are presented in **Table B4 (Attachment B)**. The results indicate that the sample materials have low total metal and metalloid concentrations in solids below the applied NEPC (HIL(C)) guideline for soils.

The results from multi-element testing (total metals/metalloids) of the 10 selected mining waste samples are discussed with respect to median crustal abundance in un-mineralised soils in **Section 4.3**.

4.2.1 Geochemical Abundance Index

Total metal/metalloid concentrations in mining waste materials can be compared to the median crustal abundance for un-mineralised soils (Bowen, 1979, COA, 2016c and INAP, 2022). The extent of enrichment is reported as the Geochemical Abundance Index (GAI), which relates the actual concentration in a sample with the median (or average) crustal abundance on a $\log_{10}$ scale. The GAI is expressed in integer increments from 0 to 6, where a GAI value of 0 indicates that the element is present at a concentration less than, or similar to, the median crustal abundance; and a GAI value of 6 indicates approximately a 100-fold enrichment above median crustal abundance (see **Table 4-5**).

Table 4-5: Geochemical abundance index values and enrichment factors

GAI	Enrichment Factor	GAI	Enrichment Factor
0	Less than 3-fold enrichment	4	24 – 48 fold enrichment
1	3 – 6 fold enrichment	5	48 – 96 fold enrichment
2	6 – 12 fold enrichment	6	Greater than 96 fold enrichment
3	12 – 24 fold enrichment		

As a general rule, a GAI of 3 or greater signifies enrichment that may warrant further examination. This is particularly the case with some environmentally important ‘trace’ elements, such as arsenic, chromium, cadmium, copper, lead, selenium and zinc, more so than with major rock-forming elements, such as aluminium, calcium, iron, manganese and sodium.

Elements identified as enriched may not necessarily be a concern for revegetation, drainage water quality or public health, but their significance should still be evaluated. While the GAI provides an indication of metals/metalloids that may be enriched relative to the global average crustal abundance, the following points should also be considered:

- The median crustal abundance varies between different literature sources, thereby affecting the calculated GAI values.
- Samples that are enriched relative to the median crustal abundance, do not necessarily leach metals/metalloids at elevated concentrations. The mobility of metals/metalloids is dependent on mineralogy, adsorption/desorption and the environment in which it occurs.

Similarly, even if an element is not enriched, it does not mean it will never be a concern, as under some conditions (e.g., low pH) the solubility of common environmentally important elements, such as aluminium, copper, cadmium, iron and zinc increase significantly.

Table B4 (**Attachment B**) provides total metal/metalloid concentrations for the 10 composite mining waste samples described in **Section 3.2.1**. The relative enrichment of metals/metalloids in the samples compared to median crustal abundance (the Geochemical Abundance Index - GAI) is presented in **Table B5** (**Attachment B**).

The GAI results indicate that of the metals/metalloids measured, none of the 10 samples are enriched compared to median crustal abundance (i.e., all samples have a GAI < 3). While the concentration of selenium appears slightly elevated relative to median crustal abundance (GAI = 2) this is generally an artefact of the concentrations used in the GAI calculation (i.e., half the laboratory LoR of 5 mg/kg).

The potential solubility of any metals/metalloids in the sample materials was investigated further through water extract and KLC tests as presented in **Sections 4.4** and **4.5**, respectively.

A total of six composite waste rock samples were selected for physical characterisation as they are classified as NAF (Barren) and could potentially report to the outer surfaces of final landforms and could also be earmarked for use in other site infrastructure and rehabilitation works. The tests focussed on exchangeable cations and allowed calculation of the effective cation exchange capacity and exchangeable sodium percentage values. The test results and calculated values are provided in **Table B4** (**Attachment B**) and summarised below.

4.3 Soil Characteristics and Sodicity

4.3.1 Soil Characteristics

The effective cation exchange capacity (eCEC) results for the six composite waste rock samples are presented in **Table B4** (**Attachment B**). The results indicate that the eCEC of the six samples ranges from 4.8 to 18.6 meq/100g and is typically in the low to moderate range as described in **Table 4-6** (Hazelton and Murphy, 2007). The calcium:magnesium ratio is low and less than one in all samples tested. For waste rock materials with a low to moderate eCEC value and low calcium:magnesium ratio, some fertiliser and gypsum addition may be required to provide a reasonable growth medium for vegetation roots as part of revegetation and rehabilitation activities.

Table 4-6: Ratings for cation exchange capacity

eCEC Rating	CEC (meq/100g)
Very low	<6
Low	6 – 12
Moderate	12 – 25
High	25 – 40
Very high	>40

4.3.2 Sodicity

The exchangeable sodium percentage (ESP) results for the six composite waste rock samples are presented in **Table B4** (**Attachment B**). The ESP results for the samples range from 10.8 to 24.6% and are typically elevated as would be expected for waste rock (overburden/interburden) materials found in this part of the Bowen Basin. Generally, samples with ESP values less than 6% are considered non-sodic, and those greater than 14% are considered strongly sodic and may be susceptible to dispersion and erosion (Isbell, 2002; and Northcote and Skene, 1972). Sodicity can result in surface crusting, low infiltration and hydraulic conductivity within the affected soils (Hazelton and Murphy, 2007).

Overall, the results of the ESP tests indicate that most waste rock materials represented by these samples are likely to be moderately to strongly sodic; and consequently, may be susceptible to dispersion and erosion and should be managed appropriately. The addition of gypsum to sodic waste rock materials has the potential to reduce the sodicity and potential for dispersion and erosion.

4.4 Water Quality Static Tests

There are no specific regulatory criteria for metal/metalloid concentrations in leachate from mining waste materials on mine sites in Queensland. As such, RGS has compared the multi-element results in water extracts from the ten composite mining waste samples (six waste rock and four coal reject) from the Project, described in **Section 4.2**, with Australian guidelines for livestock drinking water and aquatic freshwater ecosystems (ANZECC & ARMCANZ, 2000; ANZG, 2018) guideline values. These guidelines are provided for context only and are not intended to be interpreted as “maximum permissible levels” for site water storage or discharge.

It should also be recognised that direct comparison of geochemical data with guideline values can be misleading. For the purpose of this study, guideline values are only provided for broad context and should not be interpreted as “maximum” values or “trigger” values. Using sample pulps (ground to pass a 75 µm sieve size) provides a very high surface area to solution ratio, which encourages mineral reaction and dissolution of the solid phase. Therefore, the results of screening tests on water extract solutions are assumed to represent a ‘worst case’ scenario for initial surface runoff and seepage from mining waste materials.

The results from multi-element testing of water extracts (1:5 solid:water) from the 10 mining waste samples are presented in **Table B6** (**Attachment B**). The pH of the water extracts for the waste rock samples representing the Vulcan target ranges from pH 8.2 to 8.6 and is considered to be slightly alkaline. The pH of the water extracts for the waste rock samples representing the Jupiter target ranges from 6.8 to 7.1 and is considered to be neutral. The pH of the water extracts for the four coal reject samples ranges from 5.8 to 8.6. In all cases it is expected that some alkalinity will be added to contact water from these materials as the deionised water used in the tests ranged from pH 5.4 to 5.7. The pH results for all samples (except one coarse reject sample) are within the range (pH 6 to 9) for 95% species protection in freshwater aquatic ecosystems as set out in ANZECC & ARMCANZ (2000) and ANZG (2018).

The water extracts from the 10 mining waste samples have moderate EC values ranging from 54 to 788 µS/cm, with higher values seen in the samples representing the Vulcan target (median 544 µS/cm) than those representing the Jupiter target (median 216 µS/cm) or coal reject (median 91 µS/cm), indicating low to moderate salinity levels (and low to moderate concentrations of dissolved solids).

The total alkalinity in the water extracts from the Vulcan waste rock samples ranges from moderate to elevated (564 to 2,980 mg $CaCO_3$/L). The total alkalinity from the two composite samples from the Jupiter target is lower and ranges from 34 to 144 mg $CaCO_3$/L. For the coal reject samples, the total alkalinity ranges from 24 to 1,032 mg $CaCO_3$/L. All of the alkalinity in the water extract samples is in the form of bicarbonate (HCO_3), with carbonate values being less than the laboratory LoR (1 mg/L). The acidity in the water extracts from the waste rock samples is generally low, ranging from less than the laboratory LoR (1 mg/L) to 3 mg $CaCO_3$/L for Vulcan samples, 5 to 8 mg $CaCO_3$/L for Jupiter samples, and 19 to 178 mg $CaCO_3$/L for coal reject samples, respectively, leading to a positive net alkalinity value for all samples.

The total concentration of major ions in the water extracts is dominated by bicarbonate, sodium, chloride and sulfate. The concentration of sulfate in the water extracts from all 10 samples ranges from 18 to 46 mg/L (median 29 mg/L), and therefore is more than an order of magnitude below the applied (ANZECC & ARMCANZ, 2000; ANZG, 2018) water quality guideline criterion (1,000 mg/L) for livestock drinking water for this anion.

The concentration of trace metals/metalloids tested in the water extracts is typically low and predominantly below the laboratory LoR. Most metal/metalloid concentrations tested in the water extracts are below the applied water quality guideline criteria. The main exceptions are aluminium (four samples) and copper (three samples), which have concentrations in some of the water extracts above the applied freshwater aquatic ecosystem water quality guideline value for 95% species protection (ANZECC & ARMCANZ, 2000; ANZG, 2018), but are below the applied guideline values for livestock drinking water.

Given that the pH values in the relevant water extracts are pH neutral to slightly alkaline, the elevated aluminium concentrations in these water extracts may in some part be due to the formation of colloidal materials in the water extracts, which can pass through the (0.45 µm filter) filtration stage used in the standard

laboratory preparation procedure. This can occur due to the physical preparation of the sample at the laboratory to pass a 75 µm particle size.

On the basis of these results, it is expected that the risk of potential impact on the quality of surface runoff and groundwater from bulk mining waste materials at the Project will be low. Based on the water extract results presented in this section, the quality of any leachate from any co-disposed coal reject materials would be similar to leachate at areas of the dumps where co-disposal does not occur.

The dynamic quality of mining waste contact water (if these materials are left exposed to the atmosphere (i.e., oxidising conditions) and any potential risk to water resources at the site was investigated further using KLC tests in **Section 4.5.**

4.5 Water Quality Kinetic Tests

KLC tests were completed on six composite samples of mining waste materials (four waste rock and two coal reject samples) using the methodology described in **Section 3.2.2** and **Attachment A**. The composition of the six composite samples used in the KLC tests is summarised in **Table 4-7** and detailed in **Table B7** (**Attachment B**). The six KLC tests cover the range of waste rock (sandstone, claystone and siltstone) and coal reject (coarse and fine reject) likely to be generated by the Project. The KLC tests on waste rock were operated for a period of six months from June 2019 to December 2019 under a monthly watering and leaching regime. The KLC tests on coal reject were operated from December 2019 to June 2020 under a monthly watering and leaching regime. The KLC tests were operated following mining industry guidelines for such tests (AMIRA, 2002; COA, 2016).

The leachate results from the KLC test program are presented alongside Australian water quality guideline values for livestock drinking water quality (ANZECC & ARCANZ, 2000; ANZG, 2018). These guidelines are provided for context only and are not intended to be interpreted as “maximum permissible levels” for site water storage or discharge. It should be noted that the KLC samples were crushed to pass a 10 mm sieve size, where required, and therefore have a high surface area for potential geochemical reaction. The ratio of sample to water in the KLC tests was approximately 3:1 (w/v) (i.e., concentrated), whereas the ratio of sample to water generally used in tests (where results can be compared against guideline concentrations to provide relevant context) is over an order of magnitude more dilute at 1:5 (w/v). Whilst approximate comparisons against guideline concentrations can be helpful in some situations to provide relevant context, such comparisons cannot be directly extrapolated to the field situation at the Project.

Table 4-7: Composite mining waste samples selected for KLC tests

KLC Sample Number	RGS Composite ID	Description
KLC1	Composite 2 Waste Rock	Mainly Vulcan sandstone
KLC2	Composite 4 Waste Rock	Mainly Vulcan claystone
KLC3	Composite 5 Waste Rock	Mainly Jupiter sandstone
KLC4	Composite 6 Waste Rock	Mainly Jupiter siltstone
KLC5	Composite Fine Reject	Vulcan Fine Reject
KLC6	Composite Coarse Reject	Vulcan Coarse Reject

The monthly KLC test results for the four composite waste rock samples are presented in **Attachment C**. Tables **KLC 1** to **KLC 4** provide the KLC test data for seven leach events on waste rock samples (over six months), selected components of which are also shown graphically. For the two coal reject samples (**KLC 5** and **KLC 6**), data from the seven leach events (over six months) is provided in **Attachment C**. The KLC test results indicate that:

- Leachate from the six KLC tests has a pH in the range of 5.55 to 8.27 over the test period. Whilst some pH fluctuations are noted within this range, the majority of pH values generally lie in the range pH 6 to 8. The lowest pH value is still greater than the deionised water used in the test program. Therefore, it is

likely that the mining waste materials add some alkalinity to contact/leaching water. These results suggest that pH values in any surface runoff and seepage from bulk mining waste materials exposed to oxidising conditions will be in the range pH 6 to 8.

- Leachate from the six KLC tests has an EC value in the range of 54 to 1,796 µS/cm over the test period. Most EC values in leachate show a downward trend over time; however, leachate from KLC1 (Vulcan Sandstone) shows and increasing EC trend, before reducing again at the end of the test period. These results indicate EC values from most bulk mining waste materials exposed to oxidising conditions will be low to moderate. The slightly elevated EC value in the initial 'first flush' from the some of the mining waste sample materials is probably due to the increased solubility of minerals through crushing/preparation of the sample materials before loading into the KLC test columns.
- The acidity value in leachate from the six KLC tests over the test period is very low, ranging from below the laboratory LoR (<1 mg/L, as $CaCO_3$) to 8 mg/L. The alkalinity values in leachate from the KLC tests are also relatively low, but generally more than sufficient to create net alkalinity values that are either positive or close to zero (i.e., the alkalinity is predominantly greater than the acidity) during the test period.
- The concentration of major ions in leachate from the six KLC tests is typically dominated by variable concentrations of sodium, chloride and sulfate (and bicarbonate). Lower concentrations of other major ions are also likely to be present in leachate from these materials. The concentration of calcium in leachate from the fine rejects (KLC 5) is an order of magnitude greater than observed in leachate from the other KLC tests.
- The sulfate release rate from the six KLC samples generally shows a relatively stable trend over the test period for most samples. The exception is the sulfate release rate from the fine rejects sample which increases before decreasing towards the end of the test period. The highest sulfate release rate is displayed by the fine rejects (KLC 5). Notwithstanding, the sulfate concentration in leachate from all of the KLC tests is well below the applied guideline value of 1,000 mg/L (ANZECC & ARMCANZ, 2000; ANZG, 2018).
- The four waste rock materials used in the KLC tests retain at least ~81.3% of their inherent total sulfur content after six months of exposure to idealised oxidising conditions, which reflects a slow rate of sulfide oxidation (and low potential for acid generation) for these materials. The two coal reject samples show similar characteristics and retain at least 95% of their inherent total sulfur content at the end of the six month test period.
- The four KLC waste rock samples retain at least ~99.1% of their inherent ANC value after six months of exposure to idealised oxidising conditions, which reflects the slow release of alkalinity from these materials. The two coal reject samples show similar sample characteristics and retain at least 88% of their inherent ANC value at the end of the six month test period.
- The concentration of trace metals/metalloids in the leachate from the six KLC tests is generally low and typically below the laboratory LoR. Most trace metals/metalloids are therefore sparingly soluble at the current pH of the KLC leachate. The concentrations of all metals/metalloids are typically below the applied water quality guideline criteria for livestock drinking water (ANZECC & ARMCANZ, 2000; ANZG, 2018). The only exception is selenium in some of the leachate collected from the two coal reject samples, which show concentrations marginally above the livestock drinking water low risk trigger levels (0.02 mg/L). Based on the KLC results presented in this section, the quality of leachate from any co-disposed coal reject materials in terms of trace metal/metalloid concentrations would be similar to leachate at areas of the dumps where co-disposal in cells was not used.
- The sulfate generation rate results obtained for the six KLC test samples have been used to determine the rate of sulfide oxidation in these materials. Most sulfate salts generated from sulfide reaction involving materials with a relatively low sulfide sulfur concentration are highly soluble, and therefore will be collected in column leachate. The dissolved sulfate (and calcium) concentrations in most of the KLC leachate are typically much less than the solubility limit of gypsum ($CaSO_4$), for example, which indicates that sulfate generation is not controlled by gypsum dissolution in the KLC test materials. Therefore, the sulfate

concentrations and oxidation rate calculations provide reasonable estimates of these parameters and the results align well with existing static and dynamic geochemical data derived from a wide range of mining waste materials (AMIRA, 1995). The sulfate generation rate and associated sulfide oxidation rate for the KLC tests are shown in **Table 4-8**.

- The sulfate generation rate from the KLC samples ranges from 1.71 to 24.78 mg/kg/week which is equivalent to a sulfide oxidation rate ranging from 6.99 x 10^{-10} to 1.01 x 10^{-8} kg $O_2/m^3/s$. Mining waste materials with an oxidation rate less than 5 x 10^{-8} kg $O_2/m^3/s$ and a moderate ANC level have an increased factor of safety and are likely to generate leachate that is pH neutral and/or has a low level of acidity (AMIRA, 1995; Bennett *et al*., 2000). Hence, all of the mining waste materials tested fall into this category. Overall, the KLC results reflect the range of material characteristics predicted from the static geochemical test results shown in **Section 4.1**.

  Potential implications of these results with respect to the management of the mining waste materials at the Project are discussed further in **Section 5.**

Table 4-8: Sulfate generation and sulfide oxidation rates for KLC tests

KLC Sample Number	Sample Description	Sulfate Generation Rate (mg/kg/week)	Oxidation Rate (kg $O_2/m^3/s$)
KLC1	Vulcan sandstone	3.42	1.37 x 10^{-9}
KLC2	Vulcan claystone	1.71	6.99 x 10^{-10}
KLC3	Jupiter sandstone	3.97	1.66 x 10^{-9}
KLC4	Jupiter siltstone	4.32	1.78 x 10^{-9}
KLC5	Fine reject	24.78	1.01 x 10^{-8}
KLC6	Coarse reject	7.82	3.18 x 10^{-9}

5 DISCUSSION

5.1 AMD Potential and Management

The results of the static and kinetic geochemical tests demonstrate that the overwhelming majority of the waste rock materials contain negligible sulfide content, have excess ANC, and are classified as NAF. These samples represent materials with a very low risk of acid generation and a high factor of safety with respect to generating acidic drainage.

The static and kinetic geochemical test results for coal reject demonstrate that most of the coal reject materials represented by the samples tested have relatively low sulfide content and excess ANC. As a bulk mixed material, it is expected that coal reject will be classified as NAF and have a relatively low risk of generating acidic drainage. Based on the KLC results presented in **Section 4.5**, apart from slightly elevated sulfate, it is expected that the quality of leachate from any coal reject materials co-disposed with waste rock would be similar to leachate from areas of the dumps where co-disposal does not occur.

It is expected that from a geochemistry viewpoint, co-disposal of coarse and fine reject materials within waste rock dumps would be beneficial. This is because coal reject materials typically remain moist and any oxidation will only occur at surface (i.e., the fine reject will fill the gaps between the coarse reject particles and generally limit oxygen ingress). The coarse rejects also would also provide some geotechnical stability to a mixed reject cell structure. The disposal of mixed coarse and fine reject materials within waste rock dumps is also a low-risk strategy as the much larger volume of waste rock typically has very low sulfur content and excess ANC. This mining waste management strategy is currently used at a number of coal mines in the Bowen Basin.

Further management measures to reduce the risk of the generation of AMD are presented in **Section 5.4**.

5.2 Multi-Element Composition and Water Quality

5.2.1 Multi-Element Composition and Enrichment

The multi-element concentrations of metal/metalloids in mining waste materials are presented in **Section 4.2**, along with a comparison against applied guideline values and median crustal abundance in soils. The results indicate that the mining waste materials are not significantly enriched with metals/metalloids compared to guideline values and median crustal abundance in un-mineralised soils.

5.2.2 Water Quality

The static and kinetic geochemical test results presented in this report indicate that the surface runoff and seepage from NAF mining waste materials is likely to be pH neutral to slightly alkaline and have a low to moderate EC value indicating low to moderate salinity levels (and low to moderate concentrations of dissolved solids). Surface runoff and seepage from mining waste materials is likely to fall within the range for 95% species protection in freshwater aquatic ecosystems (pH 6 to 9) as set out in ANZECC & ARMCANZ (2000) and ANZG (2018).

The major ion concentrations in leachate from mining waste materials are relatively low and dominated by sodium, chloride, bicarbonate and sulfate. Lower concentrations of other major ions are also likely to be present in leachate from these materials. The sulfate concentration in leachate from all mining waste samples is well below the applied ANZECC & ARMCANZ and ANZG stock water quality guideline criterion (1,000 mg/L).

The water extract and KLC test results for mining waste materials indicate that most trace metals/metalloids are sparingly soluble, and that the concentration of dissolved metals/metalloids in surface runoff and seepage is relatively low, predominantly below the laboratory LoR, and below the applied water quality guideline criteria. Minor exceptions may include aluminium, copper and selenium in pore water, which can occasionally be greater than the applied guideline concentrations (ANZECC & ARMCANZ, 2000; ANZG, 2018) in selected samples. The KLC test data over the test period indicates that the concentrations of most dissolved trace metal/metalloid in contact water are typically low and well within applied livestock drinking water guideline values.

Whilst significantly elevated metal/metalloid concentrations in contact water are not expected at the Project, it is recommended that the suite of metals/metalloids described in the static and KLC test in this report be included from time to time, where appropriate, in the site water quality monitoring program.

It is recommended that samples of surface runoff and seepage from areas used to store mining waste materials and coal be included in the site water quality monitoring program.

5.3 Revegetation and Rehabilitation

From a soil chemistry viewpoint, bulk waste rock materials are classified as NAF and are likely to be pH neutral to slightly alkaline and have low to moderate levels of salinity. Most waste rock materials may be susceptible to dispersion and erosion, although these material characteristics may be improved to some extent by the addition of gypsum. In addition, fertiliser supplementation may also need to be considered for surface mining waste materials for the purpose of providing a reasonable growth medium for revegetation and rehabilitation.

Additional confirmatory sampling and testing should be completed on bulk mining waste materials when available during the operational phase of the Project to determine the best management option for progressive rehabilitation of these materials during operations and at mine closure. Sampling should focus on collecting representative samples of any waste rock (i.e., spoil) materials planned to be used at the surface of final landforms to supplement any existing subsoil and topsoil salvaged re-used in revegetation and rehabilitation activities. Testing should include typical soil parameters including pH, EC, exchangeable cations, organic matter, total organic carbon, Emerson aggregate, particle size distribution, and nutrients (including available K, P, S, as well as nitrogen (N) species (TKN, TN, nitrite and nitrate).

5.4 Management Measures

Table 5-1 provides a summary how the waste rock, coal reject and coal materials will be managed through all stages of the mine life including construction, operations, rehabilitation and decommissioning.

Table 5-1: Material management over mine life

Project Phase	Waste Rock	Coal Rejects	Coal
Construction	Stored at out-of-pit WRD	None produced	None produced
Operations	Stored at out-of-pit WRD and/or backfilled in-pit.	Co-disposed / backfilled within cells in-pit or ex-pit waste rock dumps. Contact water monitored for quality and managed in the mine water management system as part of Water Management Plan	Temporarily stockpiled at ROM and product coal stockpiles. Contact water monitored for quality and managed in the mine water management system as part of Water Management Plan
Rehabilitation	Final landforms rehabilitated/ revegetated	Final landforms rehabilitated/ revegetated	ROM removed and footprint rehabilitated/revegetated
Decommissioning	Final landform performance monitoring moving towards lease relinquishment	Final landform performance monitoring moving towards lease relinquishment	None

5.4.1 Waste Rock

5.4.1.1 Monitoring of waste rock material

This geochemical assessment has found that waste rock has low sulfur content, excess ANC, and is classified as NAF. Bulk waste rock has a high factor of safety and a very low risk of generating acid, saline or metalliferous drainage. Notwithstanding, monitoring of waste rock will continue throughout operations. Representative samples of any carbonaceous waste rock materials will be collected ahead of mining from blast hole drill cuttings to be assessed to identify any PAF material.

The drillhole cutting samples will be sent to an external National Association of Testing Authorities, Australia, (NATA) accredited laboratory for total sulfur (LECO analyser) analysis.

The geochemical assessment has demonstrated that bulk waste rock materials have very low total sulfur content and samples with a total sulfur content up to 0.3 %S are either NAF or very low risk. This finding is consistent with other open cut coal mines in this area of the Bowen Basin, which mine similar coal measures within similar stratigraphy. Therefore, a total sulfur cut-off value of 0.3 % will be used to identify any carbonaceous waste rock that may have a reduced factor of safety (possibly PAF).

5.4.1.2 Management of PAF waste rock material

Whilst the results of this assessment indicate that the occurrence of any PAF materials is unlikely, if any carbonaceous waste rock is identified as having a reduced factor of safety (possibly PAF) through sampling and total sulfur analysis, this will be selectively handled and buried within NAF waste rock in a manner similar to that described for coal rejects in **Table 5-1**. Short term planning and truck management planning will be updated upon identification of any carbonaceous waste rock that is possibly PAF to ensure that this material is hauled directly to the correct emplacement areas used for storing coal rejects and without storage in temporary stockpiles.

Any carbonaceous waste rock material identified as possibly PAF (and all coal reject materials) will be preferentially stored in the in-pit waste rock dumps when sufficient capacity is available and below predicted post-mining groundwater level, where practical, to reduce the potential oxidation of materials in the longer term post-closure (**Figure 5-1**). Early in the mine life when there is insufficient storage capacity within the open pit areas, possibly PAF carbonaceous waste rock (and all coal rejects) will be stored in ex-pit emplacements (**Figure 5-2**). In all cases, these materials will be buried in the core of the waste rock emplacements, at least 5 m away from final outer surfaces of the emplacements and under at least 5 m of NAF waste rock materials[6]. To further minimise any risk associated with out-of-pit emplacements, any PAF carbonaceous waste rock (and all coal reject materials) will be placed within areas that slope/drain toward the open pit and any seepage will be monitored and managed within the mine water management system as part of the Water Management Plan.

The extents of any PAF carbonaceous waste rock (and all coal reject materials) transferred to emplacement areas will be tracked with regular surveys. Spatial data files in an appropriate format will be created to record the extents/dimensions of the storage areas.

All possibly PAF carbonaceous waste rock and all coal reject materials will be paddock dumped, traffic compacted and covered by NAF overburden to limit the infiltration of air and water into covered materials.

5.4.1.3 Emplacement sampling and testing

To confirm the effectiveness of the waste rock (and coal reject) management procedures, strategic sampling and total sulfur testing of emplaced materials will be undertaken on an annual basis over the operational life of the Project. The results of this process will be used to validate that emplacements are being constructed

[6] If sufficient NAF waste rock material is available then the 5 m of NAF waste rock should be increased to 10 m of NAF waste rock.

according to design specifications and that any PAF carbonaceous waste rock (and all coal reject materials) are encapsulated with at least 5 m of NAF waste rock materials[6].

Representative samples of emplaced materials will be collected and analysed externally by a NATA accredited laboratory for total sulfur . As above, samples with a total sulfur concentration a total sulfur concentration of less than or equal to 0.3 %S will be classified as NAF and greater than 0. 3 %S will be classified as PAF.

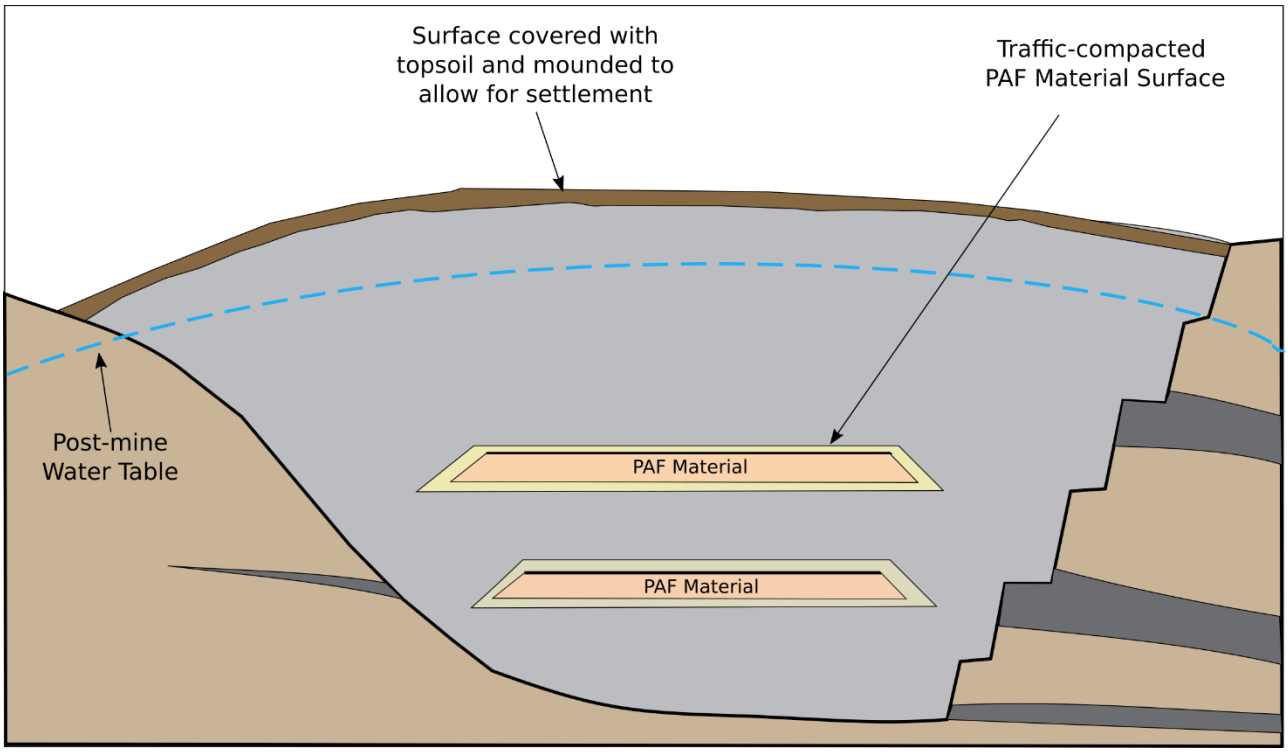


Figure 5-1: Schematic cross-section of in-pit PAF material emplacements

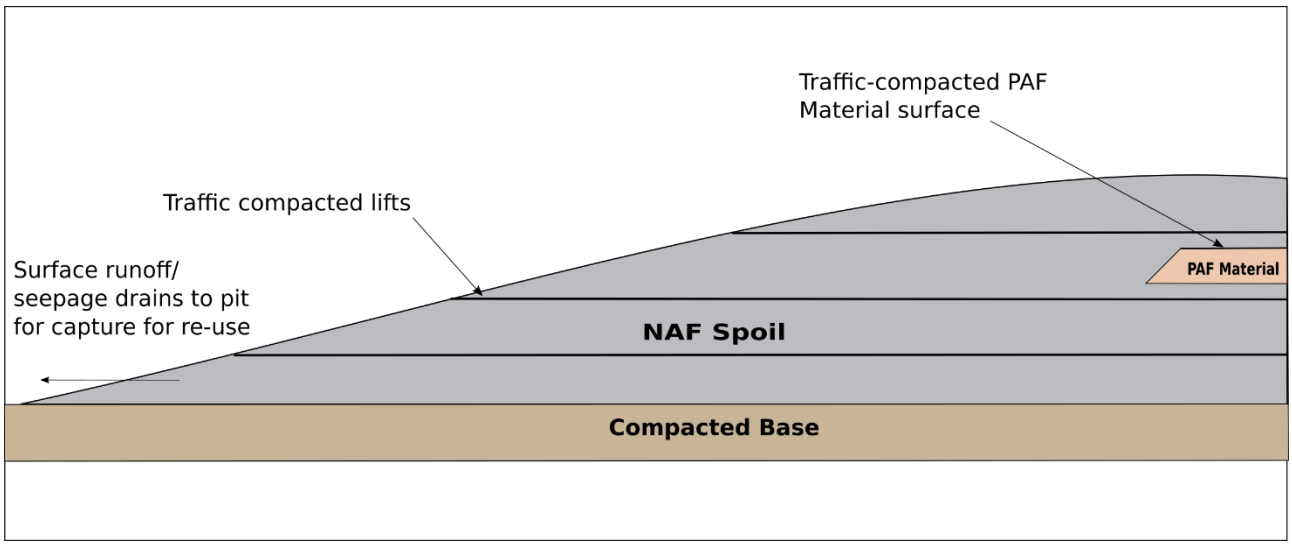


Figure 5-2: Schematic cross-section of ex-pit PAF material emplacement

5.4.2 Coal Rejects

As a bulk mixed material, it is expected that coal reject will have a relatively low risk of generating acidic drainage. Notwithstanding, co-disposal of coarse and fine reject materials and subsequent encapsulation within NAF waste rock materials is likely to be beneficial and eliminate any residual risk.

If it is assumed that up to 10 % of ROM coal will become coal reject at the CHPP, less than 2 % by volume of the materials in the emplacements will be coal rejects. As described in **Table 5-1** and **Section 5.4.1.2**, coal rejects will be preferentially placed within in-pit dumps, below the predicted post-mining groundwater table. Coal rejects will be co-disposed with any identified possibly PAF carbonaceous waste rock materials and traffic compacted which will minimise the available pore space within any PAF materials, reducing the risk of the any AMD generation by limiting the ingress of oxygen and water into the pore spaces. Rejects will be placed sufficiently deep within the emplacements that they are covered with a minimum of 5 m of NAF material and no closer than 5 m to the external surfaces of the emplacements[6]. If coal rejects are placed in ex-pit dumps they will be traffic compacted and covered as soon as practicable. Drainage from ex-pit dumps will be captured and directed toward the mine void. A risk assessment of the emplacement of coal rejects within ex-pit dumps is included in **Attachment E**.

5.4.3 Coal Rejects

As a bulk mixed material, it is expected that coal will have a relatively low reactive sulfur content and subsequently a low risk of generating AMD. Notwithstanding, seepage may occur from mined coal temporarily stockpiled at the ROM area prior to processing and in coal product stockpiles following processing at the CHPP.

Any water seeping from the coal stockpiles will be monitored for quality and managed in the mine water management system as part of Water Management Plan as described in **Table 5-1**.

5.4.4 Water Quality Monitoring

Surface run-off and seepage from the waste rock and coal reject emplacement areas and coal stockpiles will be monitored for quality and managed in the mine water management system as part of Water Management Plan as described in **Table 5-1**.

5.4.5 Contingency Measures

In the unlikely event that AMD is identified in surface runoff and/or seepage from emplacement areas or coal stockpiles, Vitrinite will investigate the potential source of the issue and implement any required additional sampling and testing measures. Remediation options may include addition of agricultural limestone to any identified PAF materials during placement and/or reducing the amount of time that any identified PAF material is exposed to weathering conditions prior to covering with NAF material.

6 CONCLUSIONS

RGS has completed a geochemistry assessment of mining waste (waste rock and coal reject) and coal materials at the Project. The main findings of the assessment are as follows:

- The overwhelming majority of the waste rock materials have low sulfide content, excess ANC, and are classified as NAF (Barren). These materials have a very low risk of acid generation and a high factor of safety with respect to potential for generation of acidity.
- Coal reject materials have relatively low sulfide content and excess ANC. As a bulk mixed material, it is expected that coal reject will be classified as NAF and have a relatively low risk of generating acidic drainage. Co-disposal of reject materials in waste rock dumps is likely to have a beneficial impact on the quality of the reject leachate.
- Coal is likely to have similar geochemical characteristics to coal reject materials and will be temporarily stockpiled at the ROM area prior to being transferred to the CHPP. As is standard practice at coal mining operations in the Bowen Basin, any surface runoff and seepage from the ROM coal stockpile will be monitored for quality and managed in the mine water management system as part of the Water Management Plan.
- Initial and ongoing surface runoff and seepage from mining waste materials is expected to be pH neutral to slightly alkaline and have a low level of salinity.
- There is no significant metal/metalloid enrichment in mining waste materials compared to applied guideline values and median crustal abundance in un-mineralised soils.
- Most metals/metalloids are sparingly soluble at the neutral to slightly alkaline pH of leachate expected from bulk NAF mining waste materials. Dissolved metal/metalloid concentrations in surface runoff and leachate from bulk NAF mining waste materials are expected to be low and unlikely to pose a significant risk to the quality of surface and groundwater resources at relevant storage facilities.
- NAF waste rock materials should be amenable to revegetation as part of rehabilitation activities, although, gypsum and fertiliser addition may need to be considered for sodic materials to limit dispersion and erosion and to provide a reasonable growth medium for revegetation and rehabilitation.

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Attachment A Geochemical Assessment of Mining Waste Materials

GEOCHEMICAL ASSESSMENT OF MINING WASTE MATERIALS

ACID GENERATION AND PREDICTION

Acid generation is caused by the exposure of sulfide minerals, most commonly pyrite (FeS_2), to atmospheric oxygen and water. Sulfur assay results are used to calculate the potential acidity that could be generated by the sample typically by determining the sulfidic S content directly. Pyrite reacts under oxidising conditions to generate acid according to the following overall reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \text{ ---> } Fe(OH)_3 + 2\ H_2SO_4$$

According to this reaction, the maximum potential acidity (MPA) of a sample containing 1% S as pyrite would be 30.6 kg H_2SO_4/t. The chemical components of the acid generation process consist of the above sulfide oxidation reaction and acid neutralization, which is mainly provided by inherent carbonates and to a lesser extent silicate minerals. The amount and rate of acid generation is determined by the interaction and overall balance of the acid generation and neutralisation components.

Net Acid Producing Potential

The net acid producing potential (NAPP) is used as an indicator of materials that may be of concern with respect to acid generation. The NAPP calculation represents the balance between the maximum potential acidity (MPA) of a sample, which is derived from the sulfide sulfur content, and the acid neutralising capacity (ANC) of the material, which is determined experimentally. By convention, the NAPP result is expressed in units of kg H_2SO_4/t sample. If the capacity of the solids to neutralise acid (ANC) exceeds their capacity to generate acid (MPA), then the NAPP of the material is negative. Conversely, if the MPA exceeds the ANC, the NAPP of the material is positive. A NAPP assessment involves a series of analytical tests that include:

Determination of pH and EC

pH and EC measured on 1:5 w/w water extract. This gives an indication of the inherent acidity and salinity of the waste material when initially exposed in a waste emplacement area.

Total sulfur content and Maximum Potential Acidity (MPA)

Total sulfur content is determined by the Leco high temperature combustion method. The total sulfur content is then used to calculate the MPA, which assumes that the entire sulfur content is present as reactive pyrite. Direct determination of the pyritic sulfur content can provide a more accurate estimate of the MPA.

Acid neutralising capacity (ANC)

By addition of acid to a known weight of sample, then titration with NaOH to determine the amount of residual acid. The ANC measures the capacity of a sample to react with and neutralise acid. The ANC can be further evaluated by slow acid titration to a set end-point in the Acid Buffering Characteristic Curve (ABCC) test through calculation of the amount of acid consumed and evaluation of the resultant titration curve.

Net Acid Generation (NAG)

The net acid generation (NAG) test involves the addition of hydrogen peroxide to a sample of mine rock or process residue to oxidise reactive sulfide, then measurement of pH and titration of any net acidity produced by the acid generation and neutralisation reactions occurring in the sample. A significant NAG result (i.e., final $NAG_{pH} < 4.5$) indicates that the sample is potentially acid forming (PAF) and the test provides a direct measure of the net amount of acid remaining in the sample after all acid generating and acid neutralising reactions have taken place. A $NAG_{pH} > 4.5$ indicates that the sample is non-acid forming (NAF). The NAG test can provide a direct assessment of the potential for a material to produce acid after a period of exposure and weathering and is used to refine the results of the theoretical NAPP predictions. The NAG test can be used as a stand-alone test but it is recommended that this only be considered after site specific calibration work is carried out. The standard NAG test is generally unsuitable for coal mining projects as the high organic content of some materials can cause erroneous results (Stewart et al., 2003; ACARP, 2008).

ASSESSMENT OF ELEMENT ENRICHMENT AND SOLUBILITY

In mineralised areas it is common to find a suite of enriched elements that have resulted from natural geological processes. Multi-element scans are carried out to identify any elements that are present in a material (or readily leachable from a material) at concentrations that may be of environmental concern with respect to surface water quality, revegetation and public health. The samples are generally analysed for the following elements:

Major elements	Al, Ca, Fe, K, Mg, Na and S.
Minor elements	As, B, Cd, Co, Cr, Cu, F, Hg, Mn, Mo, Ni, Pb, Sb, Se and Zn.

The concentration of these elements in samples can be directly compared with relevant state or national environmental and health-based concentration guideline criteria to determine the level of significance. Water extracts are used to determine the immediate element solubilities under the existing sample pH conditions of the sample. The following tests are normally carried out:

Multi-element composition of solids.

Multi-element composition of solid samples determined using a combination of ICP-mass spectroscopy (ICP-MS), ICP-optical emission spectroscopy (OES), and atomic absorption spectrometry (AAS).

Multi-element composition of water extracts (1:5 sample:deionised water).

Multi-element composition of water extracts from solid samples determined using a combination of ICP-mass spectroscopy (ICP-MS), ICP-optical emission spectroscopy (OES), and atomic absorption spectrometry (AAS).

Under some conditions (*e.g.* low pH) the solubility and mobility of common environmentally important elements can increase significantly. If element mobility under initial pH conditions is deemed likely and/or subsequent low pH conditions may occur, kinetic leach column test work may be completed on representative samples.

KINETIC LEACH COLUMN TESTS

Kinetic leach column (KLC) tests can be used to provide information on the reaction kinetics of mining waste materials. The major objectives of kinetics tests are to:

- Provide time-dependent data on the kinetics and rate of acid generation and acid neutralising reactions under laboratory controlled (or onsite conditions);
- Investigate metal release and drainage/seepage quality; and
- Assess treatment options such as addition of alkaline materials.

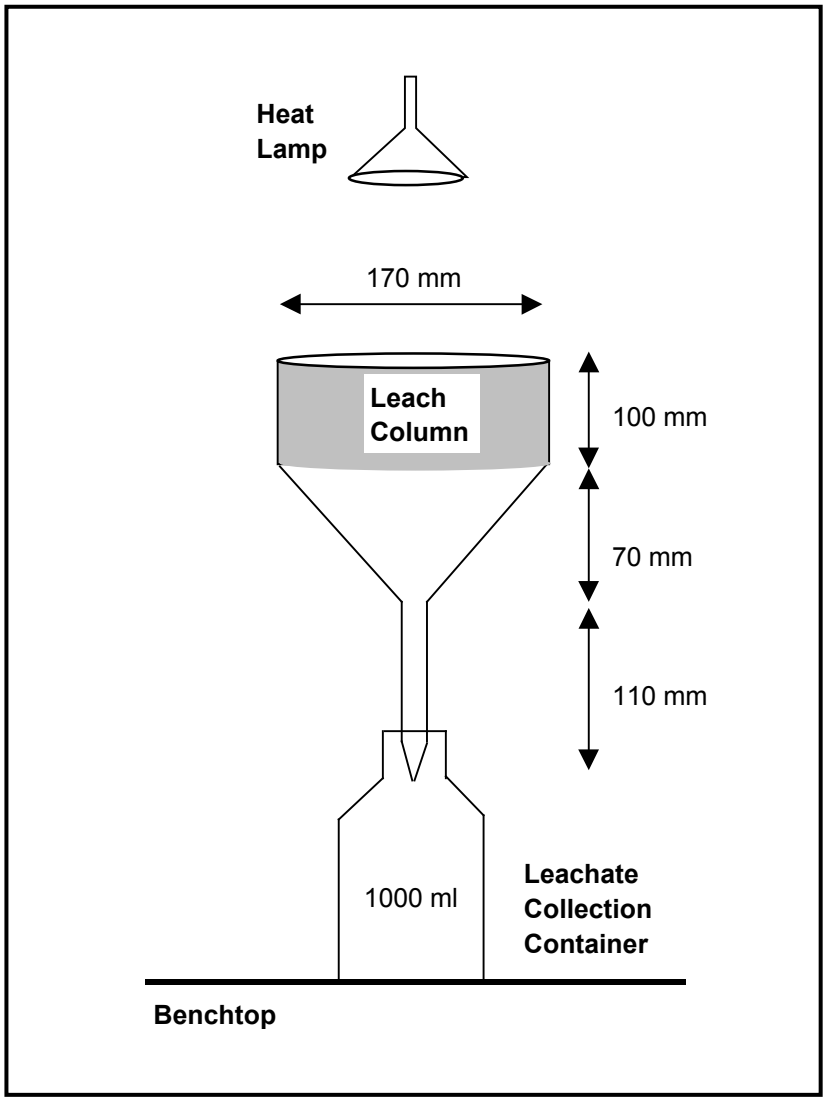
The KLC tests simulate the weathering process that leads to acid and base generation and reaction under laboratory controlled or site conditions. The kinetic tests allow an assessment of the acid forming characteristics and indicate the rate of acid generation, over what period it will occur, and what management controls may be required.

In KLC tests, water is added to a sample and the mixture allowed to leach products and by-products of acid producing and consuming reactions. Samples of leachate are then collected and analysed. Intermittent water application is applied to simulate rainfall and heat lamps are used to simulate sunshine. These tests provide real-time information and may have to continue for months or years. Monitoring includes trends in pH, sulfate, acidity or alkalinity, and metals, for example. The pH of the collected leachate simulates the acid drainage process, acidity or alkalinity levels indicate the rate of acid production and acid neutralisation, and sulfate production can be related to the rate of sulfide oxidation. Metal concentration data provides an assessment of metal solubility and leaching behaviour.

Figure A1 shows the kinetic leach column set up typically used by RGS adapted from *AMIRA, 2002*. The columns are placed under heat lamps to allow the sample to dry between water additions to ensure adequate oxygen ingress into the sample material.

Approximately 2 kg of sample is accurately weighed and used in the leach columns and depending on the physical nature of the material and particle size can be used on an as-received basis (i.e., no crushing as with process residues) or crushed to nominal 5-10 mm particle size (as with waste rock). The sample in the column is initially leached with deionised water at a rate of about 400 ml/kg of sample and the initial leachate from the columns collected and analysed. Subsequent column leaching is carried out at a rate of about 400 ml/kg per month and again collected and analysed. The leaching rate can be varied to better simulate expected site conditions or satisfy test program data requirements. The column must be exposed to drying conditions in between watering events. The residual water content and air void content in the column can be determined by comparing the wet and dry column weights. A heat lamp is generally used above the sample during daylight hours to maintain the leach column surface temperature at about 30°C.

Figure A1: Kinetic leach column setup



Attachment B Static Geochemical Test Results

Table B1: List of waste rock and coal reject samples

RGS Sample No.	ALS ID	Deposit	Vitronite Sample ID	Drillhole ID	Sample Lithology	Sample Type	From	To	Interval
							(m)		
Vulcan Prospect									
Overburden									
Composite 18	EB1914213018	Vulcan	134781	VSW082_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 26	EB1914213026	Vulcan	134789	VSW083_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 34	EB1914213034	Vulcan	163117	VSW084_C	Soil 100%	Overburden	0.0	3.0	3.0
Composite 36	EB1914213036	Vulcan	163119	VSW084_C	Sand 100%	Overburden	7.0	11.0	4.0
Composite 53	EB1914213053	Vulcan	163001	VSW087_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 54	EB1914213054	Vulcan	163002	VSW087_C	Soil 100%	Overburden	1.0	3.0	2.0
Composite 63	EB1914213063	Vulcan	163014	VSW088_C	Soil 100%	Overburden	0.0	3.0	3.0
Composite 70	EB1914213070	Vulcan	134807	VSW089_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 84	EB1914214014	Vulcan	134832	VSW092_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 91	EB1914214021	Vulcan	163038	VSW095_C	Soil 100%	Overburden	0.0	3.0	3.0
Composite 101	EB1914214031	Vulcan	163251	VSW099_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 109	EB1914214039	Vulcan	163233	VSW104_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 55	EB1914213055	Vulcan	163003	VSW087_C	Alluvium 100%	Overburden	3.0	4.0	1.0
Composite 93	EB1914214023	Vulcan	163041	VSW095_C	Alluvium 100%	Overburden	8.0	9.0	1.0
Composite 8	EB1914213008	Vulcan	145303	VSW070_C	Calcrete 100%	Overburden	6.0	7.0	1.0
Composite 37	EB1914213037	Vulcan	163120	VSW084_C	Gravel 100%	Overburden	11.0	14.0	3.0
Composite 39	EB1914213039	Vulcan	163122	VSW084_C	Gravel 100%	Overburden	16.0	18.0	2.0
Composite 4	EB1914213004	Vulcan	145166	VSW052_C	Conglomerate 100%	Overburden	30.0	32.4	2.4
Composite 5	EB1914213005	Vulcan	145167	VSW052_C	Conglomerate 100%	Overburden	32.4	37.4	5.0
Composite 9	EB1914213009	Vulcan	145304	VSW070_C	Sandstone 100%	Overburden	7.0	16.0	9.0
Composite 10	EB1914213010	Vulcan	145305 - 145306	VSW070_C	Sandstone 100%	Overburden	16.0	23.0	7.0
Composite 11	EB1914213011	Vulcan	145307	VSW070_C	Sandstone 100%	Overburden	23.0	25.0	2.0
Composite 21	EB1914213021	Vulcan	134784	VSW082_C	Sandstone 100%	Overburden	5.0	16.0	11.0
Composite 28	EB1914213028	Vulcan	134791	VSW083_C	Sandstone 100%	Overburden	4.0	20.0	16.0
Composite 41	EB1914213041	Vulcan	163124 - 163125	VSW084_C	Sandstone 100%	Overburden	19.0	26.0	7.0
Composite 43	EB1914213043	Vulcan	163127 - 163128	VSW084_C	Sandstone 100%	Overburden	27.0	37.0	10.0
Composite 56	EB1914213056	Vulcan	163004	VSW087_C	Sandstone 100%	Overburden	4.0	9.0	5.0
Composite 57	EB1914213057	Vulcan	163005 - 163006	VSW087_C	Sandstone 100%	Overburden	9.0	13.0	4.0
Composite 58	EB1914213058	Vulcan	163007 - 163009	VSW087_C	Sandstone 100%	Overburden	13.0	18.0	5.0
Composite 59	EB1914213059	Vulcan	163010	VSW087_C	Sandstone 100%	Overburden	18.0	21.0	3.0
Composite 66	EB1914213066	Vulcan	163018 - 163019	VSW088_C	Sandstone 100%	Overburden	12.0	18.0	6.0
Composite 67	EB1914213067	Vulcan	163020 - 163022	VSW088_C	Sandstone 100%	Overburden	18.0	23.0	5.0
Composite 68	EB1914213068	Vulcan	163023	VSW088_C	Sandstone 100%	Overburden	23.0	29.0	6.0
Composite 94	EB1914214024	Vulcan	163042 - 163043	VSW095_C	Sandstone 100%	Overburden	9.0	12.0	3.0
Composite 95	EB1914214025	Vulcan	163044	VSW095_C	Sandstone 100%	Overburden	12.0	14.0	2.0
Composite 97	EB1914214027	Vulcan	163046 - 163047	VSW095_C	Sandstone 100%	Overburden	15.0	18.0	3.0
Composite 98	EB1914214028	Vulcan	163048 - 163050	VSW095_C	Sandstone 100%	Overburden	18.0	24.0	6.0
Composite 99	EB1914214029	Vulcan	163201	VSW095_C	Sandstone 100%	Overburden	24.0	25.0	1.0
Composite 103	EB1914214033	Vulcan	163253 - 163254	VSW099_C	Sandstone 100%	Overburden	3.0	7.0	4.0
Composite 104	EB1914214034	Vulcan	163255 - 163256	VSW099_C	Sandstone 100%	Overburden	7.0	14.0	7.0
Composite 105	EB1914214035	Vulcan	163257 - 163258	VSW099_C	Sandstone 100%	Overburden	14.0	19.0	5.0
Composite 111	EB1914214041	Vulcan	163236	VSW104_C	Sandstone 100%	Overburden	4.0	7.0	3.0
Composite 112	EB1914214042	Vulcan	163237	VSW104_C	Sandstone 100%	Overburden	7.0	14.0	7.0
Composite 113	EB1914214043	Vulcan	163238 - 163240	VSW104_C	Sandstone 100%	Overburden	14.0	20.0	6.0
Composite 1	EB1914213001	Vulcan	145163	VSW052_C	Clay 100%	Overburden	0.1	5.0	4.9
Composite 2	EB1914213002	Vulcan	145164	VSW052_C	Clay 100%	Overburden	5.0	10.0	5.0
Composite 3	EB1914213003	Vulcan	145165	VSW052_C	Clay 100%	Overburden	25.0	30.0	5.0
Composite 6	EB1914213006	Vulcan	145301	VSW070_C	Clay 100%	Overburden	0.0	3.0	3.0
Composite 7	EB1914213007	Vulcan	145302	VSW070_C	Clay 100%	Overburden	3.0	6.0	3.0
Composite 19	EB1914213019	Vulcan	134782	VSW082_C	Clay 100%	Overburden	1.0	2.0	1.0
Composite 20	EB1914213020	Vulcan	134783	VSW082_C	Clay 100%	Overburden	2.0	5.0	3.0
Composite 27	EB1914213027	Vulcan	134790	VSW083_C	Clay 100%	Overburden	1.0	4.0	3.0
Composite 35	EB1914213035	Vulcan	163118	VSW084_C	Clay 100%	Overburden	3.0	7.0	4.0
Composite 38	EB1914213038	Vulcan	163121	VSW084_C	Clay 100%	Overburden	14.0	16.0	2.0
Composite 40	EB1914213040	Vulcan	163123	VSW084_C	Clay 100%	Overburden	18.0	19.0	1.0
Composite 46	EB1914213046	Vulcan	134797	VSW085_C	Clay 100%	Overburden	0.0	2.0	2.0
Composite 47	EB1914213047	Vulcan	134798 - 134799	VSW085_C	Clay 100%	Overburden	2.0	8.0	6.0
Composite 48	EB1914213048	Vulcan	1347800	VSW085_C	Clay 100%	Overburden	8.0	14.0	6.0
Composite 49	EB1914213049	Vulcan	1347801 - 1347802	VSW085_C	Clay 100%	Overburden	14.0	18.0	4.0
Composite 50	EB1914213050	Vulcan	1347803 - 1347804	VSW085_C	Clay 100%	Overburden	18.0	25.0	7.0
Composite 51	EB1914213051	Vulcan	1347805	VSW085_C	Clay 100%	Overburden	25.0	29.0	4.0
Composite 52	EB1914213052	Vulcan	1347806	VSW085_C	Clay 100%	Overburden	29.0	30.7	1.7
Composite 64	EB1914213064	Vulcan	163015 - 163016	VSW088_C	Clay 100%	Overburden	3.0	7.0	4.0
Composite 65	EB1914213065	Vulcan	163017	VSW088_C	Clay 100%	Overburden	7.0	12.0	5.0
Composite 71	EB1914214001	Vulcan	134808 - 134809	VSW089_C	Clay 100%	Overburden	1.0	3.0	2.0
Composite 72	EB1914214002	Vulcan	134810	VSW089_C	Clay 100%	Overburden	3.0	14.0	11.0
Composite 73	EB1914214003	Vulcan	134811	VSW089_C	Clay 100%	Overburden	14.0	16.0	2.0
Composite 74	EB1914214004	Vulcan	134812	VSW089_C	Clay 100%	Overburden	16.0	28.0	12.0
Composite 75	EB1914214005	Vulcan	134813	VSW089_C	Clay 100%	Overburden	28.0	30.2	2.2
Composite 76	EB1914214006	Vulcan	134814	VSW090_C	Soil 100%	Overburden	0.0	1.0	1.0
Composite 77	EB1914214007	Vulcan	134815	VSW090_C	Clay 100%	Overburden	1.0	5.0	4.0
Composite 78	EB1914214008	Vulcan	134816 - 134818	VSW090_C	Clay 100%	Overburden	5.0	10.0	5.0
Composite 79	EB1914214009	Vulcan	134819	VSW090_C	Clay 78%, Claystone 22%	Overburden	10.0	19.0	9.0
Composite 85	EB1914214015	Vulcan	134833	VSW092_C	Clay 100%	Overburden	1.0	6.0	5.0
Composite 86	EB1914214016	Vulcan	134834 - 134835	VSW092_C	Clay 100%	Overburden	6.0	12.0	6.0
Composite 92	EB1914214022	Vulcan	163039 - 163040	VSW095_C	Clay 100%	Overburden	3.0	8.0	5.0
Composite 102	EB1914214032	Vulcan	163252	VSW099_C	Clay 100%	Overburden	1.0	3.0	2.0
Composite 110	EB1914214040	Vulcan	163234 - 163235	VSW104_C	Clay 100%	Overburden	1.0	4.0	3.0
Composite 12	EB1914213012	Vulcan	145308	VSW070_C	Claystone 100%	Overburden	25.0	26.0	1.0
Composite 42	EB1914213042	Vulcan	163126	VSW084_C	Claystone 100%	Overburden	26.0	27.0	1.0
Composite 80	EB1914214010	Vulcan	134820	VSW090_C	Claystone 100%	Overburden	19.0	20.0	1.0
Composite 96	EB1914214026	Vulcan	163045	VSW095_C	Claystone 100%	Overburden	14.0	15.0	1.0
Composite 100	EB1914214030	Vulcan	163202	VSW095_C	Claystone 100%	Overburden	25.0	25.8	0.8

Table B1: List of waste rock and coal reject samples

RGS Sample No.	ALS ID	Deposit	Vitronite Sample ID	Drillhole ID	Sample Lithology	Sample Type	From	To	Interval
							(m)		
Interburden									
Composite 16	EB1914213016	Vulcan	145312	VSW070_C	Sandstone 100%	Interburden	32.0	37.0	5.0
Composite 17	EB1914213017	Vulcan	145313	VSW070_C	Sandstone 100%	Interburden	37.0	41.0	4.0
Composite 25	EB1914213025	Vulcan	134788	VSW082_C	Sandstone 100%	Interburden	20.0	26.1	6.1
Composite 33	EB1914213033	Vulcan	134796	VSW083_C	Sandstone 100%	Interburden	25.0	30.9	5.9
Composite 115	EB1914214045	Vulcan	163242	VSW104_C	Sandstone 100%	Interburden	21.0	28.0	7.0
Composite 116	EB1914214046	Vulcan	163243	VSW104_C	Sandstone 100%	Interburden	28.0	30.0	2.0
Composite 24	EB1914213024	Vulcan	134787	VSW082_C	Siltstone 100%	Interburden	18.7	20.0	1.3
Composite 32	EB1914213032	Vulcan	134795	VSW083_C	Siltstone 100%	Interburden	24.0	25.0	1.0
Composite 82	EB1914214012	Vulcan	134822	VSW090_C	Claystone 100%	Interburden	26.0	27.0	1.0
Composite 83	EB1914214013	Vulcan	134823	VSW090_C	Claystone 100%	Interburden	27.0	30.9	3.9
Composite 90	EB1914214020	Vulcan	134839	VSW092_C	Claystone 100%	Interburden	21.0	23.2	2.2
Composite 108	EB1914214038	Vulcan	163262	VSW099_C	Carb Sandstone 100%	Interburden	24.0	29.6	5.6
Roof, floor and partings									
Composite 15	EB1914213015	Vulcan	145311	VSW070_C	Sandstone 100%	Floor (Alex)	28.0	32.0	4.0
Composite 31	EB1914213031	Vulcan	134794	VSW083_C	Sandstone 100%	Floor (Alex)	22.0	24.0	2.0
Composite 23	EB1914213023	Vulcan	134786	VSW082_C	Weathered Coal 25%, Siltstone 75%	Floor (Alex)	17.7	18.7	1.0
Composite 62	EB1914213062	Vulcan	163013	VSW087_C	Carb Siltstone 100%	Floor (Alex)	24.9	29.0	4.1
Composite 29	EB1914213029	Vulcan	134792	VSW083_C	Sandstone 100%	Roof (Alex)	20.0	21.8	1.8
Composite 44	EB1914213044	Vulcan	163129 - 163131	VSW084_C	Sandstone 100%	Roof (Alex)	37.0	42.8	5.8
Composite 60	EB1914213060	Vulcan	163011	VSW087_C	Sandstone 100%	Roof (Alex)	21.0	24.0	3.0
Composite 106	EB1914214036	Vulcan	163259 - 163260	VSW099_C	Sandstone 100%	Roof (Alex)	19.0	22.8	3.8
Composite 69	EB1914213069	Vulcan	163024	VSW088_C	Siltstone 100%	Roof (Alex)	29.0	30.0	1.0
Composite 22	EB1914213022	Vulcan	134785	VSW082_C	Claystone 100%	Roof (Alex)	16.0	17.7	1.7
Composite 13	EB1914213013	Vulcan	145309	VSW070_C	Carb Sandstone 100%	Roof (Alex)	26.0	27.5	1.5
Composite 87	EB1914214017	Vulcan	134836	VSW092_C	Clay 100%	Roof (Dysart LL)	12.0	13.0	1.0
Composite 81	EB1914214011	Vulcan	134821	VSW090_C	Claystone 98%, Carb Claystone 2%	Roof/Seam/Floor (Alex)	20.0	26.0	6.0
Composite 14	EB1914213014	Vulcan	145310	VSW070_C	Weathered Coal 100%	Seam (Alex)	27.5	28.0	0.5
Composite 30	EB1914213030	Vulcan	134793	VSW083_C	Weathered Coal 100%	Seam (Alex)	21.8	22.0	0.2
Composite 114	EB1914214044	Vulcan	163241	VSW104_C	Sandstone 80%, Carb Siltstone 20%	Seam (Alex)	20.0	21.0	1.0
Composite 45	EB1914213045	Vulcan	163132	VSW084_C	Carb Claystone/Sandstone (38%/62%)	Seam (Alex) / Floor (Alex)	42.8	43.7	0.9
Composite 88	EB1914214018	Vulcan	134837	VSW092_C	Clay 99%, Weathered Coal 1%	Seam (Dysant LL)	13.0	17.7	4.7
Composite 107	EB1914214037	Vulcan	163261	VSW099_C	Claystone 89%, Carb Claystone 11%	Seam/Floor (Alex)	22.8	24.0	1.2
Composite 89	EB1914214019	Vulcan	134838	VSW092_C	Claystone 35%, Weathered Coal 51%, Carb Claystone 14%	Seam/Floor (Dysart LL)	17.7	21.0	3.3
Jupiter Prospect									
Overburden									
Composite 117	EB1914214047	Jupiter	335480	VSW017_C	Sand 100%	Overburden	0.1	1.0	0.9
Composite 121	EB1914214051	Jupiter	335477	VSW019_C	Sand 97%, Soil 3%	Overburden	0.0	3.0	3.0
Composite 129	EB1914214059	Jupiter	134772	VSW077_C	Sand 50%, Sandstone 50%	Overburden	0.0	1.0	1.0
Composite 134	EB1914214064	Jupiter	134770	VSW080_C	Sand 100%	Overburden	0.0	1.0	1.0
Composite 118	EB1914214048	Jupiter	335481	VSW017_C	Sandstone 100%	Overburden	1.0	3.0	2.0
Composite 119	EB1914214049	Jupiter	335482	VSW017_C	Sandstone 100%	Overburden	3.0	6.0	3.0
Composite 120	EB1914214050	Jupiter	335483	VSW017_C	Sandstone 100%	Overburden	6.0	7.6	1.6
Composite 130	EB1914214060	Jupiter	134773	VSW077_C	Sandstone 100%	Overburden	1.0	3.0	2.0
Composite 135	EB1914214065	Jupiter	134770	VSW080_C	Sandstone 100%	Overburden	1.0	2.9	1.9
Composite 125	EB1914214055	Jupiter	145152	VSW022_C	Shale 100%	Overburden	1.0	10.0	9.0
Composite 137	EB1914214067	Jupiter	134872	VSW103_C	Siltstone 100%	Overburden	2.0	5.0	3.0
Composite 138	EB1914214068	Jupiter	134873	VSW103_C	Siltstone 100%	Overburden	5.0	8.0	3.0
Composite 139	EB1914214069	Jupiter	134874	VSW103_C	Siltstone 100%	Overburden	8.0	11.0	3.0
Composite 124	EB1914214054	Jupiter	145151	VSW022_C	Clay 100%	Overburden	0.0	1.0	1.0
Composite 136	EB1914214066	Jupiter	134871	VSW103_C	Clay 50%, Claystone 50%	Overburden	0.0	2.0	2.0
Composite 122	EB1914214052	Jupiter	335478	VSW019_C	Coaly Shale 100%	Overburden	3.0	7.5	4.5
Composite 131	EB1914214061	Jupiter	134774	VSW077_C	Carbonaceous Siltstone 100%	Overburden	3.0	4.0	1.0
Interburden, roof, floor and partings									
Composite 123	EB1914214053	Jupiter	335479	VSW019_C	Sandstone 100%	Interburden	14.3	24.9	10.6
Composite 133	EB1914214063	Jupiter	134767	VSW078_C	Siltstone 100%	Floor (Alex)	4.5	6.0	1.6
Composite 127	EB1914214057	Jupiter	145154	VSW022_C	Sandstone 100%, Carb Claystone <1%	Floor (Dysart LL) / Roof (May)	20.0	33.0	13.0
Composite 128	EB1914214058	Jupiter	145155	VSW022_C	Siltstone 100%, Carb Claystone <1%	Floor (May)	33.0	43.2	10.2
Composite 132	EB1914214062	Jupiter	134764	VSW078_C	Sand 16%, Sandstone 84%	Roof (Alex)	0.0	3.2	3.2
Composite 126	EB1914214056	Jupiter	145153	VSW022_C	Carb Siltstone 100%	Roof (Dysart LL Ply4)	10.0	12.0	2.0
Coal Rejects									
1	EB1929251001	Vulcan	IP19006604R005	VSW069_C	Coarse (Wash 2, -50+2mm) reject	Coarse Reject			
2	EB1929251003	Vulcan	IP1900410R298	VSW086_C	Coarse (Wash 2, -50+2mm) reject	Coarse Reject			
5	EB1932449003	Jupiter	IP19002032R587	VSW019_C	Coarse (Wash 2, -50+2mm) reject	Coarse Reject			
6	EB1932449005	Jupiter	IP19003592R466	VSW022_C	Coarse (Wash 2, -50+2mm) reject	Coarse Reject			
7	EB1932449001	Vulcan	IP19004096R302	VSW079_C	Coarse (Wash 2, -50+2mm) reject	Coarse Reject			
3	EB1929251004	Vulcan	IP1900410R299	VSW086_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			
4	EB1929251002	Vulcan	IP19006604R006	VSW069_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			
8	EB1932449007	Vulcan	IP19004601R298	VSW096_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			
9	EB1932449002	Vulcan	IP19004096R303	VSW079_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			
10	EB1932449004	Jupiter	IP19002032R588	VSW019_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			
11	EB1932449006	Jupiter	IP19003592R467	VSW022_C	Fine (Wash 3, -2+0.25 & -0.25+0mm)	Fine Reject			

Table B2: Acid Base Account test results for waste rock samples

RGS Sample ID	ALS Sample ID	Deposit	Vitronite Sample ID	Drill Hole ID	Sample Lithology	Sample Type	From	To	Interval	pH[1]	EC[1]	Total S	Scr	MPA[2]	ANC[2]	NAPP[2]	ANC:MPA Ratio	Sample Classification[3]
							(m)				(µS/cm)	(%)		($kg\ H_2SO_4/t$)				
1	EB1914213018	Vulcan	134781	VSW082_C	Soil 100%	Soil	0.00	1.00	1.00	7.38	368	0.02		0.6	18.3	-17.7	29.9	Non Acid Forming (Barren)
2	EB1914213026	Vulcan	134789	VSW083_C	Soil 100%	Soil	0.00	1.00	1.00	8.61	229	0.005		0.2	17.6	-17.4	114.9	Non Acid Forming (Barren)
3	EB1914213034	Vulcan	163117	VSW084_C	Soil 100%	Soil	0.00	3.00	3.00	8.3	839	0.02		0.6	16.9	-16.3	27.6	Non Acid Forming (Barren)
4	EB1914213036	Vulcan	163119	VSW084_C	Sand 100%	Soil	7.00	11.00	4.00	9.19	433	0.005		0.2	27.2	-27.0	177.6	Non Acid Forming (Barren)
5	EB1914213053	Vulcan	163001	VSW087_C	Soil 100%	Soil	0.00	1.00	1.00	8.41	178	0.005		0.2	12.6	-12.4	82.3	Non Acid Forming (Barren)
6	EB1914213054	Vulcan	163002	VSW087_C	Soil 100%	Soil	1.00	3.00	2.00	9.00	672	0.03		0.9	27.9	-27.0	30.4	Non Acid Forming (Barren)
7	EB1914213063	Vulcan	163014	VSW088_C	Soil 100%	Soil	0.00	3.00	3.00	8.54	475	0.005		0.2	15.8	-15.6	103.2	Non Acid Forming (Barren)
8	EB1914213070	Vulcan	134807	VSW089_C	Soil 100%	Soil	0.00	1.00	1.00	8.13	196	0.005		0.2	32.7	-32.5	213.6	Non Acid Forming (Barren)
9	EB1914214014	Vulcan	134832	VSW092_C	Soil 100%	Soil	0.00	1.00	1.00	9.05	401	0.02		0.6	81.2	-80.6	132.6	Non Acid Forming (Barren)
10	EB1914214021	Vulcan	163038	VSW095_C	Soil 100%	Soil	0.00	3.00	3.00	8.60	878	0.02		0.6	23.0	-22.4	37.6	Non Acid Forming (Barren)
11	EB1914214031	Vulcan	163251	VSW099_C	Soil 100%	Soil	0.00	1.00	1.00	7.17	123	0.02		0.6	7.5	-6.9	12.2	Non Acid Forming (Barren)
12	EB1914214039	Vulcan	163233	VSW104_C	Soil 100%	Soil	0.00	1.00	1.00	8.66	205	0.04		1.2	22.8	-21.6	18.6	Non Acid Forming (Barren)
13	EB1914214006	Vulcan	134814	VSW090_C	Soil 100%	Soil	0.00	1.00	1.00	8.82	307	0.005		0.2	29.8	-29.8	194.6	Non Acid Forming (Barren)
14	EB1914213055	Vulcan	163003	VSW087_C	Alluvium 100%	Alluvium	3.00	4.00	1.00	8.61	525	0.02		0.6	15.6	-15.0	25.5	Non Acid Forming (Barren)
15	EB1914214023	Vulcan	163041	VSW095_C	Alluvium 100%	Alluvium	8.00	9.00	1.00	8.09	658	0.03		0.9	16.5	-15.6	18.0	Non Acid Forming (Barren)
16	EB1914213008	Vulcan	145303	VSW070_C	Calcrete 100%	Calcrete	6.00	7.00	1.00	9.72	430	0.02		0.6	307.0	-306.4	501.2	Non Acid Forming (Barren)
17	EB1914213037	Vulcan	163120	VSW084_C	Gravel 100%	Gravel	11.00	14.00	3.00	9.16	329	0.005		0.2	19.2	-19.0	125.4	Non Acid Forming (Barren)
18	EB1914213039	Vulcan	163122	VSW084_C	Gravel 100%	Gravel	16.00	18.00	2.00	8.48	441	0.005		0.2	13.4	-13.2	87.5	Non Acid Forming (Barren)
19	EB1914213004	Vulcan	145166	VSW052_C	Conglomerate 100%	Conglomerate	30.00	32.40	2.40	8.92	126	0.005		0.2	3.8	-3.6	24.8	Non Acid Forming (Barren)
20	EB1914213005	Vulcan	145167	VSW052_C	Conglomerate 100%	Conglomerate	32.40	37.40	5.00	8.18	222	0.005		0.2	6.1	-5.9	39.8	Non Acid Forming (Barren)
21	EB1914213009	Vulcan	145304	VSW070_C	Sandstone 100%	Sandstone	7.00	16.00	9.00	9.03	127	0.005		0.2	3.2	-3.0	20.9	Non Acid Forming (Barren)
22	EB1914213010	Vulcan	145305 - 145306	VSW070_C	Sandstone 100%	Sandstone	16.00	23.00	7.00	9.59	176	0.005		0.2	10.6	-10.4	69.2	Non Acid Forming (Barren)
23	EB1914213011	Vulcan	145307	VSW070_C	Sandstone 100%	Sandstone	23.00	25.00	2.00	8.45	131	0.02		0.6	0.9	-0.3	1.5	Non Acid Forming (Barren)
24	EB1914213015	Vulcan	145311	VSW070_C	Sandstone 100%	Sandstone	27.99	32.00	4.01	8.74	234	0.09		2.8	12.6	-9.8	4.6	Non Acid Forming (Barren)
25	EB1914213016	Vulcan	145312	VSW070_C	Sandstone 100%	Sandstone	32.00	37.00	5.00	9.12	174	0.04		1.2	13.9	-12.7	11.3	Non Acid Forming (Barren)
26	EB1914213017	Vulcan	145313	VSW070_C	Sandstone 100%	Sandstone	37.00	41.00	4.00	9.11	187	0.05		1.5	17.2	-15.7	11.2	Non Acid Forming (Barren)
27	EB1914213021	Vulcan	134784	VSW082_C	Sandstone 100%	Sandstone	5.00	16.00	11.00	8.28	754	0.005		0.2	8.0	-7.8	52.2	Non Acid Forming (Barren)
28	EB1914213025	Vulcan	134788	VSW082_C	Sandstone 100%	Sandstone	20.00	26.08	6.08	8.24	279	0.03		0.9	10.5	-9.6	11.4	Non Acid Forming (Barren)
29	EB1914213028	Vulcan	134791	VSW083_C	Sandstone 100%	Sandstone	4.00	20.00	16.00	9.11	555	0.005		0.2	7.8	-7.6	50.9	Non Acid Forming (Barren)
30	EB1914213029	Vulcan	134792	VSW083_C	Sandstone 100%	Sandstone	20.00	21.77	1.77	8.83	172	0.02		0.6	8.6	-8.0	14.0	Non Acid Forming (Barren)
31	EB1914213031	Vulcan	134794	VSW083_C	Sandstone 100%	Sandstone	21.97	24.00	2.03	7.83	522	0.005		0.2	11.2	-11.0	73.1	Non Acid Forming (Barren)
32	EB1914213033	Vulcan	134796	VSW083_C	Sandstone 100%	Sandstone	25.00	30.86	5.86	8.00	213	0.005		0.2	8.2	-8.0	53.6	Non Acid Forming (Barren)
33	EB1914213041	Vulcan	163124 - 163125	VSW084_C	Sandstone 100%	Sandstone	19.00	26.00	7.00	9.07	417	0.02		0.6	9.1	-8.5	14.9	Non Acid Forming (Barren)
34	EB1914213043	Vulcan	163127 - 163128	VSW084_C	Sandstone 100%	Sandstone	27.00	37.00	10.00	8.64	132	0.02		0.6	6.8	-6.2	11.1	Non Acid Forming (Barren)
35	EB1914213044	Vulcan	163129 - 163131	VSW084_C	Sandstone 100%	Sandstone	37.00	42.84	5.84	8.39	98	0.005		0.2	2.4	-2.2	15.7	Non Acid Forming (Barren)
36	EB1914213056	Vulcan	163004	VSW087_C	Sandstone 100%	Sandstone	4.00	9.00	5.00	9.57	460	0.02		0.6	92.1	-91.5	150.4	Non Acid Forming (Barren)
37	EB1914213057	Vulcan	163005 - 163006	VSW087_C	Sandstone 100%	Sandstone	9.00	13.00	4.00	8.98	481	0.02		0.6	26.9	-26.3	43.9	Non Acid Forming (Barren)
38	EB1914213058	Vulcan	163007 - 163009	VSW087_C	Sandstone 100%	Sandstone	13.00	18.00	5.00	9.11	273	0.005		0.2	6.9	-6.7	45.1	Non Acid Forming (Barren)
39	EB1914213059	Vulcan	163010	VSW087_C	Sandstone 100%	Sandstone	18.00	21.00	3.00	8.60	224	0.02		0.6	5.3	-4.7	8.7	Non Acid Forming (Barren)
40	EB1914213060	Vulcan	163011	VSW087_C	Sandstone 100%	Sandstone	21.00	24.02	3.02	8.71	111	0.02		0.6	3.0	-2.4	4.9	Non Acid Forming (Barren)
41	EB1914213066	Vulcan	163018 - 163019	VSW088_C	Sandstone 100%	Sandstone	12.00	18.00	6.00	9.73	270	0.005		0.2	52.0	-51.8	339.6	Non Acid Forming (Barren)
42	EB1914213067	Vulcan	163020 - 163022	VSW088_C	Sandstone 100%	Sandstone	18.00	23.00	5.00	9.34	132	0.005		0.2	6.4	-6.2	41.8	Non Acid Forming (Barren)
43	EB1914213068	Vulcan	163023	VSW088_C	Sandstone 100%	Sandstone	23.00	29.00	6.00	9.08	85	0.005		0.2	3.5	-3.3	22.9	Non Acid Forming (Barren)
44	EB1914214024	Vulcan	163042 - 163043	VSW095_C	Sandstone 100%	Sandstone	9.00	12.00	3.00	8.37	570	0.03		0.9	28.3	-27.4	30.8	Non Acid Forming (Barren)
45	EB1914214025	Vulcan	163044	VSW095_C	Sandstone 100%	Sandstone	12.00	14.00	2.00	8.84	553	0.03		0.9	63.9	-63.0	69.6	Non Acid Forming (Barren)
46	EB1914214027	Vulcan	163046 - 163047	VSW095_C	Sandstone 100%	Sandstone	15.00	18.00	3.00	8.60	591	0.03		0.9	16.8	-15.9	18.3	Non Acid Forming (Barren)
47	EB1914214028	Vulcan	163048 - 163050	VSW095_C	Sandstone 100%	Sandstone	18.00	24.00	6.00	8.89	194	0.02		0.6	15.9	-15.3	26.0	Non Acid Forming (Barren)
48	EB1914214029	Vulcan	163201	VSW095_C	Sandstone 100%	Sandstone	24.00	25.00	1.00	8.56	124	0.02		0.6	6.4	-5.8	10.4	Non Acid Forming (Barren)
49	EB1914214033	Vulcan	163253 - 163254	VSW099_C	Sandstone 100%	Sandstone	3.00	7.00	4.00	7.98	224	0.04		1.2	0.25	1.0	0.2	Non Acid Forming (Barren)
50	EB1914214034	Vulcan	163255 - 163256	VSW099_C	Sandstone 100%	Sandstone	7.00	14.00	7.00	8.97	253	0.005		0.2	5.1	-5.1	33.3	Non Acid Forming (Barren)
51	EB1914214035	Vulcan	163257 - 163258	VSW099_C	Sandstone 100%	Sandstone	14.00	19.00	5.00	8.61	212	0.02		0.6	6.6	-6.0	10.8	Non Acid Forming (Barren)
52	EB1914214036	Vulcan	163259 - 163260	VSW099_C	Sandstone 100%	Sandstone	19.00	22.80	3.80	8.28	214	0.005		0.2	0.25	-0.1	1.6	Non Acid Forming (Barren)
53	EB1914214041	Vulcan	163236	VSW104_C	Sandstone 100%	Sandstone	4.00	7.00	3.00	9.46	375	0.005		0.2	45.6	-45.6	297.8	Non Acid Forming (Barren)
54	EB1914214042	Vulcan	163237	VSW104_C	Sandstone 100%	Sandstone	7.00	14.00	7.00	8.98	240	0.03		0.9	13.2	-12.3	14.4	Non Acid Forming (Barren)
55	EB1914214043	Vulcan	163238 - 163240	VSW104_C	Sandstone 100%	Sandstone	14.00	20.00	6.00	8.67	283	0.005		0.2	10.1	-10.1	66.0	Non Acid Forming (Barren)
56	EB1914214045	Vulcan	163242	VSW104_C	Sandstone 100%	Sandstone	21.00	28.00	7.00	8.27	276	0.005		0.2	8.1	-8.1	52.9	Non Acid Forming (Barren)
57	EB1914214046	Vulcan	163243	VSW104_C	Sandstone 100%	Sandstone	28.00	30.00	2.00	9.03	163	0.02		0.6	12.9	-12.3	21.1	Non Acid Forming (Barren)
58	EB1914213024	Vulcan	134787	VSW082_C	Siltstone 100%	Siltstone	18.70	20.00	1.30	7.76	820	0.02		0.6	9.7	-9.1	15.8	Non Acid Forming (Barren)
59	EB1914213032	Vulcan	134795	VSW083_C	Siltstone 100%	Siltstone	24.00	25.00	1.00	7.93	355	0.02		0.6	11.1	-10.5	18.1	Non Acid Forming (Barren)
60	EB1914213069	Vulcan	163024	VSW088_C	Siltstone 100%	Siltstone	29.00	30.00	1.00	8.16	129	0.02		0.6	9.2	-8.6	15.0	Non Acid Forming (Barren)
61	EB1914213001	Vulcan	145163	VSW052_C	Clay 100%	Clay	0.10	5.00	4.90	8.92	607	0.02		0.6	21.1	-20.5	34.4	Non Acid Forming (Barren)
62	EB1914213002	Vulcan	145164	VSW052_C	Clay 100%	Clay	5.00	10.00	5.00	8.98	687	0.02		0.6	92.0	-91.4	150.2	Non Acid Forming (Barren)
63	EB1914213003	Vulcan	145165	VSW052_C	Clay 100%	Clay	25.00	30.00	5.00	8.47	342	0.02		0.6	5.8	-5.2	9.5	Non Acid Forming (Barren)
64	EB1914213006	Vulcan	145301	VSW070_C	Clay 100%	Clay	0.00	3.00	3.00	8.62	675	0.02		0.6	23.4	-22.8	38.2	Non Acid Forming (Barren)
65	EB1914213007	Vulcan	145302	VSW070_C	Clay 100%	Clay	3.00	6.00	3.00	6.44	644	0.02		0.6	11.7	-11.1	19.1	Non Acid Forming (Barren)
66	EB1914213019	Vulcan	134782	VSW082_C	Clay 100%	Clay	1.00	2.00	1.00	8.54	818	0.005		0.2	38.7	-38.5	252.7	Non Acid Forming (Barren)
67	EB1914213020	Vulcan	134783	VSW082_C	Clay 100%	Clay	2.00	5.00	3.00	8.22	655	0.005		0.2	25.6	-25.4	167.2	Non Acid Forming (Barren)
68	EB1914213027	Vulcan	134790	VSW083_C	Clay 100%	Clay	1.00	4.00	3.00	8.45	250	0.02		0.6	66.2	-65.6	108.1	Non Acid Forming (Barren)
69	EB1914213035	Vulcan	163118	VSW084_C	Clay 100%	Clay	3.00	7.00	4.00	8.68	879	0.005		0.2	85.6	-85.4	559.0	Non Acid Forming (Barren)
70	EB1914213038	Vulcan	163121	VSW084_C	Clay 100%	Clay	14.00	16.00	2.00	8.29	725	0.02		0.6	20.4	-19.8	33.3	Non Acid Forming (Barren)
71	EB1914213040	Vulcan	163123	VSW084_C	Clay 100%	Clay	18.00	19.00	1.00	7.88	776	0.02		0.6	9.6	-9.0	15.7	Non Acid Forming (Barren)

Table B2: Acid Base Account test results for waste rock samples

RGS Sample ID	ALS Sample ID	Deposit	Vitronite Sample ID	Drill Hole ID	Sample Lithology	Sample Type	From	To	Interval	pH[1]	EC[1]	Total S	Scr	MPA[2]	ANC[2]	NAPP[2]	ANC:MPA Ratio	Sample Classification[3]
							(m)				(µS/cm)	(%)		(kg H_2SO_4/t)				
72	EB1914213046	Vulcan	134797	VSW085_C	Clay 100%	Clay	0.00	2.00	2.00	8.41	313	0.02		0.6	27.1	-26.5	44.2	Non Acid Forming (Barren)
73	EB1914213047	Vulcan	134798 - 134799	VSW085_C	Clay 100%	Clay	2.00	8.00	6.00	8.43	755	0.005		0.2	127.0	-126.8	829.4	Non Acid Forming (Barren)
74	EB1914213048	Vulcan	1347800	VSW085_C	Clay 100%	Clay	8.00	14.00	6.00	8.34	674	0.005		0.2	50.4	-50.2	329.1	Non Acid Forming (Barren)
75	EB1914213049	Vulcan	1347801 - 1347802	VSW085_C	Clay 100%	Clay	14.00	18.00	4.00	8.03	662	0.005		0.2	33.8	-33.6	220.7	Non Acid Forming (Barren)
76	EB1914213050	Vulcan	1347803 - 1347804	VSW085_C	Clay 100%	Clay	18.00	25.00	7.00	8.15	440	0.02		0.6	23.7	-23.1	38.7	Non Acid Forming (Barren)
77	EB1914213051	Vulcan	1347805	VSW085_C	Clay 100%	Clay	25.00	29.00	4.00	7.94	255	0.02		0.6	8.5	-7.9	13.9	Non Acid Forming (Barren)
78	EB1914213052	Vulcan	1347806	VSW085_C	Clay 100%	Clay	29.00	30.71	1.71	8.05	291	0.03		0.9	5.9	-5.0	6.4	Non Acid Forming (Barren)
79	EB1914213064	Vulcan	163015 - 163016	VSW088_C	Clay 100%	Clay	3.00	7.00	4.00	8.87	944	0.02		0.6	106.0	-105.4	173.1	Non Acid Forming (Barren)
80	EB1914213065	Vulcan	163017	VSW088_C	Clay 100%	Clay	7.00	12.00	5.00	9.16	342	0.02		0.6	91.5	-90.9	149.4	Non Acid Forming (Barren)
81	EB1914214001	Vulcan	134808 - 134809	VSW089_C	Clay 100%	Clay	1.00	3.00	2.00	8.65	696	0.005		0.2	218.0	-218.0	1423.7	Non Acid Forming (Barren)
82	EB1914214002	Vulcan	134810	VSW089_C	Clay 100%	Clay	3.00	14.00	11.00	8.3	614	0.03		0.9	26.5	-25.6	28.8	Non Acid Forming (Barren)
83	EB1914214003	Vulcan	134811	VSW089_C	Clay 100%	Clay	14.00	16.00	2.00	8.61	492	0.005		0.2	18.9	-18.9	123.4	Non Acid Forming (Barren)
84	EB1914214004	Vulcan	134812	VSW089_C	Clay 100%	Clay	16.00	28.00	12.00	7.97	401	0.02		0.6	22.1	-21.5	36.1	Non Acid Forming (Barren)
85	EB1914214005	Vulcan	134813	VSW089_C	Clay 100%	Clay	28.00	30.23	2.23	8.40	107	0.005		0.2	7.1	-7.1	46.4	Non Acid Forming (Barren)
86	EB1914214007	Vulcan	134815	VSW090_C	Clay 100%	Clay	1.00	5.00	4.00	8.08	713	0.005		0.2	11.3	-11.3	73.8	Non Acid Forming (Barren)
87	EB1914214008	Vulcan	134816 - 134818	VSW090_C	Clay 100%	Clay	5.00	10.00	5.00	8.52	869	0.02		0.6	107.0	-106.0	174.7	Non Acid Forming (Barren)
88	EB1914214009	Vulcan	134819	VSW090_C	Clay 78%, Claystone 22%	Clay	10.00	19.00	9.00	8.56	972	0.02		0.6	70.1	-69.5	114.4	Non Acid Forming (Barren)
89	EB1914214015	Vulcan	134833	VSW092_C	Clay 100%	Clay	1.00	6.00	5.00	8.49	694	0.005		0.2	29.6	-29.6	193.3	Non Acid Forming (Barren)
90	EB1914214016	Vulcan	134834 - 134835	VSW092_C	Clay 100%	Clay	6.00	12.00	6.00	8.88	517	0.005		0.2	111.0	-111.0	724.9	Non Acid Forming (Barren)
91	EB1914214017	Vulcan	134836	VSW092_C	Clay 100%	Clay	12.00	13.00	1.00	8.32	486	0.005		0.2	49.4	-49.4	322.6	Non Acid Forming (Barren)
92	EB1914214022	Vulcan	163039 - 163040	VSW095_C	Clay 100%	Clay	3.00	8.00	5.00	6.73	430	0.02		0.6	10.3	-9.7	16.8	Non Acid Forming (Barren)
93	EB1914214032	Vulcan	163252	VSW099_C	Clay 100%	Clay	1.00	3.00	2.00	9.08	510	0.02		0.6	18.8	-18.2	30.7	Non Acid Forming (Barren)
94	EB1914214040	Vulcan	163234 - 163235	VSW104_C	Clay 100%	Clay	1.00	4.00	3.00	9.21	583	0.005		0.2	158.0	-158.0	1031.8	Non Acid Forming (Barren)
95	EB1914213012	Vulcan	145308	VSW070_C	Claystone 100%	Claystone	25.00	26.00	1.00	8.55	244	0.02		0.6	2.4	-1.8	3.9	Non Acid Forming (Barren)
96	EB1914213022	Vulcan	134785	VSW082_C	Claystone 100%	Claystone	16.00	17.70	1.70	8.61	243	0.02		0.6	5.4	-4.8	8.8	Non Acid Forming (Barren)
97	EB1914213042	Vulcan	163126	VSW084_C	Claystone 100%	Claystone	26.00	27.00	1.00	7.95	251	0.02		0.6	8.4	-7.8	13.7	Non Acid Forming (Barren)
98	EB1914214010	Vulcan	134820	VSW090_C	Claystone 100%	Claystone	19.00	20.00	1.00	9.19	430	0.02		0.6	74.0	-73.4	120.8	Non Acid Forming (Barren)
99	EB1914214012	Vulcan	134822	VSW090_C	Claystone 100%	Claystone	26.00	27.00	1.00	9.13	220	0.005		0.2	12.2	-12.2	79.7	Non Acid Forming (Barren)
100	EB1914214013	Vulcan	134823	VSW090_C	Claystone 100%	Claystone	27.00	30.85	3.85	8.77	112	0.005		0.2	7.0	-7.0	45.7	Non Acid Forming (Barren)
101	EB1914214020	Vulcan	134839	VSW092_C	Claystone 100%	Claystone	21.00	23.20	2.20	7.95	458	0.02		0.6	12.1	-11.5	19.8	Non Acid Forming (Barren)
102	EB1914214026	Vulcan	163045	VSW095_C	Claystone 100%	Claystone	14.00	15.00	1.00	7.89	634	0.03		0.9	10.6	-9.7	11.5	Non Acid Forming (Barren)
103	EB1914214030	Vulcan	163202	VSW095_C	Claystone 100%	Claystone	25.00	25.84	0.84	8.73	147	0.005		0.2	6.7	-6.7	43.8	Non Acid Forming (Barren)
104	EB1914213013	Vulcan	145309	VSW070_C	Carb. Sandstone 100%	Carbonaceous	26.00	27.53	1.53	9.19	224	0.08		2.5	14.7	-12.3	6.0	Non Acid Forming (Barren)
105	EB1914213014	Vulcan	145310	VSW070_C	Weathered Coal 100%	Carbonaceous	27.53	27.99	0.46	8.29	270	0.30	0.15	4.7	5.8	-1.1	1.2	Uncertain
106	EB1914213023	Vulcan	134786	VSW082_C	Weathered Coal 25%, Siltstone 75%	Carbonaceous	17.70	18.70	1.00	8.19	333	0.03		0.9	13.3	-12.4	14.5	Non Acid Forming (Barren)
107	EB1914213030	Vulcan	134793	VSW083_C	Weathered Coal 100%	Carbonaceous	21.77	21.97	0.20	7.31	682	0.04		1.2	16.0	-14.8	13.1	Non Acid Forming (Barren)
108	EB1914213045	Vulcan	163132	VSW084_C	Carb Claystone 38%, Carb Sandstone 62%	Carbonaceous	42.84	43.74	0.90	8.26	232	0.005		0.2	8.3	-8.1	54.2	Non Acid Forming (Barren)
109	EB1914213062	Vulcan	163013	VSW087_C	Carb Siltstone 100%	Carbonaceous	24.88	28.95	4.07	8.80	172	0.02		0.6	7.0	-6.4	11.4	Non Acid Forming (Barren)
110	EB1914214011	Vulcan	134821	VSW090_C	Claystone 98%, Carb Claystone 2%	Carbonaceous	20.00	26.00	6.00	8.38	467	0.005		0.2	18.5	-18.3	120.8	Non Acid Forming (Barren)
111	EB1914214018	Vulcan	134837	VSW092_C	Clay 99%, Weathered Coal 1%	Carbonaceous	13.00	17.69	4.69	8.00	560	0.02		0.6	18.3	-17.7	29.9	Non Acid Forming (Barren)
112	EB1914214019	Vulcan	134838	VSW092_C	Claystone 35%, Weathered Coal 51%, Carb Claystone 14%	Carbonaceous	17.69	21.00	3.31	8.24	648	0.02		0.6	14.8	-14.2	24.2	Non Acid Forming (Barren)
113	EB1914214037	Vulcan	163261	VSW099_C	Claystone 89%, Carb Claystone 11%	Carbonaceous	22.80	24.00	1.20	8.26	365	0.005		0.2	6.2	-6.0	40.5	Non Acid Forming (Barren)
114	EB1914214038	Vulcan	163262	VSW099_C	Carb Sandstone 100%	Carbonaceous	24.00	29.60	5.60	9.30	220	0.02		0.6	13.6	-13.0	22.2	Non Acid Forming (Barren)
115	EB1914214044	Vulcan	163241	VSW104_C	Sandstone 80%, Carb Siltstone 20%	Carbonaceous	20.00	21.00	1.00	7.84	481	0.005		0.2	7.1	-6.9	46.4	Non Acid Forming (Barren)
1	EB1914214047	Jupiter	335480	VSW017_C	Sand 100%	Soil	0.10	1.00	0.90	6.91	166	0.02		0.6	0.25	0.4	0.4	Non Acid Forming (Barren)
2	EB1914214051	Jupiter	335477	VSW019_C	Sand 97%, Soil 3%	Soil	0.00	3.00	3.00	6.12	81	0.005		0.2	1.7	-1.5	11.1	Non Acid Forming (Barren)
3	EB1914214059	Jupiter	134772	VSW077_C	Sand 50%, Sandstone 50%	Soil	0.00	1.00	1.00	6.59	43	0.02		0.6	0.25	0.4	0.4	Non Acid Forming (Barren)
4	EB1914214064	Jupiter	134770	VSW080_C	Sand 100%	Soil	0.00	1.00	1.00	6.17	109	0.02		0.6	5.9	-5.3	9.6	Non Acid Forming (Barren)
5	EB1914214054	Jupiter	145151	VSW022_C	Clay 100%	Clay	0.00	1.00	1.00	6.57	152	0.02		0.6	1.6	-1.0	2.6	Non Acid Forming (Barren)
6	EB1914214066	Jupiter	134871	VSW103_C	Clay 50%, Claystone 50%	Clay	0.00	2.00	2.00	6.63	192	0.005		0.2	5.1	-4.9	33.3	Non Acid Forming (Barren)
7	EB1914214048	Jupiter	335481	VSW017_C	Sandstone 100%	Sandstone	1.00	3.00	2.00	8.22	120	0.005		0.2	0.25	-0.1	1.6	Non Acid Forming (Barren)
8	EB1914214049	Jupiter	335482	VSW017_C	Sandstone 100%	Sandstone	3.00	6.00	3.00	7.07	151	0.005		0.2	1.2	-1.0	7.8	Non Acid Forming (Barren)
9	EB1914214050	Jupiter	335483	VSW017_C	Sandstone 100%	Sandstone	6.00	7.59	1.59	6.14	159	0.11	0.08	2.5	2.2	0.3	0.9	Non Acid Forming (Barren)
10	EB1914214053	Jupiter	335479	VSW019_C	Sandstone 100%	Sandstone	14.26	24.86	10.60	7.22	136	0.08		2.5	6.0	-3.6	2.4	Non Acid Forming (Barren)
11	EB1914214057	Jupiter	145154	VSW022_C	Sandstone 100%, Carb Claystone <1%	Sandstone	20.00	33.01	13.01	8.60	225	0.09		2.8	12.8	-10.0	4.6	Non Acid Forming (Barren)
12	EB1914214060	Jupiter	134773	VSW077_C	Sandstone 100%	Sandstone	1.00	3.00	2.00	6.11	110	0.02		0.6	0.25	0.4	0.4	Non Acid Forming (Barren)
13	EB1914214062	Jupiter	134764	VSW078_C	Sand 16%, Sandstone 84%	Sandstone	0.00	3.17	3.17	6.25	52	0.03		0.9	11.0	-10.1	12.0	Non Acid Forming (Barren)
14	EB1914214065	Jupiter	134770	VSW080_C	Sandstone 100%	Sandstone	1.00	2.94	1.94	7.46	187	0.02		0.6	7.2	-6.6	11.8	Non Acid Forming (Barren)
15	EB1914214055	Jupiter	145152	VSW022_C	Shale 100%	Siltstone	1.00	10.00	9.00	7.01	331	0.02		0.6	8.8	-8.2	14.4	Non Acid Forming (Barren)
16	EB1914214058	Jupiter	145155	VSW022_C	Siltstone 100%, Carb Claystone <1%	Siltstone	33.01	43.21	10.20	8.78	145	0.04		1.2	6.6	-5.4	5.4	Non Acid Forming (Barren)
17	EB1914214063	Jupiter	134767	VSW078_C	Siltstone 100%	Siltstone	4.45	6.00	1.55	5.05	112	0.08		2.5	7.7	-5.3	3.1	Non Acid Forming (Barren)
18	EB1914214067	Jupiter	134872	VSW103_C	Siltstone 100%	Siltstone	2.00	5.00	3.00	7.92	266	0.005		0.2	7.8	-7.6	50.9	Non Acid Forming (Barren)
19	EB1914214068	Jupiter	134873	VSW103_C	Siltstone 100%	Siltstone	5.00	8.00	3.00	9.01	152	0.02		0.6	15.4	-14.8	25.1	Non Acid Forming (Barren)
20	EB1914214069	Jupiter	134874	VSW103_C	Siltstone 100%	Siltstone	8.00	11.00	3.00	8.86	154	0.02		0.6	14.2	-13.6	23.2	Non Acid Forming (Barren)
21	EB1914214052	Jupiter	335478	VSW019_C	Coaly Shale 100%	Carbonaceous	3.00	7.53	4.53	7.26	312	0.03		0.9	11.1	-10.2	12.1	Non Acid Forming (Barren)
22	EB1914214056	Jupiter	145153	VSW022_C	Carb Siltstone 100%	Carbonaceous	10.00	12.02	2.02	8.03	243	0.02		0.6	9.4	-8.8	15.3	Non Acid Forming (Barren)
23	EB1914214061	Jupiter	134774	VSW077_C	Carb Siltstone 100%	Carbonaceous	3.00	4.00	1.00	6.27	65	0.03		0.9	5.7	-4.8	6.2	Non Acid Forming (Barren)

1. Current pH, EC, Alkalinity and Acidity provided for 1:5 sample:water extracts
2. Scr = Chromium Reducible Sulfur; MPA = Maximum Potential Acidity; ANC = Acid Neutralising Capacity; and NAPP = Net Acid Producing Potential.
3. Sample classification criteria detail provided in report text.

* Where total sulfur or ANC results are less than the laboratory LoR a value of half of the LoR is used in Table B2.

Table B3: Acid Base Account test results for coal reject samples

RGS Sample ID	ALS ID	Prospect	Drill Hole	Vulcan Sample ID	Sample Description	Reject Type	From (mm)	To (mm)	pH[1]	EC[1] (µS/cm)	Total S (%)	Scr (%)	MPA[2] (kgH_2SO_4/t)	ANC[2] (kgH_2SO_4/t)	NAPP[2] (kgH_2SO_4/t)	ANC:MPA Ratio	Sample Classification[3]
1	EB1929251001	Vulcan	VSW069_C	IP19006604R005	Coarse (Wash 2, -50+2mm) reject	Coarse	-50	2	8.4	176	0.72	0.388	11.9	8.4	3.5	0.7	Uncertain
2	EB1929251003	Vulcan	VSW086_C	IP1900410R298	Coarse (Wash 2, -50+2mm) reject	Coarse	-50	2	8.0	401	0.28	0.047	1.4	1.8	-0.4	1.3	Non Acid Forming (Barren)
3	EB1932449003	Jupiter	VSW019_C	IP19002032R587	Coarse (Wash 2, -50+2mm) reject	Coarse	-50	2	4.5	454	0.31	0.049	1.5	10.9	-9.4	7.3	Non Acid Forming (Barren)
4	EB1932449005	Jupiter	VSW022_C	IP19003592R466	Coarse (Wash 2, -50+2mm) reject	Coarse	-50	2	7.6	213	0.20	0.055	1.7	22.8	-21.1	13.5	Non Acid Forming (Barren)
5	EB1932449001	Vulcan	VSW079_C	IP19004096R302	Coarse (Wash 2, -50+2mm) reject	Coarse	-50	2	8.3	116	0.82	0.569	17.4	11.3	6.1	0.6	Potentially Acid Forming
6	EB1929251004	Vulcan	VSW086_C	IP1900410R299	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	7.0	595	0.38	0.220	6.7	7.2	-0.5	1.1	Uncertain
7	EB1929251002	Vulcan	VSW069_C	IP19006604R006	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	7.3	484	0.41	0.190	5.8	8.5	-2.7	1.5	Uncertain
8	EB1932449007	Vulcan	VSW096_C	IP19004601R298	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	6.8	398	0.12	0.018	0.6	36.0	-35.4	65.3	Non Acid Forming (Barren)
9	EB1932449002	Vulcan	VSW079_C	IP19004096R303	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	7.4	564	0.60	0.382	11.7	13.5	-1.8	1.2	Uncertain
10	EB1932449004	Jupiter	VSW019_C	IP19002032R588	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	5.6	193	0.41	0.027	0.8	16.9	-16.1	20.4	Non Acid Forming (Barren)
11	EB1932449006	Jupiter	VSW022_C	IP19003592R467	Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm) reject	Fine	-2	0.25	7.6	466	0.22	0.152	4.7	23.3	-18.6	5.0	Non Acid Forming

Notes

1. Current pH, EC, Alkalinity and Acidity provided for 1:5 sample:water extracts
2. Scr = Chromium Reducible Sulfur; MPA = Maximum Potential Acidity; ANC = Acid Neutralising Capacity; and NAPP = Net Acid Producing Potential
3. Sample classification criteria detail provided in report text.

Table B4: Multi-element test results for waste rock and coal reject samples

			RGS Sample Number →	Composite 1	Composite 2	Composite 3	Composite 4	Composite 5	Composite 6	Composite 7	Composite 8	Composite 9	Composite 10
			ALS Laboratory ID →	EB1916203003	EB1916203004	EB1916203005	EB1916203006	EB1916203007	EB1916203008	EB1931850005	EB1931850006	EB1933850008	EB1933850009
			Sample description →										
Parameters	Limit of Reporting	NEPC[1] Health-Based Investigation Level (HILs)-C		Vulcan Soil	Vulcan Sandstone	Vulcan Clay	Vulcan Claystone	Jupiter Sandstone	Jupiter Siltstone	Vulcan Coarse Reject	Vulcan Fine Reject	Jupiter/Vulcan Coarse Reject	Jupiter/Vulcan Fine Reject
Major Cations				All units mg/kg									
Calcium (Ca)	50	-		5,710	2,420	9,470	1,890	370	460	2,650	2,090	1600	4780
Magnesium (Mg)	50	-		4,080	2,140	8,890	2,320	760	1,430	2,160	1,120	680	2700
Potassium (K)	50	-		270	680	290	950	1,180	2,200	500	720	1270	1280
Sodium (Na)	50	-		950	490	1,670	730	260	770	120	150	410	470
Major, Minor & Trace Elements				All units mg/kg									
Aluminium (Al)	50	-		9,520	2,090	10,900	5,120	2,280	3,000	1,100	1,790	2770	3360
Antimony (Sb)	5	-		<5	<5	<5	<5	<5	<5	<5	<5	0.1	0.1
Arsenic (As)	5	300		<5	<5	<5	<5	<5	5	7	12	16	11
Barium (Ba)	10	-		150	50	170	80	70	50	80	230	313	256
Beryllium (Be)	1	90		<1	<1	<1	1	<1	2	<1	1	1	1
Boron (B)	50	20,000		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Cadmium (Cd)	1	90		<1	<1	<1	<1	<1	<1	<1	<1	0.1	0.1
Chromium (Cr) - hexavalent	2	300 **		46	38	53	34	69	24	<2	<2	0.6	2.1
Cobalt (Co)	2	300		17	3	19	11	4	10	5	22	5	6
Copper (Cu)	5	17,000		7	6	11	13	8	27	23	44	55	46
Iron (Fe)	50	-		17,200	8,640	25,400	17,700	12,200	22,200	46,900	11,200	7,940	6,340
Lead (Pb)	5	600		6	6	<5	10	12	30	6	15	14	19
Manganese (Mn)	5	19,000		538	103	466	188	126	331	1,100	179	85	74
Mercury (Hg)	0.1	80		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.1	<0.1	0.1
Molybdenum (Mp)	2	2		<2	<2	<2	<2	<2	<2	1	3	1	1
Nickel (Ni)	2	1,200		24	6	34	18	10	18	6	23	7	12.9
Reactive Phosphorus (P)	0.1	-		<0.1	<0.1	0	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Selenium (Se)	5	700		<5	<5	<5	<5	<5	<5	<5	<5	2	2
Thallium (Tl)	5	-		<5	<5	<5	<5	<5	6	<5	<5	<5	<5
Thorium (Th)	0.1	-		-	-	-	-	-	-	-	-	1.9	2.0
Uranium (U)	0.1	-		0.3	0.3	0.8	0.7	0.3	0.8	0.6	1.0	0.8	5.4
Zinc (Zn)	5	30,000		14	17	31	50	31	91	62	145	49	72
Exchangable Cations				All units meq/100g (except Exchangable Sodium & Moisture Content (%))									
Exch. Calcium	0.1			6.2	0.9	3.0	1.0	0.8	0.9	-	-	-	-
Exch. Magnesium	0.1			9.1	3.1	12.3	3.4	1.9	5.3	-	-	-	-
Exch. Potassium	0.1			0.2	1.1	0.2	0.4	1.0	1.4	-	-	-	-
Exch. Sodium	0.1			1.9	0.7	3.0	0.7	0.9	2.5	-	-	-	-
Cation Exchange Capacity	0.1			17.4	5.8	18.6	5.6	4.8	10.2	-	-	-	-
Calcium:Magnesium Ratio	-			0.7	0.3	0.2	0.3	0.4	0.2	-	-	-	-
Magnesium:Potassium Ratio	-			37.6	2.7	60.5	8.8	1.8	3.8	-	-	-	-
Exchangable Sodium Percentage	0.1%			10.8	12.1	16.3	13.0	20.4	24.6	-	-	-	-
Moisture content	1.0%			4.0	<1.0	4.8	1.6	<1.0	<1.0	-	-	-	-

Notes: < indicates less than the laboratory limit of reporting. Shaded cells exceed applied guideline limit.

** Guideline level for Cr(VI) = 300 mg/kg. Guideline level for Cr(III) = 24% of total Cr.

1. NEPC (2013). National Environmental Protection Council (NEPC). *National Environmental Protection (Assessment of Site Contamination) Measure (NEPM)*, Amendment of Schedule B1-B7 of 1999 version. Guideline on Investigation Levels for Soil and Groundwater. Health-Based Investigation Level - HIL(C); public open spaces - recreational use.

Table B5: Geochemical Abundance Index results for waste rock and coal reject samples

	RGS Sample Number →		Composite 1	Composite 2	Composite 3	Composite 4	Composite 5	Composite 6	Composite 7	Composite 8	Composite 9	Composite 10
	ALS Laboratory ID →		EB1916203003	EB1916203004	EB1916203005	EB1916203006	EB1916203007	EB1916203008	EB1931850005	EB1931850006	EB1933850008	EB1933850009
	Sample description →		Vulcan Soil	Vulcan Sandstone	Vulcan Clay	Vulcan Claystone	Jupiter Sandstone	Jupiter Siltstone	Vulcan Coarse Reject	Vulcan Fine Reject	Jupiter/Vulcan Coarse Reject	Jupiter/Vulcan Fine Reject
Parameters	Limit of Reporting	Average Crustal Abundance[1]										
Major Elements	all units mg/kg		Geochemical Abundance Index									
Calcium (Ca)	50	15,000	0	0	0	0	0	0	0	0	0	0
Magnesium (Mg)	50	5,000	0	0	0	0	0	0	0	0	0	0
Potassium (K)	50	14,000	0	0	0	0	0	0	0	0	0	0
Sodium (Na)	50	5,000	0	0	0	0	0	0	0	0	0	0
Major, Minor & Trace Elements	all units mg/kg		Geochemical Abundance Index									
Aluminium (Al)	50	71,000	0	0	0	0	0	0	0	0	0	0
Antimony (Sb)	5	5	0	0	0	0	0	0	0	0	0	0
Arsenic (As)	5	6	0	0	0	0	0	0	0	0	1	0
Barium (Ba)	10	500	0	0	0	0	0	0	0	0	0	0
Beryllium (Be)	1	6	0	0	0	0	0	0	0	0	0	0
Boron (B)	50	100	0	0	0	0	0	0	0	0	0	0
Cadmium (Cd)	1	0.35	0	0	0	0	0	0	0	0	0	0
Chromium (Cr) - hexavalent	2	70	0	0	0	0	0	0	0	0	0	0
Cobalt (Co)	2	8	1	0	1	0	0	0	0	1	0	0
Copper (Cu)	5	30	0	0	0	0	0	0	0	0	0	0
Iron (Fe)	50	40,000	0	0	0	0	0	0	0	0	0	0
Lead (Pb)	5	35	0	0	0	0	0	0	0	0	0	0
Manganese (Mn)	5	1000	0	0	0	0	0	0	0	0	0	0
Mercury (Hg)	0.1	0.06	0	0	0	0	0	0	0	0	0	0
Molybdenum (Mo)	2	2	0	0	0	0	0	0	0	0	0	0
Nickel (Ni)	2	50	0	0	0	0	0	0	0	0	0	0
Reactive Phosphorus (P)		800	0	0	0	0	0	0	0	0	0	0
Selenium (Se)	5	0.4	2	2	2	2	2	2	2	2	2	2
Thallium (Tl)	5	2.5	0	0	0	0	0	1	0	0	0	0
Thorium (Th)	0.1	9	-	-	-	-	-	-	-	-	0	0
Uranium (U)	0.1	2	0	0	0	0	0	0	0	0	0	1
Zinc (Zn)	5	90	0	0	0	0	0	0	0	0	0	0

Notes: GAI's greater than or equal to 3 are highlighted.

1. Average Crustal Abundance values sourced from the "GARD Guide", Chapter 5 (INAP, 2009). When no GARD Guide value is available for a particular element, then values are taken from Bowen H.J.M.(1979) Environmental Chemistry of the Elements, pages 60-61.

Table B6: Multi-element test results for water extracts from waste rock and coal reject samples

		RGS Sample Number →	Composite 1	Composite 2	Composite 3	Composite 4	Composite 5	Composite 6	Composite 7	Composite 8	Composite 9	Composite 10
		ALS Laboratory ID →	EB1916203003	EB1916203004	EB1916203005	EB1916203006	EB1916203007	EB1916203008	EB1931850005	EB1931850006	EB1933850008	EB1933850009
		Sample description →	Vulcan Soil	Vulcan Sandstone	Vulcan Clay	Vulcan Claystone	Jupiter Sandstone	Jupiter Siltstone	Vulcan Coarse Reject	Vulcan Fine Reject	Jupiter/Vulcan Coarse Reject	Jupiter/Vulcan Fine Reject
		Water Quality Guidelines:										
Parameters	Limit of Reporting	Aquatic Ecosystems (freshwater)[1]	Livestock Drinking Water[2]									
pH	0.01 pH unit	6 to 9	-	8.2	8.6	8.5	8.2	6.8	7.1	8.6	7.4	5.8	6.2
Electrical Conductivity	1 µS/cm	<1,000#	3,580^	552	346	788	490	167	264	86	154	96	54
Carbonate Alkalinity ($mgCaCO_3/L$)	1 mg/L	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity ($mgCaCO_3/L$)	1 mg/L	-	-	1,768	564	2,980	546	35	144	24	33	56	1,032
Total Alkalinity ($mgCaCO_3/L$)	1 mg/L	-	-	1,768	564	2,980	546	35	144	24	33	56	1,032
Acidity ($mgCaCO_3/L$)	1 mg/L	-	-	2	<1	<1	3	8	5	19	48	46	178
Net Alkalinity ($mgCaCO_3/L$)	1 mg/L	-	-	1,766	564	2,980	543	27	139	6	33	56	854
Major Ions	All units mg/L			All units mg/L									
Calcium (Ca)	2	-	1,000	12	2	4	4	<2	<2	<2	4	<2	2
Magnesium (Mg)	2	-	-	12	6	10	8	<2	<2	<2	4	<2	4
Potassium (K)	2	-	-	<2	6	<2	8	12	8	<2	<2	<2	4
Sodium (Na)	2	-	-	92	54	146	84	26	52	26	26	24	24
Chloride (Cl)	2	-	-	60	48	140	82	18	36	8	24	10	26
Fluoride (F)	0.2	-	2	0.8	0.4	1.8	0.8	<0.2	0.2	<0.2	1.0	0.2	0.4
Sulfate (SO_4)	2	-	1,000	30	28	46	44	30	24	18	32	24	20
Trace Metals/Metalloids	All units mg/L			All units mg/L									
Aluminium (Al)	0.02	0.055	5	<0.02	0.06	0.04	0.04	0.36	0.48	0.14	<0.02	<0.02	<0.02
Antimony (Sb)	0.002	-	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	0.004	<0.002
Arsenic (As) - pentavalent	0.002	0.013 **	0.5	<0.002	0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002
Barium (Ba)	0.002	-	-	0.028	0.012	0.016	0.008	0.004	0.002	<0.002	0.002	<0.002	0.004
Beryllium (Be)	0.002	-	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Boron (B)	0.2	0.37	5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cadmium (Cd)	0.002	0.0002	0.01	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Chromium (Cr) - total	0.002	0.001 (hex)*	1 (total)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cobalt (Co)	0.002	-	1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Copper (Cu)	0.002	0.0014	1	0.006	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	0.004	<0.002	<0.002
Iron (Fe)	0.2	-	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Lead (Pb)	0.002	0.0034	0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Manganese (Mn)	0.002	1.90	-	0.008	<0.002	<0.002	<0.002	0.004	0.004	<0.002	0.004	<0.002	<0.002
Mercury (Hg)	0.0001	0.0006	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum (Mo)	0.002	-	0.15	0.002	0.004	0.002	0.004	<0.002	0.006	0.034	0.020	0.008	0.002
Nickel (Ni)	0.002	0.011	1	0.006	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002
Selenium (Se)	0.02	0.011	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Silica (SiO_2)	0.2	-	-	10.2	9.0	10.4	10.0	12.8	14.4	<0.2	<0.2	16.2	8.6
Thorium (Th)	0.002	-	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Uranium (U)	0.002	-	0.2	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Vanadium (V)	0.02	-	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Zinc (Zn)	0.01	0.008	20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

* Cr (VI) = hexavalent. ** 0.024 mg/Lfor trivalent Arsenic (III).

for still water bodies only, moving rivers at low flow rates should not exceed 2,200µS/cm

^ calculated based on total dissolved solids (TDS) conversion rate of 0.67% of EC. TDS is an approximate measure of inorganic dissolved salts and should not exceed 2,400mg/L for livestock drinking water.

Notes: < indicates concentration less than the detection limit. Shaded cells exceed applied guideline values.

1. ANZG (2018). Trigger values for aquatic ecosystems (95% species protection level)
2. ANZG (2018. Recommended guideline limits for Livestock Drinking Water.

Table B7: Waste rock and coal reject samples selected for KLC tests

RGS Sample ID	ALS ID	Deposit	Vitronite Sample ID	Drillhole ID	Sample Lithology	From	To	Interval	RGS KLC No.
						(m)			
9	EB1914213009	Vulcan	145304	VSW070_C	Sandstone 100%	7.00	16.00	9.00	
10	EB1914213010	Vulcan	145305 - 145306	VSW070_C	Sandstone 100%	16.00	23.00	7.00	
11	EB1914213011	Vulcan	145307	VSW070_C	Sandstone 100%	23.00	25.00	2.00	
15	EB1914213015	Vulcan	145311	VSW070_C	Sandstone 100%	27.99	32.00	4.01	
16	EB1914213016	Vulcan	145312	VSW070_C	Sandstone 100%	32.00	37.00	5.00	
17	EB1914213017	Vulcan	145313	VSW070_C	Sandstone 100%	37.00	41.00	4.00	
21	EB1914213021	Vulcan	134784	VSW082_C	Sandstone 100%	5.00	16.00	11.00	
25	EB1914213025	Vulcan	134788	VSW082_C	Sandstone 100%	20.00	26.08	6.08	
28	EB1914213028	Vulcan	134791	VSW083_C	Sandstone 100%	4.00	20.00	16.00	
29	EB1914213029	Vulcan	134792	VSW083_C	Sandstone 100%	20.00	21.77	1.77	
31	EB1914213031	Vulcan	134794	VSW083_C	Sandstone 100%	21.97	24.00	2.03	
33	EB1914213033	Vulcan	134796	VSW083_C	Sandstone 100%	25.00	30.86	5.86	
41	EB1914213041	Vulcan	163124 - 163125	VSW084_C	Sandstone 100%	19.00	26.00	7.00	
43	EB1914213043	Vulcan	163127 - 163128	VSW084_C	Sandstone 100%	27.00	37.00	10.00	
44	EB1914213044	Vulcan	163129 - 163131	VSW084_C	Sandstone 100%	37.00	42.84	5.84	
56	EB1914213056	Vulcan	163004	VSW087_C	Sandstone 100%	4.00	9.00	5.00	
57	EB1914213057	Vulcan	163005 - 163006	VSW087_C	Sandstone 100%	9.00	13.00	4.00	
58	EB1914213058	Vulcan	163007 - 163009	VSW087_C	Sandstone 100%	13.00	18.00	5.00	
59	EB1914213059	Vulcan	163010	VSW087_C	Sandstone 100%	18.00	21.00	3.00	KLC1
60	EB1914213060	Vulcan	163011	VSW087_C	Sandstone 100%	21.00	24.02	3.02	
66	EB1914213066	Vulcan	163018 - 163019	VSW088_C	Sandstone 100%	12.00	18.00	6.00	
67	EB1914213067	Vulcan	163020 - 163022	VSW088_C	Sandstone 100%	18.00	23.00	5.00	
68	EB1914213068	Vulcan	163023	VSW088_C	Sandstone 100%	23.00	29.00	6.00	
94	EB1914214024	Vulcan	163042 - 163043	VSW095_C	Sandstone 100%	9.00	12.00	3.00	
95	EB1914214025	Vulcan	163044	VSW095_C	Sandstone 100%	12.00	14.00	2.00	
97	EB1914214027	Vulcan	163046 - 163047	VSW095_C	Sandstone 100%	15.00	18.00	3.00	
98	EB1914214028	Vulcan	163048 - 163050	VSW095_C	Sandstone 100%	18.00	24.00	6.00	
99	EB1914214029	Vulcan	163201	VSW095_C	Sandstone 100%	24.00	25.00	1.00	
103	EB1914214033	Vulcan	163253 - 163254	VSW099_C	Sandstone 100%	3.00	7.00	4.00	
104	EB1914214034	Vulcan	163255 - 163256	VSW099_C	Sandstone 100%	7.00	14.00	7.00	
105	EB1914214035	Vulcan	163257 - 163258	VSW099_C	Sandstone 100%	14.00	19.00	5.00	
106	EB1914214036	Vulcan	163259 - 163260	VSW099_C	Sandstone 100%	19.00	22.80	3.80	
111	EB1914214041	Vulcan	163236	VSW104_C	Sandstone 100%	4.00	7.00	3.00	
112	EB1914214042	Vulcan	163237	VSW104_C	Sandstone 100%	7.00	14.00	7.00	
113	EB1914214043	Vulcan	163238 - 163240	VSW104_C	Sandstone 100%	14.00	20.00	6.00	
115	EB1914214045	Vulcan	163242	VSW104_C	Sandstone 100%	21.00	28.00	7.00	
116	EB1914214046	Vulcan	163243	VSW104_C	Sandstone 100%	28.00	30.00	2.00	
12	EB1914213012	Vulcan	145308	VSW070_C	Claystone 100%	25.00	26.00	1.00	
13	EB1914213013	Vulcan	145309	VSW070_C	Carbonaceous Sandstone 100%	26.00	27.53	1.53	
14	EB1914213014	Vulcan	145310	VSW070_C	Weathered Coal 100%	27.53	27.99	0.46	
22	EB1914213022	Vulcan	134785	VSW082_C	Claystone 100%	16.00	17.70	1.70	
23	EB1914213023	Vulcan	134786	VSW082_C	Weathered Coal 25%, Siltstone 75%	17.70	18.70	1.00	
30	EB1914213030	Vulcan	134793	VSW083_C	Weathered Coal 100%	21.77	21.97	0.20	
42	EB1914213042	Vulcan	163126	VSW084_C	Claystone 100%	26.00	27.00	1.00	
45	EB1914213045	Vulcan	163132	VSW084_C	Carbonaceous Claystone 38%, Carbonaceous Sandstone 62%	42.84	43.74	0.90	
62	EB1914213062	Vulcan	163013	VSW087_C	Carbonaceous Siltstone 100%	24.88	28.95	4.07	
80	EB1914214010	Vulcan	134820	VSW090_C	Claystone 100%	19.00	20.00	1.00	
81	EB1914214011	Vulcan	134821	VSW090_C	Claystone 98%, Carbonaceous Claystone 2%	20.00	26.00	6.00	KLC2
82	EB1914214012	Vulcan	134822	VSW090_C	Claystone 100%	26.00	27.00	1.00	
83	EB1914214013	Vulcan	134823	VSW090_C	Claystone 100%	27.00	30.85	3.85	
88	EB1914214018	Vulcan	134837	VSW092_C	Clay 99%, Weathered Coal 1%	13.00	17.69	4.69	
89	EB1914214019	Vulcan	134838	VSW092_C	Claystone 35%, Weathered Coal 51%, Carbonaceous Claystone 14%	17.69	21.00	3.31	
90	EB1914214020	Vulcan	134839	VSW092_C	Claystone 100%	21.00	23.20	2.20	
96	EB1914214026	Vulcan	163045	VSW095_C	Claystone 100%	14.00	15.00	1.00	
100	EB1914214030	Vulcan	163202	VSW095_C	Claystone 100%	25.00	25.84	0.84	
107	EB1914214037	Vulcan	163261	VSW099_C	Claystone 89%, Carbonaceous Claystone 11%	22.80	24.00	1.20	
108	EB1914214038	Vulcan	163262	VSW099_C	Carbonaceous Sandstone 100%	24.00	29.60	5.60	
114	EB1914214044	Vulcan	163241	VSW104_C	Sandstone 80%, Carbonaceous Siltstone 20%	20.00	21.00	1.00	
118	EB1914214048	Jupiter	335481	VSW017_C	Sandstone 100%	1.00	3.00	2.00	
119	EB1914214049	Jupiter	335482	VSW017_C	Sandstone 100%	3.00	6.00	3.00	
120	EB1914214050	Jupiter	335483	VSW017_C	Sandstone 100%	6.00	7.59	1.59	
123	EB1914214053	Jupiter	335479	VSW019_C	Sandstone 100%	14.26	24.86	10.60	KLC3
127	EB1914214057	Jupiter	145154	VSW022_C	Sandstone 100%, Carbonaceous Claystone <1%	20.00	33.01	13.01	
130	EB1914214060	Jupiter	134773	VSW077_C	Sandstone 100%	1.00	3.00	2.00	
132	EB1914214062	Jupiter	134764	VSW078_C	Sand 16%, Sandstone 84%	0.00	3.17	3.17	
135	EB1914214065	Jupiter	134770	VSW080_C	Sandstone 100%	1.00	2.94	1.94	
122	EB1914214052	Jupiter	335478	VSW019_C	Coaly Shale 100%	3.00	7.53	4.53	
125	EB1914214055	Jupiter	145152	VSW022_C	Shale 100%	1.00	10.00	9.00	
126	EB1914214056	Jupiter	145153	VSW022_C	Carbonaceous Siltstone 100%	10.00	12.02	2.02	
128	EB1914214058	Jupiter	145155	VSW022_C	Siltstone 100%, Carbonaceous Claystone <1%	33.01	43.21	10.20	
131	EB1914214061	Jupiter	134774	VSW077_C	Carbonaceous Siltstone 100%	3.00	4.00	1.00	KLC4
133	EB1914214063	Jupiter	134767	VSW078_C	Siltstone 100%	4.45	6.00	1.55	
137	EB1914214067	Jupiter	134872	VSW103_C	Siltstone 100%	2.00	5.00	3.00	
138	EB1914214068	Jupiter	134873	VSW103_C	Siltstone 100%	5.00	8.00	3.00	
139	EB1914214069	Jupiter	134874	VSW103_C	Siltstone 100%	8.00	11.00	3.00	
140	IP19006604 R006	Vulcan	134725_28 + 162507_09	VSW069_C	Fine Rejects				KLC 5
141	IP19004101 R299	Vulcan	145437-442 to 145447-448	VSW086_C	Fine Rejects				
142	IP19006604 R005	Vulcan	134725_28 + 162507_09	VSW069_C	Coarse Rejects				KLC 6
143	IP19004101 R298	Vulcan	145437-442 to 145447-448	VSW086_C	Coarse Rejects				

Notes

1. Current pH, EC, Alkalinity and Acidity provided for 1:5 sample:water extracts
2. CRS = Chromium Reducible Sulfur; MPA = Maximum Potential Acidity; ANC = Acid Neutralising Capacity; NAPP = Net Acid Producing Potential; and NAG = Net Acid Generation
3. Sample classification criteria detail provided in report text.

* Where total sulfur or ANC results are less than the laboratory LoR a value of half of the LoR is used in Table B5.

Attachment C Kinetic Geochemical Test Results

Vulcan Sandstone

KLC 1

Weight (kg)	2.00	**Total S (%)**	0.02	**ANC**	15.1
pH (1:5)	8.79	**Scr (%)**	0.020	**NAPP**	-14.6
EC (µS/cm)	283	**MPA**	0.6	**ANC:MPA**	26.5

Date			**25-Jun-19**	**22-Jul-19**	**27-Aug-19**	**25-Sep-19**	**22-Oct-19**	**26-Nov-19**	**24-Dec-19**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1916412001	EB1918957001	EB1922363001	EB1925267001	EB1927981001	EB1931659001	EB1934601001
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.609	0.580	0.512	0.454	0.467	0.375	0.281
Cum. Volume (L)			0.61	1.19	1.70	2.15	2.62	3.00	3.28
Pore Volumes			0.5	0.9	1.3	1.6	1.9	2.2	2.4
pH (RGS Measurement)			8.21	6.74	6.91	7.77	7.75	8.06	7.66
pH (ALS Measurement)			6.87	7.02	7.25	7.45	7.15	7.85	8.03
pH (deionised water used in test)			5.45	5.46	6.01	5.89	5.67	5.87	5.95
EC (RGS Measurement) (µS/cm)			54	150	268	848	1,156	1,796	442
EC (ALS Measurement) (µS/cm)			56	171	282	930	1,150	1750	462
Acidity (mg/L)*			1	1	1	7	2	5	<1
Alkalinity (mg/L)*			7	5	8	26	25	47	80
Net Alkalinity (mg/L)*			6	4	7	19	23	42	80
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	0.5	2	3	7	12	16	3
Potassium (K)	1	-	<1	<1	<1	1	<1	2	1
Magnesium (Mg)	1	-	0.5	5	7	22	38	49	8
Sodium (Na)	1	-	12	22	44	146	142	258	91
Chloride (Cl)	1	-	10	33	52	222	318	456	64
Fluoride (F)	0.1	2	<0.1	<0.1	0.1	0.5	0.3	0.7	0.9
Sulfate (SO_4)	1	1,000	3	20	39	107	95	186	47
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	1.09	0.22	0.13	0.01	<0.01	<0.01	0.77
Arsenic (As)	0.001	0.5	<0.001	<0.001	<0.001	0.002	0.001	0.006	0.004
Boron (B)	0.05	5	<0.05	<0.05	<0.05	0.06	<0.05	0.09	0.14
Cadmium (Cd)	0.0001	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt (Co)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium (Cr)	0.001	1	<0.001	<0.001	<0.001	<0.001	0.021	<0.001	0.001
Copper (Cu)	0.001	1	<0.001	0.001	<0.001	<0.001	0.002	0.002	0.005
Iron (Fe)	0.05	1	0.21	<0.05	<0.05	<0.05	0.16	<0.05	0.10
Manganese (Mn)	0.001	2	0.002	0.02	0.005	0.009	0.024	0.035	0.003
Molybdenum (Mo)	0.001	0.15	<0.001	<0.001	0.001	0.008	0.005	0.012	0.013
Nickel (Ni)	0.001	1	<0.001	<0.001	<0.001	0.001	0.002	0.002	0.001
Lead (Pb)	0.001	0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	0.001	-	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
Selenium (Se)	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Calculations**									
SO_4 Release Rate			1	6	10	24	22	35	7
Cumulative SO_4 Release			1	7	17	41	63	98	105
Ca Release Rate			0.2	0.6	0.8	1.6	2.8	3.0	0.4
Cumulative Ca Release			0.2	0.7	1.5	3.1	5.9	8.9	9.3
Mg Release Rate			0.2	1.5	1.8	5.0	8.9	9.2	1.1
Cumulative Mg Release			0.2	1.6	3.4	8.4	17.3	26.4	27.6
Residual ANC (%)			100.0	99.9	99.9	99.7	99.4	99.2	99.1
Residual Sulfur (%)			99.8	98.8	97.0	92.7	88.7	82.5	81.3
SO_4/(Ca+Mg) molar ratio			0.9	0.8	1.1	1.0	0.5	0.8	1.2

< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2018). Livestock drinking water (low risk trigger levels). (Irrigation Levels used for Fe and Mn).

Vulcan Claystone

KLC 2

Weight (kg)	2.00	**Total S (%)**	0.03	**ANC**	13.4
pH (1:5)	8.42	**Scr (%)**	0.030	**NAPP**	-12.4
EC (µS/cm)	352	**MPA**	1.0	**ANC:MPA**	13.3

Date			**25-Jun-19**	**22-Jul-19**	**27-Aug-19**	**25-Sep-19**	**22-Oct-19**	**26-Nov-19**	**24-Dec-19**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1916412002	EB1918957002	EB1922363002	EB1925267002	EB1927981002	EB1931659002	'EB1934601002
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.562	0.489	0.360	0.575	0.829	0.536	0.687
Cum. Volume (L)			0.56	1.05	1.41	1.99	2.82	3.35	4.04
Pore Volumes			0.4	0.8	1.0	1.5	2.1	2.5	3.0
pH (RGS Measurement)			7.48	6.79	6.95	7.69	7.61	7.96	8.27
pH (ALS Measurement)			6.71	6.86	6.94	6.99	6.85	7.17	7.00
pH (deionised water used in test)			5.45	5.46	6.01	5.89	5.67	5.87	7.39
EC (RGS Measurement) (µS/cm)			69	259	395	219	152	122	89
EC (ALS Measurement) (µS/cm)			76	299	414	251	150	119	94
Acidity (mg/L)*			1	2	1	8	<1	<1	2
Alkalinity (mg/L)*			6	4	8	7	8	6	11
Net Alkalinity (mg/L)*			5	2	7	-1	8	6	9
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	0.5	3	7	2	2	2	0.5
Potassium (K)	1	-	<1	<1	1	<1	<1	<1	<1
Magnesium (Mg)	1	-	0.5	9	13	6	4	3	2
Sodium (Na)	1	-	15	39	57	36	18	15	15
Chloride (Cl)	1	-	13	63	68	44	23	18	13
Fluoride (F)	0.1	2	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Sulfate (SO_4)	1	1,000	6	34	71	37	22	18	12
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	1.07	0.05	0.04	0.26	0.22	0.22	0.29
Arsenic (As)	0.001	0.5	<0.001	<0.001	<0.001	<0.001	0.002	0.004	<0.001
Boron (B)	0.05	5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium (Cd)	0.0001	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt (Co)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium (Cr)	0.001	1	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001
Copper (Cu)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	0.05	1	0.40	<0.05	<0.05	0.13	0.14	0.09	0.09
Manganese (Mn)	0.001	2	0.007	0.008	0.004	0.003	0.003	0.002	0.003
Molybdenum (Mo)	0.001	0.15	<0.001	<0.001	0.001	0.002	<0.001	0.001	<0.001
Nickel (Ni)	0.001	1	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Lead (Pb)	0.001	0.1	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Calculations**									
SO_4 Release Rate			2	8	13	11	9	5	4
Cumulative SO_4 Release			2	10	23	33	43	47	51
Ca Release Rate			0.1	0.7	1.3	0.6	0.8	0.5	0.2
Cumulative Ca Release			0.1	0.9	2.1	2.7	3.5	4.1	4.2
Mg Release Rate			0.1	2.2	2.3	1.7	1.7	0.8	0.7
Cumulative Mg Release			0.1	2.3	4.7	6.4	8.1	8.9	9.6
Residual ANC (%)			100.0	99.9	99.8	99.8	99.7	99.7	99.6
Residual Sulfur (%)			99.8	99.0	97.7	96.6	95.7	95.2	94.8
SO_4/(Ca+Mg) molar ratio			1.9	0.8	1.0	1.3	1.1	1.1	1.3

< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2018). Livestock drinking water (low risk trigger levels). (Irrigation Levels used for Fe and Mn).

Jupiter Sandstone

KLC 3

Weight (kg)	1.95	**Total S (%)**	0.05	**ANC**	5.1
pH (1:5)	7.13	**Scr (%)**	0.050	**NAPP**	-3.7
EC (µS/cm)	142	**MPA**	1.4	**ANC:MPA**	3.7

Date			**25-Jun-19**	**22-Jul-19**	**27-Aug-19**	**26-Sep-19**	**22-Oct-19**	**26-Nov-19**	**24-Dec-19**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1916412003	EB1918957003	EB1922363003	EB1925267003	EB1927981003	EB1931659003	EB1934601003
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.578	0.662	0.613	0.576	0.586	0.549	0.624
Cum. Volume (L)			0.58	1.24	1.85	2.43	3.01	3.56	4.19
Pore Volumes			0.4	0.9	1.4	1.8	2.2	2.6	3.1
pH (RGS Measurement)			5.55	6.10	5.81	6.51	6.41	6.73	7.14
pH (ALS Measurement)			5.84	6.18	6.03	5.98	6.11	6.35	6.35
pH (deionised water used in test)			5.45	5.46	6.01	5.89	5.67	5.87	5.95
EC (RGS Measurement) (µS/cm)			558	128	174	255	210	184	141
EC (ALS Measurement) (µS/cm)			616	144	181	300	208	181	148
Acidity (mg/L)*			2	1	2	7	2	1	1
Alkalinity (mg/L)*			2	1	2	5	5	5	5
Net Alkalinity (mg/L)*			0	0	0	-2	3	4	4
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	4	0.5	2	2	2	2	1
Potassium (K)	1	-	6	1	2	2	2	2	2
Magnesium (Mg)	1	-	7	2	3	4	3	2	2
Sodium (Na)	1	-	104	23	30	49	31	27	24
Chloride (Cl)	1	-	108	25	21	37	21	15	10
Fluoride (F)	0.1	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfate (SO_4)	1	1,000	111	22	40	73	51	47	41
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	0.08	0.15	0.09	0.06	0.24	0.2	0.28
Arsenic (As)	0.001	0.5	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001
Boron (B)	0.05	5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium (Cd)	0.0001	0.01	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt (Co)	0.001	1	0.039	0.007	0.006	0.008	0.004	0.002	0.001
Chromium (Cr)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	0.001	1	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	0.05	1	<0.05	0.07	<0.05	0.05	<0.05	0.08	0.09
Manganese (Mn)	0.001	2	0.153	0.101	0.134	0.229	0.121	0.098	0.058
Molybdenum (Mo)	0.001	0.15	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel (Ni)	0.001	1	0.045	0.009	0.008	0.01	0.004	0.003	0.002
Lead (Pb)	0.001	0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	0.158	0.022	0.023	0.031	0.014	0.008	0.005
Calculations**									
SO_4 Release Rate			33	7	13	22	15	13	13
Cumulative SO_4 Release			33	40	53	75	90	103	116
Ca Release Rate			1.2	0.2	0.6	0.6	0.6	0.6	0.3
Cumulative Ca Release			1.2	1.4	2.0	2.6	3.2	3.7	4.1
Mg Release Rate			2.1	0.7	0.9	1.2	0.9	0.6	0.6
Cumulative Mg Release			2.1	2.8	3.7	4.9	5.8	6.3	7.0
Residual ANC (%)			99.8	99.7	99.6	99.5	99.4	99.3	99.3
Residual Sulfur (%)			97.6	97.0	96.1	94.5	93.3	92.4	91.4
SO_4/(Ca+Mg) molar ratio			3.0	2.4	2.4	3.5	3.1	3.7	4.0

< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2018). Livestock drinking water (low risk trigger levels). (Irrigation Levels used for Fe and Mn).

Jupiter Siltstone

KLC 4

Weight (kg)	2.02	**Total S (%)**	0.03	**ANC**	9.6
pH (1:5)	7.58	**Scr (%)**	0.030	**NAPP**	-8.7
EC (µS/cm)	198	**MPA**	0.9	**ANC:MPA**	10.7

Date			**25-Jun-19**	**22-Jul-19**	**27-Aug-19**	**25-Sep-19**	**22-Oct-19**	**26-Nov-19**	**24-Dec-19**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1916412004	EB1918957004	EB1922363004	EB1925267004	EB1927981004	EB1931659004	EB1934601004
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.570	0.557	0.636	0.594	0.591	0.576	0.708
Cum. Volume (L)			0.57	1.13	1.76	2.36	2.95	3.52	4.23
Pore Volumes			0.4	0.8	1.3	1.7	2.2	2.6	3.1
pH (RGS Measurement)			6.62	6.59	6.36	6.86	6.67	6.88	6.96
pH (ALS Measurement)			6.45	6.51	6.41	6.45	6.43	6.62	6.70
pH (deionised water used in test)			5.45	5.46	6.01	5.89	5.67	5.87	5.95
EC (RGS Measurement) (µS/cm)			649	490	368	384	304	414	371
EC (ALS Measurement) (µS/cm)			720	557	382	431	310	409	384
Acidity (mg/L)*			5	6	2	3	2	1	3
Alkalinity (mg/L)*			5	2	3	5	5	4	8
Net Alkalinity (mg/L)*			0	-4	1	2	3	3	5
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Potassium (K)	1	-	6	3	2	3	2	3	3
Magnesium (Mg)	1	-	4	7	5	4	3	4	2
Sodium (Na)	1	-	150	89	71	75	51	70	71
Chloride (Cl)	1	-	193	130	74	76	48	67	56
Fluoride (F)	0.1	2	0.2	0.1	0.1	0.2	0.1	0.2	0.2
Sulfate (SO_4)	1	1,000	45	57	48	74	53	78	72
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	0.24	0.14	0.17	0.68	0.73	0.91	1.13
Arsenic (As)	0.001	0.5	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.002
Boron (B)	0.05	5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cadmium (Cd)	0.0001	0.01	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt (Co)	0.001	1	0.003	0.002	0.002	0.002	0.002	0.002	0.001
Chromium (Cr)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Copper (Cu)	0.001	1	0.001	<0.001	0.004	<0.001	<0.001	<0.001	0.002
Iron (Fe)	0.05	1	0.14	0.11	0.07	0.20	<0.05	0.27	0.42
Manganese (Mn)	0.001	2	0.041	0.045	0.042	0.048	0.034	0.04	0.033
Molybdenum (Mo)	0.001	0.15	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel (Ni)	0.001	1	0.003	0.002	0.002	0.003	0.003	0.002	0.003
Lead (Pb)	0.001	0.1	0.001	0.001	<0.001	0.002	0.001	0.002	0.003
Antimony (Sb)	0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	0.01	<0.005	0.137	<0.005	<0.005	0.008	0.005
Calculations**									
SO_4 Release Rate			12.7	15.8	15.2	21.8	16	22	25
Cumulative SO_4 Release			12.7	28.5	43.6	65.4	81	103	129
Ca Release Rate			0.1	0.1	0.2	0.1	0.1	0.1	0.2
Cumulative Ca Release			0.1	0.3	0.4	0.6	0.7	0.9	1.1
Mg Release Rate			1.1	1.9	1.6	1.2	0.9	1.1	0.7
Cumulative Mg Release			1.1	3.1	4.6	5.8	6.7	7.8	8.5
Residual ANC (%)			99.9	99.9	99.8	99.7	99.7	99.6	99.6
Residual Sulfur (%)			98.6	96.8	95.1	92.6	90.8	88.3	85.4
SO_4/(Ca+Mg) molar ratio			2.6	2.0	2.3	4.4	4.1	4.6	7.9

< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

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Vulcan Fine Rejects

KLC 5

Weight (kg)	1.38	**Total S (%)**	0.50	**ANC**	5.1
pH (1:5)	8.20	**Scr (%)**	0.218	**NAPP**	1.6
EC (µS/cm)	289	**MPA**	6.7	**ANC:MPA**	0.8

Date			**03-Dec-19**	**07-Jan-20**	**04-Feb-20**	**04-Mar-20**	**04-Apr-20**	**04-May-20**	**04-Jun-20**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1932471005	EB2000205001	EB2002875001	EB2005904001	EB2009682001	EB2011988001	EB2014636001
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.530	0.551	0.596	0.505	0.633	0.539	0.534
Cum. Volume (L)			0.53	1.08	1.68	2.18	2.82	3.35	3.89
Pore Volumes			0.4	0.8	1.2	1.6	2.1	2.5	2.9
pH (RGS Measurement)			7.38	7.30	5.75	6.04	5.96	6.79	7.22
pH (ALS Measurement)			7.35	6.69	5.77	5.59	6.03	6.58	6.48
pH (deionised water used in test)			6.38	6.43	5.20	5.71	6.43	6.35	6.75
EC (RGS Measurement) (µS/cm)			822	496	928	998	634	495	389
EC (ALS Measurement) (µS/cm)			833	504	980	1,060	660	504	426
Acidity (mg/L)*			3	1	5	6	5	2	2
Alkalinity (mg/L)*			32	9	14	3	6	8	4
Net Alkalinity (mg/L)*			29	8	9	-3	1	6	2
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	35	22	50	64	31	26	21
Potassium (K)	1	-	5	5	8	8	6	5	4
Magnesium (Mg)	1	-	31	18	42	54	30	28	21
Sodium (Na)	1	-	70	45	73	86	51	39	26
Chloride (Cl)	1	-	158	40	56	36	17	8	6
Fluoride (F)	0.1	2	1.2	0.6	0.5	0.4	0.5	0.4	0.4
Sulfate (SO_4)	1	1,000	150	143	374	487	291	215	180
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	0.02	<0.01	0.04	0.01	0.05	<0.01	<0.01
Arsenic (As)	0.001	0.5	0.002	<0.001	0.001	0.001	<0.001	<0.001	<0.001
Boron (B)	0.05	5	0.11	0.09	0.16	0.18	0.15	0.06	0.08
Cadmium (Cd)	0.0001	0.01	0.0021	0.0015	0.0068	0.0088	0.0064	0.0058	0.0052
Cobalt (Co)	0.001	1	0.07	0.099	0.423	0.552	0.346	0.320	0.262
Chromium (Cr)	0.001	1	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	0.001	1	0.006	0.006	0.020	0.025	0.029	0.018	0.016
Iron (Fe)	0.05	1	<0.05	<0.05	0.10	<0.05	0.07	<0.05	<0.05
Manganese (Mn)	0.001	2	0.016	0.023	0.108	0.198	0.195	0.202	0.174
Molybdenum (Mo)	0.001	0.15	0.05	0.013	0.010	0.007	0.006	0.005	0.002
Nickel (Ni)	0.001	1	0.046	0.072	0.271	0.352	0.233	0.221	0.184
Lead (Pb)	0.001	0.1	<0.001	<0.001	0.020	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	0.001	-	0.002	0.001	0.001	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	0.01	0.02	0.05	0.02	0.05	0.05	0.04	0.03	0.02
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	0.067	0.098	0.554	0.971	0.777	0.862	0.796
Calculations**									
SO_4 Release Rate			57.7	57.2	161.9	178.6	133.8	84.2	69.8
Cumulative SO_4 Release			57.7	115.0	276.8	455.4	589.2	673.4	743.2
Ca Release Rate			13.5	8.8	21.6	23.5	14.3	10.2	8.1
Cumulative Ca Release			13.5	22.3	43.9	67.4	81.6	91.8	100.0
Mg Release Rate			11.9	7.2	18.2	19.8	13.8	11.0	8.1
Cumulative Mg Release			11.9	19.1	37.3	57.1	70.9	81.9	90.0
Residual ANC (%)			98.4	97.4	94.9	92.2	90.5	89.1	88.1
Residual Sulfur (%)			99.6	99.2	98.2	97.0	96.1	95.5	95.0
SO_4/(Ca+Mg) molar ratio			0.7	1.2	1.3	1.3	1.5	1.2	1.4

< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

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Vulcan Coarse Rejects

KLC 6

Weight (kg)	1.28	**Total S (%)**	0.40	**ANC**	7.8
pH (1:5)	7.15	**Scr (%)**	0.205	**NAPP**	-1.5
EC (µS/cm)	540	**MPA**	6.3	**ANC:MPA**	1.2

Date			**03-Dec-19**	**07-Jan-20**	**04-Feb-20**	**04-Mar-20**	**04-Apr-20**	**04-May-20**	**04-Jun-20**
Number of Weeks			**0**	**4**	**9**	**13**	**17**	**22**	**26**
Leach Number			**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALS Laboratory Number			EB1932471006	EB2000205002	EB2002875002	EB2005904002	EB2009682002	EB2011988002	EB2014636002
Volume On (L)			1.0	1.0	1.0	1.0	1.0	1.0	1.0
Volume Off (L)			0.755	0.690	0.794	0.680	0.654	0.673	0.633
Cum. Volume (L)			0.76	1.45	2.24	2.92	3.57	4.25	4.88
Pore Volumes			0.6	1.1	1.7	2.2	2.7	3.2	3.6
pH (RGS Measurement)			7.32	7.43	6.67	7.09	6.94	7.37	7.56
pH (ALS Measurement)			7.01	6.90	6.66	6.68	6.98	7.15	7.28
pH (deionised water used in test)			6.38	6.43	5.20	5.71	6.43	6.35	6.75
EC (RGS Measurement) (µS/cm)			148	205	247	252	218	220	163
EC (ALS Measurement) (µS/cm)			151	205	263	275	225	215	173
Acidity (mg/L)*			1	1	2	2	2	<1	<1
Alkalinity (mg/L)*			12	14	23	18	17	17	21
Net Alkalinity (mg/L)*			11	13	21	16	15	17	21
Major Ions (mg/L)	**LoR**	**WQ Guidelines#**							
Calcium (Ca)	1	1,000	2	2	2	3	2	2	2
Potassium (K)	1	-	1	2	2	2	2	2	2
Magnesium (Mg)	1	-	2	2	4	4	3	4	3
Sodium (Na)	1	-	23	33	42	44	36	39	27
Chloride (Cl)	1	-	19	14	13	11	8	6	4
Fluoride (F)	0.1	2	0.4	0.5	0.9	0.6	0.8	0.7	0.6
Sulfate (SO_4)	1	1,000	32	52	78	76	77	69	48
Trace metals/ metalloids (mg/L)	**LoR**								
Aluminium (Al)	0.01	5	0.09	0.14	0.33	0.16	0.24	0.32	0.33
Arsenic (As)	0.001	0.5	0.002	0.002	0.002	0.001	<0.001	0.001	0.002
Boron (B)	0.05	5	<0.05	<0.05	0.13	0.18	0.06	<0.05	0.05
Cadmium (Cd)	0.0001	0.01	<0.0001	0.0002	0.0003	0.0004	0.0004	0.0004	0.0004
Cobalt (Co)	0.001	1	0.006	0.016	0.023	0.021	0.020	0.019	0.016
Chromium (Cr)	0.001	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	0.001	1	0.002	0.003	0.005	0.006	0.009	0.005	0.007
Iron (Fe)	0.05	1	<0.05	0.07	0.15	0.06	<0.05	<0.05	<0.05
Manganese (Mn)	0.001	2	0.002	0.004	0.004	0.006	0.010	0.007	0.007
Molybdenum (Mo)	0.001	0.15	0.036	0.046	0.052	0.058	0.035	0.054	0.027
Nickel (Ni)	0.001	1	0.005	0.015	0.023	0.024	0.020	0.018	0.014
Lead (Pb)	0.001	0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony (Sb)	0.001	-	<0.001	0.001	0.002	0.001	0.002	0.002	0.002
Selenium (Se)	0.01	0.02	0.02	0.03	0.04	0.04	0.03	0.03	0.02
Vanadium (V)	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (Zn)	0.005	20	<0.005	0.009	0.016	0.026	0.036	0.040	0.038
Calculations**									
SO_4 Release Rate			18.9	28.1	48.6	40.5	39.5	36.4	23.8
Cumulative SO_4 Release			18.9	47.1	95.7	136.2	175.7	212.1	235.9
Ca Release Rate			1.2	1.1	1.2	1.6	1.0	1.1	1.0
Cumulative Ca Release			1.2	2.3	3.5	5.1	6.1	7.2	8.2
Mg Release Rate			1.2	1.1	2.5	2.1	1.5	2.1	1.5
Cumulative Mg Release			1.2	2.3	4.8	6.9	8.4	10.5	12.0
Residual ANC (%)			99.9	99.8	99.6	99.5	99.4	99.2	99.1
Residual Sulfur (%)			99.8	99.6	99.2	98.9	98.5	98.2	98.0
SO_4/(Ca+Mg) molar ratio			2.5	4.1	3.8	3.3	4.6	3.3	2.9

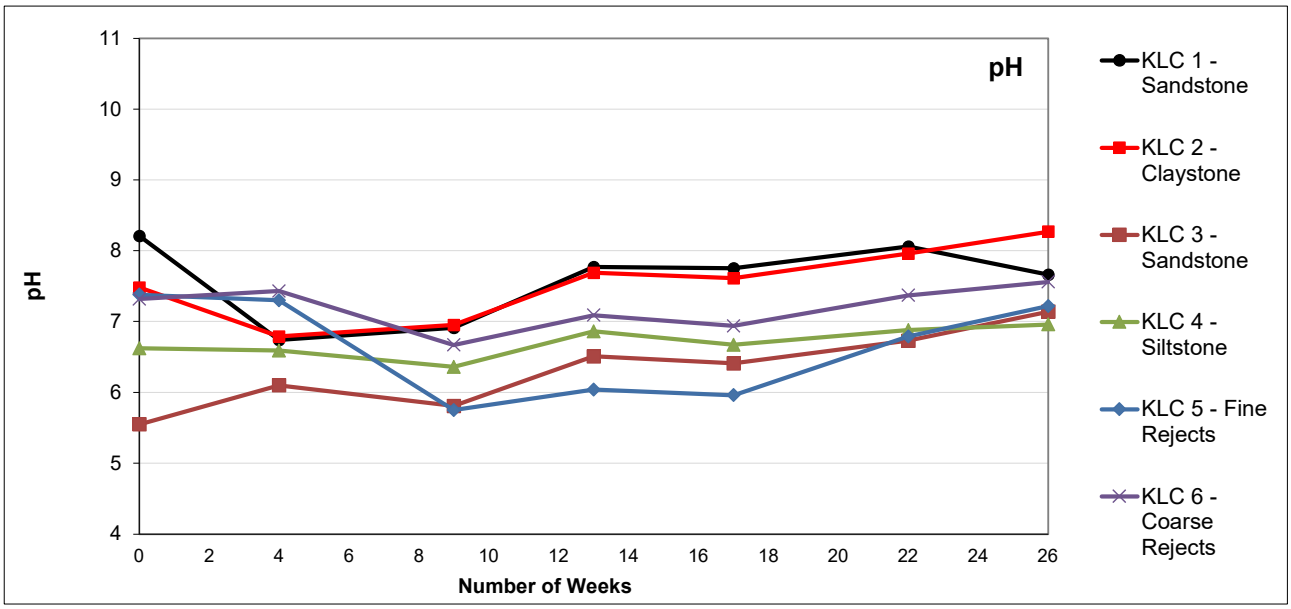
< indicates less than the analytical detection limit. * Acidity and alkalinity data calculated in mg $CaCO_3$/L.

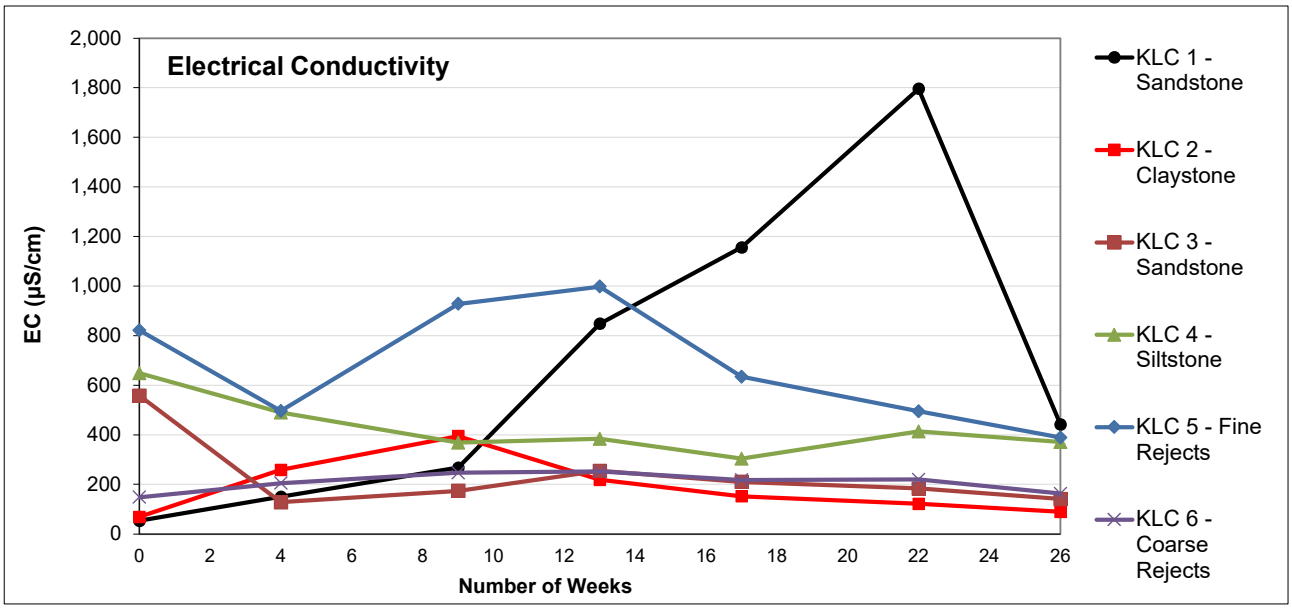
** SO_4, Ca and Mg release rates calculated in mg/kg/flush.

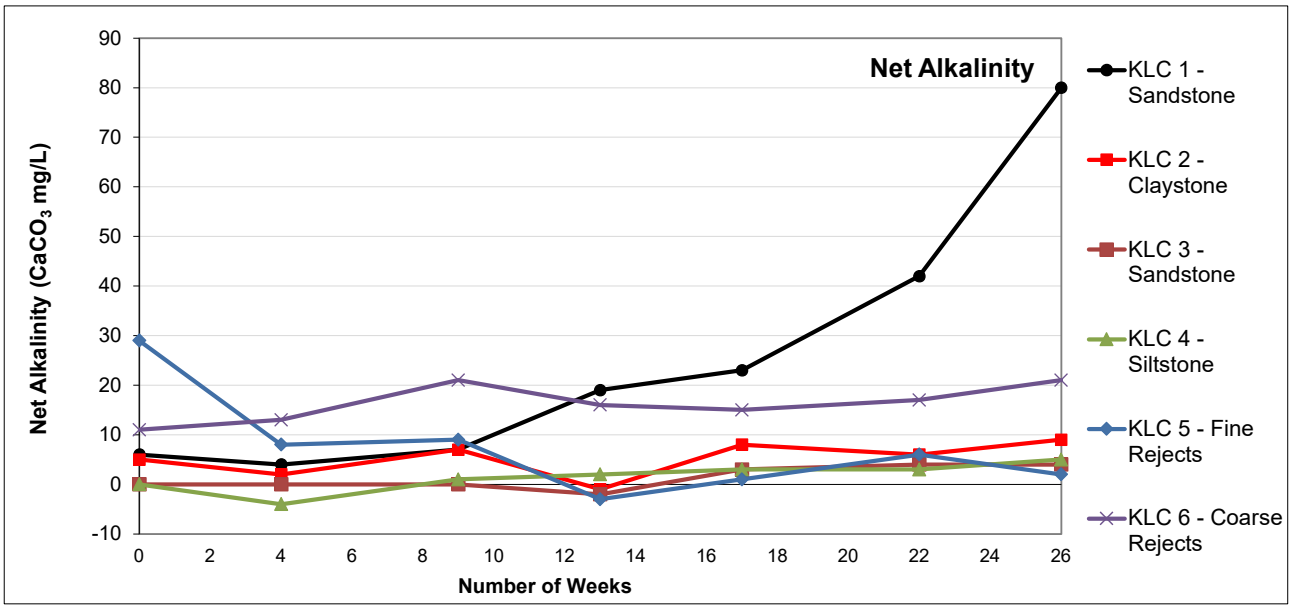
Total S = Total Sulfur; Scr = Chromium Reducible Sulfur; and ANC = Acid Neutralising Capacity.

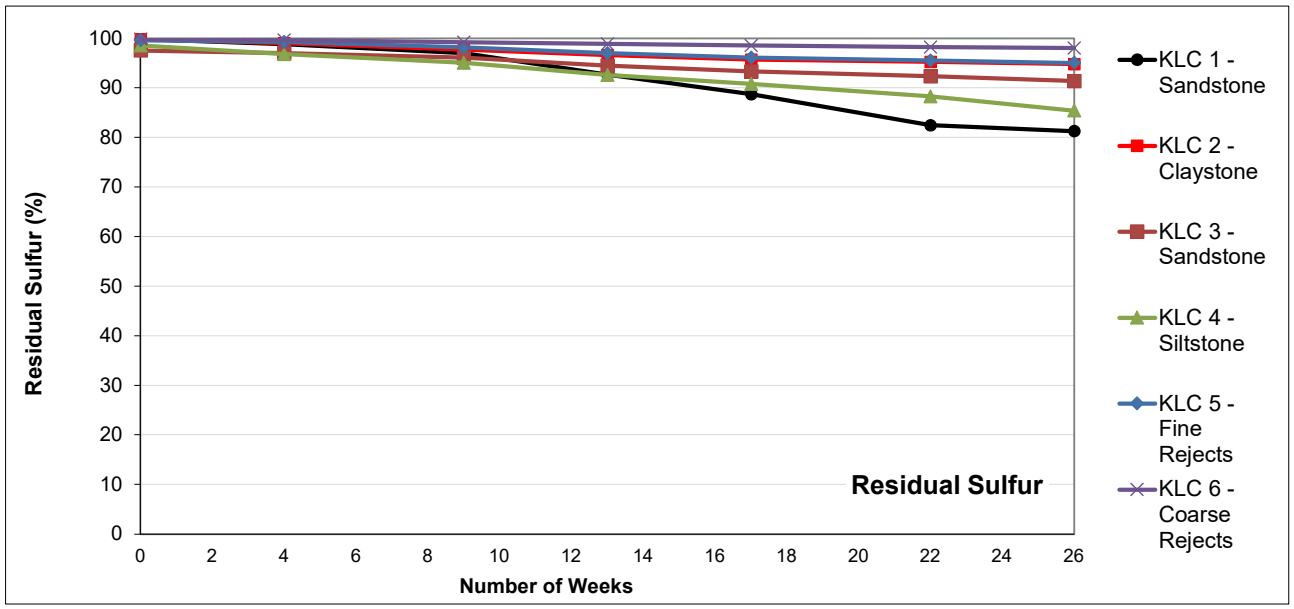
MPA = Maximum Potential Acidity, and NAPP = Net Acid Producing Potential.

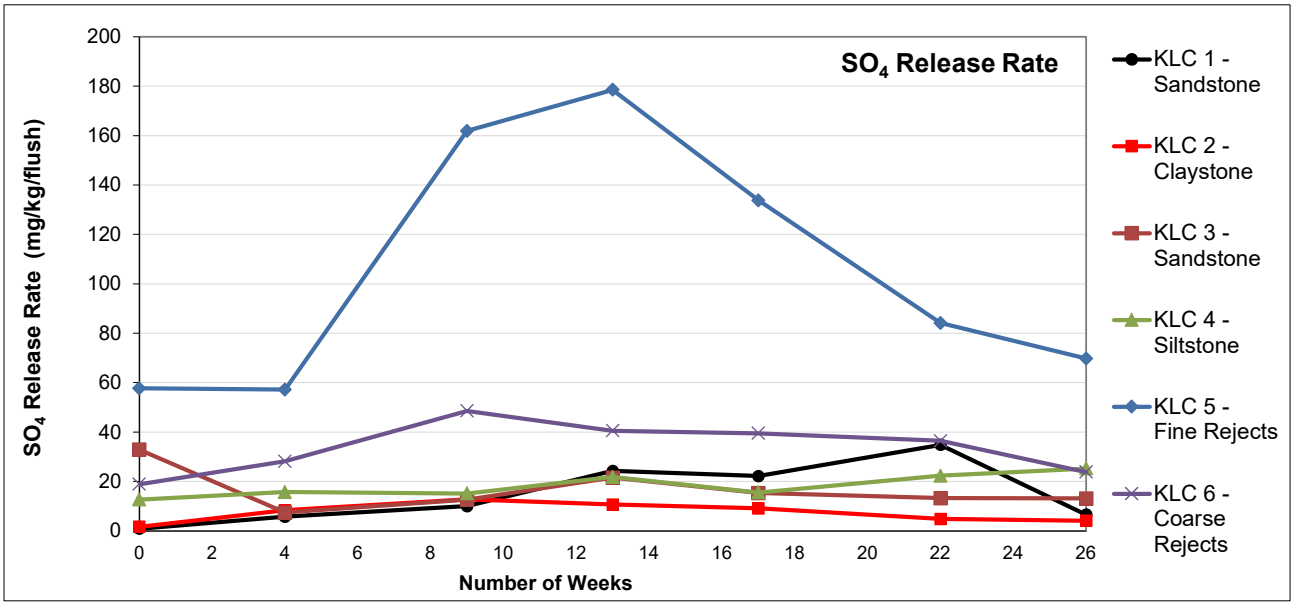
ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT (2018). Livestock drinking water (low risk trigger levels). (Irrigation Levels used for Fe and Mn).

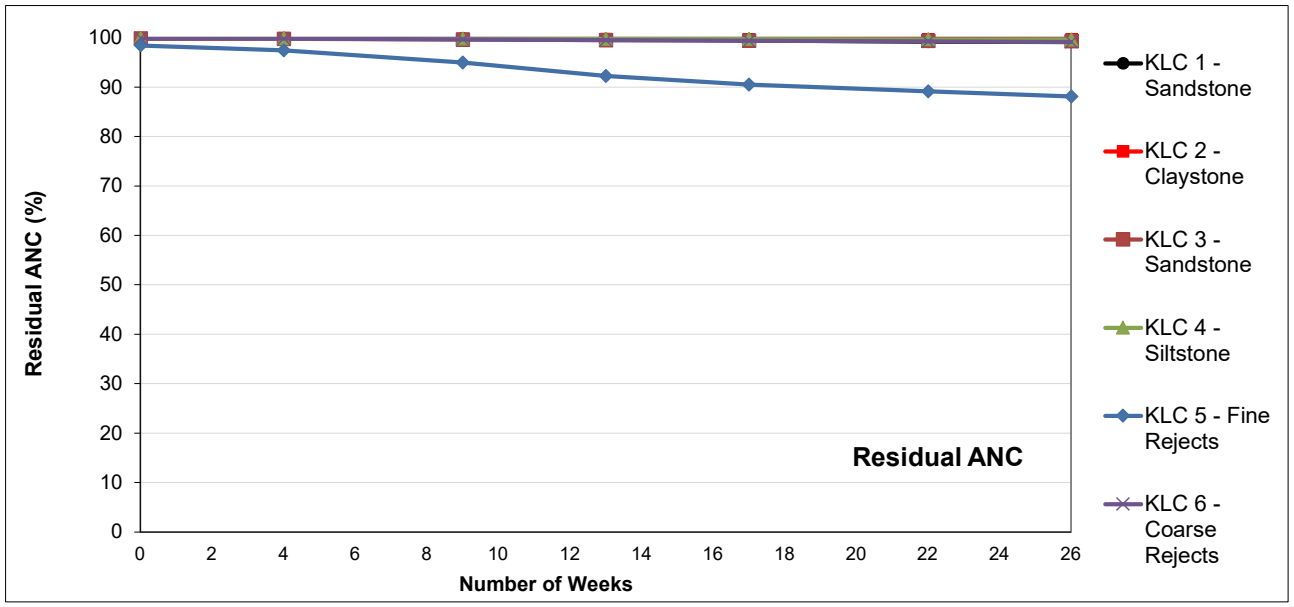

pH
pH
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

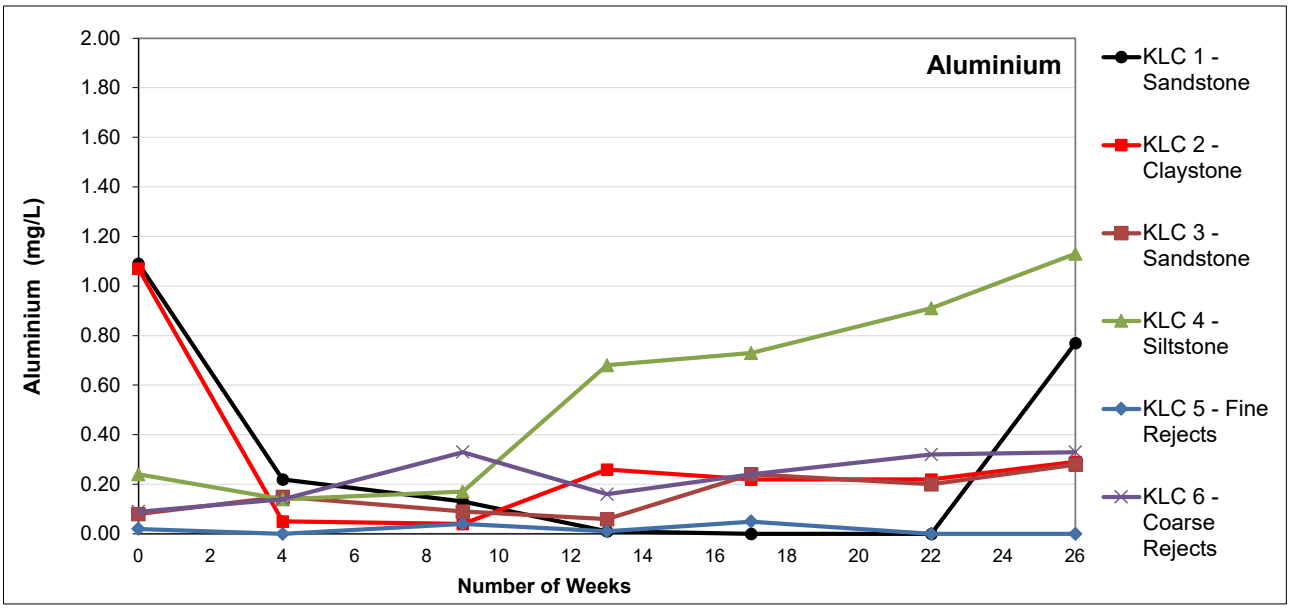

Electrical Conductivity
EC (µS/cm)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

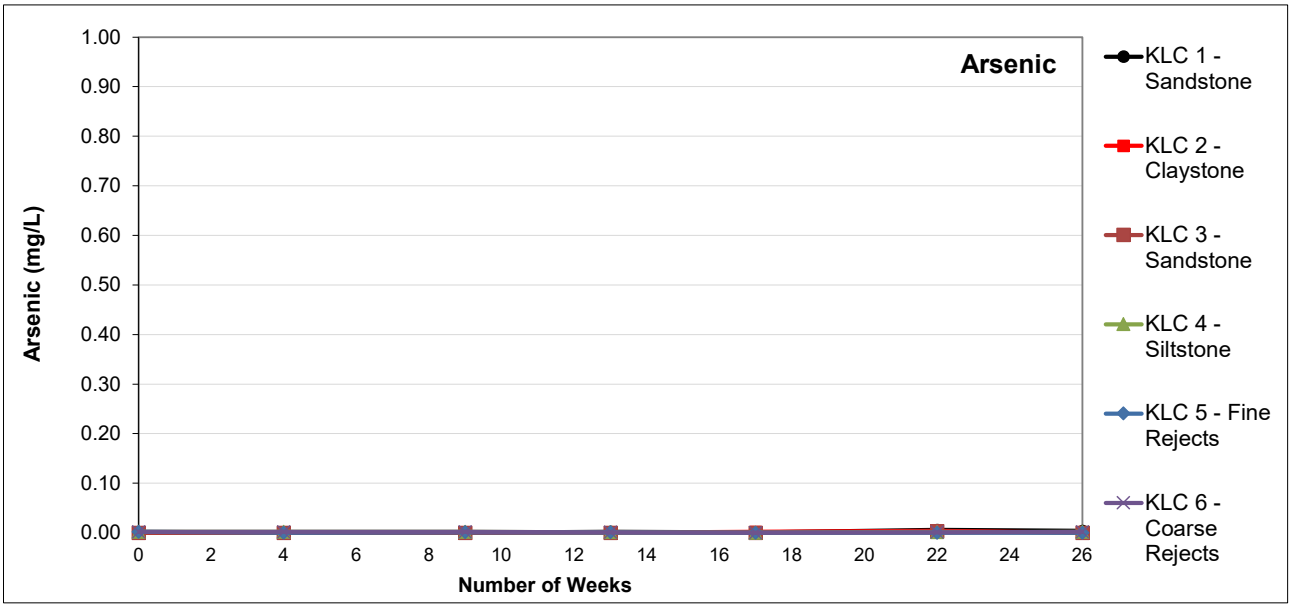

Net Alkalinity
Net Alkalinity (CaCO3 mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

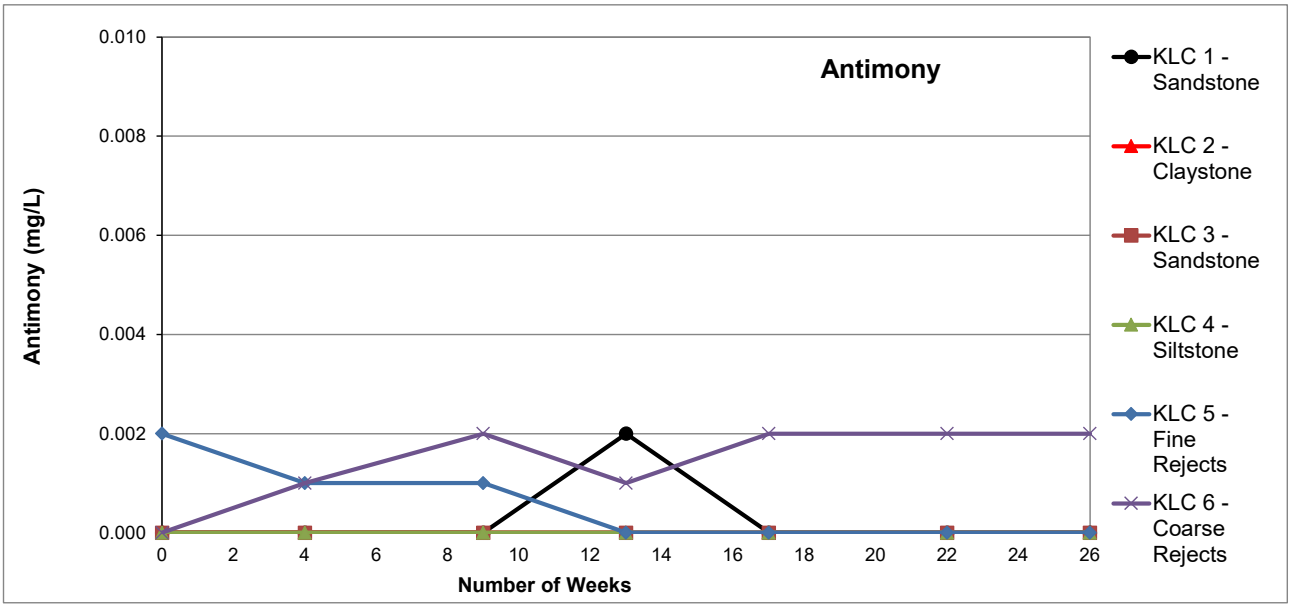

Residual Sulfur (%)
Number of Weeks
Residual Sulfur
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

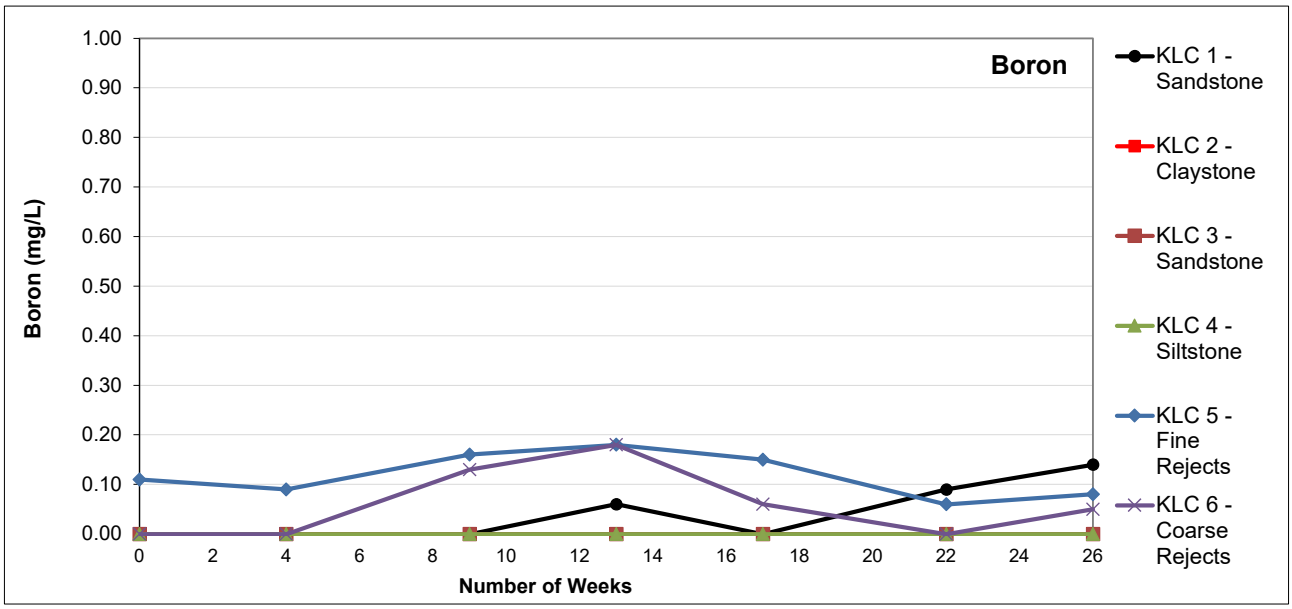

SO4 Release Rate (mg/kg/flush)
SO4 Release Rate
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

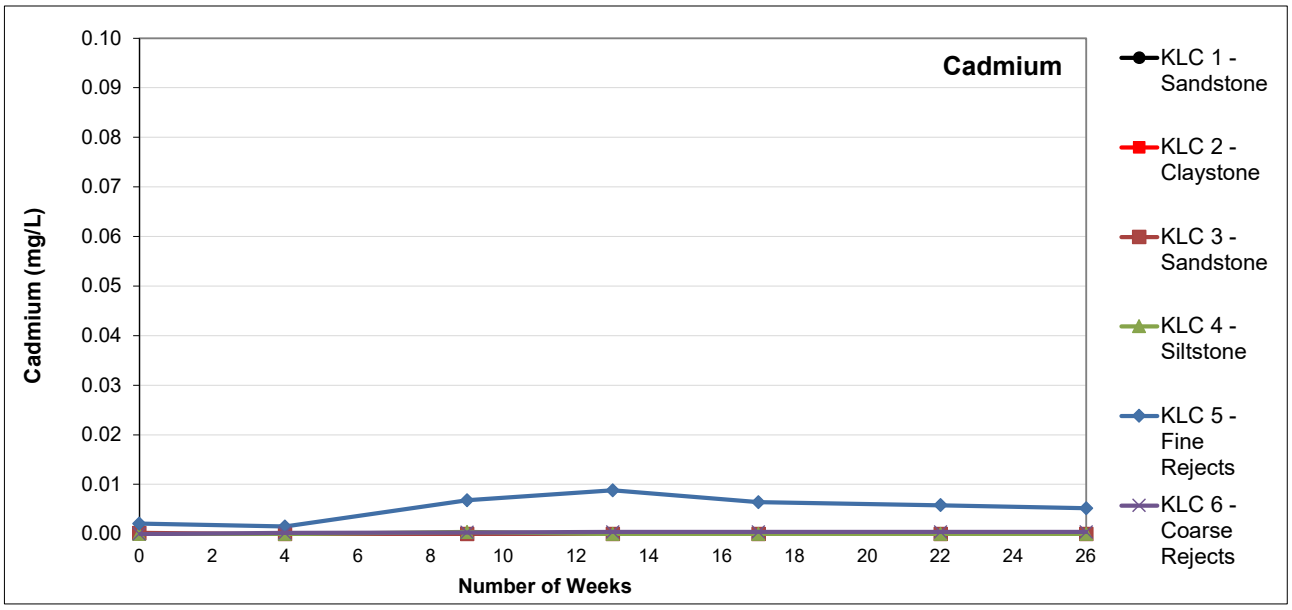

Residual ANC (%)
Number of Weeks
Residual ANC
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

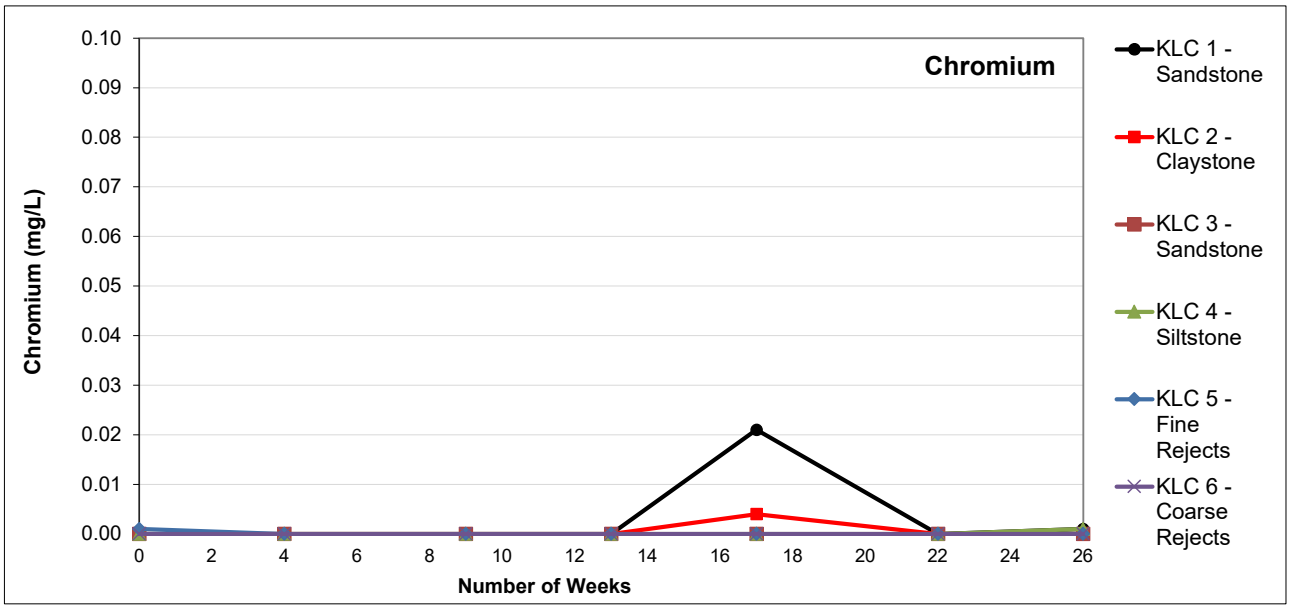

Aluminium
Aluminium (mg/L)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

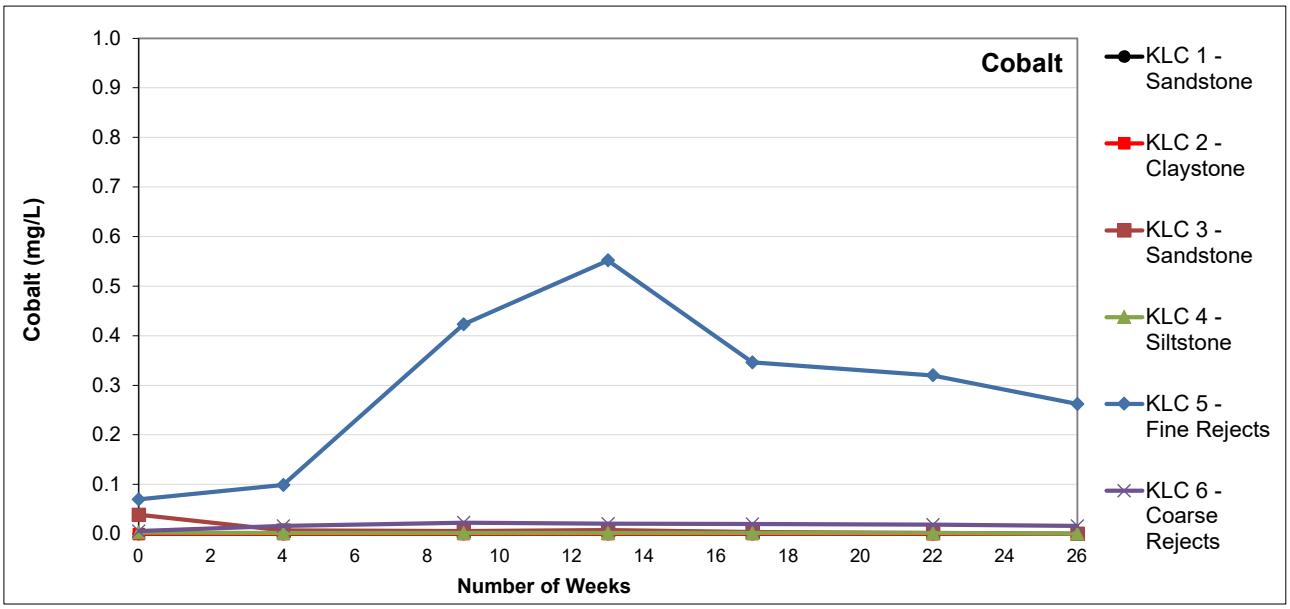

Arsenic
Arsenic (mg/L)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

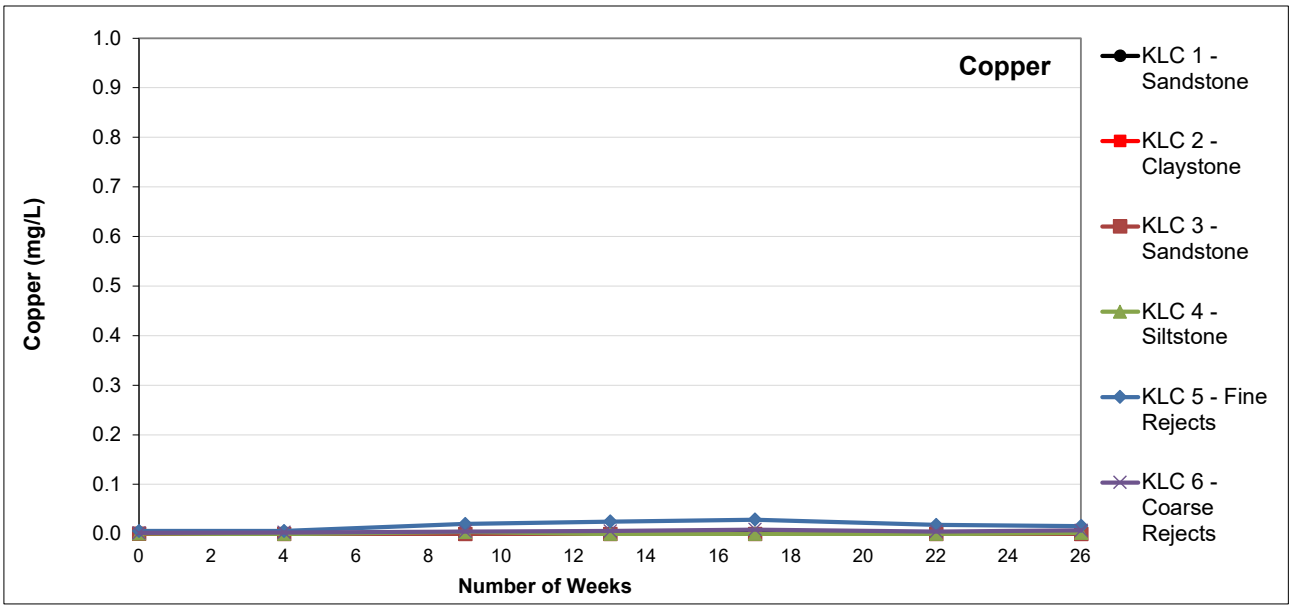

Antimony
Antimony (mg/L)
0.010
0.008
0.006
0.004
0.002
0.000
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

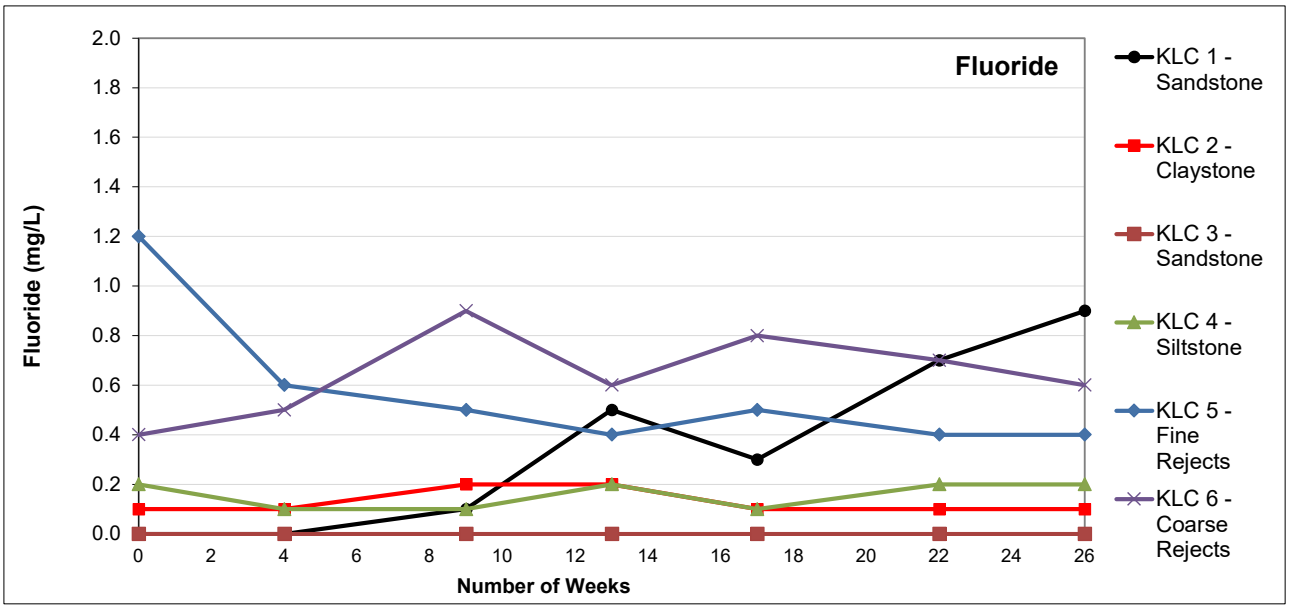

Boron
Boron (mg/L)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

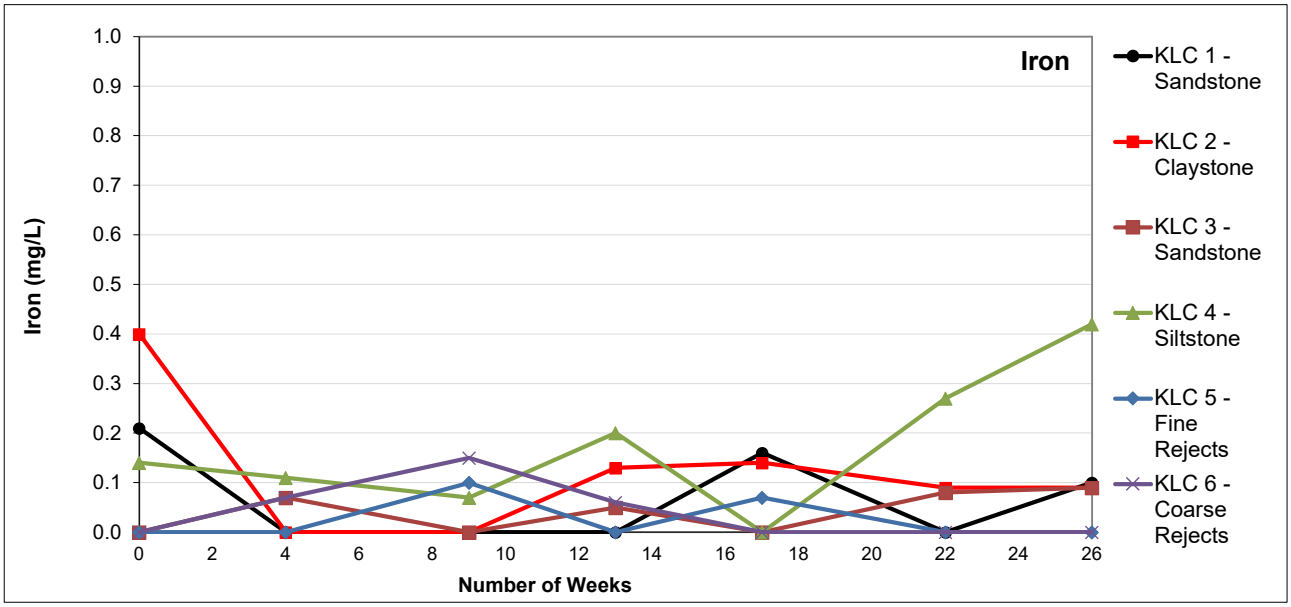

Cadmium
Cadmium (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

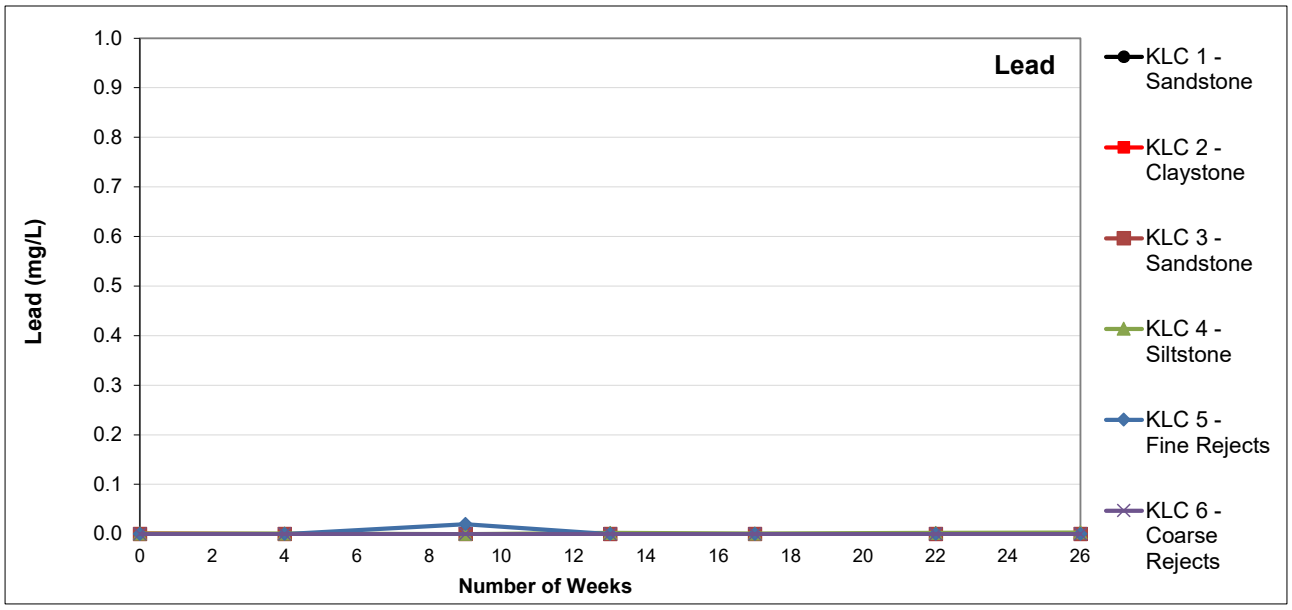

Chromium
Chromium (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

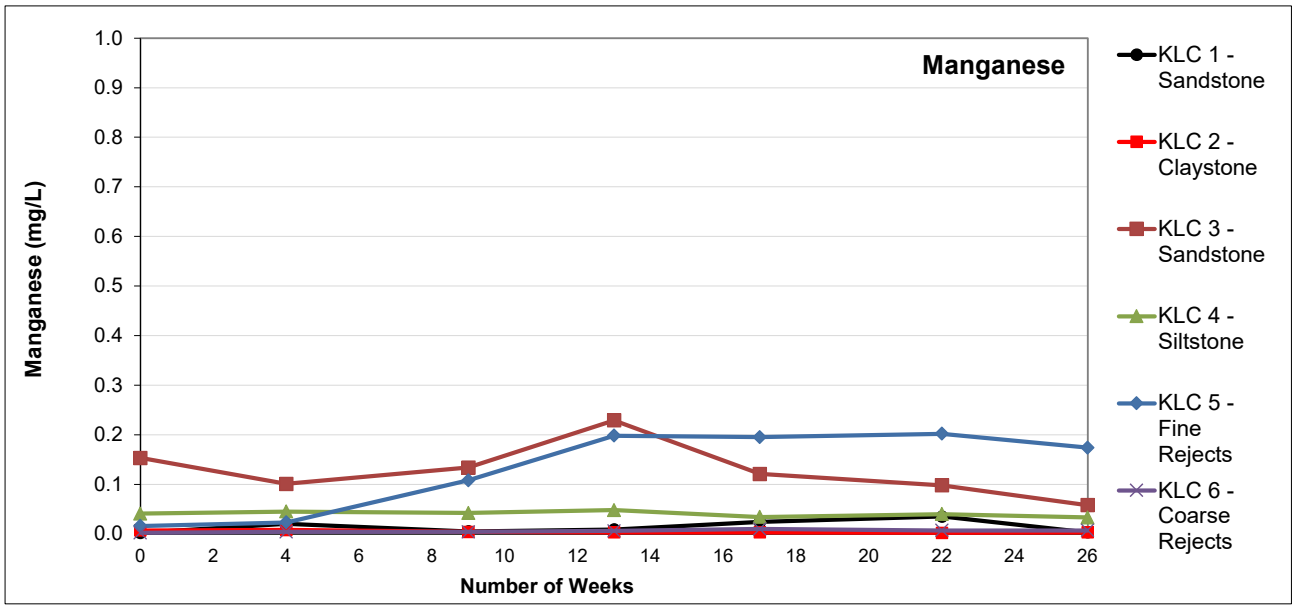

Cobalt
Cobalt (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

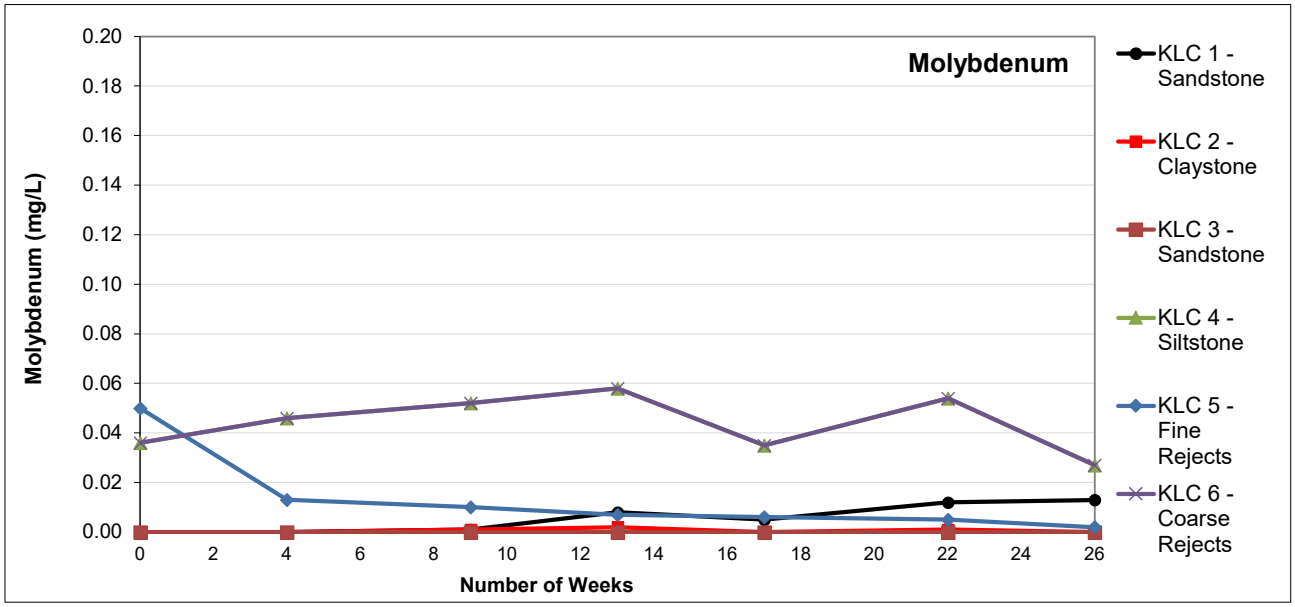

Copper
Copper (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

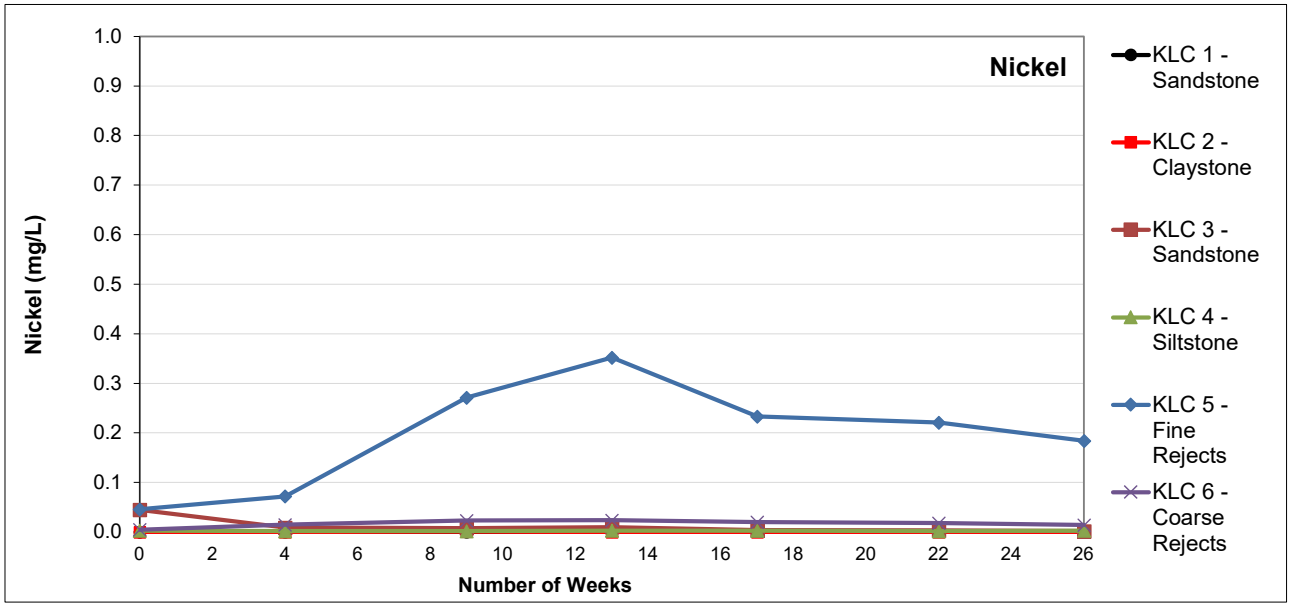

Fluoride
Fluoride (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

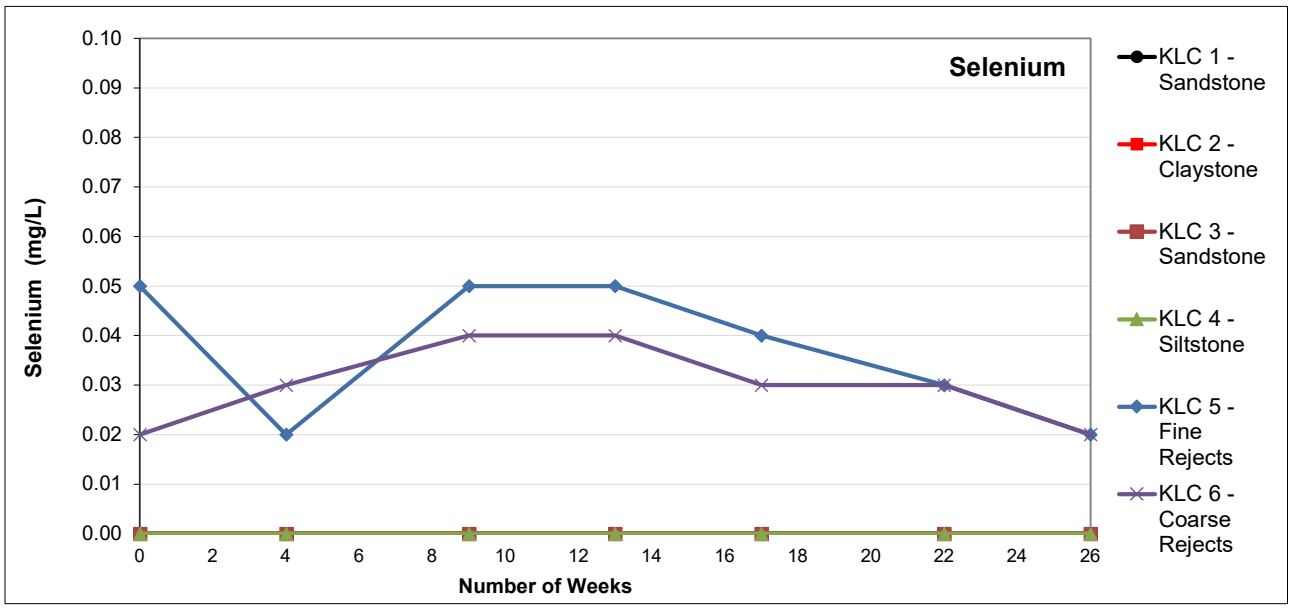

Iron
Iron (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

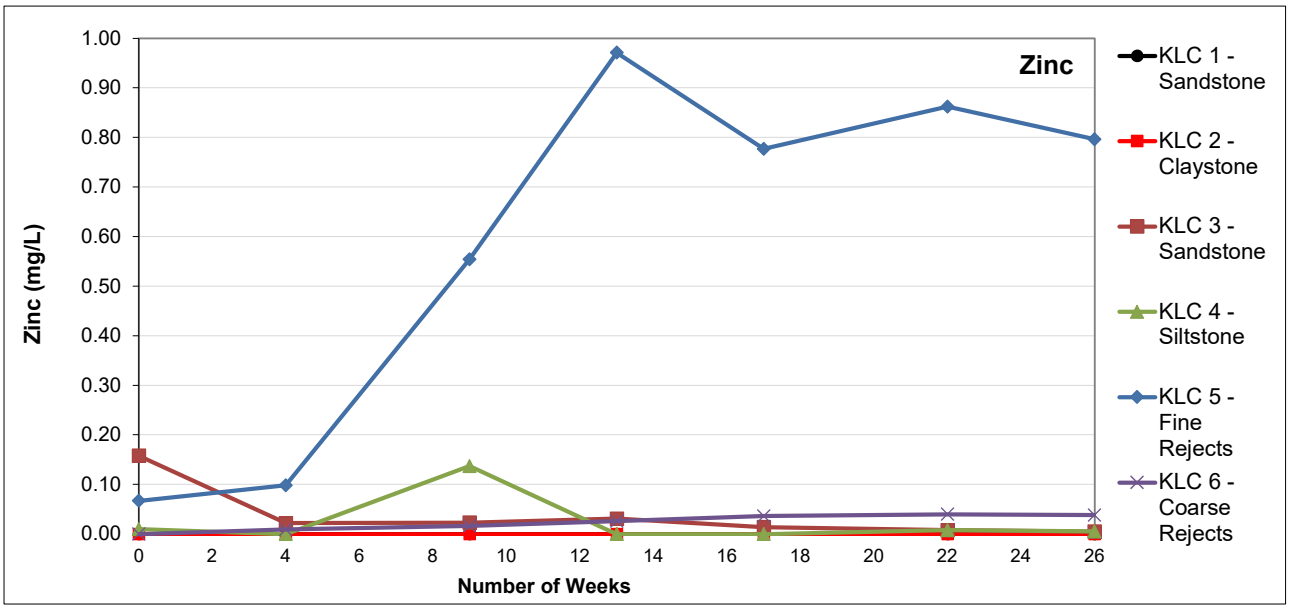

Lead
Lead (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects


Manganese
Manganese (mg/L)
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects


Molybdenum
Molybdenum (mg/L)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects


Nickel
Nickel (mg/L)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects


Selenium
Selenium (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects


Zinc
Zinc (mg/L)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Number of Weeks
KLC 1 - Sandstone
KLC 2 - Claystone
KLC 3 - Sandstone
KLC 4 - Siltstone
KLC 5 - Fine Rejects
KLC 6 - Coarse Rejects

Attachment D ALS Laboratory Results

(Certificates of Analysis)

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1914213**	Page	: 1 of 16
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan Complex (Saraji West)	Date Samples Received	: 03-Jun-2019 15:00
Order number	:	Date Analysis Commenced	: 03-Jun-2019
C-O-C number	: ----	Issue Date	: 17-Jun-2019 12:41
Sampler	: AMANDA CLEMENTS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 70		
No. of samples analysed	: 70		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EA031 (Saturated Paste pH): NATA accreditation does not cover the performance of this service.
- EA032 (Saturated Paste EC): NATA accreditation does not cover the performance of this service.
- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 1	Composite 2	Composite 3	Composite 4	Composite 5
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-001	EB1914213-002	EB1914213-003	EB1914213-004	EB1914213-005
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-20.5**	**-91.4**	**-5.2**	**-3.8**	**-6.1**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**21.1**	**92.0**	**5.8**	**3.8**	**6.1**
ANC as CaCO3	----	0.1	% CaCO3	**2.2**	**9.4**	**0.6**	**0.4**	**0.6**
Fizz Rating	----	0	Fizz Unit	**1**	**2**	**1**	**0**	**1**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**8.1**	**8.1**	**8.0**	**8.1**	**7.6**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**2580**	**2220**	**1350**	**401**	**753**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.02**	**0.02**	<0.01	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 6	Composite 7	Composite 8	Composite 9	Composite 10
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-006	EB1914213-007	EB1914213-008	EB1914213-009	EB1914213-010
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-22.8	-11.1	-306	-3.2	-10.6
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	23.4	11.7	307	3.2	10.6
ANC as CaCO3	----	0.1	% CaCO3	2.4	1.2	31.3	0.3	1.1
Fizz Rating	----	0	Fizz Unit	1	1	4	0	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	7.6	6.8	8.6	8.5	8.0
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	2340	3720	1210	652	655
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.02	0.02	0.02	<0.01	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 11	Composite 12	Composite 13	Composite 14	Composite 15
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-011	EB1914213-012	EB1914213-013	EB1914213-014	EB1914213-015
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-0.3**	**-1.8**	**-12.2**	**3.4**	**-9.8**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**0.9**	**2.4**	**14.7**	**5.8**	**12.6**
ANC as CaCO3	----	0.1	% CaCO3	<0.1	**0.2**	**1.5**	**0.6**	**1.3**
Fizz Rating	----	0	Fizz Unit	**0**	**0**	**1**	**1**	**1**
EA031: pH (saturated paste)								
ø **pH (Saturated Paste)**	----	0.1	pH Unit	**7.8**	**7.8**	**8.4**	**7.4**	**8.3**
EA032: Electrical Conductivity (saturated paste)								
ø **Electrical Conductivity (Saturated Paste)**	----	1	µS/cm	**580**	**852**	**951**	**888**	**898**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.02**	**0.08**	**0.30**	**0.09**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 16	Composite 17	Composite 18	Composite 19	Composite 20
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-016	EB1914213-017	EB1914213-018	EB1914213-019	EB1914213-020
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-12.7**	**-15.7**	**-17.7**	**-38.7**	**-25.6**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**13.9**	**17.2**	**18.3**	**38.7**	**25.6**
ANC as CaCO3	----	0.1	% CaCO3	**1.4**	**1.8**	**1.9**	**3.9**	**2.6**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**1**	**2**	**1**
EA031: pH (saturated paste)								
ø **pH (Saturated Paste)**	----	0.1	pH Unit	**8.4**	**8.4**	**6.8**	**8.0**	**7.8**
EA032: Electrical Conductivity (saturated paste)								
ø **Electrical Conductivity (Saturated Paste)**	----	1	µS/cm	**789**	**1090**	**1840**	**3200**	**3320**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.04**	**0.05**	**0.02**	<0.01	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 21	Composite 22	Composite 23	Composite 24	Composite 25
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-021	EB1914213-022	EB1914213-023	EB1914213-024	EB1914213-025
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-8.0	-4.8	-12.4	-9.1	-9.6
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	8.0	5.4	13.3	9.7	10.5
ANC as CaCO3	----	0.1	% CaCO3	0.8	0.6	1.4	1.0	1.1
Fizz Rating	----	0	Fizz Unit	1	1	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.3	7.7	7.2	7.4	8.2
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	874	1210	2930	1210	961
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	0.02	0.03	0.02	0.03

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 26	Composite 27	Composite 28	Composite 29	Composite 30
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-026	EB1914213-027	EB1914213-028	EB1914213-029	EB1914213-030
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-17.6**	**-65.6**	**-7.8**	**-8.0**	**-14.8**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**17.6**	**66.2**	**7.8**	**8.6**	**16.0**
ANC as CaCO3	----	0.1	% CaCO3	**1.8**	**6.8**	**0.8**	**0.9**	**1.6**
Fizz Rating	----	0	Fizz Unit	**1**	**2**	**1**	**1**	**1**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.8**	**8.4**	**8.4**	**7.8**	**7.4**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**864**	**2090**	**679**	**1810**	**2080**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	**0.02**	<0.01	**0.02**	**0.04**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 31	Composite 32	Composite 33	Composite 34	Composite 35
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-031	EB1914213-032	EB1914213-033	EB1914213-034	EB1914213-035
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-11.2**	**-10.5**	**-8.2**	**-16.3**	**-85.6**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**11.2**	**11.1**	**8.2**	**16.9**	**85.6**
ANC as CaCO3	----	0.1	% CaCO3	**1.1**	**1.1**	**0.8**	**1.7**	**8.7**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**1**	**1**	**2**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.8**	**7.6**	**7.6**	**7.7**	**8.0**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**1700**	**1340**	**1040**	**2550**	**2820**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	**0.02**	<0.01	**0.02**	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 36	Composite 37	Composite 38	Composite 39	Composite 40
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-036	EB1914213-037	EB1914213-038	EB1914213-039	EB1914213-040
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-27.2	-19.2	-19.8	-13.4	-9.0
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	27.2	19.2	20.4	13.4	9.6
ANC as CaCO3	----	0.1	% CaCO3	2.8	2.0	2.1	1.4	1.0
Fizz Rating	----	0	Fizz Unit	1	1	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.4	8.2	7.8	7.8	8.0
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	1520	1580	2930	2080	1950
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	0.02	<0.01	0.02

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 41	Composite 42	Composite 43	Composite 44	Composite 45
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-041	EB1914213-042	EB1914213-043	EB1914213-044	EB1914213-045
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-8.5**	**-7.8**	**-6.2**	**-2.4**	**-8.3**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**9.1**	**8.4**	**6.8**	**2.4**	**8.3**
ANC as CaCO3	----	0.1	% CaCO3	**0.9**	**0.8**	**0.7**	**0.2**	**0.8**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**1**	**0**	**1**
EA031: pH (saturated paste)								
ø **pH (Saturated Paste)**	----	0.1	pH Unit	**8.4**	**8.0**	**8.0**	**7.9**	**8.1**
EA032: Electrical Conductivity (saturated paste)								
ø **Electrical Conductivity (Saturated Paste)**	----	1	µS/cm	**1390**	**1030**	**480**	**305**	**885**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.02**	**0.02**	<0.01	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 46	Composite 47	Composite 48	Composite 49	Composite 50
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-046	EB1914213-047	EB1914213-048	EB1914213-049	EB1914213-050
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-26.5**	**-127**	**-50.4**	**-33.8**	**-23.1**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**27.1**	**127**	**50.4**	**33.8**	**23.7**
ANC as CaCO3	----	0.1	% CaCO3	**2.8**	**12.9**	**5.1**	**3.4**	**2.4**
Fizz Rating	----	0	Fizz Unit	**1**	**2**	**2**	**1**	**1**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.8**	**8.1**	**7.7**	**7.8**	**8.1**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**1630**	**2680**	**2440**	**2470**	**1120**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	<0.01	<0.01	<0.01	**0.02**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 51	Composite 52	Composite 53	Composite 54	Composite 55
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-051	EB1914213-052	EB1914213-053	EB1914213-054	EB1914213-055
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-7.9**	**-5.0**	**-12.6**	**-27.0**	**-15.0**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**8.5**	**5.9**	**12.6**	**27.9**	**15.6**
ANC as CaCO3	----	0.1	% CaCO3	**0.9**	**0.6**	**1.3**	**2.8**	**1.6**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**1**	**1**	**1**
EA031: pH (saturated paste)								
ø **pH (Saturated Paste)**	----	0.1	pH Unit	**7.9**	**7.8**	**8.0**	**8.2**	**8.0**
EA032: Electrical Conductivity (saturated paste)								
ø **Electrical Conductivity (Saturated Paste)**	----	1	µS/cm	**857**	**934**	**658**	**2430**	**2000**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.03**	<0.01	**0.03**	**0.02**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 56	Composite 57	Composite 58	Composite 59	Composite 60
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-056	EB1914213-057	EB1914213-058	EB1914213-059	EB1914213-060
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-91.5	-26.3	-6.9	-4.7	-2.4
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	92.1	26.9	6.9	5.3	3.0
ANC as CaCO3	----	0.1	% CaCO3	9.4	2.7	0.7	0.5	0.3
Fizz Rating	----	0	Fizz Unit	2	1	1	0	0
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.6	8.2	8.2	8.3	8.3
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	1260	1920	1220	1050	419
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.02	0.02	<0.01	0.02	0.02

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 62	Composite 63	Composite 64	Composite 65	Composite 66
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-062	EB1914213-063	EB1914213-064	EB1914213-065	EB1914213-066
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-6.4**	**-15.8**	**-105**	**-90.9**	**-52.0**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**7.0**	**15.8**	**106**	**91.5**	**52.0**
ANC as CaCO3	----	0.1	% CaCO3	**0.7**	**1.6**	**10.9**	**9.3**	**5.3**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**2**	**2**	**2**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**8.0**	**7.6**	**8.0**	**8.2**	**8.6**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**682**	**2300**	**3290**	**3520**	**696**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	<0.01	**0.02**	**0.02**	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 67	Composite 68	Composite 69	Composite 70	pH and EC - DI Water
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914213-067	EB1914213-068	EB1914213-069	EB1914213-070	EB1914213-071
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	----	----	----	5.6
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-6.4	-3.5	-8.6	-32.7	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	----	----	----	<1
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	6.4	3.5	9.2	32.7	----
ANC as CaCO3	----	0.1	% CaCO3	0.6	0.4	0.9	3.3	----
Fizz Rating	----	0	Fizz Unit	1	0	1	1	----
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.4	8.5	7.6	7.7	----
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	308	224	514	884	----
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	0.02	<0.01	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1914214**	Page	: 1 of 16
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan Complex (Saraji West)	Date Samples Received	: 03-Jun-2019 15:00
Order number	:	Date Analysis Commenced	: 03-Jun-2019
C-O-C number	: ----	Issue Date	: 17-Jun-2019 17:17
Sampler	: AMANDA CLEMENTS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 70		
No. of samples analysed	: 70		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Tom Maloney	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Tom Maloney	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EA031 (Saturated Paste pH): NATA accreditation does not cover the performance of this service.
- EA032 (Saturated Paste EC): NATA accreditation does not cover the performance of this service.
- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 71	Composite 72	Composite 73	Composite 74	Composite 75
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-001	EB1914214-002	EB1914214-003	EB1914214-004	EB1914214-005
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-218	-25.6	-18.9	-21.5	-7.1
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	218	26.5	18.9	22.1	7.1
ANC as CaCO3	----	0.1	% CaCO3	22.3	2.7	1.9	2.2	0.7
Fizz Rating	----	0	Fizz Unit	3	1	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.1	8.0	7.9	8.0	8.2
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	2420	2230	1710	1260	375
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	0.03	<0.01	0.02	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 76	Composite 77	Composite 78	Composite 79	Composite 80
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-006	EB1914214-007	EB1914214-008	EB1914214-009	EB1914214-010
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-29.8**	**-11.3**	**-106**	**-69.5**	**-73.4**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**29.8**	**11.3**	**107**	**70.1**	**74.0**
ANC as CaCO3	----	0.1	% CaCO3	**3.0**	**1.2**	**10.9**	**7.1**	**7.6**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**3**	**2**	**2**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**8.2**	**7.7**	**8.0**	**8.0**	**8.3**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**1120**	**2280**	**2780**	**2910**	**1430**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	**0.02**	**0.02**	**0.02**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 81	Composite 82	Composite 83	Composite 84	Composite 85
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-011	EB1914214-012	EB1914214-013	EB1914214-014	EB1914214-015
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-18.5	-12.2	-7.0	-80.6	-29.6
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	18.5	12.2	7.0	81.2	29.6
ANC as CaCO3	----	0.1	% CaCO3	1.9	1.2	0.7	8.3	3.0
Fizz Rating	----	0	Fizz Unit	1	1	1	2	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.3	8.3	8.2	8.4	8.5
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	1350	565	443	450	957
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	<0.01	0.02	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 86	Composite 87	Composite 88	Composite 89	Composite 90
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-016	EB1914214-017	EB1914214-018	EB1914214-019	EB1914214-020
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-111	-49.4	-17.7	-14.2	-11.5
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	111	49.4	18.3	14.8	12.1
ANC as CaCO3	----	0.1	% CaCO3	11.3	5.0	1.9	1.5	1.2
Fizz Rating	----	0	Fizz Unit	2	2	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	8.1	7.7	7.8	7.7	7.9
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	2100	2490	2540	2540	1350
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	0.02	0.02	0.02

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 91	Composite 92	Composite 93	Composite 94	Composite 95
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-021	EB1914214-022	EB1914214-023	EB1914214-024	EB1914214-025
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-22.4	-9.7	-15.6	-27.4	-63.0
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	23.0	10.3	16.5	28.3	63.9
ANC as CaCO3	----	0.1	% CaCO3	2.3	1.0	1.7	2.9	6.5
Fizz Rating	----	0	Fizz Unit	1	1	1	1	2
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	7.5	5.3	7.2	7.5	7.7
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	2140	2320	2160	2250	2110
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.02	0.02	0.03	0.03	0.03

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 96	Composite 97	Composite 98	Composite 99	Composite 100
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-026	EB1914214-027	EB1914214-028	EB1914214-029	EB1914214-030
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-9.7	-15.9	-15.3	-5.8	-6.7
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	10.6	16.8	15.9	6.4	6.7
ANC as CaCO3	----	0.1	% CaCO3	1.1	1.7	1.6	0.6	0.7
Fizz Rating	----	0	Fizz Unit	1	1	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	7.2	7.8	8.2	7.7	7.9
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	2440	1680	548	559	596
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.03	0.03	0.02	0.02	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 101	Composite 102	Composite 103	Composite 104	Composite 105
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-031	EB1914214-032	EB1914214-033	EB1914214-034	EB1914214-035
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-6.9**	**-18.2**	**1.2**	**-5.1**	**-6.0**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**7.5**	**18.8**	<0.5	**5.1**	**6.6**
ANC as CaCO3	----	0.1	% CaCO3	**0.8**	**1.9**	<0.1	**0.5**	**0.7**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**0**	**1**	**1**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.0**	**8.4**	**6.1**	**7.9**	**7.9**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**551**	**1100**	**771**	**787**	**869**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.02**	**0.04**	<0.01	**0.02**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 106	Composite 107	Composite 108	Composite 109	Composite 110
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-036	EB1914214-037	EB1914214-038	EB1914214-039	EB1914214-040
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	<0.5	**-6.2**	**-13.0**	**-21.6**	**-158**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	<0.5	**6.2**	**13.6**	**22.8**	**158**
ANC as CaCO3	----	0.1	% CaCO3	<0.1	**0.6**	**1.4**	**2.3**	**16.1**
Fizz Rating	----	0	Fizz Unit	**0**	**1**	**1**	**1**	**3**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.7**	**7.7**	**8.4**	**8.1**	**8.2**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**748**	**1340**	**873**	**635**	**1800**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	**0.02**	**0.04**	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 111	Composite 112	Composite 113	Composite 114	Composite 115
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-041	EB1914214-042	EB1914214-043	EB1914214-044	EB1914214-045
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-45.6**	**-12.3**	**-10.1**	**-7.1**	**-8.1**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**45.6**	**13.2**	**10.1**	**7.1**	**8.1**
ANC as CaCO3	----	0.1	% CaCO3	**4.6**	**1.3**	**1.0**	**0.7**	**0.8**
Fizz Rating	----	0	Fizz Unit	**2**	**1**	**1**	**1**	**1**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**8.3**	**8.3**	**8.0**	**7.8**	**7.5**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**1120**	**1010**	**1150**	**1820**	**1340**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	**0.03**	<0.01	<0.01	<0.01

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 116	Composite 117	Composite 118	Composite 119	Composite 120
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-046	EB1914214-047	EB1914214-048	EB1914214-049	EB1914214-050
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-12.3**	**0.6**	<0.5	**-1.2**	**1.2**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**12.9**	<0.5	<0.5	**1.2**	**2.2**
ANC as CaCO3	----	0.1	% CaCO3	**1.3**	<0.1	<0.1	**0.1**	**0.2**
Fizz Rating	----	0	Fizz Unit	**1**	**0**	**0**	**0**	**0**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**8.2**	**6.3**	**8.0**	**5.9**	**5.1**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**777**	**370**	**247**	**693**	**686**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.02**	<0.01	<0.01	**0.11**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 121	Composite 122	Composite 123	Composite 124	Composite 125
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-051	EB1914214-052	EB1914214-053	EB1914214-054	EB1914214-055
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-1.7	-10.2	-3.6	-1.0	-8.2
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	1.7	11.1	6.0	1.6	8.8
ANC as CaCO3	----	0.1	% CaCO3	0.2	1.1	0.6	0.2	0.9
Fizz Rating	----	0	Fizz Unit	0	1	1	0	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	6.0	7.6	7.4	6.7	6.6
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	240	1540	578	408	1500
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	0.03	0.08	0.02	0.02

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 126	Composite 127	Composite 128	Composite 129	Composite 130
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-056	EB1914214-057	EB1914214-058	EB1914214-059	EB1914214-060
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-8.8**	**-10.0**	**-5.4**	**0.6**	**0.6**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**9.4**	**12.8**	**6.6**	<0.5	<0.5
ANC as CaCO3	----	0.1	% CaCO3	**1.0**	**1.3**	**0.7**	<0.1	<0.1
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**1**	**0**	**0**
EA031: pH (saturated paste)								
ø **pH (Saturated Paste)**	----	0.1	pH Unit	**7.7**	**8.3**	**8.4**	**6.4**	**5.7**
EA032: Electrical Conductivity (saturated paste)								
ø **Electrical Conductivity (Saturated Paste)**	----	1	µS/cm	**970**	**1240**	**4180**	**48**	**335**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.02**	**0.09**	**0.04**	**0.02**	**0.02**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 131	Composite 132	Composite 133	Composite 134	Composite 135
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-061	EB1914214-062	EB1914214-063	EB1914214-064	EB1914214-065
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-4.8	-10.1	-5.2	-5.3	-6.6
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	5.7	11.0	7.7	5.9	7.2
ANC as CaCO3	----	0.1	% CaCO3	0.6	1.1	0.8	0.6	0.7
Fizz Rating	----	0	Fizz Unit	1	1	1	1	1
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	6.0	6.6	5.7	6.5	7.4
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	216	106	405	345	826
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	0.03	0.03	0.08	0.02	0.02

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite 136	Composite 137	Composite 138	Composite 139	pH and EC - DI Water
			Client sampling date / time	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00	03-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1914214-066	EB1914214-067	EB1914214-068	EB1914214-069	EB1914214-070
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	----	----	----	5.5
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	-5.1	-7.8	-14.8	-13.6	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	----	----	----	<1
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	5.1	7.8	15.4	14.2	----
ANC as CaCO3	----	0.1	% CaCO3	0.5	0.8	1.6	1.4	----
Fizz Rating	----	0	Fizz Unit	1	1	1	1	----
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	6.8	7.7	8.5	8.6	----
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	521	895	695	1360	----
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	<0.01	<0.01	0.02	0.02	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1916203**	Page	: 1 of 9
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan Complex (Saraji West)	Date Samples Received	: 21-Jun-2019 17:05
Order number	:	Date Analysis Commenced	: 25-Jun-2019
C-O-C number	: ----	Issue Date	: 01-Jul-2019 12:22
Sampler	: ----		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 9		
No. of samples analysed	: 9		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- ED037 (Alkalinity): NATA accreditation does not cover the performance of this service.
- ED038 (Acidity): NATA accreditation does not cover the performance of this service.
- ALS is not NATA accredited for the analysis of Exchangeable Aluminium and Exchange Acidity in soils when performed under ALS Method ED005.
- ALS is not NATA accredited for the analysis of Exchangeable Cations on Alkaline Soils when performed under ALS Method ED006.
- EG005T (Total Metals by ICP-AES): Sample EB1916203 – 005 (Composite 3) shows poor matrix spike recovery due to matrix interference. Confirmed by re-extraction and re-analysis.
- ED007 and ED008: When Exchangeable Al is reported from these methods, it should be noted that Rayment & Lyons (2011) suggests Exchange Acidity by 1M KCl - Method 15G1 (ED005) is a more suitable method for the determination of exchange acidity (H+ + Al3+).

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)			Client sample ID	Sample 14	Sample 120	Composite 1	Composite 2	Composite 3
			Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00
Compound	CAS Number	LOR	Unit	EB1916203-001	EB1916203-002	EB1916203-003	EB1916203-004	EB1916203-005
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	----	8.2	8.6	8.5
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	----	552	346	788
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	0.153	0.083	----	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	----	----	4.0	<1.0	4.8
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	----	----	6.2	0.9	3.0
ø Exchangeable Magnesium	----	0.2	meq/100g	----	----	9.1	3.1	12.3
ø Exchangeable Potassium	----	0.2	meq/100g	----	----	0.2	1.1	0.2
ø Exchangeable Sodium	----	0.2	meq/100g	----	----	1.9	0.7	3.0
ø Cation Exchange Capacity	----	0.2	meq/100g	----	----	17.4	5.8	18.6
ø Exchangeable Sodium Percent	----	0.2	%	----	----	10.8	12.1	16.3
ø Calcium/Magnesium Ratio	----	0.2	-	----	----	0.7	0.3	0.2
ø Magnesium/Potassium Ratio	----	0.2	-	----	----	37.6	2.7	60.5
ED037: Alkalinity								
ø Total Alkalinity as CaCO3	----	1	mg/kg	----	----	8840	2820	14900
ø Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/kg	----	----	8840	2820	14900
ø Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/kg	----	----	<5	<5	<5
ED038A: Acidity								
Acidity	----	1	mg/kg	----	----	12	<5	<5
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	----	----	150	140	230
Silica	7631-86-9	1	mg/kg	----	----	51	45	52
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	----	300	240	700
ED093S: Soluble Major Cations								
Calcium	7440-70-2	10	mg/kg	----	----	60	10	20
Magnesium	7439-95-4	10	mg/kg	----	----	60	30	50
Sodium	7440-23-5	10	mg/kg	----	----	460	270	730
Potassium	7440-09-7	10	mg/kg	----	----	<10	30	<10
ED093T: Total Major Cations								

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)				Client sample ID	Sample 14	Sample 120	Composite 1	Composite 2	Composite 3
				Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00
Compound	CAS Number	LOR	Unit		EB1916203-001	EB1916203-002	EB1916203-003	EB1916203-004	EB1916203-005
					Result	Result	Result	Result	Result
ED093T: Total Major Cations - Continued									
Sodium	7440-23-5	50	mg/kg		----	----	**950**	**490**	**1670**
Potassium	7440-09-7	50	mg/kg		----	----	**270**	**680**	**290**
Calcium	7440-70-2	50	mg/kg		----	----	**5710**	**2420**	**9470**
Magnesium	7439-95-4	50	mg/kg		----	----	**4080**	**2140**	**8890**
EG005(ED093)S : Soluble Metals by ICPAES									
Boron	7440-42-8	1	mg/kg		----	----	<1	<1	<1
Iron	7439-89-6	1	mg/kg		----	----	<1	<1	<1
EG005(ED093)T: Total Metals by ICP-AES									
Aluminium	7429-90-5	50	mg/kg		----	----	**9520**	**2090**	**10900**
Antimony	7440-36-0	5	mg/kg		----	----	<5	<5	<5
Barium	7440-39-3	10	mg/kg		----	----	**150**	**50**	**170**
Beryllium	7440-41-7	1	mg/kg		----	----	<1	<1	<1
Boron	7440-42-8	50	mg/kg		----	----	<50	<50	<50
Cobalt	7440-48-4	2	mg/kg		----	----	**17**	**3**	**19**
Iron	7439-89-6	50	mg/kg		----	----	**17200**	**8640**	**25400**
Manganese	7439-96-5	5	mg/kg		----	----	**538**	**103**	**466**
Molybdenum	7439-98-7	2	mg/kg		----	----	<2	<2	<2
Selenium	7782-49-2	5	mg/kg		----	----	<5	<5	<5
Thallium	7440-28-0	5	mg/kg		----	----	<5	<5	<5
Arsenic	7440-38-2	5	mg/kg		----	----	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg		----	----	<1	<1	<1
Chromium	7440-47-3	2	mg/kg		----	----	**46**	**38**	**53**
Copper	7440-50-8	5	mg/kg		----	----	**7**	**6**	**11**
Lead	7439-92-1	5	mg/kg		----	----	**6**	**6**	<5
Nickel	7440-02-0	2	mg/kg		----	----	**24**	**6**	**34**
Zinc	7440-66-6	5	mg/kg		----	----	**14**	**17**	**31**
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		----	----	<0.01	**0.01**	<0.01
Selenium	7782-49-2	0.1	mg/kg		----	----	<0.1	<0.1	<0.1
Barium	7440-39-3	0.01	mg/kg		----	----	**0.14**	**0.06**	**0.08**
Beryllium	7440-41-7	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Cadmium	7440-43-9	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Cobalt	7440-48-4	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Chromium	7440-47-3	0.01	mg/kg		----	----	<0.01	<0.01	<0.01

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)				Client sample ID	Sample 14	Sample 120	Composite 1	Composite 2	Composite 3
				Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00
Compound	CAS Number	LOR	Unit		EB1916203-001	EB1916203-002	EB1916203-003	EB1916203-004	EB1916203-005
					Result	Result	Result	Result	Result
EG020S: Soluble Metals by ICPMS - Continued									
Thorium	7440-29-1	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Copper	7440-50-8	0.01	mg/kg		----	----	**0.03**	<0.01	<0.01
Manganese	7439-96-5	0.01	mg/kg		----	----	**0.04**	<0.01	<0.01
Molybdenum	7439-98-7	0.01	mg/kg		----	----	**0.01**	**0.02**	**0.01**
Nickel	7440-02-0	0.01	mg/kg		----	----	**0.03**	<0.01	<0.01
Lead	7439-92-1	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Antimony	7440-36-0	0.01	mg/kg		----	----	<0.01	<0.01	<0.01
Uranium	7440-61-1	0.01	mg/kg		----	----	**0.01**	<0.01	<0.01
Zinc	7440-66-6	0.05	mg/kg		----	----	<0.05	<0.05	<0.05
Vanadium	7440-62-2	0.1	mg/kg		----	----	<0.1	<0.1	<0.1
Aluminium	7429-90-5	0.1	mg/kg		----	----	<0.1	**0.3**	**0.2**
EG020T: Total Metals by ICP-MS									
Uranium	7440-61-1	0.1	mg/kg		----	----	**0.3**	**0.3**	**0.8**
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		----	----	<0.0005	<0.0005	<0.0005
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		----	----	<0.1	<0.1	<0.1
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		----	----	**4**	**2**	**9**
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		----	----	<0.1	<0.1	**0.1**

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)			Client sample ID	Composite 4	Composite 5	Composite 6	----	----
			Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	----	----
Compound	CAS Number	LOR	Unit	EB1916203-006	EB1916203-007	EB1916203-008	--------	--------
				Result	Result	Result	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	8.2	6.8	7.1	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	490	167	264	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	1.6	<1.0	<1.0	----	----
ED006: Exchangeable Cations on Alkaline Soils								
ø Exchangeable Calcium	----	0.2	meq/100g	1.0	----	----	----	----
ø Exchangeable Magnesium	----	0.2	meq/100g	3.4	----	----	----	----
ø Exchangeable Potassium	----	0.2	meq/100g	0.4	----	----	----	----
ø Exchangeable Sodium	----	0.2	meq/100g	0.7	----	----	----	----
ø Cation Exchange Capacity	----	0.2	meq/100g	5.6	----	----	----	----
ø Exchangeable Sodium Percent	----	0.2	%	13.0	----	----	----	----
ø Calcium/Magnesium Ratio	----	0.2	-	0.3	----	----	----	----
ø Magnesium/Potassium Ratio	----	0.2	-	8.8	----	----	----	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	0.8	0.9	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	1.9	5.3	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	1.0	1.4	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	0.9	2.5	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	4.8	10.2	----	----
Exchangeable Sodium Percent	----	0.1	%	----	20.4	24.6	----	----
Calcium/Magnesium Ratio	----	0.1	-	----	0.4	0.2	----	----
Magnesium/Potassium Ratio	----	0.1	-	----	1.8	3.8	----	----
ED037: Alkalinity								
ø Total Alkalinity as CaCO3	----	1	mg/kg	2730	175	718	----	----
ø Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/kg	2730	175	718	----	----
ø Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/kg	<5	<5	<5	----	----
ED038A: Acidity								
Acidity	----	1	mg/kg	16	39	24	----	----
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	220	150	120	----	----
Silica	7631-86-9	1	mg/kg	50	64	72	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	410	90	180	----	----

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)				Client sample ID	Composite 4	Composite 5	Composite 6	----	----
				Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	----	----
Compound	CAS Number	LOR	Unit		EB1916203-006	EB1916203-007	EB1916203-008	--------	--------
					Result	Result	Result	----	----
ED093S: Soluble Major Cations									
Calcium	7440-70-2	10	mg/kg		20	<10	<10	----	----
Magnesium	7439-95-4	10	mg/kg		40	<10	<10	----	----
Sodium	7440-23-5	10	mg/kg		420	130	260	----	----
Potassium	7440-09-7	10	mg/kg		40	60	40	----	----
ED093T: Total Major Cations									
Sodium	7440-23-5	50	mg/kg		730	260	770	----	----
Potassium	7440-09-7	50	mg/kg		950	1180	2200	----	----
Calcium	7440-70-2	50	mg/kg		1890	370	460	----	----
Magnesium	7439-95-4	50	mg/kg		2320	760	1430	----	----
EG005(ED093)S : Soluble Metals by ICPAES									
Boron	7440-42-8	1	mg/kg		<1	<1	<1	----	----
Iron	7439-89-6	1	mg/kg		<1	<1	<1	----	----
EG005(ED093)T: Total Metals by ICP-AES									
Aluminium	7429-90-5	50	mg/kg		5120	2280	3000	----	----
Antimony	7440-36-0	5	mg/kg		<5	<5	<5	----	----
Barium	7440-39-3	10	mg/kg		80	70	50	----	----
Beryllium	7440-41-7	1	mg/kg		1	<1	2	----	----
Boron	7440-42-8	50	mg/kg		<50	<50	<50	----	----
Cobalt	7440-48-4	2	mg/kg		11	4	10	----	----
Iron	7439-89-6	50	mg/kg		17700	12200	22200	----	----
Manganese	7439-96-5	5	mg/kg		188	126	331	----	----
Molybdenum	7439-98-7	2	mg/kg		<2	<2	<2	----	----
Selenium	7782-49-2	5	mg/kg		<5	<5	<5	----	----
Thallium	7440-28-0	5	mg/kg		<5	<5	6	----	----
Arsenic	7440-38-2	5	mg/kg		<5	<5	5	----	----
Cadmium	7440-43-9	1	mg/kg		<1	<1	<1	----	----
Chromium	7440-47-3	2	mg/kg		34	69	24	----	----
Copper	7440-50-8	5	mg/kg		13	8	27	----	----
Lead	7439-92-1	5	mg/kg		10	12	30	----	----
Nickel	7440-02-0	2	mg/kg		18	10	18	----	----
Zinc	7440-66-6	5	mg/kg		50	31	91	----	----
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Selenium	7782-49-2	0.1	mg/kg		<0.1	<0.1	<0.1	----	----

Analytical Results

Sub-Matrix: PULP (Matrix: SOIL)				Client sample ID	Composite 4	Composite 5	Composite 6	----	----
				Client sampling date / time	21-Jun-2019 00:00	21-Jun-2019 00:00	21-Jun-2019 00:00	----	----
Compound	CAS Number	LOR	Unit		EB1916203-006	EB1916203-007	EB1916203-008	--------	--------
					Result	Result	Result	----	----
EG020S: Soluble Metals by ICPMS - Continued									
Barium	7440-39-3	0.01	mg/kg		**0.04**	**0.02**	**0.01**	----	----
Beryllium	7440-41-7	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Cadmium	7440-43-9	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Cobalt	7440-48-4	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Chromium	7440-47-3	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Thorium	7440-29-1	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Copper	7440-50-8	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Manganese	7439-96-5	0.01	mg/kg		<0.01	**0.02**	**0.02**	----	----
Molybdenum	7439-98-7	0.01	mg/kg		**0.02**	<0.01	**0.03**	----	----
Nickel	7440-02-0	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Lead	7439-92-1	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Antimony	7440-36-0	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Uranium	7440-61-1	0.01	mg/kg		<0.01	<0.01	<0.01	----	----
Zinc	7440-66-6	0.05	mg/kg		<0.05	<0.05	<0.05	----	----
Vanadium	7440-62-2	0.1	mg/kg		<0.1	<0.1	<0.1	----	----
Aluminium	7429-90-5	0.1	mg/kg		**0.2**	**1.8**	**2.4**	----	----
EG020T: Total Metals by ICP-MS									
Uranium	7440-61-1	0.1	mg/kg		**0.7**	**0.3**	**0.8**	----	----
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		<0.0005	<0.0005	<0.0005	----	----
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		<0.1	<0.1	<0.1	----	----
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		**4**	<1	**1**	----	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		<0.1	<0.1	<0.1	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	pH and EC of DI water	----	----	----	----
				Client sampling date / time	24-Jun-2019 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit		EB1916203-009	--------	--------	--------	--------
					Result	----	----	----	----
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		**5.4**	----	----	----	----
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		<1	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1929251**	Page	: 1 of 3
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Saraji West/Vulcan	Date Samples Received	: 04-Nov-2019 09:15
Order number	: ----	Date Analysis Commenced	: 04-Nov-2019
C-O-C number	: ----	Issue Date	: 08-Nov-2019 13:47
Sampler	: ALAN ROBERTSON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 5		
No. of samples analysed	: 5		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EA031 (Saturated Paste pH): NATA accreditation does not cover the performance of this service.
- EA032 (Saturated Paste EC): NATA accreditation does not cover the performance of this service.
- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19006604R005 "Coarse" (Wash 2, -50+2mm) reject	IP19006604R006 "Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP1900410R298 "Coarse" (Wash 2, -50+2mm) reject	IP1900410R299 "Fine (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	pH and EC - DI water
				Client sampling date / time	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00
					EB1929251-001	EB1929251-002	EB1929251-003	EB1929251-004	EB1929251-005
					Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		**----**	**----**	**----**	**----**	**5.0**
EA009: Nett Acid Production Potential									
Net Acid Production Potential	----	0.5	kg H2SO4/t		**13.6**	**4.0**	**6.8**	**4.4**	**----**
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		**----**	**----**	**----**	**----**	<1
EA013: Acid Neutralising Capacity									
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t		**8.4**	**8.5**	**1.8**	**7.2**	**----**
ANC as CaCO3	----	0.1	% CaCO3		**0.8**	**0.9**	**0.2**	**0.7**	**----**
Fizz Rating	----	0	Fizz Unit		**1**	**1**	**0**	**1**	**----**
EA031: pH (saturated paste)									
ø pH (Saturated Paste)	----	0.1	pH Unit		**8.4**	**7.3**	**8.0**	**7.0**	**----**
EA032: Electrical Conductivity (saturated paste)									
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm		**176**	**484**	**401**	**595**	**----**
ED042T: Total Sulfur by LECO									
Sulfur - Total as S (LECO)	----	0.01	%		**0.72**	**0.41**	**0.28**	**0.38**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1933850**	Page	: 1 of 6
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: 2019010 Saraji West/Vulcan	Date Samples Received	: 13-Dec-2019 11:55
Order number	: ----	Date Analysis Commenced	: 23-Dec-2019
C-O-C number	: ----	Issue Date	: 13-Jan-2020 08:27
Sampler	: ALAN ROBERTSON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 10		
No. of samples analysed	: 10		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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- Analytical Results

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

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~ = Indicates an estimated value.

- ED037 (Alkalinity): NATA accreditation does not cover the performance of this service.
- ED038 (Acidity): NATA accreditation does not cover the performance of this service.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	IP19002032R587 "Coarse" (Wash 2, -50+2mm) reject	IP19003592R466 "Coarse" (Wash 2, -50+2mm) reject	IP19004096R302 "Coarse" (Wash 2, -50+2mm)reject	IP19004601R298 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19004096R303 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject
			Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
Compound	CAS Number	LOR	Unit	EB1933850-001	EB1933850-002	EB1933850-003	EB1933850-004	EB1933850-005
				Result	Result	Result	Result	Result
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	**0.049**	**0.055**	**0.569**	**0.018**	**0.382**

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

				Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
Compound	CAS Number	LOR	Unit		EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		**----**	**----**	**5.8**	**6.2**	**5.6**
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		**----**	**----**	**96**	**54**	<1
EA026 : Chromium Reducible Sulfur									
Chromium Reducible Sulphur	----	0.005	%		**0.027**	**0.152**	**----**	**----**	**----**
ED037: Alkalinity									
ø **Total Alkalinity as CaCO3**	----	1	mg/kg		**----**	**----**	**280**	**5160**	**----**
ø **Bicarbonate Alkalinity as CaCO3**	71-52-3	1	mg/kg		**----**	**----**	**280**	**5160**	**----**
ø **Carbonate Alkalinity as CaCO3**	3812-32-6	1	mg/kg		**----**	**----**	<5	<5	**----**
ED038A: Acidity									
Acidity	----	1	mg/kg		**----**	**----**	**230**	**892**	**----**
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		**----**	**----**	**120**	**100**	**----**
Silica	7631-86-9	1	mg/kg		**----**	**----**	**81**	**43**	**----**
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		**----**	**----**	**50**	**130**	**----**
ED093S: Soluble Major Cations									
Calcium	7440-70-2	10	mg/kg		**----**	**----**	<10	**10**	**----**
Magnesium	7439-95-4	10	mg/kg		**----**	**----**	<10	**20**	**----**
Sodium	7440-23-5	10	mg/kg		**----**	**----**	**120**	**120**	**----**
Potassium	7440-09-7	10	mg/kg		**----**	**----**	<10	**20**	**----**
ED093T: Total Major Cations									
Sodium	7440-23-5	50	mg/kg		**----**	**----**	**410**	**470**	**----**
Potassium	7440-09-7	50	mg/kg		**----**	**----**	**1270**	**1280**	**----**
Calcium	7440-70-2	50	mg/kg		**----**	**----**	**1600**	**4780**	**----**
Magnesium	7439-95-4	50	mg/kg		**----**	**----**	**680**	**2700**	**----**
EG005(ED093)S : Soluble Metals by ICPAES									
Boron	7440-42-8	1	mg/kg		**----**	**----**	<1	<1	**----**
Iron	7439-89-6	1	mg/kg		**----**	**----**	<1	<1	**----**
EG005(ED093)T: Total Metals by ICP-AES									

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EG005(ED093)T: Total Metals by ICP-AES - Continued									
Aluminium	7429-90-5	50	mg/kg		----	----	**2770**	**3360**	----
Boron	7440-42-8	50	mg/kg		----	----	<50	<50	----
Iron	7439-89-6	50	mg/kg		----	----	**7940**	**6340**	----
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		----	----	<0.01	<0.01	----
Selenium	7782-49-2	0.1	mg/kg		----	----	<0.1	<0.1	----
Barium	7440-39-3	0.01	mg/kg		----	----	<0.01	**0.02**	----
Beryllium	7440-41-7	0.01	mg/kg		----	----	<0.01	<0.01	----
Cadmium	7440-43-9	0.01	mg/kg		----	----	<0.01	<0.01	----
Cobalt	7440-48-4	0.01	mg/kg		----	----	<0.01	<0.01	----
Chromium	7440-47-3	0.01	mg/kg		----	----	<0.01	<0.01	----
Thorium	7440-29-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Copper	7440-50-8	0.01	mg/kg		----	----	<0.01	<0.01	----
Manganese	7439-96-5	0.01	mg/kg		----	----	<0.01	<0.01	----
Molybdenum	7439-98-7	0.01	mg/kg		----	----	**0.04**	**0.01**	----
Nickel	7440-02-0	0.01	mg/kg		----	----	<0.01	<0.01	----
Lead	7439-92-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Antimony	7440-36-0	0.01	mg/kg		----	----	**0.02**	<0.01	----
Uranium	7440-61-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Zinc	7440-66-6	0.05	mg/kg		----	----	<0.05	<0.05	----
Vanadium	7440-62-2	0.1	mg/kg		----	----	<0.1	<0.1	----
Aluminium	7429-90-5	0.1	mg/kg		----	----	<0.1	<0.1	----
EG020T: Total Metals by ICP-MS									
Arsenic	7440-38-2	0.1	mg/kg		----	----	**16.1**	**10.7**	----
Selenium	7782-49-2	1	mg/kg		----	----	**2**	**2**	----
Barium	7440-39-3	0.1	mg/kg		----	----	**313**	**256**	----
Beryllium	7440-41-7	0.1	mg/kg		----	----	**0.9**	**1.4**	----
Cadmium	7440-43-9	0.1	mg/kg		----	----	**0.1**	**0.1**	----
Cobalt	7440-48-4	0.1	mg/kg		----	----	**5.4**	**5.9**	----
Chromium	7440-47-3	0.1	mg/kg		----	----	**0.6**	**2.1**	----
Copper	7440-50-8	0.1	mg/kg		----	----	**55.3**	**45.9**	----

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EG020T: Total Metals by ICP-MS - Continued									
Thorium	7440-29-1	0.1	mg/kg		----	----	**1.9**	**2.0**	----
Manganese	7439-96-5	0.1	mg/kg		----	----	**84.6**	**73.5**	----
Molybdenum	7439-98-7	0.1	mg/kg		----	----	**1.2**	**0.9**	----
Nickel	7440-02-0	0.1	mg/kg		----	----	**7.0**	**12.9**	----
Lead	7439-92-1	0.1	mg/kg		----	----	**14.2**	**18.9**	----
Antimony	7440-36-0	0.1	mg/kg		----	----	**0.1**	**0.1**	----
Uranium	7440-61-1	0.1	mg/kg		----	----	**0.8**	**5.4**	----
Zinc	7440-66-6	0.5	mg/kg		----	----	**49.2**	**72.2**	----
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		----	----	<0.0005	<0.0005	----
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		----	----	<0.1	**0.1**	----
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		----	----	**1**	**2**	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		----	----	**0.1**	<0.1	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1932449**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Saraji West/Vulcan	Date Samples Received	: 03-Dec-2019 15:29
Order number	: ----	Date Analysis Commenced	: 04-Dec-2019
C-O-C number	: ----	Issue Date	: 12-Dec-2019 13:24
Sampler	: ALAN ROBERTSON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 7		
No. of samples analysed	: 7		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EA031 (Saturated Paste pH): NATA accreditation does not cover the performance of this service.
- EA032 (Saturated Paste EC): NATA accreditation does not cover the performance of this service.
- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19004096R302 "Coarse" (Wash 2, -50+2mm)reject	IP19004096R303 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19002032R587 "Coarse" (Wash 2, -50+2mm) reject	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R466 "Coarse" (Wash 2, -50+2mm) reject
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1932449-001	EB1932449-002	EB1932449-003	EB1932449-004	EB1932449-005
					Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential									
Net Acid Production Potential	----	0.5	kg H2SO4/t		**13.8**	**4.9**	**-1.4**	**-4.4**	**-16.7**
EA013: Acid Neutralising Capacity									
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t		**11.3**	**13.5**	**10.9**	**16.9**	**22.8**
ANC as CaCO3	----	0.1	% CaCO3		**1.2**	**1.4**	**1.1**	**1.7**	**2.3**
Fizz Rating	----	0	Fizz Unit		**1**	**1**	**1**	**1**	**1**
EA031: pH (saturated paste)									
ø pH (Saturated Paste)	----	0.1	pH Unit		**8.3**	**7.4**	**4.5**	**5.6**	**7.6**
EA032: Electrical Conductivity (saturated paste)									
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm		**116**	**564**	**454**	**193**	**213**
ED042T: Total Sulfur by LECO									
Sulfur - Total as S (LECO)	----	0.01	%		**0.82**	**0.60**	**0.31**	**0.41**	**0.20**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19004601R298 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	----	----	----
			Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	----	----	----
Compound	CAS Number	LOR	Unit	EB1932449-006	EB1932449-007	--------	--------	--------
				Result	Result	----	----	----
EA009: Nett Acid Production Potential								
Net Acid Production Potential	----	0.5	kg H2SO4/t	**-16.6**	**-32.3**	**----**	**----**	**----**
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	**23.3**	**36.0**	**----**	**----**	**----**
ANC as CaCO3	----	0.1	% CaCO3	**2.4**	**3.7**	**----**	**----**	**----**
Fizz Rating	----	0	Fizz Unit	**1**	**1**	**----**	**----**	**----**
EA031: pH (saturated paste)								
ø pH (Saturated Paste)	----	0.1	pH Unit	**7.6**	**6.8**	**----**	**----**	**----**
EA032: Electrical Conductivity (saturated paste)								
ø Electrical Conductivity (Saturated Paste)	----	1	µS/cm	**466**	**398**	**----**	**----**	**----**
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	**0.22**	**0.12**	**----**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1931850**	Page	: 1 of 8
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan Complex (Saraji West)	Date Samples Received	: 27-Nov-2019 11:33
Order number	: ----	Date Analysis Commenced	: 29-Nov-2019
C-O-C number	: ----	Issue Date	: 11-Dec-2019 16:16
Sampler	: ALAN ROBERTSON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 7		
No. of samples analysed	: 7		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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- Analytical Results

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Sarah Ashworth	Laboratory Manager - Brisbane	Stafford Minerals - ST, Stafford, QLD
Satishkumar Trivedi	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Satishkumar Trivedi	Senior Acid Sulfate Soil Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

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Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- ED037 (Alkalinity): NATA accreditation does not cover the performance of this service.
- ED038 (Acidity): NATA accreditation does not cover the performance of this service.
- EK040S (Fluoride - Soluble) - Particular samples required dilution prior to analysis due to matrix interferences. LOR values have been adjusted accordingly.
- ED093T (Major Cations - Total): Sample Composite of 1 and 3 (EB1931850-005) shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.
- EG005T (Total Metals by ICP-AES): Sample EB1932078-010 shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.
- EG005T (Total Metals by ICP-AES): Sample EB1931809-020 shows poor duplicate results due to sample heterogeneity. Confirmed by visual inspection.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	IP19006604R005	IP19006604R006	IP1900410R298	IP1900410R299	Composite of 1 and 3
			Client sampling date / time	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00
Compound	CAS Number	LOR	Unit	EB1931850-001	EB1931850-002	EB1931850-003	EB1931850-004	EB1931850-005
				Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	----	----	----	----	8.6
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	----	----	----	----	86
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	0.388	0.190	0.047	0.219	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	----	----	----	----	1.6
ED037: Alkalinity								
ø Total Alkalinity as CaCO3	----	1	mg/kg	----	----	----	----	122
ø Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/kg	----	----	----	----	122
ø Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/kg	----	----	----	----	<5
ED038A: Acidity								
Acidity	----	1	mg/kg	----	----	----	----	94
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	----	----	----	----	90
Silica	7631-86-9	1	mg/kg	----	----	----	----	17
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	----	----	----	----	40
ED093S: Soluble Major Cations								
Calcium	7440-70-2	10	mg/kg	----	----	----	----	<10
Magnesium	7439-95-4	10	mg/kg	----	----	----	----	<10
Sodium	7440-23-5	10	mg/kg	----	----	----	----	130
Potassium	7440-09-7	10	mg/kg	----	----	----	----	<10
ED093T: Total Major Cations								
Sodium	7440-23-5	50	mg/kg	----	----	----	----	120
Potassium	7440-09-7	50	mg/kg	----	----	----	----	500
Calcium	7440-70-2	50	mg/kg	----	----	----	----	2650
Magnesium	7439-95-4	50	mg/kg	----	----	----	----	2160
EG005(ED093)S : Soluble Metals by ICPAES								
Boron	7440-42-8	1	mg/kg	----	----	----	----	<1
Iron	7439-89-6	1	mg/kg	----	----	----	----	<1
EG005(ED093)T: Total Metals by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	----	----	----	----	1100

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	IP19006604R005	IP19006604R006	IP1900410R298	IP1900410R299	Composite of 1 and 3
				Client sampling date / time	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00
Compound	CAS Number	LOR	Unit		EB1931850-001	EB1931850-002	EB1931850-003	EB1931850-004	EB1931850-005
					Result	Result	Result	Result	Result
EG005(ED093)T: Total Metals by ICP-AES - Continued									
Antimony	7440-36-0	5	mg/kg		----	----	----	----	<5
Barium	7440-39-3	10	mg/kg		----	----	----	----	**80**
Beryllium	7440-41-7	1	mg/kg		----	----	----	----	<1
Boron	7440-42-8	50	mg/kg		----	----	----	----	<50
Cobalt	7440-48-4	2	mg/kg		----	----	----	----	**5**
Iron	7439-89-6	50	mg/kg		----	----	----	----	**46900**
Manganese	7439-96-5	5	mg/kg		----	----	----	----	**1100**
Molybdenum	7439-98-7	2	mg/kg		----	----	----	----	<2
Selenium	7782-49-2	5	mg/kg		----	----	----	----	<5
Thallium	7440-28-0	5	mg/kg		----	----	----	----	<5
Arsenic	7440-38-2	5	mg/kg		----	----	----	----	**7**
Cadmium	7440-43-9	1	mg/kg		----	----	----	----	<1
Chromium	7440-47-3	2	mg/kg		----	----	----	----	<2
Copper	7440-50-8	5	mg/kg		----	----	----	----	**23**
Lead	7439-92-1	5	mg/kg		----	----	----	----	**6**
Nickel	7440-02-0	2	mg/kg		----	----	----	----	**6**
Zinc	7440-66-6	5	mg/kg		----	----	----	----	**62**
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		----	----	----	----	**0.01**
Selenium	7782-49-2	0.1	mg/kg		----	----	----	----	<0.1
Barium	7440-39-3	0.01	mg/kg		----	----	----	----	<0.01
Beryllium	7440-41-7	0.01	mg/kg		----	----	----	----	<0.01
Cadmium	7440-43-9	0.01	mg/kg		----	----	----	----	<0.01
Cobalt	7440-48-4	0.01	mg/kg		----	----	----	----	<0.01
Chromium	7440-47-3	0.01	mg/kg		----	----	----	----	<0.01
Thorium	7440-29-1	0.01	mg/kg		----	----	----	----	<0.01
Copper	7440-50-8	0.01	mg/kg		----	----	----	----	**0.01**
Manganese	7439-96-5	0.01	mg/kg		----	----	----	----	<0.01
Molybdenum	7439-98-7	0.01	mg/kg		----	----	----	----	**0.17**
Nickel	7440-02-0	0.01	mg/kg		----	----	----	----	**0.01**
Lead	7439-92-1	0.01	mg/kg		----	----	----	----	<0.01
Antimony	7440-36-0	0.01	mg/kg		----	----	----	----	**0.01**
Uranium	7440-61-1	0.01	mg/kg		----	----	----	----	<0.01
Zinc	7440-66-6	0.05	mg/kg		----	----	----	----	<0.05
Vanadium	7440-62-2	0.1	mg/kg		----	----	----	----	<0.1

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	IP19006604R005	IP19006604R006	IP1900410R298	IP1900410R299	Composite of 1 and 3
				Client sampling date / time	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00	01-Nov-2019 00:00
Compound	CAS Number	LOR	Unit		EB1931850-001	EB1931850-002	EB1931850-003	EB1931850-004	EB1931850-005
					Result	Result	Result	Result	Result
EG020S: Soluble Metals by ICPMS - Continued									
Aluminium	7429-90-5	0.1	mg/kg		----	----	----	----	**0.7**
EG020T: Total Metals by ICP-MS									
Uranium	7440-61-1	0.1	mg/kg		----	----	----	----	**0.6**
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		----	----	----	----	<0.0005
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		----	----	----	----	**0.3**
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		----	----	----	----	<5
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		----	----	----	----	<0.1
ME-ICP81: Silica and Metals Oxides by Peroxide Fusion									
Silica as SiO2	7631-86-9	0.01	%		----	----	----	----	**28.0**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	Composite of 2 and 4	pH & EC of DI Water	----	----	----
			Client sampling date / time	01-Nov-2019 00:00	27-Nov-2019 00:00	----	----	----
Compound	CAS Number	LOR	Unit	EB1931850-006	EB1931850-007	--------	--------	--------
				Result	Result	----	----	----
EA002: pH 1:5 (Soils)								
pH Value	----	0.1	pH Unit	**7.4**	**5.7**	----	----	----
EA010: Conductivity (1:5)								
Electrical Conductivity @ 25°C	----	1	µS/cm	**154**	<1	----	----	----
EA055: Moisture Content (Dried @ 105-110°C)								
Moisture Content	----	1.0	%	**1.7**	----	----	----	----
ED037: Alkalinity								
ø Total Alkalinity as CaCO3	----	1	mg/kg	**166**	----	----	----	----
ø Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/kg	**166**	----	----	----	----
ø Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/kg	<5	----	----	----	----
ED038A: Acidity								
Acidity	----	1	mg/kg	**242**	----	----	----	----
ED040S : Soluble Sulfate by ICPAES								
Sulfate as SO4 2-	14808-79-8	10	mg/kg	**160**	----	----	----	----
Silica	7631-86-9	1	mg/kg	**8**	----	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	10	mg/kg	**120**	----	----	----	----
ED093S: Soluble Major Cations								
Calcium	7440-70-2	10	mg/kg	**20**	----	----	----	----
Magnesium	7439-95-4	10	mg/kg	**20**	----	----	----	----
Sodium	7440-23-5	10	mg/kg	**130**	----	----	----	----
Potassium	7440-09-7	10	mg/kg	<10	----	----	----	----
ED093T: Total Major Cations								
Sodium	7440-23-5	50	mg/kg	**150**	----	----	----	----
Potassium	7440-09-7	50	mg/kg	**720**	----	----	----	----
Calcium	7440-70-2	50	mg/kg	**2090**	----	----	----	----
Magnesium	7439-95-4	50	mg/kg	**1120**	----	----	----	----
EG005(ED093)S : Soluble Metals by ICPAES								
Boron	7440-42-8	1	mg/kg	<1	----	----	----	----
Iron	7439-89-6	1	mg/kg	<1	----	----	----	----
EG005(ED093)T: Total Metals by ICP-AES								
Aluminium	7429-90-5	50	mg/kg	**1790**	----	----	----	----
Antimony	7440-36-0	5	mg/kg	<5	----	----	----	----
Barium	7440-39-3	10	mg/kg	**230**	----	----	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	Composite of 2 and 4	pH & EC of DI Water	----	----	----
				Client sampling date / time	01-Nov-2019 00:00	27-Nov-2019 00:00	----	----	----
Compound	CAS Number	LOR	Unit		EB1931850-006	EB1931850-007	--------	--------	--------
					Result	Result	----	----	----
EG005(ED093)T: Total Metals by ICP-AES - Continued									
Beryllium	7440-41-7	1	mg/kg		**1**	----	----	----	----
Boron	7440-42-8	50	mg/kg		<50	----	----	----	----
Cobalt	7440-48-4	2	mg/kg		**22**	----	----	----	----
Iron	7439-89-6	50	mg/kg		**11200**	----	----	----	----
Manganese	7439-96-5	5	mg/kg		**179**	----	----	----	----
Molybdenum	7439-98-7	2	mg/kg		**3**	----	----	----	----
Selenium	7782-49-2	5	mg/kg		<5	----	----	----	----
Thallium	7440-28-0	5	mg/kg		<5	----	----	----	----
Arsenic	7440-38-2	5	mg/kg		**12**	----	----	----	----
Cadmium	7440-43-9	1	mg/kg		<1	----	----	----	----
Chromium	7440-47-3	2	mg/kg		<2	----	----	----	----
Copper	7440-50-8	5	mg/kg		**44**	----	----	----	----
Lead	7439-92-1	5	mg/kg		**15**	----	----	----	----
Nickel	7440-02-0	2	mg/kg		**23**	----	----	----	----
Zinc	7440-66-6	5	mg/kg		**145**	----	----	----	----
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		<0.01	----	----	----	----
Selenium	7782-49-2	0.1	mg/kg		<0.1	----	----	----	----
Barium	7440-39-3	0.01	mg/kg		**0.01**	----	----	----	----
Beryllium	7440-41-7	0.01	mg/kg		<0.01	----	----	----	----
Cadmium	7440-43-9	0.01	mg/kg		<0.01	----	----	----	----
Cobalt	7440-48-4	0.01	mg/kg		<0.01	----	----	----	----
Chromium	7440-47-3	0.01	mg/kg		<0.01	----	----	----	----
Thorium	7440-29-1	0.01	mg/kg		<0.01	----	----	----	----
Copper	7440-50-8	0.01	mg/kg		**0.02**	----	----	----	----
Manganese	7439-96-5	0.01	mg/kg		**0.02**	----	----	----	----
Molybdenum	7439-98-7	0.01	mg/kg		**0.10**	----	----	----	----
Nickel	7440-02-0	0.01	mg/kg		<0.01	----	----	----	----
Lead	7439-92-1	0.01	mg/kg		<0.01	----	----	----	----
Antimony	7440-36-0	0.01	mg/kg		<0.01	----	----	----	----
Uranium	7440-61-1	0.01	mg/kg		<0.01	----	----	----	----
Zinc	7440-66-6	0.05	mg/kg		<0.05	----	----	----	----
Vanadium	7440-62-2	0.1	mg/kg		<0.1	----	----	----	----
Aluminium	7429-90-5	0.1	mg/kg		<0.1	----	----	----	----

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID	Composite of 2 and 4	pH & EC of DI Water	----	----	----
				Client sampling date / time	01-Nov-2019 00:00	27-Nov-2019 00:00	----	----	----
Compound	CAS Number	LOR	Unit		EB1931850-006	EB1931850-007	--------	--------	--------
					Result	Result	----	----	----
EG020T: Total Metals by ICP-MS									
Uranium	7440-61-1	0.1	mg/kg		**1.0**	----	----	----	----
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		<0.0005	----	----	----	----
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		**0.1**	----	----	----	----
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		**5**	----	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		<0.1	----	----	----	----
ME-ICP81: Silica and Metals Oxides by Peroxide Fusion									
Silica as SiO2	7631-86-9	0.01	%		**34.2**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1933850**	Page	: 1 of 6
Amendment	: **1**		
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: 2019010 Saraji West/Vulcan	Date Samples Received	: 13-Dec-2019 11:55
Order number	: ----	Date Analysis Commenced	: 23-Dec-2019
C-O-C number	: ----	Issue Date	: 16-Jan-2020 11:07
Sampler	: ALAN ROBERTSON		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 10		
No. of samples analysed	: 10		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Stafford Minerals - ST, Stafford, QLD
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- ED037 (Alkalinity): NATA accreditation does not cover the performance of this service.
- ED038 (Acidity): NATA accreditation does not cover the performance of this service.
- Amendment (16/01/2020): This report has been amended and re-released to allow the reporting of additional analytical data. Total Silica results have now been provided as subcon data.

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	IP19002032R587 "Coarse" (Wash 2, -50+2mm) reject	IP19003592R466 "Coarse" (Wash 2, -50+2mm) reject	IP19004096R302 "Coarse" (Wash 2, -50+2mm)reject	IP19004601R298 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19004096R303 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject
			Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
Compound	CAS Number	LOR	Unit	EB1933850-001	EB1933850-002	EB1933850-003	EB1933850-004	EB1933850-005
				Result	Result	Result	Result	Result
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	**0.049**	**0.055**	**0.569**	**0.018**	**0.382**

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EA002: pH 1:5 (Soils)									
pH Value	----	0.1	pH Unit		----	----	**5.8**	**6.2**	**5.6**
EA010: Conductivity (1:5)									
Electrical Conductivity @ 25°C	----	1	µS/cm		----	----	**96**	**54**	<1
EA026 : Chromium Reducible Sulfur									
Chromium Reducible Sulphur	----	0.005	%		**0.027**	**0.152**	----	----	----
ED037: Alkalinity									
ø **Total Alkalinity as CaCO3**	----	1	mg/kg		----	----	**280**	**5160**	----
ø **Bicarbonate Alkalinity as CaCO3**	71-52-3	1	mg/kg		----	----	**280**	**5160**	----
ø **Carbonate Alkalinity as CaCO3**	3812-32-6	1	mg/kg		----	----	<5	<5	----
ED038A: Acidity									
Acidity	----	1	mg/kg		----	----	**230**	**892**	----
ED040S : Soluble Sulfate by ICPAES									
Sulfate as SO4 2-	14808-79-8	10	mg/kg		----	----	**120**	**100**	----
Silica	7631-86-9	1	mg/kg		----	----	**81**	**43**	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	10	mg/kg		----	----	**50**	**130**	----
ED093S: Soluble Major Cations									
Calcium	7440-70-2	10	mg/kg		----	----	<10	**10**	----
Magnesium	7439-95-4	10	mg/kg		----	----	<10	**20**	----
Sodium	7440-23-5	10	mg/kg		----	----	**120**	**120**	----
Potassium	7440-09-7	10	mg/kg		----	----	<10	**20**	----
ED093T: Total Major Cations									
Sodium	7440-23-5	50	mg/kg		----	----	**410**	**470**	----
Potassium	7440-09-7	50	mg/kg		----	----	**1270**	**1280**	----
Calcium	7440-70-2	50	mg/kg		----	----	**1600**	**4780**	----
Magnesium	7439-95-4	50	mg/kg		----	----	**680**	**2700**	----
EG005(ED093)S : Soluble Metals by ICPAES									
Boron	7440-42-8	1	mg/kg		----	----	<1	<1	----
Iron	7439-89-6	1	mg/kg		----	----	<1	<1	----
EG005(ED093)T: Total Metals by ICP-AES									

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EG005(ED093)T: Total Metals by ICP-AES - Continued									
Aluminium	7429-90-5	50	mg/kg		----	----	**2770**	**3360**	----
Boron	7440-42-8	50	mg/kg		----	----	<50	<50	----
Iron	7439-89-6	50	mg/kg		----	----	**7940**	**6340**	----
EG020S: Soluble Metals by ICPMS									
Arsenic	7440-38-2	0.01	mg/kg		----	----	<0.01	<0.01	----
Selenium	7782-49-2	0.1	mg/kg		----	----	<0.1	<0.1	----
Barium	7440-39-3	0.01	mg/kg		----	----	<0.01	**0.02**	----
Beryllium	7440-41-7	0.01	mg/kg		----	----	<0.01	<0.01	----
Cadmium	7440-43-9	0.01	mg/kg		----	----	<0.01	<0.01	----
Cobalt	7440-48-4	0.01	mg/kg		----	----	<0.01	<0.01	----
Chromium	7440-47-3	0.01	mg/kg		----	----	<0.01	<0.01	----
Thorium	7440-29-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Copper	7440-50-8	0.01	mg/kg		----	----	<0.01	<0.01	----
Manganese	7439-96-5	0.01	mg/kg		----	----	<0.01	<0.01	----
Molybdenum	7439-98-7	0.01	mg/kg		----	----	**0.04**	**0.01**	----
Nickel	7440-02-0	0.01	mg/kg		----	----	<0.01	<0.01	----
Lead	7439-92-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Antimony	7440-36-0	0.01	mg/kg		----	----	**0.02**	<0.01	----
Uranium	7440-61-1	0.01	mg/kg		----	----	<0.01	<0.01	----
Zinc	7440-66-6	0.05	mg/kg		----	----	<0.05	<0.05	----
Vanadium	7440-62-2	0.1	mg/kg		----	----	<0.1	<0.1	----
Aluminium	7429-90-5	0.1	mg/kg		----	----	<0.1	<0.1	----
EG020T: Total Metals by ICP-MS									
Arsenic	7440-38-2	0.1	mg/kg		----	----	**16.1**	**10.7**	----
Selenium	7782-49-2	1	mg/kg		----	----	**2**	**2**	----
Barium	7440-39-3	0.1	mg/kg		----	----	**313**	**256**	----
Beryllium	7440-41-7	0.1	mg/kg		----	----	**0.9**	**1.4**	----
Cadmium	7440-43-9	0.1	mg/kg		----	----	**0.1**	**0.1**	----
Cobalt	7440-48-4	0.1	mg/kg		----	----	**5.4**	**5.9**	----
Chromium	7440-47-3	0.1	mg/kg		----	----	**0.6**	**2.1**	----
Copper	7440-50-8	0.1	mg/kg		----	----	**55.3**	**45.9**	----

Analytical Results

Sub-Matrix: **SOIL**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	Client sample ID	IP19002032R588 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	IP19003592R467 "Fine" (Wash 3 & Fines, -2+0.25 & -0.25+0mm respectively) reject	Composite 3	Composite 4	pH and EC of DI water
				Client sampling date / time	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00	02-Dec-2019 00:00
					EB1933850-006	EB1933850-007	EB1933850-008	EB1933850-009	EB1933850-010
					Result	Result	Result	Result	Result
EG020T: Total Metals by ICP-MS - Continued									
Thorium	7440-29-1	0.1	mg/kg		----	----	**1.9**	**2.0**	----
Manganese	7439-96-5	0.1	mg/kg		----	----	**84.6**	**73.5**	----
Molybdenum	7439-98-7	0.1	mg/kg		----	----	**1.2**	**0.9**	----
Nickel	7440-02-0	0.1	mg/kg		----	----	**7.0**	**12.9**	----
Lead	7439-92-1	0.1	mg/kg		----	----	**14.2**	**18.9**	----
Antimony	7440-36-0	0.1	mg/kg		----	----	**0.1**	**0.1**	----
Uranium	7440-61-1	0.1	mg/kg		----	----	**0.8**	**5.4**	----
Zinc	7440-66-6	0.5	mg/kg		----	----	**49.2**	**72.2**	----
EG035S: Soluble Mercury by FIMS									
Mercury	7439-97-6	0.0005	mg/kg		----	----	<0.0005	<0.0005	----
EG035T: Total Recoverable Mercury by FIMS									
Mercury	7439-97-6	0.1	mg/kg		----	----	<0.1	**0.1**	----
EK040S: Fluoride Soluble									
Fluoride	16984-48-8	1	mg/kg		----	----	**1**	**2**	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.1	mg/kg		----	----	**0.1**	<0.1	----
ME-ICP81: Silica and Metals Oxides by Peroxide Fusion									
Silica as SiO2	7631-86-9	0.01	%		----	----	**34.9**	**29.5**	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1916412**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan (Saraji West)	Date Samples Received	: 25-Jun-2019 14:50
Order number	: 2019010	Date Analysis Commenced	: 26-Jun-2019
C-O-C number	: ----	Issue Date	: 02-Jul-2019 14:52
Sampler	: MARY MACILROY		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 4		
No. of samples analysed	: 4		

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This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC 1	KLC 2	KLC 3	KLC 4	----
			Client sampling date / time	25-Jun-2019 00:00	25-Jun-2019 00:00	25-Jun-2019 00:00	25-Jun-2019 00:00	----
Compound	CAS Number	LOR	Unit	EB1916412-001	EB1916412-002	EB1916412-003	EB1916412-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.87**	**6.71**	**5.84**	**6.45**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**56**	**76**	**616**	**720**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**7**	**6**	**2**	**5**	----
Total Alkalinity as CaCO3	----	1	mg/L	**7**	**6**	**2**	**5**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**1**	**1**	**2**	**5**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**3**	**6**	**111**	**45**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**10**	**13**	**108**	**193**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	<1	<1	**4**	<1	----
Magnesium	7439-95-4	1	mg/L	<1	<1	**7**	**4**	----
Sodium	7440-23-5	1	mg/L	**12**	**15**	**104**	**150**	----
Potassium	7440-09-7	1	mg/L	<1	<1	**6**	**6**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**1.09**	**1.07**	**0.08**	**0.24**	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	**0.0002**	<0.0001	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	**0.001**	**0.001**	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	**0.039**	**0.003**	----
Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	**0.045**	**0.003**	----
Lead	7439-92-1	0.001	mg/L	<0.001	**0.001**	<0.001	**0.001**	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.158**	**0.010**	----
Manganese	7439-96-5	0.001	mg/L	**0.002**	**0.007**	**0.153**	**0.041**	----
Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC 1	KLC 2	KLC 3	KLC 4	----
				Client sampling date / time	25-Jun-2019 00:00	25-Jun-2019 00:00	25-Jun-2019 00:00	25-Jun-2019 00:00	----
Compound	CAS Number	LOR	Unit		EB1916412-001	EB1916412-002	EB1916412-003	EB1916412-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		<0.05	<0.05	<0.05	<0.05	----
Iron	7439-89-6	0.05	mg/L		**0.21**	**0.40**	<0.05	**0.14**	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		<0.1	**0.1**	<0.1	**0.2**	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**0.48**	**0.61**	**5.40**	**6.48**	----
ø **Total Cations**	----	0.01	meq/L		**0.52**	**0.65**	**5.45**	**7.01**	----
ø **Ionic Balance**	----	0.01	%		**----**	**----**	**0.51**	**3.90**	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1918957**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: 2019010 Vulcan (Saraji West)	Date Samples Received	: 22-Jul-2019 15:05
Order number	:	Date Analysis Commenced	: 23-Jul-2019
C-O-C number	: ----	Issue Date	: 30-Jul-2019 11:01
Sampler	: MARY MACELROY		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 4		
No. of samples analysed	: 4		

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This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Ionic balances are within acceptable limits as detailed in the 21st Ed. APHA "Standard Methods for the Examination of Water and Wastewater".
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC 1	KLC 2	KLC 3	KLC 4	----
			Client sampling date / time	22-Jul-2019 00:00	22-Jul-2019 00:00	22-Jul-2019 00:00	22-Jul-2019 00:00	----
Compound	CAS Number	LOR	Unit	EB1918957-001	EB1918957-002	EB1918957-003	EB1918957-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.02**	**6.86**	**6.18**	**6.51**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**171**	**299**	**144**	**557**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**5**	**4**	**1**	**2**	----
Total Alkalinity as CaCO3	----	1	mg/L	**5**	**4**	**1**	**2**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**1**	**2**	**1**	**6**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**20**	**34**	**22**	**57**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**33**	**63**	**25**	**130**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**2**	**3**	<1	<1	----
Magnesium	7439-95-4	1	mg/L	**5**	**9**	**2**	**7**	----
Sodium	7440-23-5	1	mg/L	**22**	**39**	**23**	**89**	----
Potassium	7440-09-7	1	mg/L	<1	<1	**1**	**3**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.22**	**0.05**	**0.15**	**0.14**	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Cobalt	7440-48-4	0.001	mg/L	**0.001**	<0.001	**0.007**	**0.002**	----
Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	**0.009**	**0.002**	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	**0.001**	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.022**	<0.005	----
Manganese	7439-96-5	0.001	mg/L	**0.020**	**0.008**	**0.101**	**0.045**	----
Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC 1	KLC 2	KLC 3	KLC 4	----
				Client sampling date / time	22-Jul-2019 00:00	22-Jul-2019 00:00	22-Jul-2019 00:00	22-Jul-2019 00:00	----
Compound	CAS Number	LOR	Unit		EB1918957-001	EB1918957-002	EB1918957-003	EB1918957-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		<0.05	<0.05	<0.05	<0.05	----
Iron	7439-89-6	0.05	mg/L		<0.05	<0.05	**0.07**	**0.11**	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		<0.1	**0.1**	<0.1	**0.1**	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**1.45**	**2.56**	**1.18**	**4.89**	----
ø **Total Cations**	----	0.01	meq/L		**1.47**	**2.59**	**1.19**	**4.52**	----
ø **Ionic Balance**	----	0.01	%		**----**	**----**	**----**	**3.92**	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1922363**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MS VERONICA CANALES	Contact	: Customer Services EB
Address	:	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: Vulcan Template	Date Samples Received	: 27-Aug-2019 15:20
Order number	:	Date Analysis Commenced	: 27-Aug-2019
C-O-C number	: 3545	Issue Date	: 03-Sep-2019 16:55
Sampler	: CARSTEN EMRICH		
Site	: Vulcan L3		
Quote number	: BN/1234/19		
No. of samples received	: 4		
No. of samples analysed	: 4		

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This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Ionic Balance out of acceptable limits for some samples due to analytes not quantified in this report.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
			Client sampling date / time	27-Aug-2019 11:41	27-Aug-2019 11:44	27-Aug-2019 11:50	27-Aug-2019 11:51	----
Compound	CAS Number	LOR	Unit	EB1922363-001	EB1922363-002	EB1922363-003	EB1922363-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.25**	**6.94**	**6.03**	**6.41**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**282**	**414**	**181**	**382**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**8**	**8**	**2**	**3**	----
Total Alkalinity as CaCO3	----	1	mg/L	**8**	**8**	**2**	**3**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**1**	**1**	**2**	**2**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**39**	**71**	**40**	**48**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**52**	**68**	**21**	**74**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**3**	**7**	**2**	<1	----
Magnesium	7439-95-4	1	mg/L	**7**	**13**	**3**	**5**	----
Sodium	7440-23-5	1	mg/L	**44**	**57**	**30**	**71**	----
Potassium	7440-09-7	1	mg/L	<1	**1**	**2**	**2**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.13**	**0.04**	**0.09**	**0.17**	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	**0.0004**	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	<0.001	**0.004**	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	**0.006**	**0.002**	----
Nickel	7440-02-0	0.001	mg/L	<0.001	**0.001**	**0.008**	**0.002**	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.023**	**0.137**	----
Manganese	7439-96-5	0.001	mg/L	**0.005**	**0.004**	**0.134**	**0.042**	----
Molybdenum	7439-98-7	0.001	mg/L	**0.001**	**0.001**	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	27-Aug-2019 11:41	27-Aug-2019 11:44	27-Aug-2019 11:50	27-Aug-2019 11:51	----
Compound	CAS Number	LOR	Unit		EB1922363-001	EB1922363-002	EB1922363-003	EB1922363-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		<0.05	<0.05	<0.05	<0.05	----
Iron	7439-89-6	0.05	mg/L		<0.05	<0.05	<0.05	**0.07**	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.1**	**0.2**	<0.1	**0.1**	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**2.44**	**3.56**	**1.46**	**3.15**	----
ø **Total Cations**	----	0.01	meq/L		**2.64**	**3.92**	**1.70**	**3.55**	----
ø **Ionic Balance**	----	0.01	%		**----**	**4.92**	**----**	**6.04**	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1925267**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Customer Services EB
Address	:	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: Vulcan - 2019010	Date Samples Received	: 25-Sep-2019 15:51
Order number	:	Date Analysis Commenced	: 26-Sep-2019
C-O-C number	: 4379	Issue Date	: 02-Oct-2019 12:36
Sampler	: MARY MACELROY, VERONICA CANALES		
Site	: Vulcan L-4		
Quote number	: BN/1234/19		
No. of samples received	: 4		
No. of samples analysed	: 4		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
			Client sampling date / time	25-Sep-2019 10:05	25-Sep-2019 10:09	25-Sep-2019 10:10	25-Sep-2019 10:10	----
Compound	CAS Number	LOR	Unit	EB1925267-001	EB1925267-002	EB1925267-003	EB1925267-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.45**	**6.99**	**5.98**	**6.45**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**930**	**251**	**300**	**431**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**26**	**7**	**5**	**5**	----
Total Alkalinity as CaCO3	----	1	mg/L	**26**	**7**	**5**	**5**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**7**	**8**	**7**	**3**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**107**	**37**	**73**	**74**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**222**	**44**	**37**	**76**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**7**	**2**	**2**	<1	----
Magnesium	7439-95-4	1	mg/L	**22**	**6**	**4**	**4**	----
Sodium	7440-23-5	1	mg/L	**146**	**36**	**49**	**75**	----
Potassium	7440-09-7	1	mg/L	**1**	<1	**2**	**3**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.01**	**0.26**	**0.06**	**0.68**	----
Antimony	7440-36-0	0.001	mg/L	**0.002**	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	**0.002**	<0.001	<0.001	<0.001	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	**0.008**	**0.002**	----
Nickel	7440-02-0	0.001	mg/L	**0.001**	<0.001	**0.010**	**0.003**	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	**0.002**	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.031**	<0.005	----
Manganese	7439-96-5	0.001	mg/L	**0.009**	**0.003**	**0.229**	**0.048**	----
Molybdenum	7439-98-7	0.001	mg/L	**0.008**	**0.002**	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	25-Sep-2019 10:05	25-Sep-2019 10:09	25-Sep-2019 10:10	25-Sep-2019 10:10	----
Compound	CAS Number	LOR	Unit		EB1925267-001	EB1925267-002	EB1925267-003	EB1925267-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.06**	<0.05	<0.05	<0.05	**----**
Iron	7439-89-6	0.05	mg/L		<0.05	**0.13**	**0.05**	**0.20**	**----**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.5**	**0.2**	<0.1	**0.2**	**----**
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**9.01**	**2.15**	**2.66**	**3.78**	**----**
ø **Total Cations**	----	0.01	meq/L		**8.54**	**2.16**	**2.61**	**3.67**	**----**
ø **Ionic Balance**	----	0.01	%		**2.70**	**----**	**----**	**1.56**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1927981**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MS VERONICA CANALES	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: Vulcan Template	Date Samples Received	: 22-Oct-2019 16:15
Order number	:	Date Analysis Commenced	: 22-Oct-2019
C-O-C number	: 5170	Issue Date	: 29-Oct-2019 13:14
Sampler	: VERONICA CANALES		
Site	: Vulcan- L5		
Quote number	: BN/1234/19		
No. of samples received	: 4		
No. of samples analysed	: 4		

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Accreditation No. 825
Accredited for compliance with ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

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- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
			Client sampling date / time	22-Oct-2019 14:14	22-Oct-2019 14:15	22-Oct-2019 14:16	22-Oct-2019 14:19	----
Compound	CAS Number	LOR	Unit	EB1927981-001	EB1927981-002	EB1927981-003	EB1927981-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.15**	**6.85**	**6.11**	**6.43**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**1150**	**150**	**208**	**310**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**25**	**8**	**5**	**5**	----
Total Alkalinity as CaCO3	----	1	mg/L	**25**	**8**	**5**	**5**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**2**	<1	**2**	**2**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**95**	**22**	**51**	**53**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**318**	**23**	**21**	**48**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**12**	**2**	**2**	<1	----
Magnesium	7439-95-4	1	mg/L	**38**	**4**	**3**	**3**	----
Sodium	7440-23-5	1	mg/L	**142**	**18**	**31**	**51**	----
Potassium	7440-09-7	1	mg/L	<1	<1	**2**	**2**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	**0.22**	**0.24**	**0.73**	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	**0.001**	**0.002**	<0.001	<0.001	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	7440-47-3	0.001	mg/L	**0.021**	**0.004**	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L	**0.002**	<0.001	<0.001	<0.001	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	**0.004**	**0.002**	----
Nickel	7440-02-0	0.001	mg/L	**0.002**	<0.001	**0.004**	**0.003**	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	**0.001**	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.014**	<0.005	----
Manganese	7439-96-5	0.001	mg/L	**0.024**	**0.003**	**0.121**	**0.034**	----
Molybdenum	7439-98-7	0.001	mg/L	**0.005**	<0.001	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	22-Oct-2019 14:14	22-Oct-2019 14:15	22-Oct-2019 14:16	22-Oct-2019 14:19	----
Compound	CAS Number	LOR	Unit		EB1927981-001	EB1927981-002	EB1927981-003	EB1927981-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		<0.05	<0.05	<0.05	<0.05	----
Iron	7439-89-6	0.05	mg/L		**0.16**	**0.14**	<0.05	<0.05	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.3**	**0.1**	<0.1	**0.1**	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**11.4**	**1.27**	**1.75**	**2.56**	----
ø **Total Cations**	----	0.01	meq/L		**9.90**	**1.21**	**1.75**	**2.52**	----
ø **Ionic Balance**	----	0.01	%		**7.24**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1931659**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MARY MACELROY	Contact	: Customer Services EB
Address	: Level 7 380 QUEEN STREET BRISBANE QLD, AUSTRALIA 4000	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: Vulcan - 2019010	Date Samples Received	: 26-Nov-2019 17:07
Order number	:	Date Analysis Commenced	: 27-Nov-2019
C-O-C number	: 6210	Issue Date	: 04-Dec-2019 09:59
Sampler	: VERONICA CANALES		
Site	: Vulcan 2019010 leach 7		
Quote number	: BN/1234/19		
No. of samples received	: 4		
No. of samples analysed	: 4		

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

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Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	26-Nov-2019 15:44	26-Nov-2019 15:52	26-Nov-2019 15:56	26-Nov-2019 15:57	----
Compound	CAS Number	LOR	Unit		EB1931659-001	EB1931659-002	EB1931659-003	EB1931659-004	--------
					Result	Result	Result	Result	----
EA005P: pH by PC Titrator									
pH Value	----	0.01	pH Unit		7.85	7.17	6.35	6.62	----
EA010P: Conductivity by PC Titrator									
Electrical Conductivity @ 25°C	----	1	µS/cm		1750	119	181	409	----
ED037P: Alkalinity by PC Titrator									
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L		<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L		<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L		47	6	5	4	----
Total Alkalinity as CaCO3	----	1	mg/L		47	6	5	4	----
ED038A: Acidity									
Acidity as CaCO3	----	1	mg/L		5	<1	1	1	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA									
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L		186	18	47	78	----
ED045G: Chloride by Discrete Analyser									
Chloride	16887-00-6	1	mg/L		456	18	15	67	----
ED093F: Dissolved Major Cations									
Calcium	7440-70-2	1	mg/L		16	2	2	<1	----
Magnesium	7439-95-4	1	mg/L		49	3	2	4	----
Sodium	7440-23-5	1	mg/L		258	15	27	70	----
Potassium	7440-09-7	1	mg/L		2	<1	2	3	----
EG020F: Dissolved Metals by ICP-MS									
Aluminium	7429-90-5	0.01	mg/L		<0.01	0.22	0.20	0.91	----
Antimony	7440-36-0	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L		0.006	0.004	0.003	0.003	----
Cadmium	7440-43-9	0.0001	mg/L		<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	7440-47-3	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	----
Copper	7440-50-8	0.001	mg/L		0.002	<0.001	<0.001	<0.001	----
Cobalt	7440-48-4	0.001	mg/L		<0.001	<0.001	0.002	0.002	----
Nickel	7440-02-0	0.001	mg/L		0.002	<0.001	0.003	0.002	----
Lead	7439-92-1	0.001	mg/L		<0.001	<0.001	<0.001	0.002	----
Zinc	7440-66-6	0.005	mg/L		<0.005	<0.005	0.008	0.008	----
Manganese	7439-96-5	0.001	mg/L		0.035	0.002	0.098	0.040	----
Molybdenum	7439-98-7	0.001	mg/L		0.012	0.001	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L		<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	26-Nov-2019 15:44	26-Nov-2019 15:52	26-Nov-2019 15:56	26-Nov-2019 15:57	----
Compound	CAS Number	LOR	Unit		EB1931659-001	EB1931659-002	EB1931659-003	EB1931659-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.09**	<0.05	<0.05	<0.05	**----**
Iron	7439-89-6	0.05	mg/L		<0.05	**0.09**	**0.08**	**0.27**	**----**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.7**	**0.1**	<0.1	**0.2**	**----**
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**17.7**	**1.00**	**1.50**	**3.59**	**----**
ø **Total Cations**	----	0.01	meq/L		**16.1**	**1.00**	**1.49**	**3.45**	**----**
ø **Ionic Balance**	----	0.01	%		**4.65**	**----**	**----**	**2.03**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1932471**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MARY MACELROY	Contact	: Customer Services EB
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61-7-3243 7222
Project	: Vulcan - 2019010	Date Samples Received	: 03-Dec-2019 16:14
Order number	: -	Date Analysis Commenced	: 03-Dec-2019
C-O-C number	: 6459	Issue Date	: 11-Dec-2019 10:23
Sampler	: ALAN ROBERTSON, VERONICA CANALES		
Site	: 2019010 -Vulcan 5-6 L1		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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Accreditation No. 825
Accredited for compliance with ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	03-Dec-2019 11:00	03-Dec-2019 11:02	----	----	----
Compound	CAS Number	LOR	Unit	EB1932471-005	EB1932471-006	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**7.35**	**7.01**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**833**	**151**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**32**	**12**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**32**	**12**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**3**	**1**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**150**	**32**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**158**	**19**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**35**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**31**	**2**	----	----	----
Sodium	7440-23-5	1	mg/L	**70**	**23**	----	----	----
Potassium	7440-09-7	1	mg/L	**5**	**1**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.02**	**0.09**	----	----	----
Antimony	7440-36-0	0.001	mg/L	**0.002**	<0.001	----	----	----
Arsenic	7440-38-2	0.001	mg/L	**0.002**	**0.002**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0021**	<0.0001	----	----	----
Chromium	7440-47-3	0.001	mg/L	**0.001**	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.006**	**0.002**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.070**	**0.006**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.046**	**0.005**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.067**	<0.005	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.016**	**0.002**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.050**	**0.036**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.05**	**0.02**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-5	KLC-6	----	----	----
				Client sampling date / time	03-Dec-2019 11:00	03-Dec-2019 11:02	----	----	----
Compound	CAS Number	LOR	Unit		EB1932471-005	EB1932471-006	--------	--------	--------
					Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.11**	<0.05	----	----	----
Iron	7439-89-6	0.05	mg/L		<0.05	<0.05	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**1.2**	**0.4**	----	----	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**8.22**	**1.44**	----	----	----
ø **Total Cations**	----	0.01	meq/L		**7.47**	**1.29**	----	----	----
ø **Ionic Balance**	----	0.01	%		**4.77**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB1934601**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 24-Dec-2019 11:30
Order number	: -	Date Analysis Commenced	: 27-Dec-2019
C-O-C number	: 7040	Issue Date	: 10-Jan-2020 17:28
Sampler	: VERONICA CANALES		
Site	: Vulcan L-7		
Quote number	: BN/1234/19		
No. of samples received	: 4		
No. of samples analysed	: 4		

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- Analytical Results

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Mark Hallas	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
			Client sampling date / time	24-Dec-2019 09:26	24-Dec-2019 09:29	24-Dec-2019 09:30	24-Dec-2019 09:30	----
Compound	CAS Number	LOR	Unit	EB1934601-001	EB1934601-002	EB1934601-003	EB1934601-004	--------
				Result	Result	Result	Result	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**8.03**	**7.39**	**6.35**	**6.70**	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**462**	**94**	**148**	**384**	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**80**	**11**	**5**	**8**	----
Total Alkalinity as CaCO3	----	1	mg/L	**80**	**11**	**5**	**8**	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	<1	**2**	**1**	**3**	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**47**	**12**	**41**	**72**	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**64**	**13**	**10**	**56**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**3**	<1	**1**	<1	----
Magnesium	7439-95-4	1	mg/L	**8**	**2**	**2**	**2**	----
Sodium	7440-23-5	1	mg/L	**91**	**15**	**24**	**71**	----
Potassium	7440-09-7	1	mg/L	**1**	<1	**2**	**3**	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.77**	**0.29**	**0.28**	**1.13**	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	----
Arsenic	7440-38-2	0.001	mg/L	**0.004**	<0.001	<0.001	**0.002**	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	7440-47-3	0.001	mg/L	**0.001**	<0.001	<0.001	**0.001**	----
Copper	7440-50-8	0.001	mg/L	**0.005**	<0.001	<0.001	**0.002**	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	**0.001**	**0.001**	----
Nickel	7440-02-0	0.001	mg/L	**0.001**	<0.001	**0.002**	**0.003**	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	**0.003**	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.005**	**0.005**	----
Manganese	7439-96-5	0.001	mg/L	**0.003**	**0.003**	**0.058**	**0.033**	----
Molybdenum	7439-98-7	0.001	mg/L	**0.013**	<0.001	<0.001	<0.001	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-1	KLC-2	KLC-3	KLC-4	----
				Client sampling date / time	24-Dec-2019 09:26	24-Dec-2019 09:29	24-Dec-2019 09:30	24-Dec-2019 09:30	----
Compound	CAS Number	LOR	Unit		EB1934601-001	EB1934601-002	EB1934601-003	EB1934601-004	--------
					Result	Result	Result	Result	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.14**	<0.05	<0.05	<0.05	**----**
Iron	7439-89-6	0.05	mg/L		**0.10**	**0.09**	**0.09**	**0.42**	**----**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.9**	**0.1**	<0.1	**0.2**	**----**
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**4.38**	**0.84**	**1.24**	**3.24**	**----**
ø **Total Cations**	----	0.01	meq/L		**4.79**	**0.82**	**1.31**	**3.33**	**----**
ø **Ionic Balance**	----	0.01	%		**4.46**	**----**	**----**	**1.39**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2000205**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 07-Jan-2020 17:10
Order number	:	Date Analysis Commenced	: 08-Jan-2020
C-O-C number	: 7144	Issue Date	: 15-Jan-2020 09:53
Sampler	: CARSTEN EMRICH		
Site	: 2019010- Vulcan Saraji West (5&6) L2 January 2020		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

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Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	07-Jan-2020 13:32	07-Jan-2020 13:32	----	----	----
Compound	CAS Number	LOR	Unit	EB2000205-001	EB2000205-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.69**	**6.90**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**504**	**205**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**9**	**14**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**9**	**14**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**1**	**1**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**143**	**52**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**40**	**14**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**22**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**18**	**2**	----	----	----
Sodium	7440-23-5	1	mg/L	**45**	**33**	----	----	----
Potassium	7440-09-7	1	mg/L	**5**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	**0.14**	----	----	----
Antimony	7440-36-0	0.001	mg/L	**0.001**	**0.001**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	**0.002**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0015**	**0.0002**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.006**	**0.003**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.099**	**0.016**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.072**	**0.015**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.098**	**0.009**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.023**	**0.004**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.013**	**0.046**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.02**	**0.03**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-5	KLC-6	----	----	----
				Client sampling date / time	07-Jan-2020 13:32	07-Jan-2020 13:32	----	----	----
Compound	CAS Number	LOR	Unit		EB2000205-001	EB2000205-002	--------	--------	--------
					Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.09**	<0.05	----	----	----
Iron	7439-89-6	0.05	mg/L		<0.05	**0.07**	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.6**	**0.5**	----	----	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**4.28**	**1.76**	----	----	----
ø **Total Cations**	----	0.01	meq/L		**4.66**	**1.75**	----	----	----
ø **Ionic Balance**	----	0.01	%		**4.24**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2002875**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO Box 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 04-Feb-2020 16:27
Order number	: -	Date Analysis Commenced	: 05-Feb-2020
C-O-C number	: 7933	Issue Date	: 12-Feb-2020 14:55
Sampler	: CARSTEN EMRICH		
Site	: 2019010- Vulcan Saraji West (5&6) L3		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Dave Gitsham	Metals Instrument Chemist	Brisbane Inorganics, Stafford, QLD
Mark Hallas	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
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^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	04-Feb-2020 13:48	04-Feb-2020 13:48	----	----	----
Compound	CAS Number	LOR	Unit	EB2002875-001	EB2002875-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**5.77**	**6.66**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**980**	**263**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**14**	**23**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**14**	**23**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**5**	**2**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**374**	**78**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**56**	**13**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**50**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**42**	**4**	----	----	----
Sodium	7440-23-5	1	mg/L	**73**	**42**	----	----	----
Potassium	7440-09-7	1	mg/L	**8**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.04**	**0.33**	----	----	----
Antimony	7440-36-0	0.001	mg/L	**0.001**	**0.002**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	**0.001**	**0.002**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0068**	**0.0003**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.020**	**0.005**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.423**	**0.023**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.271**	**0.023**	----	----	----
Lead	7439-92-1	0.001	mg/L	**0.020**	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.554**	**0.016**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.108**	**0.004**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.010**	**0.052**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.05**	**0.04**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	04-Feb-2020 13:48	04-Feb-2020 13:48	----	----	----
Compound	CAS Number	LOR	Unit	EB2002875-001	EB2002875-002	--------	--------	--------
				Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Boron	7440-42-8	0.05	mg/L	**0.16**	**0.13**	----	----	----
Iron	7439-89-6	0.05	mg/L	**0.10**	**0.15**	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.5**	**0.9**	----	----	----
EN055: Ionic Balance								
ø **Total Anions**	----	0.01	meq/L	**9.65**	**2.45**	----	----	----
ø **Total Cations**	----	0.01	meq/L	**9.33**	**2.31**	----	----	----
ø **Ionic Balance**	----	0.01	%	**1.66**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2005904**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO BOX 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 03-Mar-2020 16:59
Order number	: -	Date Analysis Commenced	: 07-Mar-2020
C-O-C number	: 7143	Issue Date	: 11-Mar-2020 10:06
Sampler	: VERONICA CANALES		
Site	: 2019010- Vulcan Saraji West (5&6) L4		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

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- General Comments
- Analytical Results

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	03-Mar-2020 11:49	03-Mar-2020 11:49	----	----	----
Compound	CAS Number	LOR	Unit	EB2005904-001	EB2005904-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**5.59**	**6.68**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**1060**	**275**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**3**	**18**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**3**	**18**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**6**	**2**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**487**	**86**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**36**	**11**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**64**	**3**	----	----	----
Magnesium	7439-95-4	1	mg/L	**54**	**4**	----	----	----
Sodium	7440-23-5	1	mg/L	**86**	**44**	----	----	----
Potassium	7440-09-7	1	mg/L	**8**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.01**	**0.16**	----	----	----
Antimony	7440-36-0	0.001	mg/L	<0.001	**0.001**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	**0.001**	**0.001**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0088**	**0.0004**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.025**	**0.006**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.552**	**0.021**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.352**	**0.024**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.971**	**0.026**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.198**	**0.006**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.007**	**0.058**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.05**	**0.04**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-5	KLC-6	----	----	----
				Client sampling date / time	03-Mar-2020 11:49	03-Mar-2020 11:49	----	----	----
Compound	CAS Number	LOR	Unit		EB2005904-001	EB2005904-002	--------	--------	--------
					Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.18**	**0.18**	----	----	----
Iron	7439-89-6	0.05	mg/L		<0.05	**0.06**	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.4**	**0.6**	----	----	----
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**11.2**	**2.46**	----	----	----
ø **Total Cations**	----	0.01	meq/L		**11.6**	**2.44**	----	----	----
ø **Ionic Balance**	----	0.01	%		**1.62**	----	----	----	----

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2009682**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO BOX 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 07-Apr-2020 17:00
Order number	: -	Date Analysis Commenced	: 08-Apr-2020
C-O-C number	: 10041	Issue Date	: 17-Apr-2020 11:48
Sampler	: VERONICA CANALES		
Site	: Vulcan 5 & 6 L5		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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Signatories

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Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

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Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	07-Apr-2020 14:28	07-Apr-2020 14:29	----	----	----
Compound	CAS Number	LOR	Unit	EB2009682-001	EB2009682-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.03**	**6.98**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**660**	**225**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**6**	**17**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**6**	**17**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**5**	**2**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**291**	**77**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**17**	**8**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**31**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**30**	**3**	----	----	----
Sodium	7440-23-5	1	mg/L	**51**	**36**	----	----	----
Potassium	7440-09-7	1	mg/L	**6**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.05**	**0.24**	----	----	----
Antimony	7440-36-0	0.001	mg/L	<0.001	**0.002**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0064**	**0.0004**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.029**	**0.009**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.346**	**0.020**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.233**	**0.020**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.777**	**0.036**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.195**	**0.010**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.006**	**0.035**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.04**	**0.03**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-5	KLC-6	----	----	----
				Client sampling date / time	07-Apr-2020 14:28	07-Apr-2020 14:29	----	----	----
Compound	CAS Number	LOR	Unit		EB2009682-001	EB2009682-002	--------	--------	--------
					Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.15**	**0.06**	**----**	**----**	**----**
Iron	7439-89-6	0.05	mg/L		**0.07**	<0.05	**----**	**----**	**----**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.5**	**0.8**	**----**	**----**	**----**
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**6.66**	**2.17**	**----**	**----**	**----**
ø **Total Cations**	----	0.01	meq/L		**6.39**	**1.96**	**----**	**----**	**----**
ø **Ionic Balance**	----	0.01	%		**2.07**	**----**	**----**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2011988**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO BOX 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 06-May-2020 16:05
Order number	: -	Date Analysis Commenced	: 07-May-2020
C-O-C number	: 10786	Issue Date	: 12-May-2020 13:30
Sampler	: VERONICA CANALES		
Site	: 2019010_Vulcan_L7		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

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Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Ionic Balance out of acceptable limits due to analytes not quantified in this report.
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	06-May-2020 08:26	06-May-2020 08:27	----	----	----
Compound	CAS Number	LOR	Unit	EB2011988-001	EB2011988-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.58**	**7.15**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**504**	**215**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**8**	**17**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**8**	**17**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**2**	<1	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**215**	**69**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**8**	**6**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**26**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**28**	**4**	----	----	----
Sodium	7440-23-5	1	mg/L	**39**	**39**	----	----	----
Potassium	7440-09-7	1	mg/L	**5**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	**0.32**	----	----	----
Antimony	7440-36-0	0.001	mg/L	<0.001	**0.002**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	**0.001**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0058**	**0.0004**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.018**	**0.005**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.320**	**0.019**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.221**	**0.018**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.862**	**0.040**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.202**	**0.007**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.005**	**0.054**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.03**	**0.03**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	KLC-5	KLC-6	----	----	----
				Client sampling date / time	06-May-2020 08:26	06-May-2020 08:27	----	----	----
Compound	CAS Number	LOR	Unit		EB2011988-001	EB2011988-002	--------	--------	--------
					Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Boron	7440-42-8	0.05	mg/L		**0.06**	<0.05	**----**	**----**	**----**
Iron	7439-89-6	0.05	mg/L		<0.05	<0.05	**----**	**----**	**----**
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**0.4**	**0.7**	**----**	**----**	**----**
EN055: Ionic Balance									
ø **Total Anions**	----	0.01	meq/L		**4.86**	**1.94**	**----**	**----**	**----**
ø **Total Cations**	----	0.01	meq/L		**5.43**	**2.18**	**----**	**----**	**----**
ø **Ionic Balance**	----	0.01	%		**5.48**	**----**	**----**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EB2014636**	Page	: 1 of 4
Client	: **RGS ENVIRONMENTAL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: MR ALAN ROBERTSON	Contact	: Carsten Emrich
Address	: PO BOX 3091 SUNNYBANK SOUTH QLD, AUSTRALIA 4109	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: +61 07 3344 1222	Telephone	: +61 7 3552 8616
Project	: Vulcan - 2019010	Date Samples Received	: 02-Jun-2020 16:45
Order number	: -	Date Analysis Commenced	: 03-Jun-2020
C-O-C number	: 11564	Issue Date	: 09-Jun-2020 09:36
Sampler	: VERONICA CANALES		
Site	: 2019010_Vulcan_L7-1		
Quote number	: BN/1234/19		
No. of samples received	: 2		
No. of samples analysed	: 2		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	02-Jun-2020 10:06	02-Jun-2020 10:07	----	----	----
Compound	CAS Number	LOR	Unit	EB2014636-001	EB2014636-002	--------	--------	--------
				Result	Result	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**6.48**	**7.28**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**426**	**173**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**4**	**21**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**4**	**21**	----	----	----
ED038A: Acidity								
Acidity as CaCO3	----	1	mg/L	**2**	<1	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**180**	**48**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**6**	**4**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**21**	**2**	----	----	----
Magnesium	7439-95-4	1	mg/L	**21**	**3**	----	----	----
Sodium	7440-23-5	1	mg/L	**26**	**27**	----	----	----
Potassium	7440-09-7	1	mg/L	**4**	**2**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	**0.33**	----	----	----
Antimony	7440-36-0	0.001	mg/L	<0.001	**0.002**	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	**0.002**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0052**	**0.0004**	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.016**	**0.007**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.262**	**0.016**	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.184**	**0.014**	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.796**	**0.038**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.174**	**0.007**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.002**	**0.027**	----	----	----
Selenium	7782-49-2	0.01	mg/L	**0.02**	**0.02**	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	KLC-5	KLC-6	----	----	----
			Client sampling date / time	02-Jun-2020 10:06	02-Jun-2020 10:07	----	----	----
Compound	CAS Number	LOR	Unit	EB2014636-001	EB2014636-002	--------	--------	--------
				Result	Result	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Boron	7440-42-8	0.05	mg/L	**0.08**	**0.05**	**----**	**----**	**----**
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	**----**	**----**	**----**
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.4**	**0.6**	**----**	**----**	**----**
EN055: Ionic Balance								
ø **Total Anions**	----	0.01	meq/L	**4.00**	**1.53**	**----**	**----**	**----**
ø **Total Cations**	----	0.01	meq/L	**4.01**	**1.57**	**----**	**----**	**----**
ø **Ionic Balance**	----	0.01	%	**0.16**	**----**	**----**	**----**	**----**

Attachment E Risk Assessment for the Ex-Pit Emplacement of Coal Rejects

Descriptions of Likelihood Rankings

Likelihood	Description
Rare (1)	Unlikely to occur in a lifetime; or very unlikely to occur; or no known occurrences in broader worldwide community.
Unlikely (2)	Could occur about once during a lifetime; or more likely not to occur than to occur; or has occurred at least once in the broader worldwide industry.
Possible (3)	Could occur more than once during a lifetime; or as likely to occur as not to occur; or has occurred at least once in the mining/commodities trading industry.
Likely (4)	May occur about once per year; or more likely to occur than not occur; or has occurred at least once on a mine site in the Bowen Basin.
Almost Certain (5)	May occur several times per year; or expected to occur; or has occurred several times on a mine site in the Bowen Basin.

Descriptions of Consequence Rankings

Consequence	Description
Negligible (1)	No lasting impact; requires minor or no remediation; minor management intervention may be required.
Minor (2)	Short-term impact; requires minor remediation or intervention.
Moderate (3)	Medium-term (<2 years) impact; requires moderate intervention.
Major (4)	Long-term (2-10 years) impact; major remediation measures required.
Catastrophic (5)	Unconfined and widespread environmental damage; impacts reaching into surrounding areas; major remediation measures required.

Risk Rating Matrix

RISK CALCULATOR (Risk Rating = Consequences x Likelihood)					
	CONSEQUENCE				
LIKELIHOOD	Negligible (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Rare (1)	L (1)	L (3)	M (6)	M (10)	H (15)
Unlikely (2)	L (2)	L (5)	M (9)	H (14)	E (19)
Possible (3)	L (4)	M (8)	H (13)	E (18)	E (22)
Likely (4)	M (7)	H (12)	H (17)	E (21)	E (24)
Almost Certain (5)	M (11)	H (16)	E (20)	E (23)	E (25)

Table E1: Risk Assessment for the Ex-Pit Emplacement of Coal Rejects

Hazard	Impact	Inherent Risk			Risk Control Measures	Residual Risk		
		Consequence	Likelihood	Risk Rating		Consequence	Likelihood	Risk Rating
Loss of acidic, saline, and/or metalliferous drainage to the surrounding environment.	Increased acidity, increased salinity, and/or increased dissolved metal/metalloid concentrations in receiving groundwater or surface water.	3	2	**M (9)**	**Engineering** – Any identified PAF materials with be placed in the central core of the ex-pit emplacement facility and encapsulated with at least 5 m of NAF waste rock material[6]. The PAF materials will be placed at a location that allows any seepage to be directed toward the open pits. PAF materials will be paddock dumped and traffic compacted to reduce the ingress of oxygen and water. Drains to catch seepage from selected locations at the ex-pit emplacements will be created to direct seepage back into the pits. **Administration** - Seepage from the ex-pit dumps will be monitored as part of the site Water Management Plan.	2	1	**L (3)**
Uncovering of previously covered PAF materials during landform reshaping.	Reduced stability of the final landform due to erosion and sediment loss. Downstream/downgradient areas impacted by sediment load. The inability to establish, or reduced performance of, vegetation to be established on the surface of the final landform.	3	2	**M (9)**	**Isolation** - Tailings and rejects will not be placed closer than 5 m to the external batters of the ex-pit dumps and under at least 5m of NAF waste rock[6]. **Administration** - The extents of dumped coal tailings and rejects within the ex-pit waste rock dumps will be surveyed and recorded.	2	1	**L (3)**

Hazard	Impact	Inherent Risk			Risk Control Measures	Residual Risk		
		Consequence	Likelihood	Risk Rating		Consequence	Likelihood	Risk Rating
Poor mixing of coal reject and spoil.	Altered geotechnical properties (reduced bearing capacity) leading to landform instability.	3	3	**H (13)**	**Administration** - The timing of dumping will be scheduled to ensure that both waste rock and coal rejects are adequately combined when emplaced in the ex-pit dumps. Visual inspection of the co-disposed material in ex-pit dumps will be undertaken periodically to confirm the adequate mixture of materials.	3	1	**M (6)**
Drying process at the CHPP is less effective than planned.	Altered material handling characteristics. Altered geotechnical properties leading to landform instablility.	3	3	**H (13)**	**Administration** - Waste materials from the CHPP will be periodically assessed to ensure the materials have moisture contents within the appropriate bounds.	3	1	**M (6)**
Coal rejects exposed at the surface of the emplacements	Reduced stability of the final landform due to erosion and sediment loss. Downstream/downgradient areas impacted by sediment load.	3	3	**H (13)**	**Isolation** – Coal Rejects will not be placed closer than 5m to the external surface of the ex-pit dumps and under at least 5 m of NAF waste rock[6]. **Administration -** The extents of dumped coal rejects within the ex-pit waste rock dumps will be surveyed and recorded.	2	1	**L (3)**

Hazard	Impact	Inherent Risk			Risk Control Measures	Residual Risk		
		Consequence	Likelihood	Risk Rating		Consequence	Likelihood	Risk Rating
Capillary rise of acidic, saline, and/or metalliferous drainage generated by PAF materials.	The inability to establish, or reduced performance of, vegetation to be established on the surface of the final landform.	3	3	**H (13)**	**Isolation** - Tailings and rejects will not be placed closer than 5 m to the external batters of the ex-pit dumps and under at least 5 m of NAF waste rock below the cover of the final landform to create a capillary break[6].	2	1	**L (3)**
Saturation of exposed PAF materials during rain events.	Generation of acidic, saline, and/or metalliferous drainage from the tailings and rejects materials. Altered geotechnical properties.	3	3	**M (9)**	**Engineering** - The coal rejects and waste rock will be traffic compacted after paddock dumping and covered with NAF waste rock to further reduce the size of the pore spaces in the dump, reducing the ingress of air and water.	2	1	**L (3)**
Drying of uncovered, unconsolidated PAF materials generating dust.	Contamination of downwind areas by PAF material dust.	2	1	**L (3)**	**Isolation** – PAF materials will not be placed closer than 5 m to the surface of the ex-pit emplacement and will be covered by at least 5 m of NAF waste rock[6]. **Engineering -** PAF materials will be traffic compacted as soon as possible after paddock dumping	1	1	**L (1)**



MINE WASTE AND
WATER MANAGEMENT

Appendix I – Supporting Information and Responses to Surface Water Request

Vulcan South EA Application

Supporting information and responses to the Department of Environment and Science Information Request relating to surface water

Vitrinite Pty Ltd
1571-20-D2, 14 March 2023

Report Title	Vulcan South EA Application. Supporting information and responses to the Department of Environment and Science Information Request relating to surface water
Client	Vitrinite Pty Ltd
Report Number	1571-20-D2

Revision Number	Report Date	Report Author	Reviewer
0 [DRAFT]	30 January 2023	RN	JO
1	12 February 2023	RN	JO
2	14 March 2023	RN	JO

For and on behalf of WRM Water & Environment Pty Ltd
Level 9, 135 Wickham Tce, Spring Hill
PO Box 10703 Brisbane Adelaide St Qld 4000
Tel 07 3225 0200

Julian Orth

Principal Engineer

NOTE: This report has been prepared on the assumption that all information, data and reports provided to us by our client, on behalf of our client, or by third parties (e.g. government agencies) is complete and accurate and on the basis that such other assumptions we have identified (whether or not those assumptions have been identified in this advice) are correct. You must inform us if any of the assumptions are not complete or accurate. We retain ownership of all copyright in this report. Except where you obtain our prior written consent, this report may only be used by our client for the purpose for which it has been provided by us.

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1 Introduction

This report has been prepared in response to an information request by the Department of Environment and Science (DES) for the Vulcan South project (the Project). The Notice of Information Request dated 1 August 2022 was provided in response to the Vulcan South Environmental Authority (EA).

WRM Water & Environment (WRM) previously completed the Vulcan South Surface Water Assessment (SWA) (WRM, 2022), which included an operational water balance model, a flood model and the proposed surface water monitoring program. This report was prepared in response to DES comments and provides further details for the Vulcan South SWA report. This report includes updates to the water management strategy, the surface water monitoring program and the water quality objectives (WQO).

WRM's responses to the DES comments are provided in Appendix A and were formed with direct consultation and approval of Vitrinite following their review.

2 Water management system

2.1 CONCEPTUAL DRAINAGE PLANS

2.1.1 Overview

The proposed strategy for the management of surface water at the Project is based on the separation of water from different sources based on anticipated water quality. Figure 1.3 to Figure 1.13 of the Vulcan South SWA report (WRM, 2022) shows the conceptual drainage plans for the Project during various mining stages. Water management at the Project is reliant on topography, as well as constructed surface water, diverted water and mine water drains. The proposed sediment dams are designed and located to capture surface water runoff via proposed surface water drains to ensure separation from any mine affected water. In the event that surface water within sediment dams is contaminated, this water will be pumped into a mine water dam (MWD).

The waste rock dump has been classified as ‘surface water runoff’ as it will be managed by sediment control structures in accordance with a proposed Erosion and Sediment Control Plan (ESCP) and will not be mixed with tailings, pit or processing water. This is consistent with the definitions provided by DES (2017). A geochemical assessment of the waste rock material has also been undertaken by RGS (2022). The results of the static and kinetic geochemical tests demonstrate that the overwhelming majority of the waste rock materials contain negligible sulphide content, have excess acid neutralising capacity (ANC), and are classified as non-acid forming (NAF). RGS concluded that the samples represent materials with a very low risk of acid generation and a high factor of safety with respect to generating acidic drainage.

Areas proposed to be 'disturbed by mining operations' will be separated from the surface water system using mine water dams which are proposed to capture mine affected runoff via proposed mine water drains. Section 3 of this report provides the review of water quality sample data at monitoring point locations and the proposed receiving waters trigger values in the event that mine affected water potentially contaminates surface runoff water.

2.1.2 Vulcan Main mining area

Figure 2.1 shows the updated conceptual drainage plan for the Stage 2 Vulcan Main mining area (Figure 1.6 of the Vulcan South SWA report), which amended an incorrectly shown surface water catchment boundary.

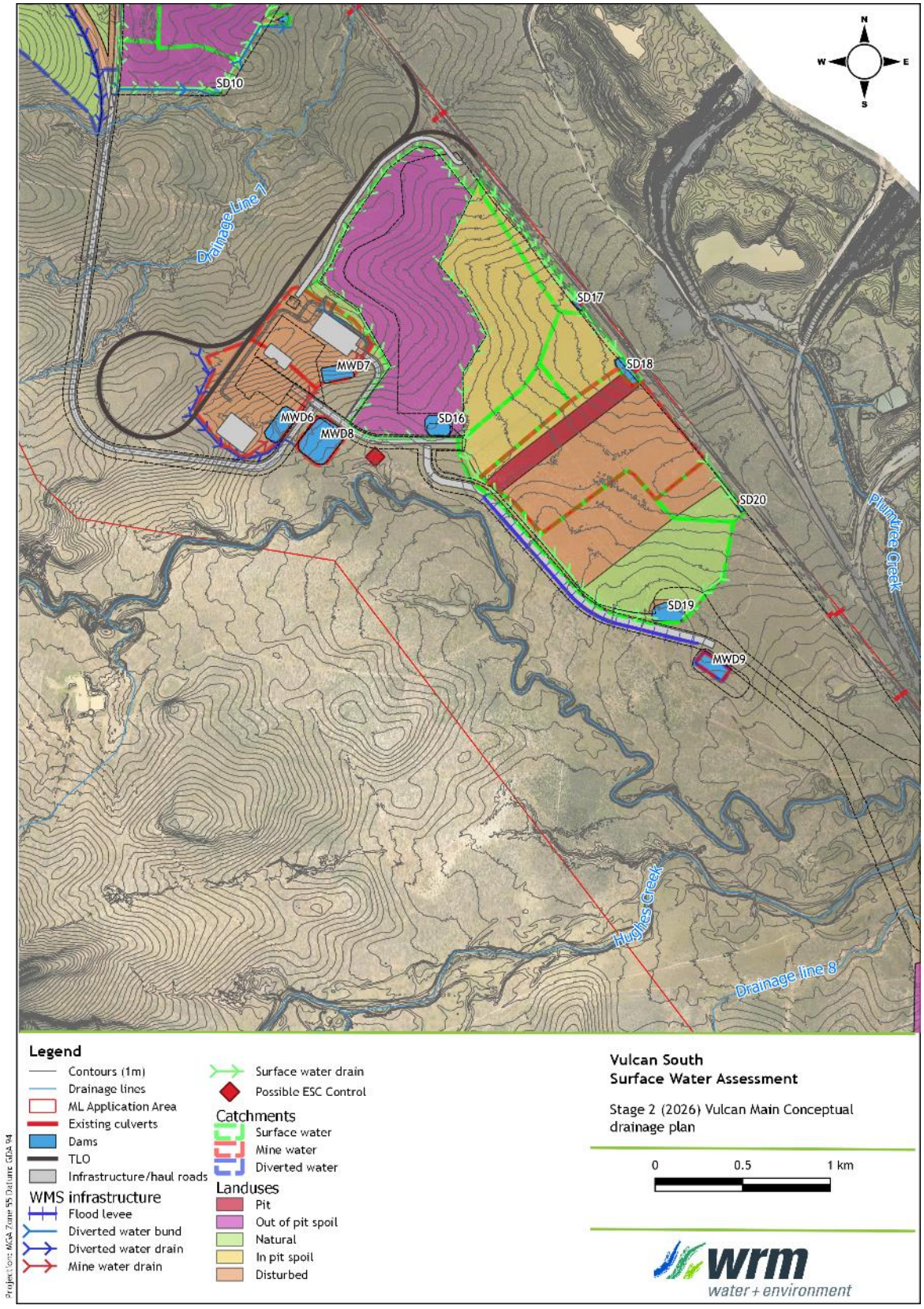


Figure 2.1 – Updated Stage 2 (Year 2026) Vulcan Main mining area conceptual drainage plan

2.1.3 Highwall mining water management strategy

Figure 2.2 shows the proposed mine affected water management strategy for the Project to address DES's comments regarding the management of mine affected water during the highwall mining stages. The active mining area (MAW catchment) is proposed to progressively shift as highwall mining panels are completed and rehabilitated to surface runoff water catchments. The key components of the mine water management strategy throughout the highwall mining stage of the Project include:

- clean water drains/contour banks and rock chutes/drop structures above the plunges will divert natural catchment runoff to the proposed surface water drains/sediment control structures and prevent contamination where active plunges are located;
- bunds along the bench will be built as required. These will direct MAW into the adjacent plunges. Bunds will also divert haul road runoff to the surface water drainage systems;
- direct mine water runoff (via gravity) either directly into a plunge or via a sump that dewaters to the plunge;
- as the highwall miner progresses, a mobile coal stockpile will keep pace within 100 m of the highwall miner before being trucked to the CHPP for processing. Disused coal stockpiles that are greater than 100 m from the highwall miner will be rehabilitated; and
- where plunges are no longer active, rehabilitation will commence to cover the voids at the surface. After covering the voids, surface runoff water would not be classified as MAW, and can be treated through the proposed sediment control structures.

The MAW catchment consists of an approximate area of 3.2 ha based on 318 m in length of highwall mining panels (4 active longwall mining panels + 2 panels with rehabilitation commenced) and a 100 m wide bench (including haul road and batter). This is based on:

- Each longwall mining panel is approximately 53.0 m in length and consists of 10 x 3.5 m wide x 1.5 m high plunges. Each panel will include 9 x 1.5 m wide pillars that will be left between each plunge with a 4.5 m wide pillar every 10 plunges; and
- MAW catchment extends from edge of highwall bench to the clean water contour bank on batter slope above highwall batter/plunges (nominally 100 m width).
- One (1) panel (10 plunges) would store approximately 9.9 ML. This is based on the void capacity of each completed plunge of approximately 990 m^3 assuming plunge dimensions of 1 m high, 3.5 m wide and 300 m deep at 3% gradient;
- Each panel will take approximately 1 to 2 weeks to complete;
- MAW catchment runoff for a 10% AEP 72 hour storm event containment (extreme storm storage [ESS]) = 6.1 ML (rainfall depth = 189 mm, catchment area of 3.2 ha, assumed all rainfall is converted to runoff). This is equivalent to two thirds of the storage capacity of a panel;
- Runoff from MAW catchments would be directed to the designated water storage panel using bunds, drains and pumps (where required). Where possible, there will be an interim panel separating the active panel and the water storage panel to limit the amount of seepage through the coal seam into the seam being actively mined. As mining progresses, the water storage panel plunge openings will be buried, with any water stored in the plunge to remain within the voids. The adjacent panel would then be designated the water storage panel;
- Runoff from areas external to the active mining area including haul roads and batters are considered surface runoff water and not MAW provided the two waters do not mix. Surface runoff water would be managed with erosion and sediment control (ESC) structures and can be released after passing through an ESC structure. Surface runoff water does not require water containment; and

- Mobile coal stockpiles will be located within the MAW catchment within 100 m of the highwall miner. The mobile coal stockpile will keep pace with the highwall miner. Coal will be loaded into trucks and hauled to the VS operations. Abandoned coal stockpile areas that are more than 100 m away from the highwall miner will be cleared of any residual coal material (including fines and rejects). Once the area is cleared of residual coal material and the plunges, runoff will be classified as surface runoff water and can be directed to ESC controls.

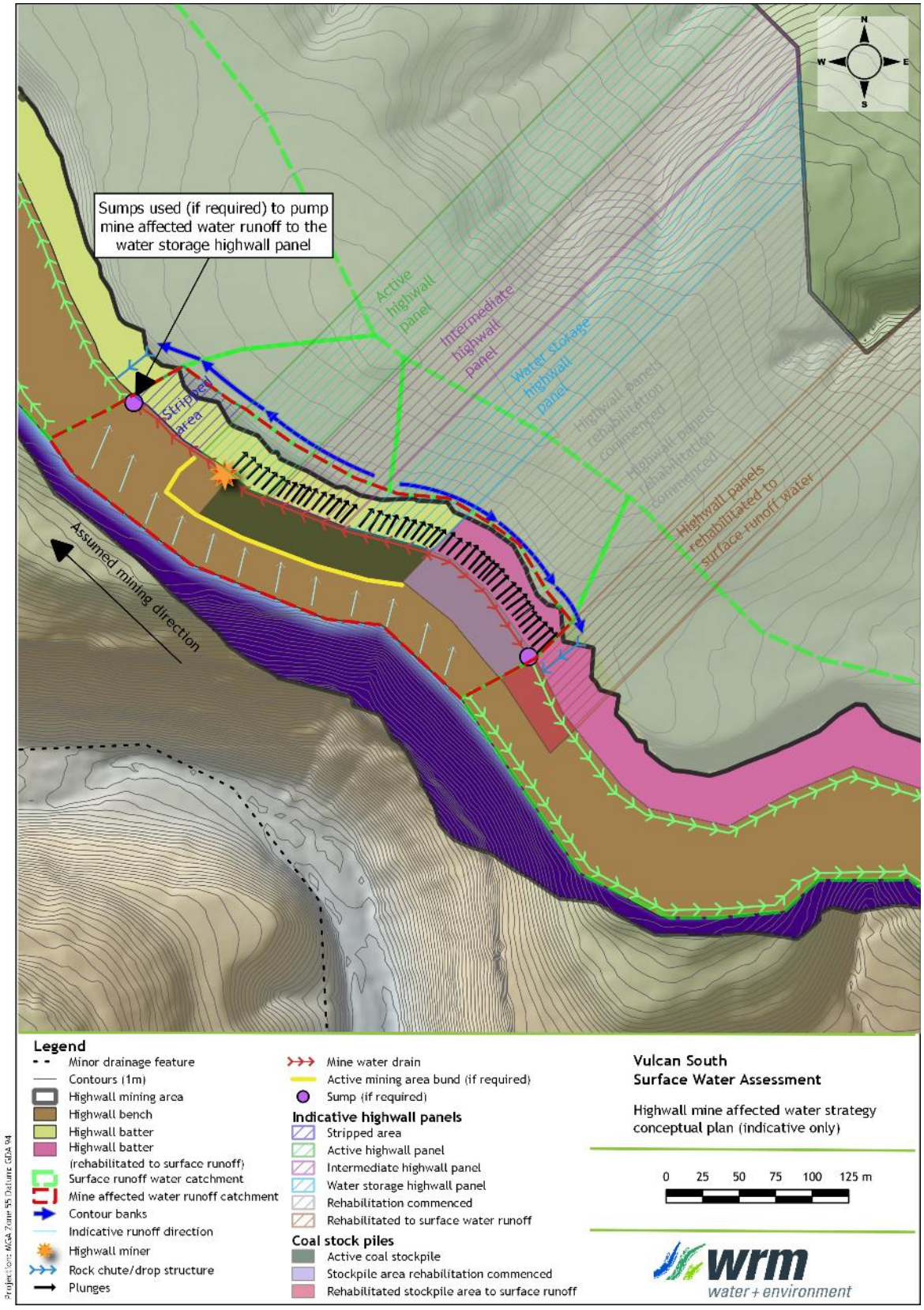


Figure 2.2 – Highwall mine affected water strategy conceptual plan

3 Surface water quality data

3.1 OVERVIEW

Vitrinite has implemented a routine baseline water quality monitoring network since February 2020 within and in the vicinity of the Project to collect baseline (reference) surface water quality along natural drainage lines. A review of the available baseline (reference) surface water quality data has been undertaken to develop locally derived receiving waters trigger values for the Project. The assessment was undertaken in accordance with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality guidelines (ANZG, 2018) for deriving site specific guideline value (SSGVs) for aquatic ecosystems protection from local reference data.

The review has been undertaken using natural surface water quality measurements at relevant baseline (reference) monitoring sites. The available data included monitoring sites on the following drainage lines (see Figure 3.1):

- upstream monitoring points: VSW3, VSW5, VSW11, VESW2, VESW3 and VESW4;
- downstream monitoring points: VSW2, VSW4, VSW7, VSW8, VSW9, VSW10 and VESW1; and
- VSW1 was excluded from the assessment as sampling at this location shows anomalies and could have been potential influenced from external factors or catchments..

The six (6) upstream monitoring points were used for the baseline surface water quality assessment and includes receiving waters locations to the south and north of the Project. These monitoring points have been selected because the catchment characteristics across these drainage lines are similar to those crossing the Project disturbance area and are relevant for setting baseline trigger values for the Vulcan South EA.

Downstream monitoring points will be used to assess the water quality of the receiving waters in the context of the Project. Once the Project commences operations within the downstream monitoring point catchments, these sites will be monitored directly after release events to assess the effect of Project releases.

Prior to operations commencing in the upstream catchment, samples collected at VSW3 and VSW11 are included in the baseline monitoring assessment. Once mining operations commence in the upstream catchment, VSW3 and VSW11 will potentially be affected by the Project disturbance area. Notwithstanding this, VSW3 and VSW11 will be retained as a downstream monitoring points for compliance.

3.1.1 Baseline surface water quality assessment methodology

Vitrinite provided site water quality data collected from February 2020 to October 2022 for this review. Samples were provided at the monitoring sites during ten natural flow events between February 2020 and October 2022.

Locally derived receiving waters trigger values have been proposed for the Project using the 80th percentile of recorded reference site data in accordance with ANZG (2018). The 80th percentile values were compared against the Project Water Quality Objective (WQO) default trigger values provided in Table 3.1 of the SWA report and the DES Model Mine Conditions (MMC) guidelines (DES, 2017). ANZG (2018) states that reference data can be used to derive SSGVs for water quality when natural background concentrations of a toxicant exceed the Project WQO default trigger value.

ANZG (2018) also states that data collected over 2 years of monthly sampling (18 to 24 samples) is regarded as sufficient to indicate ecosystem variability to derive guideline values based on reference site data. To establish local water quality objectives, the Queensland Water Quality Guidelines (QWQG) require that with 3 or more reference sites, 12 samples are collected over at

least 12, but preferably 24 months. Vitrinite has established more than 3 reference sites, which will continue to be either upstream reference sites or reference sites until mining commences.

3.1.2 Comparison of baseline surface water quality data with the Project WQO and MMC default trigger values

The site monitoring data to date has been sampled for at least two (2) and up to ten (10) events across the upstream monitoring site locations. As data collection is limited to periods of flow in an ephemeral system, the samples collected from upstream monitoring sites were combined so that the 80th percentile values could be analysed. In total, 33 samples were taken between February 2020 and October 2022. Table 3.1 shows the 80th percentile values for all parameters measured for the combined upstream monitoring points data set as well as the Project WQO default trigger values and MMC (DES, 2017) default trigger values.

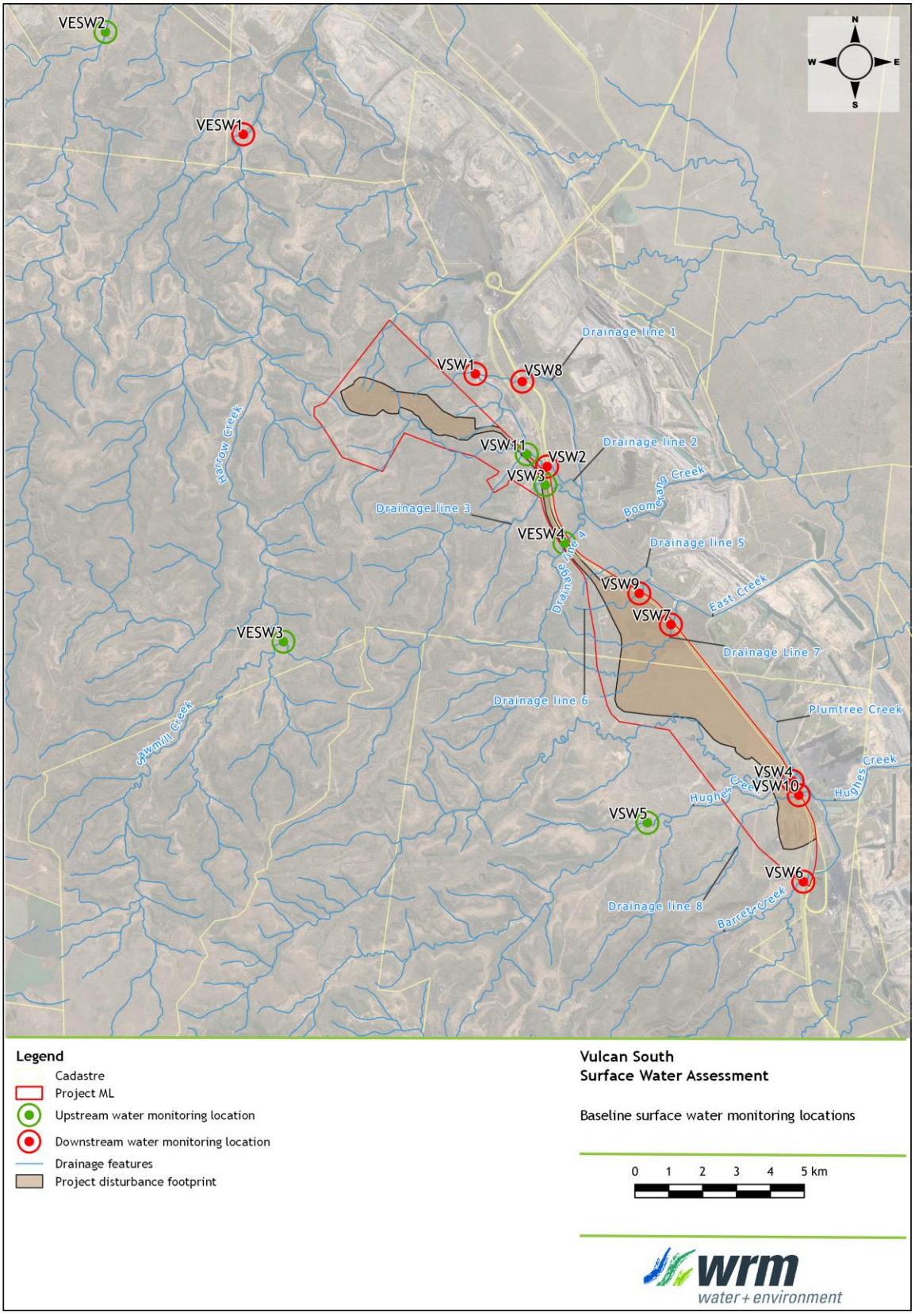


Figure 3.1 – Baseline surface water monitoring locations

Table 3.1 – 80th percentile values for the combined upstream monitoring points data set compared with the receiving water WQO default trigger values and MMC Table F3 trigger values

Parameter	Unit	Upstream monitoring points samples - 80th percentile values	WQO default trigger values (see Table 3.1 of SWA report)	MMC trigger
No. of Samples		33	-	
Physico-chemical parameters				
pH Value	-	7.49	less than 6.5 or greater than 8.5	-
Sodium Adsorption Ratio	-	1.976	-	
Electrical Conductivity	µS/cm	239	> 720 (baseflow) > 250 (high flow)	- -
Total Dissolved Solids (Calc.)	mg/L	155	> 2,000	-
Suspended Solids (SS)	mg/L	**211**	> 55	-
Turbidity	NTU	**464**	> 50	-
Dissolved Oxygen	mg/L	9.56	less than 4	-
Dissolved Metals				
Aluminium	mg/L	0.712	> 0.055	> 0.055
Arsenic	mg/L	< 0.001	> 0.024	> 0.013
Cadmium	mg/L	< 0.0001	> 0.0002	> 0.0002
Chromium	mg/L	< 0.001	> 0.001	> 0.001
Cobalt	mg/L	0.0016	-	> 0.09
Copper	mg/L	0.002	> 0.0014	> 0.002
Lead	mg/L	< 0.001	> 0.0034	> 0.004
Manganese	mg/L	0.0892	> 1.9	> 1.9
Molybdenum	mg/L	< 0.001	> 0.034	> 0.034
Nickel	mg/L	0.003	> 0.011	> 0.011
Selenium	mg/L	< 0.01	> 0.011	> 0.01
Silver	mg/L	< 0.001	-	> 0.001
Uranium	mg/L	< 0.001	> 0.1	> 0.001
Vanadium	mg/L	< 0.01	> 0.5	> 0.01
Zinc	mg/L	0.01	> 0.008	> 0.008
Boron	mg/L	0.056	> 0.37	> 0.37
Iron	mg/L	0.636	-	> 0.3
Mercury	mg/L	< 0.0001	> 0.0006	> 0.0002
Total Metals				
Aluminium	mg/L	12.52	> 5	-
Arsenic	mg/L	0.003	> 0.5	-
Cadmium	mg/L	< 0.0001	> 0.01	-

Parameter	Unit	Upstream monitoring points samples - 80th percentile values	WQO default trigger values (see Table 3.1 of SWA report)	MMC trigger
Chromium	mg/L	0.009	> 1	-
Cobalt	mg/L	0.0076	> 0.1	-
Copper	mg/L	0.012	> 1	-
Lead	mg/L	0.011	> 0.1	-
Manganese	mg/L	0.2816	> 10	-
Molybdenum	mg/L	< 0.001	> 0.05	-
Nickel	mg/L	0.011	> 1	-
Selenium	mg/L	< 0.01	> 0.02	-
Silver	mg/L	< 0.001	-	-
Uranium	mg/L	< 0.001	-	-
Vanadium	mg/L	0.02	-	-
Zinc	mg/L	0.035	> 5	-
Boron	mg/L	0.06	> 5	-
Iron	mg/L	12.5	> 10	-
Mercury	mg/L	< 0.0001	> 0.002	
Major cations and anions				-
Total Hardness as CaCO3	mg/L	38.6	> 150	> 150
Hydroxide Alkalinity as CaCO3	mg/L	< 1.0	-	-
Carbonate Alkalinity as CaCO3	mg/L	< 1.0	-	-
Bicarbonate Alkalinity as CaCO3	mg/L	43.4	-	-
Total Alkalinity as CaCO3	mg/L	43.4	-	-
Sulphate as SO4 - Turbidimetric	mg/L	19.0	> 770	-
Chloride	mg/L	34.6	-	-
Calcium	mg/L	7.6	-	-
Magnesium	mg/L	5.6	-	
Sodium	mg/L	23.6	> 30	-
Potassium	mg/L	7.0	-	-
Fluoride	mg/L	< 0.2	> 2	> 2
Ammonia as N	mg/L	0.396	> 0.02	> 0.9
Nitrite as N	mg/L	< 0.01	-	-
Nitrate as N	mg/L	0.372	> 2.4	> 1.1
Nitrite + Nitrate as N	mg/L	0.476	-	-
Total Kjeldahl Nitrogen as N	mg/L	2.0	-	-
Total Nitrogen as N	mg/L	3.12	-	-

Parameter	Unit	Upstream monitoring points samples - 80th percentile values	WQO default trigger values (see Table 3.1 of SWA report)	MMC trigger
Total Phosphorus as P	mg/L	0.266	-	-
Reactive Phosphorus as P	mg/L	< 0.01	> 0.02	-
Total Anions	meq/L	2.012	-	-
Total Cations	meq/L	2.332	-	-
Ionic Balance	%	7.162	-	-
Hydrocarbons				-
C6 - C10 Fraction	µg/L	< 20	-	> 20
>C10 - C40 Fraction (sum)	µg/L	118	-	> 100
Biological				
Chlorophyll a	mg/m³	5.0	-	-

Notes:
The critical parameter value of the upstream monitoring points samples, WQO default trigger values and the MMC trigger have been shaded in grey.
The ">" symbol indicates an exceedance of a trigger will occur if greater than the trigger value.
The "<" symbol indicates a value that is below the limit of reporting.
Bold/underline indicates the parameter is included as a receiving waters trigger value in the current Vulcan Coal Mine EA. It is proposed to adopt these parameters for the Vulcan South EA.
MMC: Model Mine Conditions ESR/2016/1936 (DES, 2017).
WQO: Relevant Water Quality Objective from Table 3.1 of WRM (2022).

3.2 RECOMMENDED RECEIVING WATERS TRIGGER VALUES

Table 3.2 shows the recommended receiving waters parameters and their trigger values for Vulcan South based on the results presented in Section 3.1. The receiving waters parameters adopted by the current Vulcan Coal Mine EA are proposed for the Vulcan South EA. Updated trigger values for locally derived parameters have been proposed based on the updated review of baseline water quality data. The recommended receiving waters trigger values for all other parameters are based either on the Project WQO, MMC default guideline value or the approved Vulcan Coal Mine EA values.

The summary of the recommended receiving water trigger values to be adopted for the Vulcan South EA include:

- Adopt the 80th percentile values given in Table 3.2 as locally derived trigger values for Filtered Aluminium, total suspended solids, and turbidity. Further monitoring of receiving waters should be continued to update these values;
- Adopt the WQO default trigger values in Table 3.1 of the Vulcan South SWA report (WRM, 2022) for pH, Electrical Conductivity, dissolved oxygen and Filtered Arsenic;
- Adopt the MMC (DES, 2017) default trigger values for Filtered Lead, Filtered Molybdenum, Filtered Selenium, and Filtered Mercury; and
- Adopt the Sulphate trigger value of 770 mg/L based on 95% species protection from Dunlop et al. (2016).

Table 3.2 – Proposed sediment dam release and receiving waters quality trigger values

Parameter	Sediment Dam release point trigger value	Downstream monitoring point trigger value	Source	Frequency
pH (pH units)	6.5 - 8.5	6.5 - 8.5	WQO (aquatic ecosystem)	Upon commencement (the first sample must be taken within 2 hours of commencement of release), daily during release, and within 2 hours after cessation of release.
Electrical Conductivity (µS/cm)	Low Flow[1] <864 Medium Flow[2] <600 High Flow[3] <300	Low Flow[1] <720 Medium Flow[2] <500 High Flow[3] <250	Vulcan Coal Mine EA	
Total suspended solids (mg/L)[4]	253	211	Locally derived	
Turbidity (NTU)[4]	557	464	Locally derived	
Dissolved oxygen	64% - 132% saturation	80% - 110% saturation	WQO (aquatic ecosystem)	
Sulphate (mg/L)	924	770	Dunlop et al. (2016)	
Filtered metals and metalloids				
Filtered Lead (µg/L)	4.8	4.0	MMC (aquatic ecosystem)	Upon commencement (the first sample must be taken within 2 hours of commencement of release), daily during release, and within 2 hours after cessation of release.
Filtered Mercury (µg/L)	0.72	0.6	WQO (aquatic ecosystem)	
Filtered Arsenic (µg/L)	28.8	24.0	WQO (aquatic ecosystem)	
Filtered Aluminium (µg/L)	859	716	Locally derived	
Filtered Molybdenum (µg/L)	40.8	34.0	WQO (aquatic ecosystem)	
Filtered Selenium (µg/L)	13.2	11.0	WQO (aquatic ecosystem)	

1 = Less than 0.5 m^3/s.
2 = (> 0.5 – 5.0 m^3/s).
3 = > 5.0 m^3/s where 10 m^3/s is the maximum release rate in a high flow event.
4 = Interim dam release point trigger values for total suspended solids and turbidity can be exceeded for water discharged from the sediment dam during uncontrolled releases during a heavy rainfall event over and above the sediment dam's design storage capacity.
Note: Above flow rates to be recorded at downstream monitoring points where catchments are disturbed by Project operations.

3.3 RECEIVING WATER QUALITY MONITORING

The DES information request had requested sediment dam release water trigger values for the Project to confirm that surface water runoff is of a suitable water quality to be managed by sediment control structures in accordance with an Erosion and Sediment Control Plan. It is recommended that the Vulcan South EA adopt the values shown in Table 3.2 which are 20% higher than the adopted receiving waters trigger values. It is noted that for most cases, these values would be below the maximum value recorded at the upstream monitoring point locations. This would allow for some dilution with receiving waters upstream of the receiving waters monitoring location. The adopted values can continue to be refined as additional water quality testing is undertaken to better define the surface runoff characteristics from the Project.

It is recommended that water samples be taken at the spillway or pipe outlet during sediment dam release events. It is also recommended that any conditioning of sediment dam water quality be related to the receiving waters water quality sample results. If it is found that sediment dam releases consistently exceed the sediment dam release water trigger values at the same time that the receiving waters water trigger values are exceeded, it is recommended

that an investigation into the exceedances be trigger by EA conditions. Conditions should also require the results of the investigation and associated mitigation and management measures to be reported to the administering authority.

The mitigation measures that are implemented should be undertaken with the aim of preventing these exceedances from reoccurring. This may include investigating the potential source of poorer quality water and/or dewatering runoff from the affected catchment area to the mine water system until the contamination source can be identified and remediated. Exceedance of sediment dam triggers should not trigger the requirement for a sediment dam to be converted to a mine affected water dam.

3.4 DISSOLVED INORGANIC NITROGEN

Dissolved inorganic nitrogen (DIN) loads were assessed using the baseline surface water quality samples to support the aim of reducing end-of-basin fine-sediment and DIN loads. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018) provides guideline values for DIN based on findings within *Updating nitrate toxicity effects on freshwater aquatic species* (C.W. Hickey, 2013). Table 3.3 provides the Guideline concentration for Nitrate-N, derived using the ANZECC methodology and the updated species database. It should be noted that the guideline values presented are for Nitrate as N values which make up only part of calculated DIN loads.

DIN loads are calculated as the sum of Ammonia as N, Nitrite as N and Nitrate as N. Vitrinite also samples monitoring points located at the sediment dams currently approved for the Vulcan Coal Mine. The sediment dam samples represent the indicative water quality data for any potential releases to receiving waters for the Project. Table 3.4 shows the comparison of 80th percentile values for upstream monitoring point locations and sediment dam DIN loads to the guideline Nitrate as N value.

The comparison shows that the 80th percentile values for the upstream monitoring point and the sediment dam samples, DIN concentrations are below the threshold guideline nitrate concentration value for 95% protection. As such, in the event of an uncontrolled release from sediment dams, DIN concentrations on site are likely to have negligible impact and result in ‘no net decline’ in water quality.

In an event where DIN loads contained in sediment dams on site exceed the guideline value, it is recommended that water is pumped to the mine water dam system and an investigation into the cause for exceedance of the guideline value is undertaken. Any mitigation or management measures as a result of the investigation should be implemented and reported to the administering authority.

Table 3.3 – Guideline derivations for Nitrate-N, grading guidelines are based on species NOEC values and Surveillance guideline threshold effect concentration (TEC) values.

Guideline type	Grading Nitrate concentration (mg NO3-N /L)	Surveillance Nitrate concentration (mg NO3-N /L)	Description of Management Class
Chronic – high conservation value systems (99% protection)	1.0	1.5	Pristine environment with high biodiversity and conservation values.
Chronic – slightly to moderately disturbed systems (95% protection)	**2.4**	**3.5**	**Environments which are subject to a range of disturbances from human activities, but with minor effects**
Chronic – highly disturbed systems (90% protection)	3.8	5.6	Environments which have naturally seasonally elevated concentrations for significant periods of the year (1-3 months).
Chronic – highly disturbed systems (80% protection)	6.9	9.8	Environment which are measurably degraded and which have seasonally elevated concentrations for significant periods of the year (1-3 months).
Acute	20	30	Environments which are significantly degraded. Probable chronic effects on multiple species
Method of comparison	Annual median	Annual 95th percentile	-

Note: Bold indicates default guideline values applicable to most waters (C.W. Hickey, 2013)

Table 3.4 – Comparison of Nitrate as N guideline value to dissolved inorganic nitrogen surface water quality data

Parameter	Unit	80th percentile at upstream monitoring point	80th percentile site samples from sediment dams	Guideline value of Nitrate as N (C.W. Hickey, 2013)
Ammonia as N	mg/L	0.396	0.26	-
Nitrate as N	mg/L	0.372	1.71	2.40
Nitrite plus Nitrate as N	mg/L	0.476	1.71	-
Dissolved inorganic nitrogen	mg/L	1.146	1.82	-

4 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 (2000).
ANZG, 2018	*'Australian and New Zealand Guidelines for Fresh and Marine Water Quality'*, Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia, Available at www.waterquality.gov.au/anz-guidelines
C. W. Hickey, 2013	*'Updating nitrate toxicity effects on freshwater aquatic species'*, C. W. Hickey, National Institute of Water & Atmospheric Research Ltd, prepared for Ministry of Building, Innovation and Employment, January 2013.
DES, 2017	*'Guideline Model Mining Conditions'*, ESR/2016/1936, Version 6.02, Effective 07 March 2017.
Dunlop et al., 2016	*'Toxicity guideline values for sulphate in hard waters'*, Australiasian Bulletin of Ecotoxicology & Environmental Chemistry, Volume 3, 2016, pp. 1-10.
IECA, 2008	*'Best Practice Erosion and Sediment Control Guideline'*, International Erosion Control Association (IECA), November 2008.
RGS, 2022	*'01_2022014_Geochemical Assessment of Waste Rock, Coal Reject and Coal_Rev 01'*, prepared for METServe by RGS Environmental Consultants Pty Ltd, March 2022.
WRM, 2022	*'Vulcan South Surface Water Assessment'*, report prepared for Vitrinite Pty Ltd by WRM Water & Environment, May 2022.

Appendix A - WRM responses to DES information request

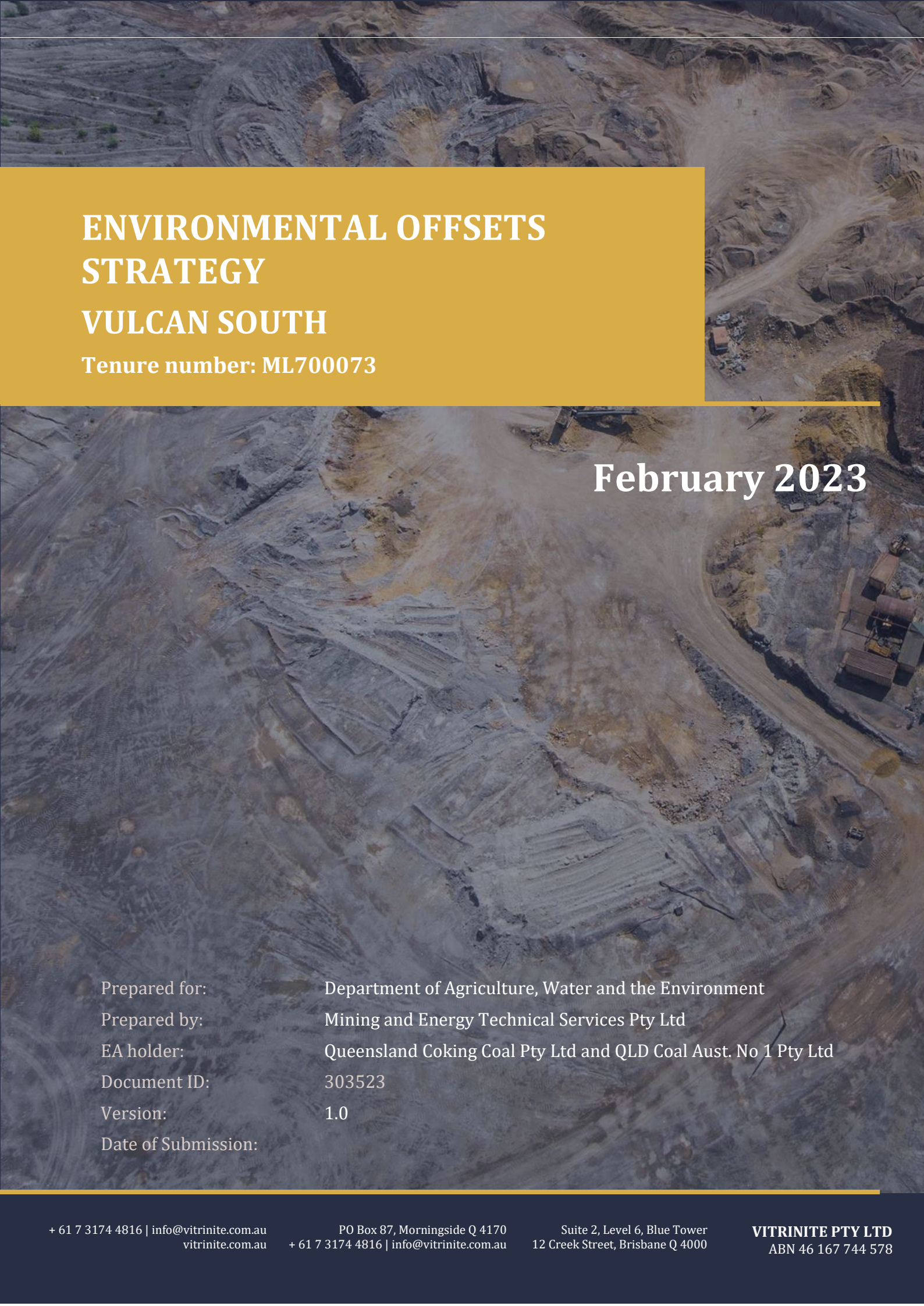
Table A.1: WRM responses to DES information request relating to Surface Water Management

Item	Relevant document section	Comment	Requirement	Response
1.8	**Section 5.3 Water management strategy overview**	Appendix A, section 5.3 contends that 'surface water' (i.e. non-mine affected water [MAW]) should include surface water run-off that has come into contact with areas disturbed by mining operations including out-of-pit waste rock emplacements. Additionally, it is argued that whilst this surface water may have a high sediment load, it will remain compliant with water quality objectives (WQOs). The department notes that the applicant proposes to manage this surface water via sediment removal at sediment dams prior to any release. However, additional evidence is required to support the determination that any surface water released will be compliant with the WQOs for the receiving waters. The applicant must demonstrate that this water can be managed appropriately and will not cause environmental harm to the receiving environment if released. Further, it is unclear how areas disturbed by mining operations could be effectively managed to prevent the contamination of surface water with coal, carbonaceous material or other contaminants. Coal and carbonaceous material would likely be present on haul road surfaces, laydowns and the exposed surfaces of out-of-pit waste rock dump.	(a) Provide additional details, including maps of the 'areas disturbed by mining operations' proposed to produce 'surface water' as opposed to MAW. (b) Provide additional evidence to support the proposed management of 'surface water'. Evidence in the form of water quality monitoring data from the VCP and/or an appropriate analogous site/s is permissible. (c) Provide additional details of the management measures to be employed to prevent the contamination of surface water with coal, carbonaceous material and other contaminants. Where surface water becomes contaminated, provide additional details as to how this is proposed to be managed and monitored	(a) Section 2.1.1 of this report presents the overview of the water management strategy and separation of mine affected water and surface/diverted water catchments and Section 2.1.2 of this report presents the updated catchment and water management strategy for Stage 2 (Year 2026) of the Vulcan Main mining area. Figure 1.3 to Figure 1.13 of the SWA report (WRM, 2022), provide the proposed catchment plans for each stage of the Project. (b) Section 3 of this report provides a review of baseline monitoring data and trigger values to determine recommended receiving water trigger contaminant values for the Project. (c) Section 2.1.1 to 2.1.3 of this report presents the details of the water management strategy for the Project and additional details regarding the proposed MAW management strategy during the highwall mining stages of the Project.
1.9	Section 9.2 Reef discharge standards	Section 2.1.2.2 *Release source – waste water from the relevant activity* of the department's guideline – 'Reef discharge standards for industrial activities' (Version 1.02) [ESR/2021/5627] specifies when section 41AA of the Environmental Protection Regulation 2019 (EP Reg) applies. Assuming that surface water is justifiably determined to contain sediment only, and no coal, carbonaceous material or other contaminants, section 41AA does not apply. The department notes that nitrogen may also be relevant where blasting is carried out. However, regardless of this determination, appropriate erosion and sediment control measures will be conditioned through the pending environmental authority to prevent as much sediment as is practical from entering the Great Barrier Reef catchment waters. The applicant is advised to propose an updated Erosion and Sediment Control Plan (ESCP) that is robust and effective in minimising contributions of total suspended sediment (TSS) and dissolved inorganic nitrogen (DIN) so as to support the aim of reducing end-of-basin fine-sediment and DIN loads.	(a) Confirm potential sources of DIN for the project. (b) Update the contents and requirements of the proposed ESCP.As a minimum, the ESCP should include: (i) an assessment of the size and characteristics of all catchment areas; and (ii) an assessment of relevant properties of soils and waste materials; and (iii) identification of receiving waters environmental values, water quality objectives and management intent; and (iv) specification of minimum design criteria for erosion and sediment control structures to achieve the management intent of receiving waters; and (v) locations and descriptions of all erosion and sediment control measures; and (vi) an audit schedule to ensure erosion and sediment control measures are maintained.	(a) Section 3.4 of this report presents the water quality results from sediment dams and the downstream monitoring points of the VCM project. The results of this assessment shows that DIN values are below the 95% protection values from ANZG (2018). Potential sources of DIN associated with project would include: • naturally occurring within the formation and overburden material; • the pit area where blasting occurs. Runoff from the pit will be managed within the Mine Water System and will not be discharges offsite; and • within the onsite explosives storage facility, which will be stored in sealed containers. Notwithstanding this, significant sources of exposed DIN are not expected to be located within surface water catchments or diverted water catchments. (b) An ESCP/WMP will be developed prior to operations to address DES comments. As per Section 9.2, the ESCP will address: • the fullest separation possible of diverted, surface and mine-affected water runoff; • the diversion of upstream runoff from disturbed areas; • the stabilisation of soils in disturbed areas; and • the installation and maintenance of control measures such as sediment and erosion control devices (e.g., silt fences, swales, settling basins, energy dissipaters and vegetated buffers). The WMP will address: • description of measures that are in place to separate clean water from areas where it may collect fine sediment; • description of treatment measures to remove fine sediment from water before being released (such as settlement ponds); • modelling to demonstrate effectiveness of these measures; and • contingency measures for unforeseen storm events.
1.10	Section 7.3.10 Release Scenarios	Appendix A, section 7.3.10 includes an assessment of the effects of releases from sediment dams on the water quality of receiving waters. However, these scenarios only account for the electrical conductivity and release flow rate from sediment dams. It is unclear why TSS or other relevant WQOs have not been included in the modelled scenarios.	(a) Justify why the 'worst-case' scenario modelling for impacts to receiving waters only includes EC and flow rate; and (b) Pending the response to (a), provide additional modelling that accounts for key contaminants including TSS and heavy metals – selenium, arsenic and molybdenum.	(a) As outlined in EPP (WWB), salinity is used as the adopted indicator of water quality as it is typically the key limiting contaminant of concern for coal mines and is historically of most interest for agricultural and domestic use. (b) Other contaminants have not been modelled, however, if baseline water quality monitoring samples shows that other contaminants within runoff may be of concern, the assessment can be updated to include additional water quality parameters.

<table>
<tr><th>Item</th><th>Relevant document section</th><th>Comment</th><th>Requirement</th><th>Response</th></tr>
<tr><td>1.13</td><td>Section 5 Proposed surface water management strategy and infrastructure</td><td>The department notes that MAW will be generated in areas disturbed by highwall mining.
With reference to Appendix A, Figures 1.9 and 1.10, it is unclear how MAW will be effectively managed so as to prevent releases to the receiving environment and maintain separation of MAW from other waters such as surface run-off.
Specifically, Figures 1.9 and 1.10 do not appear to include mine water infrastructure needed to manage MAW such as mine water dams – or in place of dams – drains, sumps and/or piping for the conveyance of MAW to a suitable storage.</td><td>a) Provide additional details as to how surface water is to be managed within the extent of areas disturbed for highwall mining, with specific regard to MAW.
Clarification should include conceptual drainage plans for all years of active highwall mining before rehabilitation is completed.</td><td>(a) Section 2.1.3 of this report presents the proposed MAW management strategy for the highwall mining trial area.
The highwall mining test area will last 1 year and consist of general earthworks associated with benching, battering, haul roads and rehabilitation. Runoff from earthworks associated with these activities will be managed using erosion/sediment control structures.
As the highwall miner progresses, the plunges where coal is extracted will be buried, battered and rehabilitated. Hence, the expected active disturbance area of the highwall miner is expected to be up to a 3.2 ha area along the coal face at any given time before completed exposed coal faces are buried and rehabilitation works to surface water runoff is completed. Hence, runoff will have minimum contact with coal surfaces. In addition, the pad will be graded towards the exposed coal face so that surface runoff in the vicinity of the highwall miner will drain into the voids left behind by the highwall miner. Proposed sumps will collect any other mine affected water runoff from contamination of rehabilitated or undisturbed surface water runoff catchments. Where possible, contour banks and drop structures will divert natural catchments around the active mining area. Hence, the environmental risk of mine affected water runoff from the highwall mining test area is considered low and the proposed water management system is considered suitable.
Notwithstanding this, erosion and sediment control measures will be monitored in the vicinity of the active highwall mining areas. Mine water dams can be proposed if this is the case, and pumped out to MWDs within the main project area.</td></tr>
<tr><td>1.14</td><td>Section 5.5.1 Sediment dam locations and sizing</td><td>Appendix A, section 5.5.1 discusses the sizing and placement of sediment dams for surface water management. However, this section also explains that runoff from haul roads and access roads is to be captured by sediment basins, before being either released to the receiving environment or returned to the mine water system.
Additional justification is required to support the treatment of surface water collected from haul roads as surface water and not MAW.</td><td>(a) Provide additional details of water collected from haul roads, including whether this water will be MAW and if said water will be contaminated by coal, carbonaceous material, hydrocarbons, or other contaminants which are predicted to exceed the identified water quality objectives for release (WQOs).
(b) Should the response to (a) confirm that water is determined to be MAW, provide updated and/or additional information pertaining to:
(i) the proposed surface water management strategy and infrastructure;
(ii) updated conceptual drainage plans; and
(iii) any further updates to the supporting information necessary to ensure consistency and accuracy (i.e. water balance modelling or water management system assessment).</td><td>(a) As per Section 5.5.1 in WRM (2022), erosion control structures for the haul road will be designed to align with Best Practice Erosion and Sediment Control Guidelines (IECA, 2008) prior to operations/construction when the haul road designs and their catchments are finalised. If it is identified that monitoring of these sediments dams that capture haul road water may exceed any WQO, these can be pumped back to the Mine Affected Water system. Per the VCM EA, haul roads constructed out of coal rejects would be considered a source of MAW. Haul roads will not be constructed using coal rejects in areas that drain to a sediment dam.
(b) The highwall mining area MAW strategy will conservatively manage any runoff from the haul road in the vicinity of the active highwall mining area as MAW runoff. The MAW will be managed as discussed in Section 2.1.3 of this report to prevent contamination of surface water runoff catchments.</td></tr>
<tr><td>1.26</td><td>Section 7.3.7 Releases/overflows to the receiving waters and Section 9.3.1 Release contaminant trigger investigation levels</td><td>Appendix A contemplates the proposed release of ‘surface water’ via sediment dams.
Section 3 of Appendix A identifies the WQO trigger levels for the receiving waters. Further, section 9.3.1 of Appendix A identifies the receiving water contaminant trigger levels. The trigger levels of Table 3.1 and Table 9.3 are compared below.
<table>
<tr><th>Parameter</th><th>Table 3.1</th><th>Table 9.3</th></tr>
<tr><td>pH</td><td>6.5 – 8.5</td><td>6.5 – 8.0</td></tr>
<tr><td>EC (µS/cm)</td><td>720 (base flow)
250 (high flow)</td><td>1,500</td></tr>
<tr><td>TDS (mg/L)</td><td>< 2,000</td><td>?</td></tr>
<tr><td>TSS (mg/L)</td><td>< 55</td><td>?</td></tr>
<tr><td>Sulphate (SO_4^{2-}) (mg/L)</td><td>25</td><td>1,000</td></tr>
</table>
It is unclear how levels have been formulated to protect environmental values (EVs) and why interim trigger levels have been developed for parameters with the exception of TDS and TSS. Further, it is unclear how impacts to the receiving waters can be managed and minimised without proposed trigger limits for TDS and TSS.</td><td>(a) Provide additional details as to how the proposed levels were formulated.
(b) Provide additional details as to how the proposed levels will protect EVs of the receiving waters.
(c) Provide additional details as to the formulation of interim trigger levels for TDS and TSS – that will protect the EVs of the receiving waters.</td><td>(a) Trigger values presented in Section 3 are default WQOs set based on regional values. Revision will be made to the baseline WQOs using the monitoring point sample data collected over recent flow events. The new WQOs will be set in accordance with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality guidelines (ANZG, 2018) for deriving site-specific guideline value (SSGVs) for aquatic ecosystems protection from local reference data.
Since the completion of the VS Surface Water Assessment, the VCM EA has assigned trigger values for dams release points and receiving waters. In addition, locally derived trigger values have been developed based on baseline surface water monitoring data for VCM and VS. On this basis, Table 3.2 will be adopted for the VS for consistency across the sites.
(b) Section 3.2 of this report presents the recommended trigger values proposed to identify any potential to affect water quality of receiving waters which are derived from local reference data at upstream (undisturbed/natural catchments) for comparison to reference monitoring points downstream of the Project disturbance area.
(c) Section 3.2 of this report presents the trigger values of receiving water quality which were formulated initially by adopting 20% above the recommended trigger values These would be less than the maximum values recorded at reference monitoring locations and these can be re-evaluated if sediment dam releases exceed these triggers.</td></tr>
</table>

Item	Relevant document section	Comment	Requirement	Response
1.27	Section 9.5 Sediment dam monitoring	Section 9.5 of Appendix A states that sediment dams will be monitored for a suite of water quality parameters. (i.e. pH, EC, major anions [sulphate, chloride and alkalinity], major cations [sodium, calcium, magnesium and potassium], TDS and a broad suite of soluble metals/metalloids). However, it is unclear if parameters will include those which are necessary to determine 'surface water' reporting to sediment dams is not MAW and is otherwise suitable for release. Specifically, parameters to be confirmed include: • Dissolved inorganic nitrogen (DIN); • Turbidity (NTU); • TSS; • Total Petroleum Hydrocarbons (TPH); and • Any other proposed parameters required to verify 'surface water' is not MAW.	(a) Provide additional details as to the parameters to be monitored for at sediment dams.	(a) Section 3.2 and Table 3.2 of this report presents the suite of water quality parameters to be monitored within sediment dams including pH, EC, TSS, NTU, Dissolved Oxygen, Sulphate and various metals including lead, mercury, arsenic, aluminium, molybdenum and selenium. Section 3.4 and Table 3.3 of this report presents the guideline values of DIN, which will also be monitored within sediment dams Mine water dams are proposed to capture mine affected runoff via proposed mine water drains. The proposed sediment dams are to capture surface water runoff via proposed surface water drains to ensure separation from any mine affected water. Per our response to 1.26, It is recommended that the parameters and trigger values in Table 3.2 for dam releases be adopted for the VS for consistency with the Vulcan Coal Mine.

Appendix J – Offsets Strategy



ENVIRONMENTAL OFFSETS STRATEGY

VULCAN SOUTH

Tenure number: ML700073

February 2023

Prepared for:	Department of Agriculture, Water and the Environment
Prepared by:	Mining and Energy Technical Services Pty Ltd
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1 Introduction

Vulcan South is an open-cut and highwall coal-mining operation proposed by Vitrinite Pty Ltd between Dysart and Moranbah, in the Bowen Basin of Queensland. It is located on lots 2SP296877, 59SP235297, 72SP137467, 26CNS125 and 2CNS109, and within mining lease ML700073 (**Figure 1-1**). Due to significant residual impacts of Vulcan South on matters of national environmental significance (MNES), the project is being referred to the Department of Climate Change, Energy, the Environment and Water (DCCEEW) for assessment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). It is anticipated that Vulcan South will be considered a controlled action by DCCEEW and environmental offsets will be required to ensure the project does not result in a net loss to any MNES.

To achieve these environmental offsets, Vitrinite Pty Ltd intends to procure, protect and restore areas of land that support the matters that will be impacted by Vulcan South. Identification of suitable land to achieve these goals is still in progress, so a draft Offset Area Management Plan (OAMP) cannot yet be developed. Instead, Vitrinite Pty Ltd has developed this Environmental Offsets Strategy to articulate and commit to a process that will be undertaken to identify and assess suitable offset sites, and to prepare a draft OAMP for approval prior to the commencement of any disturbance resulting from the amendment.

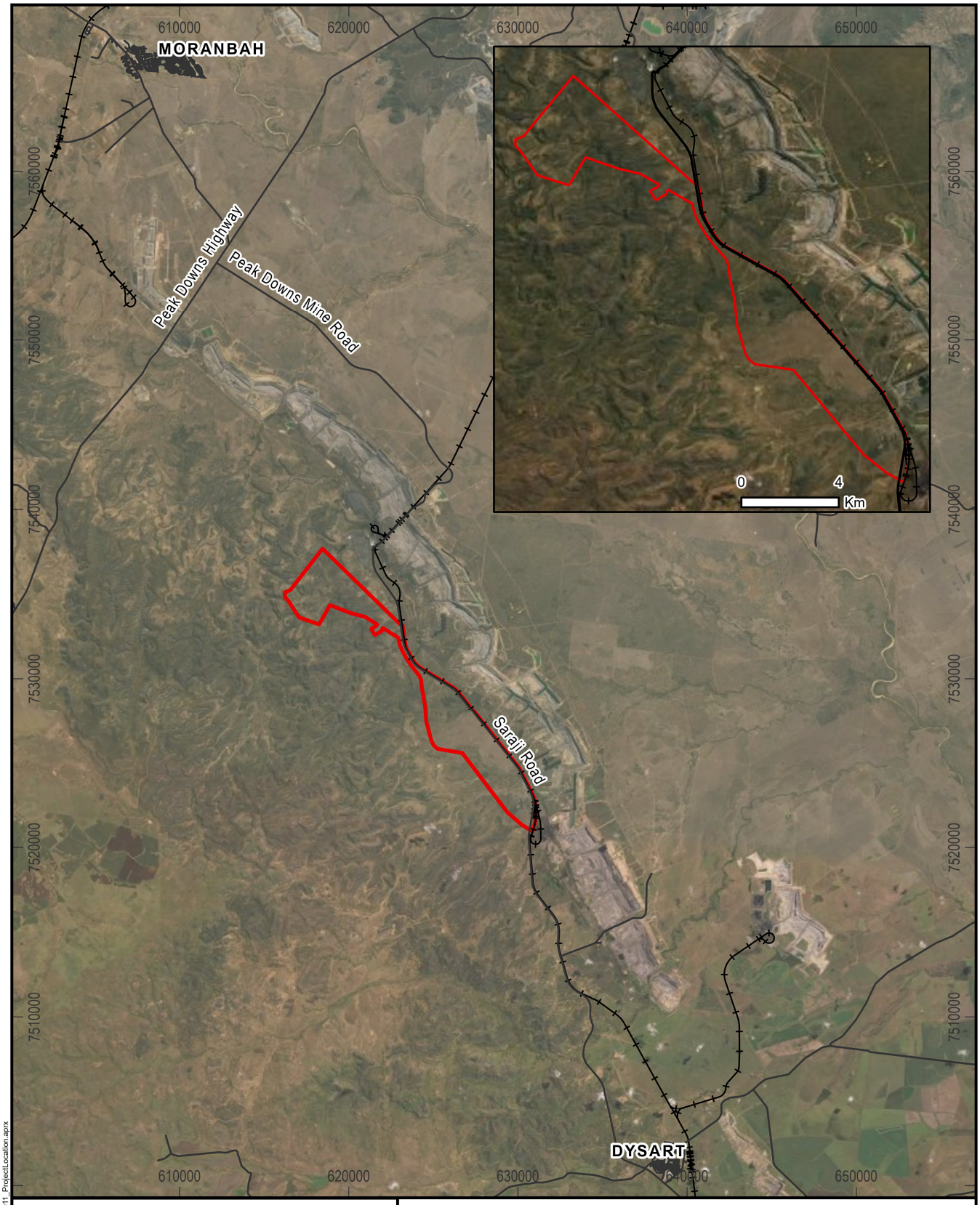
1.1 Commonwealth Government Requirements

MNES are protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Significant impacts to MNES must be compensated through the delivery of environmental offsets in accordance with the *EPBC Act Environmental Offsets Policy* (Department of Sustainability, Environment, Water, Population and Communities 2012). This policy states that an environmental offset must "deliver an overall conservation outcome that improves or maintains the viability of the protected matter as compared to what is likely to have occurred under the status quo".

The Offsets Assessment Guide, an Excel spreadsheet-based calculator, was developed by the Commonwealth Government to assist in the determination of suitable offsets. When assessing impacts of the neighbouring Vulcan Coal Mine (referral 2020/8676), the Commonwealth Government requested that, "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the *Queensland Guide to Determining Terrestrial Habitat Quality".*

The Species Profile and Threats (SPRAT) database provides ecological information about species and ecological communities listed under the EPBC Act, and impact assessments and offset designs are to consider this information.

Approval for a project under the EPBC Act requires that environmental offsets and the associated Offset Area Management Plan (OAMP) are approved by the Minister for the Environment, and legally secured, prior to the commencement of any disturbance to MNES.



Legend

- Road
- Railway
- Mine Lease Application Area

Source: State of Queensland (Department of Resources) 2019-2022, Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Project Location

0 3 6 12

Kilometers

Scale: 1:325,000 (A4)

14/02/2022

Datum: GDA20
Projection: MGA55

FIGURE 1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

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1.2 Queensland Government Requirements

Significant impacts to prescribed environmental matters must be offset in accordance with the *Environmental Offsets Regulation 2014*. Prescribed environmental matters include MNES protected by the EPBC Act, as well as some matters of state and local environmental significance. Matters of state environmental significance that are prescribed environmental matters are listed in Schedule 2 of the *Environmental Offsets Regulation 2014.* This regulation also prescribes the *Queensland Environmental Offsets Policy version 1.9*, which clarifies how environmental offsets should be delivered in Queensland.

As stated in section 1.1.3 of the *Queensland Environmental Offsets Policy version 1.9*, state governments can only impose an offset condition in relation to a prescribed activity if the same or substantially the same impact and the same or substantially the same matter has not been subject to assessment under a Commonwealth Act. Offsets are therefore only required under the Queensland framework in the following two instances:

- when the prescribed environmental matters that experience significant residual impacts are not MNES; and/or
- when the Commonwealth Government decided that the activity was not a controlled action, yet residual impacts to a matter of both state and national environmental significance qualify as significant under Queensland definitions (as defined within the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline*: DEHP 2014).

Some "Of Concern" and watercourse vegetation to be disturbed by Vulcan South are matters of state environmental significance that are not also MNES. Likewise, the impact of Vulcan South on connectivity is a state matter. These will require environmental offsets under the Queensland framework separate to the federal offsets addressed by this Environmental Offsets Strategy.

1.3 Location

1.3.1 Impact Area

Vulcan South lies within the Brigalow Belt Bioregion. Most of the mining lease is located within the Northern Bowen Basin subregion, although the clay plains in the centre of the lease are contained within the Isaac-Comet Downs subregion.

Vulcan South falls within the local government area of the Isaac Regional Council. It lies adjacent to Saraji Road, midway between Moranbah and Dysart. The land tenure is leasehold and has historically been used primarily for cattle grazing. The project area is bounded to the north and east by proposed and existing coal mining operations and existing transport infrastructure (Saraji Road and the Goonyella railway line) run along the eastern edge of the mining lease, within the lease.

The ML 700073 permit application created for Vulcan South covers an area of approximately 3,824 hectares (ha).

1.3.2 Suitable Offset Location

As stated within the *EPBC Act Environmental Offsets Policy*, "*in most cases* [a suitable location for an offset site] *will be as close to the impact site as possible. However, if it can be shown that a greater conservation benefit for the impacted protected matter can be achieved by providing an offset further away, then this will be considered*."

Not only must suitable offset areas be located near the impact area, but the tenure of this land is important, as this affects the risk that habitat will be lost in the future without the additional protection afforded by offsets. Offsets are only suitable for areas of land that are not fully protected from clearing by other laws or legal instruments.

Even though remnant vegetation is protected in Queensland as category B regulated vegetation under the *Vegetation Management Act 1999* (VM Act), a small amount of clearing occurs annually through exempt

works and illegal activities. The rate of clearing differs between tenure types (**Table 1-1**). Of the dominant land tenures in Queensland, background clearing rates of remnant vegetation are highest on freehold land, followed by leasehold. These tenures therefore stand to benefit most from the additional protection afforded by offsets. These patterns are reversed for regrowth vegetation; category C and X vegetation under the VM Act has a two to three times higher risk of clearing on leasehold than freehold land (**Table 1-2**).

Offset areas containing large amounts of non-remnant vegetation (category C, R and X vegetation under the VM Act) stand to benefit most from protection, as such vegetation is less fully protected (category C and R) or not protected (category X) under the VM Act, and experience high rates of re-clearing to maintain open landscapes for agriculture. Category C vegetation has, on average, twice the risk of clearing as remnant vegetation (category B), while category X vegetation has, on average, four times the risk (**Table 1-2**).

Table 1-1 *Clearing rates of remnant vegetation per tenure type in the Brigalow Belt Bioregion since the introduction of the* Vegetation Management Act 1999

Tenure	Percent of remnant vegetation that was cleared between 1999 and 2019*					
	Land Zone					Total
	3: Alluvial	4: Clay Plain	5: Sand Plain	9: Siltstone	10: Sandstone	
Freehold	9.40%	18.26%	17.71%	9.52%	6.75%	11.56%
Leasehold	7.02%	14.86%	16.11%	9.05%	4.48%	8.01%
State Forest	0.38%	0.16%	0.18%	0.82%	0.36%	0.30%
National Park	0.00%	0.04%	0.26%	0.18%	0.03%	0.05%

*Values represent the average of the Brigalow Belt Bioregion since the enactment of the *Vegetation Management Act 1999*, as reported by Accad *et al.* (2022).

Table 1-2 *Clearing rates of all vegetation types within the Brigalow Belt Bioregion between 2015 and 2018*

Land zone	Class under the VM Act*	Percent of vegetation class that was cleared between 2015 and 2018†	
		Freehold	Leasehold
3: Alluvial	Category B: Remnant vegetation	1.40%	1.38%
	Category C: High-value regrowth	0.53%	1.61%
	Category X: No protection	1.46%	3.00%
5: Sand Plain	Category B: Remnant vegetation	1.45%	1.16%
	Category C: High-value regrowth	0.62%	2.69%
	Category X: No protection	4.79%	5.08%
10: Sandstone	Category B: Remnant vegetation	1.27%	0.65%
	Category C: High-value regrowth	1.57%	6.08%
	Category X: No protection	4.34%	7.92%

*Category R regulated vegetation (regrowth along watercourses) was not recognised under the VM Act during the period of data collection, so is not included.

†Data was calculated by overlaying the Statewide Landcover and Trees Study (SLATS) clearing data for the periods 2015-2016 and 2016-2017 with version 10 of regional ecosystem mapping, and SLATS data for 2017-2018 with version 11 of regional ecosystem mapping. This ensured that the clearing data corresponded with the vegetation present at the start of each period. This analysis will be repeated for other land zones and to include the latest year of SLATS data, to inform the baseline risk of loss at prospective offset sites.

A suitable offset area for Vulcan South is one that:

- is located within Isaac Regional Council area, the Northern Bowen Basin subregion or Isaac-Comet Downs subregion. If no suitable offset area can be located within these areas, an alternate location will be chosen that lies within the northern half of the Brigalow Belt Bioregion;
- has freehold or leasehold tenure; and
- contains some areas with category C and X vegetation under the VM Act.

1.4 Matters Requiring Offsets

A Terrestrial Ecological Assessment (METServe 2022) has examined the environmental values in and near the project area. The significance of impacts of Vulcan South on MNES was assessed against the *Matters of National Environmental Significance Significant Impact Guidelines 1.1* (Department of the Environment, Water, Heritage and the Arts 2013) within the EPBC Act referral documentation accompanying this Environmental Offsets Strategy. This assessment determined that the following listed threatened species and ecological communities are likely to experience significant residual impacts as a result of Vulcan South:

- Koala (combined populations of Queensland, NSW and the ACT), *Phascolarctos cinereus* (endangered);
- Squatter Pigeon (southern subspecies), *Geophaps scripta scripta* (vulnerable);
- Central Greater Glider, *Petauroides armillatus* (endangered); and
- Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community.

Negligible residual impacts to other MNES are anticipated.

The three species listed above are also listed as endangered and vulnerable respectively under the *Nature Conservation Act 1992*, while the regional ecosystems that comprise the Brigalow ecological community are listed as endangered under the *Vegetation Management Act 1999.* If Vulcan South is not considered a controlled action under the EPBC Act, offsets may be required within the Queensland framework. As offsets for the same matters and impacts will be a likely condition of approval under the EPBC Act, there are no additional requirements under Queensland legislation regarding offsets for these three species.

The size of impacts to each matter depends on the amount and quality of habitat for each species that will be disturbed/removed. How quality will be assessed is discussed in **Section 3** of this Environmental Offsets Strategy. The "matter area" for each habitat type is the area that contains or represents the extent of an individual prescribed environmental matter. Matter areas typically comprise a fraction of the total disturbance footprint, and matter areas pertaining to different matters or habitat types can partly or fully overlap. Matter areas are the impact footprints identified in the Terrestrial Ecological Assessment (METServe 2022). The area and location of each matter area is shown on **Table 1-3, Figure 1-2** and **Figure 1-3**.

Vulcan South has a life of nine years, although the duration of impacts (time until habitat has been effectively restored on the rehabilitated mined land) is expected to be 23 years for the Koala, Central Greater Glider and Squatter Pigeon (refer to the referral for details). The Progressive Rehabilitation and Closure Plan (PRCP) for Vulcan South includes rehabilitation completion criteria reflecting habitat for the Koala, Greater Glider and Squatter Pigeon.

Table 1-3 Size of matter areas within the impact site

Prescribed Matter		Size of Matter Area (ha)
Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community		120.3
Koala		1,023.6
Central Greater Glider		71.1
Squatter Pigeon:	Foraging Habitat	671.2
	Breeding Habitat*	426.8
	Dispersal Habitat	692.9

*All breeding habitat for the Squatter Pigeon overlaps with foraging habitat

Squatter Pigeon
Breeding Habitat

Squatter Pigeon
Foraging Habitat

Squatter Pigeon
Dispersal Habitat

Legend

- MLA Area
- Impact Site
- Matter Area

Source: Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Squatter Pigeon Matter Areas

0 1 2

Kilometers

Scale: 1:62,000 (A3)

18/08/2022

Datum: GDA2020
Projection: MGA55

FIGURE 1-2

VITRINITE
BRIGHTER COAL

METSERVE
Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Offset_Strategy\VI011_VS_OffsetStrategy_MatterAreas.aprx

Brigalow Threatened Ecological Community

Koala Habitat

Greater Glider Habitat

Legend

- MLA Area
- Impact Site
- Matter Area

Source: Vitrinite 2022, METServe 2022, Earthstar Geographics.

Vulcan South

Matter Areas for Brigalow, the Koala and the Greater Glider

0 1 2

Kilometers

Scale: 1:62,000 (A3)

18/08/2022

Datum: GDA2020
Projection: MGA55

FIGURE 1-3

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\V011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Offset_Strategy\V011_VS_OffsetStrategy_MatterAreas.aprx

2 Habitat Needs of Listed Species

The Offsets Assessment Guide requires evidence-based habitat quality scores for the impact and offset areas. Habitat quality is to consider site condition, site context and species stocking rates, but no federal guidelines or manuals exist that prescribe how habitat quality is to be assessed. During assessment for the neighbouring Vulcan Coal Mine, the Commonwealth Government requested that, "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the Queensland *Guide to Determining Terrestrial Habitat Quality*". A similar approach will be taken to assess habitat quality of the footprint of Vulcan South.

The *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a) recommends undertaking a comprehensive literature review of the species to identify the factors that constitute, and have the ability to affect, the following components of habitat quality:

- Quality and availability of food and habitat required for foraging;
- Quality and availability of habitat required for shelter and breeding;
- Quality and availability of habitat required for mobility; and
- Exposure to threats.

The following subsections summarise key habitat requirements of the Koala, Central Greater Glider and Squatter Pigeon.

2.1 Koala

Koala populations within Queensland, New South Wales and the Australian Capital Territory are listed as endangered under the EPBC Act as of February 2022. Koalas were recorded 11 times within the project area, and three times in areas immediately west in a survey conducted in February 2019. There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the SPRAT profile for the species (DCCEEW 2022a).

2.1.1 Habitat Requirements

On the western slopes, tablelands and plains in Queensland, Koalas are found in sub-humid *Eucalyptus*-dominated forests and woodlands in riparian and non-riparian environments, and some *Acacia*-dominated forests and woodlands in non-riparian environments (DCCEEW 2022a). The main habitat requirement is availability of suitable food trees and, to a lesser extent, shelter trees, which tend to have shadier foliage, be taller and/or be located in sheltered locations in gullies (Crowther *et al.* 2013).

Food

While Koalas have been observed sitting in or eating up to 120 species of eucalypt (Phillips 1990), the diet of individual Koalas is usually limited to one or a few species (Moore and Foley 2000). Preferences also vary between regions or seasons (Moore and Foley 2000). Chemical anti-feedants, soil nutrients and leaf water content in semi-arid areas may limit or prevent koalas feeding on foliage of individual trees even when the species is considered preferred (Lawler *et al.* 1998; Moore *et al.* 2005). In the northwest of their range in Queensland (including the project area), Koala distribution is limited by heat and water availability, with the highest densities of Koalas occurring along creek lines (Munks *et al.* 1996; Sullivan *et al.* 2003). Variability in leaf nutrition creates patchiness such that species-based assessments of habitat likely overestimate the availability of high-quality habitat (Threatened Species Scientific Committee 2012).

Despite limitations in habitat mapping caused by varying leaf nutrition, a conservative approach to habitat mapping is appropriate, which assumes that any individuals of tree species known to be eaten by Koalas could constitute a potential food tree. Likewise, the SPRAT profile defines Koala habitat as "any forest or woodland containing species that are known Koala food trees, or shrubland with emergent food trees"

(DCCEEW 2022a). These vegetation types need not be defined as remnant vegetation to be used extensively by Koalas (Barth *et al.* 2019). Assessment of habitat quality for Koalas therefore relies on the identification of local preferences for species and the quantification of the availability of those species (DCCEEW 2022a).

The Australian Koala Foundation (2015) maintains a database that lists seven food species used by Koalas within the Isaac Regional Council area. *Eucalyptus camaldulensis* and *Eucalyptus tereticornis* are considered to be the primary food trees. Secondary food trees include *Eucalyptus brownii*, *Eucalyptus coolabah*, *Eucalyptus ochrophloia*, *Eucalyptus orgadophila* and *Eucalyptus populnea*. Of these species, *E. camaldulensis, E. populnea* and *E. orgadophila* are found within the impact area.

The Australian Koala Foundation (2015) acknowledges that *Eucalyptus crebra* can sometimes constitute an additional secondary food species in localised areas with better soils and nutrient availability. Given that this tree species is eaten by Koalas at nearby sites (Ellis *et al.* 2002; Melzer *et al.* 2014), it is conservatively considered a food tree for the purposes of habitat mapping. This species is widespread across the impact area and surrounding region, being a dominant component of most of the ecosystems occurring on site. Given the low fertility of local sandy soils, it is unlikely that most local *E. crebra* is utilised to a significant extent by Koalas. Nevertheless, in accordance with the SPRAT definition of Koala habitat (i.e., any forest or woodland containing species that are known Koala food trees), vegetation containing *E. crebra* is included as potential habitat.

In addition to tree species, tree size is an important factor affecting the quality of foraging habitat (e.g., Callaghan *et al.* 2011; Smith *et al.* 2013), presumably because larger trees possess a greater quantity of food, and individuals feeding in large trees do not need to move between different food trees as often. Trees with a trunk diameter at 1.3 m height of >10 cm are used by Koalas, but trees with a diameter >30 cm are used to a significantly greater extent (Callaghan *et al.* 2011).

Both the quantity and quality of potential food affect Koalas. Directly measuring the amount of food available to Koalas within a habitat patch is onerous and destructive (usually involves the felling and measurement of leaf biomass of whole trees: Burrows *et al*. 2000). However, studies of *E. crebra* and *E. populnea* elsewhere in central Queensland have shown that trunk circumference is highly correlated to leaf biomass in these species (Burrows *et al.* 2000), as it is for other tree species (Catchpole and Wheeler 1992). Furthermore, the relationship is remarkably congruent between eucalypt species (Burrows *et al*. 2000), suggesting that measuring trunk basal areas of food trees within a habitat patch (a simple and widely used technique for assessing vegetation structure) is a valid proxy for the total quantity of food available to Koalas in an area.

The quality of available food is reflected by the proportion of trees that are primary food trees—a strong predictor of Koala presence elsewhere in Queensland (McAlpine *et al.* 2006)—and the density of "large" food trees (as defined by Department of Science, Information Technology, Innovation and the Arts (2015) in the *BioCondition Assessment Manual version 2.2*).

Shelter

Koalas often select non-food trees in which to shelter during the day, especially during hot weather. Shelter trees tend to have shadier foliage, be taller and/or be located in sheltered locations in gullies (Crowther *et al.* 2013). However, the minimum height or shadiness for a tree to be considered a shelter tree has not been published. Definitions of shelter trees (for the purposes of habitat quality assessment) have been developed based on available data, which are discussed below.

The *Queensland Environmental Offsets Policy* considers non-juvenile Koala habitat trees to be those with a height greater than 4 m or a trunk diameter (1.3 m above ground) greater than 10 cm (Department of Environment and Science 2020b). This broadly accords with the findings of Callaghan *et al.* (2011), who found utilisation of trees with a diameter as small as 10-20 cm. However, White (1999) found that trees with a diameter less than 15.5 cm were rarely utilised.

Shelter trees are known to be larger than food trees (Crowther *et al.* 2013; Callaghan *et al.* 2011; Marsh *et al.* 2014), and defining these based on larger minimum sizes is appropriate. Marsh *et al.* (2014) found that shelter trees have trunk diameters that are, on average, 55% larger than feeding trees. Trunk diameter has a roughly linear relationship with tree height for most *Eucalyptus* species (particularly young trees), such that a doubling of diameter is associated with a doubling in height (Bernardo *et al.* 1998). Based on this limited data, for the purposes of habitat assessment at Vulcan South, a potential Koala shelter tree is at least 6 m tall.

Non-food trees used for shelter tend to have dense crowns that cast heavy shade (Ellis *et al.* 2010; Crowther *et al.* 2013). Based on estimates of the typical canopy density of non-food species known to be used by Koalas (e.g., *Casuarina* spp., *Callitris* spp., *Brachychiton populneus, Acacia harpophylla, Endiandra sieberi, Melaleuca* spp.: Ellis *et al.* 2010; Callaghan *et al.* 2011; Crowther *et al.* 2013), shelter trees are defined as having a minimum foliage projective cover of 75%. Given that Koalas prefer to shelter in the largest trees, an abundance of "large" non-food trees (as defined by Department of Science, Information Technology, Innovation and the Arts (2015) in the *BioCondition Assessment Manual version 2.2* is likely to be an additional indicator of the existence of favourable shelter sites.

In addition to the presence of specific trees with physical characteristics that make them valuable as Koala shelter sites during the day, the overall vegetation density reflects a measure of protection, as it is negatively proportional to the distance Koalas must move across the ground (when highly vulnerable to predation) between trees.

Mobility

Koalas have extensively overlapping home ranges. These vary in size from 10-30 ha in coastal areas of New South Wales (Lassau *et al.* 2008) to 100-135 ha at Blair Athol in central Queensland (Ellis *et al.* 2002). Home ranges in the impact and offset areas are likely to be similar in size to that recorded at Blair Athol, given the proximity.

Koalas move an average of 50 m during a single night, and habitat patches separated by gaps narrower than 50 m represent effectively connected habitat units (Rus *et al.* 2020). In fragmented rural landscapes of subcoastal south-eastern Queensland, telemetry records that were at least 30 days apart showed that 50% of movements were between 200 and 500 m, a further 35% were between 500 m and 1 km, and the remainder were less than 5 km (White 1999). This study revealed home ranges up to 94.1 ha in size (White 1999), which are comparable to findings at Blair Athol, suggesting that these movements are likely to be representative of the Vulcan South region. In rural south-eastern Queensland, White (1999) found that Koalas regularly moved between habitat patches separated by up to 2 km of cleared paddocks, such that the spatial configuration and inter-patch distance was of minor importance compared with the total area of habitat. However, in a mixed urban-rural landscape at Noosa, a landscape with more numerous, smaller patches is less likely to be occupied than one with fewer, larger patches (McAlpine *et al.* 2006). This is consistent with a higher risk from domestic dogs and vehicles to dispersing Koalas in urban environments. At Noosa, the amount of forest within 1 km was one of the strongest predictors of habitat use by Koalas (McAlpine *et al.* 2006). Habitat patch size had a moderately positive effect on occupation by Koalas, while forest patch density, mean nearest neighbour distance and road density all had moderate negative effects on the probability of koala occurrence (McAlpine *et al.* 2006).

Dispersing individuals can occasionally cover distances of several kilometres over land with little vegetation; however, this places them at higher risk of predation. The average distance between natal and breeding home ranges is 3.5 km, although maximum dispersal distances of 9-16 km have been recorded (DCCEEW 2022a; White 1999).

In light of the above information, the main factor that affects the ability of Koalas to move within rural landscapes is the existence of large (>2 km) treeless areas through which Koalas are reluctant to move and are vulnerable to predation if they do. Smaller habitat gaps are unlikely to constitute a significant barrier to movement.

Threats

The chief threats to the Koala are habitat clearing, vehicle strike, predation by domestic and feral dogs, drought and disease (DCCEEW 2022a). In rural areas of Queensland with low densities of human habitation (such as the impact site), habitat clearing and drought are the principal threats, with vehicle strikes and dog attacks being localised threats (near roads and human habitation, respectively).

The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

In rural landscapes on the Sunshine Coast, Queensland, McAlpine *et al.* (2006) found that the density of sealed roads within 1 km was a predictor of Koala presence. Given that a home range of 100 ha (a reasonable expectation at Vulcan South: refer to **Mobility**) has an average diameter of 1.1 km, roads located within 1 km of a nominated location are likely to represent a threat to Koalas inhabiting that location.

The density of dogs is relatively low in sparsely populated areas, such as the impact site, but may be high in potential offset sites if these are located near human habitation. Wild-roaming dogs have home ranges of 10 km^2 to 272 km^2 (radius of 1.8 km to 9.3 km) (Robley *et al.* 2010; McNeill *et al.* 2016). This implies that any site within 18 km of human habitation (or other sources of supplementary food, such as dumps, mine camps, etc) could have elevated dog densities as a result of access to this nearby food. Distance from supplementary food and the existence of current control programs are the principal factors dictating risk from dog attack in rural Queensland. In some parts of southeast Queensland, attacks from wild dogs and dingos are the leading cause of Koala mortality (Beyer *et al.* 2017).

The prevalence of disease in local Koala populations is unknown, but this threat is likely to vary little geographically (*Chlamydia* is thought to be present in all Koala populations on the mainland of the eastern states: DCCEEW 2022a) and little can be done to manage this threat at offset sites. It is therefore not considered important when assessing variation in threat level between different habitat patches.

Drought is an important threat to Koalas in semi-arid regions such as the impact site. Droughts lead to widespread mortality, and the regional persistence of Koalas exposed to regular drought may rely on the protection of refugial habitats around waterholes and creeks, where high leaf moisture levels are maintained during drought (Gordon *et al*. 1988; DCCEEW 2022a). Koalas obtain most of their dietary water from foliage but need to drink in extreme climatic conditions (Mella *et al.* 2019). Proximity to water is therefore important during drought, both as a source of drinking water and because nearby trees have leaves with higher moisture content.

Droughts are forecast to become increasingly frequent and severe with climate change. CSIRO's (2021) Climate Analogues Tool forecasts Moranbah's climate to be analogous to that of Hughenden, QLD by 2050. Hughenden is currently the western limit for the distribution of Koalas, where they are confined to the vicinity of watercourses (Melzer *et al.* 2014). Habitat modelling by Adams-Hosking *et al*. (2011) supports the notion that the Moranbah region will represent the western limit of the species' distribution by 2050 and will be uninhabitable by 2070. If Koalas are to persist locally in the face of climate change, riparian vegetation and access to permanent surface water will become increasingly important.

2.2 Squatter Pigeon

The southern subspecies of the Squatter Pigeon is listed as vulnerable under the EPBC Act. This species was recorded widely within the project's ML and in surrounding areas. There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (Threatened Species Scientific Committee 2015) and the SPRAT profile for the species (DCCEEW 2022b).

2.2.1 Habitat Requirements

The Squatter Pigeon is a ground-dwelling bird that inhabits the grassy understorey of open eucalypt woodland, and less often savannas. It also inhabits altered landscapes such as improved pastures, beside railway lines and around settlements (Threatened Species Scientific Committee 2015). It often occurs in burnt areas and is sometimes found on tracks and roadsides (Threatened Species Scientific Committee 2015a). It is nearly always found near permanent water such as rivers, creeks and waterholes (Threatened Species Scientific Committee 2015). Sandy areas dissected by gravel ridges, which have open and short grass cover, allowing easy movement, are preferred (Threatened Species Scientific Committee 2015). It is less commonly found on heavier soils with dense grass (Threatened Species Scientific Committee 2015).

Provided land is not overgrazed, Squatter Pigeons coexist readily with cattle grazing; however, the species has largely disappeared from the southern part of its distribution (e.g., New South Wales and southern Queensland), where sheep grazing is widespread and rabbit densities are high (Threatened Species Scientific Committee 2015).

Food

The SPRAT profile defines foraging habitat for the Squatter Pigeon as remnant or regrowth open-forest to sparse, open-woodland or scrub dominated by *Eucalyptus*, *Corymbia*, *Acacia* or *Callitris* species, on sandy or gravelly soils (Queensland land zones 5 and 7), within 3 km of a suitable, permanent or seasonal waterbody (DCCEEW 2022b).

Squatter Pigeons feed on seeds among sparse and low grass (Threatened Species Scientific Committee 2015). Typically, the ground-covering vegetation layer in foraging habitat is considerably patchy, consisting of native, perennial tussock grasses or a mix of perennial tussock grasses and low shrubs or forbs. This patchy, ground layer of vegetation rarely exceeds 33% of the ground area (DCCEEW 2022b). The remaining ground surface consisting of bare patches of gravelly or dusty soil and areas lightly covered in leaf litter and coarse, woody debris. Excessive densities of ground layer vegetation and/or litter reduce the quality of foraging habitat by impeding movement or obscuring fallen seed.

A wide diversity of different seeds are eaten by Squatter Pigeons, with plants in the families Fabaceae (peas) and Poaceae (grasses) being the most important (Crome 1976). Both native and introduced species are consumed, with exotic pasture legumes (especially *Stylosanthes* spp.) comprising 30% of the diet in northern Queensland (Crome 1976). Favourable habitats are those where a broad diversity of grasses and forbs grow in the understorey, providing a year-round supply of seed.

Squatter Pigeons drink at least once a day, and prefer to drink where there is gently sloping, bare ground on which to approach and stand at the water's edge (DCCEEW 2022b). Such habitat may occur in permanent or seasonal rivers, creeks, lakes, ponds, waterholes and artificial dams (DCCEEW 2022b). Squatter Pigeons have also been recorded drinking from raised cattle troughs (Adani and GHD 2015).

Shelter and Nesting

The Squatter Pigeon nests on the ground, usually laying two eggs among or under vegetation (Threatened Species Scientific Committee 2015). Breeding habitat occurs on rises occurring on sandy or gravelly soils, within 1 km of a suitable, permanent waterbody (DCCEEW 2022b). The structure of the vegetation in favourable breeding habitat is as described for foraging habitat.

When disturbed, Squatter Pigeons flush from the ground and land in nearby trees. A minimum density of woody vegetation appears to be required for shelter from predators. DCCEEW (2022b) suggests that a maximum spacing of 100 m between standing trees is required to meet the protective needs of Squatter Pigeons; however, this assertion is not based on any publicly available data.

METServe (2020) used an extensive set of local Squatter Pigeon records (60 individuals recorded in 28 one-hectare cells) to identify minimum woody vegetation density in habitats known to support Squatter Pigeons. The Normalised Difference Vegetation Index (NDVI), as measured during the late dry season,

when woody vegetation comprises the sole source of greenness in the landscape, was used as a measure of woody vegetation density. This analysis identified habitat as providing sufficient cover for Squatter Pigeons when the NDVI exceeds 0.125. This corresponds to an approximate spacing of 60 m between large trees or 25 m between smaller shrubs.

Mobility

The size of the average home range of a pair of Squatter Pigeons is not known, but the related Partridge Pigeon (*Geophaps smithii*) is thought to occupy a home range of approximately 8 ha (Fraser *et al.* 2003).

Squatter Pigeons are largely sedentary where permanent water is available but may be locally nomadic if food or water becomes seasonally unavailable (DCCEEW 2022b).

Squatter Pigeons are able to disperse through a wide range of woodland and forest habitats that are unsuitable for feeding or nesting, including those on clay soils, with excessively dense grass cover, or with dense leaf litter instead of bare ground (DCCEEW 2022b). Any habitats with trees closer than 100 m apart are likely to facilitate movement through the landscape (DCCEEW 2022b). Likewise, cleared areas less than 100 m wide constitute dispersal habitat.

No published studies have examined the dispersal ability of Squatter Pigeons or characterised movement barriers. Given their ability to fly, there are likely to be few significant barriers to dispersal, although extensive treeless areas possibly discourage movement.

Threats

Current threats to the Squatter Pigeon include habitat loss and fragmentation, habitat degradation from overgrazing, invasive weeds such as Buffel Grass (*Cenchrus ciliaris*), and introduced predators (DCCEEW 2022b).

The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

The threat posed to Squatter Pigeons by introduced predators has not been quantified by any studies. The species is eaten by native snakes and other birds, as well as the introduced Dingo (*Canis lupus dingo*), Red Fox (*Vulpes vulpes*) and Feral Cat (*Felis catus*) (DCCEEW 2022b), but the relative importance of each predator is unknown. Foxes and cats are thought to be the principal threats (DCCEEW 2022b), although no data exist to confirm this. The threat posed by these individual predators is further complicated by interactions between them; Dingoes moderate populations of foxes (Johnson and VanDerWal 2009; Letnic *et al.* 2010) and to a lesser extent cats (Allen *et al.* 2014), while foxes also influence cat foraging behaviour (Molsher *et al.* 2017), such that controlling one predator may inadvertently elevate the risks posed by others. The threat posed by predators (e.g. foxes and cats) is likely to be fairly consistent within any one region, except where elevated in the vicinity of urban areas, dumps or other sources of supplementary food supplies for predators. Studies elsewhere suggest that cats typically roam within a radius of up to 1.3 to 2.6 km (Edwards *et al.* 2001; Metsers *et al.* 2010; Bengsen *et al.* 2012), while dogs generally roam within a radius of up to 9.3 km (Robley *et al.* 2010). This implies that elevated predation pressure can be expected within 18 km of a supplementary food source.

Provided land is not overgrazed, Squatter Pigeons coexist readily with cattle grazing; however, the species has largely disappeared from the southern part of its distribution (e.g., New South Wales and southern Queensland), where sheep grazing is widespread and rabbit densities are high (Threatened Species Scientific Committee 2015a). A moderate amount of land modification probably benefits the species, reflected by long-term population increases (between 1934 and 1999) in grazing properties elsewhere in the Brigalow Belt (Woinarski and Catterall 2004). This is also supported by data comparing undisturbed woodlands near Townsville with areas disturbed by grazing or military activities; the latter two land uses supported ten times more Squatter Pigeons (Woinarski and Ash 2002). These patterns are likely to stem from moderate to light grazing by cattle creating favourable open patches of ground for foraging by

Squatter Pigeons. Cattle grazing, in itself, is therefore unlikely to represent an important direct threat to Squatter Pigeons in the Isaac region. Rather, overgrazing affects Squatter Pigeons indirectly via a reduction of grass cover, reducing food supply and protective cover. As the quality of foraging habitat is already assessed in habitat quality assessments, no additional assessment of the threat of "grazing" was deemed necessary.

Density of Buffel Grass is one attribute that varies widely across small scales and, along with habitat loss through clearing, underlies most of the spatial variation in threat level posed to Squatter Pigeons in the Isaac region. Density of Buffel Grass varies widely according to soil type and management history. Invasion by Buffel Grass displaces native species and leads to a reduced diversity of forbs and grasses (Fairfax and Fensham 2000; Franks 2002; Marshall *et al.* 2012). Buffel Grass also forms tall, dense swards that impede the movement and foraging of Squatter Pigeons.

2.3 Central Greater Glider

The Greater Glider (*Petauroides volans*) is listed as endangered under the EPBC Act. Recent studies have suggested that this taxon comprises three genetically distinct species, with the Central Greater Glider (P. *armillatus*) being present in the survey area (McGregor *et al*. 2020). Its taxonomy under the EPBC Act is yet to be revised in accordance with this recent study. Central Greater Gliders were widely recorded within the ML (METServe 2022). There is no recovery plan in place for the species. However, the Commonwealth Government has provided advice about the species' ecology and priority actions to mitigate key threats within the conservation advice (DCCEEW 2022c). Further information about the species' ecology is provided by Eyre *et al.* (2022), in a report commissioned by the Commonwealth Government titled *Guide to Greater Glider Habitat in Queensland.*

2.3.1 Habitat Requirements

The Central Greater Glider typically inhabits tall forests dominated by large, hollow eucalypts (DCCEEW 2022c). Water availability limits populations near the western edge of the species' distribution, such as at Vulcan South (Kearney *et al.* 2010). Local populations are largely restricted to riparian environments, where large, hollow trees are most abundant, and subsoil moisture allows suitable food trees to grow fresh leaves over extended periods of the year.

Food

The Central Greater Glider is primarily folivorous, with a diet consisting of eucalypt leaves and occasional flowers (DCCEEW 2022c). Central Greater Gliders forage on a wide range of *Eucalyptus* and *Corymbia* species, and individuals feed on 1–11 individual trees of 1–6 different species in a single night (Kehl and Borsboom 1984).

Certain tree species contribute the bulk of the diet in any one area (Foley *et al.* 1990; Comport *et al.* 1996). Young foliage is preferred (Comport *et al.* 1996), and dietary preferences vary seasonally, according to which tree species has new growth.

Corymbia citriodora and *Eucalyptus tereticornis* are the most important food species for Central Greater Gliders in southern Queensland, although a large number of other species have been recorded in their diet (Eyre *et al.* 2022). Local tree species known to be eaten by Central Greater Gliders include *Corymbia tessellaris, Eucalyptus crebra* and *Eucalyptus melanophloia. Eucalyptus camaldulensis*, *Corymbia clarksoniana*, *Corymbia trachyphloia* and *Eucalyptus exserta* are also utilised in an unspecified context (food or dens) (Eyre *et al.* 2022). Trunk circumference is highly correlated to leaf biomass in local eucalypts (Burrows *et al.* 2000) and is a valid proxy for the total quantity of food available to Greater Gliders in an area.

Central Greater Gliders preferentially feed in trees with a trunk diameter (at 1.3 m height) larger than 30 cm, although trees as small as 20 cm are occasionally used for foraging (Eyre *et al.* 2022).

Shelter and Nesting

Central Greater Gliders shelter during the day in dens within the hollow branches of live or dead trees. Hollow availability is the habitat feature most likely to limit the distribution of Central Greater Gliders (Andrews *et al.* 1994). Hollow openings greater than 8 cm in diameter are suitable for denning, with trees greater than 50 cm in trunk diameter commonly supporting such hollows (Eyre 2005). Tree trunks wider than 50 cm also provide sufficient buffering and refuge against high daytime temperatures (Kearney *et al.* 2010). Each glider requires at least 2-4 large, hollow-bearing trees within its home range of 1-4 ha in order to inhabit an area of forest (Comport *et al.* 1996).

As a consequence of the high variability and low reliability in determining hollows in trees from the ground, hollow-bearing trees is no longer an assessable attribute in BioCondition assessments in Queensland or New South Wales and has been replaced by a 'large tree' attribute which is determined by a direct measure of tree diameter (Eyre *et al.* 2022). Density of 'large trees' is a more accurate reflection of hollow availability than direct estimates of hollow abundance made from the ground (Eyre *et al.* 2022). What constitutes a 'large tree' varies according to tree species and ecosystem, as different species are variably sensitive to hollow formation. In most of Queensland, 'large trees' are those that exceed 50 cm diameter, while in the Brigalow Belt, 'large trees' exceed 46 cm diameter on average (Eyre *et al.* 2022).

Mobility

Queensland populations of greater gliders (various species) have average home ranges of 5.8 ha and 2.9 ha of males and females, respectively (Eyre *et al.* 2022). The largest home ranges (19.3 ha) have been recorded in the Brigalow Belt bioregion (Smith *et al.* 2007). Home range size is largely determined by hollow density and forest productivity.

Due to their small home ranges and sedentary lifestyle, greater gliders can persist in favourable habitat patches of a remarkably small size, provided the surrounding matrix contains woody vegetation (e.g., regrowth, pine plantations, or burnt forest: Taylor *et al.* 2007; Eyre *et al.* 2022) through which they can disperse. Possingham *et al.* (1994) suggests an average dispersal distance of 8 km to access habitat patches within a matrix of native regrowth, while Taylor and Goldingay (2009) suggest dispersal distances of 1–7 km. Small habitat patches located 1 km from contiguous forest and surrounded by pine plantations had equally high genetic diversity as the source population (Taylor *et al.* 2007), suggesting greater gliders readily disperse through treed landscapes. No published studies have examined the ability of Central Greater Gliders to disperse across treeless expanses. Of greater gliders marked and released during tree felling for forestry operations, half moved less than 0.5 km, while the remainder moved 0.8–2.8 km through the fallen timber to other areas of native forest (Taylor *et al.* 2007). Even small gaps created by major roads (~50 m wide) likely constitute important barriers to dispersal (Taylor and Goldingay 2009).

All gliding possums are limited in their movement by the maximum gliding distance between successive trees. They are thought to be highly sensitive to habitat fragmentation and easily isolated by gaps in their habitat, as they do not readily cross open ground (Jackson 2000; Eyre *et al.* 2022). Other species of gliders (Mahogany Glider, Sugar Glider and Yellow-bellied Glider) achieve a glide angle of 28–31˚, which corresponds to a distance of 1.8–1.9 m per 1 m loss in altitude (Jackson 2000). However, Wakefield (1970) suggests a glide angle of only 40˚ for the greater glider, corresponding to a distance of 1.2 m per 1 m loss in altitude. This suggests that gaps between trees should not exceed the height of those trees, in order to facilitate movement and dispersal. Greater gliders are at high risk of mortality (by feral predators) when they come to ground (Eyre 2005).

Threats

DCCEEW (2022c) identified habitat clearance for agriculture and forestry, fires and climate change as the three most severe threats to all species/populations of the greater glider. Hyper-predation by Powerful Owls can also have moderate localised impacts, although this native predator is largely absent from the Brigalow Belt. The threat of habitat loss through clearing is accounted for in the Offset Assessment Guide calculator independently of habitat quality. Consequently, only those threats that contribute to habitat quality scores are discussed further.

High-intensity fires in Victorian Mountain Ash (*Eucalyptus regnans*) and Alpine Ash (*Eucalyptus delegatensis*) forest during 2009 resulted in a drastic reduction in canopy cover and hollow availability (measured four years after the fires), and the localised extinction of Southern Greater Gliders (*Petauroides volans*) (Berry *et al.* 2015). Studies of wet and dry sclerophyll forests in the Southern Tablelands of New South Wales, which burnt extensively in the mega-fires of 2019-2020, revealed a similar pattern; greater gliders were able to persist at sites that experience low-intensity fire (where the canopy did not burn), but mostly vanished from sites where fires burnt the canopy (May-Stubbles *et al.* 2022). The effects of fires were still evident (burnt sites had half the population density of unburnt sites) after ten years in warm temperate eucalypt forests in north-eastern New South Wales (McLean *et al.* 2018). The Southern Greater Glider not only responds negatively to fire severity at the site level, but also negatively to the amount of forest burned in the surrounding landscape (Lindenmayer *et al.* 2013), presumably a reflection of the extent of local fire refuges. Gullies tend to experience lower fire intensities and may therefore act as fire refuges (Berry *et al.* 2015). Australia-wide, 29% of greater glider (all species) habitat burned in the 2019–2020 mega-fires (Ashman *et al.* 2021).

No studies have examined the impact of fires on Central Greater Gliders in Queensland. The threat posed by fire in Queensland is likely to be much lower than that experienced by gliders in New South Wales and Victoria. Queensland's summer rainfall and less rugged terrain generally produce fires of smaller scale and lower intensity than the devastating bushfires that occur in temperate regions of the country. Most of central Queensland is subject to infrequent to frequent low-intensity grass fires, rather than the shrub and canopy fires that can occur in tall, temperate forests (Murphy *et al.* 2013). During the 2019-2020 mega-fire season, 11.4 % of greater glider habitat in Victoria and New South Wales experienced fires of a "very high" severity, while only 2.7 % of glider habitat in Queensland experienced the same class of fire (Ashman *et al.* 2021). Nevertheless, climate change is worsening fire conditions throughout Australia, including in Queensland (Clarke and Smith 2012).

Climate change is not only expected to impact Central Greater Gliders indirectly (through increasing intensity and frequency of fires), but also directly, through heat stress and drought. Greater gliders are known to be sensitive to temperatures higher than 20°C (Rübsamen *et al.* 1984). Higher temperatures are associated with panting and intense licking of the belly and extremities to facilitate evaporative cooling (Rübsamen *et al.* 1984). Such behaviour is associated with substantial water loss. Greater gliders are thought to obtain their entire water requirements from foliar water content, dew and rain on foliage and water trapped in tree hollows (Kearney *et al.* 2010). Reproduction (milk production) is limited in the northern and inland parts of the species' distribution by water availability (Kearney *et al.* 2010). Increasing temperatures have already been implicated in the contraction of greater glider populations near Sydney towards high altitudes (Smith and Smith 2018). A similar contraction has been observed across Victoria, where aridity and extreme weather conditions, such as number of nights warmer than 20°C, were highly significant predictors of Southern Greater Glider occurrence (Wagner *et al.* 2020). Given that the Bowen Basin lies at the drier, western limit of the species' current distribution, drought and heat stress are likely to be major threats to local populations. In light of the above information, drought is considered a relatively more important risk to Central Greater Gliders in central Queensland than fire, and this is taken into account when developing habitat quality scores (**Section 3.1.5**).

Drought refuges are of great importance to the local persistence of Central Greater Gliders in central Queensland. Drought refuges include areas buffered from climatic extremes due to higher altitudes or protected aspects (shaded gorges and south-facing slopes), as well as forests that maintain a year-round, high foliar water content by accessing groundwater or permanent watercourses. Groundwater-dependent ecosystems and riparian vegetation also tend to support the largest trees in most local landscapes. A study at Townsville found that hollows with larger entrances, hollows highest on trees and hollows in the largest trees (by trunk diameter) had the coolest daytime temperatures, and were favoured by possums (Isaac *et al.* 2008).

3 Habitat Quality

A robust assessment of habitat quality within the impact and proposed offset areas is necessary for confirming the appropriateness of offsets for three reasons:

- The *Offsets Assessment Guide* requires evidence-based quality scores for the impact and offset areas, in order for the Commonwealth Government to assess the offset proposal.
- Improvement in habitat quality over time is one of two means by which conservation gains can be achieved via offsets (the other is via increased levels of habitat protection), and the assessment of baseline habitat quality and improvements over time are important for monitoring the success of offsets.
- In accordance with section 7.1 of the *EPBC Act Environmental Offsets Policy*, an offset area must possess, as a minimum, the quality of the habitat at the impact site, or be managed and resourced over a defined period of time so that its habitat quality is improved to meet the quality of habitat originally impacted.

In its document titled *How to Use the Offset Assessment Guide*, the Australian Government recommends that habitat quality is to consider site condition, site context and species stocking rates, with the weighting given to each component being dependent on the ecological requirements of the impacted species. In response to EPBC referral 2020/8676 (the neighbouring Vulcan Coal Mine), the Australian Government requested that "to inform the inputs of the Offsets Assessment Guide… [quality is to be assessed] using the Queensland *Guide to Determining Terrestrial Habitat Quality*".

The following subsections explain how habitat quality will be assessed within the Vulcan South impact area, and within potential offset areas. The approach adopts methodology prescribed by the *Guide to Determining Terrestrial Habitat Quality.* These scores are weighted and combined to generate a single overall score of habitat quality for each species within the impact (or offset) area.

3.1 Methodology for Assessing Habitat Quality

3.1.1 Assessment Guidelines

The methodology to be adopted when undertaking habitat quality assessments with regard to environmental offsets in Queensland is prescribed by the *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a). The Australian Government recommended that this guideline was used to inform habitat quality inputs in the *Offsets Assessment Guide* for the neighbouring Vulcan Coal Mine, and the same approach will be used for Vulcan South.

This guideline proposes two methodologies for assessing habitat quality:

- BioCondition assessments conducted in accordance with the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015); and
- Specially tailored, species-specific habitat quality scores developed by considering the foraging, breeding, sheltering and dispersal requirements of each species, along with local threat levels.

The former provides a general assessment of the overall state of the vegetation community. BioCondition assesses both site-specific habitat quality attributes, as well as landscape-scale attributes such as connectivity, size of habitat patch and regional context. The site-specific component of BioCondition is broadly analogous to the "site condition" score suggested within *How to Use the Offset Assessment Guide.* The landscape-scale component is broadly analogous to "site context" score. Meanwhile, the species-specific habitat quality scores indirectly reflects the potential stocking rate of the listed species that the habitat is able to support, by specifically targeting habitat features that are likely to be limiting local populations.

3.1.2 Sampling Design

The impact and offset sites are to be assessed using identical methodology and sampling designs. Each will be assessed using the sampling design framework described by the *Guide to determining terrestrial habitat quality version 1.3*. This defines a 'matter area' for each prescribed environmental matter requiring offsets as the area that contains or represents the extent of an individual prescribed environmental matter. The matter areas for the impact site are described in **Section 1.4.** A habitat quality score will be assigned to each separate matter area within the impact and offset sites.

Matter areas will be divided into assessment units. An assessment unit is a defined area or group of areas of at least 1 ha in total size within the matter area that is relatively homogenous in that it contains only one regional ecosystem type that is of a reasonably consistent broad condition state (i.e., remnant, high-value regrowth or non-remnant). Assessment units should also consider variation that exists within each broad condition state. For example, non-remnant pastures can have no woody vegetation or dense, young regrowth.

The assessment units assigned to the impact site will be based upon field-verified regional ecosystem mapping undertaken as part of the Terrestrial Ecological Assessment (METServe 2022). Within each regional ecosystem, the high-value regrowth and remnant broad condition states are expected to be sufficiently homogenous and should not warrant further division of these assessment units. However, the non-remnant broad condition state is expected to vary from completely disturbed sealed roads and railway lines to thinned forest with a mostly native pasture and scattered young trees. Hence, non-remnant states will be divided into three condition classes: non-habitat (existing sealed roads, railways, buildings and car parks), highly disturbed habitat (extensively cleared pasture that no longer qualifies as woody vegetation due to the canopy cover being less than 5%) and moderately disturbed habitat (woody vegetation is present with >5% canopy cover, but doesn't meet the definition of high-value regrowth or remnants).

Field assessments of condition are not considered necessary for the highly disturbed class of non-remnant land, as this is not considered part of any matter area.

Sampling will cover the entire footprint of the impact site, and habitat scores for each of the prescribed matters will be based on the relative proportions of the different assessment units within each respective matter area.

Each assessment unit will be surveyed at multiple sampling sites. The number of sampling sites per assessment unit is based on the density suggested by the *Guide to determining terrestrial habitat quality version 1.3* (**Table 3-1**). 19 assessment units are contained within the Vulcan South impact site, requiring 51 sampling sites (**Table 3-2**). Sampling sites will be selected at random prior to arriving at the sites, in order to avoid biases in their placement and ensure that they were representative of their respective assessment unit.

Table 3-1 Recommended number of sampling sites per assessment unit

Assessment unit size	Number of sampling sites
1-50 ha	At least two
50-100 ha	Three
100-500 ha	Four
500-1,000 ha	Five
More than 1,000 ha	Six

Table 3-2 Assessment units within the impact site

Assessment Unit	Description	Area (ha)	$N_{sampling\ locations}$
AU1	Remnant 11.3.2	12.4	2
AU2	Remnant 11.3.7	4.1	2
AU3	Remnant 11.3.25	21.3	2
AU4	Remnant 11.4.8	114.9	4
AU5	Remnant 11.4.9	1.3	2
AU6	Remnant 11.5.3	20.6	2
AU7	Remnant 11.5.9	282.9	4
AU8	Remnant 11.9.2	227.7	4
AU9	Remnant 11.10.1	47.9	2
AU10	Remnant 11.10.1x1	73.9	3
AU11	Remnant 11.10.3	182.3	4
AU12	Remnant 11.10.7	38.1	2
AU13	Regrowth 11.4.8	4.0	2
AU14	Regrowth 11.5.3	43.6	2
AU15	Regrowth 11.5.9	3.8	2
AU16	Regrowth 11.10.3	30.1	2
AU17	Regrowth 11.10.7	5.4	2
AU18	Woody (>5% canopy cover) non-remnant	296.9	4
AU19	Non-woody (<5% canopy cover) non-remnant	301.4	4
n/a	Vegetation absent	44.2	0
	Total	**1,756.7**	**51**

North

South

Legend

- Sampling Site
- MLA Area
- Impact Site

Assessment Units

- AU1
- AU2
- AU3
- AU4
- AU5
- AU6
- AU7
- AU8
- AU9
- AU10
- AU11
- AU12
- AU13
- AU14
- AU15
- AU16
- AU17
- AU18
- AU19

Source: Vitrinite 2022, METServe 2022, Maxar.

Vulcan South

Proposed Sampling Design within the Impact Site

0 0.5 1

Kilometers

Scale: 1:34,000 (A3)

19/08/2022

Datum: GDA2020
Projection: MGA55

FIGURE 3-1

VITRINITE BRIGHTER COAL

METSERVE Mining & Energy Technical Services Pty Ltd

Path: S:\Projects\VI011_VCP_Stage2\ArcGIS\ProjectFiles\Projects\Offset_Strategy\VI011_VS_OffsetStrategy_SamplingDesign.aprx

3.1.3 Proposed Offset Site

The approach used to sample the offset site will be similar to that for the impact site. However, prior to stratifying the proposed offset site into assessment units, ground-truthing of the certified regional ecosystem mapping will be required. To achieve this, the methodology described by Neldner *et al.* (2020) will be adopted to produce a field-verified regional ecosystem map of the proposed offset site.

Matter areas within the proposed offset site will be defined using the same habitat definitions as applied to the impact area. The only exception is that cleared, non-remnant vegetation that may not currently qualify as habitat for a matter may be included within the matter area at the offset site if it has potential to develop into habitat for the matter in the next 20 years, contingent on the proposed management measures.

3.1.4 Landscape-scale Assessments

For fragmented landscapes, such as those containing the impact site, the following landscape-scale attributes will be assessed:

- Size of patch (area in hectares of any remnant or regrowth vegetation, irrespective of regional ecosystem or tenure, that is connected to the site via corridors wider than 200 m);
- Context (proportion of local region that comprises remnant or regrowth vegetation); and
- Connectivity (the proportion of a site's perimeter that is connected to remnant or regrowth vegetation).

The same attributes will be assessed for the offset site, once its location has been confirmed.

The methodology used for generating a score out of 20 for the impact site is described in the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). The landscape-scale attributes will be calculated using data stored in Geographical Information Systems (GIS). Regional ecosystem mapping (remnant) and regrowth (non-remnant) vegetation mapping will be used to assess landscape-scale attributes. Field-verified mapping (surrounding the impact site) is planned to be used in the assessment where it is available. For the remaining portions of the landscape lacking field-verified mapping, certified mapping (version 12.2) downloaded from the Queensland Government QSpatial website will be used.

The methodology used for calculating scores for size of patch and connectivity will follow the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). However, the methodology for assessing context is expected to require some adjustment. According to the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), landscape-scale attributes should be assessed "at the overall site level, rather than at the matter area level". Furthermore, these assessments are intended as a description of "the landscape surrounding the offset site" not within it. These intentions conflict with the methodology proposed in the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015), which nominates a 1 km radius circle around the midpoint of a single sampling location as the zone in which context should be measured. As the impact site exceeds 19 km in length, the 1-km-radius-circle approach largely characterises the extent of vegetation within the impact site, rather than surrounding it. As a compromise between the intentions of the *BioCondition Assessment Manual version 2.2* and the *Guide to determining terrestrial habitat quality version 1.3*, context will be assessed by calculating the proportion of the land that comprises remnant or regrowth vegetation contained within a 1 km buffer around the boundaries of the site.

3.1.5 Site-based Assessments

Site-based attributes will be assessed at all sampling locations within the impact site. In accordance with the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), two approaches for assessing site-based attributes will be adopted:

- BioCondition scores; and
- Specially tailored, species-specific, fauna habitat quality scores.

Both approaches will be used to assess different aspects of habitat quality for the three listed species. BioCondition scores alone will be used to assess the quality of the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community. Site-based assessments of the impact and offset sites (once selected) will be assessed during a similar time of year, to ensure impact and offset sites can be directly comparable.

BioCondition

BioCondition will be assessed following the methodology prescribed by the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015). This methodology uses quadrat sampling to generate measurements of native plant richness, recruitment, shrub and tree cover, native perennial grass cover, litter cover, amount of coarse woody debris, non-native plant cover, tree height and number of large trees. These measurements are then compared to benchmarks published by the Queensland Herbarium compiled from various reference sites. The most recent revision (version 3.2) of these the benchmarks will be used.

The scoring system prescribed by the *BioCondition Assessment Manual version 2.2* (Department of Science, Information Technology, Innovation and the Arts 2015) results in a score out of 80, while the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a) requires that this score is out of 100. To achieve this conversion, the original score will be multiplied by 1.25.

Species Habitat Quality

In addition to BioCondition, which assesses the overall quality of the vegetation within the impact and offset sites, species-specific habitat attributes will also be assessed at each sampling location. As prescribed by the *Guide to determining terrestrial habitat quality version 1.3* (Department of Environment and Science 2020a), habitat attributes must include indicators for food availability, suitability for breeding and shelter, suitability for mobility and level of ongoing threats. These four habitat attributes are to have equal weighting when generating overall scores for habitat quality for any one species.

Based on the literature reviewed in **Section 2**, a project-specific set of indicators and a scoring system has been devised in order to assess habitat quality for the Koala, Central Greater Glider and Squatter Pigeon (**Table 3-4**). Some of the species-specific habitat attributes may overlap with the BioCondition assessment (e.g., number of large trees for the Koala and Central Greater Glider, and understorey richness for the Squatter Pigeon). The following attributes are additional assessments to be undertaken at sampling locations:

- Basal area per hectare of Koala food trees (*Eucalyptus camaldulensis, Eucalyptus populnea and Eucalyptus crebra*) and Central Greater Glider food trees (most *Eucalyptus* and *Corymbia* species) will be assessed via 360° sweeps with a Bitterlich gauge at the 0 m, 50 m and 100 m marks of the transect used to assess canopy cover for BioCondition. The mean of the three estimates will be used to represent the amount of food available at the site for Koalas and Central Greater Gliders.
- Canopy cover (based on the vertical projection of crowns) of trees taller than 4 m (the minimum height likely to be used by Koalas) will be assessed as for total canopy cover for BioCondition, except only trees taller than 4 m are included in the estimate. This reflects the density of trees tall enough for Koalas to climb to escape predators.
- The presence/absence of at least one dense shade tree (at least 6 m tall with >75% foliage projective cover within the crown) within the 100 m × 50 m quadrat used for BioCondition will be recorded. This indicates whether favourable shelter trees are available to Koalas at the site.

- The proportion of trees that are within gliding distance of other trees (i.e., with spacing ≤ tree height) will be estimated in each 100 m × 50 m quadrat used for BioCondition.
- Elevated fine fuel hazard will be estimated based on the methodology and hazard classes described in the *Overall fuel hazard assessment guide* (Department of Sustainability and Environment 2012). A summary of the classification system is provided in **Table 3-3**. The elevated fine fuel hazard largely determines if a fire will spread to the forest canopy or be maintained at ground level, where it is of little threat to Central Greater Gliders. Elevated fine fuel hazards that are high, very high or extreme have the potential to cause canopy fires.

Table 3-3 Elevated fine fuel hazard classes.

Key attributes					Fuel hazard rating	Effect on fire behaviour (at FFDI 25)[4]
Plant Cover	% dead	Vertical continuity	Vegetation density	Thickness of fuel pieces		
<20% or low flammability species	<20%		Easy to walk in any direction without needing to choose a path between shrubs.		Low	Little or no effect.
20–30%	<20%	Most of the fine fuel is at the top of the layer.	Easy to choose a path through but brush against vegetation occasionally.		Moderate	Does not sustain flames readily.
30–50%	<20%	Most of the fine fuel is at the top of the layer.	Moderately easy to choose a path through, but brush against vegetation most of the time.		High	Causes some patchy increases in the flame height and/or rate of spread of a fire.
50–80%	20–30%	Continuous fine fuel from the bottom to the top of the layer.	Need to carefully select path through.	Mostly less than 1–2mm thick.	Very High	Elevated fuels mostly dictate flame height and rate of spread of a fire.
>70%	>30%	Continuous fine fuel from the bottom to the top of the layer.	Very difficult to select a path through. Need to push through vegetation.	Large amounts of fuel <2mm thick.	Extreme	Elevated fuels almost entirely determine the flame height and rate of spread of a fire.

- The percentage cover of Buffel Grass will be estimated by dividing the 50 m × 10 m quadrat used for BioCondition into 1/8s, visually estimating the percentage cover of Buffel Grass in each 1/8, then calculating the mean of the eight estimates. This reflects the threat posed by the weed on foraging habitat for the Squatter Pigeon.
- The percentage of bare ground will be estimated at five 1 m × 1 m quadrats used for BioCondition, and the mean of the five estimates is calculated. Bare ground is an important feature of foraging habitat for the Squatter Pigeon.

In addition to these field-measured attributes, the following suite of spatial attributes are planned to be measured using GIS tools:

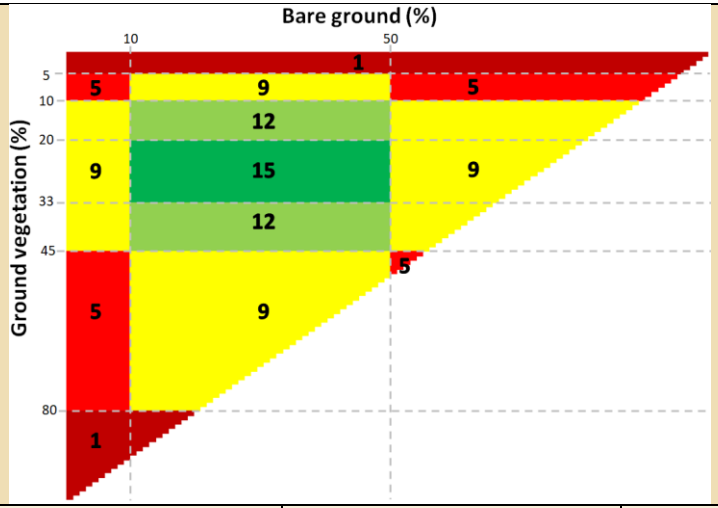
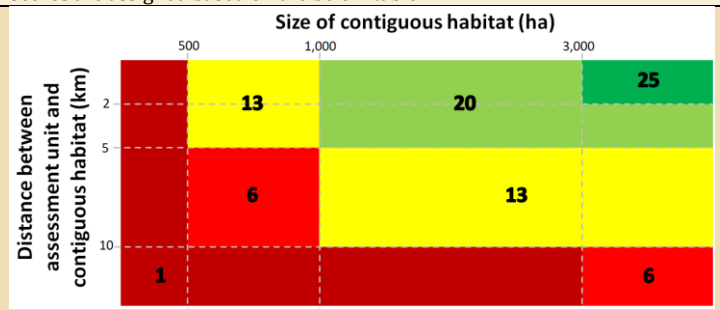
- Distance from the assessment unit boundary to the nearest watercourse (refuge from drought for Koalas and Central Greater Glider) and road (vehicle threat to Koalas).
- Proportion of the assessment unit that overlaps with groundwater-dependent ecosystems (GDEs) mapped in the National GDE Atlas (Bureau of Meteorology 2022) (drought refuge for the Central Greater Glider).
- Maximum altitude (based on the Australian Height Datum) of the assessment unit. Temperature decreases linearly with altitude (6.5°C for every 1,000 m), so assessment units higher than 450 m are buffered from an increase in global temperatures of 3°C (such sites are forecast to have the same temperatures as nearby sites at sea level currently have).

- Size of the habitat patch connected to the assessment unit, and distance to large habitat patches will be used to assess habitat for all three species.
- The percentage of the assessment unit that comprises one-hectare cells with an NDVI > 0.125, when assessed in the dry season (a measure of the extent of woody vegetation cover for Squatter Pigeons).

Table 3-4 Species-specific habitat quality scoring system proposed for the impact and offset sites

<table>
<tr><td rowspan="15">Koala</td><td rowspan="6">1 Threats to species</td><td>Score</td><td>0</td><td>3</td><td>6</td><td>8</td><td></td></tr>
<tr><td>Risk of road-based mortality</td><td>High: Assessment unit borders a public road with 100 kph speed limit.</td><td>Moderate: Assessment unit is within 1 km of a public road with 100 kph speed limit, OR borders a public road with 60-100 kph speed limit.</td><td>Low: Assessment unit lies 1-2 km from public roads, AND any private tracks through or near the unit are used infrequently at night (less than once per week) and at low speeds (less than 50 kph).</td><td>Nil: Assessment unit lies >2 km from a public road, AND any private tracks through or near the unit are used infrequently at night (less than once per week) and at low speeds (less than 50 kph).</td><td></td></tr>
<tr><td>Score</td><td>0</td><td>5</td><td>8</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Risk of dog attack</td><td>High: Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, and no control programs are in place.</td><td>Moderate: Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, but active control measures (baiting, trapping or shooting) occur within the assessment unit and effectively reduce dog densities (as shown by monitoring).</td><td>Low: Assessment unit is further than 18 km from a town, dump or other source of supplementary food for dogs.</td></tr>
<tr><td>Score</td><td>0</td><td>5</td><td>9</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Importance as a drought refuge</td><td>Low: The assessment unit is further than 2 km from a watercourse or source of surface water, OR is 1-2 km from a watercourse, but no vegetation occurs along the watercourse.</td><td>Medium: The assessment unit is 1-2 km from a watercourse or source of surface water and is connected to vegetation along the watercourse.</td><td>High: The assessment unit is within 1 km of a watercourse or source of surface water.</td></tr>
<tr><td rowspan="9">2 Quantity and quality of food</td><td>Score</td><td colspan="5">Scores are assigned based on combination of basal area and proportion of primary food trees, as shown in the below table</td></tr>
<tr><td>Density and quality of food trees</td><td colspan="5"><table>
<tr><td colspan="2"></td><td colspan="5">Percentage of total food tree basal area that comprises primary food trees (E. camaldulensis or E. tereticornis)</td></tr>
<tr><td colspan="2"></td><td>0</td><td><10</td><td>10-40</td><td>40-70</td><td>70-100</td></tr>
<tr><td rowspan="6">Combined basal area of all food trees (m²/ha)</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td><2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>2-5</td><td>2</td><td>3</td><td>5</td><td>7</td><td>8</td></tr>
<tr><td>5-8</td><td>3</td><td>5</td><td>7</td><td>10</td><td>12</td></tr>
<tr><td>8-10</td><td>4</td><td>7</td><td>10</td><td>13</td><td>16</td></tr>
<tr><td>>10</td><td>5</td><td>8</td><td>12</td><td>16</td><td>20</td></tr>
</table></td></tr>
<tr><td>Score</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Number of large food trees</td><td>None: No large food trees</td><td>Poor: 1 or 2 large food trees per 0.5 ha</td><td>Moderate: 3 to 6 large food trees per 0.5 ha</td><td>High: 7 to 10 large food trees per 0.5 ha</td><td>Very high: >10 large food trees</td></tr>
<tr><td rowspan="2">3 Quality and availability of shelter</td><td>Score</td><td>1</td><td>2</td><td>4</td><td>7</td><td>10</td></tr>
<tr><td>Canopy cover of trees taller than</td><td>None: No trees taller than 4 m.</td><td>Poor: <10% cover.</td><td>Moderate: 10-30% cover.</td><td>High: 30-60% cover.</td><td>Very high: >60% cover.</td></tr>
</table>

		4 m.					
		Score	0	2	4	7	10
		Number of large non-food trees	0	1	2-4	5-10	>10
		Score	0	5			
		Presence of dense shade trees	Trees taller than 6 m and with a crown that has >75% cover are absent	Trees taller than 6 m and with a crown that has >75% cover are present			
	4 Species mobility capacity	Score	1	5	10	17	25
		Extent of contiguous habitat.	**Very poor:** Assessment unit is further than 5 km from contiguous habitat larger than 200 ha.	**Poor:** Assessment unit is 2-5 km from contiguous habitat larger than 200 ha	**Moderate:** Assessment unit is connected to, or within 2 km of, a contiguous landscape that is 200-500 ha.	**Good:** Assessment unit is within 2 km of a contiguous landscape that is 500-1,000 ha.	**Very good:** Assessment unit is connected to or within 2 km of a contiguous landscape that is >1,000 ha.
Squatter Pigeon	**1 Threats to species**	Score	1	6	11	16	
		Invasion by Buffel Grass	**High:** Buffel Grass has a ground cover >40%	**Moderate:** Buffel Grass has a ground cover of 10-40%.	**Low:** Buffel Grass has a ground cover of 0.1-9.9%.	**None:** Buffel Grass is absent.	
		Score	0	3	7	9	
		Predation by feral predators	**Very High:** Assessment unit is within 5 km of a town, dump or other source of supplementary food for dogs and cats, and no control programs are in place.	**High:** Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs, and no control programs are in place.	**Moderate:** Assessment unit is within 18 km of a town, dump or other source of supplementary food for dogs and cats, but active control measures (baiting, trapping or shooting) occur within the assessment unit and effectively reduce cat and dog densities (as shown by monitoring).	**Low:** Assessment unit is further than 18 km from a town, dump or other source of supplementary food for dogs and cats.	
	2 Quality and availability of food and foraging	Score	**0**	**1**	*Unlike for other habitat attributes and species, the score for distance to water is multiplied by the sum of the other foraging scores to generate an overall foraging habitat score for Squatter Pigeons.		
		Distance to water*	**High:** Assessment unit is >3 km from water.	**Low:** Assessment unit is within 3 km of water.			
		Score	Scores (1-15) are assigned based on the percentage of ground covered by low vegetation (<1 m) and bare ground, as shown in the below table				

	habitat	Ground cover					
		Score	**1**	**3**	**5**	**8**	**10**
		Understorey richness	**Very low:** <5 species of grasses and forbs.	**Low:** 5-14 species of grasses and forbs.	**Moderate:** 15-24 species of grasses and forbs.	**High:** 25-29 species of grasses and forbs.	**Very high:** >30 species of grasses and forbs.
	3 Quality and availability of habitat for shelter and breeding	Score	**0**	**1**	*Unlike for most other habitat attributes and species, the score for distance to water is multiplied by the other breeding habitat score below to generate an overall breeding habitat score for Squatter Pigeons.		
		Distance to water*	**High:** Assessment unit is >1 km from permanent water	**Low:** Assessment unit is within 1 km of permanent water.			
		Score	**1**	**4**	**11**	**18**	**25**
		Normalised Difference Vegetation Index (NDVI)	**Very poor:** the assessment unit does not contain any 1-ha cells with a mean NDVI > 0.125.	**Poor:** <30% of the assessment unit has NDVI > 0.125.	**Moderate:** 30-60% of the assessment unit has NDVI > 0.125.	**Good:** 60-80% of the assessment unit has NDVI > 0.125.	**Very good**: >80% of the assessment unit has NDVI > 0.125.
	4 Species mobility capacity	Score	Scores are assigned based on the below table				
		Extent of, and distance to, large patches of contiguous habitat					
Central	**1 Threats to**	Score	Scores are assigned based on the below table				

<table>
<tr><td rowspan="8">Greater Glider</td><td rowspan="3">species</td><td>Threat of intense canopy fires</td><td colspan="5"><table><tr><td rowspan="2"></td><td></td><td colspan="3">Position in landscape</td></tr><tr><td></td><td>Valley</td><td>Midslope</td><td>Crest</td></tr><tr><td rowspan="3">Elevated Fine Fuel Hazard</td><td>Low</td><td>10</td><td>9</td><td>8</td></tr><tr><td>Moderate</td><td>7</td><td>5</td><td>4</td></tr><tr><td>High to extreme</td><td>5</td><td>2</td><td>1</td></tr></table></td></tr>
<tr><td>Score</td><td>0</td><td>5</td><td>10</td><td>13</td><td>15</td></tr>
<tr><td>Importance as a climate change refuge</td><td>None: Assessment unit is further than 1 km from a drought refuge OR occurs within 1 km of a drought refuge but there is a vegetation gap > 0.5 km between the unit and the drought refuge.</td><td>Low: Assessment unit is <1 km from a permanent watercourse or an area mapped as a ‘moderate’ or ‘high’ potential groundwater-dependent ecosystem in the National GDE Atlas AND is connected to these drought refuges by woody vegetation.</td><td>Moderate: Assessment unit is within 100 m of a farm dam or other water impoundment, OR overlaps with a ‘low’ potential groundwater-dependent ecosystem in the National GDE Atlas.</td><td>High: Assessment unit is adjacent to a permanent watercourse or overlaps with a ‘moderate’ or ‘high’ potential groundwater-dependent ecosystem in the National GDE Atlas.</td><td>Very high: Assessment unit is above 450 m in altitude.</td></tr>
<tr><td rowspan="3">2 Quality and availability of food</td><td>Score</td><td colspan="5">Scores are assigned based on combination of basal area and proportion of primary food trees, as shown in the below table</td></tr>
<tr><td>Density and quality of food trees</td><td colspan="5"><table><tr><td rowspan="2"></td><td></td><td colspan="5">Species richness of Eucalyptus and Corymbia in 0.5 ha</td></tr><tr><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5+</td></tr><tr><td rowspan="6">Total basal area of food trees (m²/ha)</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr><tr><td><2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr><tr><td>2-5</td><td>2</td><td>3</td><td>5</td><td>7</td><td>8</td></tr><tr><td>5-8</td><td>3</td><td>5</td><td>7</td><td>10</td><td>12</td></tr><tr><td>8-10</td><td>4</td><td>7</td><td>10</td><td>13</td><td>16</td></tr><tr><td>>10</td><td>5</td><td>8</td><td>12</td><td>16</td><td>20</td></tr></table></td></tr>
<tr><td>Score</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Number of large food trees (>30 cm DBH)</td><td>None: No large food trees</td><td>Poor: 1 or 2 large food trees per 0.5 ha</td><td>Moderate: 3 to 6 large food trees per 0.5 ha</td><td>High: 7 to 10 large food trees per 0.5 ha</td><td>Very high: >10 large food trees</td></tr>
<tr><td rowspan="2">3 Quality and availability of shelter</td><td>Score</td><td>0</td><td>5</td><td>12</td><td>18</td><td>25</td></tr>
<tr><td>Number of large shelter trees (>50 cm DBH).</td><td>None: No eucalypt trees with >50cm DBH.</td><td>Poor: 1 or 2 eucalypt trees with >50cm DBH.</td><td>Moderate: 3 to 5 eucalypt trees with >50cm DBH.</td><td>High: 6 to 8 eucalypt trees with >50cm DBH.</td><td>Very high: > 8 eucalypt trees with >50 cm DBH</td></tr>
<tr><td>4 Species</td><td>Score</td><td colspan="5">Scores are assigned based on a combination of size of the habitat patch and connectivity to other patches, as shown in the below table.</td></tr>
</table>

	mobility capacity	Size and connectivity of habitat patch			**Connectivity to nearest patch**					
					Patches <1 km apart and connected by woody vegetation*	**Patches 1-8 km apart and connected by woody vegetation***	**Patches >8 km apart and connected by woody vegetation***	**Patches <0.5 km apart and separated by open areas***	**Patches 0.5-3 km apart and separated by open areas***	**Patches >3 km apart and separated by open areas***
			Size of habitat patch†	**>300 ha**	**25**	**23**	**21**	**20**	**18**	**15**
				100-300 ha	**24**	**20**	**17**	**15**	**12**	**10**
				50-100 ha	**23**	**17**	**10**	**8**	**6**	**4**
				<50 ha	**22**	**14**	**8**	**6**	**3**	**1**
			*Distinction between open areas versus wooded vegetation is defined by the gliding distance of Greater Gliders (i.e., average spaces between trees should not exceed the height of trees in wooded vegetation). †Habitat patch size classes are based on ability of the patch to support a viable population of 100 Greater Gliders, assuming a mean home range size of 3 ha.						

3.2 Offset Starting Quality

In accordance with section 7.1 of the *EPBC Act Environmental Offsets Policy,* any direct offset must meet, as a minimum, the quality of the habitat at the impact site, or its habitat quality is to be improved so that it meets the quality of habitat originally impacted. Consequently, the minimum starting quality of a suitable offset site is contingent on the potential for this value to be improved via management measures. This potential improvement is discussed in the following subsections.

3.2.1 Koala

Management measures have the potential to improve habitat quality for Koalas in offset areas by improving the following components of the species-specific habitat quality score (refer to **Table 3-4**):

- Risk of dog attack;
- Vegetation connectivity with watercourses;
- Basal area of food trees;
- Number of large food trees (only likely to be improved when there are numerous trees marginally smaller than the "large size" when offsets commence);
- Canopy cover of trees taller than 4 m;
- Number of large non-food trees (only likely to be improved when there are numerous trees marginally smaller than the "large size" when offsets commence); and
- Presence of dense shade trees.

Collectively, these components comprise approximately half of the total species-specific habitat quality score (setting a maximum possible improvement of 5/10). However, a more realistic improvement of 1/10 to 2/10 is achievable across most starting values. To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Koala should have the following attributes as a foundation:

- High starting scores for attributes that cannot be improved via management (e.g., small distance to watercourses, large distance to roads, extensive contiguous habitat);
- A starting habitat quality score that is close to, or greater than, the impact site, such that a likely gain of 1 or 2 will result in a total that exceeds the impact site;
- A dense cover of trees less than 4 m tall, but few trees taller than 4 m (i.e., a very low current canopy cover, but a high cover can be expected within 5-10 years);
- Areas containing regrowth of primary food trees (*Eucalyptus camaldulensis* and/or *Eucalyptus tereticornis*); and
- Low levels of current vegetation protection.

3.2.2 Squatter Pigeon

Through management measures to improve habitat quality for the Squatter Pigeon, offsets have the potential to improve the following components of the species-specific habitat quality score:

- The density of feral predators;
- Extent of protective cover provided by woody vegetation;
- Density of Buffel Grass (possible, but logistically difficult, to improve);
- Ground cover composition (cover of low vegetation and bare ground); and
- Distance to water.

There is potential for management measures to contribute towards habitat gains through the removal of Buffel Grass from infested offset sites (maximum gain of ~1/10). However, such measures are only feasible on small scales, due to the very high demands on time and money required for this to be successful. Consequently, this is considered to be an inefficient means to achieve conservation gains for Squatter Pigeons.

The single component with the greatest effect on habitat score, as well as the potential to be rapidly improved, is distance to water. The installation of artificial water points within landscapes that otherwise constitute optimal habitat for the Squatter Pigeon, but that are further than 1 km (for breeding habitat) or 3 km (for foraging habitat) from existing water, has the potential to immediately improve habitat scores by up to 5/10 within the first year of offsets. Even at sites with existing water, there is the potential for management measures (e.g., grazing intensity, managing density of woody regrowth) to improve ground cover composition and woody vegetation density to improve within a reasonable timeframe (10-20 years).

To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Squatter Pigeon should otherwise meet the ecological needs of Squatter Pigeons, but be located more than 3 km from fresh water. Alternatively, a suitable offset site should possess as many of the following attributes as possible:

- Located within 1 km of fresh water and have a dense regrowth of young trees and shrubs that produces an NDVI that is slightly under 0.125; and
- Dense grass and other ground vegetation that exceeds 45% cover;
- Little existing management of feral predators;
- High starting scores for attributes than cannot be improved via management (e.g., high understorey richness, high connectivity to contiguous habitat and low densities of Buffel Grass);
- Starting habitat quality score that is close to, or greater than, the impact site, such that a likely gain of 1 or 2 will result in a total that exceeds the impact site (lower scores are suitable if the addition of water to the landscape will result in immediate gains); and
- Low levels of current vegetation protection.

3.2.3 Central Greater Glider

Through management measures to improve habitat quality for the Central Greater Glider, offsets have the potential to improve the following components of the species-specific habitat quality:

- The elevated fine fuel hazard;
- Vegetation connectivity with drought refuges;
- Basal area and species richness of food trees;
- Number of large food trees and large shelter trees (only likely to be improved when there are numerous trees marginally smaller than the “large size” when offsets commence); and
- Habitat patch size and connectivity.

As for the Koala, an improvement in habitat quality of 1/10 to 2/10 is potentially achievable across most starting values. To maximise the habitat gains that can be reasonably achieved, a suitable offset site for the Central Greater Glider should have the following attributes as a foundation:

- High starting scores for attributes than cannot readily be improved via management (e.g., presence of drought refugia, abundant large trees, presence of nearby tracts of habitat to which the offset site can be connected);
- Numerous trees slightly smaller than the threshold for large trees; and
- Areas containing regrowth of food trees; and
- Low levels of current vegetation protection.

3.2.4 Brigalow Threatened Ecological Community

The quality improvements that can potentially be achieved within Brigalow ecological communities over a 20-year period depend greatly on the starting state. Peeters and Butler (2014) list the following four alternate condition states into which mature Brigalow has often been converted:

- Mature Brigalow that is disturbed and where exotic grasses have invaded, creating a grassy open forest or woodland that is fire-prone.
- Widespread clearing and/or damage causes suckering, which produces "Sucker Brigalow" (multi-stemmed, highly branched and generally less than 4 m in height) in areas typically mapped in Queensland as non-remnant category X vegetation. This may ultimately form into "Whipstick Brigalow" (Johnson 1964), which typically consists of high densities of many straight, slender stems about 4 to 8 m tall, with spindly or dead lower branches. Such areas are often mapped as category C regulated vegetation (regrowth) in Queensland.
- If clearing was done with blade ploughs or herbicides, the resulting grassland or cropland usually lacks any woody vegetation.
- Brigalow where native rainforest species have invaded can transition into dry rainforest communities.

Mature Brigalow can be restored if the damaging processes cease, and their effects are counteracted by managing fire and grazing, controlling weeds, promoting Brigalow suckering, and in some cases reintroducing native woody plants (Peeters and Butler 2014). Biomass accumulation rates of Brigalow regrowth ranges from 1.3 to 4.6 t ha^{-1} yr^{-1} for living biomass, whereas mature Brigalow possess approximately 100 t ha^{-1} of above-ground live biomass (Peeters and Butler 2014). In Brigalow regrowth, species richness and other diversity indices (primary driven by the species-rich herbaceous layer) increase rapidly to a maximum after 2–4 years, decline until the 30th year when they again increase (Johnson *et al.* 2016). This suggests that offset sites containing regrowth younger than 30 years may experience short-term declines in species richness as the canopy thickens and shades out the understorey. At least 90 years of recovery is required post-clearing, before regrowth woodlands regain 90% of the species richness and structural characteristics of mature woodlands (Bradley *et al.* 2010). Plant species richness returns to that of remnant Brigalow woodlands within 30–40 years of regrowth, but the floristic composition of older regrowth remains distinct from remnant Brigalow (Le Brocque and Wagner 2018).

As the Brigalow contained within the impact site mostly comprises grazed, remnant woodlands, these are expected to achieve relatively high quality scores. In order for Brigalow within an offset site to achieve equivalent scores within a 20-year period, it is anticipated that the starting scores at the offset site should be within 1 or 2 points (out of 10) of the score at the impact site.

3.2.5 Ecological Corridors

The impact site is not connected to any state-wide terrestrial or riparian ecological corridors as shown on the "Queensland biodiversity and vegetation offsets special features" map. The impact site is 20 km from the nearest riparian corridor and 2.5 km from the nearest terrestrial corridor. In order to achieve a similar value as an ecological corridor as the impact site, there is no requirement for a suitable offset site to be within or connected to a state-wide terrestrial or riparian ecological corridor as shown on the "Queensland biodiversity and vegetation offsets special features" map. Nevertheless, such a location would be desirable if it were available.

3.2.6 Presence of Species

In accordance with the *EPBC Act Environmental Offsets Policy,* assessment of potential offsets must consider level of certainty that the proposed offset will be successful. Offset sites that already support the Koala, Central Greater Glider and Squatter Pigeon, or that are located close to known populations, have a lower risk of failure than sites that require colonisation from distant source populations. For this reason, the presence of each species within the proposed offset site, or within approximately 8 km of the proposed offset site, is to be confirmed through field observations during habitat quality assessment.

Likewise, the presence of the Brigalow ecological community is to be confirmed through field observations.

4 Proposed Management of Offsets

While the primary consideration in determining suitable offsets is delivering a conservation gain for the impacted protected matter, the delivery of offsets that establish positive social or economic co-benefits is encouraged by the *EPBC Act Environmental Offsets Policy.* Three examples provided within the policy include an offset:

- Contributing to an area recognised as important to increasing landscape connectivity, above and beyond what is required by the impacted protected matter;
- That employs local Indigenous rangers to undertake management actions; and
- Delivered by paying rural landholders to protect and manage land for conservation purposes.

The approach to be taken for Vulcan South is one based on one or more of the above social benefits listed above.

Several options are currently being investigated through a broker to identify an offset site that supports the Brigalow ecological community, meets the habitat needs of the Koala, Central Greater Glider and Squatter Pigeon (refer to **Section 2**), and possesses attributes that allow offsets to achieve substantial conservation gains for the four matters (refer to **Section 3.2**). As the proposed management of an offset site is contingent on the starting quality and attributes that are most sensitive to improvement, specific management measures cannot be prescribed until a final site has been chosen. Nevertheless, a range of management options are presented in **Table 4-1** and **Table 4-2**, as examples of the types of actions that will be considered for improving habitat attributes that are deficient at the offset site at the time of acquisition.

The principal means through which offsets will achieve environmental gains for the Koala and Squatter Pigeon is expected to be through the protection of regrowth vegetation that otherwise has a high risk of repeated clearing. This vegetation may already qualify as habitat for these two species at the procurement of the offset(s) or be expected to develop into suitable habitat in the near future. If required, supplementary water points will be installed in the offset area to maximise the amount of foraging and breeding habitat for the Squatter Pigeon and offer drinking sites for Koalas during droughts. As young regrowth is unable to support Central Greater Gliders unless mature, hollow trees were left standing during clearing, suitable offset sites must also contain ample remnant vegetation to provide a source of den sites. Nevertheless, protection of regrowth will have the benefit of increasing connectivity between habitat patches for Central Greater Gliders. Regrowth adjacent to existing den sites also increases food availability for gliders.

It is expected that offsets for the Koala, Central Greater Glider and Squatter Pigeon are not mutually exclusive of cattle grazing, provided the stocking rates are sustainable. All three species coexist readily with cattle, and some amount of grazing is probably beneficial (Woinarski and Ash 2002). Grazing promotes bare ground required by the Squatter Pigeon for foraging and reduces the density of grass swards that may otherwise hinder the movement of Koalas between trees. By reducing grass density, grazing also facilitates movement between trees by arboreal marsupials (Neilly and Schwarzkopf 2017) and decreases the risk posed by uncontrolled fires, which is a major threat of both the Koala and Central Greater Glider (DCCEEW 2022a, 2022c).

On the other hand, cattle grazing may pose a risk to the success of offsets if it leads to heavy browsing of regenerating trees, insufficient grass cover for Squatter Pigeons, or depleted understorey richness. Furthermore, grazing typically results in reduced condition of the Brigalow ecological community (Le Brocque and Wagner 2018). Regular monitoring of the offset site (every five years) will identify whether such damage is likely to threaten the achievement of the projected conservation goals and, in such an event, stocking densities would be modified accordingly. Cattle-exclusion fencing around patches of the Brigalow ecological community may also be warranted in some circumstances. Furthermore, as Squatter Pigeons nest on the ground, their nests may be susceptible to trampling by cattle, such that removal of cattle from the offset site during breeding periods may be prudent.

Other management measures may be adopted (**Table 4-1** and **Table 4-2**), contingent on the specific attributes of the final offset site(s), and the site-specific potential for improving habitat quality. Further details of the

management measures to be adopted within the final offset site(s) will be provided in a draft Offset Area Management Plan (OAMP), to be submitted for approval prior to implementation (**Section 8**).

Table 4-1 Potential management options for improving Koala habitat quality within an offset site

Potential Scenario	Habitat Deficiency	Management Measures	Expected Improvements
K1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection at least for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and level of protection under the VM Act within the offset site (see **Section 1.3.2**). This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government. Protecting regrowth and allowing it to develop will improve the habitat quality for Koalas by increasing the basal area of food trees, increasing the canopy cover of trees taller than 4 m, and allowing dense shade trees to form.
K2	Low cover of trees taller than 4 m (large enough to be used by Koalas)	Allowing the passive regeneration of woody vegetation.	Seedlings and suckers of canopy trees that are <1 m tall are expected to reach ≥4 m within five years in central Queensland. Regrowth as young as four to seven years is regularly used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014). The success of passive regeneration depends on the clearing methods originally used at the offset site, with pulled vegetation recovering faster than that killed with herbicide (Back *et al.* 2009a). Recruitment is also stronger when clumps of standing trees have been retained in the cleared landscape (Back *et al.* 2009a). In most grazed areas of central Queensland, a moderate to high amount of natural recruitment is expected, and the amount can be anticipated at the start of offsets (by observing the presence of seedlings or suckers).
K3	Lack of access to surface water during drought	Installation of tanks and troughs at 1.4 km intervals (so that no areas fail to fall within 1 km of water). Tanks are to be regularly refilled, and troughs are to be checked and maintained at regular intervals.	Sites that lack nearby surface water are unlikely to be suitable as offsets for the Koala and Squatter Pigeon, as they will not meet the definition of suitable habitat for the latter. Koalas readily and frequently drink from artificial water placed on the ground (Mella *et al.* 2019) and are expected to make use of water provided for Squatter Pigeons, provided the design of the troughs allows access by Koalas. Use of supplementary water by Koalas is highest during hot, dry weather (Mella *et al.* 2019), indicating that it can be important for sustaining Koala populations during drought.
K4	Lack of connectivity between surface water and Koala habitats located 1-2 km away.	Allowing the passive regeneration of woody vegetation surrounding water sources.	Regrowth as young as four to seven years is regularly used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014), and there is therefore a high likelihood that connectivity would be restored within 10 years.
K5	Absence of trees and natural recruitment	Direct seeding and/or tubestock planting of food and shelter tree species	Expansive treeless areas will not constitute suitable offset sites on their own, as these are unlikely to achieve habitat scores comparable to the impact site in a reasonable timeframe (e.g., 20 years). Nevertheless, if small, treeless areas form a minor subset of the total offset site, high habitat scores within the remaining forested subset of the offset site could deliver average habitat scores across the offset site that meet targets set by the impact site. Generally, such small treeless areas experience natural recruitment via seed blown from nearby forest. In the event that this does not occur, active planting of Koala food trees is a highly successful means of introducing these to the site (Kavanagh and Stanton 2012;

Potential Scenario	Habitat Deficiency	Management Measures	Expected Improvements
			Rhind *et al.* 2014). Planted trees as young as four to seven years old are used by Koalas (Kavanagh and Stanton 2012; Rhind *et al.* 2014).
K6	Deficiency of large trees and dense regrowth of small trees (many of which are non-food trees), inhibiting their development into "large trees".	Thinning of midstorey non-food and non-shelter tree species, so that these constitute less than half of the total woody vegetation basal area.	The rate at which trees develop into "large trees" depends on their initial size and extent of competition with other trees. In forested areas, *Eucalyptus crebra* and *Eucalyptus melanophloia* generally increase in trunk diameter by 0.16 to 0.22 cm per year in the 600-800 mm annual rainfall regions of Queensland (Ngugi *et al.* 2015). This implies that only those trees with a diameter within 3.5 cm of the "large tree" threshold (as per BioCondition) are likely to develop into large trees within a 20-year timeframe. Growth rates can be accelerated by thinning dense regrowth (Back *et al.* 2009b). Over a 20-year period at Dingo, Queensland, *E. populnea* trees in unthinned plots increased in circumference by 20%, while those in thinned plots increased by 50% (Back *et al.* 2009b). The extent of thinning used in this study was much higher (80% of trees removed) than would be considered appropriate within an offset site, and the relative benefits of thinning an offset site would be accordingly lower.
K7	Elevated risk of dog attack within 18 km of supplementary food sources (towns, dumps, mine camps)	Where practicable, exclusion fencing around supplementary food sources to be installed.	Preventing access by wild-roaming dogs and dingoes to nearby supplementary food sources would limit their local population densities (and associated risk to Koalas) to background levels. Such measures are only feasible in specific circumstances (e.g., fencing off waste storage areas at a nearby mine camp, or fencing off a public landfill), but would not be employed for isolating whole towns.
		Implementation of a wild dog control program, involving baiting, trapping and shooting.	Dog control programs in south-eastern Queensland, where dogs constitute a major cause of death, successfully reduced mortality rates of adult Koalas by 85-92% (Beyer *et al.* 2017). Any improvements in Koala survivorship are expected to be short-lived, however, due to ongoing recolonisation of the site by new dogs. Consequently, such a control program would need to continue throughout the life of the offsets (at a minimum, for the duration of the impact at Vulcan South).

Table 4-2 Potential management options for improving Squatter Pigeon habitat quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
S1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
S2	Low woody vegetation cover providing inadequate protection (based on NDVI)	Allowing the passive regeneration of woody vegetation.	Protecting regrowth and allowing it to develop will improve the habitat quality for Squatter Pigeons via increasing the NDVI (protective woody vegetation cover) at sites where this is initially deficient.
S3	High density of grass swards limiting the extent of bare ground required for foraging.	Allowing the passive regeneration of woody vegetation.	Density of grass in *E. populnea* and *E. crebra* woodlands in Queensland has a strong negative association with the basal area of trees and shrubs (Scanlon and Burrows 1990). As regrowth is allowed to grow, overly dense groundcover vegetation is expected to naturally thin to provide more favourable foraging habitat for Squatter Pigeons.
		Modifying cattle grazing intensities to reduce overall grass biomass and provide open areas for foraging.	Grazing management generally has a more pronounced effect on ground-storey composition of plant communities than tree density (Jones *et al.* 2009; Good *et al.* 2012). These effects are also more immediate, compared to those achieved through passive regeneration of trees. Grazing can be an effective conservation tool for managing excessive pasture densities in Queensland, although secondary invasion by the exotic grass Indian Couch (*Bothriochloa pertusa*) may undermine the biodiversity benefits gained by grazing in conservation areas (Lebbink *et al.* 2021).
S4	Insufficient amount of ground -storey vegetation due to shading and litter fall beneath overly dense woody vegetation.	Thinning of the midstorey and/or trees (of species not used by Koalas or Central Greater Gliders for food or shelter).	Woody regrowth is commonly much denser than undisturbed forest, leading to a suppression of ground-storey vegetation and diversity (Jones *et al.* 2014). Thinning has been demonstrated to restore the ground-storey vegetation to a state similar to remnant forest (Jones *et al.* 2014). Reducing the cover of overly dense woody vegetation leads to the (mostly) rapid expansion of grass cover, and greater representation within the understorey community of large-seeded, perennial grasses such as *Themeda triandra* and *Heteropogon contortus* (Scanlon and Burrows 1990). Effectiveness of thinning varies with vegetation community, with the understorey being less responsive to the removal of *Eucalyptus melanophloia* than *Eucalyptus populnea* (Hall *et al.* 2016). Thinning only successfully restores ground-storey vegetation communities at sites with few weeds; otherwise, thinning can promote the proliferation of weeds (Jones *et al.* 2014).
		Controlled burning designed to reduce biomass within the midstorey.	Regular fires encourage the growth of grasses, forbs and sub-shrubs, at the expense of sapling trees (Williams *et al.* 2003). However, unlike targeted thinning, burning is expected to have some collateral damage on Koala and glider food and shelter tree species. Furthermore, areas with too little ground-storey vegetation may have insufficient fuel to initiate or support a sufficient burn (MacLeod *et al.* 2014). Prescribed burns are therefore likely to be more valuable for maintaining a favourable understorey composition, once established, than for converting areas of dense regrowth to an open, patchy forest favourable for Squatter Pigeons.
S5	Insufficient amount of ground-storey	Reduction in grazing intensity.	Grazing management generally has a more pronounced effect on ground-storey

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
	vegetation due to overgrazing		composition of plant communities than tree density (Jones *et al.* 2009; Good *et al.* 2012). On average, heavily degraded pastures (>60% bare ground, erosion visible and/or few palatable perennial grasses) need to be "rested" for approximately four years to recover their condition (Hunt *et al.* 2014).
S6	Low species richness of grasses and forbs in the ground-storey	Modifying cattle grazing intensity to improve species diversity.	Generally, the composition of ground-storey vegetation is slow to respond to changes in grazing intensity, compared to the density of this vegetation (Grice and Barchia 1995). However, de-stocking heavily grazed sites in northern Queensland resulted in a 19% to 37% increase in native species richness (measured within 10 m^2 per site) within ten years (Kemp and Kutt 2020). In some locations, namely those dominated by palatable, perennial grasses such as *Themeda triandra* and *Heteropogon contortus*, intermediate levels of grazing results in an increase in diversity, as grazing releases other plant species from competition (Calvert 2001). These studies indicate that modest improvements to understorey diversity may be achieved over medium timeframes by optimising grazing intensities.
S7	Lack of nearby water	Installation of tanks and troughs at 1.4 km intervals (so that no areas fail to fall within 1 km of water). Tanks are to be regularly refilled, and troughs are to be checked and maintained at regular intervals.	Squatter Pigeons readily use artificial water sources. The provision of artificial water points rapidly increased the numbers and diversity of birds inhabiting semi-arid woodlands in Victoria (Starks 2015). The installation of permanent water points within habitat that otherwise provides favourable foraging and breeding habitat for Squatter Pigeons would have large, immediate benefits.
S8	Elevated risk of predation by cats and dogs within 18 km of supplementary food sources (towns, dumps, mine camps)	Where practicable, exclusion fencing around supplementary food sources to be installed.	Preventing access by wild-roaming dogs and cats to nearby supplementary food sources would limit their local population densities (and associated risk to Squatter Pigeons) to background levels. Such measures are only feasible in specific circumstances (e.g., fencing off waste storage areas at a nearby mine camp, or fencing off a public landfill), but would not be suitable for isolating whole towns.
		Implementation of a wild dog and cat control program, involving baiting, trapping and shooting.	There is no available data on the effects of predator-control programs on the Squatter Pigeon, but this ground-nesting species is expected to benefit from measures implemented for the Koala. Due to ongoing colonisation of the site by new individual cats and dogs, any control program would need to continue throughout the life of the offsets (at a minimum, for the duration of the impact at Vulcan South).

Table 4-3 Potential management options for improving Central Greater Glider habitat quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
G1	A low level of pre-existing vegetation protection places this at a high risk of	Habitat within the offset area is to be protected and will retain this	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
	future loss through clearing for agriculture.	protection for at least for the duration of impacts arising from Vulcan South.	the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).
G2	High elevated fine fuel hazard, leading to a high risk of canopy fires.	Implementation of a controlled fire regime, reducing midstorey fuel load.	Semi-frequent, low intensity burns of open eucalypt forests are a well-recognised tool for reducing their fuel load and the intensity of wildfires they experience (Fernandes 2015). As the midstorey shrubs and saplings removed by prescribed burns are not utilised by Central Greater Gliders for shelter or food (Eyre 2002), risk of fire can be reduced without compromising habitat quality.
		Thinning of midstorey non-food trees, and either lying felled debris flat or piling it in forest gaps, so it does not act as a ladder for fire to reach the canopy.	Mechanical fuel load reduction is a relatively new approach in Australia (Ximenes *et al.* 2017). Only a small number of trials have been undertaken to date. Eucalypt forests burnt after experimental thinning experienced lower-severity fires than un-thinned forest, due to the reduction in elevated fuel (Volkova and Weston 2019). However, thinned debris left on the ground can fuel intense fires during severe fire weather (Weston *et al.* 2022), suggesting that the value of thinning versus prescribed burning as a means of fuel reduction should be ascertained on a case-by-case basis.
		Installation of fire breaks around or within the offset area.	Firebreaks (e.g., cleared tracks) are a useful tool for stopping the spread of low-intensity grass fires, but are ineffective at stopping larger fires (Price *et al.* 2007). They are primarily useful for containing low-intensity prescribed burns.
		Reducing risk of ignition, by limiting public access to the offset area and implementing rules for land managers pertaining to the lighting of fires or use of machinery that could generate sparks during risky weather conditions.	In Australia, most bushfires are initiated by humans, whether intentionally, accidentally or through negligence (Ganteaume and Syphard 2017). Natural causes (of which lightening is the most frequent) ignite less than one-quarter of Australian bushfires (Ganteaume and Syphard 2017). By reducing the risk of local ignition through human actions, the overall chance of fire is substantially reduced.
G3	Deficiency of large trees and dense regrowth of small trees, inhibiting their development into "large trees" and shelter for Central Greater Glider.	Thinning of midstorey non-food tree species, so that these constitute less than half of the total woody vegetation basal area.	The rate at which trees develop into "large trees" depends on their initial size and extent of competition with other trees. In forested areas, *Eucalyptus crebra* and *Eucalyptus melanophloia* generally increase in trunk diameter by 0.16 to 0.22 cm per year in the 600-800 mm annual rainfall regions of Queensland (Ngugi *et al.* 2015). This implies that only those trees with a diameter within 3.5 cm of the "large tree" threshold (as per BioCondition) are likely to develop into large trees within a 20-year timeframe. Growth rates can be accelerated by thinning dense regrowth (Back *et al.* 2009b). Over a 20-year period at Dingo, Queensland, *E. populnea* trees in un-thinned plots increased in circumference by 20%, while those in thinned plots increased by 50% (Back *et al.* 2009b). The extent of thinning used in this study was much higher (80% of trees removed) than would be considered appropriate within an offset site, and the relative benefits of thinning an offset site would be accordingly lower.

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
G4	Lack of connectivity between drought refuges (groundwater-dependent ecosystems and riverine forests) and Central Greater Glider habitat located less than 1 km away.	Allowing the passive regeneration of woody vegetation surrounding drought refuges.	While regrowth will not provide hollows for Central Greater Gliders in the timeframe of offset management, it will allow Central Greater Gliders the opportunity to more effectively move through the landscape without having to go to the ground. This will not only improve the "mobility" component of habitat quality, but also an offset area's value as a refuge against drought.
G5	Protection of hollow-bearing trees providing shelter habitat for the Central Greater Glider from forestry.	No food or shelter trees for Central Greater Gliders will be removed when constructing tracks or undertaking thinning within the offset site.	Queensland landholders are legally allowed to remove otherwise protected vegetation on their land if this is to be used as construction timber to maintain existing buildings and structures (e.g., sheds, stockyards and fences) on the land. This constitutes a type of exempt clearing work under the VM Act. Selective harvesting of eucalypts for construction is a common practice on grazing properties throughout central Queensland. By explicitly protecting trees of value to the Central Greater Glider from harvest, the offset will maintain existing sources of food and dens.

Table 4-4 Potential management options for improving Brigalow ecological community quality within an offset site

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
B1	A low level of pre-existing vegetation protection places this at a high risk of future loss through clearing for agriculture.	Habitat within the offset area is to be protected and will retain this protection for at least for the duration of impacts arising from Vulcan South.	The benefits of additional habitat protection depend on the pre-existing risk of loss, which is to be determined based on recent historical clearing patterns associated with the tenure, land zone and pre-existing level of protection under the VM Act within the offset site. This data is available from Accad *et al.* (2022) and the Statewide Landcover and Trees Study datasets published by the Queensland Government (see **Section 1.3.2**).
B2	High density of exotic grasses, such as Buffel Grass, elevates the risk of fire damaging or killing mature Brigalow trees.	Periodic intense grazing to reduce grass fuel loads	Brigalow is fire-sensitive, but intact Brigalow communities rarely burn due to a lack of fine grass fuels within the ground layer. Fire within Brigalow invaded by Buffel Grass results in widespread tree death and exacerbation of weed infestations (Butler and Fairfax 2003). The risks associated with grazing (extinction of grazing sensitive species, spread of weed seeds and trampling) may be lower than those posed by fire (Butler and Fairfax 2003).
		Removal of Buffel Grass using herbicides	Removal of large Buffel Grass infestations is likely to be costly, and result in substantial collateral damage to native understorey plants. However, the targeted removal of small, newly establishing infestations may be prudent. Furthermore, removal of Buffel Grass within an outer ring can act as a firebreak for the interior of the Brigalow patch. Herbicide treatments are known to be effective and more efficient than manual removal (Dixon *et al.* 2002).
		Enhancement of crown cover around the edges of the Brigalow patch, by ripping strips around the edges of Brigalow remnants to	This approach was proposed by Butler and Fairfax (2003), but has not been subject to widespread testing. Dense clusters of Brigalow are known to impair grass growth underneath (Scanlon 1991), so this measure may prove effective.

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
		encourage sucker growth dense enough to shade out grass.	
		Installation of fire breaks around or within the offset area.	Firebreaks (e.g., cleared tracks) are a useful tool for stopping the spread of low-intensity grass fires, but are ineffective at stopping larger fires (Price *et al.* 2007). They are primarily useful for preventing low-intensity prescribed burns ignited in neighbouring eucalypt woodlands from entering patches of Brigalow.
		Reducing risk of ignition, by limiting public access to the offset area and implementing rules for land managers pertaining to the lighting of fires or use of machinery that could generate sparks during risky weather conditions.	In Australia, most bushfires are initiated by humans, whether intentionally, accidentally or through negligence (Ganteaume and Syphard 2017). Natural causes (of which lightening is the most frequent) ignite less than one-quarter of Australian bushfires (Ganteaume and Syphard 2017). By reducing the risk of local ignition through human actions, the overall chance of fire is substantially reduced.
B3	High density of Buffel Grass reduces species richness of ground vegetation.	Removal of Buffel Grass using herbicides	Managing Buffel Grass infestations through heavy grazing is the cheapest option for reducing cover of this invasive weed, but can have substantial negative effects, such as elevated soil erosion and water runoff (Thornton and Elledge 2021). Removal via herbicide treatment retains dead clumps as soil protection. Herbicide treatments are known to be effective and more efficient than manual removal (Dixon *et al.* 2002). Buffel Grass removal resulted in substantial improvements to the richness and quantity of native forbs and annual grasses near Alice Springs (Wright *et al.* 2020). Due to feasibility, removal of Buffel Grass using herbicides is only feasible over small scales (Lebbink *et al.* 2021).
		Periodic intense grazing to reduce Buffel Grass cover	Pulse grazing implemented at the end of the summer growing season results in an increase in native grasses and herbs in pastures containing Buffel Grass (Lebbink *et al.* 2021). This approach is only appropriate where Indian Couch (*Bothriochloa pertusa*) is absent; otherwise, the gaps will be filled by this other invasive species (Lebbink *et al.* 2021).
B4	High stem density of small trees, inhibiting the growth rates of trees and slowing development into mature Brigalow woodland.	Selective thinning to achieve a target stem density that maximises structural development of the ecological community.	Experimental thinning trials and simulation models revealed that thinning Brigalow to 6,000 stems ha^{-1} (the density of mature Brigalow forest is usually 1,250–2,070 stems ha^{-1}: Ngugi *et al.* 2011) is optimal for expediting development of a regrowth ecosystem towards the structure of mature reference forest over a 20-year period (Dwyer *et al.* 2010). Plots with high initial stem densities accumulate less aboveground biomass over the subsequent 45 years, compared to those that have lower stem densities (Ngugi *et al.* 2011). Thinning is not recommended in areas containing Buffel Grass, as this flammable species will invade the gaps created by thinning and the increased fire risk surpasses the potential gains from improved growth rates of unthinned trees (Dwyer and Mason 2017).
B5	Excessive dominance of rainforest species	None advised	While the identity of the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community could be maintained through the selective removal of rainforest

Potential Scenario	Habitat Attribute	Management Measure	Expected Improvements
			species, this is not justified. The types of rainforest communities into which Brigalow is most likely to transition belong to another endangered community (Semi-evergreen vine thickets of the Brigalow Belt and Nandewar Bioregions), and are therefore protected. Careful selection of offset sites that are sufficiently dominated by *Acacia harpophylla* is important to avoid this issue.
B6	Absence of grazing-sensitive plant species	Excluding cattle or reducing grazing pressure	Exclusion of grazing from *Acacia* shrubland in New South Wales improved the species richness of ground vegetation by 19% over 18 years (Daryanto and Eldridge 2010). Decreased grazing pressure will only improve ground vegetation diversity in the absence of Buffel Grass, which otherwise spreads and excludes native species (Clarke *et al.* 2005). The presence of Indian Couch also reduces the ability of native perennial grasses to colonise and spread, although over extended periods of low grazing pressure (>10 years) native species do increase in dominance in pastures dominated by Indian Couch (Bartley *et al.* 2014).
B7	Deficiency of coarse woody debris	Thinning excessively dense Brigalow regrowth and leaving dead stems as debris for fauna habitat.	Improvements will be immediate at sites with dense regrowth and little existing woody debris. This approach is only suitable at sites with stem densities exceeding 6,000 stems ha^{-1} (Dwyer *et al.* 2010), or else thinning existing vegetation will jeopardise other ecosystem structural traits (e.g., canopy cover, basal area, etc).

5 Monitoring

Permanent monitoring locations will be installed within the offset site, coinciding with the locations to be used in the initial habitat quality assessments. The start and end points of each transect will be marked with star pickets.

The offset site will be monitored in the late wet season (February-April) every five years by qualified ecologists.

The methodology to be adopted is to be consistent with that used for assessing habitat quality at the impact site (see **Section 3**), so that data is directly comparable. The only exceptions are additional pieces of information to be collected at the offset site, including:

- (if a pest animal control program is implemented at the offset site), records are to be kept of all measures implemented, and surveys are to be conducted every five years to determine the effectiveness of this program, based on detection rates of cats, foxes and dogs;
- (if surface water is absent in part or all of the offset site), regular (e.g., weekly) monitoring of the functioning of tanks and troughs, with records to be kept of each inspection and any maintenance required;
- records are to be kept of grazing regimes (what stocking rate and over which period) implemented annually within the offset site, to allow for modifications of this regime should milestone monitoring indicate this is required;
- records are to be kept of any targeted thinning that takes place in the offset area, noting the date and number of stems per hectare removed; and
- records are to be kept of all fires within the offset site (both controlled burns and bushfires), which includes their date, the approximate boundaries of the burn scar and approximate scorch height (if known).

The success criterion to be adopted for each protected matter is that, after 20 years, the offset site achieves the improvement in habitat quality forecast within the Offset Assessment Guide, which is to be detailed within an Offset Area Management Plan (OAMP), once an offset site has been located.

Interim criteria (for each five years, coinciding with each round of monitoring) will also be developed within the OAMP. Interim criteria will not necessarily be based on incremental improvements of exactly one quarter of the total based on the success criteria. Instead, they will consider the shapes of expected improvement curves for each attribute potentially improving with offset management.

Some habitat quality attributes (e.g., availability of surface water, structure of the ground cover, predator control) are expected to show rapid early improvements, followed by negligible change after the first five years. Other attributes (e.g., species richness of understorey vegetation, BioCondition of Brigalow, and basal area of Koala and Central Greater Glider food trees) are expected to show a gradual, linear improvement over time. Others may not display any detectable improvement until considerable time has elapsed (e.g., number of large shelter trees for the Central Greater Glider).

Both the final and interim success criteria are site-specific and cannot be developed until an offset site has been chosen.

6 Protection Measures

Once an offset site has been approved by the Commonwealth and Queensland Governments, it is to be legally secured through a voluntary declaration under the *Vegetation Management Act 1999* (VM Act). Once a declaration is made, it is registered in title and is binding on all current and future owners of the land until the intent and outcomes of an associated Offset Area Management Plan have been achieved. The offset site is to remain protected until all impacts of Vulcan South on the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon have ceased (i.e., until habitat has been returned to the rehabilitated mine). Declared areas under the VM Act are displayed as category A vegetation on a property map of assessable vegetation (PMAV).

The environmental gains that will be achieved through this additional protection depend on the risk that the habitat would otherwise have been cleared in the absence of offset declaration. This risk varies according to landform, tenure and vegetation category under the VM Act. For remnant vegetation (i.e., category B regulated vegetation under the VM Act), risk of loss at the offset site in the absence of offsets will be inferred from recent historical clearing patterns in the bioregion (data published by Accad *et al.* 2022; refer to **Table 1-1**). Recent historical clearing patterns for category C (high-value regrowth), and X (other non-remnant) regulated vegetation will be inferred from the Statewide Landcover and Trees Study spatial data published by the Queensland Department of Environment and Science (2020c) (refer to **Table 1-2**). With the added protection of offset declaration, it will be assumed that the offset area will have a similarly low risk of clearing as a National Park or State Forest.

7 Offset Suitability

Once a suitable offset site has been located and has undergone the necessary habitat quality assessments (refer to **Section 3.1.3**), the Commonwealth Government's Offset Assessment Guide will be used to confirm the suitability of the proposed offset. Habitat quality assessments will be undertaken using the same methodology as will be used for the impact site. All other inputs to the Offset Assessment Guide will be informed, wherever available, by published data on land-clearing rates, rates of vegetation regrowth in nearby areas, and effectiveness of management measures. To maintain a high confidence in the output of this calculator, conservative values will be used whenever there is uncertainty in inputs. An offset area that possesses the qualities described in **Section 1.3.2** and **Section 3.2** is likely to meet the requirements of the *EPBC Act Environmental Offsets Policy* (**Table 7-1**).

Table 7-1 Accordance with the EPBC Act Environmental Offsets Policy

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
1. Deliver an overall conservation outcome that improves or maintains the viability of the protected matter	• By proposing an offset site and management strategy that, when assessed using the Offset Assessment Guide, indicates No Net Loss or a Net Gain for the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon; • By achieving a positive conservation outcome for the same protected matters as being impacted (i.e., the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon) and the same attributes (i.e., foraging, breeding and dispersal habitat for the Squatter Pigeon will be assessed separately); • By providing evidence that the Brigalow ecological community, Koala, Greater Glider and Squatter Pigeon are either on the offset site, or are nearby (with connecting habitat) and likely to inhabit the offset site once management makes it suitable; • By implementing the offset for the duration of the impact (at least 20 years), not just the action itself (9 years) • By recreating native vegetation communities and ecosystems, rather than non-native ones; • By committing to a future quality that is equal to, or greater than, the quality of the impact site, and which is to be attained by the nominated time until ecological benefit and then maintained for the duration of the impact;
2. Be built around direct offsets but can include other compensatory measures	• By being a 100% direct offset, which provides a measurable conservation gain for the impacted protected matters; • By acknowledging and managing key threats to the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon; • By being secured for conservation purposes for at least the duration of the impact, as there is a risk of loss or degradation of the site without offset;
3. Be in proportion to the level of statutory protection that applies to the protected matter	• By considering the level of statutory protection (vulnerable, endangered or critically endangered) for the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon when applying the Offset Assessment Guide;
4. Be of a size and scale proportionate to the	• By describing the attributes of the protected matters being impacted, the quality and importance of those attributes, the nature of the impact (e.g. permanent or temporary), the level of threat applicable to the offset site, the time it will take to achieve a

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
residual impacts on the protected matter	conservation gain for the protected matter, and risk of the conservation gain not being realised; • By ensuring that offsets calculations are as accurate as possible and implementing the Precautionary Principle where there is scientific uncertainty;
5. Effectively account for and manage the risks of the offset not succeeding	• By using direct offsets instead of other compensatory measures; • By including a risk analysis within the draft OAMP, which considers factors that could affect the success of the offset (i.e. attain the completion criteria by the nominated time until ecological benefit and maintain this for the duration of the impact), with input from multiple environmental specialists; • By proposing compensatory measures within the draft OAMP for if the offset fails, such as additional offsets to compensate for both the impact and failed offset; • By detailing within the draft OAMP how and when the Precautionary Principle has been applied;
6. Be additional to what is already required, determined by law or planning regulations, or agreed to under other schemes or programs	• By detailing the duty of care requirements applicable to the offset site within a draft OAMP, such as the landowner's responsibility to control certain weeds and feral animals, and managing stocking rates and maintain water troughs; • By calculating the risk of loss based on existing environmental planning laws (e.g., *Vegetation Management Act 1999*) that apply to the offset site; • By delivering conservation gains that have not been paid for, or achieved, while participating in other schemes (e.g. carbon offset scheme); • By providing conservation gains that are in addition to duty of care or environmental planning laws;
7. Be efficient, effective, timely, transparent, scientifically robust and reasonable	• By allocating resources, including any required for management and monitoring, in an efficient manner that maintains or improves the viability of the Brigalow ecological community, Koala, Central Greater Glider and Squatter Pigeon; • By implementing offsets before, or at the same time as, the impact occurring; • By being based on scientifically robust and verifiable information, including published peer-reviewed studies, the Australian Government's Species Profile and Threats Database, expert opinion, and field-collected data from the local area; • By implementing the Precautionary Principle if there is not scientific certainty; • By using scientifically robust and peer-reviewed methods for collecting and analysing environmental data; • By having realistic offset commitments and completion criteria that are likely to be achieved despite any potential threats or risks;
8. Have transparent governance arrangements	• By detailing governance of the offset site within a draft OAMP, including ensuring that offset actions are fully funded for the required timeframe; • By committing to measure and monitor the performance of the offset, and reporting on this every five years to the Department;

Principles of the EPBC Act Environmental Offsets Policy	How this will be achieved by Vulcan South
including being able to be readily measured, monitored, audited and enforced	• As appropriate, by delivering the offset through contractual arrangements with a third party (e.g., local landholder or Aboriginal ranger group); and • By ensuring that offset commitments are measurable and specific so that they can be audited and enforced.

8 Documents to be Prepared

A draft Offset Area Management Plan (OAMP) is to be prepared and submitted for assessment and approval by DCCEEW. The draft OAMP is to be prepared by a suitably qualified ecologist and in accordance with the Department's *Environmental Management Plan Guidelines* (Department of the Environment 2014).

The draft OAMP is to provide the following:

- details to demonstrate how the environmental offset compensates for residual significant impacts of the project on the Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community and habitat for the Koala, Central Greater Glider and Squatter Pigeon, in accordance with the principles of the *EPBC Act Environmental Offsets Policy* and all requirements of the Offsets Assessment Guide;
- a description of the environmental offset, including location, size, condition, environmental values present and surrounding land uses;
- baseline data, including from field validation surveys, and other supporting evidence that documents the presence of the relevant listed threatened species, and the quality of their habitat within the environmental offset area;
- an assessment of the offset site habitat quality using the *Guide to Determining Terrestrial Habitat Quality version 1.3* (Department of Environment and Science 2020a);
- details of how the environmental offset will provide connectivity with other habitats and biodiversity corridors and/or will contribute to a larger strategic offset for the relevant listed threatened species;
- maps and shapefiles to clearly define the location and boundaries of the offset area, accompanied by the offset attributes (e.g. physical address of the offset area, coordinates of the boundary points in decimal degrees, the listed threatened species that the environmental offset compensates for, and the size of the environmental offset area in hectares);
- specific offset success criteria derived from the site's habitat quality to demonstrate the improvement in the quality of habitat in the environmental offset area over an appropriate period;
- details of the management actions, and timeframes for implementation, to be carried out to meet the offset completion criteria;
- interim milestones that set targets at 5-yearly intervals for progress towards achieving the offset completion criteria;
- details of the nature, timing and frequency of monitoring to inform progress against achieving the 5-yearly interim milestones (the frequency of monitoring must be sufficient to track progress towards each set of milestones, and sufficient to determine whether the environmental offsets are likely to achieve the completion success criteria in adequate time to implement all necessary corrective actions);
- proposed timing for the completion of internal monitoring reports which provide evidence demonstrating whether the interim milestones have been achieved;
- timing for the implementation of corrective actions if monitoring activities indicate the interim milestones have not been achieved;
- risk analysis and a risk management and mitigation strategy for all risks to the successful implementation of the OAMP and timely achievement of the offset completion criteria, including a rating of all initial and post-mitigation residual risks in accordance with a risk assessment matrix;
- evidence of how the management actions and corrective actions take into account relevant approved conservation advices and are consistent with relevant recovery plans and threat abatement plans; and

- details of the legal mechanism for legally securing the environmental offset, such that legal security remains in force for at least 20 years to provide enduring protection for the environmental offset area against development incompatible with conservation.

9 Timeframes

Offsets for Vulcan South are to be legally secured within 12 months of any disturbance to the Brigalow ecological community or a matter area for the Koala, Central Greater Glider and/or Squatter Pigeon. In order for Vulcan South to be approved in time for a commencement date in Q3 2023, an approximate timeline as described in **Table 9-1** will be followed.

Table 9-1 Timeframe for delivering offsets

Date	Tasks to be completed
Q4 2022	Identification of a suitable offset area and undertaking of habitat quality assessments
Q4 2022	Preparation of a draft OAMP and submission to DCCEEW for approval
Q2 2023	Anticipated approval of the OAMP
Q2 2023	Signed agreement with landholder and implementation of the OAMP

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